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METER ENGINEERING

A PRACTICAL BOOK ON THE INSTALLATION, TESTING, AND MAINTENANCE OF ELECTRICITY METERS

BY

J. L. FERNS

B.Sc. (Hons.), M.I.E.E., A.M.C.T., A.M.I.I.A.

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PREFACE

TO THE FIFTH EDITION

SINCE the Fourth Edition was published the Electricity Supply Industry in Great Britain has been nationalized. Consequently references to the Electricity Commissioners, Central Electricity Board, Meter Examiners, etc., may not always be strictly appropriate. The reader will not have any difficulty in this respect if it is borne in mind that the British Electricity Authority or the Minister of Fuel and Power has taken over, under the terms of the 1947 Electricity Act, the functions of the bodies mentioned.

The book is used in other places than Great Britain and therefore it was felt undesirable to alter its arrangement, at least until meter practice becomes more stabilized as a result of the 1947 Act. It should also be mentioned that to change certain terms (e.g. P.T. to V.T.) to conform with modern practice is not practicable at the present time. The reader will not, however, be confused by the retention of the original nomenclature. The opportunity has been taken to bring the references to the electrical units up to date.

J. L. F.

ASHLEY HOUSE,
LIFFORD ROAD,
DONCASTER.

PREFACE

TO THE THIRD EDITION

The passing of the Electricity Supply (Meters) Act in 1936 has had a profound effect on the equipment and routine work of British meter-testing stations. Since June, 1937, the Electricity Commissioners have issued their various Regulations governing testing procedure and equipment, and, as the effective law is contained in these Regulations, it has become necessary to issue a Third Edition dealing with these changes.

Since the book is also used in countries other than Great Britain, it was thought advisable, however, to confine the description of the above changes to a special chapter. Other developments which have taken place since 1935 are dealt with in the appropriate chapters so as to make the book fully up to date.

I again have pleasure in thanking those organizations and engineers—particularly T. A. G. Margary, Esq., M.I.E.E.—who have so kindly given their assistance in the work of collecting information and illustrations for this revision.

J. L. F.

PREFACE

TO THE FIRST EDITION

THE testing and maintenance of electricity meters is now a recognized profession, and in virtue of this fact a need has been felt for a book devoted solely to this phase of electrical engineering. In the following pages an attempt is made to explain simply and clearly the fundamentals of electricity meters, and the methods of testing and maintaining them. I sincerely hope that it achieves this object.

The theoretical portions of the book assume a certain amount of mathematical knowledge on the part of the reader, i.e. elementary integration, vector summation, use of the slide rule, and certain trigonometrical identities. Appendices are added, however, for the assistance of those readers who have not yet reached the corresponding stage in their mathematical studies. If the reader remembers that he is dealing with integrating meters, the necessity for the frequent appearance of the integrating sign will be appreciated.

I should like to express here my gratitude to the manufacturers who have provided me with blocks and photographs; to Mr. O. Howarth, Mr. C. L. E. Stewart, the *Electrical Times*, the Institution of Electrical Engineers, and the *Electrician* for permission to utilize material from articles or books; to my brothers, W. F. and H. H. Ferns for assistance in preparing the diagrams; and to my confrères in the Testing Department of the Manchester Corporation for useful information and advice.

J. L. FERNS.

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EAST DIDSBURY,
MANCHESTER.

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METER ENGINEERING

CHAPTER I

THE COST OF AN ELECTRICITY SUPPLY

THE cost of supplying an electricity consumer is found to be made up from the following components—

CAPITAL COSTS

Service to premises.
Share of distributing mains.
Share of feeders.
Share of sub-stations.
Share of generating stations.

STANDING CHARGES

Share of wages of generating stations' staff
Share of maintenance of mains.
Share of wages of sub-stations' staff.
Share of establishment expenditure.
Share of management expenses.

RUNNING COSTS

Share of coal, oil, waste, water, stores, etc.
Share of repairs.

The manner in which these factors can be analysed and allocated is shown in the following two examples—

EXAMPLE 1

For a large consumer, taking 500,000 kWh per annum and a maximum demand of 200 kW.

The capital charges for generation are £25 per kW of maximum demand.

∴ 200 kW at £25 per kW	£5,000
Share of mains	300
Sub-stations and service	700
∴ Total capital cost	£6,000

	Cost per kWh based on 500,000 kWh
Interest and Sinking Fund charges on £6,000 .	0·24 pence
Cost of coal	0·20 ,,
Cost of oil, waste, station wages and maintenance	0·12 ,,
Cost of mains	0·03 ,,
Establishment expenses	0·005 ,,
Management expenses	0·02 ,,
Rents and rates, etc.	0·025 ,,
Total cost per kWh . . .	0·64 pence

EXAMPLE 2

For a small consumer, taking 100 kWh per annum and a maximum demand of one-fifth of a kW.

The capital charges are £25 per kW of maximum demand.

∴ ⅕ kW at £25 per kW . . .	£5
Share of mains	5
Service	10
	£20

	Cost per kWh based on 100 kWh
Interest and Sinking Fund charges on £20 .	4·8 pence
Cost of coal	0·5 ,,
Cost of oil, waste, station wages and maintenance	0·5 ,,
Cost of mains	1·5 ,,
Establishment expenses	3·0 ,,
Management expenses	0·1 ,,
Rents and rates, etc.	0·1 ,,
Total cost per kWh . . .	10·5 pence

The above examples do not pretend to be exhaustive; they are simply for the purpose of illustration. At the same time, they give some idea of the reasons why a large consumer can be supplied at a much lower rate than a small house consumer.

It is manifestly impossible to supply a consumer and then reckon up the cost of supplying him as shown in the preceding paragraphs. Not only would it be too complicated and expensive, but the consumer would have no means of checking his bill. Also he requires to know beforehand how much a certain quantity of energy is going to cost him. He is, therefore, charged on certain criteria which can be definitely determined, viz.—

1. Quantity of electrical energy used.

2. Capital outlay of service to premises.
3. Maximum power demand.
4. Power-factor.
5. Time of demand.

The ways and means of measuring the above factors are discussed in the next five chapters. Chapter V also discusses the various commercial and psychological factors which affect the construction of electricity tariffs, but it will be understood that no attempt is made to defend any particular tariff. The construction of a tariff is a complicated matter, and it can only be done by those who are in command of all the facts and requirements, viz. the management of an undertaking.

CHAPTER II

MEASUREMENT OF ELECTRICAL ENERGY

It is essential to be familiar with the definitions of the electrical units in order to understand the methods of determining the quantities mentioned at the end of Chapter I.

Ampere. The International ampere is that steady current which, in flowing through a specified solution of silver nitrate, deposits silver on the cathode at the rate of 0·001118 grams per second.

Ohm. The International ohm is the resistance offered to an unvarying current by a column of mercury of height 106·3 cm., 1 sq. mm. cross-section, and weight 14·4521 grm. at the temperature of melting ice.

Volt. The International volt is that steady e.m.f. which, applied to the ends of a conductor whose resistance is 1 International ohm, causes a current of 1 International ampere to flow.

Watt. Energy is supplied to a circuit at the rate of 1 International watt if the current in it is 1 International ampere and the pressure across it is 1 International volt.

The British legal units (see Appendix V) are defined in terms of practical standards deposited at the National Physical Laboratory, but as they agreed—as intended—with the International electrical units within very small limits, measurements up to 1st January, 1948, were usually expressed in International units. The International electrical units were chosen so as to agree as closely as possible with the Absolute Ampere, Volt, Ohm, and Watt based on the C.G.S. System of Electromagnetic Units.

On and after 1st January, 1948, the International System of Units was superseded by the Absolute System, and Appendix V indicates how the change affects the work of the meter engineer.

Ampere-hour (Ah). This is the quantity of electricity carried past a point in an electric circuit by a steady current of 1 ampere flowing for 1 hr. It is equal to 3,600 coulombs.

Watt. This equals 10^7 ergs per second.

Kilowatt (kW). The kW = 1000 watts.

Watt-hour. If energy is supplied to a circuit at the rate of 1 watt for a period of 1 hr., then the circuit has received 1 Wh of energy, i.e. 3600×10^7 ergs.

KILOWATT-HOUR. The kWh = 1000 watt-hours = $3600 \times 10^7 \times 1000$ ergs.

kW-SECOND. This unit is much used in meter work, and it is equal to 1000×10^7 ergs. It is the energy supplied by 1 kW in 1 sec.

ELECTROMOTIVE FORCE. The practical standards of e.m.f. are the Clark and Weston cells, which have the values—

Weston cell = $1{\cdot}0184 - 0{\cdot}00004\,(t - 20)$ volts, approx.
Clark cell = $1{\cdot}434\,(1 - 0{\cdot}00077\,(t - 15))$ volts, approx.
where t = the temperature in ° C.

Necessity for the Integrating Type of Meter.

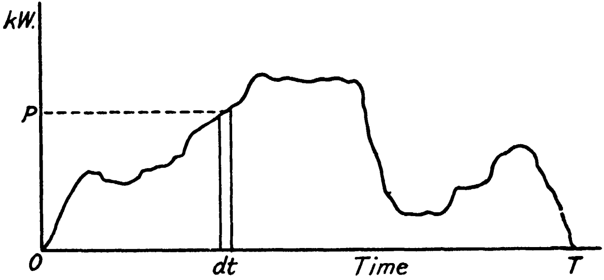


FIG. 1. CONSUMER'S LOAD CURVE

Let the curve in Fig. 1 represent the power taken by a consumer during a period of T hours. During a small interval dt the power is sensibly steady at a value of P kW.

∴ The energy supplied during interval $dt = P \cdot dt$ kWh.

∴ The energy supplied during interval $T = \int_0^T P \cdot dt$ kWh.

Thus we get the general fundamental relation—

kWh supplied $= k_1 \int_0^t$ power . dt, where k_1 depends on the units used for power and time. The instrument used for this purpose is termed a watthour meter (W.H.M.).

Therefore, if we wish to measure the amount of electrical energy supplied to a consumer over a period of time it is necessary to construct a device which will determine the quantity $k_1 \int_0^t$ power dt. The origin of the term, integrating meter, will now be clear to the reader, so let us examine the various possibilities producing such a device, bearing in mind that in the case of a constant voltage supply we can obtain the kWh used by measuring the ampere-hours supplied and multiplying by a constant. The instrument used for this purpose is termed an ampere-hour meter (A.H.M.).

Then, before going on to describe actual meters, it was thought advisable to deal with three features which are common to a great many meters, viz.—limits of accuracy, frictional effects, and eddy current braking.

Means of Obtaining an Integral Comparable with $\int_0^t$ Power . dt.

If a motor runs so that its angular velocity is always directly proportional to the power supplied to the consumer, then we have the following relations—

Number of revolutions in time t

$$= k_3 \int_0^t \text{angular velocity} \; . \; dt, \text{ where } k_3 \text{ depends on the units.}$$

But the angular velocity $= k_4$. power.

$$\therefore \text{ Number of revolutions in time } t = k_3 \, . \, k_4 \int_0^t \text{power} \; . \; dt.$$

Thus if a revolution counter is fitted to the motor spindle, it can be calibrated in terms of kWh.

If a motor on a D.C. circuit runs so that its angular velocity is proportional to the current supplied, then we have the relations:

Number of revolutions in time t

$$= k_3 \int_0^t \text{angular velocity} \; . \; dt$$

$$= k_3 \, . \, k_5 \int_0^t I \, . \, dt$$

$$= \frac{k_3 \, . \, k_5}{V} \int_0^t \text{power} \; . \; dt, \text{ if } V \text{ is a constant.}$$

Thus the revolution counter can, in this case, be calibrated in terms of either ampere-hours or kWh.

If a direct current passes through an electrolyte, then the rate of deposition at the cathode is directly proportional to the current.

$\therefore$ Weight of deposition in time t

$$= k_6 \int_0^t \text{rate of deposition} \; . \; dt$$

$$= k_6 \, . \, k_7 \int_0^t I \, . \, dt$$

$$= \frac{k_6 \, . \, k_7}{V} \int_0^t \text{power} \; . \; dt, \text{ if } V \text{ is a constant.}$$

Thus the weight, or volume, of deposition is a measure of the Ah or kWh supplied.

If two pendulums, whose normal frequencies of beat are equal, are connected to a differential gear, then the planet wheel arm will run at a speed directly proportional to the difference in frequency between the two pendulums. The pendulums are so arranged that one speeds up and the other slows down in proportion to the power supplied. The planet wheel arm is geared to a revolution counter.

$\therefore$ Number of revolutions in time t

$$= k_8 \int_0^t (\text{angular velocity of the planet wheel arm}) \,.\, dt$$

$$= k_8 \,.\, k_9 \int_0^t \text{power} \,.\, dt.$$

Thus the revolution counter can be calibrated in terms of kWh.

Limits of Accuracy. Although it is impossible to construct a perfect meter, it is quite possible to keep the errors within reasonable bounds. The British Standards Institution Specification No. 37 (1937) for electricity meters allows the following limits of error, but it should be noted that the legal British limits for all meters are now + 2½ to – 3½ per cent.

A.C. COMMERCIAL GRADE

Load	Power-factor	Error
125% – 5%	1·0	± 2%
125% – 20%	0·5 lag	± 2%
10%	0·5 lag	± 2½%

D.C. COMMERCIAL GRADE

Load	Error	
	Below 10 A	10 A and over
125% – 10%	± 2½%	± 2·0%
5%		± 2·5%

It should be noted that the above 1937 limits are somewhat different from those specified in 1930, and given in previous editions of this book.

These errors are for meters working under normal conditions, and must be modified when the conditions are abnormal as follows—

Self-heating. The following variations from time of switching on to time when registration becomes steady are allowed, provided the total error is not outside the above prescribed limits.

COMMERCIAL GRADE METERS

Induction W.H.M. at 1·0 P.F.	0·75%
at 0·5 P.F. lagging . .	1·5%
All other types	2·0%

The pressure coil, if any, must have been alive for at least 6 hours immediately before test, and no current greater than quarter load must have passed in this period.

Air Temperature Variations. None except the mercury type of 10 A or less shall have a greater temperature coefficient than 0·2 per cent per ° C. The following types shall not have a greater coefficient than 0·1 per cent per ° C.: (1) induction meters at unity power factor; (2) induction meters at 0·5 lag at marked current and at 50 cycles; and (3) mercury meters (A.H. and W.H.) for 100 A and over.

Voltage Variations. The following variations shall not cause a greater change in error than 1 per cent on any load between full load and one-twentieth load (one-tenth load, D.C.).

A.C.	± 10%
D.C.	± 5%

Frequency Variations. For ± 5 per cent alteration—

Commercial grade	at 1·0 P.F.	0·75%
	at 0·5 P.F. lagging. . . .	2·0%

Stray Field Variation. With the standard field of 1·25 c.g.s. units, the variation in error must not be greater than 1·5 per cent on any load from full load to quarter load at unity power-factor.

The standard field is produced by a coil 1 metre in diameter having 100 ampere-turns, and the meter is placed in any vertical direction at the centre. It is also produced by a straight conductor carrying 625 A at a distance of 100 cm. from the meter.

Starting Current Regulations. The rotor must start and continue running with $\frac{1}{200}$th of the rated current (a minimum of $\frac{1}{20}$A is permitted, however, for D.C. meters), the voltage circuit, if any, being energized at the rated voltage so as to give unity power-factor.

Revolution Counter Friction. Removal of the counter should not cause more than 1·5 per cent change in speed on one-twentieth load.

Effect of Friction on a Rotating Disc or Armature. Let us consider the typical meter disc mounted on a steel pivoted spindle, with a jewelled bearing at the bottom and a bush and pin bearing at the top. Friction is present in both bearings and in the gearing of the revolution counter.

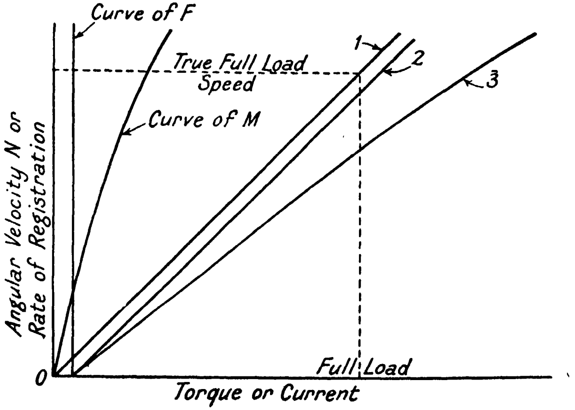


FIG. 2. TORQUE-SPEED CHARACTERISTICS

Let F = frictional torque. (This is sensibly constant at all speeds.)

T = driving torque due to the meter coils.

G = eddy current braking torque, which will be shown in the next section to be proportional to the speed.

When running steadily, the various torques must balance.

$$\therefore \quad T = F + G$$

$$= F + k_1 . N, \text{ where } N = \text{angular velocity of the disc.}$$

This relation is shown by curve 2 (Fig. 2). If F were zero, then the curve would become curve 1 (Fig. 2), and the meter would be "perfect" if the torque were directly proportional to the current or power which the meter is to integrate. (If the spindle is definitely geared to a revolution counter, then the scale of angular velocity in Fig. 2 can be converted to one of rate of registration. If the driving torque is directly proportional to the power or current as the case may be, then we can add a power or current scale alongside the torque scale. The error of the meter for a given load can then be found from the appropriate curve.) The reason for the jewelled bearing is now obvious; we wish to make F as small as possible. In certain meters we can achieve curve 1 (Fig. 2) by compensating for F, i.e. imposing a torque equal to F on the rotor independent of the currents being measured.

Dynamic or Fluid Friction. In the mercury meter there is also a friction present due to the motion of the disc in a fluid. This friction is approximately proportional to the square of the angular velocity of the disc. Let M represent this dynamic friction. Thus, in this case, for torque balance we have—

$$T = F + G + M = F + k_1N + k_2N^2$$

The above equation is represented by curve 3 (Fig. 2).

The Eddy Current Brake.

Let B = mean flux density.
v = the mean speed with which the disc cuts the flux in cm./sec.
t = thickness of the disc in cm.
w = width of the magnetic field in cm.
d = length of the magnetic field in cm.
ρ = specific resistance of the disc material.
r = effective radius of the disc in cm.

The diagram in Fig. 3 gives some idea of the lay-out of the flux and eddy currents. Consider the electrical action along the mean eddy current path K of width x. The length of this path is approximately 2·5 times the length of the magnetic field, which has been assumed rectangular for the sake of simplicity.

The e.m.f. induced in path $K = B\,.\,v\,.\,d\,.\,10^{-8}$ volts.
The resistance of path $K = 2{\cdot}5 \times d\,.\,\rho/t\,.\,x$ ohms.

∴ The eddy current in path K

$$= \frac{B\,.\,v\,.\,d}{10^{+8}} \times \frac{t\,.\,x}{2{\cdot}5d\,.\,\rho}\,\text{A.}$$

$$= B\,.\,v\,.\,t\,.\,x/\rho \times 4 \times 10^{-9}$$

This current is for the portion of width x, therefore the total eddy current in the width w is given by—

$$\text{Total current} = I = \frac{B \,.\, v \,.\, t \,.\, w}{\rho} \times 4 \times 10^{-9}\ \text{A.}$$

$\therefore$ The retarding force on the disc $= B \,.\, d \,.\, I/10$ dynes.

$\therefore$ The retarding torque on the disc

$$= B \,.\, d \,.\, I \,.\, r/10 \text{ dyne-cm.}$$

$$= \frac{B^2 \,.\, d \,.\, w \,.\, t \,.\, v \,.\, r}{\rho} \times 4 \times 10^{-10}$$

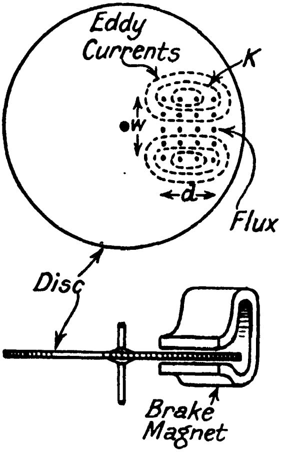


FIG. 3. THE EDDY CURRENT BRAKE

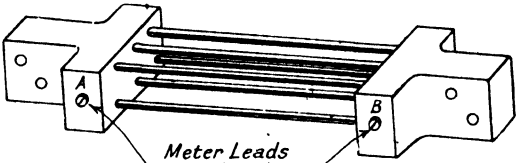
We can now perceive the factors on which the eddy current brake torque depends.

1. The importance of magnetic permanency is clear, since the brake torque is proportional to B^2. A 1 per cent change in B requires a 2 per cent change in v to restore the torque to its original value, i.e. a 2 per cent change in the meter error.
2. It is necessary to keep ρ as low as possible, which limits the disc material to either copper or aluminium. Aluminium is used when lightness is essential, but copper is used when the maximum possible braking effect is desired.
3. As v is proportional to r, it follows that the brake torque is proportional to r^2. Owing to mechanical difficulties, such as

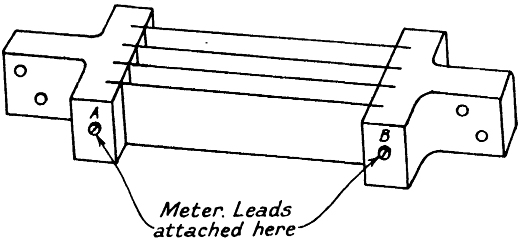
weight and overall meter size, this property cannot be given its full scope.

4. The torque is proportional to the thickness of the disc.

5. Since $B = \text{flux}/w \,.\, d$, then $B^2 = \text{flux}^2/w^2 \,.\, d^2$. Therefore the brake torque is proportional to $\text{flux}^2/w \,.\, d$. Thus it is advantageous to make $w \,.\, d$ as small as possible. If $w \,.\, d$ is made too small, however, the magnet is not so good from the point of view of permanency. It is necessary, therefore, to strike the happy medium. This property is made use of in the Ferranti type F.L. induction meter, for calibration purposes, by means of an adjustable annular iron plate on one of the poles of the fixed permanent magnet.



Rod Type



Laminated Type

FIG. 4. TWO COMMON TYPES OF SHUNTS

DIRECT CURRENT METERS

Shunts. Very often the current to be measured is far too large to be handled by a delicate meter, so a device is required whereby a definite proportion of the main current can be passed through the meter. If the proportion is the same for all loads, then the action of the meter is still proportional to the power supplied, and can be calibrated accordingly. This device is simply a resistance placed in parallel with the meter current coil. It is made of zero temperature coefficient material, such as manganin or German silver, so that its resistance will not vary due to self-heating or change of ambient temperature. In order to keep it as cool as possible, it is constructed as shown in Fig. 4. The laminated type should be fixed with its laminations vertical; the convection currents passing upwards between the laminations help to carry away the heat generated by the current.

All leads to the shunt must have a sufficient contact area to avoid overheating, and for the same reason all contact faces must be perfectly clean when the joints are made. The latter applies particularly to the contacts of the shunt leads, since a bad contact is virtually an increase in the resistance of the meter current circuit above that for which the meter was calibrated. Consider Fig. 4, and let

R = resistance of the shunt between terminals A and B.
r = resistance of the meter circuit between terminals A and B.
I_L = current to be measured.
i_s = current passing through the shunt.
i_m = current passing through the meter circuit.
E = the potential difference between terminals A and B.

$$\therefore \quad i_s = E/R$$

$$\therefore \quad i_m = E/r$$

$$\text{Now } I_L = i_s + i_m = E/R + E/r = E(R + r)/R \,.\, r$$

$$\therefore \quad \frac{i_m}{I_L} = \frac{\dfrac{E}{r}}{\dfrac{E(R + r)}{R \,.\, r}} = \frac{R}{R + r} = \frac{\text{Meter circuit current}}{\text{Current to be measured}}$$

Thus we are now in a position to find what proportion of the load current passes through the meter (at the temperature for which R and r are valid, and provided there are no other e.m.f.'s acting).

Effect of an e.m.f. in the Meter Circuit. Let the e.m.f. induced in meter current circuit equal e volts.

$$\therefore \quad i_m = (E - e)/r$$

$$\therefore \quad \frac{i_m}{I_L} = \frac{\dfrac{E - e}{r}}{\dfrac{E - e}{r} + \dfrac{E}{R}} = \frac{R(E - e)}{R(E - e) + E \,.\, r}$$

Therefore care must be taken before we can say which equation gives the correct value of the meter circuit current. In certain cases, e is quite appreciable.

Mercury Motor Ampere-hour Meters. The general features of the Chamberlain and Hookham meter are shown in Fig. 5. The moving system consists of a copper disc D mounted on a spindle. The disc is enamelled all over, except for the rim and a narrow ring round the spindle, which are amalgamated. The enamelling helps to concentrate the current in the disc and also tends to reduce the mercury friction. At the head of the spindle a pinion is fitted, and this meshes with the first wheel of a revolution counter mounted on the bracket M. The disc is pivoted by means of a jewelled bottom bearing H and a pin type top bearing N, so as to be able to rotate freely in the mercury bath E. The weight of the moving system is so designed that the disc just fails to float. (Mercury is much denser than copper or steel.) This reduces the stress on the jewel enormously and causes the friction due to this feature to be small.

The permanent magnet A is fitted with a special pole-piece arrangement (BB) made of wrought iron, the pole tips being embedded in circular brass castings (EE), whose interior faces are covered with insulating material. The pole tips are separated by a distance of approximately 2½ times the thickness of the disc. Mercury leakage is prevented by the leather-lined sealing band C. This band is fitted with a stoppered tube by means of which the bath can be filled with mercury. It is also fitted with a current collector J.

The opening by which the spindle passes through the top pole block is provided with a valve G, which is closed during transport. The valve performs two functions: it seals the mercury chamber and also clamps the rotor, thus preventing loss of mercury and damage to the jewel.

Attached to the permanent magnet is the solenoid I, whose core is mounted on the pole pieces $B'B'$ by brass plates. The effect of the solenoid on the permanent magnet can be adjusted by means of the screws LL. Screwing-in increases the effect of the solenoid, which is to decrease the flux in the bath.

The current enters the meter at the positive terminal, and is conducted to the metal insert which carries the bottom jewel H. The head of this insert is amalgamated, and from it the current passes through the mercury to the amalgamated ring at the centre of the disc. The current leaves the rim of the disc opposite the collector J, passes through the mercury to J, and thence *via* the solenoid to the negative terminal. The current passes through the disc in the region of the magnetic field and, for reasons given later, only a trifling proportion of the current passes directly through the mercury from the metal insert to the collector J.

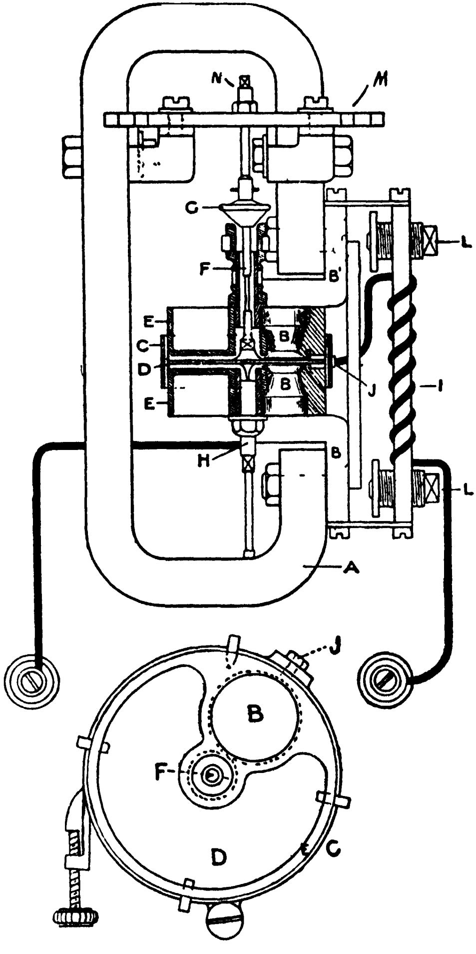
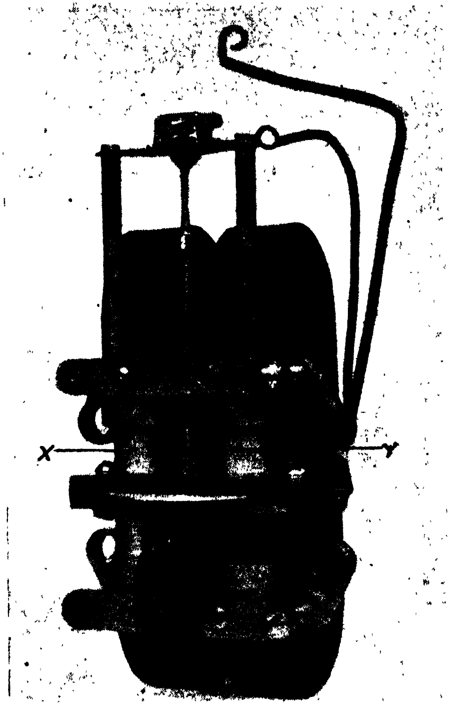


Fig. 5. The Chamberlain and Hookham 1907 Model A.H.M

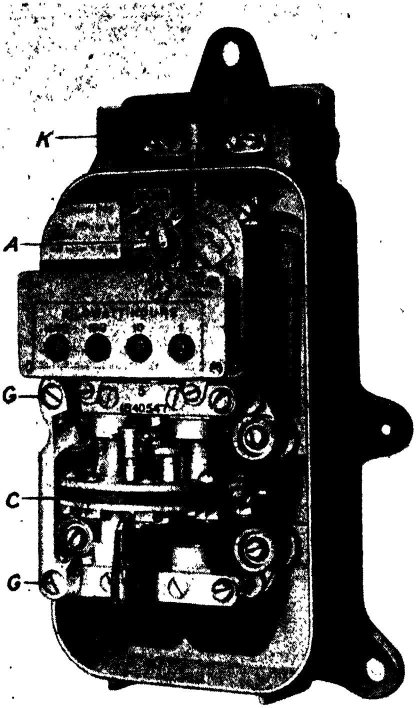
All the meter parts are mounted on the magnet, which is fixed to the case of the meter by two insulated clamps, because if the meter is connected in the live line, the meter parts are obviously at the line voltage to earth. The first wheel of the revolution counter is detachable from its spindle, being held in place by a nut and a coned seating. The number of teeth on this wheel determines the calibration constant of the meter and varying the size of this wheel provides the sole means of calibration. The makers supply charts which give the connection between wheel size and constant. The theory of the mercury meter is discussed on page 19.



(*Ferranti, Ltd.*)

FIG. 6. THE FERRANTI F.H. TYPE A.H.M. (SECTIONAL VIEW)

The Ferranti F.H. Model differs from the Chamberlain and Hookham meter in the arrangement of the magnet system. Two similar permanent magnets (see Figs. 6 and 7) are used, and their adjacent poles, which are of like polarity, are commoned by means of iron bars. The lower of these bars is encircled by a coil which carries the mercury bath current. This coil creates a magnetomotive force which reduces the flux in magnet gap *X*, but increases the flux in gap *Y*. Thus the total flux is unaltered, although the driving flux is increased. (*Y* is the driving magnet, since the meter current passes through its field.) The coil wound round the magnet *Y* is to prevent demagnetization of the magnets



(*Ferranti, Ltd.*)

FIG. 7. THE FERRANTI F.H. TYPE A.H.M.

when a short circuit occurs on the consumer's installation. For calibration purposes, a magnetic shunt *C* is fitted to the magnet system. Adjusting the screws *G* enables the amount of flux diverted from the magnet gaps to be varied, giving a 5 per cent range in the speed of the meter disc.

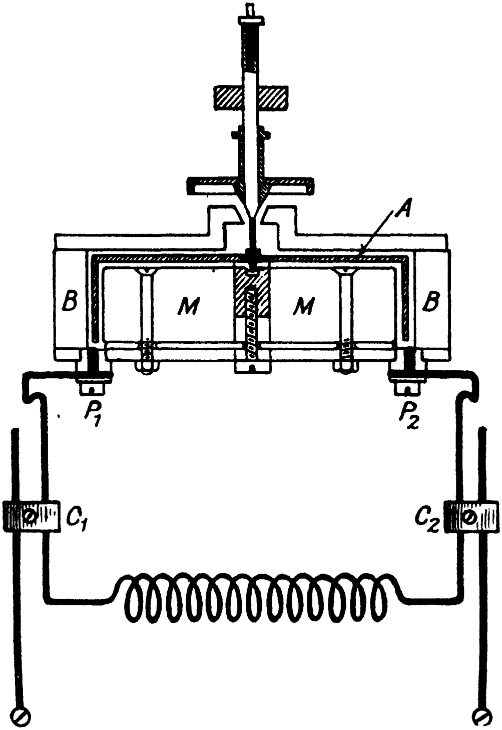


FIG. 8. THE MEASUREMENT H.M. TYPE A.H.M.

The revolution counter is driven by means of a worm on the disc spindle. The counter is fitted with an adjustable countershaft arrangement *A*, which enables the gear ratio to be altered for primary calibration purposes. The makers provide tables giving the connection between the number of teeth on the gear wheels and the meter constant. The screw *K* operates the sealing and clamping device. All the working parts of the meter are insulated from the meter case.

The Measurement H.M. Model meter is quite different in construction from the preceding ones. By employing the latest type of cobalt steel magnet, the full-load speed has been kept down to 20 r.p.m., and this enables the meter to dispense with a device for compensating for the fluid friction of the mercury. The rotor *A* is bell-shaped (see Fig. 8), and is amalgamated all over. The clearances in the bath are small, but by means of a special tool the rotor can be accurately fitted when assembling the meter. The magnet *M* is fixed diametrically in the space under the rotor, and the return path for the flux is formed by the steel ring *B*. This ring also forms the outside wall of the mercury bath, the top and bottom of which are nickel-plated brass plates.

The current is led in and out of the bath by the diametrically opposite contacts P_1P_2, which are placed so that the current in the disc passes through each magnetic field due to *M*. The one magnet thus provides two fields for driving torque purposes. A strong flux is obtained, because the thick steel ring *B* has a very low reluctance. (When repairing the meter, the magnet and ring should not be separated.)

The revolution counter is not provided with a means of altering the gear ratio, so the calibration must be effected by adjusting the positions of the contacts C_1C_2. Altering these contacts varies the ratio Bath resistance/Shunt resistance, and therefore the speed of the disc.

Theory of the Mercury A.H.M. Owing to its simplicity, let us first consider the single magnet type of A.H.M., the mercury bath being at a steady temperature.

Let k_1, k_2, etc. = various constants.
B = mean flux density in lines per sq. cm.
r_1 and r_2 = effective radii of the disc in cm.
I_L = current to be measured in amperes.
i_s = current passing through the shunt.
i_m = current passing through the meter.
N = angular velocity of disc in revolutions per sec.
F = torque required to overcome the solid friction of the pivots, mercury, and counter in dyne-cm.
M = torque required to overcome the fluid mercury friction.
T = driving torque.
G = eddy current brake torque.
v = mean velocity with which the disc cuts the flux in cm. per second.
d = radial length of the magnetic field in cm.

Since mercury has about 59 time[redacted] of copper and the area of a cross-section of copper [redacted] gap is probably nearly equal to that of the merc[redacted] majority of the current i_m will flow through the disc[redacted]owing proofs it is assumed for simplicity that all the [redacted]ent passes through the disc.

Clearly the torque $T = \frac{B \cdot i_m \cdot d \cdot r_1}{10}$ dyne-cm. . . (1)

$\therefore$ $T \propto B \cdot i_m$ . . . since d and r_1 are constants.

$\therefore$ $T \propto i_m$ . . . . . since B is a constant in this case

When the disc is rotating, an e.m.f. is induced in it which sets

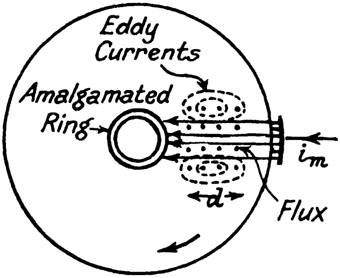


FIG. 9. DIAGRAM OF THE CONDITIONS IN THE METER DISC

up eddy currents in the regions shown in Fig. 9 and also opposes the flow of i_m.

The radial value of this e.m.f.

$$= e = \frac{B \cdot v \cdot d}{10^8} = 2\pi \cdot B \cdot d \cdot r_2 \cdot N \times 10^{-8} \text{ volts}$$

$\therefore$ $e \propto N \cdot B$ . . . since d and r_2 are constants.

Therefore by Ohm's law the eddy currents set up in the disc are proportional to $N \cdot B$.

Now $G \propto B \times$ eddy currents,

$\therefore$ $G \propto B^2 \cdot N$, ... (2)

$\therefore$ $G \propto N$ . . . since B is a constant in this case.

When the disc is running steadily, the various torques must balance,

$\therefore$ $T = F + G + M$.

Now F is reasonably constant at all speeds and M is approximately proportional to the square of the disc speed, when the temperature is steady.

$$\therefore \quad T = F + k_1 . N + k_2 . N^2,$$

$$\therefore \quad i_m \propto F + k_1 . N + k_2 . N^2 \; . \; . \; . \text{ from equation (1).}$$

But the revolution counter is calibrated in ampere-hours (or kWh if the supply voltage is assumed constant), and if it is to read correctly then N must be directly proportional to i_m, since—

Ampere-hours used in time t_1 to t_2 hours $= \int_{t_1}^{t_2} i_m . dt$, and

Ampere-hours registered in time t_1 to t_2 $= k_3 \int_{t_1}^{t_2} N . dt$, where k_3 depends on the gearing of the counter, etc.

Fig. 2 illustrates graphically the meter characteristics as determined above. Curve 1 is the one desired, curve 2 shows the effect of solid friction, whilst curve 3 represents the equation $T = F + k_1 . N + k_2 . N^2$. The effects of F and M are exaggerated in Fig. 2 in order to distinguish between the various curves. Since the meter must go on starting current, i.e. one-two-hundredth of full load, it follows that F is of the order of one-four-hundredth of the full-load driving torque.

Compensation for M. Modern meters are expected to be accurate to within ± 2 per cent, so curve 3 should not differ from curve 1 by more than 2 per cent in the region one-tenth to full load. This cannot be achieved in most meters without compensating for the effect of M. The compensation is effected by means of a coil carrying i_m, which is arranged to decrease the flux density B. The decrease in B is proportional to i_m, because of the air gaps in the magnetic circuit. Thus in the case of a compensated meter, the working flux density is given by—

$B_b = B_a - k_4 . i_m$ . . . where B_a = flux density due to the permanent magnet.

But $T \propto B . i_m$ . . . see equation (1),

$$\therefore \quad T \propto B_a . i_m - k_4 . i_m^2$$

But $G \propto B^2 . N$ . . . see equation (2),

$$\therefore \quad G \propto N(B_a^2 - 2 . k_4 . i_m . B_a + k_4^2 . i_m^2).$$

As $k_4^2 . i_m^2$ is small compared with $2 . k_4 . i_m . B_a$, we can neglect it.

$$\therefore \quad G \propto N . B_a^2 - 2 . N . k_4 . i_m . B_a$$

But i_m is approximately directly proportional to N,

$$\therefore \quad G \propto N \,.\, B_a^2 - 2 \,.\, N^2 \,.\, k_5 \,.\, B_a$$

As before, $T = F + G + M$,

$$\therefore \quad B_a \,.\, i_m - k_4 \,.\, i_m^2 \propto F + k_1 \,.\, N \,.\, B_a^2 - 2 \,.\, N^2 \,.\, k_1 \,.\, k_5 \,.\, B_a + k_2 \,.\, N^2.$$

By adjusting k_4 we can make $(-k_4 \,.\, i_m^2)$ balance the component $(-2 \,.\, N^2 \,.\, k_5 \,.\, k_1 \,.\, B_a + k_2 \,.\, N^2)$, which leaves us with the relation $i_m \propto F + k_6 \,.\, N$, since B_a is a constant and $k_6 = k_1 \,.\, B_a^2$.

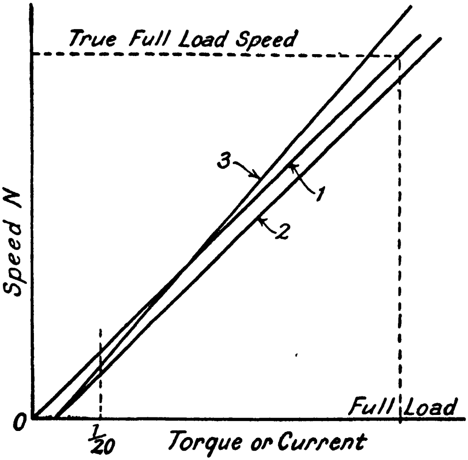


FIG. 10. METER CHARACTERISTICS

Thus we can compensate for M and make the meter characteristic equal curve 2 (Fig. 2). It is not possible to compensate for the frictional torque F on commercial meters.

For correct registration on a fully compensated meter, the relation between i_m and N must be a definite quantity, as shown by curve 1 (Fig. 10). If the friction compensation is removed, then the meter characteristic becomes curve 2. If the relation between i_m and N is altered, then the meter characteristic becomes curve 3, the constant k_6 being increased. The beneficial influence of the increase in k_6 is seen in the meter error curves (Fig. 11). The improvement is obtained by making the meter disc rotate faster for a given current by the usual methods or by altering the gear ratio of the revolution counter. In many meters the curve is first obtained and then a gear wheel is chosen to suit it. The dotted curves in Fig. 11 show the effect of incomplete compensation of M.

Temperature Variations in Unshunted Meters. A permanent magnet weakens by 0·03 per cent per ° C. rise of temperature. Now, the driving torque is proportional to B, but the braking torque is proportional to B^2, therefore the meter will speed up by 0·03 per cent per ° C. on all loads due to this cause.

The temperature coefficients of copper and mercury are 0·4 per cent and 0·07 per cent per ° C. respectively. Therefore with rise of temperature more current will pass through the mercury and less through the copper disc than formerly. The meter will run slower on this account by approximately 0·005 per cent per ° C.

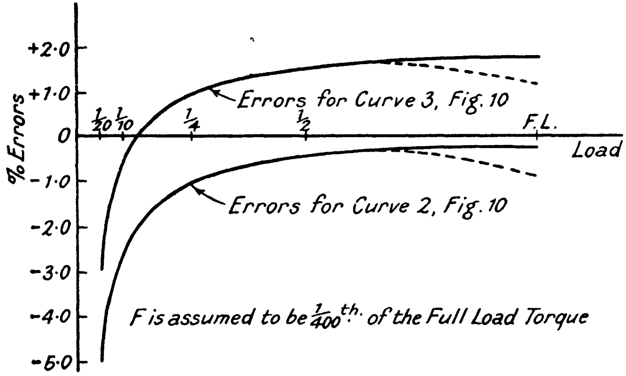


FIG. 11. METER ERROR CURVES

The increase in disc resistance with temperature rise causes a reduction in the value of the eddy currents of 0·4 per cent per ° C., and this causes the meter to speed up by the same percentage, since the eddy current brake torque is proportional to (B × eddy current).

With increase of temperature the density of the mercury becomes less and the solid friction due to it is reduced, thereby causing the meter to speed up, particularly on low loads. The fluid friction appears to increase slightly with rise of temperature.

Self-heating Errors. If a meter is tested after being idle for a long time and then tested again after running on full load for an hour, a considerable difference will be found between the results of the two tests. The two curves in Fig. 12 give the average change in a well-known type of 5A A.H.M. These curves show that the solid friction is reduced by approximately 25 per cent by the warming-up process, whilst the increase in disc resistance has altered the error at all loads by about 1 per cent. The reason for running the meter on full load for a considerable time before commencing a test is now obvious. This change is termed the self-heating error, and it is further illustrated by Fig. 13.

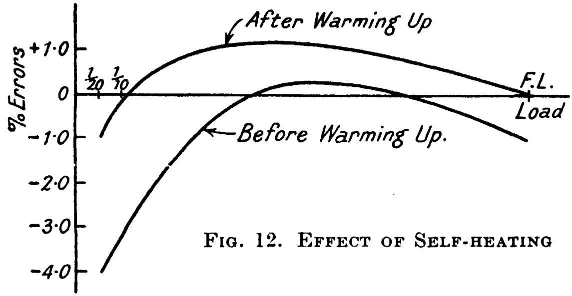


Fig. 12. Effect of Self-heating

If a number of meters are tested at two different steady temperatures and the errors compared, it will be found that the meters are faster at all loads on the higher temperature. The difference, however, is not the same for all loads, and furthermore it is very erratic on low loads due to the varying effect on the solid friction of the mercury. Thus the utilization of a temperature coefficient to obtain the meter error at 60° F. (the temperature at which the mercury meter should be within the B.S.S. limits) is somewhat of a compromise. An average figure for this coefficient for the unshunted meter is 0·36 per cent per ° C.

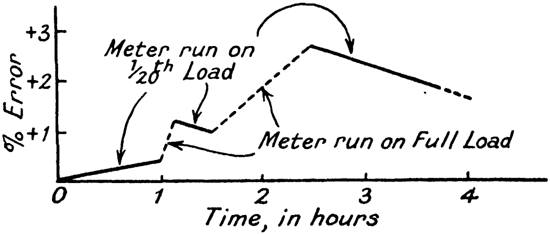


Fig. 13. Variation in $\frac{1}{20}$ Load Error Due to Self-heating and Cooling

The Two-magnet Type of Meter. In this type, both magnets act as brake magnets, but only one as a driving magnet (see page 17). The compensating coil is wound so that it strengthens the driving magnet and weakens the other by the same amount. The braking flux is, therefore, unaltered, but the driving torque is increased by an amount proportional to the square of the current, which is sufficient to balance the fluid friction. Apart from this difference, the action of the meter is as previously described.

Meters without Compensation for Fluid Friction. If the full-load speed is kept below 20 r.p.m., it is possible (see page 19) to dispense with a compensating device. This is because the fluid friction is proportional to the square of the speed and is, therefore, not excessive, and even advantageous, at 20 r.p.m. The older type of meter usually had a full-load speed of more than 40 r.p.m.

The Shunted Type of Meter. When the meter is tested with its shunt, it does not directly concern the tester what is the actual value of the ratio i_m/I_L, provided the error of the meter can be made within ± 2 per cent. This is not the case, however, when the meter is tested apart from its shunt. For separate calibration, the correct method is first to determine the resistance R of the shunt. From R the volt drop E for a shunt current i_s can be calculated. The meter is then tested to find the current i_m when the voltage E is applied to the ends of the shunt leads. During this latter test the disc must be rotating, the necessity for this having been proved on page 13. Thus we can find I_L, i.e. $i_s + i_m$, for a certain volt drop E across the shunt leads. I_L is directly proportional to E, so we can simulate any load current by providing the appropriate volt drop E. (*N.B.* The meter *must* be calibrated with its *own* shunt leads, or an equivalent resistance.)

Temperature Variations in Shunted Meters. The shunt is of low temperature coefficient material and, therefore, its change of resistance with temperature will be small. The resistance of the meter circuit, r, will increase 0·4 per cent per ° C. rise, since it consists mainly of copper. Thus the ratio i_m/I_L and, therefore, the speed of the meter, will decrease with an increase in temperature, the amount depending on the relative values of R and r, and the temperature coefficient of the shunt. The shunt improves the overall temperature coefficient of the meter to about 0·1 per cent per ° C. The self-heating variations given for the unshunted meter apply to this type also.

Temperature Compensated Mercury Motor AHM. Messrs. Metropolitan-Vickers have now introduced a mercury AHM which is compensated to a large degree for temperature changes, by means of special pole tips of copper-nickel alloy fitted to the poles of the magnets. Copper-nickel alloys have the property of large changes in permeability for small changes in temperature.

The Commutator Motor Type Meter. The moving system of the Metropolitan-Vickers O Model (see Fig. 14) consists of a hollow aluminium disc mounted on a spindle which is pivoted in a jewelled bottom bearing and a pin type top bearing. Inside the disc are arranged pancake type coils, which are connected to the three part commutator *C* at the head of the spindle. The current is fed into the coils by means of two delicate gold alloy brushes, B_1B_2.

The motion of the disc is caused by the armature coil currents reacting with the fields of the magnets M_1M_2, whilst the braking torque is created by the eddy currents set up by the motion of the disc in the magnetic fields of M_1 and M_2.

Owing to the delicate commutator and brushes, the greater part of the line current passes through the shunt *S*. Adjustment of either the shunt or armature circuit resistance (whichever is the easier) forms the means of calibrating the meter. The full-load speed is about 100 r.p.m.

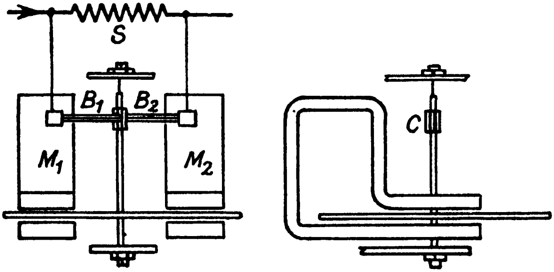


FIG. 14. M.V. TYPE O COMMUTATOR METER

The action of the meter is that of a separately excited D.C. motor (the permanent magnets correspond to the fixed separate excitation) and, therefore, does not require discussion here. Since the flux is constant, it follows from the expression for the torque of a D.C. shunt motor, i.e. $T = k_1 . \Phi . I_A . Z$, where k_1 is a constant depending on the units used, Φ equals the total flux, I_A equals the armature current, and Z equals the number of armature conductors, that the torque is proportional to the current I_A and, therefore, to the line current. It also follows from the expression for the armature e.m.f., i.e. $E = k_2 . \Phi . Z . N$, where k_2 is a constant depending on the units used and the armature connections, and N equals the angular velocity of the armature, that the back e.m.f. of the motor is directly proportional to N.

Now the armature windings are mounted on a rotor of high conductivity metal and, as in the case of the mercury A.H.M., the eddy currents and the brake torque are proportional to the speed N, since the flux is constant. Hence the disc will run at such a speed that the driving torque balances the brake torque plus the frictional torque. The meter characteristic will, therefore, be of the type shown by curves 2 (Figs. 2 and 10) and curves 1 and 2 (Fig. 11).

As a rule, no attempt is made to compensate for the frictional torque, and, consequently, the performance of the meter on low load is governed by the workmanship and the design of the brushes, bearings, and counter. Wear and tear on the brushes and bearings cause the low-load errors to change considerably, resulting in much loss of revenue. The maintenance is also costly owing to the delicate brushes and commutator. This is why the commutator A.H.M. is not extensively used at the present time.

Variations Due to Temperature. The use of a shunt makes the overall temperature coefficient practically zero, because the percentage reduction in the eddy currents per ° C. rise is almost the same as the percentage reduction in the armature current due to the rise in resistance of the copper armature windings. The actual value of the coefficient in a particular meter depends on—

1. The ratio armature resistance/shunt resistance.
2. The temperature coefficient of the shunt.
3. The temperature coefficient of the permanent magnet.

Torque Variations. Since the armature coils are not always symmetrically placed with respect to the magnets, the driving torque will vary with the position of the rotor. This does not affect the running of the rotor at medium or high speeds, because of its inertia, but at low speeds the running is a little erratic. The variations depend on the number of coils and commutator segments, and their arrangement. This variation sometimes causes trouble on starting current, because the low torque in certain positions may not be sufficient to overcome the frictional torque.

Undamped Type Commutator Meter. The early type of meter had no eddy current brake, but depended for its operation on the armature running at such a speed that the back e.m.f. was reasonably equal to the volt drop across a shunt in the circuit to be measured. If there were no friction losses, the angular speed would be directly proportional to the line current, since the flux is a constant. The frictional losses, however, require a current to flow in the armature to provide the necessary driving torque. Thus the error curve drooped at low loads very badly. The full-load speed was about 250 r.p.m., which led to rapid wear of the bearings. This type of A.H.M. is now obsolete.

Electrolytic Type Meters. The Bastian meter consists of a glass bulb N (see Fig. 15), whose upper portion has a uniform bore.

At the start the bulb is filled with an electrolyte of water *E*, containing a small percentage of sulphuric acid. To prevent evaporation in the normal way, a thin layer of paraffin *F* is poured over the surface of the water. In the lower part of the bulb are two platinum electrodes *A* and *K*, the leads to which are passed down the ebonite tubes *DD*. By means of the uniform scale *H* the height of the water can be determined, and thus the change in height between any two times. The leads *B* and *C* are in series with the mains.

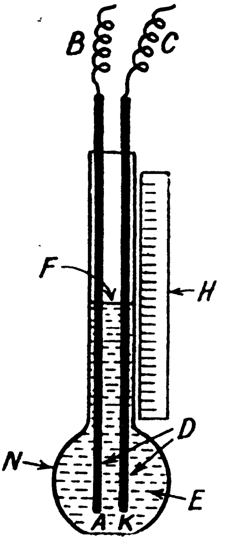


FIG. 15. THE BASTIAN METER

When a current passes between *A* and *K*, electrolysis is set up, and the water is decomposed into its constituents hydrogen and oxygen, which are exhausted into the air. By Faraday's laws, the rate of decomposition is proportional to the current passing. (The H_2SO_4 is added to assist the action of decomposition and to reduce the resistance of the electrolyte, since pure water is a non-conductor.) Thus the rate of losing water and the rate of fall of the water level in the uniform tube are proportional to the current. Therefore, the change in level of the water is a measure of $\int_{t_1}^{t_2} I \, . \, dt$, i.e. the ampere-hours supplied to the consumer.

This meter has many disadvantages which have led to its disuse, viz.—

1. The chemical back e.m.f. is 1·5 volts, and with the resistance drop causes a loss in voltage of 3 volts at full load. This means a large loss of energy in the meter and, since the meter cannot be shunted, it follows that the meter is restricted to low current circuits.
2. The tube requires refilling periodically with water, and if this is neglected all record of the consumption is lost.
3. Owing to dirt getting in the tube it becomes difficult to read the meter after several years' service.
4. The meter is troublesome to install.

Another and later form of the above meter uses an alkaline electrolyte of caustic soda with nickel electrodes. Although this reduces the internal resistance and volt drop, and the electrodes are not liable to be eaten away as in the former type, the meter still labours under the other above-mentioned disadvantages.

The connection between the loss of water and the ampere-hours is: 100 Ah. decomposes 34·64 cub. cm. of water.

The construction of the Reason meter is shown in a simplified form in Fig. 16. The bulb *B* at the start is filled with mercury, the remainder of the tube containing mercurous nitrate *E* or some other mercurous salt. The tube *T* is carefully made so as to have a uniform bore. Thus the linear scale at the side can give a measure of the weight of mercury contained in *T*. The glass tube, which is hermetically sealed, is supported on springs, and is provided with a means of being inverted for resetting purposes.

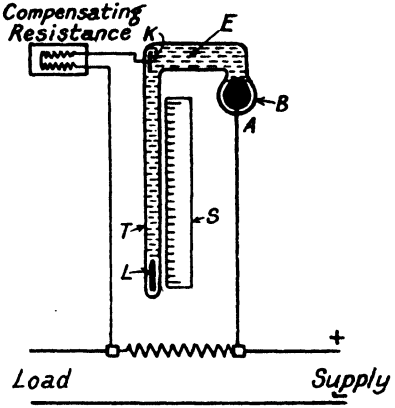


Fig. 16. Principle of the Reason Meter

The current is led in at *A* and out at *K*, and chemical action takes place according to Faraday's laws. Thus mercury is deposited at *K* at a rate proportional to the current passing through the bulb. Owing to its vertical position, the mercury cannot remain on the surface of the cathode and, therefore, falls into the tube *T*. Thus the mercury rises in *T* at a rate proportional to the current. Therefore the change in level is a measure of the ampere-hours supplied to the consumer.

The back e.m.f. of this type of electrolytic meter is only about one-ten-thousandth of a volt. If the shunt volt drop (a shunt is always used with this type of meter) is 1 volt at full load, then the error due to the back e.m.f. is only 1 per cent at one-hundredth load even.

As the electrolyte has a negative temperature coefficient, it becomes necessary to make part of the meter circuit resistance of copper, the remainder being of the same material as the shunt.

The amount of copper is adjusted until its change of resistance with temperature equals that of the electrolyte. For a given bore and scale marking, there is a definite relation between the shunt

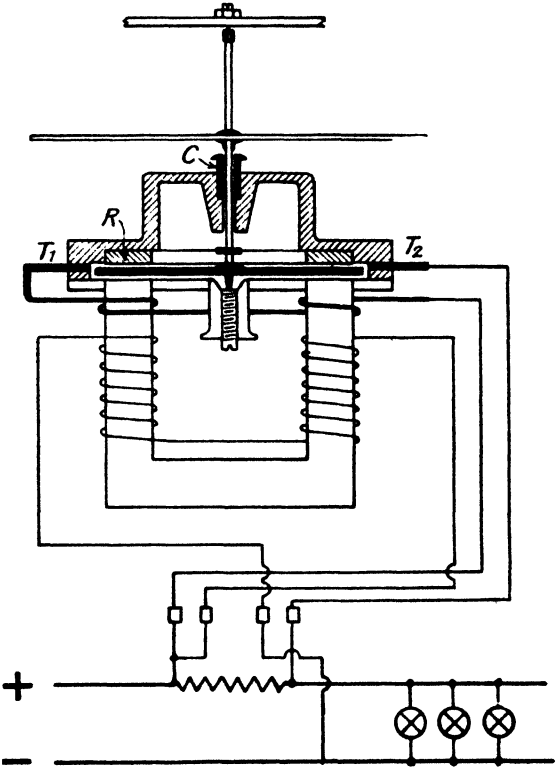


FIG. 17. THE CHAMBERLAIN AND HOOKHAM MERCURY W.H.M.

resistance and the meter circuit resistance. Thus if the meter is correctly designed and made, no calibration is necessary.

D.C. WATT-HOUR METERS

Mercury Type Watt-hour Meters. The moving system of the Chamberlain and Hookham meter, which is pivoted in the usual manner, consists of a spindle on which are mounted two discs, a copper one in the mercury bath and an aluminium one above it. The upper disc runs between the poles of a permanent magnet and thus forms the braking disc. Below the bath is mounted a U-shaped electromagnet core carrying two coils wound with fine gauge copper wire. The coils are connected in series across the mains. The return path of the flux is formed by the iron ring *R* (see Fig. 17).

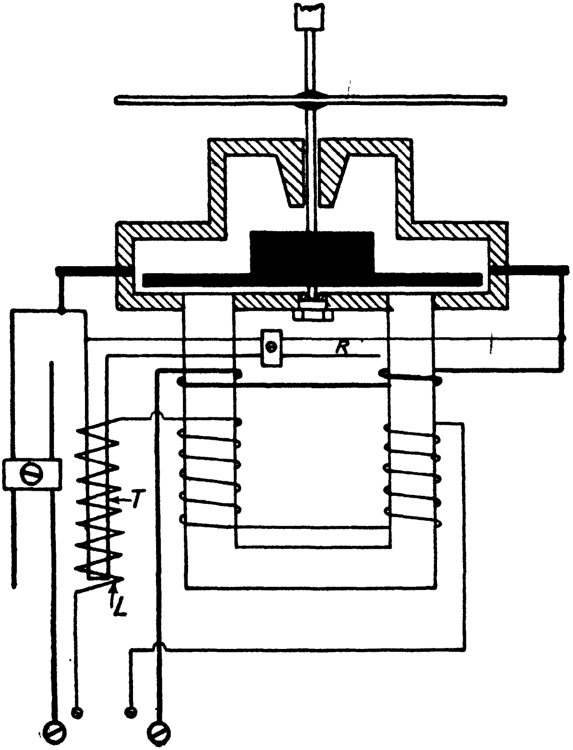


FIG. 18. THE SANGAMO MODEL D.5 MERCURY W.H.M.

The current to be measured, or a proportion of it, is passed diametrically across the bath between the contacts T_1 and T_2. Thus both the magnetic fields provide a driving torque on the disc. The bath current is also passed round the electromagnet core for a few turns, in such a direction as to increase the flux.

The mercury bath is formed on the unspillable ink-well principle, but the spindle is provided with a clamping device *C* for transport purposes. The weight of the moving system is about 50 grm., but due to the immersion of the lower disc in mercury the weight on the jewel is only about 5 grm. The other features of the meter are similar to those of the corresponding type of A.H.M.

The general arrangement of the Sangamo D.5 meter is the same as that of the C. and H. type, but it has several details worthy of mention. Above the copper disc (see Fig. 18) is a float which causes the moving system to press on the top bearing, which is jewelled, with a force of about 3 grm. The bottom bearing is simply a pin working in a jewelled hole. The buoyancy of copper in mercury is thus put to practical use.

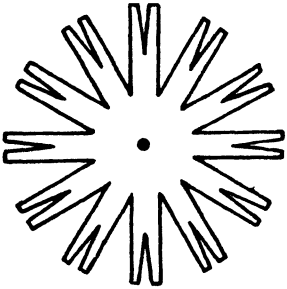


FIG. 19. METHOD OF SLOTTING THE SANGAMO DRIVING DISC

The driving disc is slotted as shown in Fig. 19, and this is claimed to give a 30 per cent greater torque than a plain disc, due to the concentration of the current in the magnetic fields.

To compensate for the frictional torque, a thermo-couple *T* is inserted inside a resistance *L* in the pressure circuit and connected to the bath circuit, as shown in Fig. 18. Its effect can be adjusted by the resistance *R*. Care must be taken to see that it sends a current in the right direction through the bath. The compensating current must not be too large, however, or the meter disc will creep forward on no-load and thus cause a false registration.

Theory of the Mercury Watt-hour Meter. From the discussion on the mercury A.H.M. we have the following relations—

$$T \propto B \,.\, i_m \text{ and } G \propto B^2 \,.\, N$$

In this case, however, the driving flux and braking flux are different, since the latter is composed of the driving flux and the permanent magnet flux. Let the driving flux density equal B_o and the effective braking flux density B_b. Now the fluid friction is compensated by means of a coil carrying i_m, which strengthens the field of the electromagnet; therefore—

$$B_o = k_8 \,.\, V + k_9 \,.\, i_m$$

if V equals the supply voltage; and

$$B_b = k_{10} \,.\, B_o + B_p$$

if B_p equals the flux density of the permanent magnet, and k_{10} is a constant to allow for the differing position and nature of B_0.

If B_0 is small compared with B_p, then B_b can be assumed to be constant if the voltage is reasonably constant, i.e. that $G \propto N$.

$$\therefore \qquad T \propto k_8 \,.\, V \,.\, i_m + k_9 \,.\, i_m^2$$

$$\text{But} \qquad T = F + G + M,$$

$$\therefore \qquad k_8 \,.\, V \,.\, i_m + k_9 \,.\, i_m^2 \propto F + k_1 \,.\, N + k_2 \,.\, N^2$$

The constant k_9 is adjusted until the components $k_9 \,.\, i_m^2$ and $k_2 \,.\, N^2$ balance each other; and since $V \,.\, i_m$ equals the watts measured by the meter (or proportional to the watts measured by the meter), we have the relation—

$$\text{Watts} \propto F + k_1 \,.\, N \text{ at balance.}$$

Thus the curves in Figs. 10 and 11 still apply if watts are read in place of amperes and watt-hours in place of ampere-hours.

It is possible with this type of meter to compensate for F, as described on page 32. The low-load errors can, therefore, be much reduced if so desired.

Temperature Variations. As the pressure coil is wound with copper wire, another variation is introduced in addition to those described in the paragraph on mercury ampere-hour meters.

Let R_c = resistance of the copper portion of the pressure circuit.

R_z = resistance of the swamping resistance, if any.

R_p = resistance of the pressure circuit.

Now R_z does not alter with temperature, but R_c increases by 0·4 per cent per ° C. rise. Thus a rise in temperature causes the meter to slow down, due to the reduction in the pressure coil current and flux, by $(0{\cdot}4 \times R_c/R_p)$ per cent per ° C. Clearly, by suitable adjustment of the ratio R_c/R_p, it is possible to make the overall temperature coefficient of the W.H.M. negligible on both the shunted and unshunted types. Makers do not always avail themselves of this possibility, and in consequence the meter will have an overall temperature coefficient which may be either positive or negative according to the value of R_c/R_p and the type of current circuit.

In common with the A.H.M., the error at low loads will fluctuate erratically with self-heating or temperature changes owing to the variability of the solid friction of the mercury.

Commutator Type Watt-hour Meter. The moving system (see Fig. 20) of the Metropolitan-Vickers meter consists of a ball type armature F (whose windings are connected to a commutator P) and a copper disc L mounted on a spindle which is pivoted in the usual manner. The copper disc runs between the poles of two permanent magnets M_1M_2, and thus forms the means of braking the motion of the armature. The armature windings are wound on a non-conducting former. On opposite sides of the armature F are placed two large coils E_1E_2, which carry the current to be measured. On the two-wire meter they are in series, but on the three-wire meter one coil is placed in each line. If the current is very large, the coils are simply bare, massive, copper conductors, and they are usually back-connected for convenience.

At the side of E_2 is centrally mounted a movable coil H, which carries the pressure coil current. Its position can be fixed when the right place for it has been found. The armature F, coil H, and the resistance bobbins C_1C_2 are connected in series across the supply mains *via* the terminals A and B. The current is fed to the armature by the gold alloy brushes D_1D_2. The permanent magnets are screened from the magnetic fields due to the coils by the iron screen K.

The action of the meter is similar to that of the separately excited D.C. shunt motor. From the theory of the shunt motor we know that the torque on the armature is proportional to the product of the field flux and armature current.

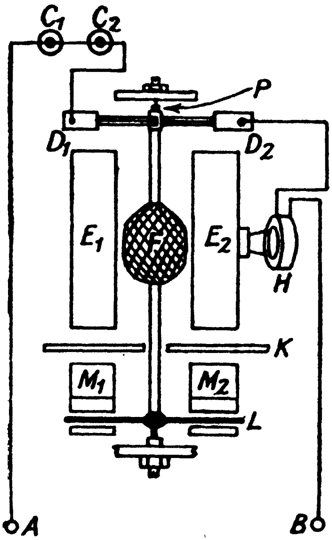


Fig. 20. The M.V. Commutator Watt-hour Meter

But the field flux $\propto$ line current I (in the two-wire case) and the armature current $\propto$ line voltage V (neglecting the back e.m.f. of the armature, which is small compared with V).

$$\therefore \text{ The driving torque } \propto V \,.\, I$$
$$\propto \text{ watts supplied to the consumer.}$$

As the retarding torque is a quantity $F + G$ (see page 9), then the speed will be closely proportional to the watts if F can be compensated, or if F is small compared with G. The quantity F can be compensated by adjusting the coil H so that the armature is on the point of moving forward when the line current is zero. This enables the low-load errors to be kept small.

The meter is calibrated by adjusting the resistance bobbins C_1C_2, and the error curve is levelled by means of coil H, provided that the armature does not creep forward when I is zero. If desired, an anti-creep device in the form of an iron wire on the spindle near the permanent magnets may be fitted. This will allow the friction to be over-compensated, if necessary, without the disc creeping more than one revolution.

A disadvantage of this type of meter is the heavy weight of the moving system, which causes rapid wear of the jewels if vibration is experienced. Such wear leads to increased errors at low loads and refusal to run on one-hundredth load.

As with the commutator A.H.M., the torque varies with the armature position, but owing to the friction compensation this does not cause much trouble on starting current and at low loads.

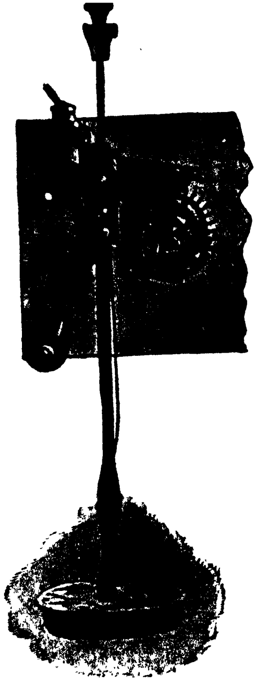
Temperature Variations. A rise in temperature causes the rotor to speed up by 0·4 per cent per ° C. due to the increase in resistance of the brake disc. A rise in temperature also causes the rotor to speed up by 0·06 per cent per ° C. due to the decrease in strength of the brake magnets ($G \propto B^2$). Thus if the meter is unshunted and the amount of copper resistance in the pressure circuit is negligible, then the meter will have the large temperature coefficient of 0·46 per cent per ° C.

The presence of copper in the pressure circuit, however, causes the meter to slow down by ($0{\cdot}4 \times R_c/R_p$) per cent per ° C. rise. Judging from actual meters, this quantity is always less than 0·1 per cent owing to the large calibrating resistances.

If a shunt is used, then the temperature coefficient is improved owing to the reduction of the ratio i_m/I_L with rise of temperature. If i_m is small compared with I_L, then the meter would slow down by 0·4 per cent per ° C. rise because the meter current circuit is all copper. Generally, however, i_m is not small compared with I_L in order to obtain a large driving torque, and the meter will slow down by something less than 0·4 per cent per ° C. Although it is possible to make the temperature coefficient of the shunted meter fairly small, this is not always done, and it results in the meter having large self-heating and ambient temperature errors. The self-heating errors are large as a rule, because of the considerable watt loss in the pressure circuit and current coils, and because the meter is fitted with an air-tight case which does not allow the heat to get away.

Pendulum Type Watt-hour Meter. When viewed as a whole, the Aron meter appears very complicated, but if the various sections are treated individually it becomes fairly easy to understand the action of the meter.

The pendulum (see Fig. 21) consists of a long brass rod pivoted by means of a steel spindle working in holes in the revolution counter plates. At one end is mounted a coil to which a current is supplied by means of flexible leads. At the other end are the adjustable weights for altering the natural frequency of the pendulum. On the boss is fixed a pallet arm, which meshes with the escapement wheel. The escapement wheel shaft is geared to both the driving differential and the recording differential. The pendulum is self-starting when the mainspring is wound up by the winding gear.



(Aron Electricity Meter, Ltd.)

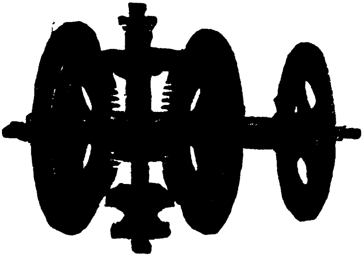
FIG. 21. THE PENDULUM OF THE ARON METER

The meter depends for its action on the difference in frequency between two pendulums. Thus the primary portions of the meter are two pendulums, whose frequencies are equal (or equal in effect) when the load is zero. As in the case of the ordinary clock, some driving force must be provided, in order to maintain the regular swinging of the pendulums. Since they are going to swing with different frequencies when a load is being supplied, it is clear that some means of adapting the driving force to the frequency of the pendulum must be used. (This is because the one driving force energizes both pendulums. If separate forces were provided the problem would be more straightforward, but the expense would be too great.) This device is the differential gear shown in Fig. 22.

The mainspring turns the central arm, on which is freely mounted a planet wheel. The sun wheels are loosely mounted on the mainshaft, and they form the drive to the right-hand and left-hand pendulums respectively. Clearly the sun wheels can revolve at differing speeds and yet be driven by the central arm, any difference in speeds causing the planet wheel to revolve. (See page 47.)

The mainspring at first sight looks a rather peculiar device, but on inspection this is found to be due to the necessity for making the spring self-winding. A D.C. motor which was continually in action would consume too much energy, so some arrangement is required whereby the winding motor only operates intermittently.

When the spring S is in the run down position, the switch K is drawn over by the arm X into the closed position (see Figs. 23 and 24). This energizes the coil A, and the consequent flux attracts the armature into the region of greatest flux and, in so doing, the spring S is wound up. A ratchet device is provided so that the spring can be wound up without interfering with the clock drive, but cannot unwind without driving the planet wheel arm of the main differential. When the mainspring is in the fully-wound position, the switch K is flung over by the arm X into the open circuit position. The winding gear comes into action every 30 sec. In order to maintain a drive on the main differential whilst the mainspring is winding up, a spiral spring is used to connect the mainspring driving spindle to the shaft of the planet wheel arm. This spring retains enough energy to supply the pendulums during the short interval of winding up.



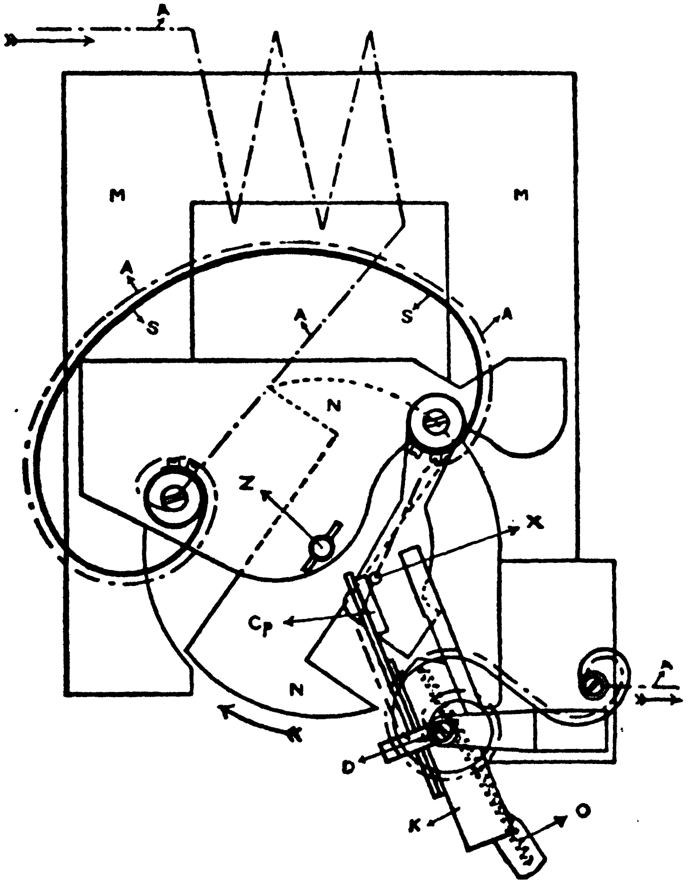
(*Aron Electricity Meter, Ltd.*)

FIG. 22. ARON DIFFERENTIAL GEAR

Revolution Counter Drive. The pendulum drives are also geared to another differential gear, but in this case the sun wheels are driven in opposite directions. Consequently the planet wheel arm revolves at a speed proportional to the difference in speed of the sun wheels. (For the theory of the differential gear, see page 47.) The shaft carrying the planet wheel arm is connected to the revolution counter via a reversing gear.

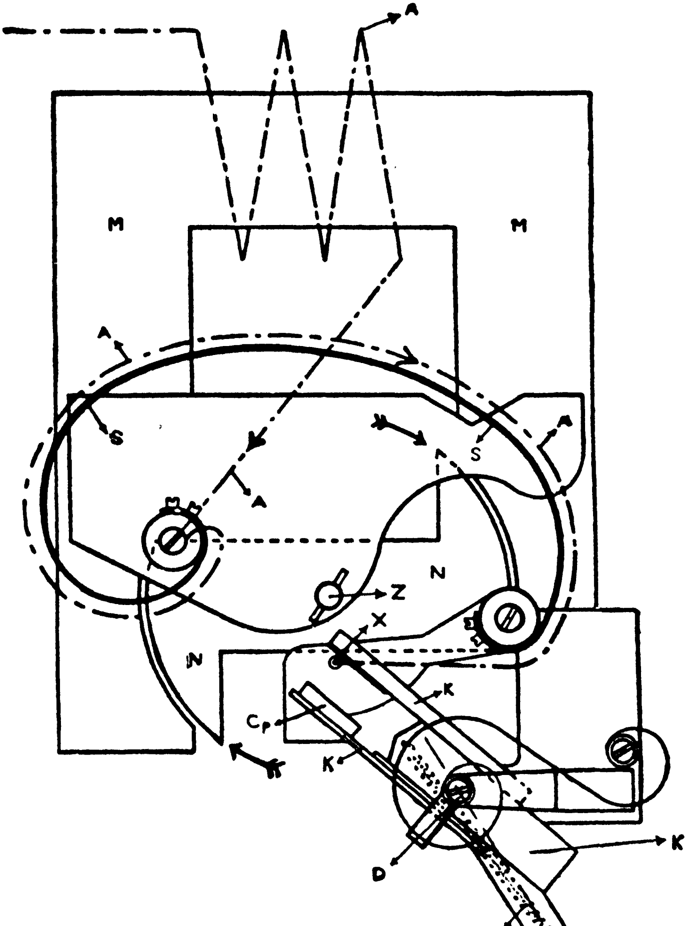
The Reversing Gear. As it is not practicable to get two commercial pendulums of the above type swinging with exactly the correct normal frequency, it follows that when the load is zero the revolution counter will advance or move back at a rate proportional to the inherent frequency difference. The direction depends on which pendulum is the faster. This is a false registration and it cannot be permitted. If, however, the drive to the counter is reversed by some means every 10 min., then the registration over an even number of 10-min. periods will be zero. The maximum false reading at any time will not be greater than that due to the lack of synchronism acting for 10 min., which is made small.

Obviously some means must be employed to reverse the direticon of motion of the planet wheel arm when the counter drive is reversed, in order that the true registration may not be lost.



(*Aron Electricity Meter, Ltd.*)

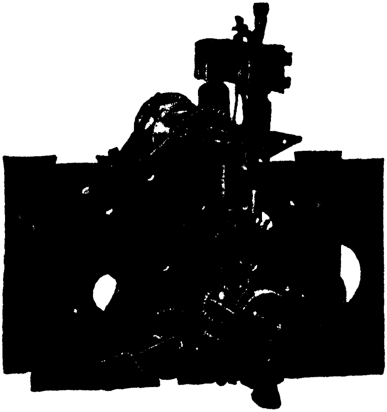
FIG. 23. ARON WINDING GEAR, SPRING RUN DOWN



(*Aron Electricity Meter, Ltd.*)

FIG. 24. ARON WINDING GEAR, SPRING FULLY WOUND

This is done by reversing the direction of the current in each pendulum coil, which causes each pendulum to be alternately the fast and slow pendulum (due to the electrical load). The action of this device may be understood from Fig. 25. The commutator spindle is turned through 180° by the mainspring every 10 min., and in so doing it reverses the pendulum connections and also oscillates the reversing gear bracket by means of an arm working in a slot. The bracket is so adjusted that when it is on the left the gear train has one more wheel in its train than when it is on the right, hence the reversing action.



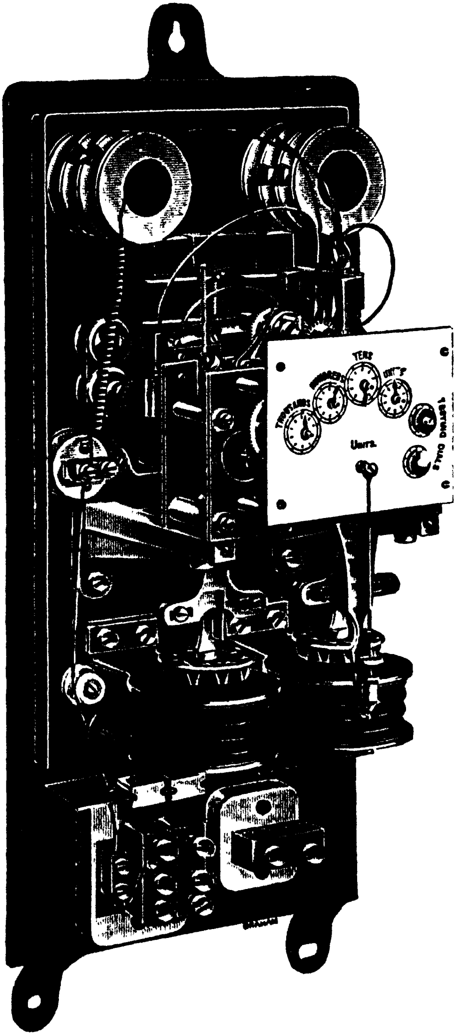
(Aron Electricity Meter, Ltd.)

FIG. 25. ARON REVERSING GEAR

The fixed coils are situated as shown in Fig. 26. Owing to the wide variations in full-load current, the number of coil types is very numerous. If the meter is to handle the total line current, then the fixed coils are the current coils, and the pendulum coils carry the pressure circuit current. (In series with the pressure coils is a resistance made of zero temperature coefficient material. This resistance can be adjusted, and it forms the means of calibrating the meter.)

If the meter is shunted, the meter current circuit only carries a small current (approx. 6A. at full load), and this enables the pendulum coils to be put in the current circuit if so desired. Usually, however, the pendulum coils carry the pressure circuit current because of the lower current to be handled and the smaller influence of a bad contact on the commutator.

When both sets of coils are energized, it obviously depends on



(*Aron Electricity Meter, Ltd.*)

FIG. 26. ARON PENDULUM METER

the way in which the coils are connected, whether there will be attraction or repulsion between the coils of each set. The coils are so connected that, at any given instant, attraction takes place in one set and repulsion in the other. We have already seen that every 10 min. the pendulum coil connections are reversed, thus attraction and repulsion change places in the two sets every 10 minutes.

Theory of the Pendulum Meter. Fig. 27 illustrates the conditions in a typical pendulum system. M and N are the centres of the fixed and moving coils respectively, and N moves over the arc PT. O is the pivoting point of the pendulum, and the point L is on the line OM and the arc PT. It will be sufficiently accurate for our purposes to assume that N is the centre of gravity of the pendulum (i.e. that the pendulum is a simple one).

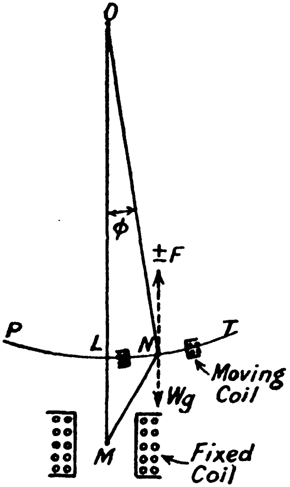


FIG. 27. PENDULUM CONDITIONS

Let d = length of the pendulum in cm. (i.e. ON).

v = distance LM.

u = distance MN.

ϕ = angular displacement of ON from OLM, in radians.

W = weight of the pendulum in grammes.

k_1 and k_2 = suitable constants.

g = the gravitational constant.

M_f = the magnetic moment of the fixed coil.

M_m = the magnetic moment of the moving coil.

F = the force of attraction or repulsion between the coils.

Owing to the absence of iron (or the presence of a large air gap), the magnetic moments of the coils are directly proportional to the currents in the coils. Now, the translatory force between two coils in the end-on position is proportional to the product of the magnetic moments and inversely proportional to the fourth power of the distance between their centres. Thus in our case F is proportional to $M_f \,.\, M_m/u^4$. Since the ratio LM/LN is at least 4/1, it follows that the coils are sensibly in the end-on position at all points of the swing and that u^4 is, to all intents and purposes, a constant. Furthermore, u varies, during a pendulum beat, in practically the same manner on all loads, and thus no appreciable error is introduced by assuming u to be a constant.

Now M_f is proportional to I and M_m is proportional to V

$$\therefore \qquad F = k_1 \,.\, \text{watts.}$$

The tangential force on the pendulum when F is zero,

$$= W \,.\, g \,.\, \sin\phi \text{ dynes}$$

$$= W \,.\, g \,.\, \frac{LN}{d}, \text{ since } LN = d \,.\, \sin\phi \text{ approx.}$$

But Force = mass × acceleration.

$\therefore$ Acceleration of point $N = g \,.\, LN/d$ cm./sec.^{2}

Therefore, by definition, the motion of the pendulum is harmonic. (If a body moves so that its acceleration is always proportional to the distance from its mean position and acts towards the mean position, then the motion is harmonic.)

$\therefore$ The natural frequency of the pendulum

$$= n_o = \frac{1}{2\pi}\sqrt{\frac{g}{d}} \text{ cycles per sec.}$$

Let us now consider the pendulum action when F is not zero.

The tangential force due to $F = k_1 \,.\, \text{watts} \,.\, \sin\phi$ dynes.

$\therefore$ The total tangential force

$$= W \,.\, g \,.\, \sin\phi \pm k_1 \,.\, \text{watts} \,.\, \sin\phi$$

$$= (W \,.\, g \pm k_1 \,.\, \text{watts}) \sin\phi$$

$\therefore$ The acceleration of point N

$$= (g \pm k_2 \,.\, \text{watts}) \times \frac{LN}{d}, \text{ if } k_2 = k_1/W$$

$\therefore$ The pendulum frequency

$$= \frac{1}{2\pi}\sqrt{\frac{g \pm k_2 \,.\, \text{watts}}{d}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{g}{d} \pm Z}, \text{ if } Z = k_2 \,.\, \text{watts}/d$$

Expanding this by the Binomial Theorem, we get—

Frequency

$$= \frac{1}{2\pi}\left[\left(\frac{g}{d}\right)^{\frac{1}{2}} + \frac{1}{2}\left(\frac{g}{d}\right)^{-\frac{1}{2}} Z - \frac{1}{8}\left(\frac{g}{d}\right)^{-\frac{3}{2}} Z^2 + \frac{1}{16}\left(\frac{g}{d}\right)^{-\frac{5}{2}} Z^3 - \ldots\right]$$

or

$$= \frac{1}{2\pi}\left[\left(\frac{g}{d}\right)^{\frac{1}{2}} - \frac{1}{2}\left(\frac{g}{d}\right)^{-\frac{1}{2}} Z - \frac{1}{8}\left(\frac{g}{d}\right)^{-\frac{3}{2}} Z^2 - \frac{1}{16}\left(\frac{g}{d}\right)^{-\frac{5}{2}} Z^3 - \ldots\right]$$

The former expression applies to the faster pendulum and the latter to the slower pendulum. Clearly the difference in frequency between the two pendulums of a two-wire meter is given by—

Difference in frequency

$$= \frac{1}{2\pi}\left[\left(\frac{g}{d}\right)^{-\frac{1}{2}} Z + \frac{1}{8}\left(\frac{g}{d}\right)^{-\frac{5}{2}} Z^3 + \ldots\right]$$

$$= \frac{1}{2\pi}\left(\frac{g}{d}\right)^{\frac{1}{2}}\left[\left(\frac{g}{d}\right)^{-1} Z + \frac{1}{8}\left(\frac{g}{d}\right)^{-3} Z^3 + \ldots\right]$$

$$= \frac{1}{2\pi}\sqrt{\frac{g}{d}}\left[\left(\frac{g}{d}\right)^{-1} Z + \frac{1}{8}\left(\frac{g}{d}\right)^{-3} Z^3 + \ldots\right]$$

$$= n_0\left[\frac{d\,.\,Z}{g} + \frac{1}{8}\cdot\frac{d^3\,.\,Z^3}{g^3} + \ldots\right]$$

We require the difference in frequency, however, to be directly proportional to the watts (within certain limits of error), so let us investigate the influence of the higher terms in the above expression. In the usual type of direct connected meter, g/d has the value of 80, n_0 is about 1·4 cycles per second, and the difference in frequency at full load is of the order of 20 per cent of n_0.

$\therefore$ $d\,.\,Z/g = 0{\cdot}2$ approximately at full load.

$\therefore$ $d^3\,.\,Z^3/8g^3 = 0{\cdot}001$ approximately at full load.

Thus the cubic term in the above expression is only ½ per cent of the linear term even at full load. The terms higher than the cubic are obviously negligible. On indirectly connected meters the value of $d\,.\,Z/g$ at full load is only about 0·1, therefore the effect of the cubic term will be even smaller than before. Therefore we can say that the above types of two-wire pendulum meter follow, to all intents and purposes, a linear law on normal loads.

Effect of Overload. The meter tends to over-register on overload, because at twice full load the cubic term for the direct connected type of meter becomes equal to 2 per cent of the linear term. Thus the error rises about 1·5 per cent between full load and twice full load. The indirectly connected meter is not so much affected, because at twice full load the cubic term is only equal to ½ per cent of the linear term. The above facts explain why the error curve for a pendulum meter has a rising characteristic (see Figs. 28 and 29) and why the overload performance of this type of meter is so good.

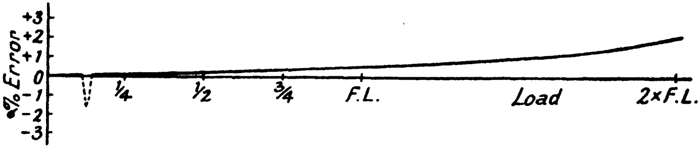


Fig. 28. Typical Error Curve for Direct Connected 2-wire Pendulum Meter

Effect Due to Sun Wheels Synchronizing. Suppose the load is such that the sun wheels of the small differential should turn at almost the same angular velocity. The slight difference creates a small force on the planet wheel arm. The inertia and friction in the revolution counter gearing require, however, a certain force before the planet-wheel arm can move, and if the driving force is not great enough then the sun wheels will run in synchronism. This will cause the meter to register slightly less accurately. A similar effect takes place in the large differential. To avoid these effects acting simultaneously, the sun wheels of the small differential are different in size, e.g. instead of two wheels having 90 teeth each, two wheels having 89 and 91 teeth respectively are used. The natural frequencies of the pendulums must be different in order to compensate for the unequal gearing, the smaller sun wheel being geared to the pendulum having the greater natural frequency.

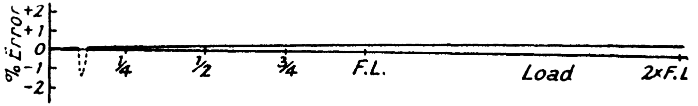


Fig. 29. Typical Error Curve for an Indirectly Connected 2-wire Pendulum Meter

The type of error involved by the synchronizing of the sun wheels is shown in Figs. 28 and 29 by the dotted part of the curve at about one-tenth load. The manufacturers claim that, owing to improvements in gear cutting and clock construction, the modern pendulum meter has no error due to the above effect.

Temperature Errors.

Let R_p = resistance of the pressure circuit.
r_c = resistance of the copper portion of the pressure circuit.
R_x = resistance of the shunt.
r_m = resistance of the meter current circuit, including the shunt leads.
r_s = swamping resistance in the meter current circuit.

If the ballast resistance has a zero temperature coefficient, then the only temperature error in the direct connected meter is that due to the copper coils in the pressure circuit. These cause the meter to under-register, with rise in temperature by ($r_c/R_p \times 0{\cdot}4$) per cent per ° C. In the average meter the value of r_c/R_p is very small and, consequently, the temperature error is also very small (of the order of 0·02 per cent per ° C.). This applies to A.C. as well as D.C. meters.

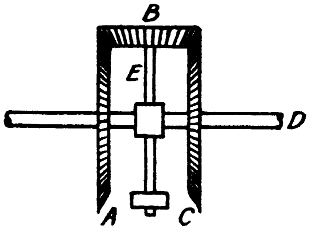


FIG. 30. DIAGRAM OF A DIFFERENTIAL GEAR

The indirectly connected meter has a larger temperature coefficient, because the shunt is made of zero temperature coefficient material, whilst the meter current circuit is formed by copper conductors plus a swamping resistance of zero temperature coefficient material. Now

$$\frac{\text{Meter current}}{\text{Line current}} = \frac{R_x}{R_x + r_m}$$

Therefore if R_x is small compared with r_m, which is usually the case, then the meter will under-register with rise of temperature by 0·4 per cent per ° C. due to this cause, if the swamping resistance r_s is zero (as it was in the early pendulum meters). If r_s is not zero, then the temperature coefficient will be reduced to $(r_m - r_s)/r_m \times 0{\cdot}4$ per cent per ° C. In the modern meter this is about 0·2 per cent per ° C.

The effect of temperature on the natural frequency of the pendulum is negligible, since the coefficient of linear expansion of brass is only 0·00001037. It is very important, however, that the mountings of the coils and pendulums are perfectly secure.

otherwise errors of an erratic nature will occur due to the coils approaching or separating with change of temperature.

Theory of the Differential Gear. Let A, B, and C in Fig. 30 represent the number of teeth on the wheels, as well as their identity. The sun wheels A and C ride freely on shaft D, and the planet wheel B rides freely on the arm E, which is rigidly fixed to shaft D. Imagine arm E to be stationary and that A rotates one revolution. Then, from the laws to be found in books on the Theory of Machines, we can draw up the following table The reasoning, however, is not difficult to understand.

Step	Revolutions of					Treatment
	A	B	C	D	E	
1	1	A/B	$-A/B \times B/C$	0	0	Revolve A once
2	X	$A/B \times X$	$-A/C \times X$	0	0	Multiply by X
3	$X + Y$	$A/B \times X + Y$	$-A/C \times X + Y$	Y	Y	Add Y

Thus if we know the number of teeth on the wheels and the motion of two wheels, we can find the motions of all the wheels. Let us first consider the conditions in the revolution counter differential. In this, A and C are geared to the escapement shafts, rotate in opposite directions, and the numbers of teeth are 89 and 91 respectively. Suppose, for example, the speeds of A and C at no load are 91 and -89 r.p.m. respectively.

$$\begin{array}{lrcl}
\therefore & X + Y & = & 91 \\
 & -A/C \times X + Y & = & -89 \\ \hline
 & (1 + 89/91)X & = & 180 \qquad \therefore X = 180 \times 91/180 = 91 \\
 & & & \qquad\qquad \therefore Y = 0 \text{ r.p.m.}
\end{array}$$

Suppose, now, that a load comes on the meter which causes a speed change of 10 r.p.m. in both wheels, i.e. that $A = 101$ and $C = -79$ r.p.m.

$$\begin{array}{lrcl}
\therefore & X + Y & = & 101 \\
 & -A/C \times X + Y & = & -79 \\ \hline
 & (1 + 89/91)X & = & 180 \qquad \therefore X = 91, \text{ and } Y = 10 \text{ r.p.m.}
\end{array}$$

When the commutator operates, the motions of A and C are so changed that we get—

$$\begin{array}{rcl}
X + Y & = & 81 \\
-A/C \times X + Y & = & -99 \\ \hline
(1 + 89/91)X & = & 180 \qquad \therefore X = 91 \\
 & & \qquad\qquad \therefore Y = -10 \text{ r.p.m.}
\end{array}$$

These examples show how the speed of the shaft D is directly proportional to the difference in speed between A and C, and is in the right direction, since the reversing gear operates at the same instant as the commutator.

In the case of the main differential, the shaft D is driven by the mainspring, and the wheels A and C are equal sized and geared to the escapement wheel shafts of the two pendulums. Suppose $A = 50$ r.p.m. and $C = 50$ r.p.m.

$$\begin{array}{rl} \therefore & X + Y = 50 \\ & -X + Y = 50 \\ \hline & 2 \,.\, Y = 100 \end{array} \qquad \begin{array}{l} \\ \text{since } A = C \text{ in this case.} \\ \therefore\ Y = 50 \text{ r.p.m.} \end{array}$$

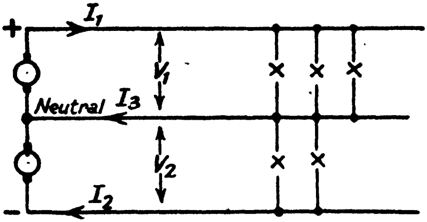


FIG. 31. THREE-WIRE D.C. SUPPLY

Suppose $A = 40$ r.p.m. and $C = 60$ r.p.m.

$$\begin{array}{rl} \therefore & X + Y = 40 \\ & -X + Y = 60 \\ \hline & 2 \,.\, Y = 100 \end{array} \qquad \therefore\ Y = 50 \text{ r.p.m.}$$

This shows how the pendulum drives accommodate themselves to the one driving force.

Three-wire D.C. Watt-hour Meters. When the consumer is supplied on the three-wire system, it saves expense and trouble if the energy can be measured on one meter instead of using one in each line. This can be conveniently done on the commutator and pendulum types, because they are already in the double element form, but the mercury type requires a special construction. Let us consider the three-wire circuit shown in Fig. 31.

Power supplied

$= V_1 \,.\, I_1 + V_2 \,.\, I_2$

$= I_2 (V_1 + V_2) +$ out of balance power

$= I_2 (V_1 + V_2) + I_3 \,.\, V_1$ in the above figure

$= I_1 (V_1 + V_2) + I_3 \,.\, V_2$ if I_3 is in the opposite direction to that in Fig. 31.

Clearly if two W.H.M.'s are used, one measuring $V_1 . I_1$ and the other $V_2 . I_2$, then the energy can be accurately integrated. We shall now see how nearly a 3-wire meter approaches the ideal.

Commutator Type Meter. In the two-wire W.H.M. the main flux is directly proportional to the current, since each fixed coil carries the same current. In this case, however, the currents in the fixed coils (see Fig. 32) differ by a quantity I_3. Suppose $I_2 = I_1 + I_3$. The current component I_1 in each coil can be considered as producing such a flux that the meter runs at a speed proportional to $I_1(V_1 + V_2)$, since the pressure circuit is connected across the outers of the supply system. Clearly the current I_3 flowing in one coil produces only half the flux which a current I_3 flowing in both coils would produce—provided that the fixed coils are absolutely symmetrical with respect to the armature. Thus the torque on the armature will be half that due to an equal balanced current. Thus the driving torque is given by

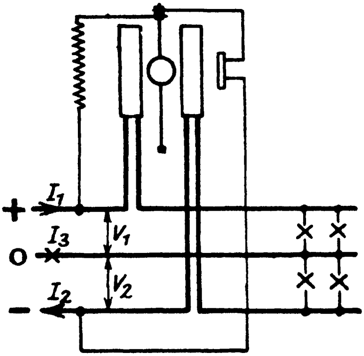


FIG. 32. CONNECTIONS FOR A COMMUTATOR TYPE 3-WIRE METER

Driving torque

$$= k\left[I_1(V_1 + V_2) + \frac{I_3(V_1 + V_2)}{2}\right], \text{ where } k = \text{a constant.}$$

If the voltages are balanced, then V_1 equals V_2, and the driving torque $= k[I_1 . V_1 + I_2 . V_2]$, which is the required law of operation. Clearly the meter is only accurate so long as the voltages are balanced and each element of the meter forms a true W.H.M. The error due to an unbalanced voltage is shown by the following example. If the out-of-balance current I_3 is 20 per cent of I_1, and V_2 (V_2 being the voltage associated with I_3) is 5 per cent different from $(V_1 + V_2)/2$, then the meter will be ½ per cent fast or slow according as V_2 is lower or higher than $(V_1 + V_2)/2$. (Assuming the meter to be perfect as a two-wire meter.)

If the two main coils are not balanced, then there will be a further error on an unbalanced load, depending on which element measures the out-of-balance power.

Pendulum Type Meter. This meter consists normally of two elements, and it can be connected so as to record the total energy in the same manner as two separate meters. (See Fig. 33.) This meter is not affected by unbalanced loads or voltages, provided the unbalance remains steady for multiples of 20 min. The reason for this statement is that the reversing gear operates every 10 min., and in order to wipe out the effect of the quadratic term in the equation for the pendulum frequency, each pendulum must operate an equal length of time on each direction of the reversing gear.

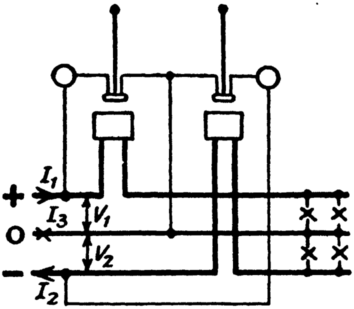


FIG. 33. CONNECTIONS FOR A 3-WIRE PENDULUM METER

The Mercury Meter. For three-wire work, two elements are so mounted as to have a common spindle and a common braking system. The spindle, however, must have an insulating coupling between the two baths, because the baths are at different potentials.

The elements are so connected that the driving torques are proportional to $I_1(V_1 + V_2)$ and $I_2(V_1 + V_2)$ respectively, since the pressure coil is connected across the outers of the supply. The effect of an unbalanced load or voltage will be the same as that on the commutator type.

SINGLE-PHASE ALTERNATING-CURRENT METERS

The Electrolytic Ampere-hour Meter. By connecting a full wave copper oxide rectifier to the secondary of a current transformer, the Reason Manufacturing Co., Ltd., have been able to apply their well-known electrolytic meter to the measurement of ampere-hours in A.C. circuits. The rectifier (which can be calibrated) forms a separate unit, and this enables it to be applied to existing D.C. meters simply by replacing the shunt by the rectifying unit. The makers claim that the A.C. meter is as accurate as the D.C. meter, but this claim is subject, of course, to the alternating current being free from harmonics. By assuming a steady voltage, this meter may be applied to the measurement of kVAh.

As yet an efficient A.C. ampere-hour motor meter has not been constructed, so all the following A.C. meters are of the watt-hour type—

The Commutator Watt-hour Meter. This type is exactly the same in construction as the one described on page 33. As it is a dynamometer instrument, it should run equally well on A.C. and D.C.; but, in practice, we find that this meter is not used on A.C. circuits for the following reasons—

1. The induction meter is cheaper, requires less maintenance, has a longer life, and is not so much affected by temperature.
2. It is not easy to compensate for the inductance of the armature in order to make the meter accurate on low power-factors.
3. When working on A.C., vibrations are inherent, and they lead to rapid wear of the heavily loaded jewel.

The Pendulum Meter. The only radical change in this meter for use on A.C. is in the winding gear, the coil of which is greatly modified by the frequency and voltage of supply. The pendulum takes about two-fifths of a second for a beat, and during this period a 50-cycle system goes through 20 cycles. Thus the force on the pendulum can still be considered as the mean force, which is shown on page 42 to be proportional to the watts. Therefore the meter is a true W.H.M. provided the phase angle errors in the meter are fully compensated. This is done by causing the flux due to the current coil to lag the current by the same angle that the pressure coil current lags the pressure, by means of the brass cheeks of the current coil formers. These brass cheeks are slotted on one side, and in order to form a complete circuit the two sides of the slot are joined by a short length of resistance wire, whose length can be adjusted.

Let Φ_I = flux due to the current I in the series coil.

e = e.m.f. induced in the brass cheeks by the alternations of Φ_I.

i = current in the brass cheeks due to e.
F = magnetomotive force due to the series coil current I.
F_1 = magnetomotive force due to i.
F_2 = magnetomotive force required to produce the flux Φ_I.

The e.m.f. e lags the flux Φ_I by 90°, and the eddy current i lags e by an angle ϕ, whose value depends on the ratio of resistance to inductance of the eddy current path in the brass cheeks. Since the eddy currents oppose the setting up of the flux (Lenz's law), then the m.m.f. due to the current I must equal the vector sum

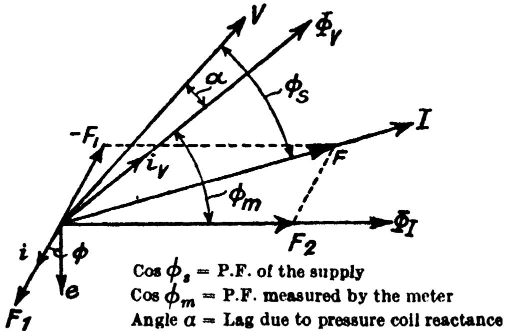


FIG. 34. QUADRATURE LOOP ACTION OF THE BRASS CHEEKS OF THE FIXED COILS

of F_2 and $-F_1$. It will now be clear from the vector diagram in Fig. 34 why it is possible to compensate for the reactance of the pressure coils.

In the same way it is possible on the current transformer operated meter to compensate for the leading phase angle error of the C.T. The compensation for this error cannot be made correct for every load, since the phase angle error of a C.T. varies with the load, but it can be made so that the meter errors are well within the B.S.S. limits. It is advisable to test a C.T. operated meter in conjunction with its own C.T.'s.

It is essential that the metal face plate on which the pressure coil is mounted should not form a closed circuit, i.e. that the slots in the face plate do not become closed. If they become closed, then the face plate acts on the pressure coil flux just as the brass cheeks act on the current coil flux, and thereby nullifies the compensating effect of the brass cheeks.

The Induction Meter. This type of meter is very simple in

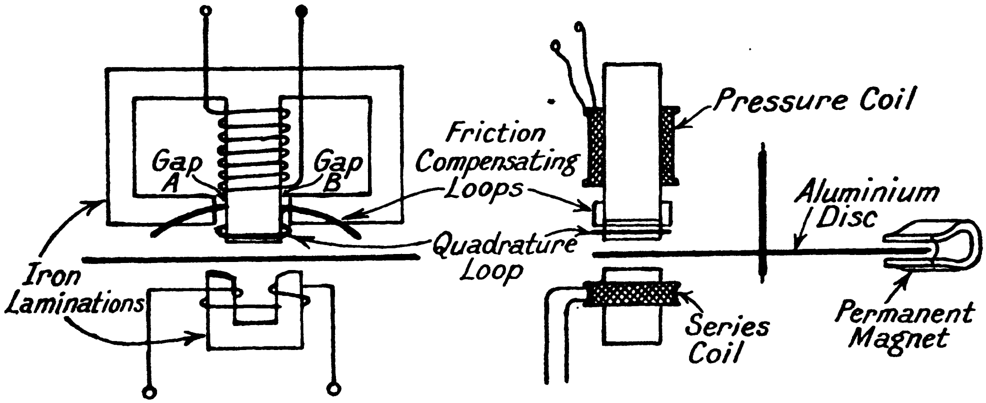


FIG. 35. THE ELEMENTAL FORM OF INDUCTION METER

construction, although its exact theory is rather difficult to understand. The moving system consists of a light aluminium disc mounted on a steel pivoted spindle, and supported by a jewelled bottom bearing and a pin type top bearing. On the spindle is mounted a pinion, or worm, which engages with the first wheel of a revolution counter. The disc runs in the gaps between the poles of two electromagnets and the poles of one or two permanent magnets. One electromagnet is supplied with a current proportional to the voltage of the supply, and the other with a current proportional to the current supplied. On one or other of the electromagnets are mounted compensating devices to enable the meter to register accurately on all normal loads.

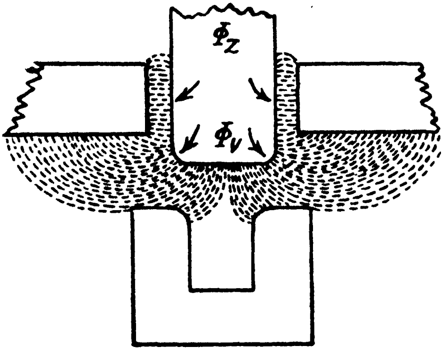


FIG. 36. PRESSURE FLUX DISTRIBUTION
Arrows indicate positive direction

A survey of modern meters shows a bewildering array of different shapes and sizes of discs, spindles, electromagnets, and compensating devices. Thus it would be better first to discuss the theory of the elemental type and then investigate the peculiarities of particular makes. The elemental form of meter is illustrated in Fig. 35.

Let V = supply voltage.
I = current supplied to the consumer.
i_p = pressure coil current.
Φ_z = main pressure coil flux.
Φ_v = pressure coil flux in the disc gap.
Φ_i = current coil flux in the disc gap.

The gaps A and B are very small, hence the pressure coil is highly inductive. Therefore the current i_p lags V by nearly 90°, and since i_v and Φ_z are in phase, then Φ_z also lags V by nearly 90°. Fig. 36 shows the flux distribution when the compensating loops are removed. Φ_z is not directly proportional to the voltage V, the exact relation depending on the air gaps and the B–H curve of the iron used in the laminations. By working at the right portion of the B–H curve, however, it is possible to make Φ_z proportional to V over a large range of voltage.

The quadrature loop is shown in Fig. 35 as a simple copper band, but, if desired, it may be a coil whose ends are either shorted or joined together by a resistance. The flux which passes through the loop induces an e.m.f. in the winding. This e.m.f. causes a current to flow in the loop, thereby creating a m.m.f. which, by Lenz's law, opposes the force setting up the flux. Fig. 37 gives the conditions if the quadrature loop action of the disc is neglected. Φ_v is the flux passing through the loop, F_v is the m.m.f. required to overcome the reluctance of the magnetic path, V_q and I_q are the voltage and current induced in the loop respectively, and F_q is the m.m.f. due to I_q. For the reasons given above, the driving m.m.f., F_z, must equal the vector sum of F_v and $-F_q$. Hence the flux Φ_v lags Φ_z by an angle θ. It will be obvious to the reader that by adjusting the impedance of the loop or the amount of flux on which it acts, we have a means of altering I_q and F_q, and therefore the angle θ. We have already seen that F_z and Φ_z do not lag V by quite 90°, but by adjusting I_q we can make Φ_v lag V by exactly 90° if so desired. This is the function of the loop; hence its name.

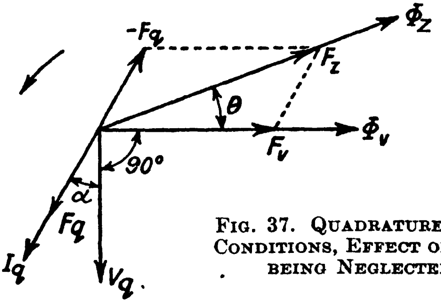


FIG. 37. QUADRATURE LOOP CONDITIONS, EFFECT OF DISC BEING NEGLECTED

It must not be forgotten that the disc also acts in the manner described above, but as it has insufficient effect it must be supplemented by a quadrature loop (see page 67 for an interesting application of this action of the disc). The friction compensating loops also have a similar action on the flux passing through them.

Conditions in the Current Electromagnet. Fig. 38 shows the flux distribution due to a current flowing in the current coil.

Owing to the large air gap, the flux is almost directly proportional to the current and lags it by only a very small angle (approx. 1° or 2°), which can normally be ignored.

Action of the Friction Compensating Loops. ✓These loops are adjusted to cause a slight phase difference between the pressure fluxes on opposite sides of the centre pole. This phase difference is sufficient to set up a torque on the disc, which will compensate for the effect of friction or other parasitic torques. The explanation of this action will be found in the next section.

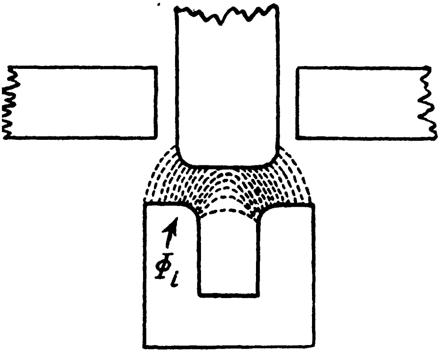


FIG. 38. CURRENT FLUX DISTRIBUTION

Arrow denotes positive direction

Eddy Current Theory of the Induction Meter. Having seen the effect of the coils acting separately, we now require to know the effect of both fluxes acting together. It should be mentioned here that it was shown by G. F. Shotter, M.I.E.E., in 1936, that the Shifting Field Theory is not applicable to the usual form of induction meter or instrument. Consequently, no attempt is made in this edition to describe the shifting field theory.

✓When a sinusoidal alternating flux passes through a metal sheet, it generates e.m.f.'s in the metal, which set up circulating, or eddy, currents concentric (very approximately) with the axis of the flux. The current lags the e.m.f.'s by a small angle depending on the ratio of inductance to resistance of the eddy current paths, but the e.m.f.'s lag the flux by 90°, since they are proportional to the rate of change of the flux. Therefore the eddy currents lag the flux by more than 90°.

If the metal sheet is quite uniform, then the reaction between the eddy currents and the flux is zero, since the forces due to the opposite sides of the eddy currents are equal and opposite, and thus balance out. If, however, the metal sheet is not uniform, there will be a resultant force in a direction depending on the position of the excess or deficit of material. This effect is very important, because it is the property usually employed to provide an anti-creep torque in the induction meter.

Suppose, however, that there are two adjacent fluxes (see Fig. 39) cutting the metal sheet, and that one flux lags the other by an angle ω (see Fig. 40). Two methods are shown in Fig. 39 whereby the flux in area B can be made to lag that in area A (see page 55). The first is to surround a portion of the laminations by a metal—usually copper—loop, whilst the second is simply to cover or shade part of the laminations by a piece of metal. (Fig. 78 illustrates an instrument which actually employs both these methods.) Many of the eddy currents due to the flux in area A flow through area B, and therefore there will be interaction between the two, resulting in a force being exerted on the metal sheet. Similarly, many of the eddy currents due to the flux in area B interact with the flux in area A. Since the force on a conductor carrying a current I in a magnetic field of strength H equals $I.H.\cos\phi$ per unit length, where ϕ is the angle between I and H, then

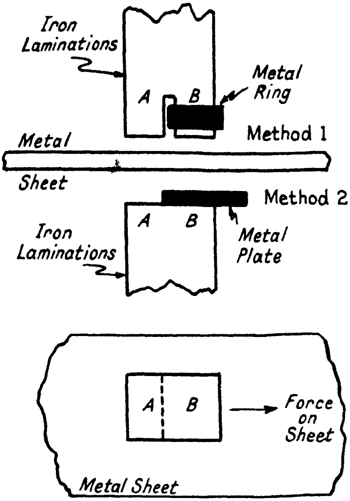


FIG. 39. FLUX LAGGING DEVICES

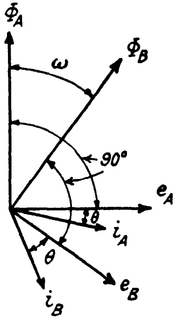


FIG. 40. VECTOR DIAGRAM FOR FIG. 39

Force on metal sheet

$$= k_1 . \Phi_B . i_A . \cos(90 - \omega + \theta) - k_1 . \Phi_A . i_B . \cos(90 + \omega + \theta)$$

The reason for the minus sign between the two terms is that the one set of eddy currents producing torque is flowing in the opposite direction to the other set, but since $\cos(90 + \omega + \theta)$ is also negative, the overall result is that the two forces are additive.

Since the eddy currents are proportional to the originating fluxes, it will also be clear from the above formula why the torque of the induction ammeter or voltmeter is proportional to the square of the current or voltage respectively.

There are many ways of obtaining adjacent alternating magnetic fluxes of different phase, but the important thing is for the reader to appreciate that, however this state of affairs is set up, a force is bound to result on the metal sheet or disc. Having realized how a force can be exerted on a metal sheet by inducing eddy currents therein, we can now consider the relationship of the fluxes and eddy currents in the elemental induction meter with a view to determining its characteristic law of operation. In the following discussion only torques on the disc are mentioned, since the various forces act at a constant radius from the axis of the disc.

Let V = voltage applied to the pressure coil.
I = current in the series coil.
Φ_v = effective flux due to V.
Φ_i = effective flux due to I.
i_v = eddy current in the disc due to Φ_v.
i_i = eddy current in the disc due to Φ_i.
i_q = current induced in the quadrature loop.
ϕ = phase difference between I and V.
a = phase difference between Φ_v and Φ_s.
x = phase difference between i_i and e_i.
y = „ „ „ i_v and e_v.
z = quadrature error of Φ_v (may be + or –).
Q = the friction compensating torque.
F = the frictional retarding torque.

N = the angular velocity of the disc.

Φ_m = the permanent magnet flux.

k_1, k_2, etc. = various constants.

N.B. Lagging angles are negative and leading angles positive.

The phase relations of the above quantities are shown in the vector diagram in Fig. 41, and the lay-out of the eddy currents and fluxes in Fig. 42. In order to appreciate the positive nature of the torque on the disc, suppose Fig. 42 represents the conditions when Φ_i is rising to a maximum value and the power-factor is unity. With the polarities shown, the directions of the eddy currents can be found by the usual rule. We can now investigate the reactions. The directions of the forces are found by Fleming's left-hand rule, and we find that they act in the same direction. If we pursued this method of treatment, we should find that over a complete cycle the mean force would be in this direction. This conclusion is important, because certain writers in the past have been confused on this point owing to the fact that in the vector diagram in Fig. 41 the current i_v is almost 180° out of phase with Φ_i (the flux with which it reacts). It must be remembered,

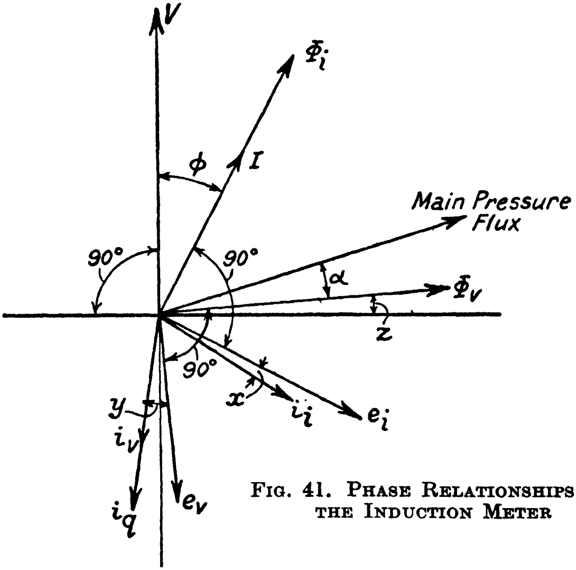


FIG. 41. PHASE RELATIONSHIPS IN THE INDUCTION METER

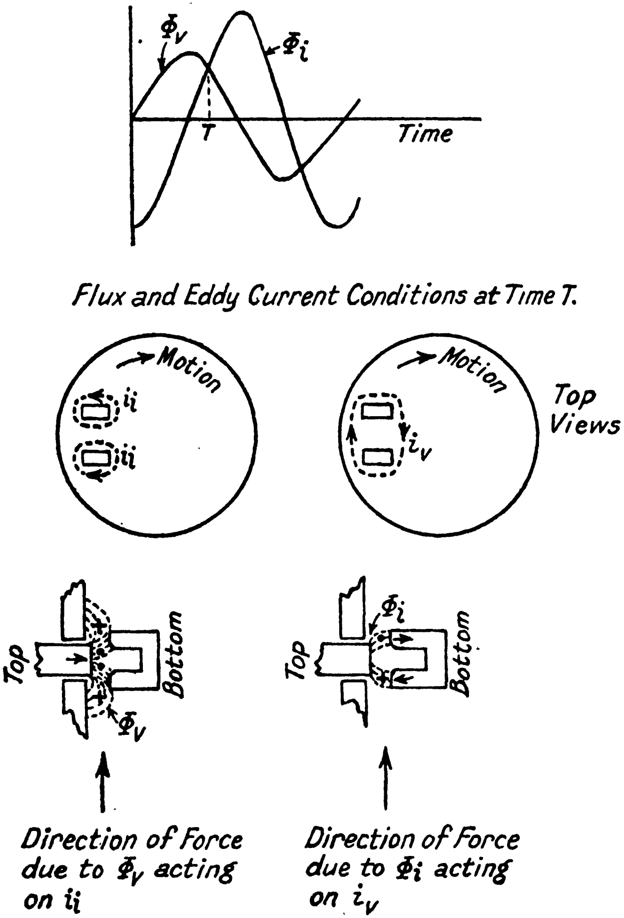


FIG. 42. THE INTERACTION OF FLUX WITH EDDY CURRENTS

however, that the vector diagram only shows the phase or time relations of the quantities concerned, and not their space relations. (See Appendix II.)

Let T_a equal the torque due to the interaction of i_i with Φ_v, and let T_b equal the torque due to the interaction of i_v with Φ_i. Since the force (using R.M.S. values) on a conductor carrying a current I in a magnetic field of strength H is equal to $I \,.\, H \,.\, \cos \phi$ per unit length, where ϕ is the phase angle between I and H, then

$$T_a = k_1 \,.\, \Phi_v \,.\, i_i \,.\, \cos (\phi - z + x)$$

and

$$T_b = k_2 \,.\, \Phi_i \,.\, i_v \,.\, \cos (\phi - z - y)$$

$\therefore$ The total driving torque

$$= Q + k_1 \,.\, \Phi_v \,.\, i_i \,.\, \cos (\phi - z + x) + k_2 \,.\, \Phi_i \,.\, i_v \,.\, \cos (\phi - z - y)$$

The constants k_1 and k_2 may or may not be equal. An important thing to notice in Fig. 41 is that the angles x and y are not negligible and they are not equal. This is because the mean eddy current path of i_v encloses, in most meters, a larger area than that of i_i, which makes the former have a higher reactance than the latter. It has been shown by several writers that the time constant of the eddy current paths is of the order of 0·0006, corresponding to a lag of 6° at 30 cycles, 10° at 50 cycles, and 20° at 100 cycles.

Braking Torque. The steady motion of the disc is retarded by the action of the following forces—

1. Friction in the bearings and revolution counter. This is practically independent of the speed of the disc.
2. Eddy current brake torque due to the permanent magnet. This is proportional to N and Φ_m^2 (see page 20).
3. Eddy current brake torque due to Φ_v, which is proportional to N and Φ_v^2.
4. Eddy current brake torque due to Φ_i, which is proportional to N and Φ_i^2.
5. Windage. This is negligible.

$\therefore$ The total braking torque

$$= F + k_3 \,.\, N \,(\Phi_m^2 + k_4 \,.\, \Phi_v^2 + k_5 \,.\, \Phi_i^2)$$

The constants k_4 and k_5 are necessary in order to accommodate the differing nature and positions of the fluxes. Therefore when the disc speed is steady, we have the relation

$$Q + k_1 \,.\, \Phi_v \,.\, i_i \,.\, \cos (\phi - z + x) + k_2 \,.\, \Phi_i \,.\, i_v \,.\, \cos (\phi - z - y)$$
$$= F + k_3 \,.\, N(\Phi_m^2 + k_4 \,.\, \Phi_v^2 + k_5 \,.\, \Phi_i^2)$$

This is the characteristic law of the induction meter.

Now Φ_i is independent of the frequency, i_i and i_v are proportional to the frequency, Φ_v is inversely proportional to the frequency, and i_i and i_v are proportional to Φ_i and Φ_v respectively. Therefore the products $\Phi_i . i_v$ and $\Phi_v . i_i$ are nominally independent of the frequency and directly proportional to the product $I . V$. (The actual effect of frequency change is discussed later.) If the meter is to work on a definite frequency, then the angles x, y, and z can be arranged so that the driving torque, neglecting Q, is closely proportional to the power $I . V . \cos \phi$. Unfortunately the brake torque, neglecting F, is not directly proportional to the disc speed (if Φ_v is constant), but contains a factor which is proportional to the product of I^2 and N. This is the cause of the characteristic droop of the uncompensated induction meter error curve as the load increases. This difficulty is overcome to some extent by keeping Φ_i small relative to Φ_m, but many modern meters incorporate devices for compensating for this characteristic droop. Such devices are (1) magnetic insert on series laminations (see Fig. 49) or (2) making the series laminations a special shape and/or a mixture of different kinds of steel. Having realized the nature of the forces in the meter, we can now consider the effect of temperature, frequency, voltage, and wave form variations.

Temperature Variations. The sources of error due to temperature are enumerated below—

1. The resistance of the copper pressure coil increases with rise of temperature 0·4 per cent per ° C. The change in coil impedance is negligible owing to its high reactance, but the change in phase angle of the coil current causes the disc to slow down on lagging power-factors and speed up on leading power-factors.

2. The resistance of the aluminium disc and the copper, brass, or aluminium quadrature compensator increases with rise of temperature 0·4 per cent per ° C. Thus the amount of quadrature compensation decreases with rise of temperature, causing the disc to slow down on lagging power-factors and speed up on leading power-factors. The flux Φ_v increases slightly with rise of temperature, which causes the disc to run a shade faster.

3. The brake magnet decreases in strength by 0·025 per cent per ° C. rise of temperature, which causes the disc to speed up by approximately 0·04 per cent per ° C.

The increase in disc resistance with rise of temperature affects the driving and braking eddy currents to the same extent, and thus no error is introduced on this account. The average changes in error per ° C. due to the above effects are given in Table I, a minus sign indicating that the disc runs slower.

The coefficients in Table I are only average figures, and particular meters may vary widely from the above figures. To reduce

TABLE I

0·7 leading P.F.	Unity P.F.	0·75 lagging P.F.	0.5. lagging P.F.
+ 0·1%	+ 0·05%	*nil*	- 0·03%

these coefficients (see page 152 for further data), the following devices are used in certain compensated meters: Magnet mounted on a bimetallic strip; variable gap in the pressure flux magnetic circuit controlled by a bimetallic bar; special magnetic shunt made of copper-nickel alloy (the permeability of this alloy alters considerably with temperature) fitted to the brake magnets; quadrature loop made of zero temperature coefficient metal; special compensating copper loops on the series magnetic circuit; pressure flux pole tip of copper-nickel alloy. The amount of compensation afforded by these devices is, of course, dependent on their design and adjustment, and because a meter is fitted with such devices it does not follow that the temperature errors are wiped out altogether. It should be noted that these temperature compensators have a time lag owing to the necessity for heating up a mass of metal before the alteration takes place.

Voltage Variations. The flux Φ_v increases with rise of voltage, and, consequently, the braking flux is increased. Thus the disc will slow down on the higher loads with rise of voltage. If $k_4 \,.\, \Phi_v^2$ is small compared with Φ_m^2, then the change in error will be very small. On low loads the disc will, in general, speed up with rise of voltage owing to the increased friction compensating torque. The latter effect accounts for the need of testing the creep preventer with a voltage 10 per cent in excess of normal applied to the pressure coil.

Frequency Variations. Apart from the fundamental changes discussed above, a variation in frequency has the following effects:

1. The pressure coil current decreases in relative magnitude with decrease in frequency, thus slowing down the disc. This is because the resistance of the coil prevents the curve of current against frequency following a hyperbola. The resistance also causes the phase angle of the current to decrease with decrease of frequency. The effect of the latter change depends on the sign of ϕ.

2. Increase of frequency causes the reactance of the eddy current paths in the disc to increase, which increases the angles x and y. The effect of these changes depends on the sign of ϕ. The increased reactance causes the currents i_i and i_v to decrease, which causes the disc to slow down.

3. The reactance of the quadrature compensator increases with

rise of frequency. This, in conjunction with the increased reactance of the eddy current paths in the disc, causes Φ_v to decrease in relative magnitude, and thus slow the disc down.

4. The changes in the relative magnitude of Φ_v cause an equivalent change in i_v.

5. The braking flux decreases with rise of frequency owing to the reduction in Φ_v, thus causing the disc to speed up.

The error-frequency curves for a typical meter are given in Fig. 43, the meter having no error on 50 cycles at unity, 0·5 leading and 0·5 lagging power-factors. The wide difference between the curves is due to the fact that the angles x and y are not equal.

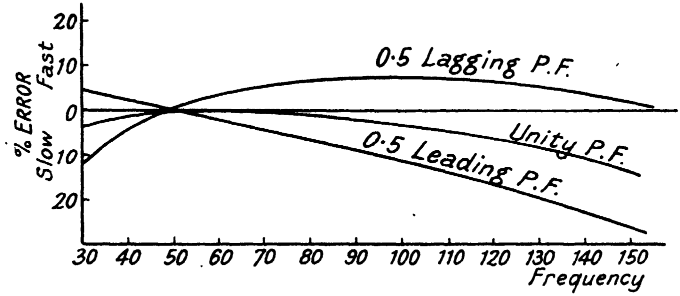


FIG. 43. TYPICAL FREQUENCY-ERROR CURVES

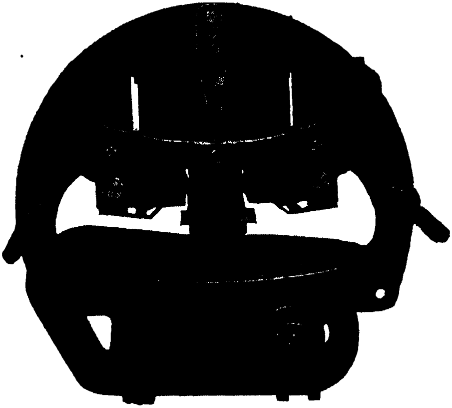
Wave Form Variations. If the current wave only possesses a harmonic, then the meter will run slower than it should do owing to the increased braking torque. The reader will know that fluxes of different frequencies cannot interact to produce a steady torque. There is also an effect due to the harmonic flux altering the magnetic characteristic of the laminations.

If both current and pressure waves contain a harmonic, then the meter error (assuming the meter to be accurate on the fundamental) may be plus or minus, depending on the power-factor of the harmonic and the excess of braking flux.

Interesting Details of Certain A.C. Meters. Only those features wherein they differ from the elemental form will be discussed, as the electrical and mechanical features will be obvious from the accompanying illustrations. Meter bearings are treated separately on page 90.

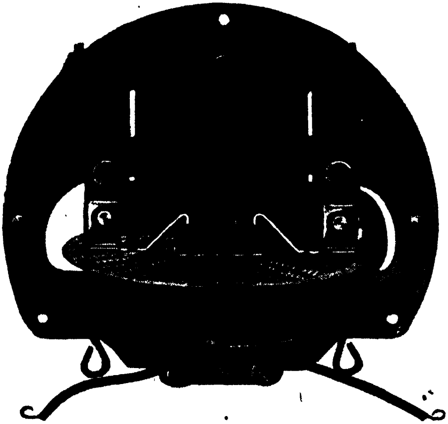
The Metropolitan-Vickers type N.A. meter is the one chosen as the elemental type, as an inspection of Figs. 35, 44, and 45 will indicate. Its functions have already been discussed.

The Rex type S.I.P.1.A. meter is interesting on account of the peculiar place for the quadrature loop. Fig. 46 shows the flux paths for each electromagnet, and obviously the quadrature loop performs the same action as that described on page 55. Its position simplifies the construction of the meter considerably, as only



(*Metropolitan-Vickers, Ltd.*)

FIG. 44. M.V. TYPE N.A. METER (FRONT VIEW)



(*Metropolitan-Vickers, Ltd.*)

FIG. 45. M.V. TYPE N.A. METER (BACK VIEW)

one screw is needed for both the loop and the friction compensator. The latter is the iron vane *V*. The function of the vane is to cause a phase difference between the flux on the right and left sides of the pole *P*. It achieves this by reason of its hysteresis, which causes the flux passing through the vane to lag the flux in the remainder of the gap. The effect of such a phase difference has already been seen.

In the Landis and Gyr type C.B.o. meter the electromagnet system is different from that of other meters. It will be seen from Fig. 47 that the main path of the pressure flux is along limb *K*, but an alternative path is offered via the disc and limb *V*. Path *V* has a higher reluctance than path *K*, because in the former the air-gap is wider and the lagging effect of the thick aluminium disc is greater than that of the thin copper plate. This explains why Φ_v is smaller than Φ_k and lags behind it considerably. Adjustment of the copper plate alters the phase of Φ_k (see Fig. 47) and hence the phase of Φ_v, since the total flux is sensibly constant in phase and magnitude.

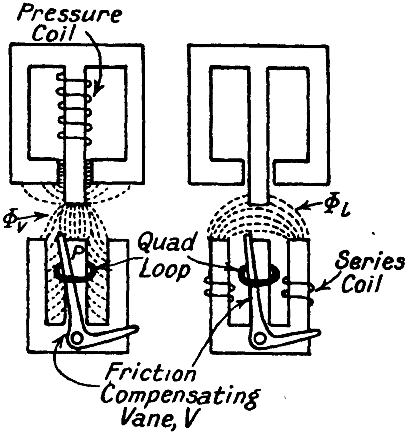
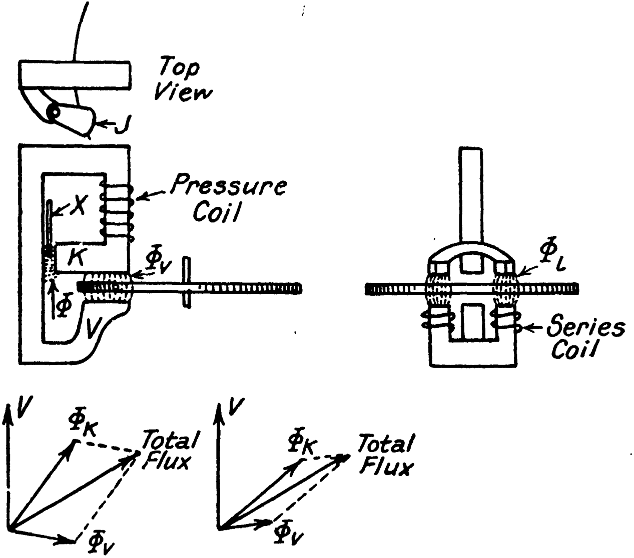


FIG. 46. FLUX DISTRIBUTION IN THE REX METER

The friction compensation is effected by the iron vane *J*. This vane creates a definite leakage field and, owing to its hysteresis, the leakage field lags the working flux Φ_v. The effect of such a phase difference has already been described.

A feature worthy of note is the special bridge piece for transferring the current flux round the pressure coil laminations. It is necessary because the shunt laminations are in the wrong plane for the easy passage of the current flux.

The Measurement type A.2 meter also has an original construction of the electromagnets, as will be seen from Fig. 48. The distribution of the flux due to the two coils is shown in Fig. 48. Clearly the quadrature loops have no effect on the current flux, because the resultant current flux passing through each loop is zero. For simplicity of construction, the two quadrature loops are made from a single stamping of copper. The necessary slight difference in the phase of the pressure flux between each side of the two sets of poles is caused by making the reluctance of path pole 1, bottom plate, and pole 4 higher than that of path pole 2, bottom plate, and pole 3. This is done by making the bottom plate take an eccentric position, this position being adjustable.



Copper Plate X Out *Copper Plate X In.*

FIG. 47. FLUX DISTRIBUTION IN THE LANDIS AND GYR TYPE C.B.o. METER

The Sangamo type H meter is interesting because it has such a good overload performance and because it uses a large proportion of the total pressure flux in the interpolar gap. The good overload characteristic is chiefly due to using a low current flux, but it is aided by using a special iron insert in the series laminations as shown in Fig. 49. The main function of this low saturation point wedge is to carry the pressure flux. Up to a certain value of current a certain proportion of the current flux is bypassed from the disc, but above this point the saturation of the

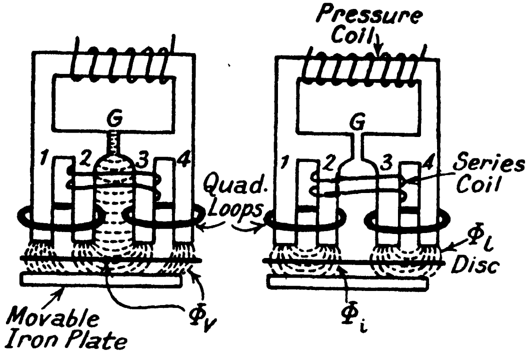


FIG. 48. FLUX PATHS IN THE MEASUREMENT A.C. METER

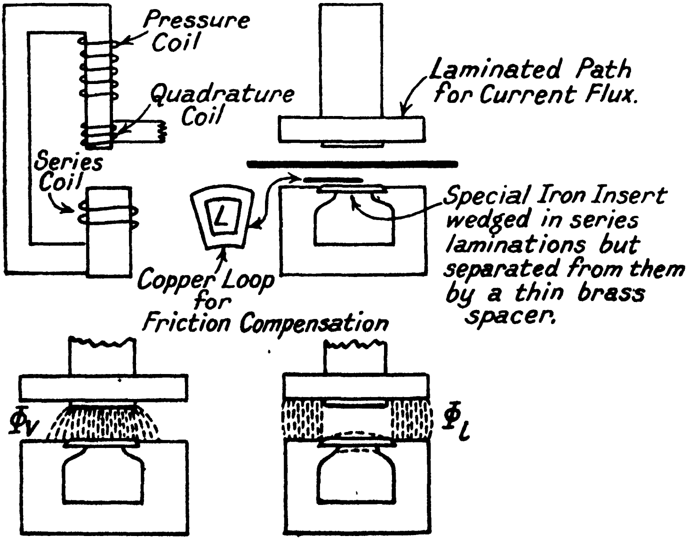


FIG. 49. CONDITIONS IN THE SANGAMO A.C. METER

wedge forces the remainder of the flux across the interpolar gap. Thus on high loads a greater proportion of the current flux passes through the disc than on low loads. The extra driving torque balances the extra braking torque due to the increase in Φ_i.

The quadrature compensation is effected jointly by the quadrature coil, the disc, and the friction compensating loop. The resistance joining the ends of the quadrature coil is adjustable, and thus enables the compensating effect to be altered. The friction compensation is obtained by offsetting the loop L so as to act more on one side of the pressure flux than the other. This causes the necessary phase difference.

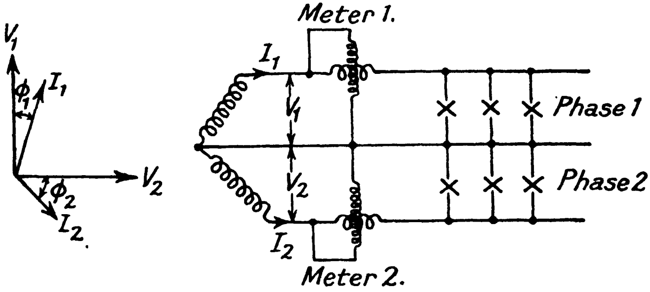


FIG. 50. METER CONNECTIONS FOR TWO-PHASE SUPPLY

More Modern Meters. Owing to the demand for smaller, lighter, more accurate, and longer-range meters, many of the types described above have now been superseded by new models. The chief changes are (1) the use of overload-droop compensation (see page 62); (2) simpler construction of the electromagnet system; (3) the use of more efficient brake magnets; (4) removal of rotor made possible without upsetting calibration; but the principles of operation are, of course, unaltered. The longer-range meter has become necessary, since the load of the All-in domestic consumer may now vary from 30 watts to 10 (or more) kW.

Prevention of Creep. In order to obtain a good calibration curve, it is sometimes necessary to over-compensate the meter for friction. If precautions were not taken, this would cause the disc to creep forward at no load and register a false consumption. The following devices are employed to prevent the disc from travelling more than one revolution due to excess friction compensation.

1. Holes or slots in the disc. The presence of the hole or slot so disturbs the eddy current paths that in a certain position a backward torque is created, since the hole or slot tends to move to the position of greatest flux density.

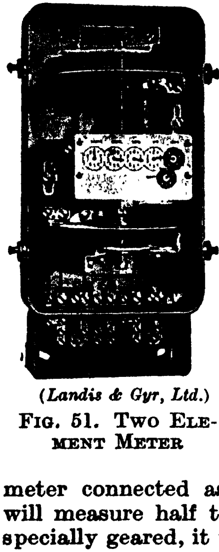
2. An iron wire is wrapped round the disc spindle. In one position the end of the wire approaches a projecting shunt lamination, the ensuing attraction overcoming the excess compensation.

3. A piece of iron stuck to the surface of the disc. When this iron approaches the permanent magnet, the resulting attraction overcomes the excess friction compensation.

The creep preventer should not be made too powerful, or else the disc will not run satisfactorily on starting current.

MEASURING ENERGY IN POLYPHASE A.C. CIRCUITS

Two-phase Three-wire System. 1. TWO SINGLE-PHASE W.H.M.'s. The most accurate method is to treat the system as two separate circuits, and use two single-phase meters connected as shown in Fig. 50. Meter 1 measures $\int_{t_1}^{t_2} V_1 . I_1 . \cos\phi_1 . dt$ and meter 2 measures $\int_{t_1}^{t_2} V_2 . I_2 . \cos\phi_2 . dt$. Thus the sum of the readings of the two meters gives the total energy supplied in time t_1 to t_2.



(*Landis & Gyr, Ltd.*)

FIG. 51. TWO ELEMENT METER

2. TWO ELEMENT METER. Instead of using two single-phase meters, it is possible to use a two-element meter (see Fig. 51), in which the disc speed is proportional to $V_1 . I_1 . \cos\phi_1 + V_2 . I_2 . \cos\phi_2$. Thus the total energy can be integrated on one dial. It also enables the average maximum total demand to be measured, which is not possible with two separate meters.

3. BALANCED LOAD METER. If the loads in each phase are equal, then a single-phase meter connected as shown in Fig. 50 for meter 1 or meter 2 will measure half the total energy. If its revolution counter is specially geared, it will read the total energy supplied, provided the system is always balanced. This method is not permitted for charging purposes, but it is sometimes useful for works costing purposes.

Three-phase Three-wire System. Consider the generator or transformer supply to be star-connected. Then the total power will be the sum of the powers generated in each phase, i.e. (see Fig. 52),

Total power

$$= V_R . I_R . \cos\theta_R + V_Y . I_Y . \cos\theta_Y + V_B . I_B . \cos\theta_B$$

Thus to measure the total energy we require three single-phase mteers connected as shown in Fig. 52. This, however, is not usually possible for practical reasons, so some other method must be found.

Consider the vector diagram in Fig. 53 and let small letters represent instantaneous values. Since there are only three wires carrying the currents, then by Kirchhoff's law

$$i_R + i_B = -i_Y$$

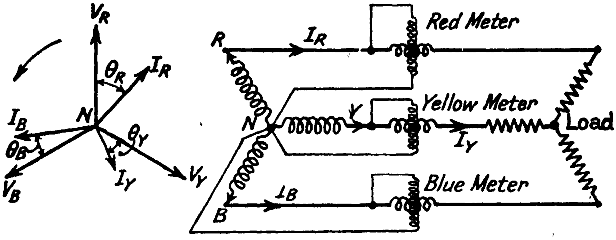


FIG. 52. CONNECTIONS FOR THREE-PHASE, THREE-WIRE SYSTEM IF THE NEUTRAL IS AVAILABLE

The arrows indicate the positive directions

Now, the total power at any instant

$$\begin{aligned} &= v_R \,.\, i_R + v_Y \,.\, i_Y + v_B \,.\, i_B \\ &= v_R \,.\, i_R + v_B \,.\, i_B - v_Y(i_R + i_B) \\ &= i_R(v_R - v_Y) + i_B(v_B - v_Y) \end{aligned}$$

$\therefore$ The total energy

$$\begin{aligned} &= \int_{t_1}^{t_2} [i_R(v_R - v_Y) + i_B(v_B - v_Y)]dt \\ &= \int_{t_1}^{t_2} (i_R e_R + i_B e_B)dt \end{aligned}$$

if $\quad v_R - v_Y = e_R$, and $v_B - v_Y = e_B$

But e_R is the instantaneous voltage between the red and yellow lines, because in a star network the positive directions are taken as shown in Fig. 52. Similarly, e_B is the instantaneous voltage between the blue and yellow lines.

Fig. 53 illustrates the derivation of the $\mathbf{E}_R$ and $\mathbf{E}_B$ vectors. If the voltages and currents follow a sine law, we have the relations

$$e_R = \mathbf{E}_R \,.\, \sin \omega t \text{ and } i_R = \mathbf{I}_R \,.\, \sin (\omega t + \phi_R)$$

where $\quad \omega t = 2\pi \,.\, t \,.\,$ frequency

$\phi_R =$ phase difference between $\mathbf{E}_R$ and $\mathbf{I}_R$.

It must be noted that a lagging phase angle is denoted by a negative sign and a leading phase angle by a positive sign. Thus

ϕ_R above is written down as positive until it is definitely known to be either lagging or leading. (Fig. 53 only shows one particular case, of course.) The student should also note the interesting fact that the cosine of an angle is the same, whether the angle is positive or negative. (Heavy type denotes maximum values.)

$$\therefore \quad i_R \, . \, e_R = \mathbf{I}_R \, . \, \mathbf{E}_R \, . \, \sin(\omega t + \phi_R) \, . \, \sin \omega t$$
$$= \mathbf{I}_R \, . \, \mathbf{E}_R \left(\tfrac{1}{2}\cos\phi_R - \tfrac{1}{2}\cos(2\omega t + \phi_R)\right).$$

See Appendix III.

$\therefore \int_{t_1}^{t_2} i_R \, . \, e_R \, . \, dt = \int_{t_1}^{t_2} \mathbf{I}_R \, . \, \mathbf{E}_R \, (\tfrac{1}{2}\cos\phi_R) dt$, if $(t_2 - t_1)$ equals a complete number of periods, since the integral of $\tfrac{1}{2}\cos(2\omega t + \phi_R)$ over a complete number of periods is zero. (See Appendix I.)

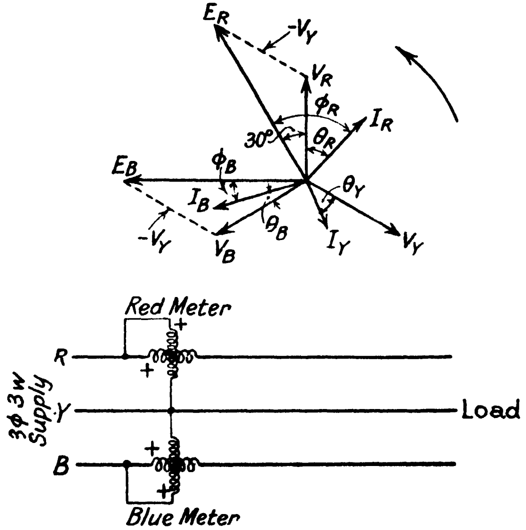


FIG. 53. CONNECTIONS FOR THREE-PHASE, THREE-WIRE SYSTEM IF THE NEUTRAL IS NOT AVAILABLE

Similarly, $\int_{t_1}^{t_2} i_B \, . \, e_B \, . \, dt = \int_{t_1}^{t_2} \mathbf{I}_B \, . \, \mathbf{E}_B \, . \, (\tfrac{1}{2}\cos\phi_B) dt$

$\therefore$ The total energy

$$= \int_{t_1}^{t_2} \frac{\mathbf{I}_R \, . \, \mathbf{E}_R \, . \, \cos\phi_R}{2} \, . \, dt + \int_{t_1}^{t_2} \frac{\mathbf{I}_B \, . \, \mathbf{E}_B \, . \, \cos\phi_B}{2} \, . \, dt$$

$$= \int_{t_1}^{t_2} (I_R \, . \, E_R \, . \, \cos\phi_R + I_B \, . \, E_B \, . \, \cos\phi_B) dt \quad . \quad \text{Equation (1)}$$

$$\text{if } \frac{\mathbf{I}_R}{\sqrt{2}} = I_R \text{ and } \frac{\mathbf{E}_R}{\sqrt{2}} = E_R, \text{ etc.}$$

But $\frac{\mathbf{I}_R}{\sqrt{2}}$ etc., are R.M.S. values, by definition, therefore equation (1) is in terms of quantities measurable by ordinary instruments.

1. **Two Single-phase Meters.** We have already shown that an induction meter can measure such a quantity as $I \,.\, V \,.\, \cos \phi$, therefore it follows from the above proof that the total energy can be measured by means of two single-phase meters connected as in Fig. 53.

$$\text{The red meter measures } \int_{t_1}^{t_2} I_R \,.\, E_R \,.\, \cos \phi_R \,.\, dt$$

$$\text{The blue meter measures } \int_{t_1}^{t_2} I_B \,.\, E_B \,.\, \cos \phi_B \,.\, dt$$

2. **Two-element Meter.** The two single-phase meters can be replaced by a two-element meter whose disc rotates at a speed proportional to $I_R \,.\, E_R \,.\, \cos \phi_R + I_B \,.\, E_B \,.\, \cos \phi_B$. This enables the total energy to be integrated on one dial and the average maximum demand to be obtained if desired.

3. **Balanced Load Meter.** If the system is balanced in all respects, then $\theta_R = \theta_Y = \theta_B = \theta$ and $\phi_R = (30 - \theta_R)$ and $\phi_B = (30 + \theta_B)$.

$$\begin{aligned}
\therefore \text{ Total power} &= I \,.\, E \,.\, [\cos (30 - \theta) + \cos (30 + \theta)\,], \\
&\qquad \text{if } I = I_R, \text{ etc., and} \\
&\qquad\quad E = E_R, \text{ etc.} \\
&= I \,.\, E \,.\, (2 \,.\, \cos \theta \,.\, \cos 30) \\
&= I \,.\, E \,.\, (2 \,.\, \frac{\sqrt{3}}{2} \,.\, \cos \theta) \\
&= \sqrt{3} \,.\, I \,.\, E \,.\, \cos \theta
\end{aligned}$$

$$\therefore \text{ The total energy} = \int_{t_1}^{t_2} \sqrt{3} \,.\, I \,.\, E \,.\, \cos \theta \,.\, dt$$

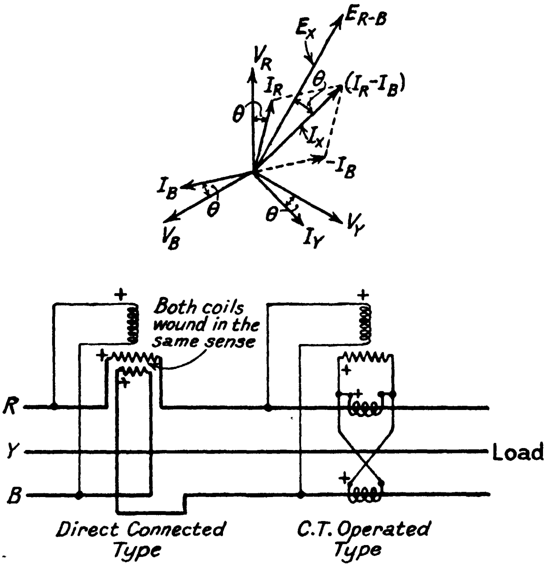
The above equations are also used when making approximate calculations of the power and energy in unbalanced three-phase systems.

Consider a single-phase meter connected so as to receive the blue to red pressure and the (red–blue) current, as shown in Fig. 54. If the system is perfectly balanced, then the current I_x lags E_x by the angle θ if the power-factor is $\cos \theta$. I_x equals $\sqrt{3} \,.\, I$.

$\therefore$ The meter measures $\int_{t_1}^{t_2} \sqrt{3} \,.\, I \,.\, E \,.\, \cos \theta \,.\, dt$, i.e. the total energy, These meters are not allowed for charging purposes, but they are useful for works costing purposes.

When this type of meter is direct connected, then two series windings of equal ampere-turns are required on the current electromagnet, as indicated in Fig. 54.

Three-phase Four-wire System. 1. THREE SINGLE-PHASE METERS. It is now possible to connect three single-phase meters as shown in Fig. 52 in order to measure the total energy, the neutral point now being accessible.



Direct Connected Type *C.T. Operated Type*

FIG. 54. CONNECTIONS FOR BALANCED LOAD METER ON A THREE-PHASE, THREE-WIRE SUPPLY

2. THREE-ELEMENT METER. Instead of having three separate meters, it is possible to combine them so as to drive a common moving system (see Fig. 55), whose speed is proportional to the total power. Thus the total energy will be registered on one dial and, if desired, the average total maximum demand can be obtained.

3. TWO SINGLE-PHASE METERS. The necessary connections are given in Fig. 56, and the vector diagram gives the conditions in each meter on a typical load. The red meter is supplied with the red to neutral pressure and I_m (red minus yellow current), whilst

the blue meter is supplied with the blue to neutral pressure and I_n (blue minus yellow current). Obviously the yellow to neutral voltage is not taken into consideration, hence this method is only suitable for polyphase circuits where

$$v_R + v_Y + v_B = 0$$

Now the total power at any instant equals

$$v_R i_R + v_Y i_Y + v_B i_B$$

Therefore, under the above condition the total power

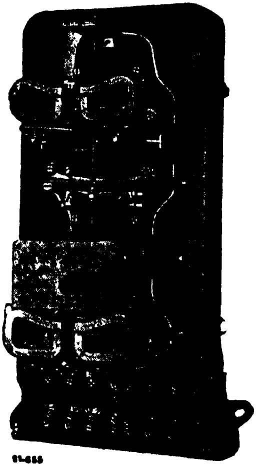
$$= v_R i_R + v_B i_B + i_Y(-v_R - v_B)$$
$$= v_R(i_R - i_Y) + v_B(i_B - i_Y)$$
$$= v_R i_m + v_B i_n \quad . \quad . \text{ see Fig. 56.}$$

∴ The total energy

$$= \int_{t_1}^{t_2} (v_R i_m + v_B i_n)dt$$
$$= \int_{t_1}^{t_2} (V_R I_m \cos \phi_R + V_B I_n \cos \phi_B)dt$$

(See page 72 for the method of deriving the above equation from the previous one.)

Now, the red meter measures $\int_{t_1}^{t_2} V_R I_m \cos \phi_R dt$, and the blue meter measures $\int_{t_1}^{t_2} V_B I_n \cos \phi_B dt$; therefore the two meters together measure the total energy.



(*Landis & Gyr, Ltd.*)

FIG. 55. THREE ELEMENT METER

With regard to the effect of voltage unbalance, the meters may be considered in the following way: The red meter measures the energy in the red phase plus $\int_{t_1}^{t_2} V_R I_Y \cos(60 + \theta_Y)dt$, whilst the blue meter measures the energy in the blue phase plus $\int_{t_1}^{t_2} V_B I_Y \cos(60 - \theta_Y)dt$. Thus the energy in the red and blue phases is measured accurately whatever the voltage conditions, but in place of $\int_{t_1}^{t_2} V_Y I_Y \cos \theta_Y dt$ the meters register

$$\int_{t_1}^{t_2} (V_R I_Y \cos(60 + \theta_Y) + V_B I_Y \cos(60 - \theta_Y))dt$$

If the voltages are unbalanced, it will be necessary to compare the last expression with $\int_{t}^{t_1} V_Y I_Y \cos \theta_Y dt$, in order to determine the extent of the inaccuracy of the meters.

4. **Two-element Meter.** Instead of using two single-phase meters a two-element meter can be used, and this is a frequent practice for three-phase four-wire measurements of energy if the load exceeds about 10 kW. It is necessary, however, to bear in mind the above stipulation regarding the supply voltages when applying and testing these meters. Also see page 319.

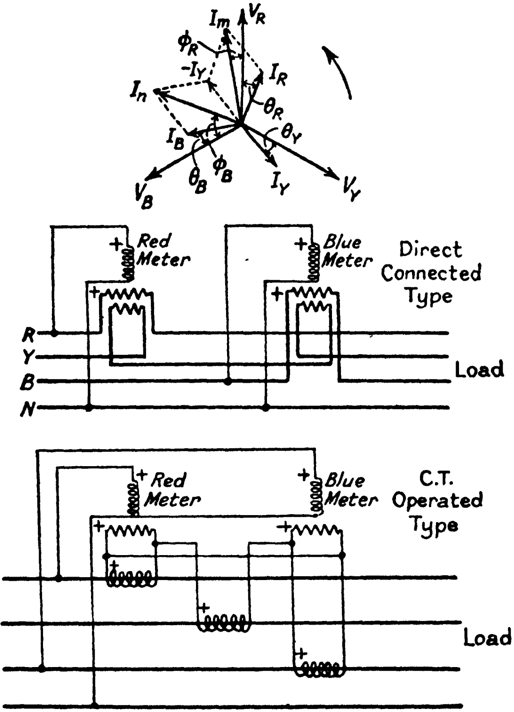


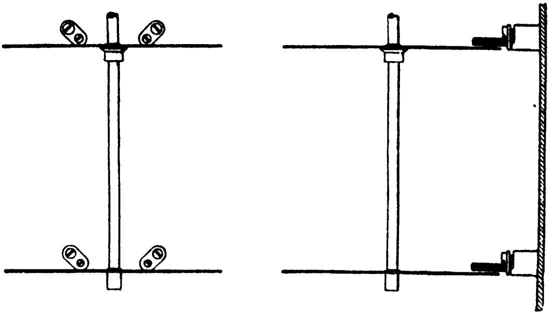
Fig. 56. Connections for Meters on a Three-phase, Four-wire Supply

5. **Balanced Load Meter.** If the system is perfectly balanced, then a single-phase meter connected so as to measure the energy in one phase will give the total energy if its readings are

multiplied by three. If desired, the counter can be geared so as to indicate the total energy directly. This method is not permitted for charging purposes.

The Polyphase Watt-hour Meter. This differs from the ordinary single-phase meter in three respects.

Each element exerts its torque on the same moving system, which therefore runs at a speed proportional to the total driving torque, since the braking system is constant (assuming the voltages to be steady and ignoring the effect of the current fluxes). We have seen in the last section that the total driving torque can be made proportional to the total power, hence the rotor speed can also be made proportional to the total power.



(*Metropolitan-Vickers, Ltd.*)

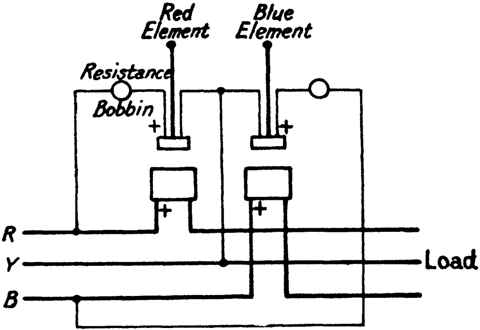
FIG. 57. THE M.V. TYPE N BALANCE ADJUSTER

Means must be provided for increasing or decreasing the torque of an element relative to the others. This device is termed the balance adjuster. This adjustment is necessary, since each element must exert an equal torque when measuring equal powers.

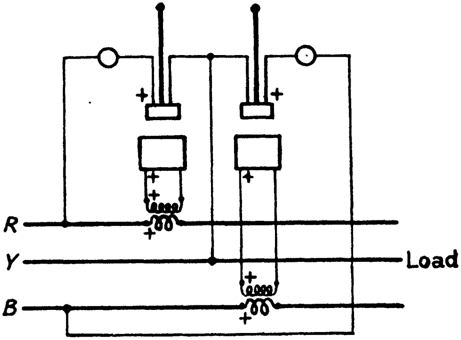
The Metropolitan-Vickers balance adjuster is shown in Fig. 57. By screwing in or out the iron grub screws, the pressure leakage flux of an element can be decreased or increased respectively, thus reducing or increasing the torque of the element concerned. It will be remembered that this type of meter employs the pressure leakage flux for driving torque purposes.

In the Chamberlain and Hookham two-element meter, the lower element is inverted, which causes the two series laminations to be adjacent. The two sets are mounted on the same base plate. This plate can be moved up or down by means of two eccentric studs working in slots cut in the base plate. To increase the torque of an element, its gap is narrowed and *vice versa*. When the base plate is moved, one element speeds up and the other slows down; this necessitates a complete re-test after an adjustment has been made.

Interaction takes place between the elements. This is due to the fact that the flux of an electromagnet does not confine itself



Direct Connected Type



C.T. Operated Type.

FIG. 58. CONNECTIONS FOR THREE-PHASE, THREE-WIRE PENDULUM METERS

to its own element; a portion of it strays into the gaps of the other element or elements. This stray flux interacts with the eddy currents in the disc and creates an unwanted torque. The effect of interaction can be largely eliminated by inverting the elements as shown in Fig. 51 or by making the series and pressure coil laminations continuous. The question of interaction is again discussed on page 235.

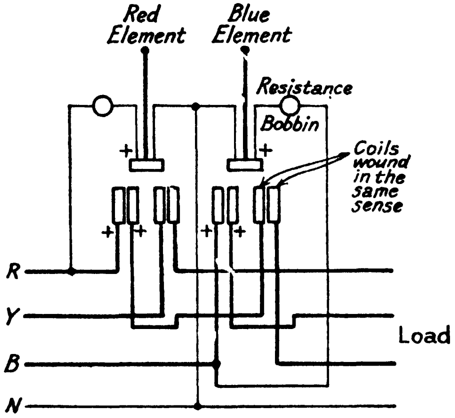
A disadvantage of the polyphase meter is that the heavy moving system causes a greater stress on the bottom jewel than occurs in the single-phase meter. This leads to more rapid wear and need for maintenance, particularly if the meter is subject to vibration.

Dynamometer Type Polyphase Watt-hour Meter. Of this type of meter, only the Aron pendulum meter has had any degree of popularity. As it is inherently a two-element meter, it is suited to the methods of measuring polyphase energy described above. The connections for the three-phase, three-wire meter are shown in Fig. 58 for both the direct and indirectly connected types. It is claimed that this type of meter is free from interaction and, therefore, independent of phase rotation, provided the two elements are balanced. The elements are balanced by adjusting the ballast resistances; increasing the resistance decreases the registration of that element.

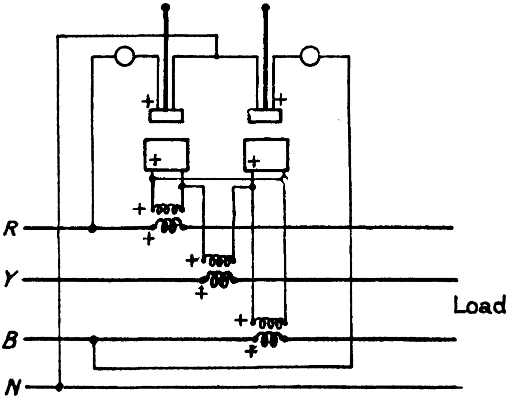
The connections of the three-phase four-wire meter are shown in Fig. 59. In the case of the direct-connected meter, each element must have two current coils, and one of the coils must be adjustable in order to equalize the effects of the two coils on the pendulum.

Sine Meters or Reactive kVAh Meters. Consider a single-phase circuit of voltage V and current I. An energy meter connected therein measures a quantity $\int_{t_1}^{t_2} V . I . \cos\phi . dt$, which we know is the energy supplied in time $(t_2 - t_1)$. Now suppose we can also measure the quantity $\int_{t_1}^{t_2} V . I . \sin\phi . dt$. Then from these two quantities we can derive the mean power-factor of the supply and also the kVAh in a manner to be described later. Thus it is important to know how we can measure $\int_{t_1}^{t_2} V . I . \sin\phi . dt$, or the reactive kVAh (now abbreviated to kVARh).

If the phase of the voltage or current flux in an induction watt-hour meter is altered by 90° from its usual position, then the speed of the disc will be proportional to $V . I . \cos(90 - \phi)$, i.e. $V . I . \sin\phi$ instead of $V . I . \cos\phi$. This can be done in several ways. If the pressure coil of the meter is in series with a sufficiently high resistance, then the pressure flux will be almost in phase with the voltage and not lagging by nearly 90°, as in the case of the watt-hour meter. Another way is to supply the current coil from the secondary of an air core current transformer, the primary of which is in the main circuit. These methods have serious objections, however, and until recently it was not possible to obtain a satisfactory single-phase sine meter. Before dealing



Direct Connected Type



C.T. Operated Type.

FIG. 59. CONNECTIONS FOR THREE-PHASE, FOUR-WIRE PENDULUM METERS

with this new development, due to Messrs. Landis & Gyr, Ltd., we will first consider the various methods of using the two-element meter which have been developed for polyphase circuits.

Reversal of Torque of the Red Element of a Three-phase Three-wire Watt-hour Meter. In the normal three-phase three-wire cosine meter the torque is given, on a balanced load, by

$$\text{Torque} \propto EI[\cos(30-\theta) + \cos(30+\theta)] \text{ (see page 73).}$$

Suppose now that the current or pressure leads of the red element are reversed, causing the torque of that element to reverse also. The total torque is now given by

$$\begin{aligned}\text{Torque} &\propto EI[-\cos(30-\theta) + \cos(30+\theta)]\\ &\propto -EI(2\sin 30^\circ \sin\theta) \text{ (see Appendix III)}\\ &\propto -EI\sin\theta\end{aligned}$$

since $\sin 30^\circ = 0{\cdot}5$, and the sine of a negative (lagging) angle is also negative.

On a three-phase balanced system the power is $\sqrt{3}EI\cos\theta$, therefore the reactive kVA equal (numerically) $\sqrt{3}EI\sin\theta$. Thus the above meter would require a multiplying constant of $\sqrt{3}$, or a change of gearing of 1 to $\sqrt{3}$, in order to give the reactive kVAh correctly.

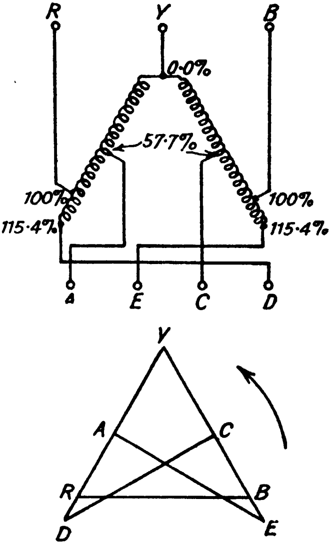


FIG. 60. WESTINGHOUSE REACTIVE COMPENSATOR

The Red Pressure Coil is supplied by $V_{A\text{-}E}$ instead of $V_{R\text{-}Y}$
The Blue Pressure Coil is supplied by $V_{D\text{-}C}$ instead of $V_{B\text{-}Y}$

In the case of a four-wire meter, it is necessary to reverse either the pressure or the current leads of the blue element in order to convert a cosine meter into a sine meter. The same gearing change or constant as before is required. The reader will realize that the above results only apply to systems with standard phase rotation, i.e. counter-clockwise. If the phase rotation is clockwise, then the conditions in the elements are interchanged, and it is necessary to reverse the opposite element to that given above. The naming of the elements "red" and "blue" is convenient, and the blue element is usually made the upper one in a two-element meter.

The Westinghouse sine meter is a normal cosine meter, but the pressure coils are supplied from a special transformer, which gives the coils pressures which are displaced 90° from those in a normal cosine meter. Fig. 60 shows the connections of the transformer and meter, and the explanatory vector diagram. By proportioning the turns as shown, the coil voltages are at the correct value, as well as phase angle. It must be remembered that with this device a common connection to the two pressure coils cannot be used. Messrs. Ferranti also employ an auto-transformer of the above type to convert a cosine meter to a reactive kVAh meter.

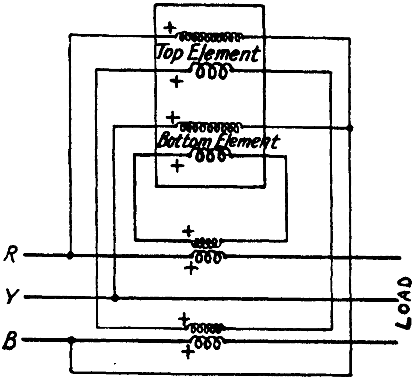


FIG. 61. M.V. SINE METER CONNECTIONS

The Metropolitan-Vickers sine meter for three-wire circuits employs the special connections shown in Fig. 61. By means of a special short-circuited coil on each series magnet and a small amount of resistance in each pressure circuit, the elements are calibrated so as to have a 60° displacement between the fluxes, compared with 90° in the normal induction element. Consequently $E_{Y-B\ eff}$ and $E_{R-B\ eff}$ are the effective voltages on the red and blue elements (see Fig. 62) respectively, if we wish to consider the elements as working under the ordinary conditions. But $E_{Y-B\ eff}$ lags E_{R-Y} by 90°, and $E_{R-B\ eff}$ lags E_{B-Y} by 90°, and thus if we compare the meter with a three-wire cosine meter, we find that this is the equivalent of shifting the pressure system through 90°. We have already seen that such a phase shift enables the meter to register reactive kVAh. This type of meter is not affected by unbalanced currents.

The Landis and Gyr sine meter has been specially developed to overcome the failings of polyphase sine meters, i.e. incorrect registration if the phase rotation is reversed, and different connections from the kWh meter. By placing resistance in series with the pressure coil and resistance in parallel with the series coil (considering now the single-phase element), the effective pressure flux and the effective current flux have been brought into phase at unity power-factor. This causes the meter speed to be proportional to $IE \sin \phi$ instead of $IE \cos \phi$, even though the connections are the same as for the kWh meter. The makers claim that this type of meter is not seriously affected by frequency variations, owing to the special manner of applying the resistances. Due to the inherent compensation, the meter may be applied to all types of A.C. circuits without special accessories. This is a great convenience, as it was previously impracticable to measure the reactive kVAh in a three-phase four-wire circuit, subject to large out-of-balance currents.

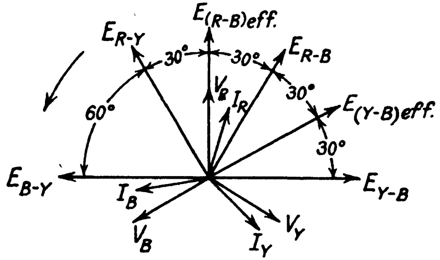


FIG. 62. VECTOR DIAGRAM FOR M.V. SINE METER

Kilovolt Ampere-hour Meters. In a three-phase four-wire circuit, the kVA are given by $(I_R \,.\, V_R + I_Y \,.\, V_Y + I_B \,.\, V_B)$ added arithmetically, and the kVAh by

$$\left(\int_{t_1}^{t_2} I_R \,.\, V_R \,.\, dt + \int_{t_1}^{t_2} I_Y \,.\, V_Y \,.\, dt + \int_{t_1}^{t_2} I_B \,.\, V_B \,.\, dt\right)$$

The former quantity can be measured, but the latter cannot be measured with sufficient accuracy at the present stage in the art of metering. Thus the only value of the kVAh which can be obtained from a meter is that defined by the vector sum definition, which is only equal to that obtained from the arithmetical sum when the power-factor of each phase is equal and in the same sense. Fig. 63 shows the current vectors added together vectorially, their lengths being corrected for any difference in the phase voltages. The respective phase angles of the currents I_R, I_Y, and I_B are θ_R, θ_Y, and θ_B.

The energy component of the currents

$$= OC = OA + AD + DC$$

The reactive component

$$= BC = BN + NM + MC$$

∴ The apparent total current

$$= OB = \sqrt{OC^2 + BC^2}$$

∴ The apparent total kVA

$$= OB \times \text{(the mean phase voltage)}$$

But the true total kVA

$$= (OR + RY + YB) \times \text{(the mean phase voltage)}$$

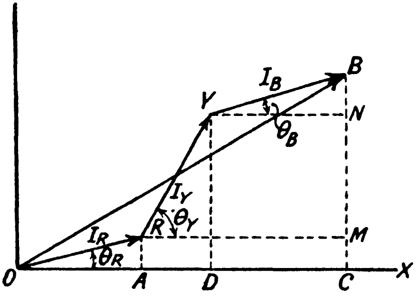


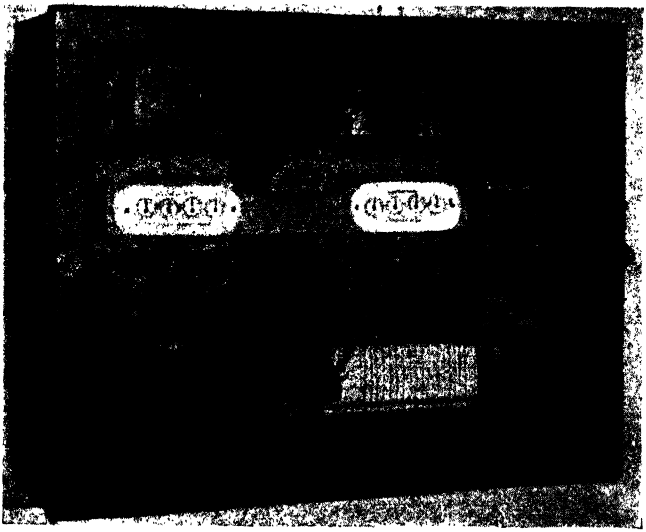
FIG. 63. VECTOR SUM OF THE CURRENTS IN A THREE-PHASE CIRCUIT

OB is obviously always less than $(OR + RY + YB)$ added arithmetically except when $\theta_R = \theta_Y = \theta_B$. Thus all the practical methods of measuring the kVAh involve the assumption of a uniform phase angle for each current, and this is only allowed in practice for the following reasons.

1. Where θ_R, θ_Y, and θ_B are not widely different, the kVAh by the vector sum definition is nearly equal to that by arithmetic sum definition.
2. It favours the consumer by making his average power-factor appear higher than it really is, i.e. it gives the kVAh a smaller value than the correct one.
3. It can be measured with reasonable accuracy.
4. There is no commercial method available by which the true kVAh can be measured.

The general construction of the Westinghouse meter is shown in Fig. 64. The left-hand meter is the sine meter (connected in the manner shown in Fig. 60) and the right-hand meter is the cosine meter. The left-hand counter registers the kVAh and the right-hand counter the kWh. The recording apparatus keeps a record of the average kW and kVA demand, the pointer being operated from the two counters by suitable shafting.

Each meter spindle drives a shaft, on the end of which is mounted a friction wheel. The two wheels, W_s and W_c, are separated by such a distance that the points of contact with a spherical ball resting on the wheels are 90° apart on the ball. Consider a sphere rotating about an axis X_1X_2 (as in Fig. 65), with an angular velocity of ω radians per second. Therefore the peripheral speed of the sphere in plane *CDO* will be $\omega \,.\, r$, where r equals the radius of the sphere, i.e. the radius of the circumference in the plane *CDO*. Thus the peripheral speed of the circumference of any other equatorial circle will equal $\omega \,.\, r_s$, where r_s equals the radius of that circle. Consider two such circles in planes *AB* and *EF*, such that angle $BOF = 90°$ and angle $X_1OB = \theta°$. Then the radii of the two circles will be $r \,.\, \sin\theta$ and



(Westinghouse)

FIG. 64. THE WESTINGHOUSE kVAh METER

$r \cdot \cos\theta$ respectively. Thus the peripheral speeds will be $\omega \cdot r \cdot \sin\theta$ and $\omega \cdot r \cdot \cos\theta$, and equal-sized wheels in contact with these circles (whatever their angle to the surface of the sphere) will have proportionate speeds.

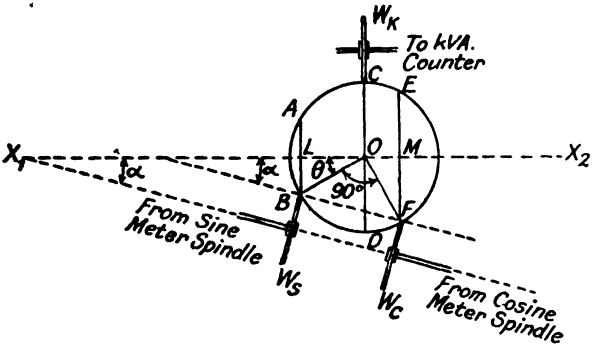


Fig. 65. On Lagging Power Factor

Direction of rotation of W_s and W_c the same

Let us now consider the action from the point of view of wheels W_s and W_c having speeds proportionate to $K \cdot \sin\phi$ and $K \cdot \cos\phi$ respectively, due to their being driven by the meter spindles. If $\theta = \phi$, then the above reasoning shows that the peripheral velocity

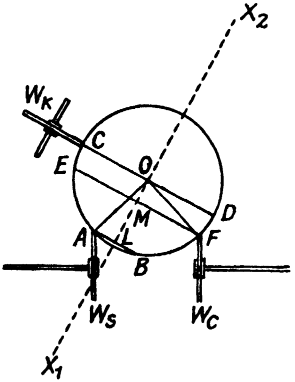
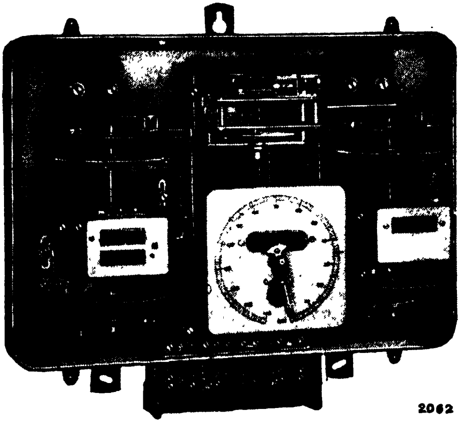


Fig. 66. On Leading Power Factor

Direction of rotation of W_s is now opposite to that of W_c

of the circumference in plane *CDO* is proportional to *K*. Thus a friction wheel W_k in contact with the sphere at *C* will have a speed proportional to *K*, i.e. the kVA by vector sum definition, since $K \cdot \cos \phi$ equals the kW. The kVAh counter is driven by the wheel W_k.

We have assumed above a definite position for the axis X_1X_2 relative to the wheels W_s and W_c. In practice the sphere automatically rotates into this position under the influence of the frictional forces caused by the weight of the sphere resting on the rotating wheels W_s and W_c. Thus the friction circles *AB* and *EF* are at right angles to the axis X_1X_2 in a very short interval after a change in the power-factor. The direction of the axis X_1X_2 relative to the direction of the axis of the wheels W_s and W_c is obviously a measure of the angle ϕ, and by means of a pointer, attached to the carriage of the sphere so as to move over a calibrated scale, the power-factor can be read directly. The great advantage of this meter is that it registers correctly on leading (except beyond 0·5) as well as on lagging power-factors, as will be seen from Fig. 66.

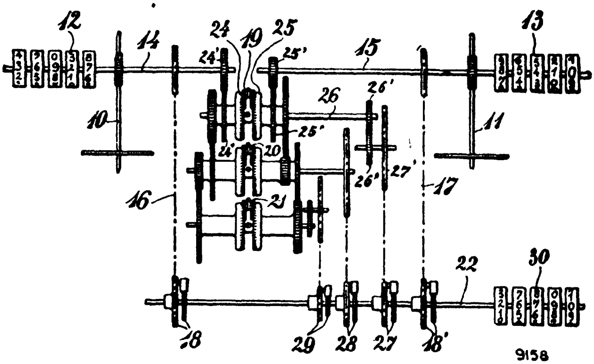


(*Landis & Gyr, Ltd.*)

FIG. 67. THE LANDIS AND GYR TRIVECTOR METER

The Landis and Gyr trivector meter consists of a cosine and sine meter mounted as shown in Fig. 67, each being fitted with an integrating counter. Between them is mounted a special summator, which drives the kVAh counter and the kVA demand indicator. The summator is illustrated diagrammatically in Fig. 68, and it consists of an ingenious system of differential gearing which enables the fastest of certain combinations of the sine and cosine meter speeds automatically to drive the kVA indicator and the kVAh counter. There are five combinations, and in order to avoid interference they drive the first spindle of the kVAh counter by means of ratchet wheels. The principle of the differential gear has already been explained on page 47. Thus the reason for the planet wheel arm in each differential revolving at a speed proportional to the sum of the speeds of the two corresponding sun wheels will be understood.

Let the differentials be termed A, B, and C, and the sun wheels connected to the sine meter termed X and those to the cosine meter Y. Let the speeds of the two meters be proportional to $K \, . \sin\phi$ and $K \, . \cos\phi$, where K is the kVA load by vector sum definition.



(*Landis & Gyr, Ltd.*)

FIG. 68. THE SUMMATOR MECHANISM OF THE TRIVECTOR METER

Differential A. The gearing between the differential and the meter counters is such that X_a rotates at a speed proportional to $0{\cdot}924 \; K \, . \sin\phi$ and Y_a at $0{\cdot}383 \; K \, . \cos\phi$. Thus the speed of the planet wheel arm is proportional to

$$0{\cdot}924 \; K \, . \sin\phi + 0{\cdot}383 \; K \, . \cos\phi$$

Differential B. The gearing of this differential is such that the speed of the planet wheel arm is proportional to

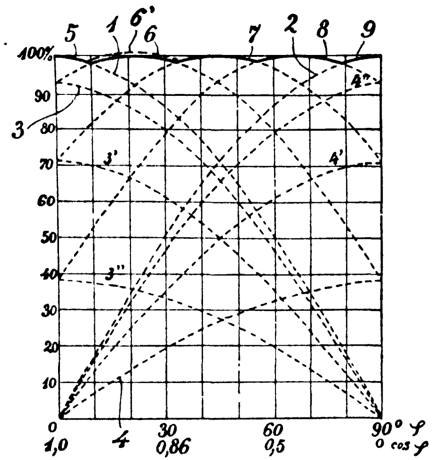
$$0{\cdot}707 \; K \, . \sin\phi + 0{\cdot}707 \; K \, . \cos\phi$$

Differential *C*. The gearing of this differential is such that the speed of the planet wheel arm is proportional to

$$0{\cdot}383\ K\,.\,\sin\phi + 0{\cdot}924\ K\,.\,\cos\phi$$

The Two Direct Drives. Each counter is geared directly to the first spindle (22) of the kVAh counter (30) as shown in Fig. 68 by the dotted lines 16 and 17. The kWh meter spindle is represented by 10.

The speed due to each of the five drives is shown graphically in Fig. 69 for a constant kVA load and varying power-factor by curves 1, 2, 6, 7, and 8. It is clear from the graph that the speed of the kVAh counter is never less than 98 per cent of the true value. By a slight alteration to the counter gearing, it is possible to make the summator over-register on some power-factors and under-register on others, and thus (see curve 6′) make the maximum possible error in summation only ± 1 per cent.



(*Landis & Gyr, Ltd.*)

FIG. 69. SUMMATOR GRAPHS FOR THE TRIVECTOR METER

The disadvantage of this kVAh meter is that the sine meter reverses when the power-factor is leading and, as the sun wheels of the differential must run in the same direction for correct operation, then the summator fails on leading power-factors. Where there is a possibility of working on a leading power-factor, a relay must be used to reverse the sine meter connections when the power-factor becomes leading, in order to obtain a positive disc rotation.

kVAh Meters for Special Power-factor Ranges. On inspecting the trigonometrical tables, we find that the sine function varies as follows—

$$\sin 80^\circ = 0{\cdot}9848$$
$$\sin 90^\circ = 1{\cdot}0$$
$$\sin 100^\circ = 0{\cdot}9848$$

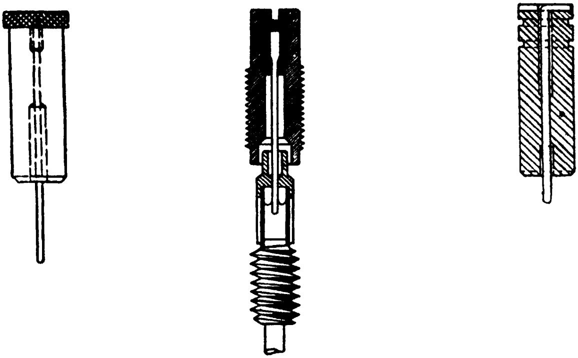
Thus through a range of 20° the sine function only changes $1\frac{1}{2}$ per cent from the maximum value.

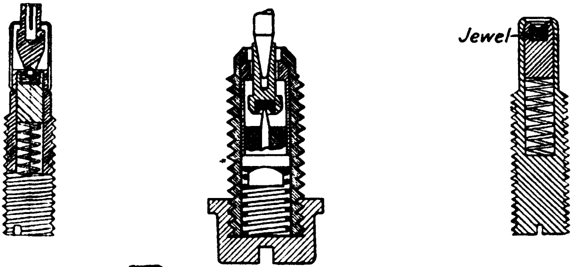
As the torque of an induction meter is proportional to the sine of the angle between the two fluxes, it follows that the speed of the meter will only change $1\frac{1}{2}$ per cent through a range of 20° phase angle, provided the phase angle is 90° at the mid-point of the range. Normally this range is from 10° leading to 10° lagging, because the ordinary cosine meter is adjusted so that the two fluxes are in quadrature at unity power-factor. Suppose, however, that the meter is so compensated that at unity power-factor the pressure flux lags the pressure by 120°. Then the power-factor range, over which the speed change is small, becomes cos 20° to cos 40°. By correctly adjusting the quadrature device, it is possible to obtain the power factor range at any desired region of 20°. If the meter is accurate at the mid-point of the chosen range, then the error at the extreme points of the range will be (assuming a perfect meter) only $1\frac{1}{2}$ per cent. If the meter error is made $+\frac{3}{4}$ per cent at the mid-point, then the error at the extreme points will be $-\frac{3}{4}$ per cent. Thus it is possible to make a meter which will register kVAh within certain error limits over a stipulated range of power-factor. If the error limits are made wider, then the working range of power-factor can be increased. These meters are not to be recommended unless the power-factor is definitely known, because the errors outside the working range are large. [If the voltage can be assumed to be constant, then it is possible to use the A.C. electrolytic A.H.M. (see page 51) for measuring kVAh.]

Meter Bearings. Almost every motor meter has its moving system supported by a jewelled bottom bearing, the top bearing being simply a guide to keep the moving system in its correct place. The latter is usually a polished steel pin working in a brass bush mounted at the head of the rotor spindle. A representative selection of these bearings is illustrated in Fig. 70.

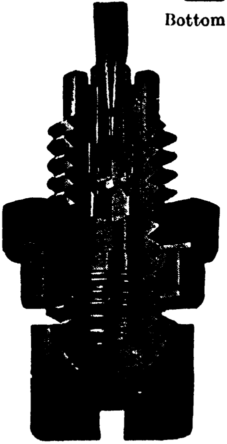
In the top bearing the steel pin must be a fairly loose fit in the bush on the spindle, in order to prevent jamming of the moving system. Some discs, however, are subject to disc chatter due to the voltage flux, and if the pin is too loose this chatter becomes objectionable. It is essential to prevent the pin from becoming sticky or rusty, and for this purpose oil wells, as shown

Top Bearings

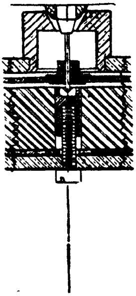




Bottom Bearings



Bottom Bearing for Induction Meter



Bottom Bearing for Mercury Meter

Fig. 70. Meter Bearings

in Fig. 70, are provided. A shroud is sometimes provided over the bush on the spindle for two reasons. Firstly, it prevents dirt from entering the bush easily; and secondly, it limits the range of side play of the spindle and thus prevents undue bending of the top pin during transport.

To minimize friction in the bottom bearing, the pivot of the spindle is shaped almost to a point, the tip being suitably rounded off to avoid penetration of the jewel surface and crushing of the pivot. The radius of the tip is of the order of 0·6 mm., and the angle of the cone-shaped end of the pivot is about 60°. (A number of modern meters make use of a small hard steel ball as the pivot. The ball is embedded in a special brass mount, which may be removed from its seating in the end of the spindle. This method of construction enables the pivot to be easily replaced when necessary.) The pivot is separate from the spindle, as it is made from special steel. Since the area of contact is extremely small, the contact pressure is tremendous—of the order of 50 tons per square inch—even though the weight of the moving system is comparatively low, i.e. 10 to 100 grams according to the type of meter; hence the necessity for an extremely hard jewel and a steel of high tensile strength for the pivot. Not only must the bearing withstand ordinary usage, but also the ill-effects of violent movements of the rotor during transport. It is for this reason that most modern A.C. meters have a spring seating for the bottom jewel. D.C. meters are usually clamped, and are thus not affected by transport.

As a result of numerous investigations, it would appear that diamond is the best material for the jewelled bearing, but unfortunately the high cost of such bearings has prevented the diamond from ousting the other materials (sapphire and ruby) from favour. Some engineers contend, however, that a financial saving can be effected by the use of diamond jewels, particularly on large capacity meters, in spite of their higher initial cost.

There is a quantity of evidence to show that synthetic sapphire is the next best to diamond, since it is more uniform in structure than natural ruby or sapphire. It has also been definitely proved that the wearing property of a sapphire jewel largely depends on how the cup is cut relative to the optic axis. The best direction of cutting is such that the optic axis is tangential to the base of the cup (see Fig. 70B). Discriminating buyers of jewels will therefore specify that their jewels must not depart from this condition by more than 10°. The reason for the better wearing properties is that the parting planes of the crystal structure are at 90° to the optic axis, and it will be seen from Figs. 70A and 70B why the jewel stands a better chance of withstanding surface cracks or crumbling when it is cut in the specified manner. A parting plane is the weakest part of a jewel, and it is obviously desirable to minimize the total length of these parting edges in the jewel cup, besides avoiding thin sections of jewel strata at the base of the cup.

The question of lubricating jewelled meter bearings has been investigated by many engineers, and the following advantages have been established.

1. Oil definitely delays, and reduces, the formation of rust, rust being a prime cause of increase of friction with use.
2. If a pivot and jewel are badly worn, then oil will reduce the frictional torque compared with the dry condition.
3. An oiled bearing has a much longer life than a dry bearing.

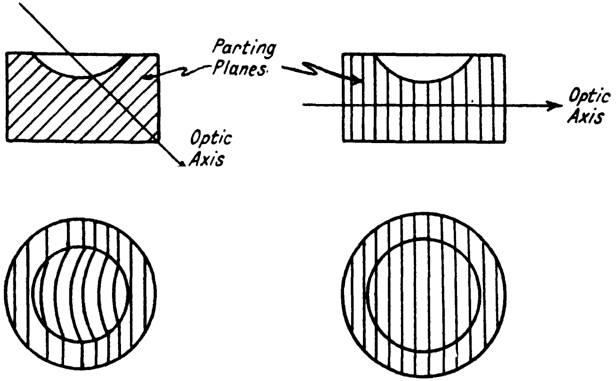


Fig. 70A

Fig. 70B

Jewel Cup Cutting

These advantages are subject to the proviso that the oil is of a suitable type and is not subjected to adverse conditions. The best oil appears to be a high-grade petroleum hydrocarbon oil—akin to medicinal paraffin—which is extremely stable and will not rancify or gum up with long exposure to the air. Several firms can supply this type of oil, but it should be mentioned that one or two other types, such as Kelly's clock oil, have given very good results. It is important to bear in mind that the primary purpose of the oil is to prevent the pivot from rusting. The lubricating properties of the oil are not used unless the pivot and jewel become badly worn. The quantity of oil in the bearing should therefore not be more than sufficient to form a pool in the working region and give the pivot a protective film of oil. In order to prevent the creepage of oil from the working region, certain engineers treat the metal parts with a 1 per cent solution of stearic acid in toluene. Whilst this treatment does prevent creepage, it unfortunately seems to attack and spoil the oil in the working area, and consequently the author does not advise its employment unless the treatment is kept away from the working area.

The common method of testing the condition of a jewel cup is by means of a sharp needle. This will usually discover any radical defects, such as cracks or pits, but care must be taken not to press too hard on the jewel in order to avoid damaging the jewel surface. A needle should not be used more than about twenty times for this work. A better method of jewel inspection is to use the binocular microscope shown on page 302.

Harmonics Due to Modern Apparatus. Until recent years comparatively little trouble was experienced due to consumers' apparatus drawing a non-sinusoidal current from the mains. Due, however, to the ever-widening applications of neon lighting, gaseous-discharge lamps and rectifiers (only the 12-phase type is really free from objectionable harmonics), the matter has become of general importance, and consequently the meter engineer has to exercise more caution in applying meters and demand indicators than was formerly the case.

Very fortunately the majority of the *power* in distorted A.C. circuits is at the fundamental frequency, and therefore the induction meter does not suffer any serious overall error. Consequently A.C. measurements of kWh and kW demand are not, in practice, seriously affected.

The measurement of kVAh and kVARh by the usual methods becomes technically impossible immediately the current or voltage wave-form appreciably departs from the sine wave. This is because the usual measurements are based on the vector sum definitions of these quantities. It also follows that kVA or kVAR cannot be accurately measured when harmonics are present. (The Hill-Shotter M.D.I. is inaccurate, because of its large frequency errors; whilst the thermal M.D.I. does not take any account of voltage. The latter also has the defect of exponential increase of reading with load, which is particularly disadvantageous with traction loads or gaseous discharge lamps.) It seems advisable, therefore, to restrict measurements on such circuits to kWh meters and adjust the kW demand charge by a suitable factor if the undertaking's general system of demand charges is on the kVA basis.

If it is desired to measure accurately the D.C. output of a rectifier having less than 12 phases, it is necessary to use the pendulum meter or unshunted commutator watt-hour meter. This is because the D.C. output contains harmonics, which cause serious errors in the mercury or shunted commutator watt-hour meters.

CHAPTER III

MEASUREMENT OF MAXIMUM POWER DEMAND

THE capacity of the cables, switching apparatus, and transformers for supplying a consumer are controlled by the maximum demand for kVA which the consumer is liable to make. Also the generating station must contain enough plant to be able to supply this demand. Thus the capital cost and the interest and sinking fund charges depend on this maximum demand for kVA. Consequently a portion of the cost of supplying a consumer depends entirely on this demand and is independent of the kWh supplied during the year. As a result of this feature, tariffs have been formulated which take account of the consumer's maximum demand. A typical industrial tariff is given below, and it illustrates the necessity for accurately measuring the maximum demand, in kW in this case—

Fixed charge of £5 per kW of maximum demand per year.
Unit charge of ½d. per kWh supplied.

As any consumer is liable to have a short circuit occur on his installation, it is manifestly unfair to use an indicating wattmeter with a maximum reading index pointer in order to obtain the demand. It is only a sustained demand for power which the indicator should measure, and to do this the following methods have been developed.

The Ammeter Type Indicator. An early form of maximum demand indicator (M.D.I.) was the Schattner, which consisted of a moving iron ammeter whose spindle carried a curved glass tube containing a number of beads and a viscous fluid. When a current passed through the ammeter, the spindle was turned so as to deflect the tube into such a position that an appropriate number of beads fell from the tube under the action of gravity. The viscous fluid prevented the beads falling out during momentary large deflections. As the moving iron ammeter followed a square law and one bead corresponded to an appreciable power demand, this type of indicator is now obsolete.

The Thermal Type Indicator. As it takes an appreciable time to heat a body up to any desired temperature, the thermal type of indicator has, inherently, the lagging characteristic which is required. In practice, the bodies which are heated are so designed that it takes about 15 to 50 min. for a steady current to raise them to a steady temperature, but there is the disadvantage to the consumer that the reading grows according to the exponential law instead of a linear law.

The Wright Maximum Demand Indicator. This works on the differential thermometer principle, and the scheme of affairs is shown in Fig. 71. Bulb *B* remains sensibly at room temperature, but bulb *A* is heated by the current in the coil which surrounds it. Changes in room temperature affect both bulbs equally, and the column of liquid is not affected by such changes. The passage of a current, however, warms the air in bulb *A*, causing it to expand and push the liquid column round the bend in the connecting tube. Initially the liquid is level with the opening to the tube *D*. Consequently when the liquid rises above this level it runs down the tube *D*. As the expansion of the air in *A* is proportional to the temperature to which it is raised, and therefore to the square of the current in the coil, then the amount of liquid in the tube *D* is a measure of the average maximum sustained current which has passed through the indicator. Like most other thermal devices, it has the serious defect of a square law characteristic, and the readings of the indicator below one-sixth load are of little value. It also has the defect of not taking the supply voltage into consideration, and the scale *S* can only be marked in terms of kVA if the supply voltage is assumed constant.

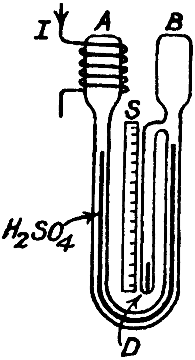


Fig. 71. Principle of the Wright M.D.I.

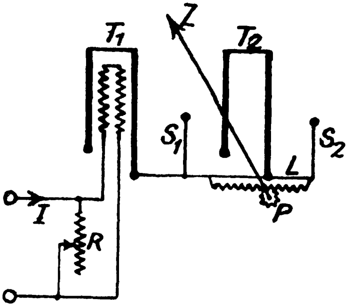


Fig. 72. Siemens Thermal M.D.I.

The Siemens Maximum Demand Indicator. The indicator contains two bimetallic strips T_1 and T_2. T_1 is heated by a resistance which carries a proportion of the main current *I*, but T_2 remains at the room temperature. The indicator can be calibrated by means of the variable shunt *R*. The free end of the heated strip is fastened to a rack *L*, which is suspended by flexible springs *SS* (see Fig. 72). The rack is in gear with the pinion *P*, whose spindle is carried in suitable bearings by the free end of T_2. On this spindle is mounted a driving pointer Z, which, in rotating, pushes round a friction held pointer, leaving it in the maximum position attained by Z. The end of the friction pointer moves over a suitably calibrated scale.

Changes of room temperature cause equal movements of the free ends of T_1 and T_2, hence there is no relative motion between P and L. Thus the room temperature does not affect the reading of the instrument. When a current passes through the heater the strip T_1 is raised in temperature by an amount proportional to the square of the current I. The rise in temperature causes its free end to move outwards, rotate pinion P and thus pointer Z.

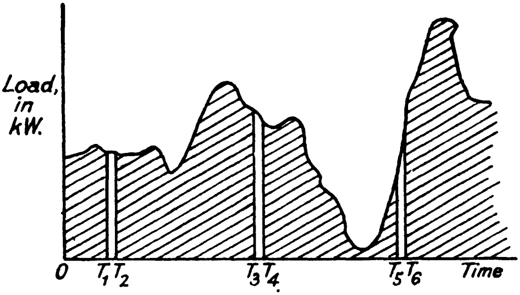


FIG. 73

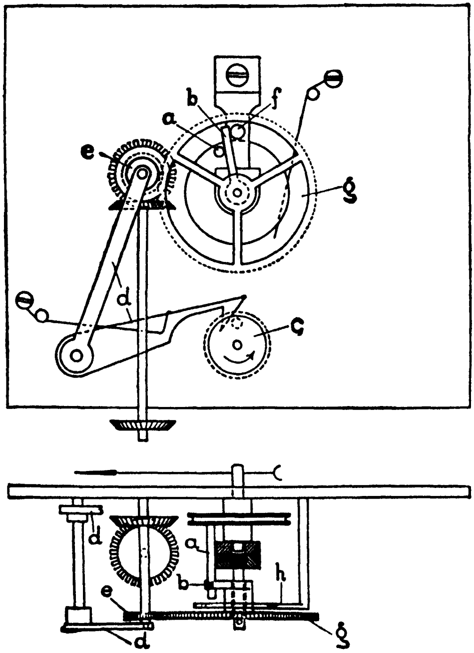
The indicator is in gear during periods O to T_1, T_2 to T_3, T_4 to T_5, etc. The resetting periods are T_1 to T_2, T_3 to T_4, etc.

By suitable design of the movement, the scale of the indicator above one-fifth load has been made fairly uniform, but below this load the scale is not calibrated. As in the case of the Wright M.D.I., this instrument also does not take into account the voltage of the supply.

The Merz Type Indicator. A counter driven by the spindle of a kWh meter during a period T_2 to T_3 (see Fig. 73) measures a quantity $k\int_{T_2}^{T_3}$ power . dt, i.e. k times the kWh supplied during the interval T_2 to T_3. Now, the average power during the time T_2 to T_3 is equal to

$$\frac{\int_{T_2}^{T_3} \text{power} . dt}{T_3 - T_2} \text{ kW} = \frac{\text{kWh supplied in time } T_2 \text{ to } T_3}{T_3 - T_2} \text{ kW}$$

Therefore the counter can be calibrated in terms of kW provided that the time interval during which the counter is in gear is a constant. As the drive must commence from zero at the beginning of each period, some means of disconnecting the counter from the disc spindle must be provided during the resetting period T_3 to T_4. Also a friction held pointer must be fitted in order to know the maximum position attained by the pointer driven by the counter gearing. The other necessary item is a device for providing the requisite time intervals during which the counter is in and out of gear. To enable accurate readings to be obtained, the scale and pointer are made much larger than those for registering the kWh.

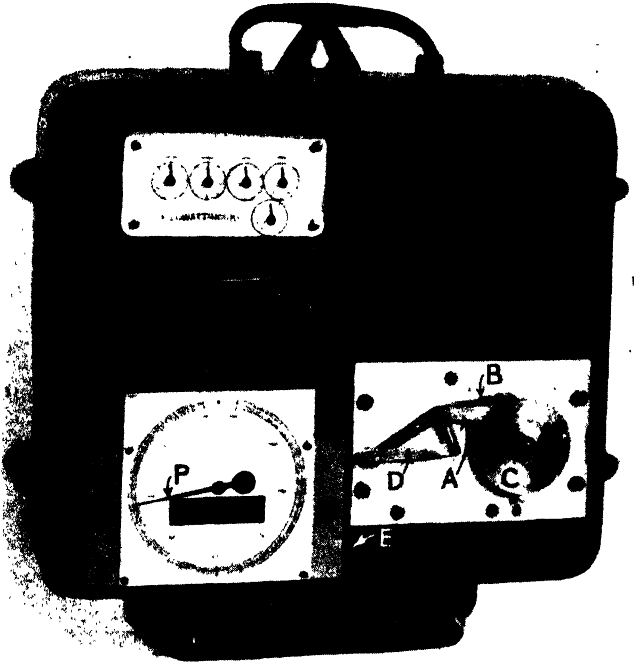


(*Aron Electricity Meter, Ltd.*)

FIG. 74. THE ARON M.D.I. MECHANISM

This type of indicator can be applied to any meter to obtain the maximum demand of the quantity which the meter is measuring, i.e. kVAh or reactive RVAh, as well as kWh. Some typical examples of these indicators will now be described.

The Aron Indicator. As the Aron pendulum meter incorporates a timing device for reversing the commutator and counter drive, it is easy to arrange for an M.D.I. The mechanism is shown in Fig. 74. The pin *a* is fixed on the arbor which carries the M.D.I. pointer, and it is driven by the arm *b*, which is fixed to the gear wheel *g*. The wheel *g* is driven by means of bevels from the first spindle of the integrating counter. Thus the rotation of *g* and the M.D.I. pointer are proportional to $\int_{t_1}^{t_2} \text{power} \, . \, dt$

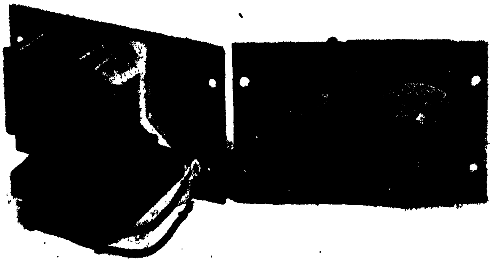


(*Chamberlain & Hookham, Ltd.*)

FIG. 75. M.D.I. METER

The wheel *c* is driven from the change-over gear and revolves once in 10 min. (if desired, the period may be altered to 15, 20, 30 or 60 min.). Thus once every 10 min. the pin on wheel *c* pushes the double lever *d* outwards, causing the wheel *e* to disengage with wheel *g*. The latter wheel is fastened to a hair spring *h*, which causes it to reset to zero when *e* is disengaged. The M.D.I. pointer is left in the maximum position attained by the arm *b*.

The Chamberlain and Hookham Indicator. The M.D.I. in the C. and H. 3-phase meter is entirely separate from the ordinary integrating counter, as will be seen from Figs. 75 and 76. This is an advantage, as an M.D.I. fault does not cause any loss of reading of the kWh when the M.D.I. is removed for repair. The timing device is driven by a synchronous motor, which runs at a speed proportional to the frequency of the supply. The gearing of the motor is so arranged that the disc *C* rotates one revolution per hour when the frequency is at the specified value. On the disc are mounted equidistant pins, the number of which depends on the time interval required, e.g. three for a 20-min. interval, four for a 15-min. interval, and so on.

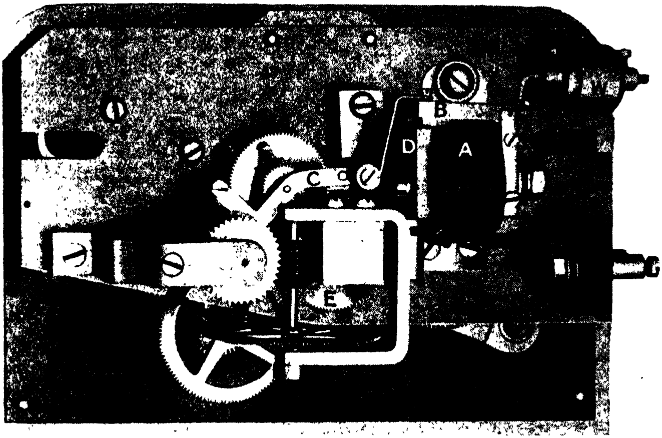


(Chamberlain & Hookham, Ltd.)

FIG. 76. M.D.I. MECHANISM

As it is necessary to provide a short interval between putting the demand counter in and out of gear, the two arms *A* and *B* are fitted to the resetting gear *D*. The arms are raised together by the pin on the disc *C*, but the arm *B* drops approximately 5 sec. after the arm *A*. Arm *A*, in falling, causes rod *D* to move a push rod and thus disconnect the pointer gearing from the meter spindle. A hair-spring causes the gearing of the pointer drive to reset to zero. The falling of arm *B* allows the push rod to return to its normal position and permit the pointer gearing to re-engage with the meter spindle. The pointer *P* is prevented from resetting when the gearing resets by means of a spring bearing on a toothed wheel mounted on the same shaft as *P*. To reset *P* to zero, the arm *E* is depressed. This moves the push rod mentioned above and also raises the spring out of contact with the toothed wheel. The pointer P is controlled by a hair-spring, which causes it to fly back to zero when the spring is raised; the pointer gearing also resets to zero at the same time.

The Metropolitan-Vickers Indicator. This mechanism is combined with the ordinary integrating counter in the manner shown in Fig. 77. When the carriage C is in the bottom position, the demand pointer gearing is in gear with the revolution counter drive. Consequently the wheel E is rotated when there is a load on the meter. A pointer P_1, which is fixed to the spindle carrying wheel E, pushes round a friction-held pointer P_2 and leaves it in the maximum position attained by P_1. (See Fig. 105 for a front view of this type of M.D.I. counter.) Every 15 min. (or other chosen interval) the coil A is de-energized, causing the armature B to be pulled out of contact with the core D by the weight W. In rising, the armature B raises the carriage C and thus pulls the demand mechanism out of gear. A spring then resets the pointer P_1 to zero. After an interval of 5 sec. or so, the coil A is re-energized, and B is again pulled into contact with D, allowing the carriage C to fall by gravity into gear again. The timing device is external to the meter, and may be any one of the various types described in Chapter IX. The coil A is connected in series with a choke or resistance across the meter supply voltage, and to de-energize the coil it is shorted by a switch in the timing



(*Metropolitan-Vickers, Ltd.*)

FIG. 77. THE M.V. ELECTRICALLY HELD-ON TYPE OF M.D.I.

device. This method is preferable to open circuiting the coil circuit, because it avoids vicious sparking at the switch contacts.

The Hill-Shotter kVA Indicator. This kVA indicator differs from those previously described in that it is restricted to kVA only, due to the basic operating device being a simple induction motor deriving its torque from the current being measured (see page 57). The torque is proportional to the square of the current, and consequently the scale of the indicator follows a square law.

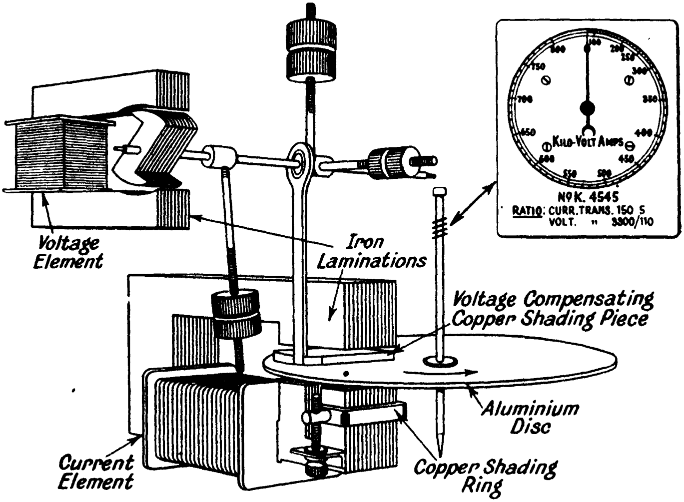


FIG. 78. PRINCIPLE OF THE HILL-SHOTTER kVA M.D.I.

The simple form of this indicator can only be scaled in kVA, of course, by assuming a constant supply voltage, but by means of an ingeniously arranged shading piece—the position of which is controlled by the voltage of the supply—the torque of an improved model can be compensated for changes of supply voltage up to ± 10 per cent. The tripping and resetting of the indicator follows the principle previously outlined.

Fig. 78 illustrates the principle of the single-phase compensated type of indicator, but the indicator can be obtained with one, two, or three elements, either compensated or uncompensated, to suit any type of A.C. circuit. This instrument is independent of the power-factor, but its accuracy is affected by serious unbalance of the loads (in the case of polyphase M.D.I.'s), distortion of the wave shape, or continual large fluctuations in the load being measured.

CHAPTER IV

METHODS OF MEASURING AVERAGE POWER-FACTOR

As the rating of a cable, switch, or transformer depends on the current supplied and not the energy supplied, it follows that the service to a consumer's premises will be cheaper if his energy requirements are at a high power-factor than if they are at a low one. Not only is the service capacity affected, but also the generating plant and main transmission lines. Thus it pays to encourage A.C. consumers to keep their power-factor as high as possible, and for this purpose many tariffs include a power-factor clause. This clause penalizes the consumer if his power-factor is below a certain value, but gives him a rebate if it is higher than this value. An example of such a tariff clause is—

Basic value of the power-factor = 80 per cent.

Bonus. Charges reduced 1 per cent for each 1 per cent improvement of power-factor above 80 per cent up to 90 per cent, and ½ per cent for each 1 per cent improvement above 90 per cent up to 95 per cent.

Penalty. Charges increased 1 per cent for each 1 per cent deterioration of the power-factor below 80 per cent.

On a single-phase circuit the power-factor can be expressed simply and correctly by $\cos \phi$, if ϕ is the phase difference between the current and voltage, and the wave shape is sinusoidal. If the wave shape is not a pure sine wave, then the power-factor must be expressed as follows—

$$\text{Power-factor} = \frac{\text{Wattmeter reading when correctly connected}}{\begin{array}{c}\text{Maximum possible wattmeter reading with the}\\ \text{current and voltage of the circuit}\end{array}}$$

The meaning of the denominator is this: Let the current in the wattmeter current coil be controlled by the circuit conditions, but feed the wattmeter pressure coil via a phase shifter of 1/1 ratio, which has no ratio or phase angle errors. The phase shifter is then turned through its full range, and the maximum reading of the wattmeter during this operation is the required value of the denominator.

The reader will appreciate the necessity for this definition because, if the supply pressure contains harmonics, then the power-factors of the fundamental and harmonic currents will only be equal on a purely resistance load. In most cases the tester is not in a position to know if harmonics are present, or to perform the above test, so he assumes a sinusoidal supply and defines the power-factor by

$$\text{Power-factor} = \frac{\text{Wattmeter reading}}{\text{Voltage} \times \text{current}}$$

On a three-phase circuit the question of power-factor is still more involved, as was seen on page 84. The true definition of the power-factor on a three-phase system—assuming that a 3-phase three-wire supply can be equilibrated to a 3-phase four-wire supply—is given by

$$\text{Power-factor} = \frac{W_R + W_Y + W_B}{V_R I_R + V_Y I_Y + V_B I_B}$$

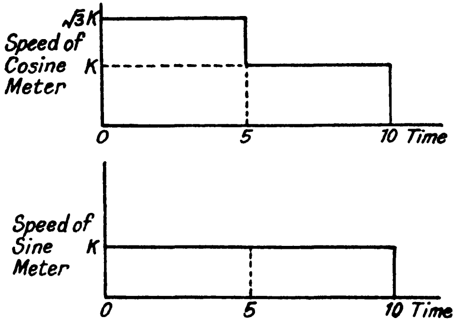


FIG. 79. LOAD-TIME CURVES

The numerator is the actual power supplied, and the denominator is the apparent power supplied. We have already seen the difficulty of measuring the latter quantity, and thus all the practical methods of measuring power-factor are based on the vector sum definition of kVA. Thus, in the absence of a legal definition, the formula usually employed is

$$\text{Power-factor} = \frac{\text{Power supplied}}{\text{kVA by vector sum definition}}$$

This can be applied to all types of three-phase circuits without involving any measurements of great difficulty.

Necessity for Average Value of Power-factor. As the consumer's load does not always have the same power-factor, it is clear that some average value must be worked out in order to apply the power-factor clause in the tariff. The average value on a time basis will not do, as the following example will show. Suppose the load is measured by a sine meter and a cosine meter over a period of 10 hr., and let the load curves be as shown in Fig. 79. Clearly the power-factor for the first 5 hr. is 0·866 lagging and in the last 5 hr. 0·707 lagging. Therefore the average on a time basis is 0·786 lagging; but if its value is estimated from the readings of the two meters after the 10 hr., the average is 0·8064 lagging. (The angle of lag ϕ is obtained in the latter case from the relation $\tan\phi = \frac{\text{Reactive kVAh}}{\text{kWh}}$). The latter value is more acceptable, because the majority of the energy was consumed at the higher power-factor. Thus all the practical methods determine the average power-factor on an energy basis and not on a time basis. The following methods are in use.

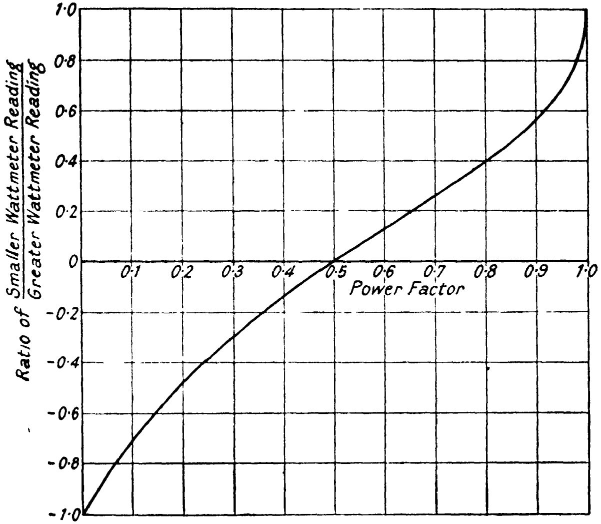


FIG. 80. CURVE CONNECTING THE POWER-FACTOR OF A THREE-PHASE BALANCED LOAD, AND THE READINGS OF TWO SINGLE-PHASE WATTMETERS (OR W.H. METERS) MEASURING THE LOAD

Cosine Meter with a Sine Meter. At the end of a quarter the advances of the two meters are C and S respectively, and the average power-factor is obtained from the relation $\tan\phi = S/C$, where $\cos\phi$ = power-factor.

Cosine Meter with a kVAh Meter. At the end of a quarter the advances of the two meters are C and K respectively, so the average power-factor is given by C/K.

Single-phase Meters. It has been shown on page 73 how to connect two single-phase meters so as to measure the total energy on a 3-phase three-wire system. On a balanced load the red meter measures $E . I . \cos(30 - \theta)$, i.e. W_R, and the blue meter measures $E . I . \cos(30 + \theta)$, i.e. W_B.

$$\therefore \quad W_B + W_R = \sqrt{3} . E . I . \cos\theta$$

$$\therefore \quad W_B - W_R = E . I . \sin\theta$$

$$\therefore \quad \frac{W_B - W_R}{W_B + W_R} = \frac{E . I . \sin\theta}{\sqrt{3} . E . I . \cos\theta} = \frac{\text{Tan}\,\theta}{\sqrt{3}}$$

$$\therefore \quad \text{Tan}\,\theta = \frac{\sqrt{3}(W_B - W_R)}{W_B + W_R}$$

From this we can obtain the power-factor at any instant, if we know the meter speeds. If we require an average value on an energy basis, however, we use the relation

$$\text{Tan}\,\theta = \frac{\sqrt{3}(B - R)}{B + R}$$

where B = the advance of the blue meter
and R = the advance of the red meter.

On a 3-phase four-wire system the red meter measures $\sqrt{3} . V . I . \cos(30 + \theta)$ and the blue meter $\sqrt{3} . V . I . \cos(30 - \theta)$. Thus the relations are now

$$\text{Tan}\,\theta = \frac{\sqrt{3} . (W_R - W_B)}{W_R + W_B} \text{ and } \tan\theta = \frac{\sqrt{3}(R - B)}{R + B} \text{ respectively}$$

The way in which the power-factor is related to the ratio R/B or W_R/W_B is given by the graph in Fig. 80, if the load is perfectly balanced and the meters are accurate. If something more precise than a small graph is desired, the reader is advised to purchase (price 5d. each) the sheet of Ratio/Power-factor Tables published by the Manchester Corporation Electricity Department. Owing to the costliness of RkVAh and kVAh meters, the use of two single-phase meters is the most popular method of determining the consumer's average power-factor. The method has the advantage that the two single-phase meters also provide a check on the total consumption of electricity. The assumption of a balanced load, however, should only be taken after careful consideration. The following points are of interest—

1. A polyphase induction motor does not necessarily give a balanced load. If the voltages are unbalanced, the currents may

be badly unbalanced. If one of the phases of a three-phase motor becomes dead (due to a blown fuse, faulty switch, etc.) the motor will continue to run on two phases, but the load will naturally be completely out of balance.

2. If the meter measures a lighting or heating load in addition to a power load, it is usually impossible to get a well-balanced load.

3. The undertaking should have a safeguarding clause in the tariff, placing the onus of balancing the load on the consumer. This prevents the consumer claiming compensation for overcharges due to metering errors, but, of course, it does not prevent loss to the undertaking if the meters credit the consumer with a higher power-factor than is actually the case.

Power-factor on Two-phase Supplies. If the voltages of a two-phase supply are balanced, then it will be clear that by suitably interchanging the pressure supplies of meters 1 and 2 in Fig. 50 they will act as sine meters instead of cosine meters. This is due to the voltages V_1 and V_2 being 90° out of phase. This method has the advantage that no special meters are required, but it should be mentioned that if there is an appreciable voltage drop along the common return on the three-wire system, then the voltages at the supply end will not be accurately in quadrature.

Power Factor at Time of Peak Load. In the case of very large supplies it is the P.F. at peak load which is of most concern to the supplier. Thus on very large supplies it is often the practice to have kW and RkVA Printometers in the metering equipment. Knowing the half hour in which the peak load occurred, the corresponding RkVA is read from the RkVA chart, and from the two readings the P.F. can be worked out. The P.F. is still an average value on an energy basis even though the time period is reduced to half an hour.

CHAPTER V

METHODS OF CHARGING TO COMPENSATE FOR CAPITAL OUTLAY

THE fact that every consumer's costs are partly fixed and partly variable (see Chapter I) makes it impossible for a flat rate tariff to be equitable for all consumers. Generally speaking, the flat rate tariff overcharges the large consumers and undercharges the small consumers, with the consequent effect of causing the larger consumers to keep down their consumption of electricity as much as possible. Therefore supply engineers have had to devise tariffs which provide a closer relation between the bill and the cost of supply, in order to encourage the use of electricity. In other words, the flat rate tariff has had to be modified so as to take into account the capital outlay involved by each consumer. The difficulty of the task will be appreciated if it is remembered that two special Commissions have investigated the question of tariffs and have both come to the conclusion that there is no such thing, as yet, as the ideal tariff for the supply of electricity to the small consumer.

In addition to the difficulty of designing a tariff to take into consideration such technical features as (1) service capacity, (2) load factor, (3) diversity factor, (4) situation factor, and (5) type of supply, there are the added troubles of making a tariff commercially and psychologically suitable. The commercial considerations make it necessary to choose one of the following principles as a foundation for the tariff—

(*a*) The bill to equal as closely as possible the true cost of supply.

(*b*) The bill to equal the commercial value of the electricity supplied.

(*c*) The bill to be kept as low as possible in order that the electricity supply may compete with some other form of energy (or supply undertaking), or that some special object (e.g. the development of a new industry) may be achieved.

As regards principle (*a*), the true cost of supply would be based on the average cost of a large number of consumers of the type concerned, except in special circumstances, such as a consumer with a special distributor. Averaging costs in this way is, of cousre, the only logical method, since it would be invidious to penalize a consumer for his position in the area of supply, providing he does not require some special equipment for his own personal use.

Principle (*b*) is commonly employed, because electricity has no competitors for certain purposes. Many forms of illuminated signs, for instance, may be operated by electricity only.

Principle (*c*) has already been explained.

We now have to consider the consumer's point of view. An intricate tariff may be quite in order for large consumers, who have engineers in their service who are capable of understanding its provisions, but such a tariff would be quite unsatisfactory to the domestic type of consumer. The smaller consumers require a tariff which is simple in structure, so that its requirements are at once obvious, and it is a great advantage if the tariff has a definite psychological appeal. The meaning of the latter point may be illustrated as follows. Suppose a tariff for a certain type of supply had been worked out, and the running charge found to be 0·55d. per kWh. Instead of using such an awkward figure, the engineer would use the value of ½d. per kWh, owing to the psychological appeal of the expression "halfpenny per unit." The appeal of the tariff in this form would ultimately offset any apparent loss due to dropping the unit rate.

Minimum Bill per Year. Having briefly dealt with the general features governing the design of tariffs, we can now proceed to discuss the various forms of tariffs which are actually in use. The first step to place the flat rate tariff on a better footing was to charge the consumer a minimum bill per year, or per quarter. This minimum charge definitely ensures that the undertaking will receive something from each consumer, which will cover the major portion of his fixed charges, even if he uses no electricity whatever. Although this tariff has the objections that it causes misunderstanding amongst the consumers, due to the varying incidence of the minimum bill and a feeling of having to pay for something which has not been received, it is, nevertheless, the easiest way of overcoming partially the main objection to the simple flat rate tariff. This form of tariff is usually restricted to lighting supplies. If a consumer desires a heating or small power supply, it is usual to charge a lower price per unit for units so used (separately metered), and to omit the minimum bill clause if the consumer also has a lighting supply with a minimum bill clause.

Owing to seasonal variations, a consumer uses more electricity in some quarters than in others and, as he is charged quarterly, it is sometimes necessary to make an adjustment to the last bill of the financial year. (This only applies to cases where the minimum bill clause covers a yearly period.) The following examples will make this point clear—

Let the number of units equivalent to the minimum bill be 80 kWh and the cost £2, i.e. 6d. per unit.

Case 1. If the consumer uses less than 20 kWh in each quarter. he will have to pay a bill of 10s. every quarter.

Case 2. Suppose the conditions are as shown in Table II.

TABLE II

Quarter	Units Used	Flat Rate Cost			Consumer's Bill		
		£	*s.*	*d.*	£	*s.*	*d.*
1st . . .	40	1	–	–	1	–	–
2nd . . .	10		5	–		10	–
3rd . . .	10		5	–		10	–
4th . . .	30		15	–		5	–
		£2	5	–	£2	5	–

The low bill in the fourth quarter is due to having nominally overcharged the consumer in the two preceding quarters.

Case 3. Suppose the conditions are now as shown in Table III.

TABLE III

Quarter	Units Used	Flat Rate Cost			Consumer's Bill		
		£	*s.*	*d.*	£	*s.*	*d.*
1st . . .	75	1	17	6	1	17	6
2nd . . .	10		5	–		5	–
3rd . . .	10		5	–		5	–
4th . . .	40	1	–	–	1	–	–
		£3	7	6	£3	7	6

In this case the consumer's bill agrees with the flat rate cost in every quarter, because the first and second bill total over £2, and the first bill was over 10s.

Sliding Scale, or Step-rate, Tariff. The next effort to overcome the difficulties of the flat rate tariff was the introduction of a scale of charges framed as follows—

First 1,000 kWh per quarter at 5d. per kWh
Next 1,000 ,, ,, 4½d. ,,
,, 3,000 ,, ,, 4d. ,,
,, 5,000 ,, ,, 3½d. ,,
,, 10,000 ,, ,, 3d. ,,

The underlying idea of this tariff is to encourage the consumption of electricity by lowering the rate per unit as the use increases. The tariff has the defect, however, of not taking load factor into consideration; the benefit merely going to the consumers using large quantities of electricity irrespective of whether their business is profitable or not. To overcome this defect, some undertakings have a sliding scale which has two modes of alteration, one as regards the number of units used and the other taking into consideration one or more of the following factors: (1) season; (2) load factor; (3) maximum demand; (4) installed load; (5) number of rooms; and (6) floor area. This form of tariff is rather complicated, and it leaves the distribution engineer with a lot of work to do in assessing the correct scale and dealing with squabbles over the assessment.

Perhaps the best form of the step-rate tariff is that provided by the special type of prepayment meter described on page 138, With this meter there are no restrictions, and yet there is a definite encouragement to a consumer to use electrical apparatus other than lamps.

The Two-part Tariff for the Small Consumer. In the majority of undertakings the fixed charges are greater than the running charges, and consequently the units generated can be sold profitably at a very much lower price than the average cost of production and delivery, provided that the consumers contribute their fair share of the fixed charges separately. The advantage of a low price per unit is that it affords every inducement to a consumer to increase his use of electricity. An all-electric house, for instance, would be an impracticable proposition if a two-part tariff with a low secondary rate was not available.

The most popular method of assessing the fixed charge is the rateable value method, but it is of interest to give a list of the various methods in use in order to demonstrate the complexity of the situation—

1. X per cent of the rateable value per year.
2. Xs. per quarter per N watts installed.
3. Xs. per quarter per assessable room.
4. Xs. per quarter per £ of rental.
5. Xs. per quarter per square yard of outside base area.
6. Xs. per quarter per square yard of floor area.
7. Xs. per quarter per first five lighting points plus Zs. per each extra lighting point.
8. Xs. per quarter per horse-power installed.
9. Xs. per quarter per kW of maximum demand (obtained by personal investigation).
10. Xs. per quarter per first N units per horse-power installed.
11. £X per year by mutual agreement.

The advantage of method 1 is that the undertaking has no difficulty in determining the fixed charge, since the rateable value of each consumer's premises is fixed by an independent authority. The other methods make it necessary for the undertaking's own engineers to determine the basis for the fixed charge. Me hods 2, 7, 8, and 10 are restrictive in that they tend to make the consumer cut down his electrical equipment to the minimum, and method 2 leads to the use of inadequate lamps. Method 9 necessitates the engineers visiting the consumer's premises to measure the load actually being taken, and naturally this load does not always represent the consumer's true maximum load. Furthermore, visits are required at various intervals to check any increase or decrease in the demand. It has the advantage, however, of avoiding expensive M.D.I. mechanisms.

Arbitrary bases of assessment produce many anomalies, e.g. rateable value takes into account many things which are quite unconnected with the possible demand for electricity, but the impossibility of applying more correct methods overrides any objections on this score, so far as small consumers are concerned. The existence of such a variety of bases for the fixed charge simply indicates the vital need for getting away from the simple flat rate tariff.

It should be noted that a Commission appointed by the Electricity Commissioners in 1929 has recommended the "Size of House" basis as the method having the fewest disadvantages. This method involves measuring the outside dimensions of the premises to obtain the ground floor area, and multiplying the result by the number of floors (due allowance being made for part floors). The fixed charge is then determined from a sliding scale of areas to fixed charges.

TABLE IV

	Consumer A	Consumer B
Units used per year	480	4,800
Fixed charge per year	£4	£4
Cost of units used	£1	£10
Total cost	£5	£14
Average price per kWh	2·5d.	0·7d.

It would be interesting to give at this stage an example demonstrating how the two-part tariff directly benefits the larger consumer. Let us compare two consumers who live in similar houses, but use widely different quantities of electrical energy. Let the rateable value be £20 and the fixed charge be based on 20 per cent of the rateable value. The unit charge is ½d. per kWh, and one consumer uses 480 units per year and the other 4,800 units per year. Table IV gives the comparison between the two consumers, and the moral is obvious.

Fixed Charge Depending on Circuit-breaker Setting. A variant of the maximum demand method which has found favour in some undertakings is to supply the consumer *via* a circuit breaker, and base the fixed charge on the tripping current for which the breaker is set. The advantages of this system are—

(*a*) It avoids overloading of the service or meter.

(*b*) The correct size of meter can be installed.

(*c*) It educates the consumer in how to distribute his load requirements over the day.

(*d*) It avoids the annoyance caused by a blown fuse, and the consumer would be able to obtain light again very shortly after an overload or short circuit.

(*e*) It deservedly penalizes the consumer who uses faulty apparatus, such as a motor which takes a heavy starting current.

The disadvantages are—

(*a*) The cost of the circuit-breaker and its maintenance.

(*b*) The additional expense entailed by their use, i.e. testers for calibrating the circuit-breakers and modifications to the meter panels for mounting the C.B.s.

(*c*) Main fuses will still be required for safeguarding the mains.

The Two-part Tariff for Large Consumers. Where the load is large enough, it is the usual practice to base the fixed charge on the consumer's maximum demand (kW or kVA), as measured by a permanently installed maximum demand indicator. If the consumer's load is a reasonably high proportion of the service capacity this method gives excellent results, but if the proportion is low, then the undertaking loses money, because the distribution fixed charges are probably not being fully met. The tariff has the advantages that it encourages the consumer to improve his load factor and that, in the average case, it provides an approximation to the "cost of supply" principle. It also penalizes the consumer who uses faulty gear, or who uses his equipment to the detriment of the undertaking.

The tariff is disliked by commercial men, however, because of the manner in which a peak load lasting only a few minutes may affect the electricity bills for a whole year. It is very irksome in some industries to have continually to keep arranging the work's processes so as to avoid excessive M.D.I. readings. (It is possible now, by the way, to obtain instruments which will give audible warning of an unduly prolonged heavy load, or which will even trip out the load under such conditions.) The consumer is also apt to think that because the undertaking is not apparently affected when his demand occasionally exceeds the normal value, he should not be charged for the extra demand. In the face of this argument, the engineer must explain that if, say, 1,000 consumers were allowed to forget about their peak loads, the undertaking's peak load would soon be seriously affected.

The plain two-part M.D. tariff does not always meet the situation fully, and in order to get over these defects the tariff is sometimes modified by clauses of the following types.

(1) COAL CLAUSE: The price per kWh is adjusted according to a stated formula so as to compensate the supplier or the consumer for rise or fall in the cost of coal from the standard cost specified.

(2) POWER FACTOR CLAUSE: This has been discussed in the previous chapter.

(3) REBATE FOR INCREASED M.D. CLAUSE: In order to encourage greater usage, some undertakings grade the M.D. charge so as to make the higher blocks of power cheaper.

(4) TIME OF DEMAND CLAUSE: This is discussed in the next chapter. The average station load factor is only about 30 per cent, yet by the use of special tariffs involving time switches one Continental undertaking has raised its load factor to over 60 per cent.

Load or Power Factor Control. It is interesting to note that several firms now market automatic control gear, which will enable a large consumer to regulate his power factor or his power load so as to obtain the maximum benefit from his electricity supply agreement.

Cost of Metering. When considering a tariff or a particular supply it must always be borne in mind that the moment something more than a kWh meter is required then the question arises as to whether the revenue earned will carry the standing and running charges of the extra apparatus. As a case in point the reader might well reflect on the fact that a two-part tariff prepayment meter may equal or exceed in cost all the remainder of a service.

Capital Outlay. Where the supply to a consumer demands special expenditure on plant and mains it is customary to require either a capital contribution or a guaranteed minimum annual bill for a period of years. The latter is sometimes assessed at 20 per cent of the special capital outlay since this percentage is the one mentioned in the 1899 Act.

CHAPTER VI

METHODS OF METERING WHICH INVOLVE TIME OF DEMAND

A TYPICAL load curve for a power station is given in Fig. 81, and its uneven character due to a community all having similar habits is very striking. The station engineer's trouble is that he must have enough generating plant to meet the peak load *P*, which is severely affected by seasonal and temporary weather changes. The highest peak is usually that which occurs between 3.30 p.m. and 5.30 p.m. in the winter. The reason for this is shown by the series of curves in Fig. 82, which illustrate the variations in the lighting load due to seasonal change and their effect on the afternoon peak load. The power load is fairly constant throughout the year, except where there is a large heating load due to having a high class of consumer. In order to reduce this peak value, it is advisable to encourage the consumer to avoid using electricity unnecessarily between 3.30 p.m. and 5.30 p.m. (or other peak load period). Various methods of attaining this end have been devised, of which the following are a representative selection.

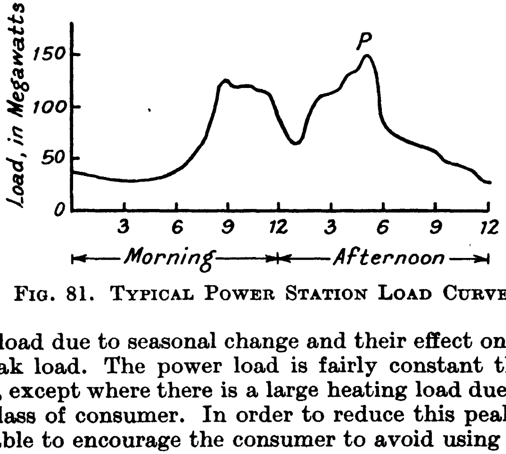


FIG. 81. TYPICAL POWER STATION LOAD CURVE

Time-switch Control. The consumer is supplied through a circuit-breaker which is controlled by a clock—the combination being termed a time switch—which is arranged to open the breaker at, say, 3.30 p.m. and to close it at 5.30 p.m. For the privilege of doing this, the supply authority reduces the tariff. This method is applied to circuits where the consumer has no essential lighting load.

Two Meters with a Change-over Time Switch. In many cases the consumer may require power during the restricted period, and to meet this situation two M.D.I. meters are installed. Each meter integrates the total energy supplied, but the M.D.I. connections (see Fig. 83) are such that one is in use from, say, 3.30 p.m. to 5.30 p.m. and the other from 5.30 p.m. to 3.30 p.m. The change-over is effected by a special time switch, one of which is illustrated in Fig. 117. In this way the consumer is not prevented from using power during the restricted period, but his tariff does not encourage him to do so. An example of such a tariff is—

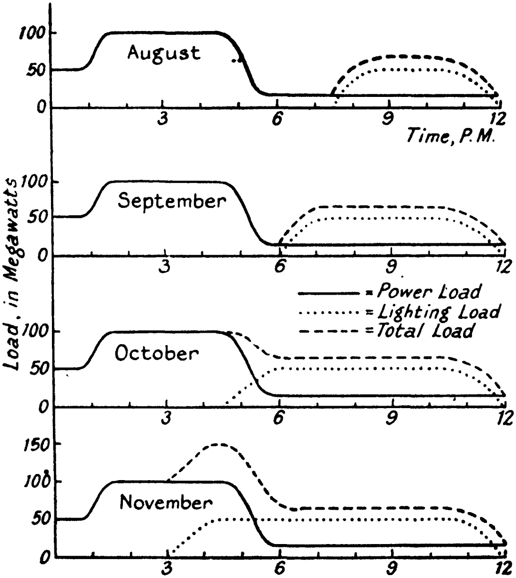


FIG. 82. EFFECT OF LIGHTING LOAD ON THE PEAK LOAD

Fixed charge = £6 per year per kW of maximum demand in the restricted period during October, November, December, January, February, and March (Saturdays and Sundays excepted), plus £3 per year per kW of maximum demand in the unrestricted period.

Unit charge = ½d. per kWh consumed.

Two-rate Meter. In this method the meter is provided with two counters, one of which is in gear during the restricted period, whilst the other is in gear during the unrestricted period. The change-over is effected by a time switch. (The self-contained type is becoming popular.) The type of tariff in this case would be—

Unit charge during the unrestricted period = ½d. per kWh.
Unit charge during the restricted period = 1½d. per kWh.

This method (although much cheaper) is not so good as the use of two M.D.I. meters, because it is the power demand which must be kept low during the restricted period. A consumer may only use a comparatively few kWh during the period, but they may be registered by a heavy load acting for a short time just as well as by a low load for a long time.

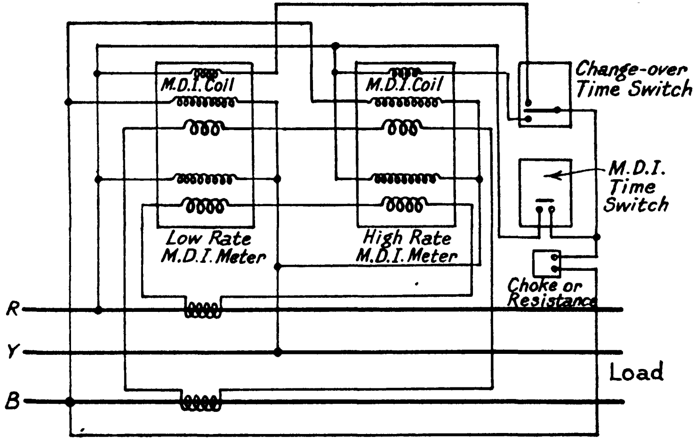


Fig. 83. Use of Change-over Time Switch with Restricted Rate M.D.I. Meters

Off Peak Loads. Whilst it is desirable to avoid unnecessary use of electricity during one particular period, it is also desirable to encourage the use of electricity during other periods. Usually the load on a generating station is comparatively low between the hours of 8 p.m. and 8 a.m., and consequently a large proportion of the generating plant is idle, or running lightly loaded, during this period. A supply authority can thus afford to supply power at a cheaper rate during the night than during the day, and to encourage night loads a cheaper tariff is provided in the following ways.

The Three-meter Method. The consumer is equipped with three meters connected as shown in Fig. 84 for a three-phase three-wire supply and in Fig. 85 for a three-phase four-wire supply. Meter

A registers the total units consumed, whilst meter *B* registers the units consumed from 8 a.m. to 8 p.m. and meter *C* the units consumed from 8 p.m. to 8 a.m. (If the tariff includes a maximum demand clause, then M.D.I. meters are used.) The consumption on *B* meter is charged in the usual way, but the consumption on *C* meter is charged at a sufficiently low price to be attractive to the consumer. The *A* meter is for checking purposes. The changeover is effected by a time switch of the type shown in Fig. 117.

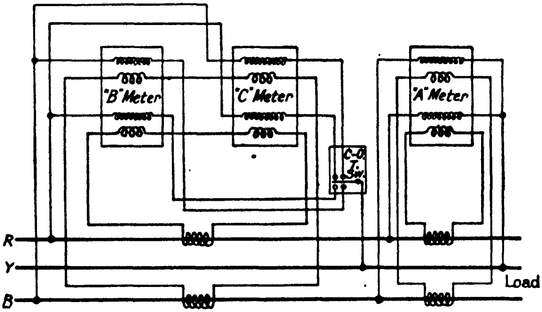


Fig. 84. Equipment for Day-Night Tariff on Three-phase, Three-wire Supply

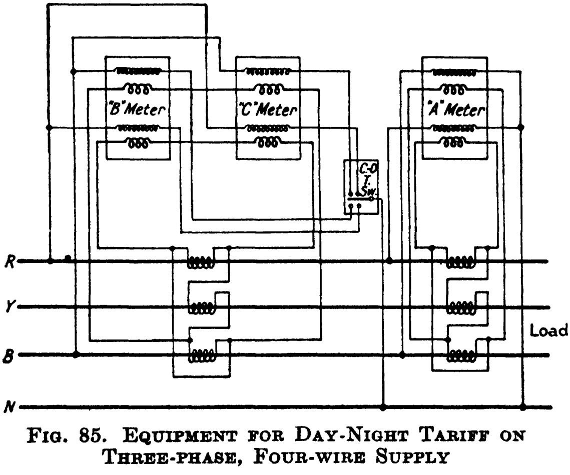


Fig. 85. Equipment for Day-Night Tariff on Three-phase, Four-wire Supply

In the two-rate meter method the meter is provided with two counters, one of which registers the consumption between 8 a.m. and 8 p.m., and the other the consumption between 8 p.m. and 8 a.m. The change-over is effected by a suitable time switch. The units registered on the night counter are charged for at a much lower rate than those on the day counter.

It should be understood, of course, that there are an immense number of different ways of employing meters and time switches (or special control switches operated in some way from the mains) to enable the consumer to obtain the benefit of a special tariff. The above methods are merely typical.

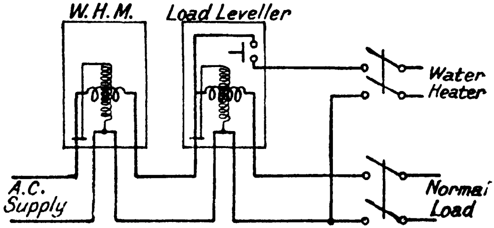


FIG. 86. CONNECTIONS FOR LOAD LEVELLER ON A SINGLE-PHASE A.C. SUPPLY

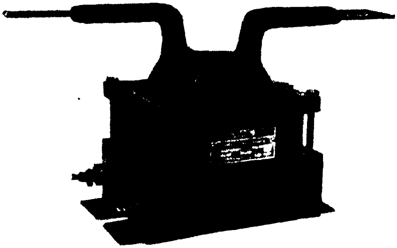
The Load Leveller. Although this device does not directly depend on time for its operation, it encourages the use of off-peak loads. The scheme of connections for the A.C. watt-hour meter type is shown in Fig. 86, the load leveller controlling such loads as would not cause the consumer any discomfort when suddenly switched off, i.e. a water heater. The load leveller may be either a form of relay or an adaptation of the house service meter. Its function is to close a switch when the consumer's normal load is less than a certain value, and to open it when the load exceeds that value. The use of this device keeps down the consumer's maximum demand, because when the ordinary load exceeds a certain value the heating load is automatically switched off. The application of this device is limited owing to the small number of consumers using electric water heaters and to the fact that the time switch method of control is a more certain method of ensuring that the heating load is confined to the off-peak period.

Change-over Switch. Another method of keeping down the demand is to connect two pieces of heavy loading apparatus to a change-over switch so that only one at once may be used.

CHAPTER VII

INSTRUMENT TRANSFORMERS

The Current Transformer. On many A.C. circuits it is both inconvenient and even dangerous to pass the line current through the meter, so some device is required whereby the meter current coil can be supplied with a current which is a definite fraction of the line current and in phase with it, and yet at the same time be isolated from the main circuit. This device is simply a closed laminated iron core carrying two coils. One coil, the primary, is connected in series with the line; and the other, the secondary, is connected to the meter. The primary coil need not necessarily be wound on the transformer, as in some cases it is quite sufficient merely to pass the line conductor through the laminated core. (The remainder of this single turn coil is constituted by the main circuit, even though it may be miles long.) When the primary is actually a definite winding on the core, the C.T. is termed "wound type" (see Fig. 87). When the primary does not form a definite part of the C.T., it is termed a "ring type" C.T. (see Figs. 88 and 89). Alternative names for the ring type C.T. are "bushing type," "through type," "hole type," "busbar type," or "single turn type." For the purposes of standardization, a C.T. is usually arranged so that 5 A in the secondary corresponds to full-load current in the primary circuit.

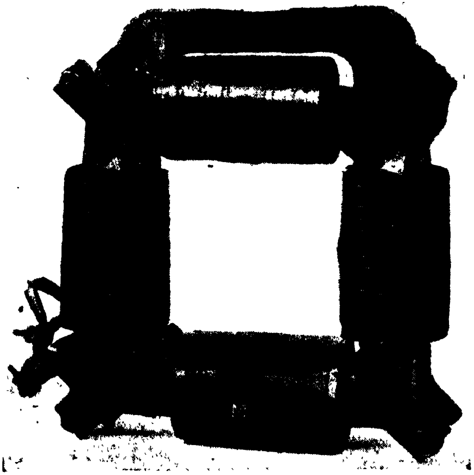


(*Metropolitan-Vickers, Ltd.*)

FIG. 87. M.V. CURRENT TRANSFORMER, WOUND TYPE

The current transformer differs from the ordinary power transformer in several ways, and to obtain successful results notice must be taken of these characteristics.

Let—
Φ = flux in the magnetic circuit.
N_p = number of primary turns.
N_s = number of secondary turns.
I_p = line current.
I_s = secondary current.
i_c = core loss component of I_p.
i_m = magnetizing component of I_p.
i_o = vectorial sum of i_c and i_m.
V_p = primary terminal voltage, if any.
V_s = secondary terminal voltage.
Z_p = primary leakage impedance.
Z_s = secondary leakage impedance.
θ = phase angle error of the C.T.
$\cos \phi$ = power-factor of secondary load.

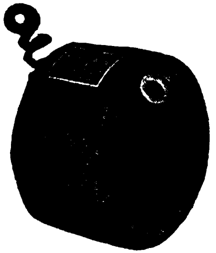


(*Ferranti, Ltd.*)

FIG. 88. FERRANTI RING-TYPE CURRENT TRANSFORMER

The iron core and its windings are so designed that it only requires a small fraction of the line current I_p to magnetize the core sufficiently, and create enough e.m.f. to drive the secondary current through the secondary circuit. Thus, during operation, the majority of the primary ampere-turns must be balanced by the secondary ampere-turns in order to keep down the flux Φ

and the e.m.f.'s induced in the windings. Magnetomotive force is a vector quantity, and thus the working conditions can only be adequately explained by the help of a vector diagram, such as Fig. 90. By drawing ampere-turn vectors instead of current vectors, the effect of ratio of transformation is overcome. The ampere-turns due to a current are, of course, in phase with that current.



(*Everett, Edgcumbe & Co.*)

FIG. 89
MODERN NICKEL-IRON RING-TYPE CURRENT TRANSFORMER

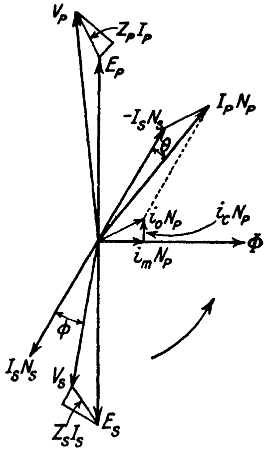


FIG. 90
CURRENT TRANSFORMER VECTOR DIAGRAM

The maintenance of an alternating magnetic field in iron requires energy, and therefore a small fraction of the primary current must be devoted to supplying the "core loss," as it is termed. Therefore the primary ampere-turns, I_pN_p, must be the vector sum of—

(*a*) $-I_sN_s$, the ampere-turns required to balance the secondary ampere-turns.

(*b*) i_mN_p, the ampere-turns required to maintain the flux Φ.

(*c*) i_cN_p, the ampere-turns entailed by the current component which supplies the core losses. These losses comprise hysteresis or iron losses, and eddy current losses.

Components (*b*) and (*c*) cause I_pN_p and $-I_sN_s$ to be, in general, different in magnitude and out of phase. An inspection of Fig. 90 shows up the following characteristics of C.T.'s.

1. Since the secondary impedance is a constant, then V_s and Φ are proportional to the secondary current. The flux, therefore, varies with the load current, but it depends on the *B:H* curve of the iron how i_m varies with respect to I_s. The importance of keeping i_m and i_c low compared with I_p will be obvious, since these current components are the root cause of C.T. errors.

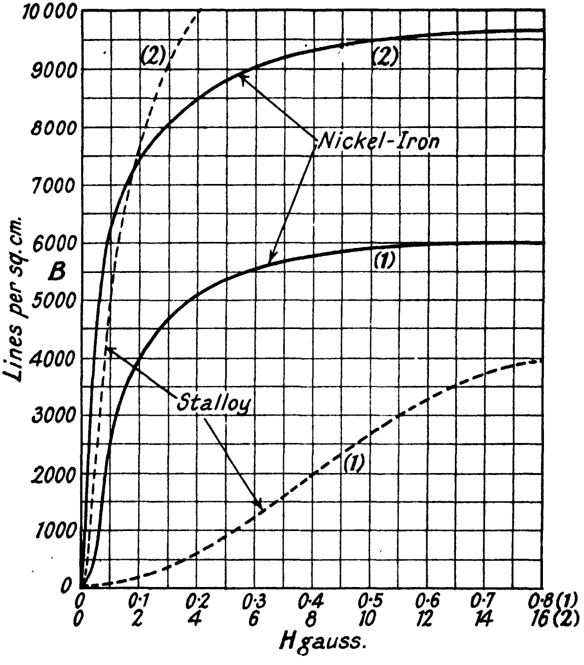


FIG. 91. B-H CURVES FOR CURRENT TRANSFORMER IRON

2. Ratio and phase angle errors depend on the phase angle ϕ of the secondary burden and the magnitude of i_0 (assuming that the turns ratio of the C.T. equals the nominal ratio). As the angle ϕ increases from zero, I_s comes more nearly into phase opposition with i_0, and thus the phase angle error decreases until I_s is in exact phase opposition to i_0. It will be noted that up to this point the phase error is a leading one, since $-I_sN_s$ leads I_pN_p. When ϕ increases still further the phase error becomes negative or lagging. Under average conditions, however, it is unusual for the phase angle error to become lagging. Usually,

if the error is found to be lagging, it denotes that one of the turns is short-circuited and that the C.T. must be rewound.

3. The primary winding impedance does not affect the C.T. ratio or phase angle errors, but the secondary impedance influences the errors, because it makes I_s lag E_s by an angle greater than ϕ, and because it increases the magnetizing and core loss currents.

Effect of the Type of Material Used for the Laminations. If Φ were directly proportional to i_m, then the C.T. errors would be almost constant at all loads, for a given secondary burden. The $B:H$ curve of a magnetic material, however, is not a straight line, as will be seen from Fig. 91, which gives the curves for silicon-iron and nickel-iron. In general, the lower the flux density the greater is the relative value of the magnetizing current; and consequently there is an increased effect on the errors of the C.T. Fig. 92 shows the typical manner in which the errors vary with the line current, due to the non-linear $B:H$ curves. The figure also shows the manner in which the secondary burden affects the errors.

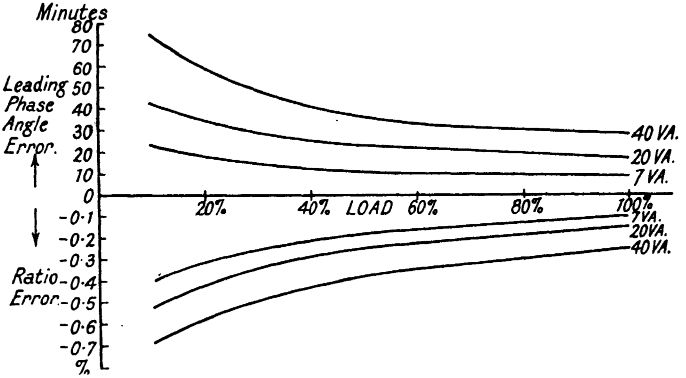


FIG. 92. TYPICAL VARIATIONS OF CURRENT TRANSFORMER ERRORS WITH LOAD AND SECONDARY BURDEN

The importance of using a high grade magnetic material for the laminations will now be apparent. Until the introduction of nickel-iron (22 per cent iron, 78 per cent nickel), the best silicon-iron did not permit the construction of ordinary C.T.'s below a value of about 600 for I_pN_p at rated full-load current. Therefore for currents below 600 amp., it was necessary to use C.T.'s with wound primaries, in spite of their disadvantages, viz.—

1. The necessity for joints in the main circuit, and massive supports.

(2) The liability to destruction on very heavy system short circuits, due to the tendency of the primary coils to expand when carrying a very heavy current.

At the low flux densities employed in current transformers, 0 to 0·5 gauss, it will be observed from Fig. 91 that nickel-iron requires only about one-tenth of the magnetizing ampere-turns required for a similar core of silicon-iron. This great advantage may be utilized in three ways—

1. Substitution of nickel-iron for silicon-iron enables the errors of a C.T. to be reduced, thus providing a more perfect C.T. It is now possible to obtain nickel-iron C.T.'s in which the ratio and phase angle errors down to one-tenth load are negligible. This is of great importance to the testing engineer, and examples of the use of these highly accurate C.T.'s will be found on pages 198 and 207.

2. If similar error limits are desired, then the weight of the core may be reduced by about 75 per cent. This will automatically reduce the weight of the windings and overall size of the C.T.

3. The lower limit for the ring C.T. may be considerably reduced. Ring C.T.'s of 100/5 amp. ratio can now be obtained as against 600/5 for silicon-iron.

There are certain features about nickel-iron, however, which must be noted—

(*a*) It saturates at a lower flux density than silicon-iron, and is thus not so suitable for use in C.T.'s connected with balance type protective gear, or where considerable overloads have to be dealt with. This disadvantage may be overcome in certain cases by having a mixed core of nickel-iron and silicon-iron. The nickel-iron portion improves the performance on low loads, whilst the presence of the silicon-iron enables the C.T. to maintain its ratio on heavy overloads.

(*b*) The core should be jointless, or a great deal of the advantage of nickel-iron is counteracted by the reluctance of the joints. Therefore whole rings or ready built tape-wound packets should be employed for the core. The advantage of the spirally-wound packet is that mechanical stresses are avoided after the final tempering process, the characteristics of the alloy being greatly dependent on this final tempering.

(*c*) Nickel-iron costs more than silicon-iron, although this consideration is nullified to a large extent by the reduced weight of material required and the practical conveniences of the ring C.T.

(*d*) Nickel-iron must not be strained beyond the elastic limit, or the magnetic properties of the alloy may be affected. Ordinary knocks and blows are of no account, but in building up the cores the laminations must not be bent or drilled. A sharp bend stresses the outer layers of the metal beyond the elastic limit, whilst drilling obviously overstrains the metal.

Having dealt with the factors on which the accuracy and functioning of a C.T. depend, let us now consider some practical points.

Danger of Open-circuiting the Secondary on Load. For the sake of example, suppose the full-load primary current is flowing. When the secondary circuit is opened, the magnetizing ampere-turns rise from $i_m N_p$ to $I_p N_p$, because $I_s N_s$ is then zero. The value of H would thus rise to approximately twenty times its normal value, and the flux density from, say, 2,000 lines per square centimetre to 12,000 lines per square centimetre. Furthermore, the wave shape of the flux would be greatly distorted. These two changes may cause the secondary e.m.f. to reach a value of 200 volts or more. This e.m.f. would be both dangerous to the insulation and to the lives of operators. Therefore, before disconnecting any apparatus from the secondary of a loaded C.T., its secondary terminals must first be *securely shorted* by a piece of binding wire.

Adjustment of Ratio Error. If a C.T. was provided with the number of primary and secondary turns to satisfy the nominal ratio, then the ratio error would be negative at full load. As the ratio error normally becomes more negative as the load decreases, the errors at the lower loads may be outside the limits (see page 258). To overcome this effect, the ratio error is made more positive at full load by reducing the number of secondary turns. This reduction may be achieved by taking off one or more whole turns, or by causing one of the turns to encircle only a portion of the laminations. The latter method enables very fine adjustment of the ratio to be obtained, but great care must be taken to protect the conductor which passes through the laminations from mechanical and electrical faults.

Ring Type C.T.'s. Whilst this type is the best form available, it must be fixed on circuit with due care to avoid accidental short-circuited turns, e.g. metallic fixing straps bolted to a metal base plate.

Effect of Excessive Secondary Burdens. We have already seen that the errors of a C.T. are dependent on the value of i_m and i_c compared with I_p, and that the errors can only be brought within the limits by keeping i_m and i_c below certain values. Now, for a given load current the secondary voltage is directly proportional to the value of the secondary burden, and thus the flux, i_m, and i_c are closely proportional to the secondary burden on a given load. It follows, therefore, that if the burden exceeds a certain value, the errors will exceed the permissible limits. It is for this reason that the full-load rated burden of a C.T. is marked on the nameplate for the guidance of the user. One cannot expect successful results, for instance, by using a C.T. rated at 5 VA to supply a measuring equipment taking 15 VA at full load.

Secondary Burden. It is usual for practical purposes to express the secondary load of a C.T. in terms of the volt-amperes consumed at the rated full load, instead of ohms. This volt-ampere value is termed the "secondary burden."

(*Ferranti, Ltd.*)

FIG. 93. FERRANTI POTENTIAL TRANSFORMER

Compensated C.T.'s. C.T.'s can be obtained which have more than two windings. The purpose of the extra winding, or windings, is to improve the error curve, which normally droops, or rises, as the load decreases (see Fig. 92). This type of C.T. was developed (before the introduction of nickel-iron) in order to obtain greater accuracy from the silicon-iron C.T. Owing to their increased bulk and cost, however, such C.T.'s are limited in their application. They have the further defect that certain types are subject to large error changes with variation of secondary burden. (For further information on these C.T.'s, the reader is recommended to read a paper entitled "Instrument Transformers," page 704, Vol. LXVIII, *I.E.E. Journal*, by Wellings and Mayo.)

The Potential Transformer. As it is impracticable to apply voltages over 600 to the meter direct, a step-down transformer must be interposed between the voltage to be measured and the meter pressure coil, if the line voltage exceeds 600 volts. This transformer is simply a small power transformer (see Fig. 93) whose windings are designed for only a low load. For the purposes of protection, the primary winding is usually provided with fuses (which are often separate from the P.T.) and sometimes with current limiting resistances. As an aid to standardization, the nominal secondary voltage is always made 110 volts. As the load is usually highly inductive, the secondary current will lag the secondary voltage by about 80°, and the typical vector diagram will be as shown in Fig. 94, the vectors being compensated for the turns ratio of the windings. V_p and V_s are the actual primary and secondary terminal voltages respectively.

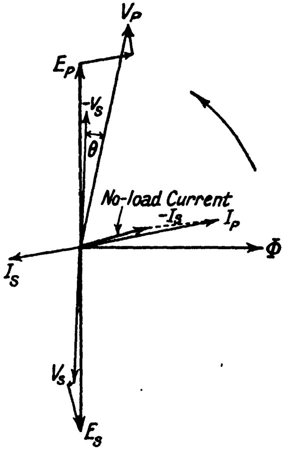


FIG. 94. VECTOR DIAGRAM FOR A POTENTIAL TRANSFORMER WITH AN INDUCTIVE LOAD

The ratio error

$$= \frac{(V_s \times \text{Nominal P.T. ratio}) - V_p}{V_p} \times 100 \text{ per cent}$$

The phase angle error

$$= \theta = \text{the angle between } V_p \text{ and } V_s \text{ reversed.}$$

Normally the P.T. works on a fairly constant voltage, and thus the internal conditions will be practically constant for a given secondary burden. Therefore the ratio and phase angle errors will also be constant. This fortunate circumstance enables meters to be tested without their P.T.'s if allowances are made for the errors as shown on page 223.

Owing to the large number of turns of fine wire required for the high tension winding, it follows that this winding has a high resistance (of the order of 2,000 ohms for a 6·6 kV P.T.). This resistance causes the phase angle error to be normally leading by about 10 min. It also causes the secondary voltage to be more readily affected by a small change of secondary burden than an ordinary power transformer, and thus it is necessary to exercise due care in applying P.T.'s to see that the secondary burdens are within the ratings of the P.T.'s. The high primary resistance, however, enables fuses to be used between the P.T. and the lines without danger of appreciably affecting the errors.

Ratio Adjustment. If the turns ratio was made equal to the nominal ratio, then the secondary voltage would be too low. The secondary turns are therefore increased (or the primary turns decreased) by about 1 per cent, in order to bring the ratio error within the appropriate limits. The large number of primary turns enables very fine adjustment of the ratio to be obtained.

Earthing Precautions. On H.T. circuits it is essential to have the secondary circuits of all instrument transformers connected to earth, in order to safeguard the lives of operators. The earth connection is preferably made at the instrument transformer position and by wires independent of the measuring circuits. Care must be taken, of course, to arrange these earth connections so that the accuracy of the metering equipment is not affected. (See Fig. 102 for an example of such earthing provision.)

Polyphase P.T.'s. Potential transformers can be obtained for single-, two-, or three-phase circuits. If the neutral is required (as it is with Hill-Shotter compensated M.D.I.'s), then the cheapest lay-out, up to 11 kV, for the polyphase circuit is the self-contained polyphase P.T. It should be noted, though, that the polyphase P.T. must be tested whilst energized and loaded as per service conditions, due to the interaction of the fluxes and windings. If the neutral is not required, or the voltage exceeds 11 kV, then it is usual to provide two single-phase P.T.'s across the lines. This has the advantages that the errors are more easily calculated (see page 224) and that greater system security is obtained.

Transformeter. Whilst it has been demonstrated above how the V.A. output of a current transformer is limited by its physical size, it should be noted conversely that if the burden can be positively limited to a small value, then the C.T. size can also be reduced to small dimensions. Messrs. Chamberlain and Hookham have taken advantage of this feature to introduce a total current A.C. meter in which the heavy current circuits are limited to the terminal block. The meter series coils are energized by means of tiny C.T.s encircling the heavy current conductors. This development is mentioned for the striking way in which it brings home to the reader the correlation between the size of a C.T. and the work it has to do.

CHAPTER VIII

SPECIAL METERS

The Prepayment Meter. During recent years there has been great progress in the manufacture and utilization of prepayment meters. The prepayment mechanisms have been made more reliable, new types of P.P. meters to suit special tariffs have been developed, and supply undertakings have made great efforts to give the poorer classes the benefit of electricity by means of assisted wiring and hire-purchase schemes. The advent of the assisted wiring scheme has enabled existing feeders and distributors to be utilized more fully, thus making greater use of the undertaking's capital.

There are also a large number of people who would genuinely rather pay for their electricity as they require it than obtain it on credit and pay a quarterly bill. This practice encourages economy in the home and at the same time it enables the undertaking to be sure of its income. So the P.P. meter is a very useful adjunct to the range of meters.

The P.P. meter consists, in general, of two parts, the integrating meter and the prepayment mechanism. The former is usually identical with the normal type for the circuit concerned. The latter is subject to considerable variation according to the type of P.P. meter.

TYPES OF PREPAYMENT METERS

Fixed charge collector.	1. Hand reset type.
	2. Time-switch type.
Flat rate tariff P.P. meter.	
Two-part tariff P.P. meter.	1. Fixed rate type.
	2. Variable rate type.
Double tariff P.P. meter.	1. Current change-over type.
	2. Time change-over type.

Fixed Charge Collector. The first type of fixed charge collector is simply a switch (see Fig. 95) which is tripped by the meter reader at each visit, and which can be reclosed by the consumer inserting the requisite number of coins. In the second type (see Fig. 96), the tripping of the switch is performed by a clock (electrically driven) mechanism, and its advantage to the consumer is that it allows more frequent operation than the hand-operated type, and thus needs fewer coins for each reclosure of the switch. This type of P.P. meter is usually used in connection with an assisted wiring or hire-purchase scheme, so that if the consumer fails on his payments, his supply is automatically cut off.

Flat Rate Tariff P.P. Meter. The most popular form of P.P. meter is the flat rate type, as in addition to its direct application it may also be used to recover capital charges. To enable consumers having assisted wiring installations to pay for the installations by gradual instalments, the undertaking charges a higher flat rate per unit than for the credit consumer. The excess over the normal rate gradually pays off the cost of the wiring. When the installation is fully paid off, the consumer may become a credit consumer, or the price change gearing may be altered to the normal figure. Although sometimes a small excess is charged to cover the extra working costs of the P.P. meter or to provide a small rebate as an incentive to keep the consumer in at reading times.

(Venner Time Switches)

FIG. 95. FIXED CHARGE COLLECTOR, HAND RESET TYPE

Broadly speaking, the action of a flat rate P.P. meter (see Figs. 97 and 98) is as follows: The turning of the coin knob, after inserting a coin in the slot, advances the credit index a suitable amount, and also closes the switch if it is not closed already. The coin is also registered on a counter which indicates the total number of coins inserted since the meter was installed. The working of the meter portion causes the credit index to progress towards zero, and when zero is reached a tripping device operates and causes the switch to break the supply circuit. Electricity cannot then be obtained until another coin is inserted.

Interference between the coin mechanism and the meter counter is prevented by some form of differential device, wherein one sun wheel is driven by the coins inserted and the other (in the opposite direction) by the revolution counter of the meter. The planet wheel arm is thus driven one way by the coins inserted and in the other by the energy supplied to the consumer. When the zero position is reached, this arm (whose spindle carries the credit index pointer and the trip lever) releases a tripping device which permits the switch to open the circuit. The requisite force to close and open the switch is derived from the turning of the coin

(*Metropolitan Vickers*)

FIG. 96. FIXED CHARGE COLLECTOR, TIME SWITCH TYPE

knob by the consumer, through the medium of a strong spring. Having now an idea of the working principle of the meter, we can consider the various parts of the P.P. mechanism in more detail.

Coin Slot and Knob. The coin slot has to be made very accurately, so that it will only accept coins of the correct denomination. Instructions are given on each meter that bent or badly worn coins must not be used. The internal mechanism is so designed that a coin can only be inserted when the knob is in the initial position and when the credit index is below its full-scale reading. These precautions prevent the consumer from jamming the mechanism or the coin in the slot.

(*Smith Meters, Ltd.*)

Fig. 97. Smith Flat Rate Prepayment Meter

Coin Drive and Coin Box. The coin forms the mechanical link between the knob and the switch-operating mechanism. When the knob has completed its travel, the coin falls into a chute, or direct into the coin box. The chute and coin box must be designed so that the coins will not pile up and jam the coin barrel.

CREDIT INDEX AND SWITCH-CLOSING MECHANISM. The spindle driven by the aid of the coin carries the gear wheels which drive the credit index forward, *via* one side of the differential, and also a cam type gear wheel, which operates the switch-closing mechanism, on those occasions when the switch is open on inserting a coin. The credit index drive usually works the coin register as well.

PRICE-CHANGE GEAR. As the price per unit may vary due to alteration of tariff, it is clear that some provision must be made to enable the meter to be altered in this respect. There are two ways of doing this: firstly, the gearing between the coin knob and the credit index may be altered: or secondly, the gearing between the kWh counter and the credit index. Either way enables the number of units per coin to be adjusted to suit the tariff. Therefore the maker arranges a portion of the mechanism so that a certain gear wheel or set of gear wheels is easily replaceable by another of the desired size. The gearing is so designed that all the possible rates of charge may be satisfactorily dealt with in this manner.

It is important to note that if the change mechanism is between the kWh counter and the differential, then the credit index should be scaled in "coins unused." If the change mechanism is between the coin knob and the differential, then the credit index should be scaled in "units unused." This is because in the first case the movement of the credit index per coin is fixed, whilst in the second case the movement per kWh is fixed.

BACKLASH. On most modern P.P. meters some efforts are made to avoid backlash in the gearing and thus improve the accuracy of the meter on individual coins. As the travel of the tripping device for one coin is very small, it is clear that any loss of motion in the gears soon affects the meter coin accuracy. On some makes the backlash is definitely taken up by means of a spring.

Some Interesting Features of Flat Rate P.P. Meters. Different makes exhibit such wide differences in construction that it is impossible to do more than deal with certain outstanding features.

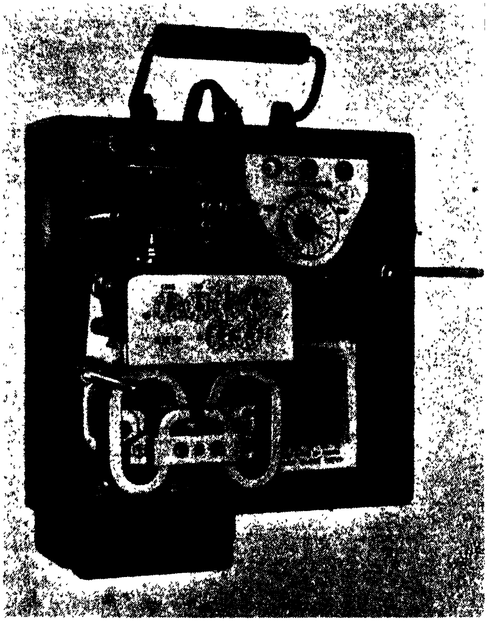
SMITH PRICE-CHANGE DEVICE. The Smith meter is illustrated by Fig. 97, and it will be seen that the coin knob and coin slot portion is separate from the rest of the meter, and that the prepayment mechanism is driven by means of a ratchet wheel. Clearly the amount of rotation imparted to the ratchet wheel (and consequently the amount credited to the consumer) depends on the setting of the slot portion in the ratchet wheel chamber. The edge of the slot portion is serrated and its position is located by means of a peg on the edge of the ratchet wheel chamber. The serrations are scaled in terms of units per coin. This mechanism has the great advantage that the price-change device is inherent in the meter, but it has the disadvantage that the choice of price per unit is limited to a certain particular set of values.

Ferranti Type "FLP" Switch. The original Ferranti P.P. meter was rather bulky and heavy, and in order to effect a great reduction in weight and overall size in the modern A.C. meter, advantage was taken of the short break switch. It has been found that a switch having a maximum contact separation of only 1/32nd of an inch can successfully break alternating currents up to 100 A., if the contacts and separation speed are correctly designed. The small travel of the moving switch contact enables a very simple toggle action to be employed, and thus the size of the switch has been considerably reduced. This permits the P.P. mechanism to be mounted compactly above the meter. Fig. 98 illustrates how effective the new construction has proved.

Fig. 98. Ferranti Flat Rate Prepayment Meters

Sangamo Three-coin P.P. Meter. By fitting the coin knob spindle with a special gauging mechanism, this firm has been able to make a meter which will accept a shilling, a sixpence, or a penny. This is a great boon to the consumer, as he is not deprived of supply because he does not happen to posses à coin of particular denomination, as occurs with other meters. It is claimed that this type of meter obtains a bigger revenue per consumer than the ordinary single coin meter.

Two-part Tariff P.P. Meters, Fixed Rate Type. Fig. 99 illustrates a meter of this type, and it will be seen that in addition



(*Metropolitan Vickers*)

FIG. 99. M.V. TWO-PART TARIFF PREPAYMENT METER, FIXED RATE TYPE

to the meter and P.P. mechanism there is a small motor, which runs at a constant speed. The meter counter and the motor are geared to a differential in such a way that the planet wheel arm travels at a speed proportional to the sum of the speeds of the meter and the motor. The planet wheel arm spindle drives the credit index in the manner described for the flat rate meter. The additional differential gear enables the meter and the motor to operate the P.P. mechanism quite independently.

The motor in Fig. 99 is of the Ferraris disc type, but if the supply frequency is controlled, then a slow speed synchronous motor is invariably used (see Fig. 99A). In the former case the fixed charge per week is altered by adjusting the speed of the motor, but in the latter case it is varied by altering some form of change gear. The change gear may be of the following three types: (*a*) fixed price brackets or wheels; (*b*) infinitely variable between two fixed prices; or (*c*) variable in definite steps between two fixed prices (see Fig. 99A).

An important feature of this type of meter is the need for scaling the credit index on both sides of zero. When the switch is tripped, the time element still continues to run and thus drive the credit index pointer beyond the zero point. It follows, therefore, that when the consumer next inserts a coin, a portion (or all of it) will be required to cancel the arrears built up by the time element. If the delay is long enough—due to holidays, for example—several coins may be required to wipe off the arrears, and it will be clear that if the consumer has insufficient coins of the right size he will be deprived of a supply of electricity. To overcome this defect, Messrs. Chamberlain & Hookham have introduced a meter with an ingenious device whereby, if the credit index is on the arrears side by more than one coin's worth, the insertion of only one coin will close the switch. The greater part of the value of the coin goes towards reducing the arrears, and the remainder to purchasing electricity. The idea of post-payment of arrears is also used by other makers but its application requires very careful consideration if bad debts are to be avoided.

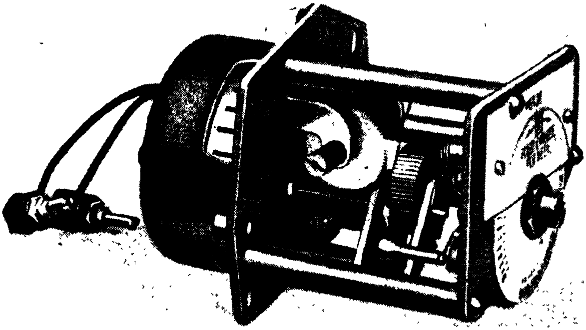
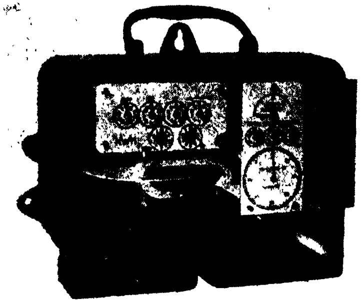


FIG. 99A. M.V. FIXED CHARGE ELEMENT (SYNCHRONOUS MOTOR TYPE)

Two-part Tariff P.P. Meters, Variable Rate Type. In order to avoid the additional running element of the fixed rate type, certain makers have modified the coin side of the credit index in the following manner: The coin knob spindle drives the planet wheel arm of a differential gear. One of the sun wheels drives the credit index system and switch-closing mechanism, whilst the other sun wheel drives a fixed charge element. In the meter illustrated in Fig. 100, the appropriate fixed charge is set up on the large dial at the right of the kWh counter. (This can be done by a special key without opening the meter cover, but the coin box must be removed first.) When a coin is inserted, the initial differential gear transmits part of the motion to the credit index, and the other part to the fixed charge element, driving its pointer towards zero. The differential gear is commonly arranged to devote 9d. of each shilling inserted towards paying off the fixed charge, and 3d. towards purchasing electricity at a low flat rate per unit. When the fixed charge pointer reaches zero, the corresponding differential sun wheel becomes stationary, and all future coins are fully utilized in driving the credit index system, and thus obtaining the low-priced units.



(*Chamberlain & Hookham, Ltd.*)

FIG. 100. C.H. TWO-PART TARIFF PRE-PAYMENT METER, VARIABLE RATE TYPE

A disadvantage of this type of meter is that it makes electricity appear very dear at the beginning of a period whilst the fixed charge is being paid off. With the above-mentioned ratio of 9d. to 3d., the average price per unit, whilst paying off the fixed charge, is four times the flat rate per kWh for which the meter is geared.

Double Tariff P.P. Meters, Current Change-over Type. Many undertakings favour the sliding scale tariff, and to meet this requirement, Messrs. Metropolitan-Vickers have marketed the meter illustrated in Fig. 101. In this meter the load current is passed through a solenoid relay, in addition to the switch and meter series coil. The relay is designed so as to operate the countershaft of a two-speed gear between the kWh counter and the credit index when the load current reaches a certain value. The gearing gives a price of, say, 4d. per unit until the load current reaches, say, 2 A., when the relay operates and changes the gearing so that the consumer may obtain electricity at, say, 1d. per unit.

This meter is very useful, as it enables a consumer to use heavy loading apparatus, such as irons, radiators, or water heaters, at a reasonable cost, yet it enables the undertaking to obtain a fair price per unit when only lighting is being used. It is unusual for lighting to exceed 400 watts in most domestic premises. Although it is possible for a consumer with this type of meter deliberately to waste electricity so as to obtain it at the cheaper rate, it is extremely unlikely that many consumers would realize how this could safely be done, or would go to the trouble of continually arranging his load to achieve this end.

(Metropolitan Vickers)

FIG. 101. DOUBLE TARIFF PREPAYMENT METER,
CURRENT CHANGE-OVER TYPE

Double Tariff P.P. Meters, Time Change-over Type. In this type of meter the two-speed gear between the kWh train and the credit index is operated by a clock at certain fixed times of the day or night. The object of this meter is to give the consumer the advantage of a low rate per unit at night or other off-peak period. This enables him to use apparatus, such as water heaters, which might be unprofitable at the normal rate per unit. Using current in this way also improves the undertaking's load factor, hence the desirability of offering an attractive off-peak tariff.

Ratchet-fitted Meters. There are some meters which under certain load conditions run in the reverse direction, e.g. a sine meter on a leading power-factor or a W.H.M. on a feeder along which power can be fed in each direction. If the reverse running is not desired, then a ratchet is fitted on the rotor spindle and a pawl is mounted on the frame in such a way as not to interfere with forward running, but definitely to prevent reverse rotation. In order to prevent jamming of the rotor, the ratchet device is sometimes fitted to the revolution counter.

Battery Meters. These are ampere-hour meters of the uncompensated type, since the disc has to run in both directions. On account of the inefficiency of the battery, however, it is necessary to make the meter register less on charge than on discharge, and this is done by a special arrangement of gearwheels and ratchets. It is important, however, that the bias suits the battery or vehicle under control, or else the dial readings are of little use.

Summation Meters. The following cases illustrate the need for summation meters.

Case 1. A consumer having two or more separate supply feeders, but only one bill for electricity.

Case 2. A power station, or sub-station, having a number of outgoing feeders, requires the total energy transmitted and the total load on the station.

Case 3. The energy and maximum load of a number of sub-stations may be required.

The type of summation meter varies widely with the circuit conditions, because the feeders may be A.C. or D.C., and they may be near together or far apart. The various methods in practical use will now be described.

Summation by Paralleling the Transformer Secondaries. The connections for the simple case of two 3-phase 3-wire feeders are shown in Fig. 102. The current coils of the summation meter must be able to carry 10 A if the feeder C.T. secondaries are each rated at 5 A. The C.T.'s must have the same ratio even if the full-load feeder currents are different. If, for instance, the feeders were of 500 A and 1,000 A capacity, then the C.T.'s used must be 500/2½ A and 1000/5 A respectively. (In this case the summation meter coils must be able to carry 7½ A.) The reason for this should be obvious to the reader, as the e.m.f.'s of each feeder are the same in phase and magnitude, and it is immaterial from which feeder the pressure coils of the summation meter are supplied. The conditions in the corresponding elements, assuming a balanced load, are as shown in Table V.

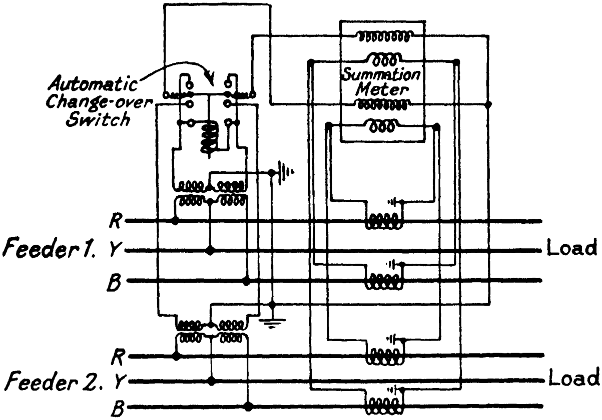


FIG. 102. SUMMATION METER FOR TWO H.T. FEEDERS

Both feeders are fed from the same source, but as either may be made "dead" separately a change-over switch is necessary to keep the pressure coils of the Summation Meter energized under such conditions. If Feeder 1 is "dead," then the action of gravity operates the switch so as to connect the pressure coils to Feeder 2 P.T.'s

TABLE V

ELEMENT	POWER MEASURED BY THE METER CONCERNED		
	No. 1 Feeder	No. 2 Feeder	Summation Meter
1	$E \,.\, I_1 \,.\, \cos(30 + \theta_1)$	$E \,.\, I_2 \,.\, \cos(30 + \theta_2)$	$E[I_1 \cos(30+\theta_1)$ $+ I_2 \cos(30+\theta_2)]$
2	$E \,.\, I_1 \,.\, \cos(30 - \theta_1)$	$E \,.\, I_2 \,.\, \cos(30 - \theta_2)$	$E[I_1 \cos(30-\theta_1)$ $+ I_2 \cos(30-\theta_2)]$

Thus the torque of the summation meter is given by

$$T \propto E[I_1 \cos(30 + \theta_1) + I_1 \cos(30 - \theta_1) + I_2 \cos(30 + \theta_2) + I_2 \cos(30 - \theta_2)]$$

$$\propto E \,.\, I_1 [\cos(30 + \theta_1) + \cos(30 - \theta_1)] + E \,.\, I_2 [\cos(30 + \theta_2) + \cos(30 - \theta_2)]$$

$$\propto \sqrt{3} \,.\, E \,.\, I_1 \cos\theta_1 + \sqrt{3} \,.\, E \,.\, I_2 \cos\theta_2$$

$\propto$ Power in feeder 1 + power in feeder 2

$\propto$ Total power.

Thus the revolution counter fitted to the summation meter will integrate the total energy supplied, and an M.D.I. will register the average maximum demand. It will be clear from the equations in Table V that the method is equally applicable to four-wire as well as three-wire feeders. Where possible, it is desirable always to common the C.T. secondary leads at the summation meter and *not* at a point near the C.T.'s, in order to reduce the voltage which is common to each C.T. secondary circuit.

Theoretically this method can be extended to any number of feeders, but in practice it is limited to two or three feeders by the effect of the idle C.T. secondaries on the summation meter accuracy when the corresponding feeders are dead. This effect is shown by the test described below on a single-phase meter measuring the power in one feeder and having varying numbers of idle C.T. secondaries connected in parallel with its series coil. The meter was first calibrated, with only the active C.T. secondary connected to the series coil, so as to be accurate on full load and one-twentieth load at unity, 0·5 lagging and 0·5 leading power-factors. The effect of connecting idle C.T. secondaries is shown in Table VI.

TABLE VI

LOAD	PERCENTAGE METER ERROR			
	On Active C.T. only	Plus One Idle C.T.	Plus Two Idle C.T.'s	Plus Three Idle C.T.'s
0·5 leading . .	O.K.	− 2	− 4	− 6
Full unity . .	O.K.	− ¼	− ½	− 1
0·5 lagging . .	O.K.	+ 1	+ 2½	+ 4
0·5 leading . .	O.K.	− 4	− 8	− 14
1/20 unity . .	O.K.	− ¼	− ¾	− 1¼
0·5 lagging . .	O.K.	+ 5	+ 6	+ 8

The above results were obtained with C.T.'s made from ordinary iron. If nickel-iron C.T.'s are used, then the above figures can be considerably improved, which enables more feeders to be accurately summated than with ordinary C.T.'s.

Summation by Use of Special Transformers. This method enables a standard meter to be used as the summation meter, because the ratios of the C.T.'s are so adjusted that with full-load unity power-factor in every feeder the summation meter series coil current is 5A for a 3-phase 3-wire circuit and 8·66A for a 3-phase 4-wire circuit, i.e. as for a normal meter. The connections of such an equipment for two feeders rated at 400A and 600A are shown in Fig. 103. Care must be taken in applying the summation C.T.'s to see that the overall ratio of feeder current to summation C.T. secondary current is the same for each feeder. This point is emphasized by the following figures

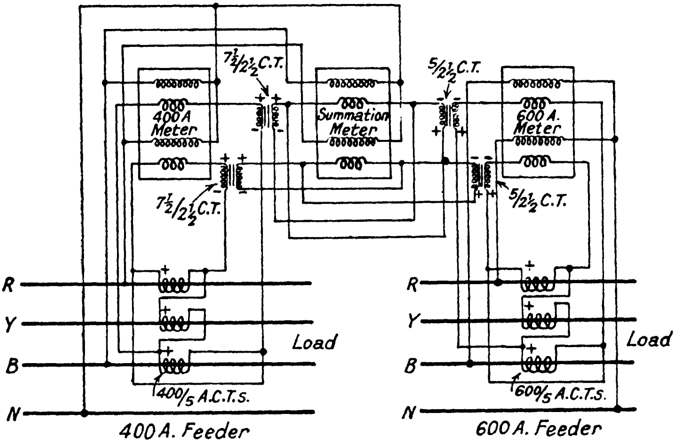


FIG. 103. SUMMATION EQUIPMENT FOR TWO THREE-PHASE, FOUR-WIRE FEEDERS WHICH ARE FED FROM THE SAME SOURCE

Overall ratio for the 400A feeder = 400/5//7½/2½A
= 600/7½//7½/2½A
= 600/2½A

Overall ratio for the 600A feeder = 600/5//5/2½A
= 600/2½A

As before, the e.m.f.'s of the two feeders are the same, and it is immaterial which feeder is used to supply the pressure coils of the summation meter. The windings of the summation C.T.'s in the case of a 3-phase 4-wire circuit are made capable of carrying double the nominal current, and the summation meter has 10A series coils, as is usual for such 3-phase 4-wire circuits.

Another form of this C.T. is shown in Fig. 104, where the various feeder C.T. secondaries are paralleled on the primary of the summation C.T., whose rating is such that its secondary current is 5A with full-load unity power-factor in each feeder.

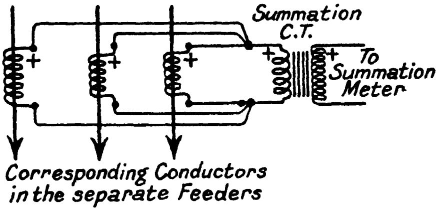


FIG. 104. CONNECTIONS FOR SUMMATION CURRENT TRANSFORMER

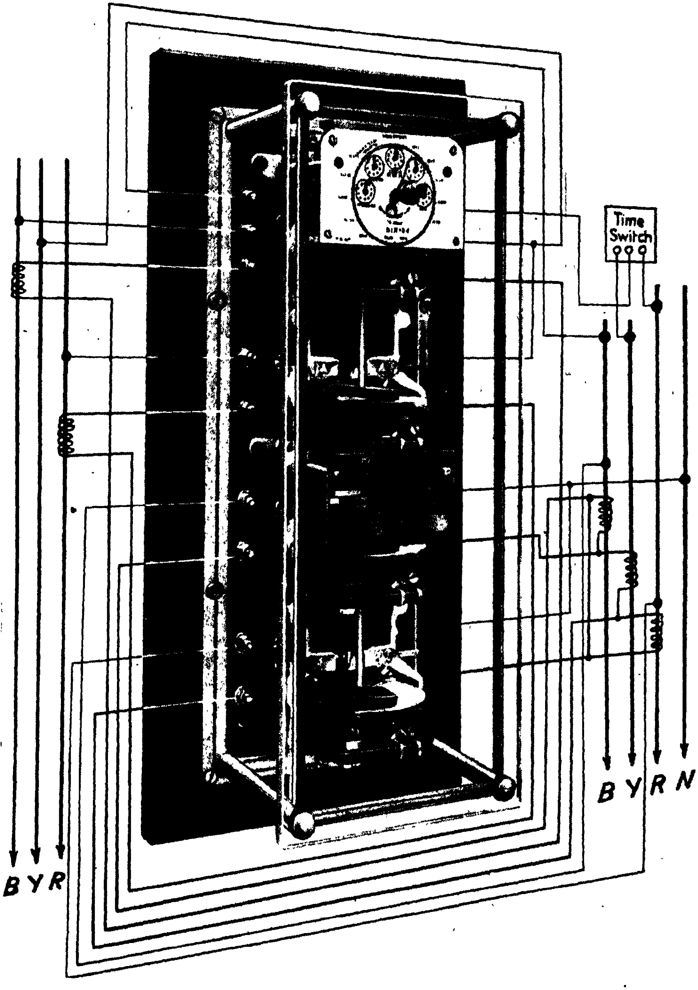
Summation by Multi-element Meter. The torque on the moving system of a W.H.M. is proportional to the power, so if we arrange a moving system so that it is acted on by two W.H.M.'s, then the total torque will be proportional to the sum of the powers measured by the two W.H.M.'s. Such a meter is illustrated in Fig. 105, where the top and bottom pairs of elements each form the usual 3-phase two-element meter. Thus the counter registers, if the meter is perfect, the total energy supplied via the two feeders, and an M.D.I. attachment would register the average maximum demand of the two feeders. The principle is not extended to more than two feeders, because of the mechanical difficulties entailed by a long and heavy moving system.

The beauty of this method is that the two feeders may be entirely independent, whereas in the two previous methods the feeder e.m.f.'s must be the same in phase and magnitude. This method, however, has the following disadvantages—

1. Interaction takes place between the two W.H.M.'s if the frequencies of the two feeders are equal.
2. The heavy moving system severely increases the duty on the bottom jewel.

Summation by Impulses. If a switch is operated by the rotation of the meter spindle, then it will make one contact for every X units integrated by the meter. This contact is arranged to operate a solenoid in a summation meter in such a way as to drive its counter through X units. By having a number of such solenoids in the summator, the units supplied by a number of feeders may be summated. The maximum demand can also be obtained from the counter in the usual Merz manner. The feeders summated may be D.C. or A.C., since the summator only takes account of kWh.

In principle this method of summation is extremely simple, but in practice numerous difficulties arise. In the first place, the contact device operated by the meter spindle is not a highly



(*Metropolitan-Vickers, Ltd.*)

FIG. 105. M.V. MULTI-ELEMENT METER

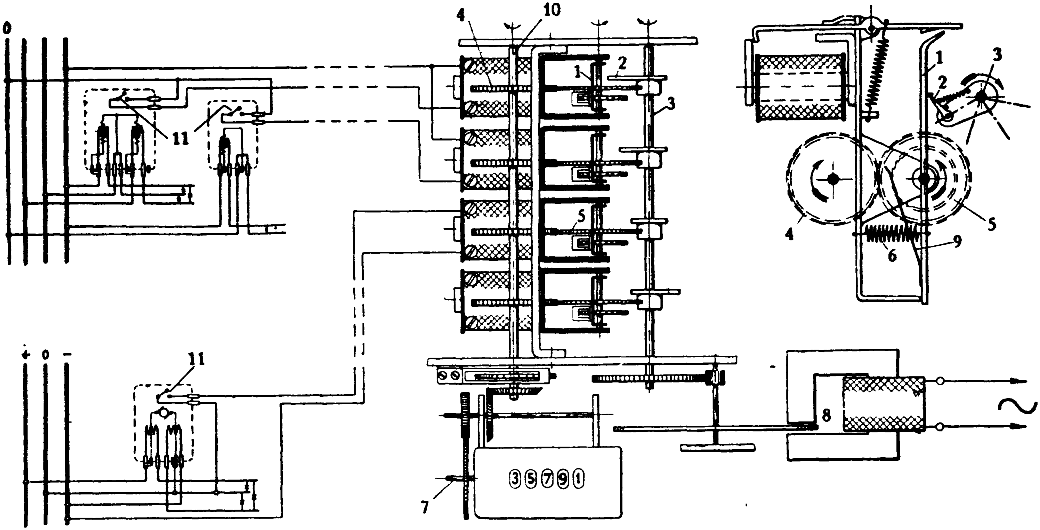
successful device, owing to the small amount of energy available for its operation. (It must be remembered that it has to operate even when the feeder load is very small.) Thus the tendency for the contacts to arc when opening the solenoid circuit, which of necessity is inductive, eventually ruins the contact faces, resulting in faulty operation. One method of overcoming this difficulty is to use a two-way switch arrangement, so that the actual operation of opening the solenoid circuit is done by a more robust switch in the summator, where the necessary energy for operation is available.

Secondly, the gearing system in the summator must be well planned if there are a large number of feeders in order to avoid losing an impulse. One impulse represents a large number of units, and consequently its loss involves a large error, particularly on low loads.

Thirdly, if the pilot-wire system is large, its capacity becomes appreciable, and trouble may occur due to capacity currents causing false impulses. This trouble may be minimized by using a low-voltage (D.C. or A.C.) supply to operate the solenoids and pilot wires of small cross-sectional area. The latter remedy keeps down the capacity of the pilot system.

With the Landis and Gyr summation equipment, the contact device on each meter is arranged so that the rotation of the meter spindle raises a bob weight which, after a certain number of revolutions of the spindle, falls back to its initial position. During its fall the bob weight makes the momentary contact (approximately one-fifteenth of a second), which energizes the appropriate solenoid in the summation meter. As this device cannot operate in the reverse direction, it is necessary to fit a ratchet and pawl to prevent reverse rotation of the bob weight on certain meters, e.g. sine meters, pendulum meters, and two-direction feeder meters. As the solenoid operating current is very low, of the order of 10 mA, the pilot wires need only be small and the duty on the contact device is not very heavy.

The fundamentals of the summator are shown in Fig. 106, together with a typical scheme of connections. When a contact is made in one of the meters, the corresponding solenoid armature is attracted, allowing the arm 1 to turn clockwise due to the pull of the spring 6. Arm 1 is free to turn on the spindle carrying wheel 5. The camshaft 3 is continuously rotated by means of a shaded pole motor, and thus the arm 2 eventually strikes the projection on arm 1, causing the arm to turn anti-clockwise. The pawl 9 and ratchet wheel 5 are so designed that, in moving anti-clockwise, the arm 1 causes wheel 5 to revolve through an arc equivalent to one tooth. The arm 1 is held in its zero position by a projection on the solenoid armature and the pull of the

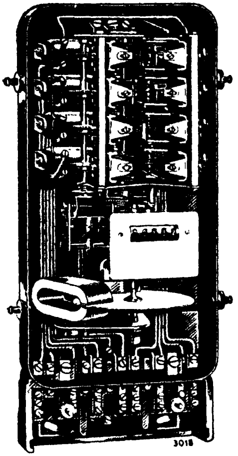


(Landis & Gyr, Ltd.

FIG. 106. DIAGRAM OF CONNECTIONS OF ELGEE SUMMATION METER

1 = lever
2 = cam
3 = camshaft
4 = toothed wheel
5 = ratchet wheel
6 = spring
7 = summation dial
8 = shaded pole motor
9 = pawl
10 = common spindle
11 = contact attachment

armature spring. As the armature is only attracted for one-fifteenth of a second, it is in the correct position to hold back the arm 1 by the time the camshaft 3 has returned it to its zero position. The rotation of wheel 5 causes wheel 4, which is geared to the summation meter counter 7, to rotate and advance the counter the appropriate number of kWh.



(*Landis & Gyr, Ltd.*)
FIG. 107. THE ELGEE SUMMATION METER

To avoid losing an impulse, it is only possible to have four solenoids working on one shaft, because the cams must be displaced by 90° to avoid interference. To obtain a summator for eight feeders, two such shaft systems are used to drive one counter. If more than eight feeders are to be summated, then the summation principle is extended a stage further, i.e. the advances of a number of sub-summators are summated by a master-summator. The appearance of the summator is shown in Fig. 107, although it can now be obtained with extra counters to indicate the impulses (or units) received on each solenoid.

In the Metropolitan-Vickers summation equipment the contact device consists of three gold alloy brushes bearing on two triple-segment commutators driven by the meter spindle (or mounted on the spindle). Each meter requires three pilot wires, as is shown by the connection diagram in Fig. 108. The advantage of this arrangement is that the contact device only makes the solenoid circuit and does not open it, which reduces the duty on the contacts considerably. The breaking of the solenoid circuit is done by a switch operated by the summator solenoid armature.

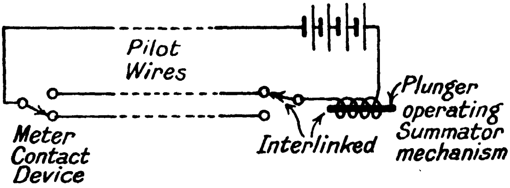
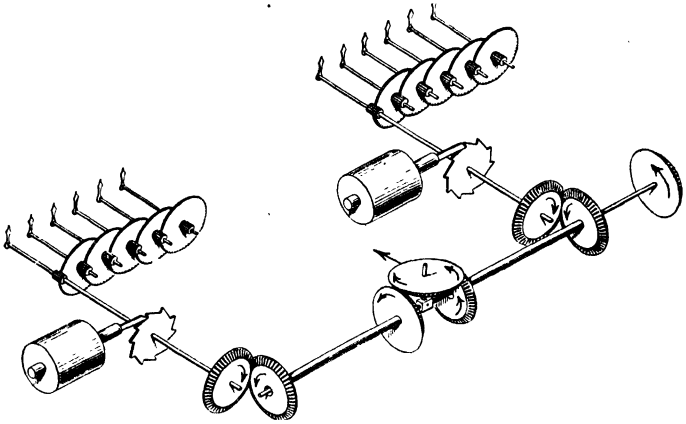


FIG. 108. CONNECTION DIAGRAM FOR M.V. SUMMATION METER

The action of the summator is shown diagrammatically in

Fig. 109, which illustrates the addition of registrations for two elements or feeders. The impulse due to a contact on a feeder meter operates the plunger of the corresponding solenoid so as to drive its toothed wheel through an arc equivalent to one tooth. This rotates the shaft of the wheel, so as to drive the pointers of its individual counter directly, and the pointers of the summator counter (via the bevel wheels and the differential gear), through an appropriate arc. The use of a differential gear prevents interference between the elements.



(By permission of the I.E.E.)

FIG. 109. ACTION OF THE M.V. SUMMATION METER

This principle cannot be extended beyond 10 or 12 feeders, because of the mechanical difficulties involved by the differential gears. A good feature of this type of summator is that the reading of each feeder meter is duplicated on the summator meter. Thus if any trouble occurs it is possible to find the faulty element directly. The M.D.I. on this summation meter is given an extended scale by using two pointers, one of which revolves ten times, whilst the other makes one revolution. If desired, a printometer attachment can be provided so as to obtain a record of the average maximum demand.

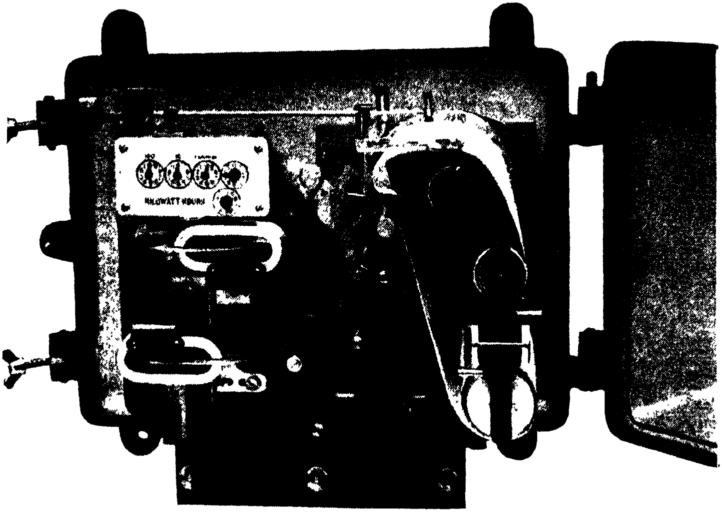
The summation by impulse method is used by the Central Electricity Board on the majority of its important metering equipments. The various meter arrangements and special devices are too extensive to describe in detail in this book, and therefore the reader is recommended to read the various I.E.E. papers on this subject, if he desires more information on this special development of meter engineering.

The Two-rate Meter. This type of meter has two revolution counters which are put in or out of gear by means of a solenoid or a push rod, which is operated by a time switch. The counter, which is in gear when the solenoid is de-energized, is usually made that which registers the normal consumption, whilst the other registers that on the restricted or off-peak period.

Traction Meters. Except for a more robust construction, these meters are similar to the ordinary type of house-service meter. Since these meters do not work on very low loads, the effect of bearing friction is small, and consequently the accuracy of the meter on working loads is little affected by wear and tear of the jewel, within reasonable limits. The windings must be capable of carrying severe overload currents, owing to the large energy input required by a tram or train when starting from standstill.

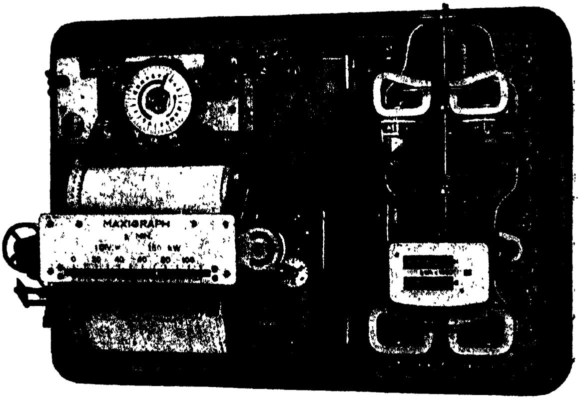
Recording Demand Meters. By fitting some form of recording system to the maximum demand mechanism of an M.D.I. meter, it is possible to obtain a continuous record of the average (kW, RkVA, or kVA) demand. This is very useful, as it enables the time of maximum demand to be determined and also the load curve of the supply. Whilst the record does not give a complete story of the variations of the load, the arrangement has the advantage that the units consumed, the average maximum demand, and an approximate load curve are obtained in one and the same meter. Figs. 110A and 110B illustrate two forms of this type of meter, one of which (Elliott Recorder) uses an inking system to provide a permanent record, whilst the other (L. G. Maxigraph) uses a special sensitized chart paper and a silver roller to obtain the record. Chart friction is eliminated in each case by a special depressing mechanism, which only allows the pen or roller to touch the paper when the process of resetting to zero is taking place. The advantage of the Maxigraph is that inking troubles are done away with, and the record lines are straight.

Another method of obtaining a record is to add a printometer mechanism to a meter. This device prints the reading of the meter on a paper chart every 15 min. (or other chosen period), and by subtraction it is possible to obtain the units supplied in any period, and hence the average demand. Its drawback, of course, is that the load curve has to be calculated, whereas the previously mentioned types give a pictorial record which immediately provides the salient facts. On the other hand, however, the printometer record has the advantage that it also provides a record of the units supplied. Both the printometer and the Maxigraph are used by the C.E.B. on their summation metering equipments.



(*Elliott Bros., Ltd.*)

FIG. 110A. RECORDING DEMAND METER



(*Landis and Gyr, Ltd.*)

FIG. 110B. MAXIGRAPH RECORDING DEMAND METER

If a number of meters of this type are employed, it is desirable, where possible, to synchronize the charts by driving them with synchronous motors.

The Outdoor Meter. In many districts it is a great convenience to the meter readers if the meter is placed on the outside of the consumer's premises, as it enables the readings to be obtained without troubling the consumer, or if the consumer is away from home. The districts referred to are those where the flat system is in vogue, or where the houses are very scattered, and repeat visits very troublesome and costly. There are also the advantages that (1) the meter reader does not create any mess on the consumer's premises in bad weather; (2) if the supply is by overhead wires the outdoor meter reduces the cost of the service; (3) if the number of meters in service is very large, the cost of reading and installation is considerably reduced; and (4) the risk of wrongful diversion of energy is reduced.

The meter has certain disadvantages, however, such as (1) liability to malicious damage by irresponsible people (2) liability to greater errors due to temperature variations on account of its exposed position. Item (1) does not appear to be serious in the districts suitable for this type of meter, judging by the number in use in other countries. Item (2), however, has necessitated the development of efficient temperature compensators for the outdoor meter, and this has led to important improvements in the induction meter—the only meter regularly used for this work. The American Westinghouse Co. claim that their new compensated induction meter has a practically negligible temperature coefficient due to the use of two compensators, one for magnitude and the other for phase angle variations. The former is a special (copper-nickel alloy) magnetic shunt applied to the braking magnets, whilst the latter consists of a special short-circuited winding on the series magnet. The curves in Fig. 111 indicate the necessity for dual temperature compensators, if wide temperature variations are encountered, and the improvement which they can effect. Fortunately for testing departments in England, the temperature variations are very much lower than obtain in U.S.A. and many other parts of the world.

Two examples of the application of outdoor meters are shown in Figs. 112 and 113. It is interesting to note that the Westinghouse O.C. meter is made in two sizes, 5A and 15A only, and that they are interchangeable. The meter portion and the metal base are separate, and the connections are automatically made by means of plugs and sockets when the meter is inserted in the base. The 5A meter will measure accurately up to 15 A. and the 15A meter up to 45 A., so practically all domestic and small power requirements are met by the two sizes. In the case of the G.E.C.

meter, the casing simply forms a watertight housing for the ordinary type of house service meter (fitted with temperature compensator if so desired). It is also interesting to note that Messrs. Metropolitan-Vickers have introduced a temperature-compensated mercury ampere-hour meter, which now makes it possible to extend the application of the outdoor meter to D.C. circuits, if so desired.

▶ **Measurement of E.H.T. Energy on the Lower Voltage Side of Power Transformers.** The measurement of energy on circuits having a pressure of over 20 kV is rather costly owing to the expensive potential and current transformers which are required. In order to avoid this expense, the practice is sometimes resorted to of measuring the energy on the lower voltage side of the step-down transformers, and compensating the meter for the losses in the transformers. The object of the compensation, of course, is to make the consumer pay for the losses in the transformer.

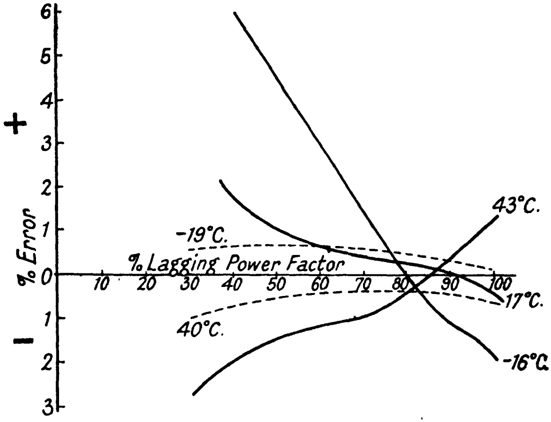
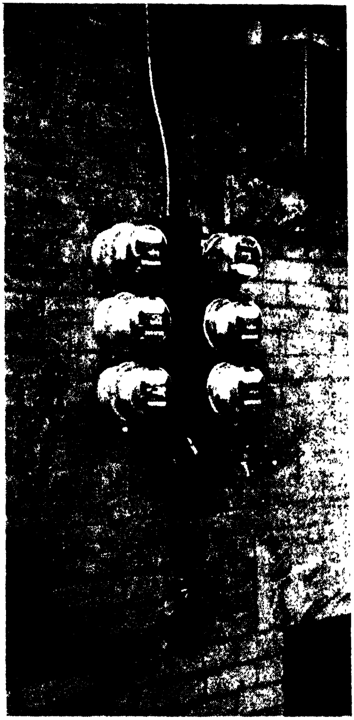


Fig. 111. Variation of Induction Meter Error with Temperature

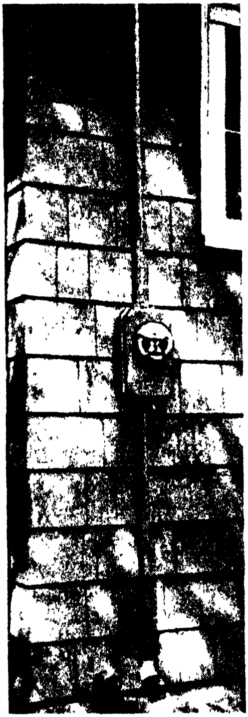
The dotted curves show the improvement effected by dual temperature compensation

A simple method of compensating the meter is to make it run on voltage only at a speed sufficient to register the iron losses of the transformer, and to make the series magnets provide (by making the coils unsymmetrical) a driving torque sufficient to register the copper losses. Although straightforward, the method has the disadvantages that the shunt running to compensate for the iron losses is rather uncertain (because the starting torque of a meter is of the same order as the torque provided by the iron losses) and the meter calibration rather difficult, since the losses are of the same order as the meter errors. This type of compensated meter is only suitable for measuring the output of one transformer.



(*Westinghouse Electric Co.*)

FIG. 112. WESTINGHOUSE OUTDOOR METER



(*General Electric Co., U.S.A.*)

FIG. 113. G.E.C. OUTDOOR METER

Another method employs special iron loss and copper loss meters on each transformer. If the total demand is required, then these individual meters transmit their registrations to a summation M.D.I. meter, together with those of the main kWh meters. The advantage of this method is that definite information on the losses is obtained and that these meters can be made to register the losses more accurately than by compensating the main kWh meters. (For further information on this method and the theory of the special meters, the reader is referred to the *Electrical World*, page 27, Vol. CII; page 260, Vol. CI; and to the *I.E.E. Journal*, page 507, Vol. LXXI.) Wherever possible, however, such meters should be avoided and reliance placed upon direct measurement of the supply at the correct point indicated by the tariff.

An excellent method of avoiding special metering arrangements is to introduce special clauses into the tariff agreement whereby the consumer pays for the iron and copper losses on a specified basis based on the known characteristics of the transformer and the consumer's load.

Synthetic Resin Cases. Since 1930 synthetic resin has been increasingly used for meter cases because it provides an all-insulated case, which is a big advantage with P.P. meters, since the consumer is compelled to touch this type of meter. Also in rural areas it is not easy to secure a good earth for metal-cased meters. Other advantages are: (*a*) no painting of off-circuit meters is required, (*b*) it is lighter than metal and (*c*) the important one that the cover exercises no effect on the errors of the meter.

The disadvantages of synthetic resin are: (*a*) it is not known at the time of writing whether the material will successfully survive thirty or forty years' service; (*b*) it is not so robust as metal and breakages are far more common; (*c*) it is possible to get a shock from a poor quality synthetic resin case in damp situations due to leakage.

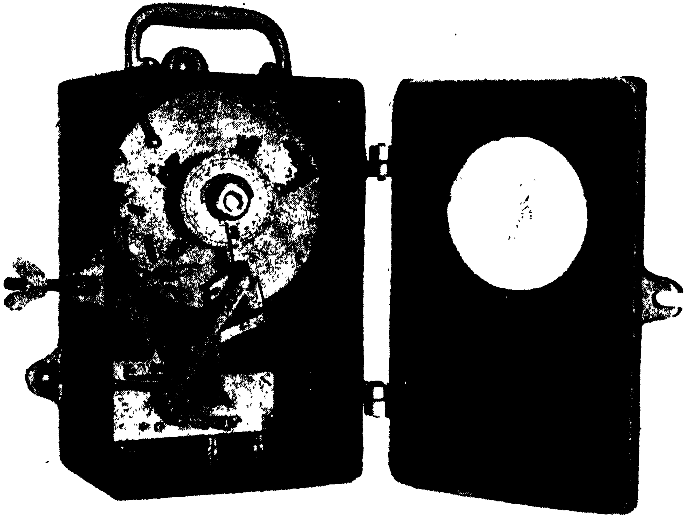
There are numerous forms of synthetic resin, but the following description of an extensively used material will indicate the main features of the substance. The moulding material is a phenolic-resin compound of (1) a synthetic resin binder produced from Phenol (a coal tar product) and Formaldehyde (a wood distillation product); and (2) a reinforcing material of wood flour made by grinding and sifting soft and medium hard woods, such as spruce. The resin and flour are intimately mixed on warm rolls and, after cooling, are ground to a powder. A measured quantity of this powder is placed in the special moulding machine and then subjected to heat (approx. 150° C. to 170° C.) and pressure (1 to 2 tons per sq. in. of projected surface area) for a short time, to produce the lovely, finished product which is now so familiar.

CHAPTER IX

TIME SWITCHES

A TIME switch has two main parts, viz., the clock and the switch. As the switch can be applied to any type of clock, we shall first of all consider the various switching arrangements.

The Open Circuiting Type. Normally, the switch is closed, but at certain times it is opened by the clock for a period depending on the apparatus under control. The period is from 5 to 10 sec. for an M.D.I. circuit and about two hours for a restricted rate circuit. The switch varies considerably, according to the duty to which it is put, as will be evident from Figs. 114 and 116.

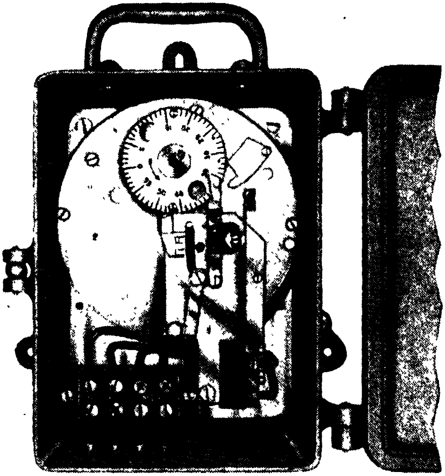


(Venner Time Switch Co., Ltd.)

FIG. 114. VENNER TYPE "C" TIME SWITCH

The Short Circuiting Type. In this case the switch is normally open, but at certain times it is closed for a period depending on the apparatus under control. For an M.D.I. circuit the period is from 5 to 10 sec. An example of this type of switch is shown in Fig. 115.

The Change-over Type. It is sometimes required to have one circuit energized for one portion of the day and another circuit during the other portion of the day, as in the case of a day-night tariff equipment. This type of switch is illustrated in Fig. 117, and in this case five contacts are provided, as it is to be used with the above type of equipment. The necessity for five contacts will be evident to the reader if he refers back to Fig. 84. If the negative pressure coil leads are commoned, then there will be a circuit between the red and blue lines, causing a current to flow, and hence a rotation of the meter rotor when it should be idle. This cannot be permitted, so the negative leads must be kept isolated when the meter is on its idle period.



(Venner Time Switch Co., Ltd.)

FIG. 115. VENNER M.D.I. TIME SWITCH, SHORT CIRCUITING TYPE

There are three types of clock in common use for time switches, i.e. pendulum, escapement, and synchronous motor. It is usual for the clock to drive either an hour dial (for M.D.I. purposes) or a 24-hour dial (for off-peak or restricted rate purposes).

The Hour-dial Type Clock. The hour dial is provided with pins of half-moon shape, the number depending on the time period required, i.e. one for a 1-hour interval, two for a ½-hour interval, etc. Two tripping arms are necessary in order to obtain the 5 to

10 sec. operating period. Both arms are raised together by a pin on the hour dial, but they drop at different times because their lengths are slightly different. When the first arm drops, the switch makes, or breaks, the circuit according to its type. Five or 10 sec. later the fall of the second arm allows the switch to reset to its normal position. This type of dial is shown in Fig. 115.

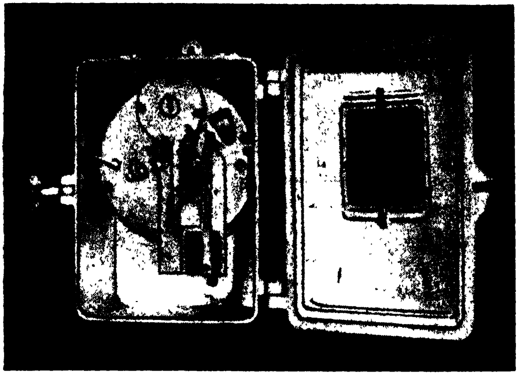
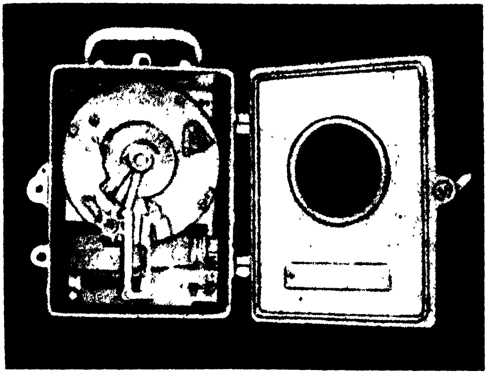


FIG. 116. VENNER M.D.I. TIME SWITCH, OPEN CIRCUITING TYPE



(Venner Time Switch Co., Ltd.)

FIG. 117. VENNER CHANGE-OVER TIME SWITCH, FIVE-CONTACT TYPE

An alternative method is sometimes employed on certain M.D.I. switches or mechanical operators. A shaded pole motor drives an escapement type clock, whose speed is such that a cam is revolved once during the desired time period. The cam is designed so that the correct operating period is obtained.

The Twenty-four Hour Dial Type. In this case the time interval required is a long one, so instead of fitting pins and drop levers, the dial is provided with two arms, which can be set to any desired times. The time of day is indicated by a pointer which nearly touches the edge of the dial. At the appointed times the arms strike the switch mechanism, causing it to open, close, or change-over as desired. This type is illustrated in Fig. 117. The dial is suitably marked to distinguish between morning and afternoon.

Week-end Feature. In many tariffs it is common practice to remove certain restrictions during the period 12 midnight Saturday to 8 a.m. Monday, and to enable this to be done the time switch must be specially adapted. In the type of time switch shown in Fig. 114, a star wheel marked with the days of the week is added in such a position that one of the radial arms will advance it one-seventh of a revolution per day. The star points of this wheel are adapted to receive pegs, and by placing pegs in the appropriate positions the normal operations of the switch mechanism may be altered to suit the tariff. The purpose of the pegs is to operate a special trip lever, which can be seen at the left-hand side of the mechanism in Fig. 114. A pointer is provided to indicate the day, but it should be noted that the correct day is not shown until a certain hour of the day is reached. This is due to the fact that the star wheel is rotated by one of the radial arms, the position of which is variable according to the tariff. Certain other makes of time-switch, however, employ a wheel (geared to the twenty-four hour spindle) which rotates once per week, and which operates the week-end feature by pegs or cams. Another method which has been introduced is to use a large dial which rotates once per week, in place of the twenty-four hour dial, and the week-end feature is easily obtained by omitting pegs on the days concerned.

Open-circuiting Type of M.D.I. Time Switch. The switch mechanism of this type of time switch should have strong springs which will prevent the contacts from separating due to vibration (accidental or malicious), and causing the M.D.I. driving pointer to reset to zero before its proper time. It is this disadvantage which makes the use of the short-circuiting type of time switch advisable where the M.D.I. circuit is suitable (see Fig. 83 and page 102).

Resetting of M.D.I.'s. The M.D.I. time switch, if any, should always be tripped before attempting to reset the M.D.I. This avoids excessive strains on the M.D.I. mechanism which might put it out of adjustment.

Modern Developments. Although the synchronous motor-driven type of time switch is very reliable, it has the defect that a failure of supply causes an error equal to the duration of the failure. To overcome this defect and the failings of other types of clock mechanism (although it is now possible to obtain electrically-wound clocks, or synchronous motor-driven clocks with special back-up springs to keep the clocks running during supply failure), there is a tendency to introduce the following alternative methods of control—

(*a*) Switching of control relays by means of pilot cables.

(*b*) Ripple switching, i.e. operation of tuned (about 1,000 cycles per second) relays by ripples superimposed on the system voltage at suitable points, at the appropriate times.

(*c*) Impulse switching, i.e. operation of relays by coded impulses after the style of the automatic telephone gear.

The reason for these developments is the great effort now being made to improve the system load factor as a means of reducing the cost of electricity.

Testing Time Switches. It is the usual practice in most undertakings to have a special department to take care of all the timing devices owned by the undertaking. All the time switches are tested by this department for accuracy of time and tripping period. This saves the meter department the trouble of testing their meters with the actual time switch, and also it enables a faulty time switch to be changed on circuit without having to retest the meter.

CHAPTER X

GENERAL REQUIREMENTS OF METER TESTING

It will be quite obvious to the reader that in a meter test room it is impossible to test under actual working conditions a meter suitable for measuring the output of a generating station. Therefore methods have been devised whereby the various load conditions can be obtained in a large capacity meter without the expenditure of a huge quantity of energy. Hence the term "phantom load." Not only are these methods applied to large capacity meters, but also to every class of meter, because of the large saving in energy and apparatus which can be effected. Provided that the currents in the coils of the meter are of the right magnitude, phase, and frequency, it is clearly immaterial from what source they are obtained. It is essential, however, that these conditions be fulfilled if accurate results are desired.

Meter Series Circuit. As the voltage drop in the series circuit of a meter at full load is very low, it is clear that the full-load current can be passed through it by applying a very low voltage to the circuit. Thus a source of low-voltage power is required to energize the meter series circuit, and the following sources are used for this purpose—

1. Low-voltage battery.
2. Transformer of low-voltage output.
3. Low-voltage homopolar dynamo.

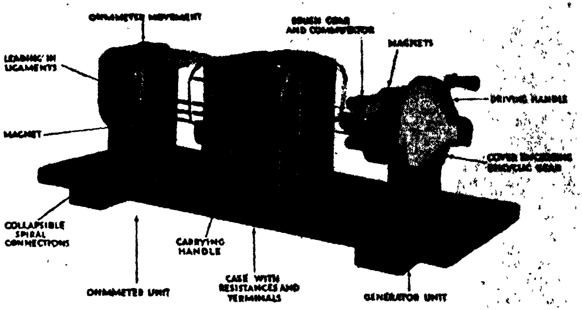
Pressure Circuit. Clearly the meter pressure coil cannot be connected during the test just as it is on circuit (except in the case of indirectly-connected meters), if we are going to use a special source of supply which is separate from that of the series circuit. Consequently, on directly connected meters a link is provided on the terminal block in order that the pressure coil may be isolated from the series coil. The source of supply may be one of the following types—

1. High-voltage battery.
2. Transformer of suitable secondary voltage.
3. The undertaking's supply mains.
4. Dynamo.
5. Alternator.

As meter testing calls for a wide range of currents and voltages, it is necessary to use efficient regulating devices in conjunction with each supply to obtain the correct conditions in the meter. Descriptions of such devices are given in the following chapters.

Terminal Markings. As the correct operation of instruments and meters is vitally dependent on the manner in which the coils are connected to the circuit, it is essential to employ a system of terminal marking and arrangement. The reader will understand, of course, that when one refers to the positive terminal of a coil or circuit on A.C., one means that this terminal has positive polarity when a corresponding terminal has positive polarity.

The test-room conductors are very often run in pairs, and the ruling is that the positive terminal of the pair must be either the left-hand one or the top one of the two, according to the way in which they are situated.



(*Evershed & Vignoles, Ltd.*)

FIG. 118. EXPANDED MEG INSULATION TESTER

Showing unit method of construction

In the case of a polyphase equipment, the terminals are painted red, yellow or white, blue, or green, according to their phase and polarity, i.e. the positive terminal is fully painted (or marked), whilst the negative terminal (if any) is given only a small distinguishing mark of the right colour.

Wattmeters are, as a rule, definitely marked as to coil polarity by the makers.

In the case of current or potential transformers, the positive terminal of the primary and secondary windings must be clearly painted the appropriate colour. The tester should be very generous with the paint, as instrument transformers are often mounted in awkward situations where the numbers are inaccessible, and the paint marks are the only clue as to the correctness of phase and polarity.

The meter terminal block must be clearly painted or marked in order to make the connections easier for the meter fixer. Where the terminals are uniform for current and pressure coils, it is advisable to arrange some scheme for differentiating between a current terminal and a pressure terminal of the same phase colouring.

In the case of a polyphase meter, it is usual to make the top element the blue element (standard phase rotation). If the meter contains a driving motor for operating an M.D.I., then the motor leads must be definitely marked so that in case of replacement the calibration of the meter will not be upset.

It is usual to maintain a colour scheme on the mains right from the power station to the consumer's cut-outs. This considerably helps the meter fixer in arranging the metering equipment.

(*Everett, Edgcumbe & Co., Ltd.*)

FIG. 119. METROHM INSULATION TESTER

General Hints on Testing.

1. The meter connections must be correctly and efficiently made, and great care taken in switching on and off the load in order to avoid ill-treatment of the instrument pointers and to obtain a steady load. A meter cannot be tested properly if the load is not reasonably steady.

2. Dirt, loose connections, and loose screws are the bane of meter testers. It is essential that the internal mechanical condition of the meter be inspected and made O.K. (as far as is humanly possible without dismantling the meter) before commencing the electrical tests.

3. The insulation resistance of the meter circuits to case must be greater than 5 megohms. Not only must the I.R. to case be tested, but also the I.R. between coils which are not electrically connected when the shunt link is open. The I.R. is usually tested by an insulation tester, such as illustrated in Figs. 118 and 119.

4. Some undertakings also have the practice of flashing the meter circuits to case at a pressure of 1,000 or 2,000 volts A.C. The flash test is carried out by an outfit, such as that outlined in Fig. 120, which consists of a wooden box containing a step-up transformer, indicating lamps and limiting resistance. Outside the box are mounted the control switch and circuit-breaker. The

latter is set to trip at 2A, and when it operates it reduces the pressure between the testing points from the high voltage to the voltage of the low-tension supply. The testing points are provided with bakelite handles and suitable guards, and are fed by means of high-voltage, flexible C.T.S. leads. A long lead is fitted on the low-tension side, suitably equipped for attaching to the nearest source of A.C. supply. The ratio of the step-up transformer depends on the L.T. voltage and the output voltage required.

5. Before returning a meter into stores, several details must be attended to—

(*a*) The shunt link, if any, must be replaced in position.

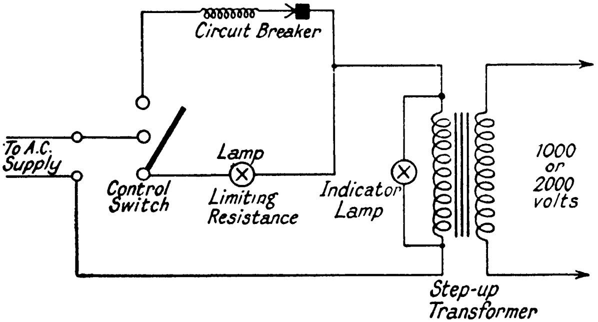


FIG. 120. FLASH TESTING OUTFIT

(*b*) The connection diagram inside the terminal cover must be the right one. If shunts, C.T.'s or P.T.'s are used, it is customary to write their numbers inside the terminal cover.

(*c*) The gasket must be in good condition.

(*d*) The dial pointers should be at zero (but see p. 172).

(*e*) The rotor must be clamped, if a clamp is provided.

(*f*) In the case of an Aron meter, the pendulums must be securely fastened by a rubber band.

(*g*) The terminal block must be correctly painted, if the undertaking uses paint marks to distinguish the terminals.

(*h*) The inspection windows must be securely fixed and also clean.

6. The dial-test may be done at any load for which the error of the meter is known. This applies particularly to the case of dial-testing a mixed batch of meters, since the dial-test load should not exceed the full load of the lowest capacity meter.

7. The meter must be tested with its own cover.

8. If the meter is fitted with a cyclometer dial, it is easier and

better to read the meter before and after a dial-test, and calculate the advance, than to reset it to zero before dial-testing.

9. A supply undertaking continually has meters being returned to the meter stores for the following reasons—

(*a*) Consumer's meter replaced by one of different capacity.

(*b*) Meter no longer required by consumer.

(*c*) Removed because of a fault.

(*d*) Removed after long service.

(*e*) Removed from consumer's premises because of a change in the type of supply, i.e. D.C. to A.C. usually.

These are termed "Off Circuit Meters," and some of them require repair and others are fit for reissue. Those meters with obvious faults, such as a burnt-out coil, are sent to the repair shop immediately, whilst the others are sent to the test room. If the errors of the meters are required for statistical purposes, then the meters are tested before the seals are broken. It is not necessary to test the off-circuit meters all the way down the curve, as the errors for full load and one-twentieth load will be quite sufficient to show up any serious defects in a meter.

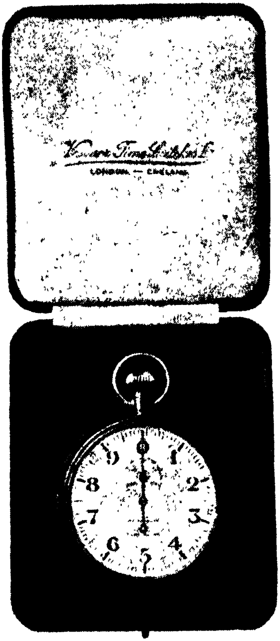
Having obtained the statistics, the seals are broken, and the meters thoroughly inspected and cleaned out. Those meters requiring repair are sent to the repair shop with the necessary instructions. The off-circuit errors will usually indicate the nature of the fault, if any exists. The good meters are now tested in the same manner as a new meter. The I.R. of the faulty as well as the good meters is tested before they are disconnected, in order that faulty insulation, if any, may be repaired whilst the meters are in the repair shop.

If statistics are not required, then the seals are broken, the meters cleaned and inspected, and tested as for new meters.

Timing of Meter Revolutions or Dial Tests. As energy involves time and power, it is clear that a testing department must be able to measure time accurately as well as power. For time intervals exceeding five minutes, the ordinary high-class pendulum clock (see Fig. 122) with a seconds finger enables time to be measured with a considerable degree of accuracy, far higher, in fact, than that obtainable when measuring power with commercial instruments. Every testing department should possess a clock of this character for timing dial tests and checking stop watches.

Intervals below five minutes require a more convenient device than a large clock, and the stop watch is employed for this purpose. A typical watch is shown in Fig. 121. Owing to the onerous duty imposed on the delicately constructed resetting mechanism, due to its frequent operation, it is necessary to check these stop watches every morning. This is usually done by comparing them with the pendulum clock, the pendulum of which should beat seconds for convenience of checking.

The rotors of all motor meters are provided with some special mark to facilitate the work of timing the revolutions. As soon as this mark reaches some definite fixed position (say, the edge of a magnet), the tester starts the stop watch (which is initially at zero). The next time the mark passes the chosen position, the tester counts one, the next time two, and so on. As soon as the mark reaches the chosen position for the occasion when the number counted equals the number of revolutions to be timed,


(Venner Time Switch Co., Ltd.)
FIG. 121. VENNER STOP WATCH

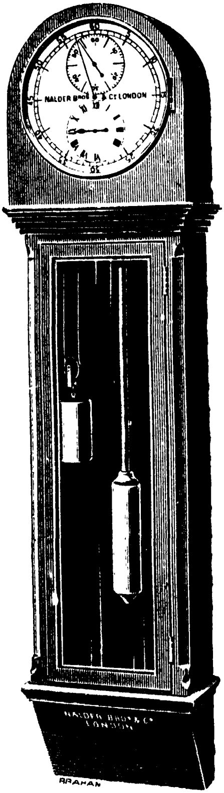


FIG. 122. TEST ROOM CLOCK

the tester stops the watch. The time for the required number of revolutions is then indicated by the watch. It is usual to choose a number of revolutions which will take not less than about 60 sec., in order to obtain sufficient accuracy of timing. The starting and stopping of the watch must be performed in a similar manner each time, or an error may be introduced due to varying the time lag between seeing the spot and actually operating the watch.

If a motor meter is tested by means of a wattmeter, it is a convenience to arrange the revolutions to be *pro rata* with the load, so as to make the timing constant the same for all loads. Since 20 contains the factors 5, 4, 2, and 1, and the usual loads are Full, one-half, one-quarter, one-fifth, one-tenth, and one-twentieth, it follows that the full-load revolutions should be a multiple of 20, for the maximum of convenience.

Where a source of fairly constant frequency is available, it is possible to use electrical timing devices. The clock element consists of a synchronous motor which is started and stopped by external switches, or, if the motor runs continuously, the pointers are clutched and declutched by external switches. With their present construction, however, these devices are more suited for testing relays than meters. Furthermore, mains frequency—even on undertakings where the frequency is controlled—is not perfectly steady and may for short periods vary as much as 1 per cent from the rated frequency. Thus, to obtain high accuracy with these devices, it is necessary to have a frequency meter checking the instantaneous frequency, or to employ an individual source of reasonably constant frequency.

Automatic Timing Device. A timing arrangement has been developed at the N.P.L. which not only times the revolutions, but also counts them and automatically operates the stop watch. This is achieved by operating an impulsing device by a light (or dark) spot on the meter rotor. The impulsing device works a counting mechanism which can count up to 99, and a relay on the counter operates an electrically controlled stop watch so as to start the watch and stop it after the meter rotor has done a predetermined number of revolutions. The advantages of the device are that it eliminates the human error which occurs with ordinary watches, and that it saves the tester the tedious duty of counting the revolutions. Its disadvantage is that it requires a specially treated rotor, and this puts it out of consideration for the majority of test rooms. It is also a rather expensive arrangement compared with the ordinary stop watch, but nevertheless it is the ideal timing device for certain types of testing work—such as are often sent to the N.P.L.

Stroboscopic Timing Methods. Where large numbers of identical meters have to be tested, it is a great help to have a quicker method of testing than timing the rotor revolutions, or comparing them with the revolutions of a sub-standard meter. The prices of modern induction meters are now so low that the manufacturers have been forced to develop the stroboscopic method to speed up the work of testing. There is also something to be said for this method on the score of higher accuracy.

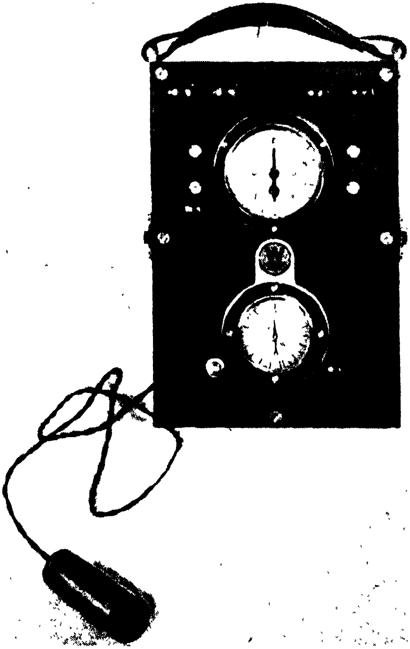
The essence of the method is as follows: The meter rotor is provided with a large number of regularly spaced marks—black lines or spots—and when it is rotating on the appropriate load it is viewed with the help of a light which pulsates at a special frequency. If the speed of the meter rotor is correct, the rotor will appear to be stationary. If it is too fast or too slow, it will appear to rotate slowly forward or backward respectively, at a speed proportional to the difference between the frequency of the passage of the rotor marks and the frequency of the light pulsations. (For further information on stroboscopic effects, the reader is referred to books on physics.) If the speed is not correct, the meter adjustments are altered until the rotor appears to be stationary. The calibration of the meter is thus only a matter of seconds, instead of minutes by other methods.

The special viewing light derives its electrical supply from a sub-standard meter which runs on the same voltage and current which drive the meter under test. The disc of the sub-standard is made with a number of holes, regularly spaced, at a constant radius from the spindle. A beam of light is focused on the disc, so that when a hole enters the beam a portion of the light passes through and energizes a photo-electric cell. The impulse from the cell causes, by the aid of suitable thermionic valves, a flash of light in the viewing lamp. Thus the frequency of the viewing light is proportional to the speed of the sub-standard rotor. In order to get a sharply defined flash of light, a neon lamp is employed to provide the viewing light.

The sub-standard meter may be calibrated to have as nearly as possible the required error curve of the meters under test, so that when the rotor under test appears stationary its errors will be within the desired limits.

The disadvantage of the stroboscopic method is that when the light pulsations are below ten per second, it is very difficult to get good results. If the rotor only has 100 spots, then this method is unsatisfactory below quarter load, if the full load speed is 24 r.p.m. Therefore to make the method applicable down to one-twentieth load, it is necessary to have 400 or 500 marks on the rotor. The majority of the English manufacturers prefer (at present) to test only the full load points stroboscopically, the lower loads being dealt with by the rotating sub-standard comparison method and thus they provide the discs with only 100 marks. The

American Westinghouse Co., however, have introduced the method as a complete means of testing, and have devised special apparatus for this purpose. Their new O.C. meter (see Fig. 112) rotors are provided with 400 serrations on the edge of the disc, so as to obtain the desired accuracy at low loads.



(*Westinghouse Electric Co.*)

FIG. 123. WESTINGHOUSE STROBOSCOPIC TESTING SUB-STANDARD

The testing equipment which they have developed is most ingenious. It consists simply of a well-made box containing a high-grade rotating sub-standard and a generator of electrical impulses. Impulses are initiated by the serrations on the edge of the sub-standard disc interfering with a beam of light passing from an incandescent lamp to a photo-electric cell. The output of the cell is magnified by thermionic valves, and the final impulses are sent out to a neon lamp, which is joined to the box by a length of flex, etc. This lamp converts the electrical impulses to light pulsations which have a frequency equal to that of the number of serrations passing per second. The disc of the meter under test is viewed by the help of this light.

Now this equipment has to be used for testing, as well as calibrating meters. Therefore the makers have arranged the brake magnets of the sub-standard so that they can be adjusted relative to the centre of the disc. The adjuster is a highly accurate device with micrometer adjustment, and by means of a pointer and a scale its position at any time is indicated relative to the position when the sub-standard errors agree with the standardization curve. This scale (the lower one in Fig. 123) is calibrated in terms of percentage error, assuming that at the zero position the sub-standard is accurate. Thus when testing a meter, the knob controlling the magnet setting is turned until the rotor of the meter under test appears stationary. The pointer on the lower dial then indicates the error of the meter, assuming the sub-standard to be correct. (The true error is the indicated error plus the sub-standard error, for the load concerned, at the zero position.) The error scale has a range of ± 5 per cent.

When calibrating, the pointer is set at the zero position or, if so desired, at a point which makes the overall sub-standard error a suitable one. If the meter under test has no stroboscopic markings, then the light impulsing unit is switched off and the equipment is used as an ordinary rotating sub-standard; the upper dial indicates the rotor revolutions, and the error adjuster is set to the desired position.

Curve Testing by Means of Dial Tests. In the following chapters the methods of testing dealt with are those involved by comparing meters against an indicating instrument and a watch, or against a rotating sub-standard. The latter test usually compares meter revolutions against sub-standard revolutions, but an extension of this method—which has found favour in many test rooms—is to compare the meter dial advance against the sub-standard dial advance. There has been a great deal of controversy on this method of testing, so it will be well to draw up a list of its various disadvantages and advantages, as compared with other testing methods.

ADVANTAGES. 1. Since the meter accuracy is finally dependent on the dial readings, it appears logical to measure the accuracy by means of dial test readings.

2. It is unnecessary to set the load with extreme precision, which obviates constant attention to the load. This allows the testers to perform other work whilst the dial test is proceeding. Warning of the end of the dial test is arranged for by a time

switch operating a bell, or by having a special meter which trips off the load just before the dial test is completed. One or two testing departments have developed their own tripping devices, but it is possible, of course, to adapt a good, ordinary flat rate P.P. meter for this duty. (The Smith meter is a suitable meter.)

3. The fact that no attention is required enables the tests still to be carried on during the hours when the staff is absent. It is usual to arrange the tests so that the low load dial runs—which of necessity take a long time—are carried out during the night.

4. Since the testers can do other work during the dial tests, it is claimed that the method is, in the long run, more rapid than other testing methods. Large numbers of meters can also be tested at once.

DISADVANTAGES. 1. It does not follow that because the error after a dial test is within the limits that the meter is really satisfactory. The meter rotor may have run erratically, or even have stopped, during the test for all the tester knows. Curve testing by the other methods rapidly shows up any erratic running, and if the running is satisfactory, then the ordinary final dial test is quite a sufficient test of the gearing. Even the dial testing method does not thoroughly test a revolution counter throughout its range.

2. When meters have to be calibrated, the method is far too slow, and ordinary methods have to be employed. The above method is only really suitable when the meters are given a preliminary test to make sure that they will behave properly on the dial tests. If these preliminary tests are taken into consideration, it is difficult to see where the method has any advantage in speed of testing.

3. It is preferable to test a meter against a standard which is capable of a much higher degree of accuracy than itself. Thus the usual dial testing method of employing a sub-standard meter of similar characteristics to the meters under test is not to be recommended, in spite of the claim that the effects of temperature errors are thereby overcome. If a high grade rotating substandard is purchased, it has little advantage over the wattmeter on the score of expense.

4. It is necessary to test large numbers of meters at once, say, 50 to 80 meters, to make the method profitable.

5. Although night testing may save time in one way, it wastes time in the respect that the testers have to plan how to arrange the tests, and if any difficulties are met the arrangements may be upset, and one or more benches held up. With other methods the testing proceeds without any worry on the score of when the tests have to be made.

6. The method is not capable of producing meters with error curves as good as those obtainable by other methods, as minor adjustments are sacrificed on the altar of mass production.

The advent of the Electricity Supply (Meters) Act, 1936, has created new conditions in Great Britain which tend to encourage the wider use of the dial-testing method. Further details are given in Chapter XXI, so, although intermediate chapters do not specifically refer to the dial-testing method, the reader has the necessary facts available in the book if he wishes to make any comparison. Whilst the dial-testing method is ideal in certain test rooms owing to its economy in labour requirements, it is not suited to other test rooms on account of adverse local conditions.

In the following chapters the method of dial testing usually described is to set all the dial pointers to zero at the commencement of the test. This method cannot be recommended, however, for every type of meter or type of test. Where the tester realizes the advantage of the dial reading method he should, of course, employ that method.

It is recognized that under the Certification procedure the dial reading method (assuming that the dials were correctly set at zero at the commencement of testing) has advantages and that no serious difficulty is caused by having to issue a meter from stock reading a few units, providing reasonable precautions are taken.

Error Definitions. It should be pointed out at this stage that the disc speed error formulae on pages 183 and 215 are not in line with the B.S.S. definitions. The denominators have been changed from T to S in order to simplify the test room slide rule work. So long as the error does not exceed 2 per cent the discrepancy is negligible on commercial meters. For special meters, or where the error exceeds 2 per cent (e.g. when testing off-circuit meters), the tester must apply the correct formula.

Desirable Error Curves. In certain cases the natural error curve or method of calibration gives the tester little scope in giving a desirable characteristic to the error curve, but in the case of modern A.C. meters the error curve is flat enough to give the tester scope for applying the policy laid down by the management. Generally speaking, experience has shown that age causes meters to slow down on the usual working loads, and consequently it has been found advisable to calibrate meters so as to make the error curves lie in the $+ 1$ per cent region. The object of this setting is to try to make the cumulative error of a meter zero over its full life.

Stray Fields. The tester must always be wary of the effects of stray fields on the meters or instruments under test. Such fields can arrive from the most unlikely sources, since a powerful electro-magnet at a distance can be just as upsetting as a nearby weak one. It is well worth mentioning that a brick wall has two sides, and that it offers no opposition to a magnetic field.

CHAPTER XI

TESTING EQUIPMENTS FOR D.C. METERS

Ampere-hour Meters. The meter or meters to be tested are connected in series with a low-voltage battery and a regulating resistance. The latter consists of a combination of variable resistances capable of varying the current from full load down to starting current. The voltage of the battery depends on the range, capacity, and number of meters which are to be tested simultaneously. It is possible to use a cell-grouping arrangement in order to save energy by applying different voltages to the testing circuit at different loads. This method is not used in practice, however, owing to the complications involved by the extra wiring and switches, and because the various battery sections may have differing e.m.f.'s which would create deleterious circulating currents. It is possible in some test rooms to use part of the undertaking's standby battery for testing purposes, if the test room is in the power station building. The battery must be kept well charged up if a steady output current is desired. As the test room is usually associated with a power or sub-station where a night shift is employed, it is easy to make it the duty of someone on the shift to attend to the batteries.

Testing Panel for 100A Output. The circuit diagram for such a panel is given in Fig. 124. A suitable size of battery is 20 volts, 2,000 Ah. capacity. The main current control is by three drum-type controllers, each of which has ten notches. The resistances are graded in the following manner—

First Controller.

Each resistance element is 200 ohms.

Second Controller.

Each resistance element is 20 ohms.

Third Controller.

First three elements, 2 ohms each.
Next two elements, 1 ohm each.
Next two elements, ½ ohm each.
Last three elements, 0·1 ohm each.

For fine adjustments a slider type rheostat is used having a range of 450 ohms, and a ballast resistance of 150 ohms.

The current measurement is by means of three shunt-operated ammeters whose top points are 1·5A, 10A, and 100A respectively.

The desired ammeter is put in circuit by the selector switch *S*, which, it will be noted, is arranged so that the tester must pass through the heavy current ranges before reaching the low current range. This helps to prevent accidental overloading of the smaller ammeters. Modern practice, however, is to use only one instrument scaled 100 divisions, in conjunction with a universal shunt as shown in Fig. 125. The initial position of the selector switch cuts out the ammeters and enables the battery to give more than 100A (if possible) without damage to the instruments.

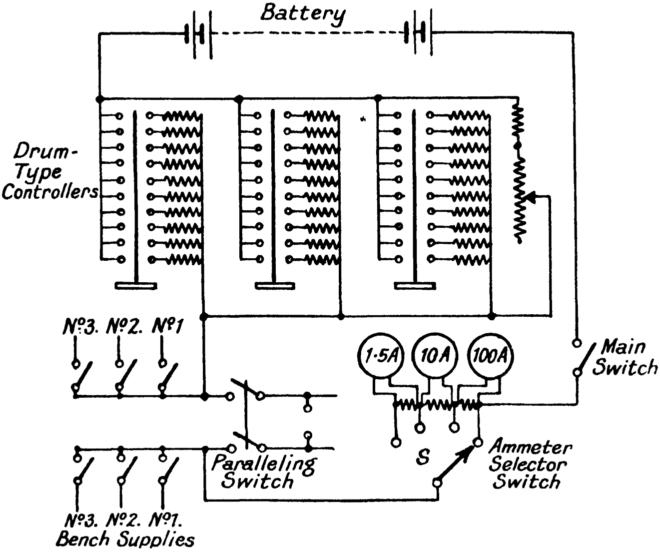


FIG. 124. D.C. TESTING PANEL CIRCUIT FOR 100A. OUTPUT

The paralleling switch is used to put the battery in parallel with those of other panels for special testing purposes, i.e. heavy current shunts or W.H.M.'s, and also for the "flashing" of magnets. "Flashing" is the colloquial term for magnetizing magnets, because it involves passing a heavy momentary current through a solenoid round the magnet, which, of course, creates considerable sparking at the switch contacts.

The other switches are selector switches. which enable the various meter benches in the test room to be supplied from the panel.

Panel and Bench Wiring. All conductors, switches, and joints must be of as liberal a cross-section as is possible, without extravagance, for several reasons.

1. The maximum current obtainable from the battery depends on the resistance of the battery plus that of conductors, switches, and joints.
2. If the conductors get hot on the passage of a fair current, it means that the circuit resistance is a variable and, therefore, the current output will not remain steady. It is essential for accurate testing that the current should remain perfectly steady.

Testing Equipment for 20A Output. In most undertakings the number of meters under 20A capacity far exceeds the number over 20A capacity. Thus a testing equipment suitable for all currents up to 20A is very useful for routine testing of low current meters. A convenient testing circuit is shown in Fig. 125. A handy way of arranging the apparatus is to place the switches, rheostats, and ammeter on the top of a table, and the ballast resistances, fuses, and terminals underneath or at the side of the table. The portion of the table top not occupied by apparatus is utilized for clerical work. Drawers are fitted to the table for storing tools and test cards, etc. To supply the equipment with current, a 12 volt, 200 Ah. battery is advisable.

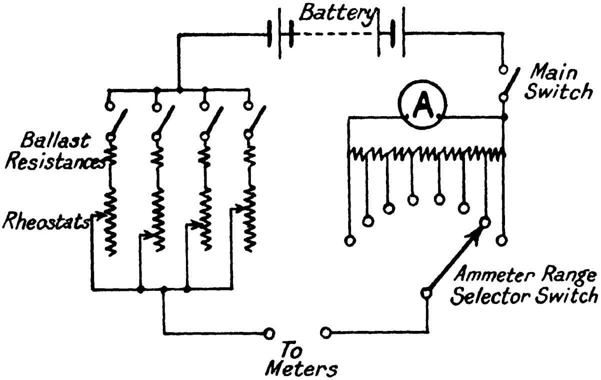


FIG. 125. LOW CURRENT TESTING CIRCUIT

The ammeter scale has 100 divisions, and is used in conjunction with a universal type of shunt to provide top points of 20, 10, 5, 2½, 1, ½, and ¼ A. The selector switch is arranged so that the higher ranges are passed through before reaching the lower ones. The initial position of the switch cuts out the instrument and shunts.

The rheostats used are graded as follows—

20A rheostat has ½ ohm range plus a ballast resistance of 0·2 ohm.

10A rheostat has 5 ohm range plus a ballast resistance of 1·0 ohm.

2A rheostat has 100 ohm range plus a ballast resistance of 5·0 ohm.

1A rheostat has 500 ohm range plus a ballast resistance of 15 ohm.

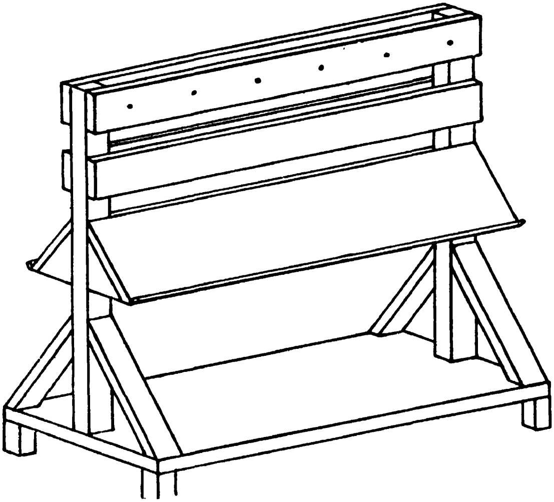


FIG. 126. BENCH FOR D.C. AMPERE-HOUR METERS

Ballast Resistance. As the ultimate position of a slider type rheostat cuts out the resistance entirely, it follows that the current would then be limited only by the conductor, battery, and meter resistance. In the latter case the current would be excessive, so some device must be used to prevent such a dangerous current. This device is termed a ballast resistance, and it consists simply of a fixed resistance placed in series with the rheostat.

The Meter Bench. The older types of mercury meters were built to stand upright without external support, so the older type of bench simply took the form of a flat table capable of holding the necessary number of meters in line. Along the side of the table is fixed a sloping board (with a fiddle) for carrying the test cards at a convenient angle. Near the edge of the table a groove is cut completely round the top. This groove prevents waste of mercury, because if any leaks out from a meter it cannot roll on to the floor. At one or two points in the groove, outlets are provided with a pot to collect the mercury. This mercury must be cleaned (see page 298) before being used again for meters. The terminals which connect the bench to the testing panels are mounted at the ends of the bench.

Other types of ampere-hour meters, however, are not made self-supporting, and they must be held in position during test by being screwed to a wooden panel. If only a few meters at a time are tested, it is easy to arrange an ordinary wooden panel; but if large numbers are to be tested, then something more permanent than a plank and a few wood screws is desirable. A suitable type of bench is illustrated in Fig. 126, and it has two features of special interest.

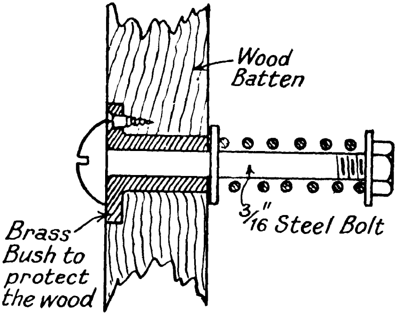


FIG. 127. METER SUPPORT

1. The meter support consists of a three-sixteenths steel bolt, which passes through the batten, and is kept in place by a steel spring as shown in Fig. 127. The spacing of these bolts should be great enough to accommodate the largest meters employed by the undertaking without interference.

2. The bench is portable. The base is at such a height from the floor that a modern lifting chassis type of storeroom truck can be wheeled underneath the base. After raising the chassis, the bench can be wheeled away to any desired place. The advantage of this arrangement is that a bench of fully tested meters can be changed for a bench of untested meters. Whilst the tester is calibrating the new batch, a labourer can disconnect and transfer to stores the tested meters, and then connect up another batch of untested meters. An alternative way of making the bench portable is to mount it on castors.

Watt-hour Meters. The supply for the current circuit is obtained from the same panels as for the ampere-hour meters. If the required current exceeds the maximum reading of the panel instruments, then the selector switch must be put on the "Through" position and the current measured by inserting a shunt-operated ammeter of the correct capacity.

Voltage Supply Panel. A typical circuit is shown in Fig. 128. The high-voltage battery has both coarse and fine tappings, the latter being controlled by the selector switch *A*. The number of coarse tappings will depend on the range of working voltages.

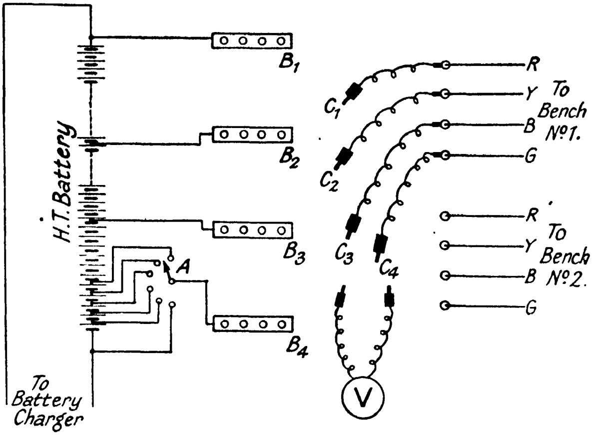


FIG. 128. VOLTAGE SUPPLY PANEL CIRCUIT

These tappings are brought to the sockets *B* and the various benches are given the correct voltage by inserting plugs *C* in the appropriate sockets. Each watt-hour meter testing bench is provided with four voltage bus-bars, in order to supply two different voltages at the same time. The pressure between any two points can be measured by the voltmeter *V*.

The Meter Bench. Owing to the popularity of the D.C. pendulum meter, the meter bench is best in the form of a large wooden panel firmly secured to a wall. This is because the pendulum meter must be set perfectly plumb if good results are desired. In the case of back-connected meters, however, an arrangement of strong battens must be provided as shown in the temperature cupboard in Fig. 130. If large numbers of meters are to be tested, the current supply bus-bar arrangement shown in Fig. 129 is very convenient, and if special leads are made the task of connecting up heavy current meters becomes relatively easy.

Temperature Cupboard. As shunt-operated watt-hour meters have a considerable temperature coefficient, it is good practice to test them at the average temperature of the room in which they

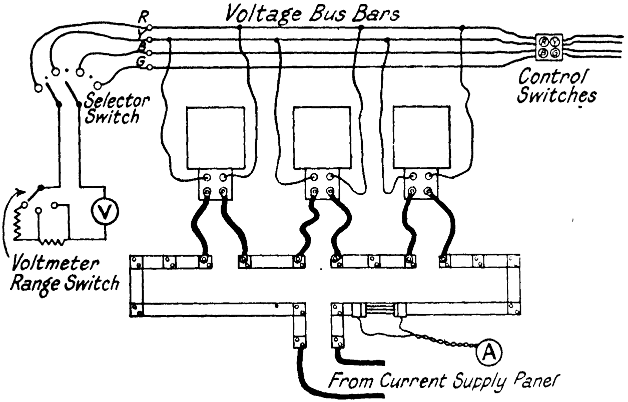


FIG. 129. HEAVY CURRENT D.C. W.H.M. TESTING PANEL

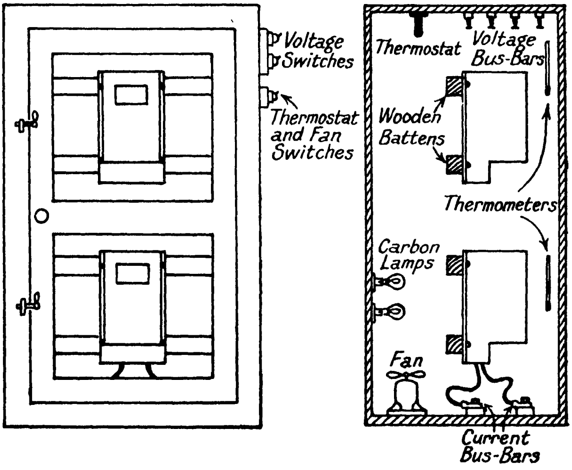


FIG. 130. TEMPERATURE CUPBOARD

are going to be used. This is generally a power or sub-station, whose average temperature will be fairly definitely known. For this purpose it is convenient to have a cupboard similar to the one sketched in Fig. 130. If the doors are tight fitting, the internal temperature can easily be raised to 80° F. by one or two carbon lamps. To keep the temperature constant, a thermostat is fitted in the cupboard so as to switch the lamps in or out as required. The temperature is maintained even by means of a small fan, which causes a continuous circulation of the air round the interior of the cupboard.

Along the bottom of the cupboard run two bus-bars to which the series circuit of the meter is connected by means of the leads which will be actually used to join the meter to its shunt. Across these bus-bars are connected (diagonally) a shunt and a millivoltmeter which has several ranges. The meter leads are connected to the bus-bars at points directly opposite. The shunt has a fairly high resistance, whose function is to form a local path for any thermo e.m.f.'s which may be developed. The millivoltmeter is suitably housed on a table near the cupboard. The voltage bus-bars run along the top of the cupboard, and are controlled by four tumbler switches. A multi-range voltmeter is mounted alongside the millivoltmeter, and by means of a selector switch it can measure the voltage across any two voltage bus-bars. Inside the cupboard are mounted four terminals, which are connected to the main panel of the test room by conductors capable of carrying 50A. These conductors are very useful for special purposes, such as finding the temperature coefficient of induction meters, etc.

CHAPTER XII

TESTING D.C. METERS

AMPERE-HOUR METERS

Mercury Meters Fitted with Change Wheels. 1. After connecting up the meters and verifying that they are all of the correct capacity, the movements are unclamped and approximately full-load current is passed through the meters. This current is allowed to flow for about one hour before commencing to time the meters for the reasons given on page 23. During this period the tester cleans down the bench, inspects the meters, and then fills in the necessary particulars on the test cards. A specimen test card is shown in Fig. 131, and it will be noticed that the number of revolutions for each load is so chosen that the timing constant is the same for every load. (This is done wherever possible.) The first operation after connecting up the meters should really be an insulation test, but as a faulty meter is rare, this test is usually left until the meters are fully calibrated.

2. The current is now accurately set (the ammeter being held at the corrected reading) at the rated full-load value, and the angular speed of the rotors is timed by means of a stop-watch. Let the number of seconds taken be represented by T.

3. The current is now set at half the full-load value and the meters timed again.

4. The current is now set at quarter load and the meters timed again.

5. As above for one-tenth load.

6. As above for one-twentieth load. Many test rooms, however. ignore two of tests 3, 4, and 5.

7. The gearing of the revolution counter is such that one revolution of the rotor corresponds to $Z \,.\, V/1000 \times 3600$ kWh, since one revolution of the rotor corresponds to Z A. sec. and V equals the voltage of the mains (assumed constant).

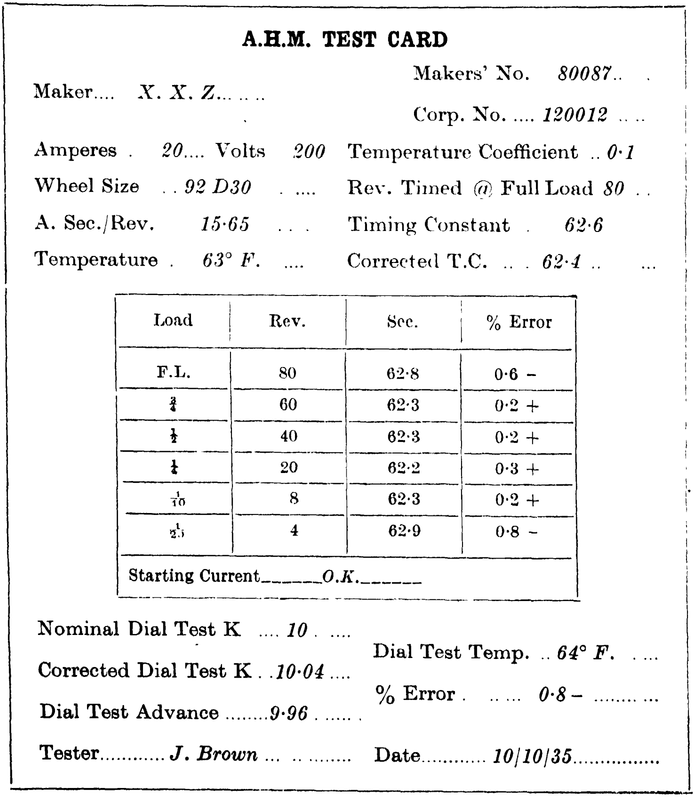
The quantity Z is termed the "ampere-seconds per revolution constant," and it is clearly marked on a label on the counter. The value of Z is controlled entirely by the gearing of the counter and the marking of the first dial. The makers provide tables giving the necessary connection between the wheel sizes and Z. It is a simple matter, however, to calculate the constant Z from first principles if the number of teeth on each wheel is known.

Thus the fundamental equation of the meter is

$$\frac{\text{Amperes} \times \text{seconds}}{\text{Revolutions}} = Z$$

If we know any three of these factors, we can calculate the fourth. In our case, we know Z, revolutions and amperes, so we can calculate the number of seconds in which the revolutions should be done as follows

$$\text{Number of seconds} = \frac{Z \times \text{revolutions}}{\text{Amperes}} = S$$



A.H.M. TEST CARD

Makers' No. *80087*

Maker.... *X. X. Z.*

Corp. No. *120012*

Amperes	*20*.... Volts *200*	Temperature Coefficient	*0·1*
Wheel Size	*92 D30*	Rev. Timed @ Full Load	*80*
A. Sec./Rev.	*15·65*	Timing Constant	*62·6*
Temperature	*63° F.*	Corrected T.C.	*62·4*

Load	Rev.	Sec.	% Error
F.L.	80	62·8	0·6 –
¾	60	62·3	0·2 +
½	40	62·3	0·2 +
¼	20	62·2	0·3 +
$\frac{1}{10}$	8	62·3	0·2 +
$\frac{1}{25}$	4	62·9	0·8 –

Starting Current______*O.K.*______

Nominal Dial Test K *10*

Dial Test Temp. .. *64° F.*

Corrected Dial Test K . .*10·04*

% Error . .... *0·8 –*

Dial Test Advance ....*9·96*

Tester............ *J. Brown*

Date........... *10/10/35*

FIG. 131. TYPICAL A.H.M. TEST CARD

S is termed the "timing constant," and is the time which the rotor should take to complete the appropriate number of revolutions, provided the meter is at 60° F. (15° C.). If the room temperature is different from 60° F., then S must be corrected to a value S'. (See pages 24 and 25 for particulars of the temperature coefficients of mercury meters. Also see page 172.)

The percentage error of the meter at each load can now be calculated from the equation

$$\% \text{ Error} = \frac{S' - T}{S'} \times 100$$

A negative result means that the meter is slow and will under-register, whilst a positive error means that the meter is fast and will over-register; at 60° F. in this case.

If the error at every load is within the limits allowed (see page 7), then the meter is ready for the further tests. If, however, the error at one or more loads falls outside the limits, then there are two courses open to the tester, depending on his judgment—

(*a*) The meter is fitted with a fresh change wheel, which gives such a value to Z and S' that the errors are within the limits. It is advisable to retime one-twentieth load after the change, in order to ensure that the gearing is in order.

(*b*) If the error curve is too bad, the meter is rejected unless the tester finds that the trouble is one which he can rectify. If a repair is made, then the meter must be retimed on all loads. If a repair cannot be effected by the tester, then the meter must be returned to the makers in the case of a new meter, and sent to the repair shop in the case of a meter owned by the undertaking. The various troubles of mercury meters are discussed on page 275.

8. The running of the meters on starting current is then tested. The regulations for this test are given on page 9.

9. The meters are now dial-tested. This is done at full load and over such a period as to obtain a dial advance which can be read to 0·2 per cent. There are two methods of dial-testing, and the choice of method depends on the size of the meter. Large current meters can give a readable advance in a very short time, but many 5A and 2½A meters require a long run at full load before a readable advance can be obtained.

Method A. All the meter dials are set to zero (except cyclometer type counters, which are read before and after the dial-test), and the full-load current is passed through the meters for one or two hours, as required. The current is maintained steady throughout the test. The meter readings at the end of the dial-test should be within ± 2 per cent of

$$\frac{I \cdot V \cdot t}{1000} \times k$$

where I = dial-test current.
V = assumed voltage of supply.
t = dial-test period in hours.
k = correction factor due to the temperature during the dial-test differing from 60° F. The same temperature coefficient is used as for correcting S.

Method B. The meters are connected in series with a sub-standard meter and all the dials are set to zero. Full-load current is then switched on and after an hour the sub-standard is timed, and its error determined (temperature is not allowed for). The load current is then allowed to look after itself until, say, the following morning, when the error of the sub-standard is again determined before switching off the current. The dial advance of the sub-standard is then corrected to obtain the true value of the kWh supplied during the test. This value, K, is adjusted to a value K' to suit the temperature coefficients of the various meters on test, and K' should agree, within $\pm$ 2 per cent, with the dial advance of the corresponding meters.

In each case there is the further stipulation that the dial-test error should not be more than 1 per cent different from the full-load disc-speed error. This is because the dial-test is used as a check on the size of gear wheels, as well as on their correct meshing.

10. If the meters have passed all the above tests successfully, they can have their dials reset to zero, I.R. tested, rotors clamped, and then be returned into stores. The test cards are next finished off and forwarded to the office.

Mercury Meters with Calibrating Device. 1. As above.

2. As the counter gearing is permanent, then the value of Z is constant for a particular size and type of meter. Therefore S' is a constant for a particular load, temperature, and number of revolutions. The speed of the rotor can be varied by means of a calibrating device (usually a shunt across the meter bath), and for a certain type of meter the tester will know by experience that to obtain a suitable error curve he must adjust the full-load error to be within a certain small range. Consequently operation 2 is to time the meters on full load and to adjust the calibrating device on such meters as require attention. The results are entered up as before.

3, 4, 5, 6. As before.

7. If all the errors of a meter are within the limits, it is ready for the further tests. If one or more of the errors are outside the limits, there are two courses open to the tester.

(*a*) It may be possible by readjusting the calibrating device to bring all the meter errors within the limits.

(*b*) As for 7*b* above.

8, 9, 10. As before.

For Commutator Motor Meters. As for mercury meters without change wheels, except that the pre-test run need not be so long as one hour.

For Electrolytic Meters. After connecting up the meters in series and entering up the particulars on the test card, the reading of each meter is taken. Full-load current is then passed through the meters for a period long enough to obtain a readable rise or fall in the indicating column. The advance registered by the meters should then be within ± 2 per cent of

$$\frac{I \,.\, V \,.\, t}{1000} \text{ kWh}$$

where V = assumed steady voltage of the supply mains.
I = dial-test current.
t = dial-test period in hours.

If the advances are within the limits, the meters can be returned to stores and the test cards sent to the office. The precautions necessary when returning the meters vary widely with the type of meter, but they should be obvious to the tester.

In case the dial-test current cannot be maintained steady during all the dial-test, the method described on page 184, or an electrolytic sub-standard, must be employed. Electrolytic meters have a negligible temperature coefficient. (Also see page 318.)

WATT-HOUR METERS

Directly Connected Motor Meters. 1. After the meters have been connected up, they must be run for an hour on a high load in order to take into account the effects of self-heating. In the case of mercury watt-hour meters, it is advisable to have the pressure circuit alive for about five hours before commencing the testing of the meters, because of the considerable mass of metal which has to be heated. Directly-connected meters are not usually tested in a temperature cupboard unless the meter is going to a place where the average temperature is high. During the self-heating run the test sheets are made out. (See Fig. 132.)

2. There are two methods of applying the voltage to the pressure circuits of the meters.

(*a*) A rheostat is placed in series with the pressure circuit supply, and by correct adjustment the exact voltage may be obtained at the meter terminals. This simplifies the calculations, but it requires constant attention if the voltage is to be kept steady. If a rheostat is used, then the voltmeter must be kept permanently alive in order to avoid changes in the volt drop in the rheostat.

D.C. W.H.M. TEST SHEET

Maker ... *X Y Z* .... Makers' No. . .... *100000* . ...

Type.... . ... *N* .... Corp. No. ....*40000*...... ...

Amperes . .*1000* .. Volts . .. *100* . .... Wheel ....*80* .....

Shunt No. ... .*999* . . .. Leads No............*999*.... . ...

R.P.U. ... .*24* ... . kWs/rev. Constant . . . *150*.. .. ..

Temp.........*65° F.* Corrected kWs/rev. Constant .. *148·5* . .

Dial Constant . *10* . . M.D.I. Constant . *1* ....

Temp. Coeff. per ° F. *+ 0·2* M.D.I. Period..... . *¼ hr.*

Load	kW	Rev.	Timing Constant	Sec.	% Error
F.	100	40	↑	60·1	1·2 –
¾	75	30		60·0	1·0 –
½	50	20		59·8	0·7 –
¼	25	10	59·4	60·0	1·0 –
1/10	10	4		60·0	1·0 –
1/20	5	2	↓	60·3	1·5 –

Dial Test		M.D.I. Test		
D.T. Temperature	. 64° F.	Load	F.	¼
D.T. Constant .	. 100·8	Corrected kW	101	25·25
D.T. Advance .	. 100·0	Reading	100·0	24·75
% Error . . .	0·8 –	% Error	1·0 –	2·0 –

Starting Current.... ... *O.K.* . ..... Creep. .... *O.K.* ... .

Tester ....*J. Summer* .. ... Date .. *11/11/35* ....

FIG. 132. TYPICAL D.C. W.H.M. TEST SHEET

(*b*) The meters are supplied direct from the battery after adjusting the tapping switch, so as to obtain as near as possible the required voltage. This method is preferable, as it enables a sensitive voltmeter (which need not be kept alive any longer than is necessary to obtain a steady reading) to be used. It is usual to read the voltage after definite intervals during a test and plot the readings on graph paper. Provided the load is steady and the battery well charged, the voltage will vary very little during an interval, which enables the voltage at any time to be obtained from the graph.

3. The current is now adjusted to the rated full-load value and the meters timed. If the timing is acceptable, the tester enters it on the test sheet. If it is not acceptable, the necessary adjustment is made to the brake magnet, so as to obtain the desired timing. In the case of the watt-hour meter, the speed of the rotor should be directly proportional to the power, which gives us the equation

$$\frac{\text{kW} \times \text{seconds}}{\text{Revolutions}} = \text{a constant} = K$$

K is termed the "kW seconds per revolution constant," which is usually abbreviated to kWs/rev. constant.

Now, if 1 kW is supplied for one hour, then, by definition, the consumer has received 1 kWh. The revolution counter is so geared that A revolutions of the disc causes the counter pointers to advance 1 kWh. A is termed the "revolutions per unit (R.P.U.) constant." Applying the above equation, we get

$$K = \frac{1 \times 3600}{A} \text{ if the meter is perfect.}$$

Thus the kWs/rev. constant is obtained by dividing 3,600 by A for all types of motor watt-hour meter, whether D.C. or A.C. The R.P.U. constant is always clearly marked on the nameplate of the meter. Knowing K, we can use the above equation to determine the timing constant as shown below

$$\text{Seconds} = \frac{K \times \text{revolutions}}{\text{kW}}$$

$\therefore$ Timing constant for N revolutions

$$= \frac{K \times N}{\text{Volts} \times \text{amperes}} \text{ for D.C. meters.}$$

This timing constant is corrected if necessary for the temperature error of the meter.

The advantage of method 2 (*a*) will now be apparent. It enables the timing constant to be easily worked out and, if the revolutions are *pro rata* with the load current, then it will be the same for every load. Method 2 (*b*) necessitates calculating out the timing constant for every load, unless the voltage remains absolutely constant.

4 (A). If the meter is fitted with a friction compensator, the current is now adjusted to one-twentieth of the full-load value. The meter is timed and the compensator is adjusted, if necessary, to obtain a timing which the tester thinks will suit the meter under test.

5 (A). The current is switched off and the voltage raised 10 per cent in excess of the normal value. The rotor is then tested to see that it does not creep forward continuously. If it does creep forward, it indicates excessive friction in the meter, and the tester must locate and remove it if possible. Otherwise the meter must be rejected and sent to the repair shop or the makers, according to its owners. If an adjustment is made, then it is necessary to retime the one-twentieth load.

6 (A). If the meter is O.K. on creep, the voltage is reduced to normal, and starting current switched on. The rotor should start and run continuously on this load. If it will not do so, it must be either rejected or the fault cured. In the latter case, operations 4 (A) and 5 (A) must be repeated.

7 (A). If the meter is O.K. on creep and starting current, the load is then adjusted to one-tenth and the meter timed. This is likewise done for $\frac{1}{4}$ and $\frac{1}{2}$ loads. The errors are now worked out and, if they are not all within the limits, then it will be necessary to readjust the magnet or friction compensator, or both, in order to bring all the errors within the limits. Any alteration of the adjustments necessitates retesting the meter completely.

4 (B). If the meter is not fitted with a friction compensator, then the loads are timed in the order $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{10}$, and $\frac{1}{20}$, and the results entered on the test sheet.

5 (B). The errors are now worked out and, if they are all within the limits, the meter can be tested on starting current. If not, then it may be possible to make the error curve satisfactory by an adjustment of the brake magnet. In case the curve cannot be brought within the limits by such an adjustment, the tester must look for excessive friction and, if possible, eliminate it. Otherwise the meter must either be sent to the repair shop or rejected, according to its owners.

6 (B). If the errors are now within the limits, starting current is applied, on which the rotor should start and run continuously.

8. The meter, having successfully passed the preceding tests, is now ready for a dial-test. The pointers of the counter are set to zero and full load (or approximately so if method 2 (*b*) is used)

is then put on the meters for one or more hours. The dial advance should be within ± 2 per cent of

$$\frac{V \,.\, I \,.\, t}{1000} \times k \text{ kWh}$$

where V = voltage during dial-test.
I = dial-test current.
t = dial-test period in hours.
k = temperature correction factor, if required.

There is the further limitation that the dial-test error should not differ by more than 1 per cent from the full-load disc-speed error.

9. If the dial-test is passed, then the pointers are reset to zero, the I.R. tested, the rotors clamped, the meters disconnected and shipped into stores. The test sheets are then copied up neatly in black and red (for the errors only) ink, and the neat copy forwarded to the office. The rough test sheet is kept in the test room for reference purposes.

Indirectly Connected Motor Meters. If the full-load current is not very high, it is preferable to test the meter with its shunt connected as on site. In this case, the testing will not differ from that described for directly connected meters. In the case of a large capacity meter, it is difficult to obtain the full-load current, so it is usual to test the shunt and meter separately.

1. The resistance of the shunt is determined as described in Chapter XVI. A common value of the shunt voltage drop at full load is 0·1 volt, although it may be as high as 0·2 volt. Let the resistance of the shunt be R ohms and the voltage drop when carrying the rated full-load current be E millivolts, i.e. E equals (current in shunt × R × 1000).

2. The meter is now connected up (in the temperature cupboard, if so desired), and the appropriate voltage is applied to the pressure circuit and E millivolts to the current circuit. (This includes the actual shunt leads which are to be used on site.) This load is maintained for an hour before commencing to test the meter. In the case of a mercury watt-hour meter, the pressure circuit should be alive for five hours before testing. During the warming-up period the test sheets are made out and the meter inspected.

3. The current taken by the meter current circuit for a voltage drop of E millivolts is then measured with the rotor running (see page 13). Let this current be i_m and the corresponding current in the shunt be i_s. Therefore the total current supplied to the consumer is I, i.e. $(i_s + i_m)$. Now, i_m is very closely

proportional to E under all conditions, therefore the current I is proportional to E.

$\therefore\ I = i_m + E/1000 \,.\, R = k \,.\, E$, where k is a constant.

Thus we can find the load current corresponding to any other millivolt drop across the meter current circuit.

4. The testing is now similar to that described for direct-connected meters, since the only difference is in the method of determining the load current from the instrument readings.

Directly Connected Aron Meters. 1. The first duty after connecting up the meters is to test them for creeping on voltage only. Although the reversing gear prevents any false registration over an even number of 10-min. periods, it is necessary to limit the motion during any one period to not more than one or two divisions of the first dial. The balance weights on the pendulums are adjusted until this limitation has been achieved. As a further check, the meter pressure circuit is kept alive overnight, and the difference between the readings at morning and evening should not be more than two divisions of the first dial.

2. The full-load current is now passed through the series coils, and the method of checking the accuracy of the meter is by means of a dial-test of sufficient duration to give a suitable advance of the dial pointers. As the reversing gear operates every 10 min., it is necessary to make the dial-test period a multiple of 20 min., in order to avoid the dial-test readings being affected by the lack of synchronism of the pendulums.

A convenient testing sheet for a pendulum meter is shown in Fig. 133, from which it will be seen that, in addition to taking readings at the start and end of the hour period, readings are also taken at intermediate stages. These additional readings are required to avoid the danger of a mistake in determining the error or the overlooking of certain types of meter faults. The extra readings are taken in the following way: those in column 1 are taken at 20-min. intervals, and those in column 2 are taken 30 sec. later than the corresponding ones in column 1. The advances in each 20-min. period should tally, and any erratic behaviour indicates a fault in the clock or counter mechanism.

The methods of measuring V and I have already been described. If the dial-test period is t hours, then the advance of the counter should be $V \,.\, I \,.\, t/1000$ kWh. Let the actual advance be Z kWh.

$$\therefore \qquad \text{The meter error} = \frac{Z - V \,.\, I \,.\, t/1000}{V \,.\, I \,.\, t/1000} \times 100\ \%$$

If the error is not that which the tester knows from experience to be desirable, then the resistance of the pressure circuit is altered so as to obtain the desired error (see Fig. 28).

3. The current is now adjusted to ¼ load and the meter error again determined.

4. The error at ½ load is now determined.

It is necessary to check the errors at ½ and ¼ loads in order to make sure of the correct meshing of the various differentials and wheel trains.

5. Having successfully passed the above tests, the meters can

PENDULUM W.H.M. TEST SHEET

Maker's No. *79000* . Corp. No.....*20020* . Shunt No. *1111* ..

Amperes ....*500*.... Volts ....*400*.... Dial Constant *10*

Leads No. *1111* ..

From Arundale Sub-station.

A.	V.	kW	Temp.	Compensated Dial-test Constant	Time	Meter Readings		% Error	M.D.I. Rdgs.	M.D.I. % Error
500	400	200	75		9.15	32·5	32·8			
					9.35	39·3	39·7		202	1·0 +
					9.55	46·1	46·3		203	1·5 +
					10.15	52·9	53·2		202	1·0 +
				200		20·4	20·4	2·0 +		
250	400	100	75		10.30	60·1	60·2			
					10.50	63·5	63·5		101	1·0 +
					11.10	66·9	67·0		102	2·0 +
					11.30	70·2	70·4		101	1·0 +
				100		10·1	10·2	1·5 +		
125	400	50	75		11.40	75·4	75·5			
					12.00	77·1	77·1		50	O.K.
					12.20	78·8	78·9		50	O.K.
					12.40	80·5	80·6		51	2·0 +
				50		5·1	5·1	2·0 +		

Creep Test... *O.K.* . *I.R.*....*O.K.* .. *Remarks.* Tested in temperature cupboard at temperature of the Sub-station.

Tester..... *T. Reen* .. .. Date. *7/7/35* .

FIG. 133. TYPICAL PENDULUM METER TEST SHEET

be disconnected and returned into stores after receiving the usual final attentions.

If a meter cannot be calibrated, the fault must be located and necessary repair effected either in the test room or repair shop according to its nature. The errors must, of course, be within the usual limits.

Indirectly Connected Aron Meters. 1. As these meters have a considerable temperature coefficient, it is usual to test them in a temperature cupboard at the average temperature of the place where they will be used. This avoids the trouble of applying a temperature coefficient during the test. The creep test is performed as in 1 above.

2. The method of determining the load current from the shunt millivolt drop has already been described on page 189. In this case, the pressure circuit must be alive and the pendulums swinging when the test for i_m is made. The correct millivolt drop for full-load conditions is applied to the meter series circuit (which includes the actual shunt leads), and the meter accuracy is tested as in operation 2 above. See Fig. 29 for the desired error curve of an indirectly connected meter. If the error is not that which the tester desires, then the pressure-circuit resistance is altered so as to obtain the desired error.

3, 4, 5. Similar to those for the directly connected meter, except for the change in the method of loading the meter.

Testing a Three-wire D.C. Meter. 1. The meter is first tested on full load as an ordinary two-wire meter, i.e. as though the mid-wire were carrying no current. The error is calculated as described above. (In the case of an Aron meter, however, the first operation is the creep test.)

2. Each element is now tested separately on full load as a two-wire meter and the errors obtained (the pressure coils being energized as in practice). If there is more than 2 per cent between the two errors, then steps should be taken to rectify this state of affairs. Where there is a pressure circuit for each element this is a simple matter, but in the case of a dynamometer type of watt-hour meter this adjustment is often difficult.

3. Having made the elements sufficiently balanced, operation 1 is repeated, and the magnets or resistances adjusted until a suitable error has been obtained.

4. The testing is now similar to that described for a two-wire meter of the same type.

Testing a Maximum Demand Indicator. If a meter is fitted with a M.D.I., the latter is tested during the dial-test. It is necessary to make the dial-test sufficiently long to enable the M.D.I. to be operated several times. The tripping period is controlled by hand, unless the time switch is an integral part of the meter or the undertaking does not test its time switches separately. The number of consecutive periods which must be checked depends on the type of tripping apparatus, e.g. if the hour dial has four pins, then the four consecutive periods must be tested.

It is advisable to test the M.D.I. on a low load, say, ¼, as well as on full load, in order to test the mechanism for back lash and accuracy of zero. Where possible, the friction pointer should be set back a little after each period, so as to get a fresh reading for each period.

A further point to notice is that the extra load on the rotor when driving the friction pointer from zero sometimes makes the first reading low. During the subsequent periods this load is absent except for a tiny interval at the end of the period. It is for this reason that the meter should be tested for disc-speed accuracy with the M.D.I. pointer well up the scale, and sufficient M.D.I. testing periŏds provided during the dial-test.

The M.D.I. error should not be greater than 2 per cent and not more than 1 per cent different from the error of the meter at the corresponding load. Certain poor types of M.D.I. may require these limits extending, but in principle the M.D.I. should be quite as accurate as the integrating mechanism. In many modern supplies, the maximum demand charges are about equal to the unit consumption charges, hence the need for equivalent accuracy.

CHAPTER XIII

TESTING EQUIPMENTS FOR A.C. METERS

THE testing requirements vary considerably with the character of the testing department and the number of meters to be handled. A manufacturer who turns out a thousand meters a week requires a testing equipment where the operations are reduced to the absolute minimum, in order to compete with his rivals. Also his equipment must be capable in many cases of working on any commercial frequency. The other extreme is the small undertaking doing, say, a dozen meters a week. In the latter case, an elaborate equipment is not essential, although a permanent arrangement of the testing apparatus is desirable.

No attempt will be made here to describe equipments employed by the manufacturers, as such equipments are subject to rapid alteration to suit new styles of meters, etc. The stroboscopic method of testing has come into vogue with the manufacturer on account of its time-saving advantages.

The equipments to be described are therefore more suited for use in the testing departments of supply undertakings. Particular users will desire modifications to suit their own needs, but they are not usually very difficult to carry out owing to the adaptability of A.C. transformer and switching arrangements.

The reader should note, however, certain limitations of transformer circuits if it is desired to test meters with sinusoidal voltages and currents. If the latter are not sinusoidal, then serious discrepancies may occur in the various measurements made, owing to the varied response of different types and makes of instruments and meters to harmonic voltages and currents.

The magnetizing current of a voltage transformer (the ordinary power transformer is, of course, a potential or voltage transformer) is not usually sinusoidal, due to the fact that the *B:H* curve of iron is non-linear. Thus to obtain a flux which alternates sinusoidally, so as to induce in the windings a sinusoidal pressure, the magnetizing current must contain harmonics—the most pronounced usually being the third. Normally there is practically no impedance in the primary circuit to interfere with the free flow of the harmonics, and thus the transformer output voltage has the same wave shape as the input voltage. If, however, impedance (resistance or inductance) is introduced into the primary circuit, the free flow of the magnetizing current harmonics is interfered with, and thus the flux wave—and hence the output voltage—will not have the same wave shape as the supply voltage. The amount of distortion depends on the magnitude of the primary impedance, and the magnitude of the harmonics in the normal magnetizing current. Therefore, to avoid wave-shape distortion, a voltage transformer must (1) be used with very little primary circuit impedance; or (2) be designed so that the magnetizing current to produce a sine wave of flux contains very small harmonics, i.e. the flux density must be kept low, as in the case of the current transformer.

It should be clear, by the way, that if the primary impedance is high enough, the transformer functions as a C.T. and not as a P.T., because then the primary current will be chiefly controlled by the primary impedance and not by the secondary load of the transformer. As the characteristics of P.T.'s and C.T.'s are quite different, the reader will appreciate that it is not usually possible for a transformer to be equally satisfactory in either capacity.

Certain testing circuits employ resistance in the primary of a transformer to obtain control of the secondary current, owing to the great convenience of the method for single-phase work. Therefore, in such cases the transformer must be designed so as to satisfy condition (2) above, i.e. it must be designed more as a C.T. than a P.T. Furthermore, it must be used as a C.T., the point being that discussed on page 126 regarding the maximum secondary burden. Also, apparatus in which it is desirable for harmonic currents to flow freely should not be tested on a step-down transformer circuit of this type, because the primary resistance constrains the secondary current to a sine wave. (For useful information on this type of circuit, the reader is referred to an I.E.E. paper by J. B. Lees, entitled *The Equipment and Operation of a Modern Meter and Test Department*, page 41, Vol. LXXV.)

Magnetizing currents also create another difficulty in certain testing circuits. If a voltage transformer supplies a testing current which is partly occupied in magnetizing iron at a high flux density, the current may contain harmonics. If it is essential that the testing current should be sinusoidal, then steps must be taken to arrange the testing circuit so that the predominant element in the secondary circuit is resistance. It is for this reason that in the equipments to be described, the output voltages of step-down voltage transformers are specified much higher than would appear necessary for a low impedance circuit. The excess voltage is absorbed, of course, by the resistance loading bank.

It will be seen therefore that although transformers are very adaptable to suit varying needs, they must be designed so that their characteristics do not conflict with the testing requirements.

If the test room contains more than three or four benches, it becomes convenient to supply them from a central panel. The necessary connections are made by means of jack plugs, which should be capable of carrying 100A. The panel also enables one test room to be connected with another, e.g. the D.C. test room with the A.C. test room, or either to the laboratory.

An All-purpose Single-phase Equipment. The wiring diagram of the bench and panels is given in Fig. 134, the supply being obtained from a low-tension three-phase four-wire system. The supplies to the voltage and current circuits are controlled by switches 1 and 2 respectively.

The voltage circuit for the meters is isolated from the mains by means of the phase shifter *PS*, which has a 1/1 ratio of transformation. Regulation is obtained by using the phase and line voltages of the phase-shifter secondary in conjunction with an auto-transformer *A*. The selector switch 3 controls the meter voltage and at the same time puts the voltmeter on the correct range. Coarse adjustment of the voltage is obtained by selector switch 4, which varies the initial tapping on *A*. The rheostat *R* in conjunction with the throw-over switch 5 enables fine adjustment of the voltage to be obtained. The rheostat *R* is permanently connected to the winding *W* on the auto-transformer, and switch 5 enables the polarity of the injected voltage due to *R* to be reversed. The output voltage is supplied to the meter bench *via* the selector panel 6, but to the wattmeter bench direct.

The current circuit for the meters is supplied *via* the step-down transformer 7, which has a transformation ratio of *X*/10 or *X*/5 volts, according as the switch 2 is in the parallel position or series position. The secondary can give an output of 1,000A without overheating.

The main regulation of the current is by the resistance bank 9, in which the resistances are so graded that any current from 0·02A to 1,000A can be obtained, provided the impedance of the meter series circuit is not too great. The switch 10 cuts out the resistance bank, and the switch 11 is provided to cut out the measuring instruments when necessary. There are two sets of output terminals. Set 12 is for handling heavy currents up to 1,000A, whilst set 13 on the selector board 6 enables the meter bench to be supplied, *via* suitable links, up to 100A. Care must be taken to see that only one set is in use at any one time. The selector board 6 is arranged so that the output can be connected either to the meter bench or to the laboratory for standardizing purposes.

The voltage is measured by means of a first grade moving iron voltmeter. The power is measured by a wattmeter having a suitable number of current and voltage ranges. The pressure coil connections are straightforward, the desired range being obtained

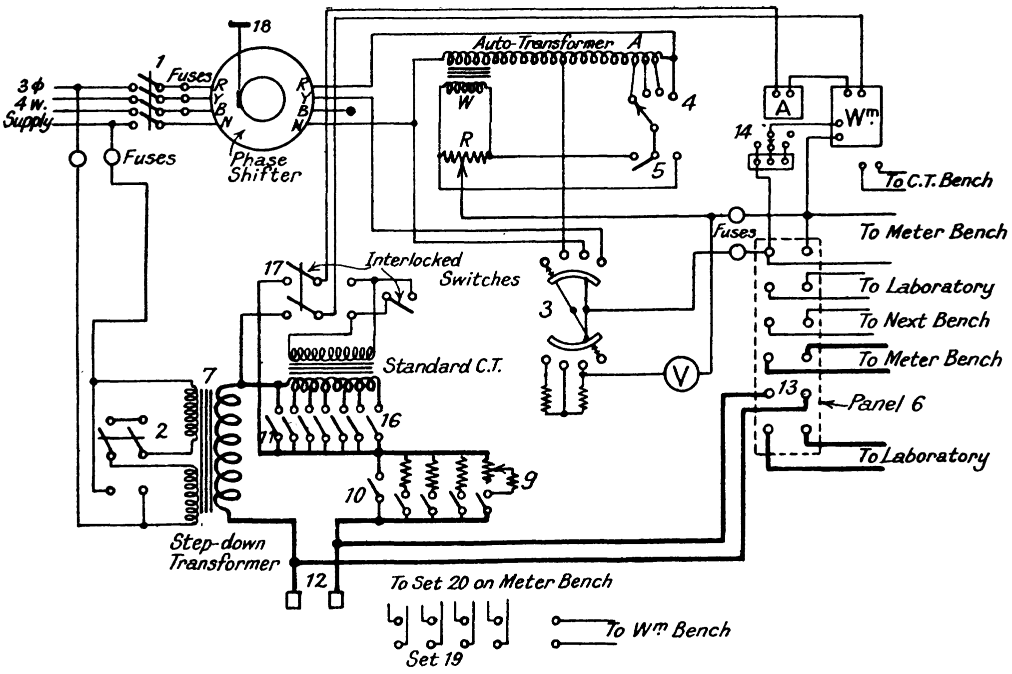


FIG. 134. SINGLE-PHASE TESTING EQUIPMENT

by the selector 14 on the wattmeter bench. As the wattmeter is fitted with a 5A series winding (and perhaps a series-parallel arrangement which enables a 2½A range to be obtained), it is necessary to employ a current transformer for currents over 5A. (Modern practice is to use a high accuracy, multi-range, ring type, nickel-iron C.T. with either the connections shown in Fig. 134, or alternatively as shown in Fig. 141.) The primary circuit of the C.T. is controlled by the selector switches 16 and the secondary circuit by the special throw-over switch 17. When not in use, the secondary of the C.T. must be shorted, hence the need for the throw-over switch. It is advisable to use a shielded type of dynamometer wattmeter and also to run the conductors as close together as possible to avoid setting up stray magnetic fields.

The phase-shifter, which has a range of 360 electrical degrees, is operated by the handle 18. It is essential to make sure that the direction of motion of the handle to obtain a lagging power-factor is clearly marked. The reader will understand that the lagging power-factor in the meter circuit is attained by leading the applied voltage relative to the current, and *vice versa*. It is easy to test whether the power-factor is leading or lagging, because on a single-phase meter the direction of motion of the quadrature loop to make the disc run faster on lagging power-factor is known. The rating of the phase-shifter should be very liberal so as to avoid any danger of wave-form distortion.

When C.T.'s are used in conjunction with the meters, they are fed from the output terminals 12, and the secondary connections are made *via* the sets of terminals 19 and 20. Set 19 is mounted near the C.T.'s on a panel, whilst set 20 is situated on the top of the meter bench. The terminals are suitably numbered and connected in the same order. Each conductor joining the terminals must be capable of carrying 10A and its resistance must be known, so that the test room C.T. wiring resistances may be approximated (by the help of a ballast resistance when necessary) to those "on circuit." Alongside set 19 are mounted two terminals which are connected to corresponding terminals on the wattmeter bench. These are employed when testing the ratio and phase errors of a C.T. by the method described on page 254.

The meter bench may be similar to that shown in Fig. 143. Another type is shown in Fig. 135, which can easily be modified to suit this equipment. It is desirable to avoid voltage switches between the meter bench and the sub-standard, to ensure that the pressure supplied to the meters is (as far as possible) identical with that supplied to the sub-standard. If plugs and sockets are used for the meter pressure connections, it is essential that they should be of good quality. If the meters are to be actually wired, it will be found that bell wire (particularly old scrap lengths, where the department also has a telephone section) is very useful for making pressure connections on the link portion.

Equipment for Particular Types of Single-phase Meters. An undertaking usually has far more consumers' supplies of 5A capacity than of higher capacities. Consequently there is a steady demand for large numbers of 5A meters, and their output is facilitated by having a testing equipment specially designed to deal with them. This principle can, of course, be extended to treat, say, 20A or 50A meters, if they are required in sufficiently large numbers. It is possible by the use of a current transformer to extend the range of operation, so as to deal with 5A, 10A, 20A, and 50A meters on the one equipment. The scheme of connections for such an equipment is given in Fig. 136.

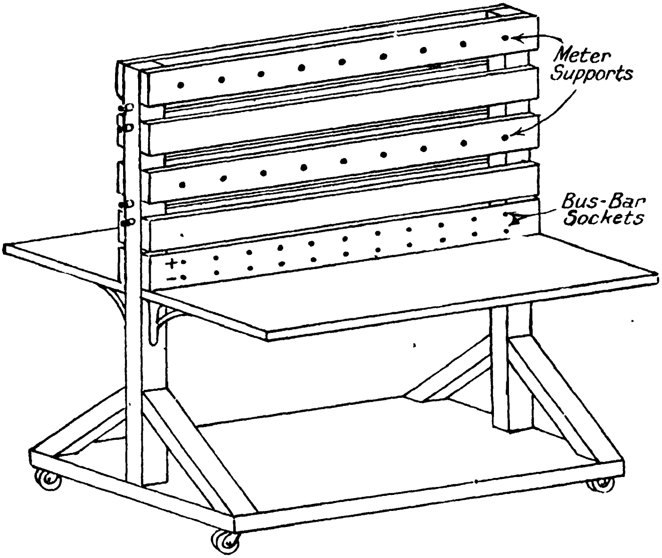


FIG. 135. BENCH FOR SINGLE-PHASE A.C. METERS

Two lines and neutral of a 3-phase 4-wire supply of the correct voltage and frequency are necessary for the operation of the apparatus, which is capable of testing meters at one rated voltage only, i.e. the phase voltage of the supply. The two lines are controlled by a two-pole main switch and the neutral is directly connected to the apparatus. The primary of the current circuit step-down transformer is connected between one of the lines (the lagging one) and neutral. The secondary is in series with the output terminals, the wattmeter (or C.T. primary depending on the position of the range switch), the resistance bank, and ammeter. The ratio of the supply transformer is $X/10$ or $X/20$ volts, according to the position of the switch 2; and the secondary is capable of carrying 50A without overheating. (X is the phase voltage of the supply.) The main resistances are controlled by single-pole knife switches, whilst the fine control is obtained by two slider type rheostats. By means of the tumbler switch, a high resistance can be placed in series with the smaller rheostat for the purpose of obtaining starting current.

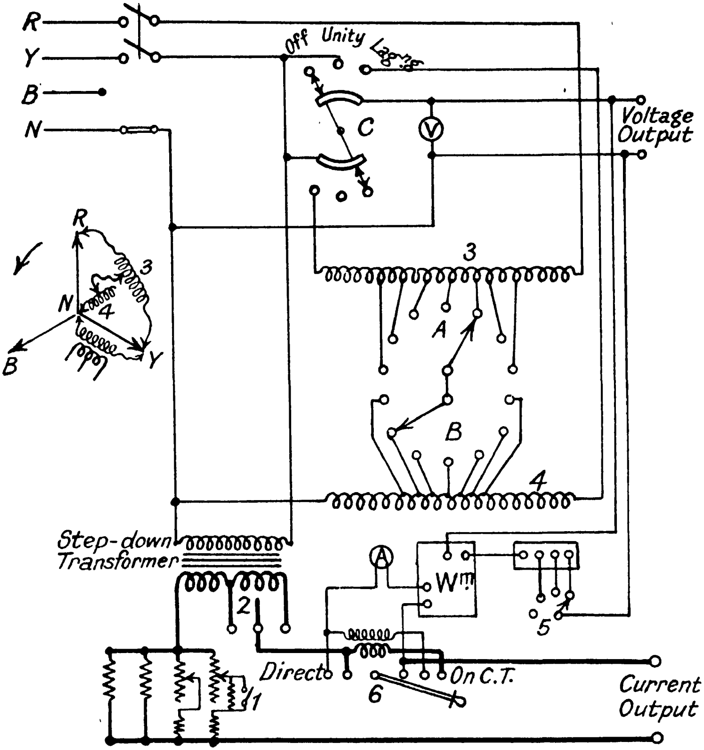


FIG. 136. CIRCUIT FOR SPECIALIZED SINGLE-PHASE METER TESTING

The pressure supply to the meters is controlled by the dial switch *C*, which has three positions, viz. off, unity P.F., and lagging P.F. For the unity P.F. conditions, the pressure coils of the meters are fed from the line and neutral, which supply the step-down transformer. The power-factor will not be quite unity owing to the fact that the step-down transformer and meter load are somewhat inductive. With a suitable transformer and resistance bank, however, the power-factor will be sufficiently near unity for many purposes.

For 0·5 lagging power-factor the pressure coils are fed by means of the combination of coils shown in Fig. 136. Coil 3 is connected between the two lines, and, by means of a dial switch *A*, coil 4 is connected between neutral and any one of the tappings on coil 3. It will be quite clear from Fig. 136 that the adjustment of *A* alters the phase angle of the voltage across coil 4. The reason for using the lagging phase to supply the step-down transformer will now be clear, since the lagging power-factor in the meters is obtained by leading the meter voltage relative to the current. Coil 4 has a number of tappings which are connected to dial switch *B*. These tappings enable the voltage supplied to the meters to be varied. They are necessary because the adjustment of *A* varies the voltage across coil 4, as well as its phase. A voltmeter is mounted on the panel to enable the tester to control the voltage correctly. It is not possible to obtain a very close adjustment of the power-factor with the above arrangement, but this disadvantage is offset by the cheapness of the device compared with the use of a phase shifter. (See page 205 for a special modification which enables the power-factor to be closely adjusted without the use of a phase shifter.)

The excess voltage for the creep test is applied to the meters by using the dial switch *C* in the lagging position and adjusting dial switch *B* to the desired position. The switch 2 must be open when testing creep.

The most convenient measuring device for use on this equipment is a wattmeter having 5A and 2½A current ranges and three available pressure ranges. The full-scale reading should be obtained with 5A and the normal phase voltage, when using the 5A current range and the highest pressure range. This enables a reading of one-fifth of full scale to be obtained on one-twentieth load when using the lowest available voltage range. The 5A and 2½A current ranges are controlled by links on the wattmeter, whilst the voltage ranges are controlled by the selector 5. To avoid electrostatic effects, the pressure and current coils of the wattmeter are commoned either solidly or through a resistance such as a lamp. The wattmeter referred to above is of the low-power factor type, and the precaution must be taken, when purchasing, of specifying that continuous use at the full-rated current will not affect the accuracy of the wattmeter (due to internal temperature rise).

The current range of the bench is extended by using a 50/5A current transformer. This C.T. is put in circuit by means of the range switch 6, whose construction and connections are shown in Fig. 136. The arrangement of the contacts must be that shown, in order to close the secondary circuit of the C.T. before the primary circuit. The wattmeter current links must be in the 5A position when the C.T. is in use, because the C.T. errors are determined with that connection of the links.

A suitable meter bench is shown in Fig. 135. The meter supports and spacing have already been discussed on page 177. To facilitate the connection of the meter series coils, four permanent conductors are run between the ends of the bench and are connected to terminals mounted on the end uprights. The connections to the meter pressure coils are effected by special leads. 'Bus-bars are run down each side of the bench, and the connection is made by inserting the plug at the lower end of the pressure lead into the appropriate socket. The other end of the lead is made suitable for easy connection to the meter terminal block. The negative lead has a plain, round brass lug (approx. $\frac{1}{8}$ in. diam.) which is capable of entering most terminal block sockets. The positive lead has a flat hook-shaped lug, which can be screwed under the small tap screw which normally connects the shunt link to the positive terminal of the pressure coil. It is necessary to provide two extra sets of 'bus-bar sockets on each side of the bench for the purpose of feeding the bench from the testing panel, and transferring the pressure from one side of the bench to the other. The table of the bench is made large enough to carry the testing cards without confusion. If desired, the bench can be mounted on castors in order to make it easily transportable.

It will be clear to the reader, of course, that a rotating substandard may be used on any of the A.C. testing equipments described in this book, in place of, or in addition to, wattmeters.

Other Useful Testing Circuits. The two descriptions above will give a good general impression of the layout of a single-phase testing equipment, but it will be appreciated that there are scores of different designs extant. Where possible, a meter engineer should visit other test rooms and note how the various problems are tackled before designing his own equipment. As local conditions, such as capital available, room available, and size of staff are extremely variable, it follows that the various equipments have to be built on different lines. Where possible, the induction phase shifter should be employed owing to its fine control and simple adjustment. Its expense, however, has made engineers devise other methods of obtaining phase angle control. The various methods are summarized below.

Method 1. Unity, 0·5 lag, 0·5 lead, zero lag, and zero lead may be obtained, approximately, by merely changing the phase

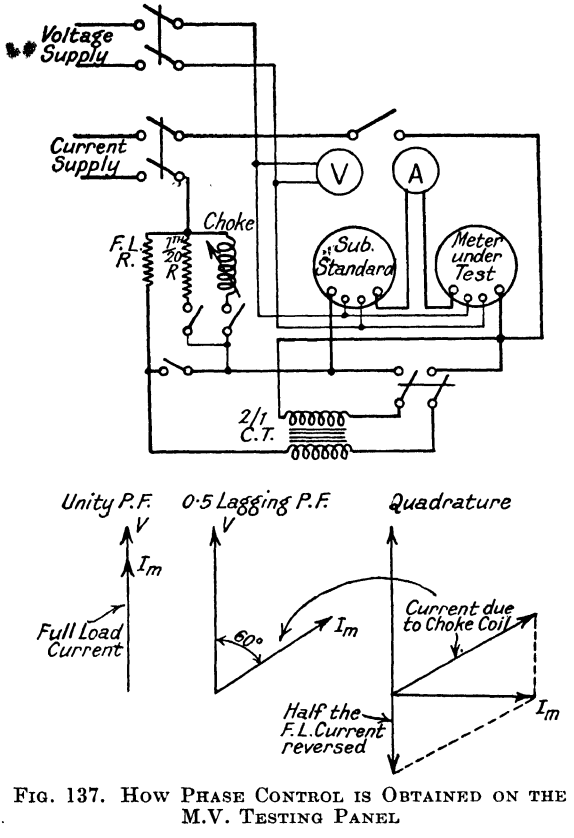


Fig. 137. How Phase Control is Obtained on the M.V. Testing Panel

connections of the current and/or voltage circuits, if the equipment is fed by a three-phase, four-wire main. The power factors are not exact, due to the inherent angle of lag in the current supply circuit, but the method is very useful for many purposes.

Method 2. If the rotor, which is normally stationary, of an induction motor is shifted relative to the stator, it is found that the phase of the rotor voltage is also shifted relative to the stator voltage. This provides a ready means of phase control if we give a supply to the stator and draw our testing circuit voltages from the rotor. The motor may be single-, two-, or three-phase. Thus the "phase shifter," as it is termed, is a modified version of the induction motor, the modifications consisting of (1) preventing the rotor from rotating by having the position controller in the form of a worm drive; and (2) winding the rotor and stator so as to give distortionless transformation. Light fuses should be used in the output of a phase shifter (see right-hand side of Fig. 142) in order to prevent a short circuit causing mechanical damage to the rotor and controller.

(*Metropolitan-Vickers, Ltd.*)

FIG. 138. SPECIAL MOTOR-ALTERNATOR SET FOR METER TESTING

METHOD 3. This method utilizes the direct way of replacing wholly or partly, the resistance bank in the testing circuit by an inductance. The latter is usually of the solenoid type, in which the position of the iron core can be varied, thus giving fine control. Messrs. Metropolitan-Vickers have employed this principle, in conjunction with a patented device to obtain zero power-factor, on some of their single-phase testing equipments. The arrangement of the circuits and the method of deriving zero power-factor are shown in Fig. 137.

Method 4. For many purposes, the following arrangement of the motor-alternator is ideal. The motor of the set drives two alternators instead of one, all the machines being in line and directly coupled. One of the alternators supplies the meter current circuit and the other the meter pressure circuit, the range of output voltage of each machine being suitable for the use to which it is put. The pole system of the current-circuit alternator is fixed, but that of the voltage alternator can be rotated through a range of 360 electrical degrees by means of a small reversible motor (or by hand, see Fig. 138). This motor is controlled by a two-way switch, which is spring-controlled, so that it automatically returns to the middle, or open circuit, position when the load holder releases the control handle. In this way the phase angle between the meter current and pressure can be adjusted to any desired value. If a motor-alternator is used for supplying the testing equipment, then this is the method of phase shifting which should be employed. The induction phase shifter is not suitable with a single alternator M.A. set, as unbalanced current loads on the alternator upset the symmetry of the output voltages (this refers to three-phase work) and thus the desired testing conditions.

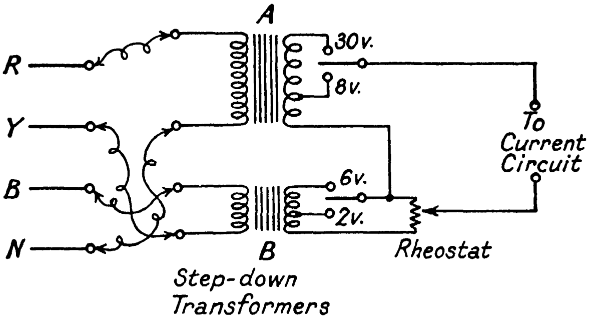


Fig. 139. Potentiometer Type of Phase Angle Control

Method 5. The potentiometer type of phase control has already been described on page 201. It is possible to use a rheostat, of course, in place of the tapped coil, but whilst this would give finer control, there would be the disadvantage of introducing resistance in the primary of a transformer. Another form of potentiometer control is shown in Fig. 139. This is serviceable for currents up to 20A, and it overcomes certain disadvantages of the type of control shown in Fig. 136. Transformer *A* provides the major part of the output voltage, whilst transformer *B* injects a small leading voltage to compensate for the angle of lag in the current circuit. The injected voltage may be adjusted (thus giving fine control of the phase angle) by means of the potentiometer rheostat, whilst large changes of phase angle are obtained by altering the primary connections of the two step-down transformers. (See *I.E.E. Journal*, page 369, Vol. 76, for a complete description.) This method of compensation may be applied to the pressure circuit instead of the current circuit (provided the rheostat is done away with and more tappings provided), and is preferable if the testing current is required to exceed 10A.

Load Regulation. The two testing equipments described above employ a resistance bank in the secondary of a voltage transformer to control the load current. It will be advisable, now, to discuss some other methods of load control.

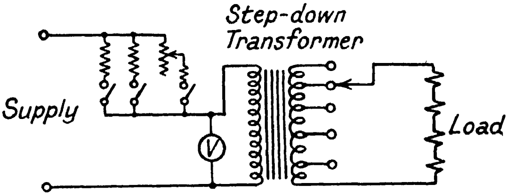


FIG. 140. CURRENT SUPPLY CIRCUIT USING PRIMARY RESISTANCE CONTROL

METHOD 1. If the circuit is supplied from a motor-alternator set, then regulation can be easily obtained by rheostats in the field circuit of the alternator. It is not advisable to push this method of control too far, as if the alternator is under-excited, the wave shape may become distorted.

METHOD 2. An induction regulator constitutes a very useful method of load control owing to the ease with which it can be finely adjusted. Unless the Barbour, Ferranti, or double-rotor type of regulator is used, however, the method has the disadvantage that load control also affects the testing power-factor.

METHOD 3. The pros and cons of using resistance in the primary of a transformer to control the secondary current have already been discussed on page 194. A typical method of arranging the circuit for this type of control is shown in Fig. 140. The voltmeter *V* should have a danger mark on its scale to warn the tester when the limiting condition of correct operation is reached.

METHOD 4. In order to reduce the amount of primary resistance in Method 3, the primary of the step-down transformer is sometimes supplied from a variable-ratio auto-transformer.

Polyphase Testing Equipments. There are numerous ways of utilizing the methods of phase control and load control, just described, to design a polyphase equipment, and the final result will depend largely on the actual purpose of the equipment. If the special points of an all-purpose equipment, suitable for carrying out practically all types of A.C. testing work, are described, then the reader will be able to modify the circuit to suit any special requirements. This equipment has been designed so as to line up with modern ideas on testing. A wiring diagram is given in Fig. 141, and the chief features of the circuit are—

1. As it is assumed that the power supply would be from a three-phase four-wire main, the phase shifter method of phase control is introduced.

2. Owing to its fine and easy control, the induction regulator is chosen for regulating the load current when holding the load. Coarse control of the current is obtained by tappings on the primary of the three-phase step-down voltage transformer (approximately 10 kW capacity), and resistance banks in each phase of the secondary circuit. The range of regulator control may be about ± 20 per cent, to provide the best overall results. Normal output voltages of 10 volts and 5 volts are suitable for most work.

3. Voltage regulation is achieved by connecting three single-phase variable-ratio transformers to the output of the phase shifter. These transformers should be liberally designed and the tappings accurately brought out, in order to obtain special voltages for testing kVAh and RkVAh meters if so desired.

4. Three voltmeters are necessary so that the balance of the voltage system may be accurately determined. Suitable links enable either line or phase voltages to be measured.

5. The power measuring instruments consist of two 1A indicating wattmeters, each supplied from a ring type, nickel-iron current transformer having ranges of 500/1, 250/1, 100/1, 50/1, 20/1, 5/1, 2½/1, and 1/1A. The three-phase power is measured by the two-wattmeter method—this applies for testing either three-wire or four-wire meters, as the testing (current) circuit is a three-wire circuit in either case. A similar C.T. is placed in the yellow line in order to help balance the three phases and to obtain an accurate measurement of the yellow current. Sub-standard grade ammeters are also provided in the red and blue phases, of course. The purpose of using a 1A wattmeter permanently connected to the secondary of its C.T. is to overcome certain objections of the ordinary arrangement of using a wattmeter both direct and in conjunction with a C.T. These advantages are—

(*a*) The wattmeter current coils can be kept isolated from the actual current circuit on all loads. This enables the ± terminals

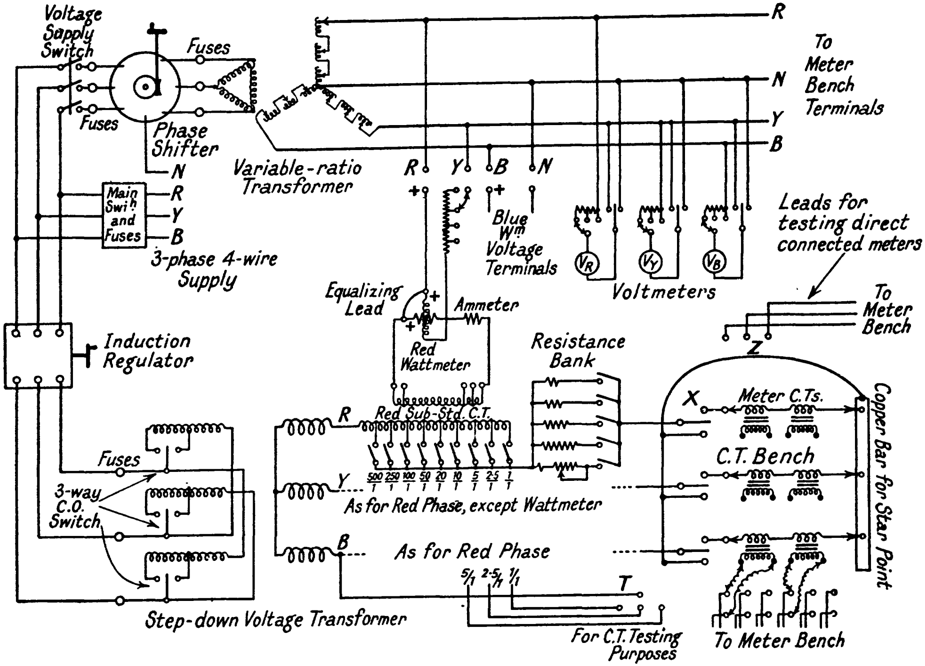


FIG. 141. POLYPHASE TESTING CIRCUIT

of the wattmeter coils to be commoned without certain practical difficulties which sometimes cause trouble on other equipments, e.g. a dropped pressure link, or the impossibility of maintaining the wattmeter coils at a common potential under all testing conditions.

(*b*) With a high grade C.T. there would be no appreciable change of error with change of range, such as would occur if the wattmeter were used both direct and C.T. operated. There is also no danger of leaving the C.T. secondary open-circuited due to faulty switching operations.

(*c*) High scale readings are obtained when testing 5A meters without having to use a low power-factor type of wattmeter. Thus the special C.T. ranges enable a robust high torque wattmeter (which is in general a better type) to be used.

The C.T. primary windings are arranged as follows: 1 turn to carry 500A, 1 turn for 250A, 3 turns for 100A, 5 for 50A, 15 for 20A, 25 for 10A, 50 for 5A, 100 for 2½A, and 300 for 1A. The secondary would be wound for 504 turns, and tappings would be bought out at 1, 2, 498, and 501 turns. The object of the tappings is to enable the mean scale error, if any, of the wattmeters to be counterbalanced, so that the overall errors would be practically zero.

6. The pressure circuit is designed so that there are no switches between the wattmeter and the meter bench, the wattmeter range connections being made by lugs and terminals. This avoids any danger of errors due to switch contact resistance. There are four pressure ranges, viz. 60, 120, 240, and 480 volts, to suit the standard pressures of 400, 230, and 110 volts. Each range is designed to stand double pressure, in order to obtain high-scale readings on low power-factors or currents below 1A.

7. The group of three single-pole throw-over switches (*X*) between the resistance bank and the C.T. bench, plus the conductor (*Z*) to the star point, greatly simplify the operation of balancing the elements of polyphase four-wire meters. The switches enable any phase to be supplied separately and thus the service conditions may be accurately reproduced. It should be mentioned that even though certain tests on C.T.-operated meters necessitate having one or more primaries dead, the secondary connections should not be disturbed.

8. By bringing out the 5, 2½, and 1A tappings (*T*) of the blue standard C.T. at the C.T. bench, the equipment is readily adapted for C.T. testing by the comparison method described on page 254. The primary of the C.T. under test would be connected between the red and yellow output phases, and the secondary to the appropriate winding of the blue standard C.T.; whilst the two wattmeters would be supplied with a common pressure. (*N.B.* It is

not permissible to use the 2½ A or 1 A ranges if this causes the burden on the C.T. under test to be excessive.) Also see page 256.

9. The equipment is equally suitable for single-phase as well as polyphase work. It is also sufficient to carry out tests on A.C. relays and instruments of all types, which is an important advantage.

10. In lieu of a direct comparison with a secondary standard, the presence of two identical wattmeters permits cross checking to be carried out.

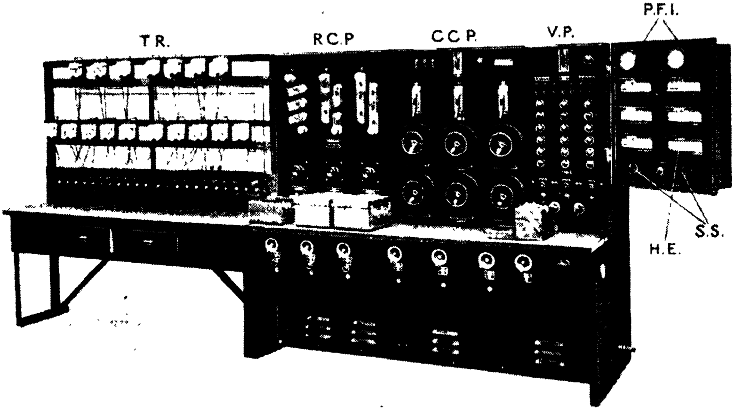


Fig. 142. M.-V. Three-phase Meter Testing Equipment and Test Rack, 1000A 2 kVA. 500 V.

T.R. = Test Rack
R.C.P. = Range Change (Current) Panel
C.C.P. = Current Control Panel
V.P. = Volt Panel
P.F.I. = Sϕ and 3ϕ Power Factor Indicators
H.E. = Horizontal Edgewise, calibrated to sub-standard accuracy
S.S. = Selector Switches to place Sϕ P.F.I. in any of the three phases

11. By the provision of a standard P.T. and a source of high voltage, the equipment may be adapted for testing P.T.'s by the comparison methods. In this case the two wattmeters would have a common current supply, and, to be able to alter the testing power-factor, this supply must be drawn from one of the variable-voltage transformers. The low voltage is applied to the red and blue current output terminals (the current circuit primary

switch being open) to obtain the circulating current, but if the 1A ranges are used there is no danger to any of the apparatus involved.

Modifications. If the supply is drawn from a motor-alternator set having two alternators, then the phase shifter and induction regulator may be dispensed with and the corresponding circuits connected direct to the alternators. Where the M-A set has only one alternator, the phase shifter must be retained, but this type of circuit is not recommended. Either method would require the addition of a speed control rheostat on the testing panel for maintaining the frequency at the desired value.

FIG. 143. POLYPHASE TEST BENCH

Two single-phase wattmeters are specified above for measuring

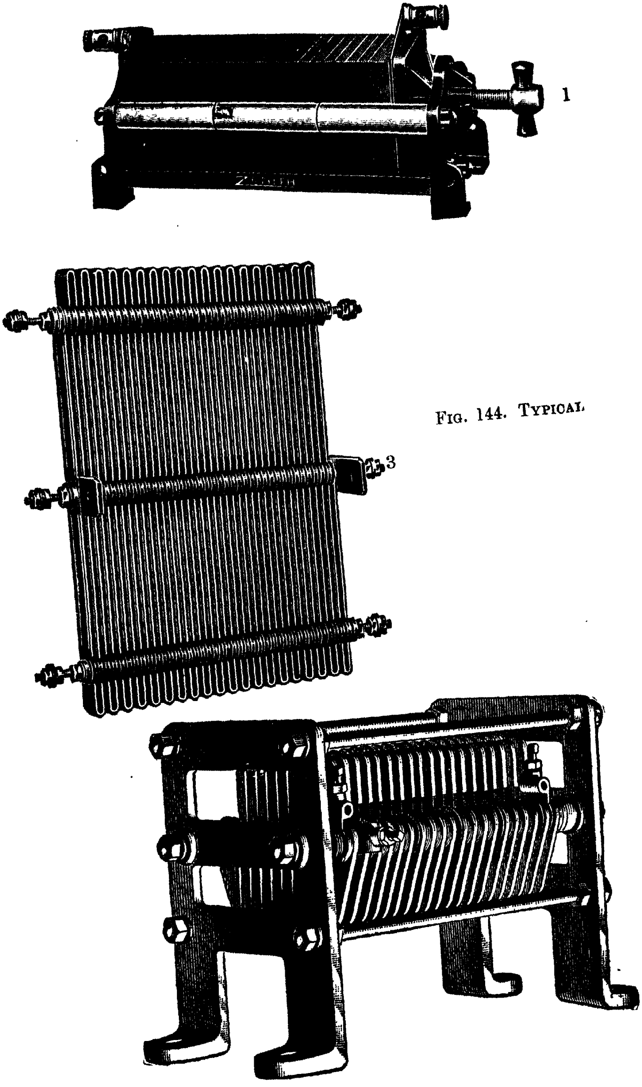
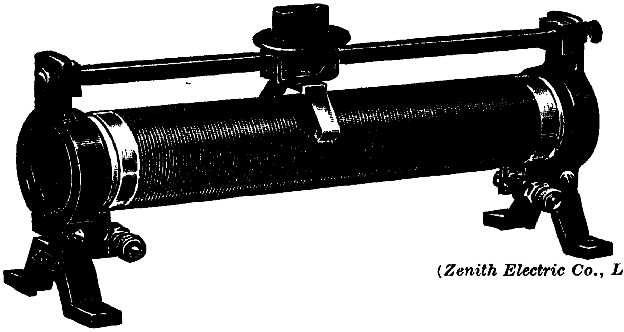


FIG. 144. TYPICAL

(Zenith Electric Co., Ltd.)



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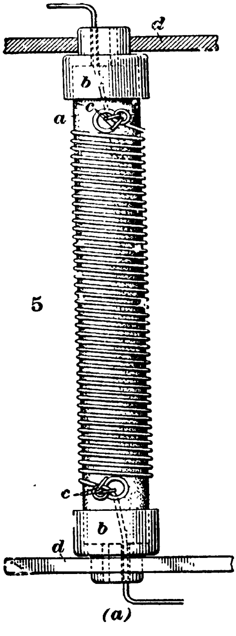
(*Zenith Electric Co., Ltd.*)

Resistance Units



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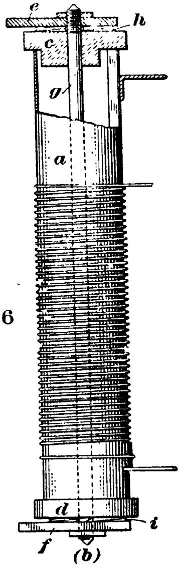
(a)



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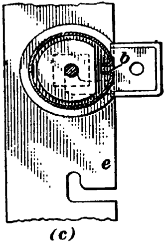
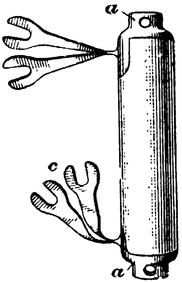
(b)



(c)



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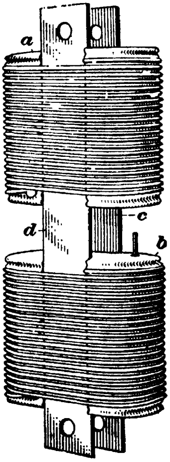
(d)



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(e)

(*International Correspondence Schools*) the power, but, if desired, the following arrangements may be employed.

1. Polyphase wattmeter.
2. Two single-phase rotating sub-standards.
3. Polyphase rotating sub-standard.
4. Three single-phase wattmeters (see Figs. 142 and 185).
5. Three single-phase R.S.S's.

The above arrangement of the sub-standard C.T.'s may, of course, be replaced by the type of secondary circuit typified by Fig. 134, if so desired.

Meter Bench. This consists (see Fig. 143) of an arrangement of stout wooden battens mounted so as to slide in the slots between the end supports of the bench. Each end of a batten is kept in position by means of an iron peg passing through holes in the uprights and batten. The bench is double-sided so as to facilitate the wiring of back-connected instruments and meters, as well as to accommodate large numbers of single-phase meters when required. A table is built into the bench for the purpose of carrying the test sheets and to enable drawers to be fitted. The various feeds connecting the bench to the pressure circuit and C.T. bench are brought out to suitable terminals, post type for the current terminals and insulated cap type for the pressure terminals. It is an advantage if special leads, having suitable lugs at the ends, are made for the connecting-up of routine work. The meters are supported on the battens by wood screws.

C.T. Bench. This consists of a low table, about 3 ft. high, 5 ft. long, and 3 ft. wide, placed near the output from the three single-pole throw-over switches. The various other interconnecting leads are brought out at post type terminals just below the table top. The space beneath the bench may be conveniently utilized as a cupboard. The resistance of each current lead connecting the C.T. bench to the meter bench should be known, in order that the burden on the C.T.'s under test may be made equivalent to that on site, where necessary.

Resistance Banks. The construction of resistances varies considerably with the maximum current to be carried. Fig. 144 illustrates a number of typical resistance units. Variable resistances or rheostats are represented by 1 and 2, the wire-wound type being only suitable for currents up to about 20A in the single tube model. The remainder are fixed resistances, of which 5, 6, 7, and 8 are suitable for currents up to 50A, whilst 3 and 4 are suitable for currents up to 500A.

Electricity Supply (Meters) Act, 1936. Improvements in equipment to help to comply with this Act and also to afford working economy will be found described on page 321.

CHAPTER XIV

TESTING A.C. WATT-HOUR METERS

THERE are two (see p. 170) methods of measuring the accuracy of an A.C. watt-hour meter. The first is to use a wattmeter plus a timing device and, the second, a rotating sub-standard. The reader is referred to Chapter X for variants of these two methods, and to page 172 for a comment on error definitions.

In the case of the wattmeter the method of determining the error is as follows. The desired load is set and adjusted by the regulators so as to obtain the nominally correct reading on the wattmeter. If the load will not remain steady of its own accord, then it must be held to the reading by an assistant called the "load holder." The W.H.M. is then timed and the results entered on the test card. The number of revolutions timed should be such that the time taken is about 60 sec. The R.P.U. constant, marked on the name-plate, divided into 3,600, gives the kWs/rev. constant. From this the timing constant is worked out for the kW and number of revolutions chosen for the test, as shown on page 187. The temperature error of the induction W.H.M. can usually be neglected in a temperate zone, so no correction for temperature is required.

∴ The nominal meter error

$$= \frac{\text{Timing constant} - \text{actual time}}{\text{Timing constant}} \times 100\ \%$$

But the wattmeter has an error of E per cent on the load and scale reading taken.

∴ The true meter error

$$= \left[\left(\frac{\text{T.C.} - \text{A.T.}}{\text{T.C.}}\right) \times 100\right] + E\ \%$$

When testing single-phase motor meters, it is often easier to make the correction for the wattmeter error on the actual timing. For instance, suppose the meter on a certain load should do 20 rev. in 60 sec., but actually does them in 60·6 sec. when the wattmeter is held at the nominally correct reading. Let the wattmeter error be + 0·5 per cent, which means that the applied watts have been 0·5 per cent lower than the nominal value. Obviously if the applied watts had been correct, the disc would have taken less time to do the twenty revolutions. In our case, the disc would have taken $\left[60{\cdot}6 - \left(\frac{0{\cdot}5 \times 60{\cdot}6}{100}\right)\right]$ sec., i.e. 60·3 sec., if the applied watts had been correct. The figure entered on the test card is 60·3. Clearly the rules for obtaining the true timing for a given load and number of revolutions are—

If the wattmeter error is positive, then the actual time must be decreased by the same percentage as the wattmeter error.

If the wattmeter error is negative, then the actual time must be increased by the same percentage as the wattmeter error.

There are two types of rotating sub-standards. For mass production work a sub-standard similar to the meter under test is used. For general work where all classes of meters are to be tested, a high grade form of rotating sub-standard is employed (see Fig. 145). In the former type the error is very easily obtained if the edge of the meter disc is provided with graduated marks. The sub-standard timing spot is set to zero (electrically as the sub-standard is sealed) and the spot of the meter under test also set to zero (by hand), and the meter cover replaced. The load is then switched on and the disc of the sub-standard run for a definite number of revolutions, R. The number of graduations, N, by which the meter under test is faster or slower than the sub-standard is determined. Let the total number of graduations be M, and N be positive if the meter disc be faster than the sub-standard disc, and *vice versa*.

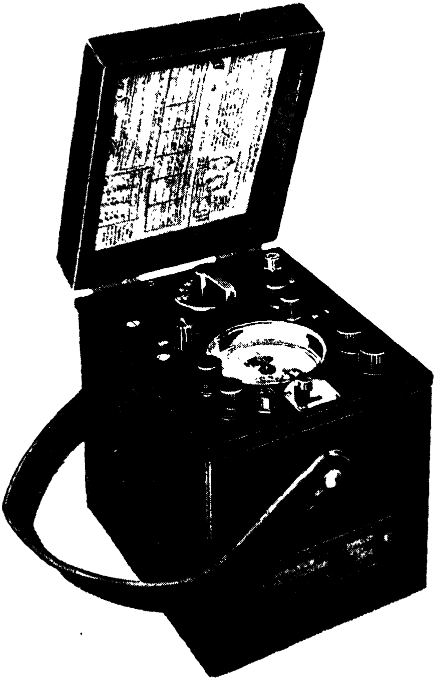
$$\therefore \text{ The nominal meter error} = \frac{N}{R \times M} \times 100\ \%$$

But the error of the sub-standard is E per cent.

$$\therefore \text{ The true meter error} = \frac{100 \,.\, N}{R \times M} + E\ \%$$

If no graduations are provided, then it is usual to run the sub-standard disc for twenty-five revolutions and estimate the error differences by the fact that one-quarter of a revolution represents 1 per cent error. This method of run-off is very useful as a quick means of getting a batch of similar meters approximately correct, even if the errors are afterwards measured by other means. This method is most useful with meters in which the removal of the cover does not affect the error curve erratically.

In the latter type of sub-standard the calculation is a little more difficult. In this case, the meter under test runs continuously, and the motion of the sub-standard is controlled by a quick-acting switch in its pressure circuit. The sub-standard is usually fitted with a dial-resetting device, which enables the pointers to be set to zero at the start of every test. This makes the testing easier, as it is not necessary for the tester to watch the sub-standard in order to determine the number of revolutions made by its disc. The load having been set and the sub-standard dial set to zero, the tester watches the meter under test and closes the switch the instant the timing spot passes a certain position. The meter disc is allowed to run for N revolutions before the switch is opened at the instant the timing spot passes the chosen position. Let the advance of the sub-standard dial show that its disc has revolved R times. (R is only rarely a whole number.) Let the R.P.U. constants of the meter and sub-standard be A_m and A_s respectively. The value of A_s will depend on the current and voltage ranges in use at the time of the test. If both the meter and sub-standard are perfect, then



(British Sangamo Co., Ltd.)

FIG. 145. SINGLE-PHASE ROTATING SUB-STANDARD

$$\frac{N}{R} = \frac{A_m}{A_s}$$

$\therefore$ R should equal $(N \times A_s)/A_m$

$$\therefore \text{ The nominal meter error } = \frac{(N \times A_s)/A_m - R}{(N \times A_s)/A_m} \times 100\ \%$$

But the error of the sub-standard is E per cent.

$$\therefore \text{ The true meter error } = \left(\frac{(N \times A_s)/A_m - R}{(N \times A_s)/A_m} \times 100\right) + E\ \%$$

Knowing how to determine the meter error, we can now explain the procedure in testing and calibrating A.C. meters.

A.C. W.H.M. TEST CARD

Maker	*X. Y. Z.*	Maker's No.	*999999*
		Corp. No.	*31333*
Amperes	*5*	Volts	*240*
R.P.U.	*2000*	kWs/rev. Constant	*1·8.*

Load	P.F.	kW	Rev.	Timing Constant	Sec.	% Error
Full	1·0 0·5 lag	1·2 0·6	40 20	60·0	60·3 60·0	0·5 – O.K.
¾	1·0 0·5 lag	0·9 0·45	30 15		60·1 59·9	0·2 – 0·2 +
½	1·0 0·5 lag	0·6 0·3	20 10		59·8 59·6	0·3 + 0·7 +
¼	1·0 0·5 lag	0·3 0·15	10 5		59·8 59·7	0·3 + 0·5 +
1/10	1·0	0·12	4		60·0	O.K.
1/20	1·0	0·06	2		60·4	0·7 –

Starting Current	*O.K.*	Creep Test	*O.K.*
Dial-test K.	*1·200*	% Error	*0·5 –*
Dial-test Rdg.	*1·194*		
Tester	*S. H. Worth*	Date	*9/9/35*

FIG. 146. TYPICAL SINGLE-PHASE METER TEST CARD

Single-phase Meters. 1. The meters are connected up and run on half-load whilst the test cards are being made out. A typical test card is shown in Fig. 146. If a R.S.S. is used, then the centre portion of Fig. 146 must be replaced by Fig. 147. Very often three-quarter, half, and one-tenth loads are omitted.

2. Full-load unity P.F. is switched on and the errors determined (see page 215). Where necessary, the meters must be adjusted, usually on a brake magnet, until the error is satisfactory. Only experience can decide what is a satisfactory error for a particular meter, but the working limits are usually within ± 2 per cent.

Load	P.F.	Approx. kW	$\frac{\text{S.S. r.p.u.}}{\text{Meter r.p.u.}}$	$\frac{\text{S.S. rev.}}{\text{Meter rev.}}$	Nom. % Error	S. S. % Error	Meter % Error
Full	1·0	1·2	$\frac{1000}{2000} = 0{\cdot}5$	$\frac{40{\cdot}4}{80}$	1·0 −	0·5 +	0·5 −
	0·5	0·6	$\frac{1000}{2000} = 0{\cdot}5$	$\frac{20{\cdot}1}{40}$	0·5 −	0·5 +	O.K.
$\frac{3}{4}$	1·0	0·9	$\frac{1000}{2000} = 0{\cdot}5$	$\frac{30{\cdot}1}{60}$	0·3 −	0·6 +	0·3 +
	0·5	0·45	$\frac{1000}{2000} = 0{\cdot}5$	$\frac{15{\cdot}0}{30}$	O.K.	0·7 +	0·7 +
$\frac{1}{2}$	1·0	0·6	$\frac{2000}{2000} = 1$	$\frac{40{\cdot}2}{40}$	0·5 −	0·4 +	0·1 −
	0·5	0·3	$\frac{2000}{2000} = 1$	$\frac{19{\cdot}9}{20}$	0·5 +	0·2 +	0·7 +
$\frac{1}{4}$	1·0	0·3	$\frac{2000}{2000} = 1$	$\frac{20{\cdot}0}{20}$	O.K.	O.K.	O.K.
	0·5	0·15	$\frac{2000}{2000} = 1$	$\frac{9{\cdot}95}{10}$	0·5 +	O.K.	0·5 +
$\frac{1}{10}$	1·0	0·12	$\frac{4000}{2000} = 2$	$\frac{8{\cdot}08}{4}$	1·0 −	0·5 +	0·5 −
$\frac{1}{20}$	1·0	0·06	$\frac{8000}{2000} = 4$	$\frac{8{\cdot}16}{2}$	2·0 −	1·0 +	1·0 −

FIG. 147. MODIFICATION OF FIG. 146, WHEN TESTING THE METER AGAINST A ROTATING SUB-STANDARD

3. Full-load 0·5 lagging P.F. is applied and the errors determined. If the error of a meter is unsatisfactory, the quadrature loop is readjusted until it is satisfactory. Unless a large alteration has been made, it will not be necessary to retest full load unity P.F. It is usual to limit the difference between the errors at unity and 0·5 lagging power-factors on any load to 2 per cent.

4. Twentieth load unity P.F. is now applied and the meter errors determined. Where necessary, the friction compensators must be adjusted to obtain the desired errors. If a large alteration is made, it will be necessary to retest 2 and 3.

5. Tenth-load unity P.F. is now tested. If the error on this load is out of limits, then the friction compensator must be readjusted until both one-twentieth and one-tenth load errors are within the limits.

6. Quarter-load unity P.F. is now tested. If the previous unity P.F. loads are within the limits, it is very unusual for the error on this load to be outside the limits.

7. Quarter-load 0·5 lagging P.F. is now tested. This is a critical load, as it is affected by all the adjustments. In general, the tester will know from experience how to set the errors on the other loads, so that the error on this load will be satisfactory. If, however, the error is outside the limits, it will rest with the tester's judgment whether to readjust the quadrature loop, brake magnet, friction compensator, or a combination of these in order to make the error satisfactory without putting the other errors outside the limits. After making such an adjustment, the meter must be completely retested.

8. Half-load unity P.F. is now tested.

9. Half-load 0·5 lagging P.F. is now tested. The errors on loads 8 and 9 are rarely out of limits if the previous loads are correct. If, however, they are out of limits, the meter adjustments must be altered accordingly until all the errors are within the limits. Experience shows that it is a waste of time to test three-quarter load, so this load is ignored.

10. If the meter errors are now all within the limits, the rotor can be tested for creeping on a voltage 10 per cent in excess of normal. If an adjustment is made to the friction compensator or anti-creep device, then twentieth load must be rechecked, and also one-tenth and quarter loads if the tester thinks it desirable. If the error on one or more of these loads is outside the limits when the meter is O.K. on creep, then it must be sent to the repair shop unless the fault is one which the tester can repair. The meter must be completely retested after such a repair.

11. Having successfully passed the above tests, the meters are then tested on starting current. This test shows up such faults

as iron in the disc and dirt in the gaps. The presence of iron in the disc can be detected by the jerky running of the disc when the iron is near the magnet. If such a fault is found and rectified, the meter must be retested.

12. There are two methods of dial-testing.

(*a*) The meter pointers are set to zero and then full-load unity P.F. is applied for one hour. In practice, the wattmeter pointer is held at the nominally correct reading, and a correction is made to the dial-test period to compensate for the wattmeter error, e.g. if the wattmeter error is + 1 per cent, then the dial-test period is made 36 sec. more than one hour. The advance of the meters should be within ± 2 per cent of (nominal kW × 1) kWh. Also the dial-test error must not be more than 1 per cent different from the corresponding disc-speed error. (If a one-hour run will not rotate the first dial pointer one revolution, then a longer dial test must be given.)

(*b*) A sub-standard meter is connected in series with the meters under test, and all the pointers are set to zero. A load is then applied, for which the errors of the sub. and meters are known. This load is maintained until the sub. has advanced by a suitable amount, i.e. $D \pm C$, where C is a correction to compensate for the error of the sub. The meter readings should be within ± 2 per cent of D and the dial-test errors within 1 per cent of the corresponding disc-speed errors.

13. The dial-test being satisfactory, the pointers are reset to zero and the I.R. is tested. If the latter is O.K., then the meters can be returned to the meter stores.

C.T.-operated Meters. In these meters the pressure and current coils are independent, and care must be taken to paint or mark the terminals clearly to avoid any danger of misconnection. The testing procedure is the same as for the directly connected meter. The secondary connections of the C.T. must not be disturbed when testing the meter for creeping. (See page 223 for P.T.-operated meter-testing instructions, and page 222 for testing without C.T.'s.)

POLYPHASE A.C. METERS

Three-phase Test *versus* the Single-phase Test. It cannot be claimed for any commercial polyphase meter that it is entirely free from interaction, and consequently the single-phase test is wrong in principle. It is granted, of course, that with meters reasonably free from interaction or with balanced interaction, the single-phase test can give satisfactory results, but nevertheless it is doubtful if some consumers would care to accept such a test in case of dispute.

The advantage of a 3-phase test is that the actual working conditions are reproduced in the meter. This is particularly important if the meter contains a motor-driven timing device. As there is no great difficulty in accurately measuring 3-phase power by the two wattmeter method, it follows that this test is a true one. The elements of the meter are also tested individually on single-phase for the purpose of balancing the elements (the pressure coils being supplied 3-phase as usual). Thus the performance of the meter on balanced or unbalanced loads will be known, whereas the ordinary single-phase test is no guarantee of the performance of the meter on a 3-phase load, whether it is balanced or unbalanced.

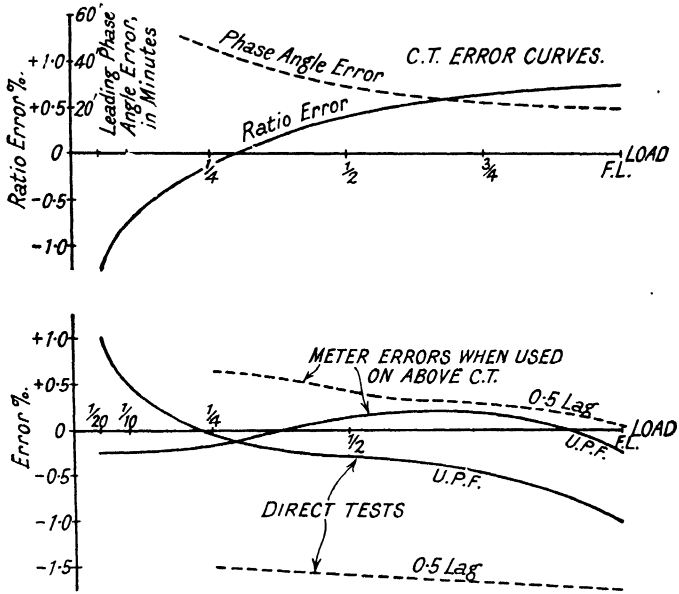


Fig. 148. Effect of Current Transformer Errors on a Meter Error Curve

The advantage of the single-phase test is that only one equipment is necessary for single-phase and polyphase meters, with a consequent saving in the capital cost of the meter test room.

Testing with Current Transformers *versus* Testing without. It is generally agreed at the present time that a current transformer-operated meter must be tested with its C.T.'s if reliable figures of the meter error are desired. The reader need not exercise much imagination to see the difficulty involved by trying to calibrate a meter to suit the ratio and phase-error curves of a C.T. or, worse still, of a group of C.T.'s with different errors.

If circumstances, however, compel the adoption of the latter method, the reader will find Fig. 148 useful. This figure indicates how the error curve of the meter must be adjusted, when tested direct, so as to compensate for the C.T. errors. If the load power-factor is cos ϕ, then the error due to the C.T. is given by

$$\text{C.T. ratio error per cent} - 100 \sin \lambda \,.\, \tan \phi$$

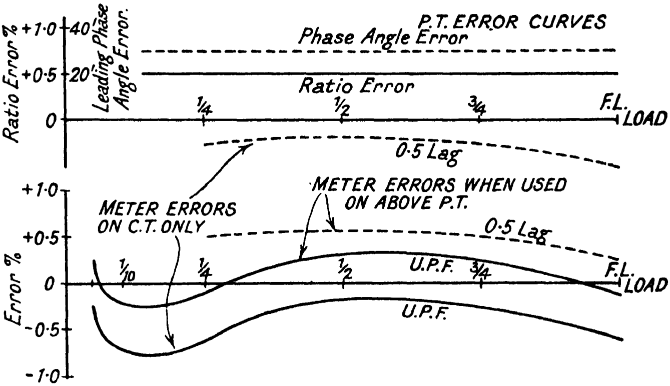


FIG. 149. EFFECT OF POTENTIAL TRANSFORMER ERRORS ON A METER ERROR CURVE

where λ is the C.T. phase angle error. At unity power-factor the second term is usually negligible. The C.T. errors must be those, of course, for the actual burden on which the C.T. has to work. This involves a difficulty in some cases, where the total VA burden cannot be actually measured, as the various VA burdens do not necessarily add up arithmetically, due to differences in power-factor of the various parts. The question of making the C.T. wiring burden equivalent to that on site, if the meters are tested with their C.T.'s, has already been discussed.

N.B. Meters should not be supplied from C.T.'s which also supply relays having variable tappings. The VA burden of such relays varies with the percentage tapping; and thus the C.T. errors, and hence the meter errors, vary with the relay tapping also.

Effect of Testing without P.T.'s. As the primary voltage applied to a P.T. is usually reasonably constant, it follows that the P.T.

errors will be constant for a particular secondary burden. Thus the errors of a P.T. do not vary with the consumer's load, as in the case of a C.T., and therefore a meter may be calibrated without its P.T.'s. The P.T. errors only alter the situation of the meter error curves relative to the zero line and not their shape, as will be seen from Fig. 149. The allowance for the P.T. errors is purely dependent on the power-factor of the load (balanced if three-phase) and not on its magnitude.

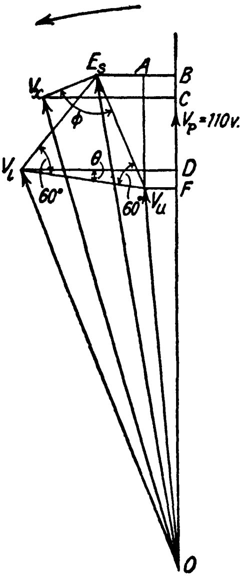


FIG. 150.
VECTOR DIAGRAM FOR DETERMINING POTENTIAL TRANSFORMER ERRORS

At unity power-factor (on a single-phase circuit) the effect of the phase angle error is negligible, and thus the error due to the P.T. equals its ratio error. As the P.F. decreases, the effect of the phase angle error increases according to the tangent law. Consequently if the phase angle error is λ, the error due to the P.T. at a power-factor of cos ϕ

$$= \text{Per cent ratio error} + \left(\frac{\cos(\phi - \lambda) - \cos\phi}{\cos\phi} \times 100\right)$$

$$= \text{Per cent ratio error} + 100 \,.\, \sin\lambda \,.\, \tan\phi$$

This formula applies to lagging and leading power-factors, if lagging angles are denoted by the negative sign and leading angles by the positive sign. Usually the phase errors are small enough to permit the use of the following rule to determine the percentage effect of the phase error on the meter at 0·5 power-factor, viz. divide the phase angle error, in minutes, by 20. It will be seen from the above formula that, on a lagging power-factor, a leading phase angle error causes a meter to under-register.

As it is not usually known at the time of purchase or test what burden will be placed on a P.T., it is best to obtain its errors on two or three particular burdens which will enable the errors at any other burden to be easily calculated. If only the errors for a certain service burden were known, it would be impossible to calculate the effect of altering the burden. The two most convenient test burdens are the rated VA at U.P.F. and rated VA at 0·5 lagging P.F., since the angle of 60° which is involved simplifies the calculations and also causes an appreciable change in the phase angle error. The calculations can be made, of course, if the errors for any two burdens are known, provided the P.T. characteristics follow a linear law. (Certain P.T.'s of poor design or faulty application do not follow this law, and in such cases tests at more than two special burdens become necessary in order to be able to determine the errors for the service burden.) The errors are best expressed by giving the actual secondary voltage for rated voltage applied to the primary, and the phase angle error in minutes. The vector diagram for determining the service errors is given in Fig. 150, where

V_p = primary voltage, compensated for P.T. ratio.
= 110, since we have assumed that rated voltage is applied to the primary.
V_u = secondary voltage at the rated VA burden at U.P.F.
V_l = secondary voltage at the rated VA burden at 0·5 lagging P.F.
E_s = secondary voltage at zero burden.
V_x = secondary voltage at the service burden.
$\angle V_pOV_u = \alpha$ = phase angle error at rated U.P.F. burden.
$\angle V_pOV_l = \beta$ = phase angle error at rated 0·5 lagging P.F. burden.
$\angle V_pOV_x = \lambda$ = phase angle error at service burden.
$\angle V_pOE_s = \psi$ = phase angle error at zero burden.
$\angle V_uV_lD = \theta$
$\angle V_xE_sV_u = \phi$ = phase angle of the service burden.

Perpendiculars are dropped from E_s, V_x, V_l, and V_u on OV_p, and from V_u on to E_sB. (The vector diagram does not explain, by the way, what is occurring in the P.T., it simply gives the derivation of E_s and V_x.) E_s is usually greater than V_p, because the secondary turns are greater than the nominal number determined by the nominal P.T. ratio. V_xE_s lags E_sV_u by about 80°, as this is the usual condition for a burden composed of meter pressure coils. Since the angles α, β, λ, and ψ are very small, it is quite in order to let OF equal OV_u, etc. The position of the triangle $V_uV_lE_s$ is determined by the phase angles α and β, and the lengths of OF and OD. (The vector diagram has been drawn out of proportion for obvious reasons.) The following calculations enable all the desired particulars to be obtained from the given test data.

$$V_uF = AB = V_u \,.\, \sin\alpha$$
$$V_lD = V_l \,.\, \sin\beta$$

$$\tan\theta = \frac{DF}{V_lD - V_uF}$$

$$V_lV_u = \frac{V_lD - V_uF}{\cos\theta}$$

$$\angle BE_sV_u = 60^\circ + \theta^\circ$$

$$BF = V_lV_u\,.\,\sin(60 + \theta)$$

$$E_sA = V_lV_u\,.\,\cos(60 + \theta)$$

$$\therefore\quad \psi : a = E_sB : V_lD$$

Thus the position of E_s is determined.

Now $V_xE_s : V_lV_u$ = service burden VA : rated VA burden.

$$\therefore\quad V_xE_s = \frac{V_lV_u \times \text{Service burden}}{\text{Rated burden}}$$

$$\therefore\quad BC = V_xE_s\,.\,\sin(180 - 60 - \theta - \phi)$$

$$V_xC = E_sB + V_xE_s\,.\,\cos(180 - 60 - \theta - \phi)$$

$$\therefore\quad \lambda = \frac{V_xC}{V_lD}$$

$$\therefore\quad OV_x = E_s - BC$$

Thus the errors at the service burden are obtained. If ϕ is not definitely known, it is usually sufficiently accurate to assume 80° in the case of meter coils.

We now require to determine the effect of two P.T.'s having different errors, on the operation of a two-element polyphase meter, the effect in the case of a single-phase meter or element having been already explained. If the load is unbalanced, then each element must be treated on its own merits as a single-phase meter and the overall effect obtained from a weighted (according to the power on each element) average of the two individual errors. If the load is balanced, or reasonably so, the following method is quicker and less likely to cause mistakes. Let the P.T. errors be

$R - Y$ . . . 0·6 + and 22′ +
$B - Y$ . . . 0·4 − and 10′ +

∴ Error due to the P.T.'s at a U.P.F. load

$$= \frac{(0{\cdot}6) + (-0{\cdot}4)}{2} + \frac{(\cos - 30^\circ\ 12' - \cos - 30^\circ)}{2\,.\,\cos - 30^\circ} \times 100$$

$$= (0{\cdot}1) + (-0{\cdot}1)$$

$$= \text{Zero}$$

The reasoning is this. The common phase-angle error of 10′ is negligible, but the excess of 12′ on the red element must be allowed for in the usual manner. At U.P.F. on a balanced load the red element is providing half the total torque, hence the factor ½ in the second expression above. It is also working at a power factor of 0·866 lag. As each element is providing an equal torque, the mean of the ratio errors must be taken.

Error due to the P.T.'s at a 0·5 lagging P.F. load

$$= -0{\cdot}4 + \left(-\tfrac{10}{20}\right) + (-0{\cdot}4)$$
$$= -1{\cdot}3$$

The reasoning this time is that since the blue element is providing almost all the torque, only the $B - Y$ ratio error should be taken into account. The common phase-angle error of 10′ is allowed for by the simple rule given on page 224, the error being negative, since the phase error is a leading one. The excess phase-angle error of 12′ + on the red element (which should be at zero lag) causes that element to exert a reverse torque equivalent to 0·4 per cent of the torque due to the blue element—hence the minus sign. An inspection of the cosine tables reveals that cos 90° 12′ equals − 0·0035, which equals 0·4 per cent of 0·866, i.e. cos 30°, the power factor at which the blue element operates when the load power factor is 0·5 lag. The $R - B$ errors are determined from the $R - Y$ and $B - Y$ errors as follows—

$R - B$ ratio error
= the mean of the $R - Y$ and $B - Y$ ratio errors, plus 86·6 sin [($B - Y$) phase error − ($R - Y$) phase error]

$R - B$ phase error
= the mean of the $R - Y$ and $B - Y$ phase errors, plus $\sin^{-1}$ (0·866 [($R - Y$) ratio error − ($B - Y$) ratio error]

In the case of polyphase P.T.'s it is best to test at the actual working burden, but if the tester is compelled to calculate from the errors at rated burdens he will find much useful information in the following papers: "Instrument Transformers," by A. Hobson, p. 147, Vol. 91, Part 2, April, 1944, *J. I. E. E.*, and "The Graphical Determination of the Errors of a Three Phase Voltage Transformer with an Unbalanced Burden," by T. Waterhouse, p. 281, April, 1944, *Metropolitan-Vickers Gazette.*

We can now proceed to describe the method of calibrating polyphase meters. The following methods assume that the meters are tested against wattmeters, but if a rotating sub-standard is employed, the necessary modifications will be clear from the discussion on page 216. Owing to the rarity of two-phase meters, no space is devoted to the testing of such meters, but the method of procedure, however, should be quite clear to a tester who understands the principles of testing three-phase meters.

For a Three-phase, Three-wire Watt-hour Meter. 1. The meter is conveniently mounted on the meter bench of a three-phase testing equipment, and connected to the appropriate pressure and C.T. inter-connector terminals. The C.T.'s are placed on the C.T. table, and the primaries and secondaries suitably connected in phase and polarity to the current output terminals and C.T. interconnector terminals. It is good practice to arrange the C.T.'s so that the lower number is in the red line and the higher in the blue line. Beyond the C.T.'s the phases are commoned. (The change in connections in the case of a directly connected meter will be obvious to the reader at this stage.) Great care must be taken when making the C.T. secondary connections to ensure good contacts. The equipment is then made alive and the meter put on quarter-load, whilst the test sheet (see Fig. 151) is being made out and the meter inspected. In the case of a repaired meter, the internal coil connections may be wrong, and this point requires checking before commencing the calibrations. This is done by disconnecting the red and blue pressure connections in turn. If the power-factor of the three-phase circuit is unity and the load is fairly balanced, then each element should give a forward rotation of the rotor. If one element gives a backward rotation, then either the pressure coil or series coil of the corresponding element must be reversed. Before altering such a connection, the tester should verify the fact that his bench and C.T. connections are quite correct.

The rotor is then tested on voltage only to see that it is not creeping, either backward or forward.

If the meter is fitted with an M.D.I., then this also must be wired up and the self-contained driving motor, if any, made alive during the tests. This is essential, as the stray field of the motor affects the accuracy of the lower loads considerably. If the M.D.I. is put in gear by a small solenoid with an external tripping device, it is necessary to have it working during the calibrating period. The friction pointer should be well up the scale, whilst the disc speed of the meter is being tested.

2. Balanced full load at U.P.F. (unity power-factor) is now applied and the meter timed. The brake magnet is adjusted, if necessary, until the error is reasonably near O.K. The error is worked out as described on page 215. The methods of determining the kW loading are described below.

POLYPHASE WATTMETER. This is a simple operation, and no more difficult than with a single-phase wattmeter. In this case the red and blue kW columns on the test sheet are left blank, as they are not determined separately. The wattmeter error is allowed for in the manner described on page 215.

TWO SINGLE-PHASE WATTMETERS. The load holder maintains the reading of the blue wattmeter at a definite figure, and the tester reads the red wattmeter before and after timing the meter.

POLYPHASE W.H.M. TEST CARD

Maker....*X Y Z*.... Maker's No.....*110000*.... Phase....*3*.... Volts....*6600/110*....

Type .... *Q* .... Corp. No..... *99000* .... Wire....*3*.... Amperes.... *50/5* ....

R.P.U.........*4*....... Dial K............ *10*........... Frequency................*50*...............

kWs/rev. *900* Testing kWs/rev. = *15* M.D.I. K. *1* M.D.I. Period *½ hr.*

C.T. Numbers	P.T. Numbers	P.T. Errors
R__*1000*___	R__*201*__	R_*0·1 + 8′ +*
Y__ – ___	Y__ – __	Y___ – ___
B__*1001*___	B__*202*__	B_*1·1 + 8′ +*

Overall P.T. Err., U.P.F. *0·6 +* 0·5 Lag *0·7 +*

Load	A.	P.F.	Red L.T. kW	Blue L.T. kW	Total L.T. kW	Rev.	Timing Constant	Sec.	% Error	Correct % Error	DIAL-TEST
F.L.	50	1·0 0·5 lag	4·675 0·095	4·795 4·725	9·470 4·820	40 20	63·4 62·2	63·4 63·0	O.K. 1·3 –	0·6 + 0·6 –	Red L.T. kW _______*4·810*_______ Blue L.T. kW_______*4·895*_______ Total L.T. kW_______*9·705*_______ Time__*1 hr.*__kWh = *9·705* × *60* × *1* = *582·3* Dial Advance = *58·2* × *10* % Error_______*0·1 –*_______ Correct % Error_______*0·5 +*_______
¾	37·5	1·0 0·5 lag	3·525 0·080	3·745 3·585	7·270 3·665	30 15	61·9 61·4	61·9 62·0	O.K. 1·0 –	0·6 + 0·3 –	
½	25	1·0 0·5 lag	2·38 0·135	2·40 2·39	4·78 2·525	20 10	62·8 59·4	62·8 59·5	O.K. 0·2 –	0·6 + 0·5 +	
⅕	10	1·0 0·5 lag	0·904 0·016	0·960 0·912	1·864 0·928	8 4	64·4 64·7	64·9 64·1	0·8 – 0·9 +	0·2 – 1·6 +	
1/10	5	1·0	0·4665	0·480	0·9465	4	63·4	64·0	0·9 –	0·3 –	
1/20	2·5	1·0	0·2275	0·240	0·4675	2	64·2	64·6	0·6 –	O.K.	

UNBALANCED LOAD TEST

Element	A.	P.F.	L.T. kW	Rev.	Timing Constant	Sec.	% Error
R	50	1·0 0·5 lag	5·5 2·75	22 11	60·0	59·4 60·2	1·0 + 0·3 –
Y	—	—	—	—	—	—	—
B	50	1·0 0·5 lag	5·5 2·75	22 11	60·0	59·6 60·5	0·7 + 0·8 –

M.D.I. TEST

Load	Total kW	M.D.I. Reading	% Error	Correct % Error
Full	9·705 × 60	580	0·4 –	0·2 +
⅕	1·805 × 60	107	1·3 –	0·7 –

Destination. Messrs. Shiner, Ardath St., Renton. *Remarks.* Test after complete overhaul.

Starting Current Test...........*O.K.*........... Creep Test...........*O.K.*........... I.R. Test...........*O.K.*...........

Tester...........*S. Warth*........... Date...........*11/1/35*........... Checked...........*J. T. T.*...........

FIG. 151. TYPICAL POLYPHASE WATT-HOUR METER TEST SHEET, WHEN TESTED AGAINST WATTMETERS

See Figs. 146 and 147 for modification of above when using Rotating Sub-standards.
Also note that the meter is tested at ⅕ load and not ¼ load in this case for convenience.
Half and three-quarter loads are often omitted.

Usually these two readings are the same, but if the difference is small, the mean reading is used for calculation purposes. If the difference is large, the meter must be retimed after the load has been made steady. The percentage correction (or scale correction in the case of zero lag) of each wattmeter is known for the current and power-factor at which it is being used, and is allowed for in the following way—

	Red W.M.	Blue W.M.
Scale reading	99·2	100
Correction	− 0·7	+ 0·2
Corrected reading	98·5	100·2
Wattmeter multiplier	0·2	
True kW	19·7	20·04
Total kW	39·74	

The wattmeter (if scaled in watts) multiplier is given by—

W.M. scale multiplier × Sub-standard C.T. ratio ÷ 1000.
The correction = − (% error × scale reading).

If the meter is operated from ring type C.T.'s in which more than one turn has been inserted to obtain the requisite primary effect, then the above wattmeter multiplier must be multiplied by the number of turns, to obtain the equivalent testing kW. The method of getting at the wattmeter errors is more fully discussed on page 271.

An alternative way of allowing for the wattmeter errors, if the testing equipment is readily controllable, is to adjust the load so that the wattmeter pointers are at the corrected readings of certain arbitrarily selected nominal kW values which give simple figures for the timing constants. This simplifies the timing procedure considerably, since the wattmeter errors are already compensated for, and the simple timing constants enable the timing errors to be easily converted to percentage errors.

$$\text{The kWs per rev. constant} = \frac{3600}{\text{R.P.U.}}$$

If the meter is used but not tested with P.T.'s, then the kW/s rev. constant for the purposes of calibrating the meter is given by

$$\frac{3600}{\text{R.P.U.} \times \text{P.T. ratio}}$$

Thus the timing constant is given by

$$\frac{\text{Tester's kWs/rev. constant} \times \text{rev.}}{\text{kW}}$$

The kW, revolutions, timing constant, and the meter timing are entered on the test sheet as shown in Fig. 151.

3. The meter is now tested on unbalanced loads in order to equalize the torques of the two elements and to adjust the quadrature devices. Which element is done first depends on the judgment of the tester. Suppose the red element is done first.

No current is passed through the blue C.T., but the secondary connections are not disturbed or any change made to the pressure coil connections. The red element is then tested on full load at U.P.F. and 0·5 lagging P.F. Only the red wattmeter (or red element in the case of a polyphase wattmeter) is in use during these two tests. The quadrature loop is adjusted, if necessary, on the lagging load, so as to obtain a certain difference between the unity P.F. and 0·5 lagging P.F. timings which the tester knows from experience to be desirable. Care must be taken when altering the quadrature loop not to alter its degree of eccentricity (if any). The latter change alters the friction compensating torque and, owing to the low speed of the disc when testing 0·5 lag on one element, it has an appreciable effect which would confuse the tester's reasoning.

The same procedure is then gone through with the blue element. In this case the red C.T. primary is dead. These two sets of timings are not entered yet into the columns provided on the test sheet, as various alterations may be necessary.

The tester now reviews these timings to see if the balance adjuster requires attention. The difference between the corresponding loads on the two elements must not be greater than 1 per cent, although it is usually found that the meter gives the best results if the difference is less than ½ per cent. If an adjustment is made, it should be done very carefully, because if it is made unsymmetrically the meter is apt to be faulty on creep. On some meters the adjustment affects both elements, and consequently a complete retest is necessary after the adjustment. On others the elements can be altered separately, and it rests with the tester's judgment and knowledge of the meter as to which element he alters. In the latter case it is only necessary to retest the altered element, unless the adjustment is very big.

(The unbalanced load errors are usually within the limits, but, if necessary, the limits can be extended to ± 3 per cent for certain poor types of polyphase meters.)

4. The elements having been correctly adjusted, the tester again applies balanced full-load U.P.F. and times the meter.

If necessary, the brake magnet is adjusted until the desired timing is obtained.

The final sets of balance figures obtained in (3) are corrected for the change in brake-magnet position, if this is small, and the corrected figures are entered in the appropriate spaces (see Fig. 151). If the change is large then the unbalanced loads must be retested.

In the case of a P.T.-operated meter, the tester must know the errors of the P.T.'s before he can calibrate the meter correctly.

The methods of allowing for the P.T. errors have already been discussed, and the tester must calibrate a H.T. meter so that when the nominal errors are corrected the final errors will be within the limits.

5. The meter is now tested on balanced full-load 0·5 lagging P.F. If the quadrature loops have been set correctly in operation (3), the error on this load will be as desired. If, however, the tester knows the error to be unsuitable, it is necessary to return to operation (3) and readjust the quadrature loops. If the error is within the limits and the tester has had no previous experience of this type of meter, he must carry on with the following operations and take a chance on having set the loops so as to suit all the remaining loads.

6. The load is now reduced to one-twentieth at U.P.F. and the meter timed. If the error is out of limits, or undesirable, the friction compensators must be adjusted until the error is satisfactory.

7. The rotor is now tested for creeping when the voltage is raised 10 per cent above normal. If the mechanical condition of the meter is good, the meter will be O.K. on this test. Excessive friction, too great a load on the rotor, or faulty setting of the anti-creep device will cause the meter to creep. The remedy is obvious. If the mechanical condition of the meter is altered or the friction compensators adjusted, then operation (6) must be repeated. If the error on one-twentieth load is now out of limits, the meter must be sent to the repair shop for overhaul, unless the tester can make the necessary alteration or repair.

8. The voltage is now reduced to normal and two-hundredth load U.P.F. applied. The rotor should start and run continuously on this load. This test shows up such faults as incorrect gearing, iron in disc, or dirt in the gaps which have not made themselves apparent in the previous tests. If such a fault is removed, then (6) and (7) must be repeated, and the compensating device readjusted if necessary.

9. The previous tests having been satisfactorily completed, the meter is tested on the following loads: one-tenth at U.P.F.; ¼ at

U.P.F. and 0·5 lagging P.F.; ½ at U.P.F. and 0·5 lagging P.F.; and ¾ at U.P.F. and 0·5 lagging P.F.

If the magnet, quadrature loops, and friction compensators were set correctly during operations (1) to (8), then the remaining loads will be within the limits, provided the correct grade of C.T.'s and meters are employed.

It is usually found that ¼ load 0·5 lagging P.F. is the critical load owing to the large C.T. ratio and phase errors at this load. If the tester finds that the error is out of limits he must reconsider carefully the full-load and one-twentieth load errors before making any readjustment. Sometimes a readjustment of the brake magnet will bring all the errors within the limits. On other occasions it will be necessary to go back to operation (3) and readjust the quadrature devices or perhaps the balance of the two elements. In the first case it will not be necessary to retest creep or starting current, but in the latter case a complete retest is essential.

10. When (9) has been completed, the meter is ready for dial test. This test may be done in three ways—

WHEN USING A POLYPHASE WATTMETER. The nominal balanced full load at U.P.F. is applied, and then switched off whilst the dial pointers are set to zero (except in the case of a cyclometer counter which is read). The load is then switched on for one hour ± a correction to compensate for the error of the wattmeter. (The load holder maintains the wattmeter deflection at the chosen figure, which is a whole number of divisions.) The kWh are then numerically equal to the kW, and the error is determined as shown on page 190. The true kWh, meter-dial reading and dial-test error are entered on the test sheet, as shown in Fig. 151.

WHEN USING TWO SINGLE-PHASE WATTMETERS. Balanced full load at U.P.F. is applied, and then switched off whilst the pointers are set to zero. (See previous remark *re* cyclometer counters.) The load is then switched on, and the load holder maintains the deflection of the blue wattmeter at a definite figure for one hour exactly. During the hour the tester takes the reading of the red wattmeter every 10 min., and the mean reading is used for the purpose of determining the total kW, as shown on page 229. The kWh are then numerically equal to the total kW and the error is obtained in the usual way. (Note the abovementioned alternative of holding the wattmeter readings to certain corrected values.)

WHEN USING A ROTATING SUB-STANDARD. Balanced full load at U.P.F. is applied and then switched off whilst the pointers are set to zero. The sub-standard is usually fitted with a pointer resetting device, which enables this to be done very easily. The load is then switched on and left until a suitable dial advance has been obtained.

The corrected reading of the sub-standard is the true kWh constant, and the error of the meter is obtained in the usual way.

N.B. In the case of a H.T. meter, the L.T. kWh must be multiplied by the P.T. ratio in order to obtain the dial-test kWh constant. One hour has been given as the dial-test period in the above method, but this must be increased if one hour at full load will not rotate the first pointer of the counter one revolution.

11. If the meter is fitted with an M.D.I., it is tested during the dial-test. It is essential to make the dial-test long enough to enable sufficient consecutive M.D.I. periods to be checked. For example, if the tripping device has an hour dial and has four pins, then the dial-test period must be at least 1¼ hours.

The error of the M.D.I. must not be greater than ± 2 per cent, and it must be within 1 per cent of the disc-speed error of the load on which the test is conducted.

There are many types of M.D.I. mechanism, and they must be wired up during test according to the needs of the tester. Some important points to watch are given below—

SELF-CONTAINED MAXIMUM DEMAND INDICATORS. These require no extra wiring as a rule. If the meter is tested on an equipment with an individual power supply, it is necessary to make the frequency the same as that of the undertaking's mains. This is very important if a synchronous motor is used to provide the time periods.

TIME SWITCH-OPERATED TRIPS. Where the time switches are tested by a department separate from the meter room, it is the usual practice for the tester to control the M.D.I. periods by a simple tumbler switch. This avoids unnecessary handling of time switches and complicated circuits in the test room.

If a number of M.D.I. meters (with external choke or resistance) of a similar type are tested together, then the coils may be connected in series and all operated by one control switch. Only one choke coil or resistance box need then be used. If an internal resistance or choke is fitted to each meter, only one control switch is required to operate all the relays.

The switching must be done so as to allow the correct number of seconds between the consecutive periods. This interval will depend on the type of time switch used, and is better underestimated than over-estimated.

If desired, the M.D.I. is also tested at ¼ load in a similar way to that given above.

12. The insulation resistance of the meter coils is now tested. Some undertakings also employ a flash test of 1,000 or 2,000 volts.

These tests being satisfactory, the meter is returned to stores after attending to the following details—

(*a*) All pointers of the meter set to zero.

(*b*) The meter C.T. and P.T. numbers clearly written inside the terminal cover.

(*c*) The meter and C.T. terminals correctly painted. (It is not usual to paint the P.T.'s, except for polarity, until they are in position on the consumer's premises owing to the varying types of P.T. chambers.)

(*d*) The meter and C.T.'s clearly labelled for the benefit of the storekeepers and meter-fixers.

(*e*) Any special markings, such as " Day, Night, Total, Special," etc., to be painted in a conspicuous position on the meter.

(*f*) After firmly securing the cover of the meter, the M.D.I. resetting device must be tested for correct operation. When the sealing wire is in place it should not be possible to touch the M.D.I. friction pointer in any position it may take.

These having been attended to and the meter sent to the stores, the tester makes a neat copy of his rough pencil test sheet, using black and red ink. The latter is used for the errors only. The figures and calculations are checked by another tester before the inked test sheet is sent to the office for book-keeping purposes. The rough sheet is kept in the test room for reference purposes.

For a Three-phase, Four-wire, Two-element Meter. The testing procedure is the same as that for a three-wire meter, except in the way the elements are tested for balance in operation (3). Suppose the red element is tested first. To do this the red C.T. primary only is energized (see page 209 for a simple switching arrangement for this purpose) and the red element of the measuring equipment is supplied with the appropriate pressure, viz. red to neutral voltage. The meter C.T. secondary connections are not disturbed in any way and the red element is then tested at full-load U.P.F., and full load 0·5 lagging P.F.

When the blue element is tested, the blue C.T. primary only is energized and the blue element of the measuring equipment supplied with the blue to neutral pressure. Tests at the previously mentioned loads are taken.

The tester now reviews the timings obtained and decides whether the balance adjusters require attention. If an adjustment is made, then one or both elements must be retested according to the type of adjusting device.

In order to check the yellow C.T. (or the yellow series coils in the case of a directly connected meter) it is necessary to energize the yellow current element only (from the red and yellow phases) and supply both meter pressure coils with a common pressure, say, red to neutral pressure. Tests are made at full-load U.P.F.

and full-load 0·5 lag, the measuring equipment being connected as for testing the red element. The meter loading will be twice the single-phase load measured by the sub-standard. Owing to the difference in rotor speed, interaction, and pressure coil connections, the tester should not expect these timings to balance closely with the previous unbalanced load timings. The test shows up, however, if any radical fault exists in the yellow current element. Also see page 318 for further comments.

Having completed these tests satisfactorily, the proper C.T. primary connections are restored and operation (4) commenced.

For a Three-phase, Four-wire, Three-element Meter. Again, the procedure is the same as for a three-phase three-wire meter, except for operation (3). The tests in this case are quite straightforward, although the balance adjustments are not, as a rule, easy to make. Each element is tested on full load at U.P.F. and 0·5 lagging P.F., the quadrature loops being altered as the tester thinks fit. The voltages on the meter are not altered during these tests. The methods of altering the pressure connections of the measuring equipment and the meter C.T. primary connections have already been explained.

From the three sets of timings the tester can determine whether any balance adjustments are necessary. The altered elements, if any, must be retested, after which operation (4) is commenced.

Testing Polyphase Meters on Single-phase Circuits. It has been shown by Mr. O. Howarth that the majority of the interaction in a two-element polyphase meter is due to the stray flux of the two pressure coils, and that it is possible to find two simple expressions for this interaction as follows—

Torque due to the stray red-pressure coil flux acting on the blue element

$$= K\,(E_R I_B \cos\phi_1)$$

Torque due to the stray blue-pressure coil flux acting on the red element

$$= L\,(E_B I_R \cos\phi_2)$$

where E_R = red pressure coil voltage.
E_B = blue pressure coil voltage.
I_R = red current coil current.
I_B = blue current coil current.
K and L = constants.
ϕ_1 = phase difference between E_R and I_B.
ϕ_2 = phase difference between E_B and I_R.

The values of K and L are determined in the following manner: Full load at U.P.F. is applied to the blue element, and the red pressure coil is supplied with the blue pressure. The meter is timed and the percentage error determined. The leads to the red pressure coil are then reversed and the percentage error of the meter again determined. The difference between the two errors equals $(2K) \times 100$.

The value of L is similarly determined. Care must be taken to perform the test the same way each time, as L may be either positive or negative with respect to K.

Thus the torque due to interaction is given by

$$R = K \,.\, E_R \,.\, I_B \,.\, \cos\phi_1 + L \,.\, E_B \,.\, I_R \,.\, \cos\phi_2$$

If we consider a 3-phase 3-wire meter working on a balanced load of standard phase rotation which has a power-factor of $\cos a$, then

$$\begin{aligned} R &= EI\,[K \,.\, \cos(90 - a) + L \,.\, \cos(270 - a)] \\ R &= EI\,[K \,.\, \sin a - L \,.\, \sin a] \\ &= EI \,.\, \sin a \,.\, [K - L] \end{aligned}$$

Now the true torque on the rotor for zero error is $\sqrt{3} \,.\, EI \,.\, \cos a$.

Therefore the percentage effect of interaction is equal to

$$\frac{E \,.\, I \,.\, \sin a \,.\, [K - L]}{\sqrt{3} \,.\, E \,.\, I \,.\, \cos a} \times 100$$

$$= \frac{100\,(K - L)\tan a}{\sqrt{3}}$$

If the phase rotation is non-standard, then the above expression becomes

$$\frac{100\,(L - K)\tan a}{\sqrt{3}}$$

These expressions also apply to the 3-phase 4-wire two-element meter.

Clearly if K equals L, then the effect of interaction on a balanced 3-phase load is negligible. If the load is unbalanced, then the error will depend on the power-factor and the numerical value of K or L.

From the above method of determining K and L, it follows that the best way of calibrating a two-element meter on a single-phase circuit is as follows —

1. General instructions regarding meters under test will be found in Chapter X.
2. Each element is tested individually on full load at U.P.F. and 0·5 lagging P.F. The quad loops and balance adjusters are arranged so that the errors for each element are approximately

the same on corresponding loads, and that the correct difference between the U.P.F. and 0·5 lagging P.F. errors is obtained. [The errors need not be within the limits at this stage.]

3. Both elements are now loaded (see Fig. 152) and tested at full load at U.P.F. If necessary, the brake magnets are adjusted so as to obtain the desired disc-speed error. The errors in (2) are corrected for such brake-magnet alteration and entered on the test sheet.

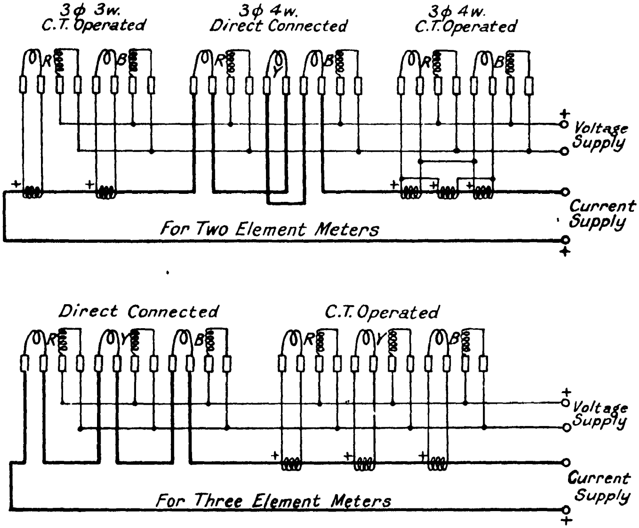


FIG. 152. CONNECTIONS FOR TESTING POLYPHASE METERS ON SINGLE-PHASE CIRCUITS

4. After switching off the load, the pressure and current leads to one element are reversed, and the meter again loaded and timed on full load at U.P.F. The disc-speed error is again worked out.

5. The mean error is calculated, and this is taken as the error of the meter on a 3-phase balanced load, and it is this mean error which should be within the limits. It is the mean error which is entered up on the test sheet. The reader will understand now why the single-phase test is only suited to meters where K is approximately equal to L. Taking the mean error on the single-phase test overcomes the effect of interaction, but if K does not equal L this does not give a true reflection of the error on a

three-phase balanced load, when the interaction would not be negligible.

6. The meter is now tested at full-load 0·5 lagging P.F. in the manner indicated above for obtaining the mean error. If operation 2 was correctly done, then no further adjustment will be necessary.

7. The meter is now tested to obtain the mean error on one-twentieth load at U.P.F. If necessary, the compensators must be adjusted until the mean error is within the limits.

8. The current coils are made dead, and a voltage 10 per cent in excess of normal is applied to the pressure coils. The rotor is now tested for creeping. If any alteration is made, then operation No. 7 must be repeated.

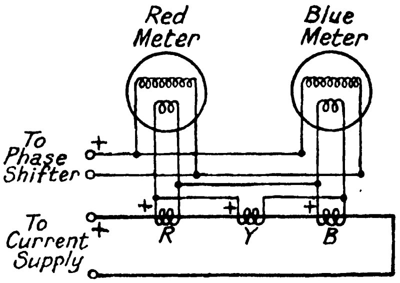


Fig. 153. Testing Connections for Two Single-phase Meters for a 3-phase 4-wire Supply

9. The voltage is now reduced to normal, and two-hundredth load at U.P.F. is applied. The rotor should start and run continuously on this load.

10. The meter is now tested on one-tenth load at U.P.F., one-quarter load at U.P.F. and 0·5 lagging P.F., and one-half load at U.P.F. and 0·5 lagging P.F. If the adjustments have been made correctly, then the mean errors will be within the limit. If any readjustments are necessary, it will rest with the tester's judgment as to which loads require retesting.

11. The dial-test is done at full-load U.P.F., care being taken to compare the dial-test error with the appropriate disc-speed error. (See page 232 for particulars of dial-testing.)

12. See page 234 for information regarding the returning of meters to stores.

It is not advisable to test three-element meters, or meters containing a motor-driven timing device, on single-phase circuits as it is difficult, if not impossible, to estimate the nature or the amount of the interaction in such meters. If, however, the tester is compelled by circumstances to use a single-phase testing circuit, then he must proceed as follows—

THREE-ELEMENT METER. Each element is timed individually on full load at U.P.F. and 0·5 lagging P.F. The quad loops and balance adjusters are altered until the elements are balanced and the desired differences between the unity and lagging errors are obtained.

The meter is now connected as shown in Fig. 152 and tested in the same manner as a single-phase meter, except that the kW loading of the meter is three times the kW loading of the wattmeter. If the brake magnet is readjusted, then the unbalanced load timings must be altered accordingly, or retested.

This test is only a compromise, and the single-phase errors are no guarantee of the performance of the meter on a 3-phase circuit.

METER CONTAINING A MOTOR-DRIVEN TIMING DEVICE. The meter is first tested with the motor out of action in the manner described above.

The effect of the motor being in action is then determined on one-tenth load U.P.F., the motor winding being connected in turn in each of the two possible ways. The tester must use his judgment as to whether he needs to alter any of the meter adjustments as a result of the data obtained from these two tests. The best thing to do is to try and leave the errors on the safe side (i.e. negative) in order to avoid the danger of a disputed account.

Testing Single-phase Meters for Use on Polyphase Circuits. FOR THREE SINGLE-PHASE METERS MEASURING A 3-PHASE 4-WIRE SUPPLY. The meters are tested individually as single-phase meters, as described on page 219.

FOR TWO SINGLE-PHASE METERS MEASURING A 3-PHASE 3-WIRE SUPPLY. As above.

FOR TWO SINGLE-PHASE C.T.-OPERATED METERS MEASURING A 3-PHASE 4-WIRE SUPPLY. These are tested single-phase with the C.T.'s connected, as shown in Fig. 153. The load on each meter will, of course, be twice the nominal single-phase load.

It is desirable to check the operation of the meters on a 3-phase circuit before shipping them, and this is done in the following way. The meters and C.T.'s are connected upon a 3-phase testing equipment, as they will be in service, and the desired load put on the meters. The meters are timed simultaneously whilst the load is held steady. From the timings the kW on each meter can be calculated, and the sum of the two should equal the true total kW within 2 per cent. The number of loads tested will depend on the tester's judgment and knowledge of the meter and C.T. characteristics.

CHAPTER XV

TESTING SPECIAL METERS

kVARh Meters. The majority of sine meters are adaptations of cosine meters, and consequently they are fairly simple to calibrate. The elements are first connected as for a cosine meter and the meter tested by one of the methods described above. The connections are then altered to suit its normal use as a sine meter. Its accuracy as a sine meter can be tested in the following ways—

1. The kVA loading is calculated from the readings of ammeters and voltmeters in the requisite phases, and the kW loading obtained from the wattmeter or wattmeters. From these two figures it is easy to calculate the power-factor, and thence the reactive kVA with the help of the sine and cosine tables. The meter is then timed and its error determined. This is done at a sufficient number of loads and power-factors to ensure that the sine meter is accurate at all working parts of the curve. The permissible errors are larger than for a cosine meter, i.e. ± 3 per cent instead of ± 2 per cent.

Starting current, creep and dial-test are preferably done whilst the meter is connected as a cosine meter.

2. In the case of a 3-phase testing equipment employing two single-phase wattmeters, there is an alternative way of calculating the reactive kVA, provided the load is accurately balanced. From the corrected readings of the two wattmeters, the power-factor can be calculated as shown on page 105. From this and the kW loading, the kVA and the reactive kVA can easily be calculated with the aid of the trigonometric tables. The meter is tested on the loads mentioned in (1).

3. Another method is to supply the wattmeters (or wattmeter elements) from a quadrature transformer, such as the one described on page 82, and thus measure the reactive kVA direct.

kVAh Meters. In the case of the summator type of kVAh meter, the cosine and sine meter portions are first calibrated separately. The accuracy of the summator is then tested in the following manner. The meter is connected up on a 3-phase testing equipment and loaded so as to reproduce the working conditions. As the summator can only be checked by dial-testing, it is necessary to do a dial-test on full load U.P.F., full load 0·86 lag, full load 0·5 lag, ¼ load U.P.F., and ¼ load 0·5 lag. The dial-test period must be long enough to give a readable advance of the dial pointers and also long enough to include at least two

M.D.I. periods—a kVAh meter is invariably associated with a M.D.I. If the M.D.I. time switch is of the motor-driven hour-dial type, then the setting of the pins must be checked by making one of the full-load dial-test periods extend over a sufficient number of consecutive M.D.I. periods. The methods of determining the kVA have already been explained on page 240.

In the case of the polyphase Hill-Shotter type of kVA M.D.I., the testing procedure is as follows—

1. The M.D.I. is connected up so as to reproduce working conditions. The train wheels are then counted to work out the constant B, i.e. the number of disc revolutions to give 360° scale deflection of the pointer. B is marked on the dial in the form $360° = 1{,}600$ rev. The angular deflections ($Y°$) from zero of five or six cardinal kVA points are then measured by a special protractor (home-made if necessary) and entered on the test sheet. For each of these points the theoretical disc speed is calculated from the relationship.

X kVA corresponds to $Y°$ or $\dfrac{Y \times B}{360 \times 1{,}794}$ rev. per sec. for a 30 min. interval.

The figure 1,794 is obtained by subtracting the T.Sw. tripping period from 30 min. expressed in seconds. If the M.D.I. period is different from 30 min., then the figure 1,794 is altered to suit. Thus, although the M.D.I. does not possess a R.P.U. constant like a kWh meter, there is nevertheless a definite connection between the disc speed and the corresponding scale reading.

2. The elements are now tested for balance of torque (within 1 per cent) and the M.D.I. train checked to ensure the coincidence of the zero positions of the main wheel, driving arm, and friction pointer.

3. The kVA loads corresponding to the above points are now applied, and the actual revolutions per second timed with a stop-watch. If any point disagrees with the calculated figures by more than ± 2 per cent of full-scale reading, then the brake magnet is adjusted until all the points are within the limits.

4. The M.D.I. is then given an actual dial test on one or two loads to verify that everything is working correctly. The dial test error will not agree exactly with the disc speed error because of the square-law scale (e.g. at quarter scale 1 per cent dial error corresponds to 2½ per cent disc speed error), but due allowance is made for this helpful feature. If the M.D.I. is fitted with voltage compensators, it is usual to accept the maker's settings, and rely on an operation test and the fact that the above test would be done at the working voltage.

An alternative method is simply to dial test the M.D.I. on the desired loads to find the errors, but it will be appreciated that the time required will be much greater. The suggested method also has the merit that it definitely ensures a good mechanical job. Owing to the square-law scale, any backlash in the zero settings will seriously affect the lower scale errors, so it is most important to test a low scale point as well as a high one.

In the case of the over-quaded type of kVAh meter, the tests are conducted in the following manner—

1. The meter is connected up on a 3-phase test bench in the same way as the corresponding type of cosine meter. The elements are tested for balance in the manner described for the cosine meter, except that the power-factor of the loads will be cos X lagging and cos $(60 + X)$ lagging instead of unity and cos 60 lagging respectively. X is the angle of over-compensation.

2. Balanced 3-phase full load at a power-factor of cos $(X - A)$ is applied and the meter error determined. (See page 240 for information regarding the calculation of the kVA.) The disc-speed error is calculated in the same manner as for an energy meter, except that in the various equations kVA is substituted for kW. Angle $2A$ is the range of phase angle for which the meter is supposed to be a kVAh meter.

The error is also determined for the power-factors cos X and cos $(X + A)$. If the errors are not within the limits, the adjustment must be altered and all the above tests repeated.

3. Twentieth load at power-factor cos X is applied and the friction compensators altered, if necessary, until the error is within the limits. The limits for this type of meter are, of course, wider than for the ordinary kWh meter, as will be appreciated from the discussion on page 90.

4. The meter is tested on creep and starting current in the same way as a cosine meter.

5. The above tests being satisfactory, the meter is tested on the following loads: One-tenth load at P.F. cos X, $\frac{1}{4}$ load at P.F. cos $(X - A)$, $\frac{1}{4}$ load at P.F. cos $(X + A)$, $\frac{1}{2}$ load at P.F. cos $(X - A)$, and $\frac{1}{2}$ load at P.F. cos $(X + A)$.

6. If all the disc-speed errors are within the limits, the meter is now dial-tested at full load at P.F. cos X. The dial-test error must be within the usual limits. The M.D.I. is also tested during the dial test.

7. See pages 163 and 234 for general data regarding the testing and returning of a meter to stores.

N.B. It is essential when testing kVAh and kVARh meters to make sure that the testing currents and voltages do not contain any appreciable harmonics, or otherwise errors will be introduced.

Flat Rate Prepayment Meters. The watt-hour or ampere-hour portion is first tested in the ordinary way (the P.P. mechanism being in gear). Then the P.P. mechanism is usually tested in the following manner—

The credit is used up by running the kWh counter by hand after disconnecting the kWh train from the disc spindle by a suitable mechanical release, such as the removal of the top pin, or by the special clutch provided for that purpose. The kWh reading is then noted, and a coin passed through the meter—or the equivalent if the coin chute is on the cover. The credit is again used up (slowly at tripping point) until the switch just trips. The kWh advance should agree with the price calibration of the meter, e.g. if the price per unit is 4d. and the coin was a penny, then the dial advance should be 0·25 kWh.

This test is repeated a number of times to make sure that the tripping device is reasonably consistent and that the average error over a number of tests is very small. If required, the test can also be done for other numbers of coins. It will be obvious that the errors for single coin insertions will be more subject to variation than for multi-coin insertions, owing to the reduced distance of travel of the tripping cam. The average consumer, however, usually operates on the basis of single coin insertions, and it is therefore essential to avoid serious discrepancies in the units received per coin even though the meter may be 100 per cent accurate over, say, 100 coins. Whilst errors up to ± 5 per cent are passable on single coin tests, the average accuracy over four or five coins should be within ± ½ per cent. The tests are especially important for new meters or meters which have had a change of price compound.

If a meter does not satisfy the above tests, the cause must be found and remedied. It is not usual to put any errors on the test card or book for the P.P. mechanism test, since it is found in practice that if the gears are correct, then the error of the meter over hundreds of coins is *nil*. Thus, the purpose of the P.P. mechanism test is simply to establish the correctness of the gear wheels and the consistency of the tripping device.

It is most important to ensure, before the meter is sent to the stores, that the credit pointer accurately reads zero when the switch trips out and that all the dials are at zero reading.

Some engineers believe, however, that the tests should be done electrically. In this case the procedure is similar to that given above, except that the tripping is done by running the meter on full load (or overload) and that fewer coin tests are taken on account of the time factor. It is on account of the latter point that the average error limits have to be widened to ± 1 per cent, which makes the method compare unfavourably with the hand test quite apart from the question of labour costs.

Where large numbers of meters are to be tested, electrically, the simple series circuit makes the testing procedure very troublesome, as it is not easy to determine which meter has tripped. Furthermore, a testing method is desirable which does not require the continual presence of a tester and which does not require all the meters to pass out together. If a testing circuit is built to suit the latter case, then the meter dial test must be carried out with the curve test as for an ordinary meter, and the coin tests alone done on the special P.P. test bench. A circuit (current only) suitable for this purpose is shown in Fig. 154, and it will be seen that the meter series coils are connected to tappings on a special resistance. (If the current rating of the resistance is very liberal, it follows that the testing current may be adjusted to suit different capacities of meters.) Thus the tripping out of a meter does not seriously affect the running of the other meters, as the total testing current then flows through the resistance at that point until a further coin is inserted or a fresh meter put in its place. A ballast resistance is used to prevent the tripping of meters seriously reducing the testing current during an all-night run.

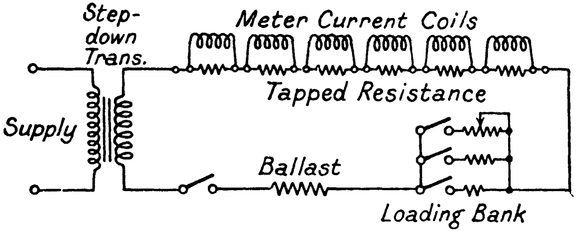


FIG. 154. SPECIAL PREPAYMENT METER TESTING CIRCUIT (CURRENT ONLY)

With the above equipment the tester need only visit the bench periodically to attend to those meters which have tripped during his absence. The loss of time due to non-running of meters is thus reduced to a minimum. Further, the equipment may be left running during the night, so that by the morning all the meters will have tripped out and be ready for readings.

Double Tariff P.P. Meters, Current C-O Type. These have to be tested in the above manner (by hand) on each of the gear-box settings and, in addition, it is necessary to check the functioning of the change-over device to make sure that it is operating correctly with change of load current.

The method of testing the time change-over type of double tariff P.P. meter will be clear from the above remarks.

Two-part Tariff P.P. Meters, Fixed Rate Type. A complete test of this type of meter would involve the following tests in addition to the usual meter tests.

1. The speed of the time element is checked. This applies more particularly to the type of meter using the Ferraris disc motor.
2. The coin mechanism is tested with no load on the meter, but the time element working.
3. The coin mechanism is tested with the time element stopped and the meter working on about full load.
4. The coin mechanism is tested with both elements working.

This procedure would take far too long and, in practice, the following tests are found to be sufficient.

(*a*) The meter element is tested in the usual manner.

(*b*) The price per unit gearing is checked by hand, as previously described. The running—if any—of the time element does not matter owing to the shortness of the test.

(*c*) The fixed charge gearing is tested by *electrically* tripping the P.P. mechanism and then inserting a coin or coins so that it will require from 24 to 80 hours to run off this credit. Suppose the time is 50 hours. The test is run for 49 hours, and any meter which has tripped is over 2 per cent in error. The test is then carried on for another 2 hours. Any meter which has not tripped at the end of the 51 hours is also over 2 per cent in error. The faulty meters must be overhauled and then retested, although in many cases the test is repeated before attempting an overhaul.

Two-part Tariff P.P. Meters, Variable Rate Type. This type of meter is tested as follows—

1. The coin mechanism accuracy is checked in the usual way with the fixed charge pointer at zero.
2. The fixed charge mechanism is then checked by setting up its pointer to some particular value and inserting coins until the pointer reaches zero. The number of coins inserted should then correspond with the fixed charge wiped off, plus the credit indicated on the credit index (the credit being initially at zero).

No error limits have been specified for the above special types of P.P. meters, as there are no recognized values extant. It rests with the tester's judgment whether the results obtained are satisfactory enough to pass the tests, but the error limits given for the flat rate meter will provide some guide in this matter.

Disputed Account Meters. If a consumer disputes the accuracy of his meter, there are three courses open to him—

1. A check meter may be installed. This method is not to be advocated on H.T. or heavy current A.C. circuits, unless ring-type C.T.'s are used for the check meter, since it is difficult to insert wound-type C.T.'s in an existing circuit. Its chief advantage is that the meter is checked under working conditions both as

regards situation and loading, and that the consumer's meter is in no way disturbed.

2. The meter may be removed and tested in the undertaking's test room. See page 313 for the effect of the Meters Act.

3. The meter may be removed and tested by an independent authority, such as the National Physical Laboratory.

It is usual to arrange an agreement based on the test results, as to who will bear the cost of the investigation before removing the meter or inserting a check meter. If the meter is measuring a large supply, the consumer or his representative must be present when the meter is removed and also during the testing operations. In cases where the amount at stake is only small, as with most domestic consumers, it is usual for them to trust the testing department to give the meter an honest test.

To avoid people making unnecessary demands for a test on their meter, they are called upon to pay a deposit (5s. to 10s.) before the meter is tested. If the mean error exceeds 2½ per cent fast, the consumer receives back the deposit plus the amount by which he has been overcharged during the last quarter. If slower than 2½ per cent fast, then the consumer loses his deposit.

When the meter equipment is received in the test room, it is tested on the loads specified for normal routine testing. No seals, except those on the terminal block or the M.D.I., must be touched. One method of working out the mean error is as follows. The meter is supposed to run for an equal length of time on each load, and the resulting dial advance is calculated, taking into account the meter errors. The percentage difference between the calculated dial advances and the dial advance if the meter was perfect is called the mean proportional error.

In the case of an M.D.I. meter, it must be tested with the accessories actually used on the consumer's premises. The M.D.I. is tested on the approximate maximum load used by the consumer, and sufficient consecutive periods must be tested if the timing device is of the hour-dial type.

The treatment of a meter which creeps on pressure only is discussed on page 285.

Sample Meters. Before buying a new type of meter, a supply undertaking usually obtains one or two samples and subjects them to a very searching test. In this way the good and bad qualities of the meter are discovered, and they enable the meter engineer to say whether the meter is suitable or not for the conditions in the undertaking. The test is conducted in the manner described below—

1. The meter is first tested to determine its "As Received" errors without any preliminary run whatever. The test should be commenced at one-twentieth load.

2. After being on load, say, quarter load, for several hours, the "As Received" errors are again determined. These two tests will show up the amount of the self-heating errors.

3. If one or more of the errors are out of limits, the reason must be found, e.g. bad calibration, etc.

4. The extent of the adjustments are now determined by placing them in their maximum and minimum positions. The meter must be tested on full-load (both U.P.F. and 0·5 lagging P.F. in the case of A.C. meters) and twentieth load after each variation, in order to see how the adjuster affects other loads, in addition to the one with which it is primarily concerned.

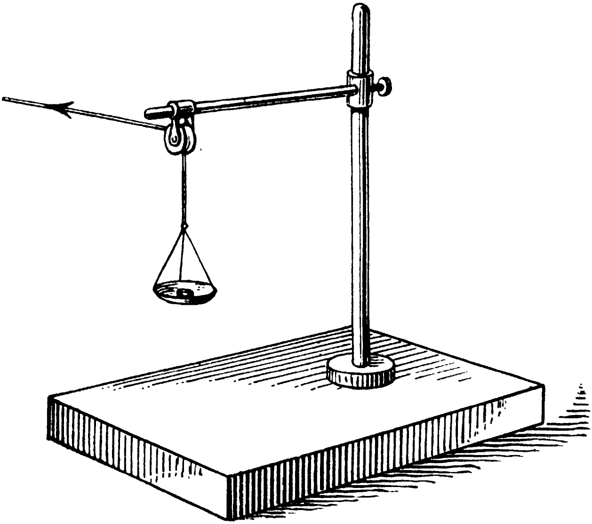


Fig. 155. Gravity Type Torque Measurer

5. If possible, the rotor (if any) is removed and weighed. After replacing the adjusting devices and rotor in their normal positions, the full-load torque of the meter is measured. The torque may be measured directly by means of a smooth-running pulley and weights, as shown in Fig. 155, or it may be measured by means of a spring-controlled pointer like the one illustrated in Fig. 156. In each case care must be taken to see that the thread is at right angles to the line joining the point of attachment to the centre of the rotor spindle, and that the thread does not foul any intermediate object. Another point to watch is that

the method of attaching the thread to the rotor should not involve using any iron owing to the danger of the magnetic fields creating a torque due to its presence.

The instrument reading gives the actual pull P, in grammes weight, along the thread when balance has been obtained. If R cm. equals the radius of action of the thread, then the torque equals PR grm. cm. If the weight of the rotor is W grm., then the torque weight ratio is $\frac{PR}{W}$.

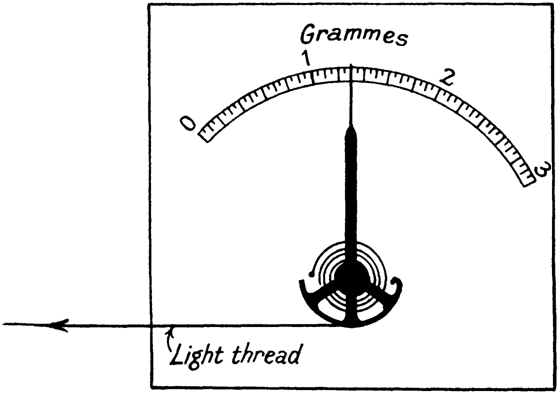


FIG. 156. SPRING TYPE TORQUE MEASURER

6. The meter is now calibrated so as to obtain the best possible error curve. Fortieth load is also tested after the meter is calibrated.

7. The losses in the meter on full load are carefully measured.

8. The insulation resistance is measured both between windings and from windings to case.

9. In the case of a watt-hour meter, the effect of voltage variation is found by giving the meter a complete test at voltages 10 per cent above and below the normal voltage.

10. The effect of temperature variation is now determined by testing the meter at three or four different steady temperatures. From these results the temperature coefficients of the meter can be calculated. (In the case of A.C. meters, the coefficient varies with the power-factor.) See page 179 for the description of a temperature cupboard. When doing these tests, the tester must be careful to avoid the results being affected by the self-heating errors as far as possible.

11. The errors of the meter on 50 per cent and 100 per cent overloads are now obtained.

12. The effect of a very severe overload is then determined, and the best way to do this is to apply four or five times full load for one or more minutes.

If possible, the error at this overload is determined. The period for which this load is maintained will depend on the construction of the meter. Some meters will carry this load indefinitely and also be reasonably accurate, whereas others would have the insulation ruined in a little over a minute. The tester maintains the overload as long as he thinks fit, and takes particular notice if the meter shows any signs of distress.

The error of the meter on full load is carefully determined immediately before and after the overload, and also one or two hours after the overload. This enables the tester to see if the overload has any immediate or lasting effect on the calibration of the meter.

13. The effect of the meter cover on the calibration is measured by timing the meter on full load, first with the cover firmly secured, then with the cover slack, and finally, with the cover off.

14. All the above data are entered up in a concise manner on a test report, together with the following items—

(*a*) One or two drawings of the meter.

(*b*) Details of the marking of the counter and its method of gearing.

(*c*) Details of the bearings.

(*d*) Statement as to the accessibility of the meter, e.g. whether the rotor can be removed without altering the calibration, etc.

(*e*) The weight of the meter in pounds.

(*f*) Special features, both advantageous and disadvantageous, discussed with particular reference to the needs of the testing department.

In addition to the above routine, there are certain special tests to be made in the case of particular types of meters. Some of these are described below.

Polyphase A.C. Meters. The amount of the interaction between the elements must be measured in the manner shown on page 235.

The extent of the adjustment provided by the balancing device must be determined.

If a motor is used to drive the M.D.I. timing mechanism, then the effect of reversing its connections must be measured at full load and twentieth load.

Three-wire D.C. Meters. The effect of unbalanced loads must be investigated, and also the facilities, if any, afforded for balancing the elements.

D.C. Mercury Meters. If the meter is fitted with a fluid friction compensator, then the effect of a reverse current (giving reverse rotation) must be obtained by timing the meter on all the usual loads. The difference between the forward rotation error curve and the backward rotation error curve will indicate the amount of the fluid friction compensation.

Prepayment Meters. The coin mechanism should be given an exhaustive test in order to investigate thoroughly the action of the tripping device, and to determine if the P.P. mechanism is sufficiently strong, reliable, and accurate.

Generator Acceptance Tests. When a large steam-driven generator set has been supplied to an undertaking and put into commission, it is usual to conduct an acceptance test. If the performance is not good enough, the set may not be accepted or the manufacturers may be penalized under the terms of the contract. Small generator sets are tested, as a rule, at the manufacturers' works under the inspection of a representative of the undertaking.

The metering equipment is given a full test on all the usual loads before being installed in the power station, as it is impossible for the station engineer to specify beforehand the exact loads at which the test will be conducted.

The meter engineer is notified by the station engineer of the capacities of the main generator and the various auxiliaries. It is usual to measure the output of the main generator by the two-wattmeter method, as well as by a watt-hour meter. The wattmeters may or may not be operated from the same instrument transformers as the W.H.M., according to the opinion of the meter engineer.

The energy given out or taken by the A.C. auxiliaries is measured by induction W.H.M.'s, and the D.C. auxiliaries by ammeter and voltmeter, since the load is kept reasonably steady during the testing period.

In many cases the manufacturer also installs a similar equipment for the main generator, for checking purposes.

The station engineer also informs the meter engineer of the approximate temperature of the room and, if possible, the main instruments are tested at this temperature. The main W.H.M. should also be tested at one or two other temperatures, in order to determine the value of the temperature coefficients. If these are appreciable, the reading of the W.H.M. will have to be corrected if the room temperature is different from that at which the W.H.M. was tested. The indicating wattmeters should be little affected by the change in temperature.

In order to co-ordinate all the readings, it is necessary to have signal lamps and a signalling code. After the generator has been under load for some time, the station engineer arranges the controls so as to obtain the desired load and power-factor as determined by the testing department's wattmeters. The load having become steady and arrangements made for the other generators to absorb the varying parts of the station load, the warning signal is given for the assistants to get ready.

When the starting signal is given the various assistants, armed with previously prepared tabulated sheets, commence their sequence of readings. This sequence is repeated every 5, 10, or 15 min., according to the nature of the data required, the correct times being signalled to the assistants by the lamps. The electrical readings are conveniently taken at quarter-hour intervals. The length of the test period will depend on the method of measuring the steam input, but at least one hour should be provided.

From the various readings the energy input to the turbine and the energy output to the mains, and the various auxiliaries, can be calculated. The overall efficiency is given by—

$$\frac{\begin{array}{c}\text{Energy supplied to the mains and station services}\\ \text{not directly associated with the generator set during}\\ \text{the test period}\end{array}}{\begin{array}{c}\text{Energy supplied from the boilers to the generator}\\ \text{set plus energy supplied from external sources}\\ \text{during the test period}\end{array}} \times 100$$

The above scheme is repeated for the other loads which require investigation.

CHAPTER XVI

TESTING OF SHUNTS, CURRENT TRANSFORMERS AND POTENTIAL TRANSFORMERS

Shunts. The most satisfactory method is to use a Kelvin double bridge in conjunction with standard shunts. The bridge, standard shunts, and the shunt to be tested are wired up as shown in Fig. 157. The bridge is usually arranged in the manner shown by Fig. 157 and, when balance has been obtained, the resistance of the shunt is given by $R \times \frac{\text{Multiplier}}{\text{Divisor}}$. A universal shunt is used with the galvanometer for its protection from violent treatment during the early stages of the balancing.

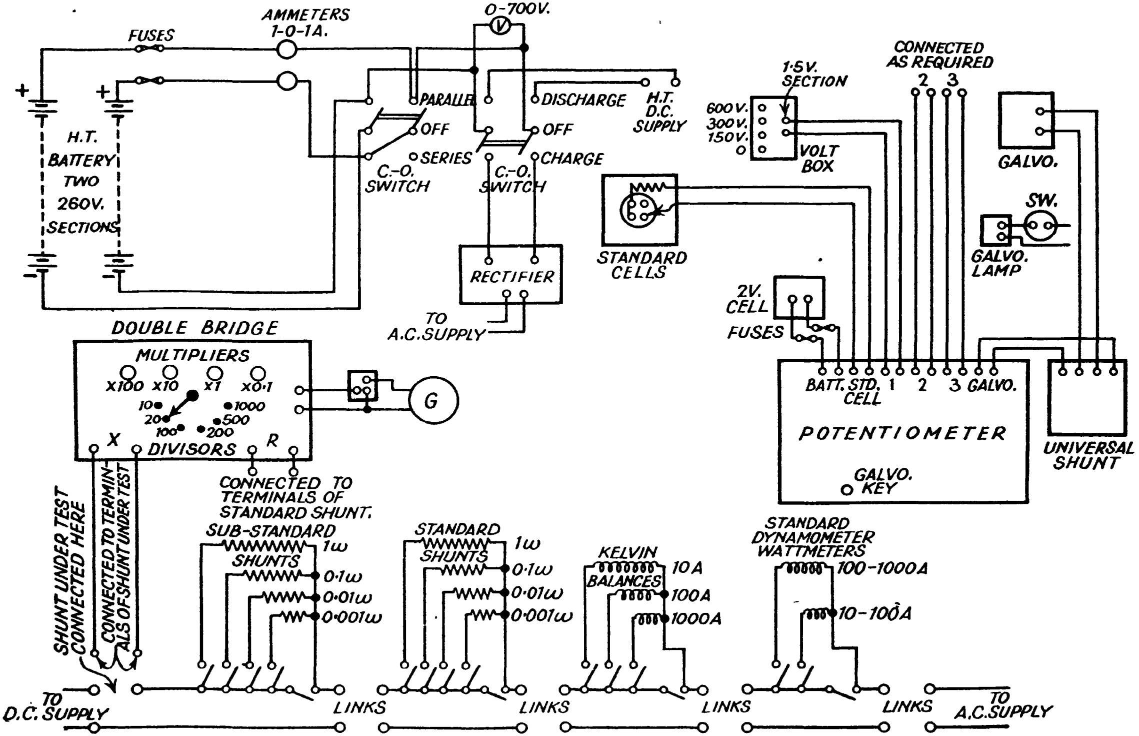
The standard shunts are preferably of the oil-cooled type, which have been standardized by the N.P.L. These are usually kept in the laboratory and wired up to a selector switch. Means should be provided for easily connecting them in circuit with other apparatus, such as dynamometer wattmeters, since they have many standardizing uses.

If the meter department does not possess a Kelvin double bridge, then the shunt must be checked against a standard shunt by means of a potentiometer. The potentiometer is used to measure the volt drop across each shunt when they are carrying the same current. This current is regulated until the volt drop across the standard shunt indicates that a certain chosen current is flowing—usually the rated current of the shunt under test. It is essential that the current be quite steady, or accurate results will not be obtainable. The volt drop across the shunt under test is then measured. From this reading and the known shunt current the resistance of the shunt can be calculated.

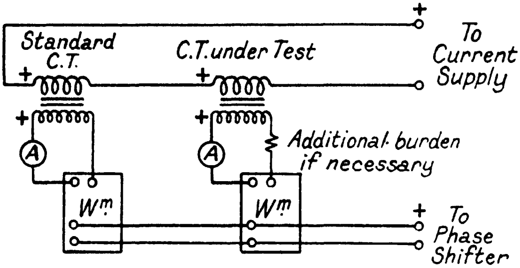
If a considerable amount of shunt testing is to be done, then it is advisable to calibrate some sub-standard shunts by the oil-cooled standard shunts and to use the sub-standards for routine work. The sub-standards must, of course, be checked periodically against the secondary standards, as they are not usually quite stable in resistance value.

CURRENT TRANSFORMERS

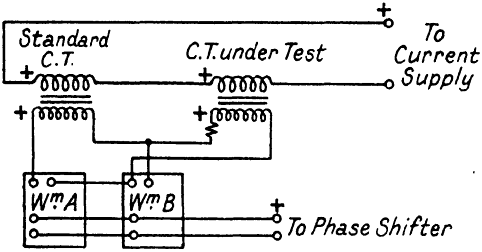
There are numerous methods of testing C.T.'s, and it is only possible to discuss in this chapter those of practical importance to the average tester. For the more refined methods, the reader is referred to the various I.E.E. papers on this interesting subject.


FUSES
AMMETERS 1-0-1A.
0-700V.
V
+
+
H.T. BATTERY TWO 260V. SECTIONS
-
-
PARALLEL
OFF
SERIES
C.-O. SWITCH
DISCHARGE
OFF
CHARGE
C.-O. SWITCH
H.T. D.C. SUPPLY
RECTIFIER
TO A.C.SUPPLY
1·5V. SECTION
600 V.
300 V.
150 V.
0
VOLT BOX
CONNECTED AS REQUIRED
2
3
GALVO.
SW.
GALVO. LAMP
STANDARD CELLS
2V. CELL
FUSES
BATT. STD. CELL
1
2
3
GALVO.
POTENTIOMETER
GALVO. KEY
UNIVERSAL SHUNT
DOUBLE BRIDGE
MULTIPLIERS
X100
X10
X1
X0·1
10
20
100
200
500
1000
X
DIVISORS
R
G
CONNECTED TO TERMINALS OF STANDARD SHUNT.
SHUNT UNDER TEST CONNECTED HERE
CONNECTED TO TERMINALS OF SHUNT UNDER TEST
SUB-STANDARD SHUNTS
1ω
0·1ω
0·01ω
0·001ω
STANDARD SHUNTS
1ω
0·1ω
0·01ω
0·001ω
KELVIN BALANCES
10A
100A
1000A
STANDARD DYNAMOMETER WATTMETERS
100-1000A
10-100A
TO D.C. SUPPLY
LINKS
LINKS
LINKS
LINKS
TO A.C.SUPPLY

Wattmeter Comparison Method. If the testing department possesses a polyphase equipment of the type described in Chapter XIII, it is easy to test a C.T. by connecting it up in the manner shown in Fig. 158. The advantage of this test is that it is generally applicable, whereas many methods depend on having a C.T. of equivalent ratio to the one under test. It has the disadvantage, though, that the errors cannot be measured to a high degree of accuracy (ratio within ± 0·2 per cent and phase angle within ± 5 min. under the best conditions), owing to the difficulties in reading the wattmeters and allowing correctly for the various errors. By replacing the wattmeters by two very good induction meters, the accuracy of the measurements may be raised, but naturally the tests take up much more time. The advantage of the wattmeter method is that it utilizes existing testing equipment for C.T. testing.



WATTMETER COMPARISON METHOD.



SPILL-OVER METHOD.

FIG. 158. COMPARISON METHODS OF TESTING CURRENT TRANSFORMERS

The wattmeter connected to the C.T. under test should have (where possible) a current rating or range corresponding to the secondary current of the C.T. The common pressure supplied to the two wattmeters should have such a value as will enable high scale readings to be obtained both on unity power-factor and 0·5 lagging power-factor tests. All the various errors of the two wattmeters and the sub-standard C.T. must be accurately known to obtain reliable results. (It is possible to manage without knowing the absolute wattmeter errors, provided one knows the comparative errors and the true errors of the sub-standard C.T.) It is not sufficient merely to know that the various errors are within $\pm \frac{1}{4}$ or $\pm \frac{1}{2}$ per cent. The testing procedure is as follows—

(*a*) Full-load current I is passed through the C.T. under test (this may or may not be the full-load current of the standard C.T.) and a suitable voltage V is applied to the two wattmeter pressure coils. The power-factor is then adjusted to unity, and the load holder adjusts the reading of the standard wattmeter to the desired value, which is $\dfrac{I \times V}{\text{Standard W.M. Constant}}$ corrected for the overall (see page 270) errors of the standard C.T. and its associated wattmeter. The tester reads the test C.T. wattmeter when the load holder signals that his reading is steady at the desired value. The reading of the test C.T. wattmeter is then corrected and the result should be

$$\frac{I \times V}{\text{C.T. Nominal Ratio} \times \text{Test C.T. W.M. Constant}}$$

From these two figures the error of the C.T. under test may be easily calculated. Let this error be U per cent.

(*b*) The power-factor is now adjusted to 0·5 lagging, and the load holder adjusts the reading of the standard wattmeter to $\dfrac{I \times V}{2 \times \text{Standard W.M. Constant}}$, corrected for the overall errors of the standard C.T. and its associated wattmeter. The tester reads the test C.T. wattmeter when the load holder signals that the load is steady. This reading is corrected and the result should be

$$\frac{I \times V}{2 \times \text{C.T. Nominal Ratio} \times \text{Test C.T. W.M. Constant}}$$

Let the error worked out from these figures be L per cent.

Since the ordinary C.T. has a leading phase angle error on the usual type of burden, then L should be more positive than U. If L is found to be more negative than U, it means that either the accuracy of the test is insufficient or that one or more of the C.T. turns must be short-circuited. (This statement only refers to non-compensated C.T.'s.) In the latter case the C.T. must be rewound, but to determine if the test results are reliable, a number of similar C.T.'s may be tested first.

(*c*) U is known as the "ratio error" of the C.T., since the phase angle error does not appreciably affect this test. The phase angle error in minutes is given by 20 $(L - U)$, since a change of 1° causes a change of 3 per cent in the value of the cosine function in the region of 60°, i.e. $\cos 60° = 0{\cdot}5$ and $\cos 59° = 0{\cdot}515$.

(*d*) The C.T. is now tested in a similar way for the other loads which require checking. The B.S.S. requirements for C.T.'s are given on page 258.

Spill-over Method. If the tester has a sub-standard C.T. of similar ratio to the one under test, a more accurate method (with suitable wattmeters) of testing is to employ the circuit shown in Fig. 158. Wattmeter A is used to indicate the test conditions, whilst wattmeter B measures the difference current of the two secondaries. If the two C.T.'s are identical in ratio and phase angle errors, then there will be no flow of current in B, since the easier path for the secondary current is the series path through the two windings. If the two currents differ, then a current equal to their vector difference will flow through the current coil of B. (This statement assumes that the current coil impedance of wattmeter B is sufficiently low to avoid upsetting the working conditions of the C.T.'s. The difficulty in this respect is that, usually, the lower the current rating of a wattmeter, the higher is its impedance.) The spill-over current is measured and the errors determined as follows—

1. After setting the load current, the phase shifter is adjusted until the power-factor is unity, as determined by wattmeter A, and the reading of B taken (the pressure coil being reversed if necessary). An advantage of this test is that the load can be unsteady without seriously affecting the reading of B. If the reading of B is forward, it means that the standard C.T. is providing the greater current, and *vice versa.* It will be noted that the polarity and connections of B correspond with those of A. If the ratio error of the standard C.T. is S per cent for the load concerned, then the ratio error of the C.T. under test equals

$$S - \frac{\text{Corrected reading of } B \text{ in watts} \times 100}{\text{Corrected reading of } A \text{ in watts}} \text{ per cent,}$$

the reading of B being positive if forward, and *vice versa.*

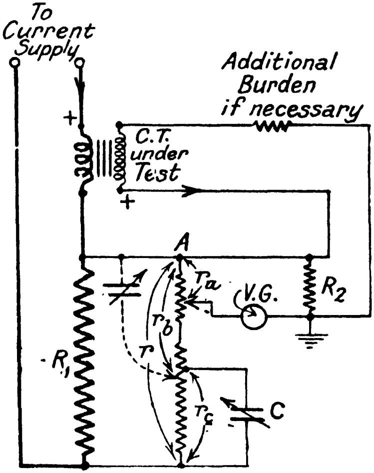
2. The phase shifter is now adjusted until zero lagging power-factor is obtained on wattmeter A. Wattmeter B is then read, the pressure coil being reversed if necessary, and the reading corrected. If the reading is forward, with the specified connections, the phase angle error of the standard C.T. is more leading

than that of the C.T. under test, and *vice versa*. Thus the phase angle error of the C.T. is given, in minutes, by

$$P - \frac{\text{Reading of } B \text{ in watts}}{0{\cdot}00029 \times \text{Reading of } A \text{ in watts, at U.P.F.}}$$

if P equals the phase angle error of the standard C.T., and the reading of B is given the appropriate sign.

3. The C.T. is now tested in a similar manner at the other required loads.



(*By permission of the I.E.E.*)

FIG. 159. POTENTIAL DIVIDER BRIDGE CONNECTIONS FOR C.T. TESTING

Potential Divider Bridge Method. In this method[1] the circuit used is that shown in Fig. 159. R_1 is of such a value that the voltage drop is 2 volts at the rated primary current of the C.T. under test. R_2 is 0·1Ω, thus causing a volt drop of 0·5 volt if the secondary current is 5A. The resistance r is 200Ω and the tapping point of the vibration galvanometer is variable, and in the region 48 to 52Ω from A if ratio errors up to ± 4% are to be measured.

The amount of capacity required depends on the phase angle

---

[1] For a more complete description, see "Precision Testing of Current Transformers," by A. H. M. Arnold, Ph.D., in the *I.E.E. Journal*, Vol. lxviii, July, 1930.

of the C.T. and that of the standard shunt. If the secondary current leads the voltage drop across the shunt R_1, the capacity is connected so that r_c is 136·1Ω. In this position and with a frequency of 50, then 0·01 μF. corresponds to a phase angle of 1 min. If the secondary current lags the voltage drop, the capacity is connected so that r_b is 72·8Ω. In this case, 0·02 μF. corresponds to 1 min.

If R_1 and R_2 have no errors, then the ratio and phase errors of the C.T. can be read directly from the setting of the galvanometer tapping point and the value of the capacity required to obtain balance. If R_1 and R_2 have volt drop and phase errors, then these must be used to correct the nominal errors.

ERROR LIMITS FOR METERING C.T.'S. B.S.S. NO. 81, 1936

	Absolute Errors				Variation in Error	
	120% to 20% of Rated Current		20% to 10% of Rated Current		120% to 10% of Rated Current	
Class	Ratio (%)	Phase (min.)	Ratio (%)	Phase (min.)	Ratio (%)	Phase (min.)
A M	± 1	± 30	± 1	30	± 0·5	± 15
B M	± 1	± 35	± 1·5	50	± 1·0	± 25
C M	± 1	± 90	± 2	120	± 1·5	± 60

ERROR LIMITS FOR INSTRUMENT C.T.'S. B.S.S. NO. 81, 1936

	Absolute Errors					
	120% to 60% of Rated Current		60% to 20% of Rated Current		20% to 10% of Rated Current	
Class	Ratio (%)	Phase (min.)	Ratio (%)	Phase (min.)	Ratio (%)	Phase (min.)
A L	± 0·15	± 3	± 0·15	± 4	± 0·15	± 6
B L	± 0·3	± 10	± 0·4	± 15	± 0·5	± 20
A	± 0·5	± 35	± 0·5	± 35	± 1·0	± 50
B	± 1·0	± 60	± 1·0	± 60	± 1·5	± 90
C	± 1·0	± 120	± 1·0	± 120	± 2·0	± 180
D	± 5·0	—	± 5·0	—	—	—

POTENTIAL TRANSFORMERS

Wattmeter Comparison Method. This test is similar in nature to that described above for current transformers. The additional equipment required comprises a H.T. supply, suitable control gear, and a standard potential transformer. The fundamental circuit is shown in Fig. 160. Due precautions must be taken when using the circuit to interpret correctly the action of the phase shifter, owing to the altered connections, viz. the phase shifter now operates on the current circuit and not the pressure circuit.

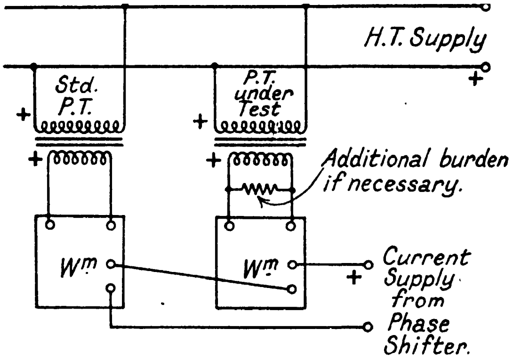


FIG. 160. WATTMETER COMPARISON METHOD OF TESTING POTENTIAL TRANSFORMERS

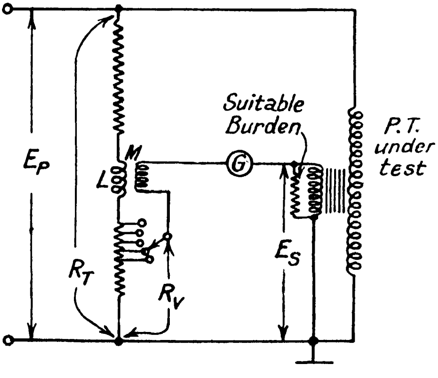


FIG. 161. P.T. TESTING CIRCUIT

Also, if the phase angle error of the P.T. under test is leading, then the 0·5 lagging power-factor error will be more negative than the unity power-factor error, and *vice versa.* The possible accuracy of measurement is ratio within ± 0·2 per cent, and phase angle within ± 5 min. under good conditions.

As mentioned before, this test may be made more accurate by using two induction meters instead of two wattmeters, but the above limits would be sufficient for many undertakings. The advantage of this method is, again, the utilization of existing testing equipment. If desired, the differential method may be used instead of the above method.

Potential Divider Method. The principle of this method is very simple, but the practical difficulties are not easy to overcome. The circuit is shown in Fig. 161. The resistance tapping point gives the ratio adjustment, and the mutual inductance the means of balancing the phase angle error. When balance has been obtained, as shown by zero deflection of the vibration galvanometer, the P.T. errors can be calculated from the readings by the following formulae, provided there are no inherent errors in the apparatus used, such as capacity error in the H.T. resistor.

$$\text{Ratio} = \left(1 + \frac{R_T - R_V}{R_V}\right) \cos\theta = N$$

$$\text{Phase error} = \frac{3438 \times 2\pi f}{R_V} . \left(M - \frac{L}{N}\right) \text{ min.} = \theta$$

where L = inductance of the primary of the mutual inductance.
M = mutual inductance to obtain balance.

Error Limits for Metering P.T.'s. B.S.S. No. 81, 1936

	90% to 100% of Rated Voltage and 25% to100% of Rated Burden at U.P.F.		90% to 106% of Rated Voltage and 10% to 50% of Rated Burden at 0·2 P.F. lag	
Class	Ratio Error, %	Phase Error	Ratio Error, %	Phase Error
A	± 0·5	± 20 min.	± 0·5	± 40 min.
B	± 1·0	± 30 min.	± 1·0	± 70 min.
C	± 2·0	± 30 min.	—	—
D	± 5·0	—	—	—

The P.T. should be tested with a load equivalent to that which will be used in practice, and also with its fuses and limiting resistances, if any, in circuit. (For more detailed information on this apparatus, the reader is referred to Pamphlet 516 issued by the Bureau of Standards, U.S.A., 1926.)

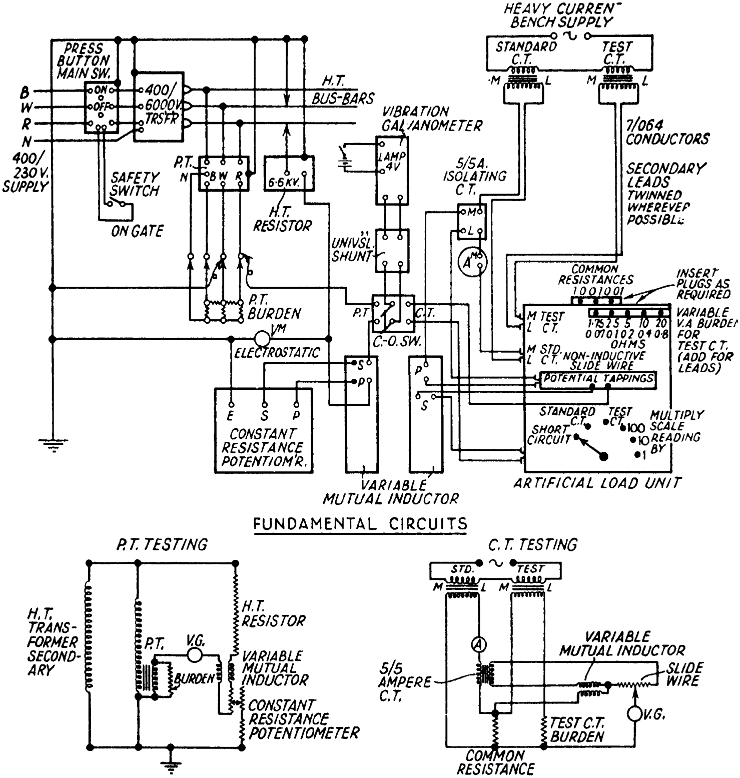


FIG. 161A. P.T. AND C.T. TESTING EQUIPMENT

Ratio Error. It should be mentioned that ratio error in this book is treated as the error in magnitude of the secondary current or voltage, which is the desirable way of looking at such errors. To be strictly correct, however, ratio error is opposite in sign to the secondary magnitude error, and it is essential for the reader to bear this in mind when dealing with N.P.L. Certificates and certain apparatus markings.

Modern Developments. The art of C.T. manufacture has improved so much that it is now possible to obtain sub-standard C.T.'s having extremely small errors. Thus modern C.T. testing equipments do not use shunts, but C.T.'s; and Messrs. Tinsley and Co. (for example) have developed a highly accurate and speedy equipment of this type. They also make an improved form of P.T. testing equipment, which is similar in principle to Fig. 161, but of the direct reading pattern, and Fig. 161A illustrates a laboratory circuit utilizing both these equipments. The mutual inductors are calibrated to read phase angle error, whilst the adjustable resistances are calibrated to read ratio error in the case of C.T.'s, and actual secondary voltage for P.T.'s, assuming application of correct rated H.T. voltage.

CHAPTER XVII

STANDARDIZATION OF BENCH INSTRUMENTS

WHERE possible, this must be done with the instruments under working conditions, in order to ensure that the errors will be strictly applicable. The secondary standards owned by the undertaking are usually permanently housed in the laboratory which is attached to the meter room. The connections between the standards and benches are preferably made permanent. This can best be done by means of two relay circuits, which are wired as shown in Fig. 162.

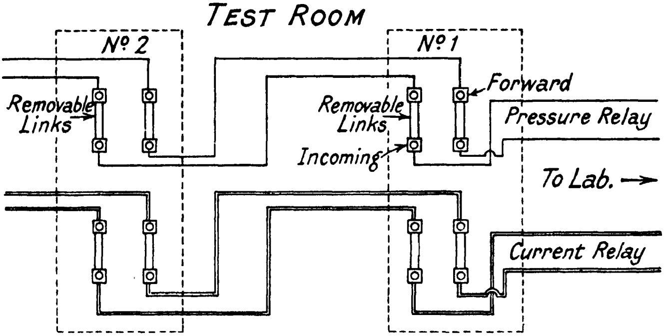


FIG. 162. RELAY CIRCUITS FOR CONNECTING METER BENCHES TO LABORATORY

The conductors of the pressure relay must be of large cross-section, in order to avoid any danger of an appreciable voltage drop. The size of conductor for the current relay circuit is determined by the maximum current to be carried and the length of the circuit. The impedance must be as low as possible, or the supply transformer or battery may not have sufficient voltage to circulate the necessary current. The above type of relay circuit is only suitable for currents up to 100A. In the case of a testing equipment which has a maximum current of 500A to 1,000A, it is advisable to connect the laboratory and the bench by two copper bus-bars capable of carrying 1,000A without appreciable loss.

Communication between the laboratory and test room may be by shouting, by ringing a bell, or by telephone, depending on the distance between the two rooms. The telephone or bell circuit is best made permanent in order to save trouble on future occasions. The telephone leads are connected to the circuit when required by means of jack plugs inserted into wall boxes.

It is a great help to the load holder if he uses a magnifying glass to observe the pointer of the instrument under test. The magnifying power of the glass need only be about × 2 to obtain a much greater accuracy of reading. To avoid eye-strain, the load holder should wear or place a screen of some kind over the eye which is not in use.

ERRORS. The interpretation of an instrument error is best shown by means of a practical example. Suppose on testing a wattmeter against a secondary standard wattmeter we get the following results—

Wattmeter Reading	Indicated Watts	Standard Reading	Corrected Standard Reading	True Watts	Wattmeter Error Percentage
600	1,200	60·45	60·54	1210·8	0·9 −
300	600	99·82	99·90	599·4	0·1 +

The errors are those shown in the last column, because in order to give 1,200 watts we must have the wattmeter reading 0·9 per cent lower than 600, and in order to give 600 watts, we must have it reading 0·1 per cent higher than 300. Thus we have the following rules—

1. If the instrument error is positive, then the indicated (or nominal) load is higher than the true (or actual) load.

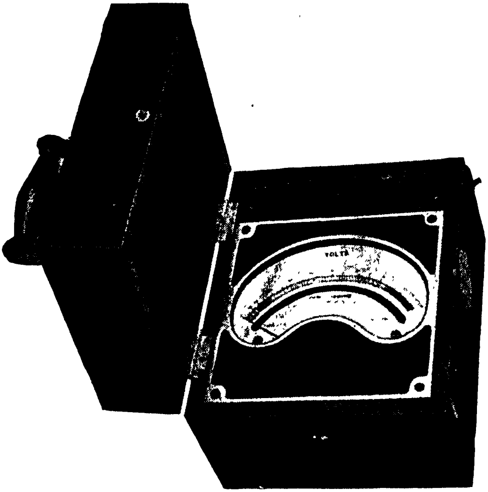
2. If the instrument error is negative, then the indicated (or nominal) load is lower than the true (or actual) load.

D.C. Ammeter. This is checked by a standard shunt and potentiometer connected as shown in Fig. 165. The shunt is either a secondary standard which has been certified by the N.P.L., or a sub-standard which has been calibrated by a secondary standard. The potentiometer should be a high-grade instrument, which has also been checked at the N.P.L. or against an N.P.L. certified instrument. The method of standardizing the ammeter is as follows—

1. The current circuit having been completed, and the instrument zeros correctly adjusted, then the main switch is closed

and the current regulated so as to obtain the desired ammeter reading. Whenever standardizing an instrument, the reading must always be a whole number of divisions, as it is very hard for a load holder to estimate fractions of a division with sufficient accuracy.

2. The tester keeps the reading of the ammeter at the chosen figure, whilst the assistant in the laboratory measures the voltage drop across the standard shunt. From this voltage drop and the known resistance of the shunt the true value of the current can be calculated.



(Everett, Edgcumbe & Co., Ltd.)

FIG. 163. EVERETT EDGCUMBE VOLTMETER

3. The ammeter percentage error can now be calculated for the scale reading and range employed. These operations are repeated for as many scale readings and ranges as desired.

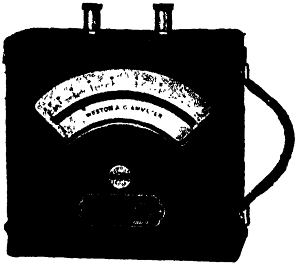
In the case of a dynamometer instrument, it is necessary to test each reading twice, the connections being reversed between the two readings. The mean error is taken as the error of the ammeter for the point concerned.

D.C. Voltmeter. The procedure is similar to that given for the ammeter. In this case the potentiometer is used in conjunction with a volt box, and the circuit is fed from a H.T. battery. A dynamometer type voltmeter, however, must be tested on reverse readings and the mean error taken as the error of the voltmeter at that point. A popular type of voltmeter is shown in Fig. 163.

A.C. Ammeter. 1. The ammeter is connected in series with a suitable current supply and a Kelvin balance (or other secondary standard ammeter) of the correct capacity. The zeros of the instruments are adjusted if necessary.

2. The load holder then switches on and adjusts the current to a definite value. When the pointer is steady at this reading, he signals accordingly to the assistant reading the Kelvin, who takes his final reading when the balance is steady at, or swinging symmetrically about, the zero line.

3. From the reading of the balance and the N.P.L. corrections, the true value of the current can be determined and thus the error of the ammeter. These operations are repeated for as many scale readings and ranges as required.



(Weston Electrical Instrument Co.)

FIG. 164. WESTON MOVING IRON AMMETER

Certain types of ammeters are equally accurate on A.C. or D.C., and consequently they may be tested either as above or by the D.C. method. A useful type of moving iron ammeter is illustrated in Fig. 164.

A.C. Voltmeter (not of the Dynamometer Type). If a Kelvin volt balance is used as the standard, then the procedure is similar to that for the ammeter. Only a few undertakings have a Kelvin volt balance, so the method usually adopted is to test a dynamometer voltmeter on D.C. and then use it as a sub-standard to find the errors of the A.C. voltmeter.

The Single-phase Dynamometer Wattmeter. A good make of dynamometer wattmeter is equally useful on A.C. or D.C., provided reverse readings are taken on D.C. This is a big advantage to an undertaking which does not possess a secondary standard dynamometer wattmeter, as it means that the wattmeter can be standardized on D.C. Many undertakings have standard shunts, volt box, and potentiometer to enable this to be done. (If two potentiometers are available, the testing is made somewhat easier.)

The Potentiometer Method. The wattmeter is wired up as shown in Fig. 165. It is essential for accurate results that the pressure supplied be quite steady, as simultaneous readings of the pressure and current cannot be taken with one potentiometer.

1. The desired load is applied after adjusting the zero and the load holder signals to the laboratory assistant when the pointer is steady at the chosen reading. The regulation is performed on the current circuit.

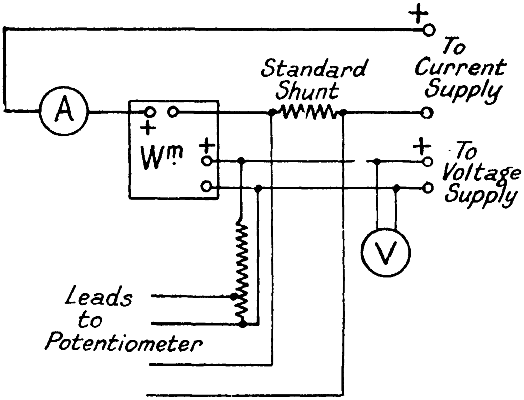
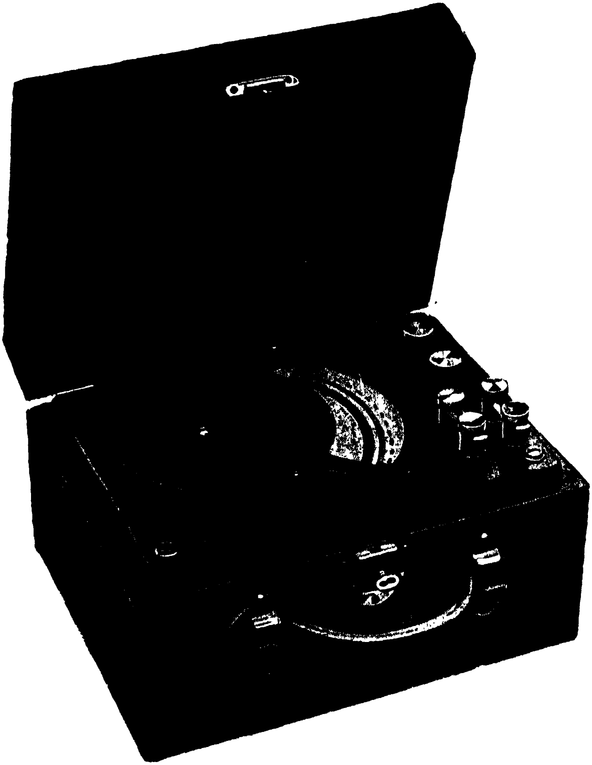


FIG. 165. STANDARDIZING OF INSTRUMENTS AGAINST A D.C. POTENTIOMETER

2. The laboratory assistant first measures the pressure accurately, and then switches over to the current circuit and measures the current when the load holder signals that the pointer is steady. He then re-measures the pressure in order to see if the H.T. battery is stable. The two pressure measurements should differ by less than 0·1 per cent if the test is to be of any value.
3. With the help of the potentiometer corrections, if any, the true pressure and current are worked out, and the product gives the true watts. The error of the wattmeter can now be calculated for the deflection and range employed.
4. The current in each coil of the wattmeter is reversed and the above operations repeated.
5. The mean of the two errors is taken as the error of the wattmeter.

These operations are repeated for as many deflections and ranges as desired. A typical wattmeter is illustrated in Fig. 166.

Secondary Dynamometer Wattmeter Method. The sub-standard wattmeter in this case is usually tested *in situ* by means of the relay circuits described on page 263. The supply to the test circuit is that on which the wattmeter is commonly used.



(Weston Electrical Instrument Co.)

FIG. 166. WESTON SINGLE-PHASE WATTMETER

1. After completing the wiring up of the instruments and the communication circuit, the zeros of the instruments are adjusted, if necessary.

2. The desired load is applied, and the load holder signals when

the pointer of the sub-standard is steady at the chosen deflection. The laboratory assistant adjusts the torsion head of the secondary standard (an example of this type of wattmeter is shown in Fig. 169) and takes his final reading when the load holder signals that his reading is perfectly steady. It is possible, of course, for the reading of the secondary standard to be unsteady and yet have the deflection of the sub-standard quite steady. In such a case the assistant must exercise a little more patience and judgment before deciding on his final reading. If his pointer will not remain steady, he must see that the swings are symmetrical about the zero line.

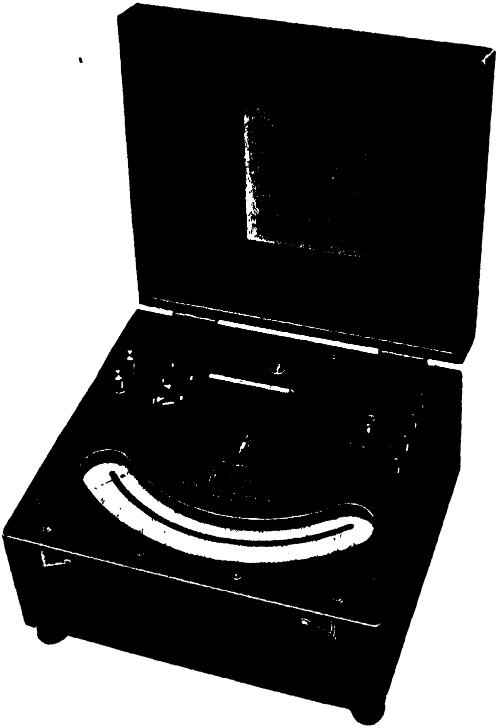
3. With the aid of the N.P.L. corrections the laboratory assistant works out the true watts, and hence the error of the sub-standard for the deflection and range in use. These operations are repeated for as many deflections and ranges as desired.

A sub-standard wattmeter is usually provided with two current ranges and two or more voltage ranges. When a wattmeter is delivered by the makers, it should be tested to see if a change of range alters the error appreciably for any given scale reading. If the error is more than $\frac{1}{4}$ per cent different on any two different ranges, the wattmeter should be rejected. A sub-standard wattmeter to be of real practical use must have its scale errors almost independent of the ranges in use. It would be too confusing to have to use a fresh error curve for every combination of voltage and current range.

If a sub-standard has been accepted as correct, it is only necessary on subsequent standardizing tests to check the scale errors completely on one combination of the ranges and to check the effect of range change at one or two points only. The latter part of the test is necessary in order to determine if a resistance element or terminal connection has become faulty.

On certain testing equipments the wattmeter is only used on a limited number of loads which are always the same. In this case the tester need only be supplied with the errors of the wattmeter for the particular loads concerned, since each load is always tested with the same combination of voltage and current ranges. The work of standardization is thus very straightforward on this type of equipment.

Three-phase Dynamometer Wattmeter. This is standardized on a single-phase circuit in the same manner as the single-phase wattmeter, both elements being connected up. If a polyphase wattmeter exhibits appreciable interaction, then it should not be accepted from the makers, because there are very few places in England where a three-phase standardizing test can be given. Also the interaction leads to difficulties when doing special tests. Another important point which must be tested before accepting a polyphase wattmeter is the balance of the elements. If the balance is not within 0·1 or 0·2 per cent, the wattmeter must not be accepted. (See page 269 for note on the effect of range changing.) A polyphase wattmeter is shown in Fig. 169, and this type is suitable for use as a secondary standard.



(*Elliott Bros., Ltd.*)

FIG. 167. ELLIOTT LABORATORY STANDARD WATTMETER

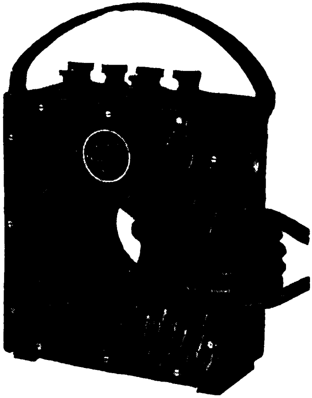
The effect of interaction is obtained by loading one element so as to obtain a high scale reading, and then determining the wattmeter error under the following conditions—

1. The other element dead.
2. Voltage only applied to the other element. This is done with the voltage having various phase angles in turn.

3. Current only applied to the other element. This also is done with various phase angles for the current. Interaction should not affect the error by more than 0·2 per cent, or preferably 0·1 per cent.

Rotating Sub-standards. These are standardized by testing them against secondary or sub-standard wattmeters in the same manner as an ordinary meter.

C.T. Operated Wattmeter. If the laboratory possesses a heavy current A.C. secondary standard (not necessarily a total current instrument, of course), the overall error of the wattmeter and its C.T. may be obtained by direct test. Otherwise the wattmeter and the C.T. must be tested separately. (It should be mentioned here that this chapter assumes that the scale error of a dynamometer wattmeter is not seriously affected by the power-factor of the load, provided the power-factor is above 0·4: also that the wattmeter correctly reads zero when the power-factor is zero. All good wattmeters will satisfy these conditions, but if a wattmeter has to be used which does not comply with them, it will be necessary to obtain its error curve at other power-factors than unity, viz. 0·86 lag, 0·5 lag, zero lag, and 0·86 lead. In the case of zero lag, the errors must be expressed in terms of scale reading and not percentage.)



(Everett, Edgcumbe & Co., Ltd.)

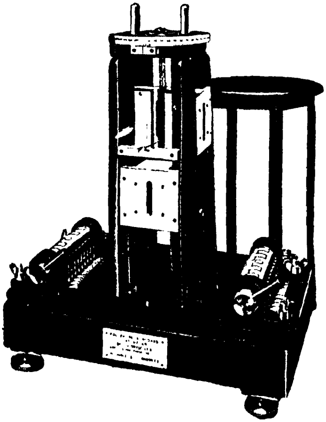
FIG. 168. SUB-STANDARD NICKEL-IRON RING TYPE CURRENT TRANSFORMER

The C.T. should be standardized with the value of secondary burden which will be applied in actual service. If this burden is not known at the time of test, it will be necessary to test the C.T.

at several burdens, so that the errors for any future burden may be interpolated. The overall percentage error of a C.T. operated single-phase wattmeter is thus given by—

$$\text{Wattmeter scale error per cent} + \text{C.T. ratio error per cent} - 100 \sin \lambda \,.\, \tan \phi$$

if $\cos \phi$ is the power-factor of the load, λ is the phase angle error of the C.T., and the angles are given the usual signs. In actual practice, the last term in the above expression would present no difficulty, since the various values for the angles concerned would be known, and memorized or jotted down.



(*H. Tinsley & Co.*)

FIG. 169. DRYSDALE STANDARD WATTMETER

Overloading of Wattmeter Coils. Precautions must be taken when using wattmeters not to overload the coils for too lengthy periods. Such overloads seriously raise the internal temperature and thus affect the springs, causing the errors to alter. Certain wattmeters are very susceptible to over-running of the coils, and a close watch must be kept for such instruments or otherwise unexplainable discrepancies will occur in the test room. These statements apply particularly to wattmeters where voltages or currents in excess of the marked values are permitted by the makers.

Reasons for Standardizing. 1. Even though the error of an indicating sub-standard may not exceed ± ¼ per cent of full-scale reading, at any scale point, the actual error may be quite appreciable, e.g. 2½ per cent at one-tenth full scale. The act of standardizing enables the actual errors at all points of the scale to be determined.

2. Continual use of sub-standards is always liable to alter the characteristics of the resistances and springs, particularly if overloading of the coils is carried on to any degree.

3. The greater part of an undertaking's revenue is derived from the readings of its electricity meters, and is therefore directly dependent on the accuracy of the meters. Meter accuracy can only be ensured by having accurate sub-standards, and accurate sub-standards can only be ensured by having secondary standards.

4. If a consumer was to dispute successfully the accuracy of his meter, the reputation of the undertaking would be badly tarnished, and the news would lead to other (even though not justifiable) disputed accounts. Therefore an efficient standardizing equipment may be regarded as an insurance against such trouble.

Potentiometer Precautions. For the theory and construction of potentiometers, the reader is referred to textbooks on instruments, but it will be of practical assistance to give here a number of hints based on experience. A potentiometer lay-out is shown in Fig.157.

(*a*) Use a comparatively large battery for the potentiometer circulating current, and keep it permanently connected so that the potentiometer is maintained at a steady temperature. It also prevents any danger of trouble from dampness.

(*b*) Keep the shunts permanently wired up to accurate individual fuses to prevent anyone accidentally ruining a shunt by an overload.

(*c*) Place a resistance in series with the standard cell output so as to prevent serious damage to the cell if an accidental short circuit occurs.

(*d*) A D.C. galvanometer is extremely sensitive, so it is most important to keep the wiring and supports permanently dry to avoid leakage currents affecting the readings.

(*e*) When testing a wattmeter, it will be found much easier to determine the errors if the testing voltage is first of all set to the exact rated value by setting the potentiometer dials and then adjusting the voltage until the galvanometer spot is at zero deflection. If this is done, then the wattmeter error can be measured by the discrepancy between the measured current and the calculated current value. This procedure avoids the nuisance of multiplying together six figure numbers.

CHAPTER XVIII

TYPICAL METER FAULTS AND THEIR TREATMENT

THE faults are classified as far as possible according to the nature of the meter, but the reader will realize that in certain cases they overlap. Where the remedy to the fault is obvious, comments are omitted as being superfluous.

Motor Meters. 1. Jewel surface cracked or rough. There is only one remedy, and that is to fit a new jewel. The pivot should also be replaced, or at least repolished (if possible), as the fault may have been due to a crushed or worn pivot. The tester must take care to replace the bottom bearing so that the rotor occupies the same position in the gaps as it did before receiving attention.

2. Iron filings and dirt in the gaps. Owing to the strong magnetic fields, iron filings are attracted very easily, and care must be taken to avoid making such filings when using a screwdriver on iron screws. The gaskets of the meter must be in good condition before it is returned to stores, and if the meter is to go to a particularly dusty works the gasket should be greased.

3. Iron in disc. In the manufacture of copper and aluminium discs, it is unavoidable that tiny particles of iron will be present in some of the discs. This iron makes itself known by the jerky running of the rotor on one-twentieth load and stoppage on two-hundredth load. The correct detection test, however, is to make the meter dead and then put the rotor into various positions until the iron is near the poles of the permanent magnet. The ensuing attraction will cause the disc to move. It is not possible, as a rule, to find the particle of iron, and the remedy is to change the disc. If the iron can be seen on or near the surface of the disc, then the remedy is obvious.

4. Faulty top pin. This results in poor performance on one-twentieth load and jerky running or stopping on two-hundredth load. The trouble may be due to one of the following causes—

(*a*) Rough surface due to wear or rust.

(*b*) Worn spindle bushing.

(*c*) Pin bent.

(*d*) Pin fouling the top or bottom of the bushing.

(*e*) On some meters the top pin is cut to length by pliers, and no attempt is made to smooth the jagged end. This end is apt to cause scoring of the bushing; and if the pin is not correctly adjusted, the jagged end fouls the bushing, causing excessive friction.

(*f*) Dirt or sticky oil in the bushing.

5. Disc fouling the magnets due to rotor wobble. This may be due to a bent top pin, bent bottom pivot, untrue disc or buckled disc.

6. Friction in the revolution counter. This causes trouble on creep test and on low loads. The friction may be due to—

(*a*) Spindle bearings faulty.

(*b*) Gear wheels too tightly, or too lightly, meshed.

Some trains have an adjustable bracket, and this may have been set wrongly. Elliptical gear wheels are not unknown, also.

(*c*) Dirt on the teeth of the gear wheels.

(*d*) A bent tooth on one of the gear wheels. This is a difficult one to detect, as it only occurs once every revolution of the wheel concerned.

(*e*) Rough surface on worm.

(*f*) One of the dial pointers may be eccentric, and thus foul the dial plate in a certain position.

7. Excessive friction due to the brushes bearing too hard on the commutator.

8. Faulty insulation. Generally speaking, the item concerned must be replaced or repaired. If the fault is due to one of the coil leads touching the frame or case of the meter, the remedy is to fit Sistoflex in the case of a thin wire. A thick, stiff lead can easily be levered into a position where it will not touch the case.

9. Open circuit in the pressure circuit. This often occurs at the junction of the leads with the coil ends owing to the slender wire of the pressure coil.

Mercury Meters. 1. Excessive friction due to the rotor fouling the sealing valve.

2. An air bubble in the mercury. This may sometimes be removed by a vigorous twirling of the rotor. Otherwise the mercury bath must be emptied, cleaned, and refilled with fresh mercury.

3. Floating of the rotor due to insufficient sinking weight being provided. The driving torque is unbalanced and, consequently, the rotor is pulled to one side. If the downward force is insufficient, this pull causes the bottom pivot to foul the seating of the jewel.

4. Jerky running, failure to run, overheating, or open circuit may be due to loss of mercury caused by careless transport or a leaky mercury bath.

A.C. Induction Meters. 1. Excessive forward or backward torque due to the pressure element. This often makes it difficult or impossible to calibrate the meter. The trouble may be due to the unsymmetrical position of the quad loop, voltage coil laminations, current coil laminations, or balance-adjusting device about the centre line of the meter. The remedy is obvious.

2. A shorted turn, or turns, in the pressure coil will cause overheating. The coil must be scrapped.

3. A loud humming noise. This is usually due to the quad loop not being stiff enough or not being tightly in contact with the laminations.

4. Shorted turn in series coil. This makes itself known by the meter running on voltage only (as an induction voltmeter), or by the errors being out of the ordinary.

5. Disc chatter. A loose-fitting top pin or bottom jewel is often the cause of this trouble.

The Pendulum Meter. 1. Open circuit in the winding gear or pressure circuit. This may be due to one of the following faults.

(*a*) Defective soldering.

(*b*) Defective commutator contact.

(*c*) Burnt-out armature winding due to a mechanical fault causing the resetting device to fail.

(*d*) Broken pendulum connection due to the constant to-and-fro motion.

(*e*) Broken mainspring.

2. Erratic errors. These may be due to an intermittent short circuit in a resistance bobbin or pressure coil.

3. Stoppage of the pendulum. This may be due to one of the following faults—

(*a*) Failure of the winding gear, due to dirty, worn, or fused contacts.

(*b*) Broken winding-gear springs.

(*c*) Worn pallets, or incorrectly-adjusted pallets.

4. Erratic functioning of the winding gear may be due to the following troubles—

(*a*) Too much end-play in armature bearings.

(*b*) Worn or bad teeth on the ratchet wheel.

(*c*) Weakening of a new mainspring.

(*d*) Corrosion due to dampness.

(*e*) Earthed contacts or winding due to faulty insulation.

(*f*) The spring connection between the winding gear and the main differential may not have sufficient take-up to supply the driving force during the winding period of the armature.

5. Meter case alive. Sometimes when the mainspring breaks, it comes into contact with the case of the meter, making it alive. The tester must be very careful when removing the cover to avoid the cover touching any other metallic object.

6. Excessive creeping is usually due to incorrect balancing of the pendulums.

7. Large negative error at or near the point of synchronism. This is usually caused by excessive friction due to the following items—

(*a*) Worn pendulum bearings.

(*b*) Incorrect meshing of two gear wheels due to wear or bad assembly. The former occurs on the differentials due to the irregular motion of the gear wheels.

(*c*) Worn or incorrectly-adjusted pallets.

(*d*) Dirt on the gear-wheel teeth (dust, paint, or corrosion).

(*e*) Broken teeth.

(*f*) Bad alignment of the reversing gear.

8. Meter not plumb. This may be caused by careless fixing, vibration, or subsidence of the meter board.

Maximum Demand Indicators (Merz Type). 1. A high reading may be caused by—

(*a*) Too short a resetting period. The driving pointer is reset by a spring, and naturally the pointer bounces for an appreciable time before becoming steady at zero. Consequently if the reset period is too short, the indicator is put in gear again whilst the driving pointer is on the bounce.

(*b*) Incorrect gear ratio.

(*c*) Low speed of the synchronous motor driving the timing mechanism. This may be due to the system frequency being low or to a faulty bearing.

(*d*) Incorrect adjustment of the push rod on mechanically-operated resetting devices.

(*e*) Time switch clock slow.

(*f*) Incorrect setting of the tripping pins on the hour dial of the time switch.

(*g*) Failure to trip the driving gear. This may be due to several things.

(i) Residual magnetism in the tripping relay causing the armature to remain in a closed position.

(ii) Sticking of the time-switch contact springs.

(iii) Failure of the time-switch contacts to make a proper contact. It is sometimes found that the two platinum contacts are out of alignment due to maltreatment or bad adjustment.

(iv) Failure of the movable wheel carriage to come out of gear when the resetting relay operates.

2. A low reading may be caused by—

(*a*) The zero of the friction pointer not coinciding with that of the driving pointer.

(*b*) Chatter of the resetting relay armature allowing the driving carriage to slip out of gear.

(*c*) Time switch clock fast.

(*d*) High system frequency in the case of a timing device driven by a synchronous motor.

(*e*) Excessive friction on the friction pointer due to a burr on the friction device or due to the pointer fouling some object on the revolution counter.

(*f*) Incorrect gear ratio.

Prepayment Meters. 1. Erratic operation of tripping mechanism. Generally speaking, this fault involves taking the P.P. mechanism out of the meter case in order that the various parts may be inspected under operating conditions. There are very few P.P. mechanisms in which the action of the vital parts is visible when the meter is built up. An immense number of detail faults (due to the widely different types of P.P. mechanisms in existence) are possible, of which the following may be cited—

(*a*) Bearings binding due to faulty cleansing of the metal parts (after the dipping operation) leaving undesirable rust-creating chemicals in the bearings.

(*b*) Too much play in a bearing causing the wheel either to jam or slip.

(*c*) Incorrect adjustment of the switch toggle or release mechanism causing the tripping to be either very difficult or affected by slight vibrations.

(*d*) Burrs on the surfaces of sliding or rolling parts sometimes causing erratic action.

(*e*) Backlash in the gearing. In some makes the backlash may be nullified by a spring, but in others nothing can be done except to adjust the meshing of the gearwheels to the best position.

The reader will appreciate that, although the subject of P.P. meter faults is (unfortunately) a very large one, it is impracticable to give more than this brief paragraph, since the various important faults are peculiar to particular makes or models of meter (see also page 310).

Thermal Maximum Demand Indicators. In spite of certain theoretical disadvantages, this type of indicator is very widely used. It is therefore important to realize the need for making good terminal connections, since any abnormal heat developed at the terminal contacts will affect the accuracy of the M.D.I.

CHAPTER XIX

INSTALLATION AND MAINTENANCE OF METERS

INSTALLATION

WHEN a consumer asks for a supply of electricity, he gives the undertaking full details of all the apparatus which he is going to use. From these particulars the mains engineer determines the capacity and type of service which must be given. The meter and rentals department are notified accordingly. The rentals department arranges with the consumer the type of tariff and the charges, and informs the meter department of the result. The meter engineer can now prepare the necessary equipment from the data received. The majority of metering requirements can, of course, be met with meters drawn from stock. In the case of supplies exceeding 200 kW it is desirable to provide duplicate metering so that if one meter becomes faulty the record of units consumed is not lost.

In the case of an alternator, feeder, or sub-station meter, the necessary information as to capacity, M.D.I. or non-M.D.I., and type of supply is provided by the department concerned. It is not usual to provide duplicate metering for feeders or sub-stations, as the readings are only used for statistical purposes.

The above description is only intended as a rough idea of the procedure, because the departmental arrangements and office routine differ so enormously between different undertakings.

All metal P.P. meters must be securely earthed.

In those undertakings where the meter-fixers are separate from the testing staff, it is desirable that all large capacity meters should be inspected and passed as correct by one of the testing staff before the circuit is made alive. In the case of a polyphase equipment, the tester makes the following tests—

1. The wiring is checked before connecting up the meters or instrument transformers. Where the wires cannot be traced by sight, a buzzer must be used to identify the wires. A great help in the wiring of polyphase meters is the use of coloured wires.

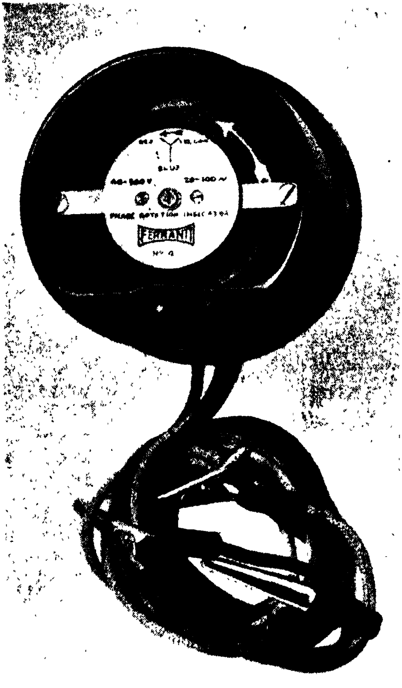
2. The insulation resistance of the wiring is tested by means of a megger.

3. The meter, P.T., C.T., and M.D.I. wires having been connected to the appropriate terminals, the circuit can be made alive.

4. The phase rotation at the meter terminal block must be checked. If wrong, the mains must be reconnected. This will necessitate the reversing of two of the consumers' leads if the original motor rotation is to be maintained.

5. If an M.D.I. is fitted, then its operation must be checkec and the time switch wound up.

6. The internal cleanliness of the meter is checked, as dirt o iron filings may have got into the gaps during transport. Phase rotation indicators (see Fig. 170) of a handy size are now marketed



(*Ferranti, Ltd.*)

FIG. 170. FERRANTI PHASE ROTATION INDICATOR

by several electrical instrument firms, but a simple indicator can be arranged by connecting two lamps and a condenser, as shown in Fig. 171. To obtain good results, the impedance of the condenser should be approximately equal to that of one of the lamps. The three terminals are marked as shown, and if the phase rotation of the system is correct, then the " blue" lamp will be much brighter than the "red" lamp. The reason for this should be perfectly clear from the accompanying vector diagram. If the phase rotation is wrong, then the "red" lamp will be brighter than the "blue" lamp. If a choke coil is used in place of the condenser, then the brighter lamp will be the opposite of that in the case of using a condenser. If the yellow line is not accessible, then it is quite satisfactory to use the neutral in its place to obtain the phase rotation.

The meter-fixing staff should require no supervision in the correct fixing of 2-wire meters. If the terminal arrangement of a meter is non-standard, then a diagram of connections should be placed under the terminal cover or the terminals painted according to the undertaking's colour scheme. An important point in connection with 2-wire meters is that the series coil should be placed in the live line. This will cause it to register if an earth fault occurs on the consumer's wiring. Not only will this bring attention to the fault, but also the undertaking will not suffer loss of revenue due to consumer's faults.

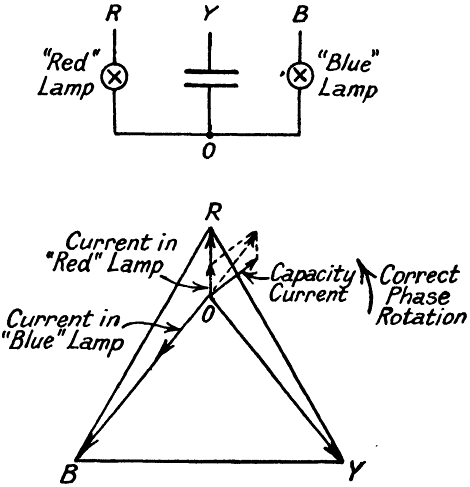


FIG. 171. VARLEY PHASE ROTATION TEST

In places where duplicate metering has been installed, it is advisable to visit the works two or three days later and check the advances of the two sets of meters. If a discrepancy greater than 3 per cent is found, the reason for it must be determined and rectified, if possible. This practice avoids the danger of registering a large quantity of energy falsely and causing trouble over the settlement of bills.

Position of the Meter. Generally speaking, the meter-fixer has little choice in choosing a position for the meter, and consequently it is impossible to lay down hard-and-fast rules as to this choice. There are, however, a few limitations, such as the following—

1. The meter must not be mounted near the floor if this is regularly swept and cleaned, owing to the danger of the cleaner hitting the meter with the sweeping brush or swilling water over it.
2. If the meter has to be mounted in a coal place, it must be placed well above the coal, and the gasket greased to prevent the entrance of coal dust.
3. The meter must not be mounted behind wooden frameworks, such as shop-window panels, or in the way of a door.

Where possible, the meter department should make arrangements with the Mains Department as to the basic principles of choosing the site of the meter board. A good meter site should not be sacrificed for the sake of a yard or two of cable, and furthermore the convenience of the consumer has to be considered. The latter point applies particularly where meters are situated in cupboards used for household purposes. In the case of new houses, the undertaking should have some means of liaison with the builders so as to arrange a suitable meter situation, e.g. a special narrow cupboard in the hall where the cable entry is at the front of the house. A new development is the use of a special service unit which has been produced under the auspices of the Electrical Development Association. In this unit the undertaking's intake chamber and the consumer's main switch and fuses (single pole) are combined together with provision for the meter to be connected with concealed leads.

MAINTENANCE

Typical meter complaints (the treatment suggested below is not necessarily in line with the Meters Act regulations) are—

1. FROM THE METER READING DEPARTMENT.

(*a*) Meter not registering.

(*b*) Consumption very low compared with that of the previous corresponding quarter.

(*c*) Consumption very high relative to that of the previous corresponding quarter.

(*d*) Difference in advances greater than 3 per cent, where duplicate metering is employed.

2. FROM THE CONSUMER.

(*a*) Meter noisy.
(*b*) Registered consumption too high.
(*c*) M.D.I. reading too high.
(*d*) Meter running back.

(*e*) Incorrect time on time switch, or time switch stopped.
(*f*) Burning, in or around the meter.
(*g*) Meter glass broken.
(*h*) Meter registering when no apparatus is in use.
(*i*) Meter case alive.

Complaints 1 (*a*, *b*, *c*) and 2 (*b*, *c*, *d*) are not necessarily faults, as they may be due to a change in the habits or apparatus used by the consumer. In the case of a change in apparatus, the tester must investigate the change to see if it warrants a change in the capacity of the meter.

If, however, the meter is faulty, then the treatment should be as follows—

1 (*a*). This fault has many causes, of which a large number are discussed in Chapter XVIII. If the remedy involves any danger of the calibration being affected, it is better to have the meter replaced. Such faults as rough or cracked jewel, dirt in the meter gaps, and faulty top pin can be rectified without any danger of the calibration being materially affected. If a jewel is found to be in a very bad condition, it is also advisable to change (if possible) the bottom pivot, because a faulty pivot would soon make a good jewel into a bad one. The tester must make a mental note of the setting of the rotor in the gaps before removing the jewel, and the new jewel and pivot must be fitted so as to reproduce this setting.

Occasionally this fault is due to the meter-fixer neglecting to unclamp the meter.

1 (*b*). The above treatment also applies in this case.

1 (*c*). This fault is very rare, as a decent brake magnet requires very severe treatment to weaken even 10 per cent. This complaint often occurs after the supply to a consumer has been changed from D.C. to A.C., owing to the failings of the mercury motor meter on low loads and temperatures. Thus the trouble is due to the old meter reading low, not to the new one reading high. The tester cannot prove this, as the old meter is probably retested and in other premises by the time the complaint is made. It rests with his discretion whether he explains this to the consumer or not.

1 (*d*). This difference is usually due to the faults discussed in 1 (*a*), and the same treatment applies.

2 (*a*). Some A.C. meters are subject to disc chatter, which in a house is sometimes objectionable. The best thing to do in such a case is to replace the meter and use the old meter in a place where the chatter will not be objectionable, if it cannot be rectified in the test room. In other cases the noise is due to the vibrations of the quad loop. This can usually be cured by a slight

pressure on the quad loop, causing it to change its position by a small amount. This change must be small, or else the calibrations will be materially altered, particularly if the loop is moved sideways. It rests with the tester's discretion whether the meter will require replacement or not.

On many occasions the consumer complains of a noisy A.C. meter, when really it is the fault of the cut-outs. These are often of cast iron, with a loose-fitting cover. When a current flows in the supply wire, the cut-out case becomes magnetized and, if the cover is loose, then chatter will be set up.

To remedy this fault, the cover must be screwed up tightly or packed. Also the mains engineer should be notified in order to avoid repetition of this trouble.

✓2 (*b*). The causes of this complaint are wrong connections, incorrect reading of the meter, weakened brake magnet, faulty coils, etc. The first two faults can soon be found and rectified by an experienced tester, but the others will necessitate the equipment being returned to the test room. The rentals department, on the advice of the meter engineer, will come to some agreement with the consumer regarding the rebate to be made. The "As Received" test errors will usually form the basis of the agreement.

2 (*c*). This is a common complaint, as it is often based on erratic estimations by the consumer or his engineer. Generally speaking, if the M.D.I. becomes faulty, it either reads approximately double the normal load or goes over scale. These faults are dealt with on page 277.

If the M.D.I. is operating correctly, the tester must investigate the consumer's load to see if the reading is reasonable. There are several ways of estimating the load.

1. The lamps and motors are investigated and the various loads totalled. The load attributed to a motor must not be based solely on the name-plate markings, but on its mechanical load and probable efficiency.
2. If an ammeter (or ammeters) is provided, then the load can be calculated approximately if a suitable figure is chosen for the power-factor.
3. The best method is to time the W.H.M. and calculate the kW from the timing.

The estimation must be taken when the consumer is working at full pressure and not when the works are comparatively idle. As it is difficult to choose the correct time to visit the consumer, and because the consumer cannot easily be convinced, it may be necessary to install a recording wattmeter for a week or more to vindicate the M.D.I. The consumer must bear the cost of installing the recording wattmeter if the M.D.I. is proved to be right.

The wattmeter is operated from the same transformers as the W.H.M., provided its series windings have a low volt-ampere burden.

2 (*d*). This may be due to the meter connections being incorrect or due to a low power-factor in the case of two single-phase meters measuring a 3-phase load. In the former case, the remedy is, or should be, obvious. In the latter case the scheme of operations must be explained to the consumer, in order to make him realize that the reverse rotation is quite legitimate.

2 (*e*). If the error of the time switch is only a few minutes, the hour dial may be reset to the correct time. In other cases the time switch must be replaced by a fresh one. If the stoppage of a time switch is simply due to its being run down, then the tester only needs to rewind it, set it to time, and notify the time switch winder that he has missed his call.

2 (*f*). This fault may be due to overloading the meter, a bad internal contact, or a faulty coil. In every case the meter should be cut out of action and replaced by a fresh meter of the correct size as soon as possible. If the fault is due to a badly-connected external lead to the terminal block, it is not necessary to change the meter after making good the connection.

2 (*g*). The breaking of meter glasses chiefly occurs when the meter is installed in a crowded pantry or lumber room. The remedy is obvious. Care should be taken to see that no particles of glass are left inside the meter.

2 (*h*). If the consumer has an earth fault on his installation between the meter and the switches, then the meter will register even when no apparatus is connected to the supply. The remedy rests with the consumer, who should keep his main switch open, or fuses out, if possible, until the fault is rectified.

In the case of a 2-wire meter whose series coil is connected in the earthed line, it will not register with an earth fault on the consumers' positive leads, but it may run backwards if there is an earth fault on one of the consumers' negative leads (see Fig. 172).

The tester must always verify the correctness of the series coil connections when inspecting a meter and, if necessary, he must reconnect the meter.

✓ In the case of a meter which creeps forward on pressure only, it is usual for the tester to time the speed of the disc when he visits the consumer, after the complaint has been made. From this speed the kWh erroneously registered can be calculated for the period during which the fault has existed, not exceeding one quarter. The consumer is credited with this quantity of energy. The meter is then replaced by a fresh one. If the meter creeps backward, the undertaking should not reclaim the loss of reading.

The meter is also replaced in this case. (It is not permissible to alter the setting of friction compensators unless the accuracy of the meter can be checked *in situ.*)

2 (*i*). This fault may be due to—

(*a*) A breakage in the electrical circuit causing a lead to come into contact with the meter case.

(*b*) Foreign matter, such as a screw or washer, bridging the gap between a terminal and the case.

(*c*) Faulty insulation.

The remedies will be obvious to the tester.

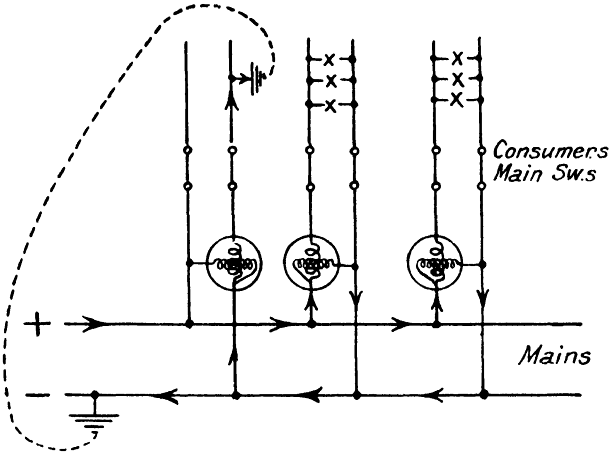


FIG. 172. CAUSE OF BACKWARD RUNNING WHEN THE METER SERIES COIL IS IN THE EARTHED LINE

Prepayment Meters. Owing to their complicated nature, P.P. meters require more maintenance than ordinary house service meters. The faults of the P.P. mechanism are, as a rule, peculiar to the various makes, so it is impossible to do more in this section than discuss certain outstanding faults.

1. Complaint of no lights. After verifying that the fuses are in order (the average consumer does not understand fuses and switches, etc.), the meter is inspected. The following faults are typical.

(*a*) The meter requires a coin. The average credit index is too small to be a thoroughly reliable guide as to credit.

(*b*) Faulty, loose gearing between credit index and kWh train allowing the credit to fall to zero and thus trip the switch, however many coins are inserted.

(*c*) Small particles of dirt between the switch contacts causing the supply to fail, on one make of P.P. meter.

(*d*) Broken or loose parts preventing the tripping device from holding-in the switch.

(*e*) On certain meters the insertion of a coin when the P.P. mechanism is at the tripping point will cause the switch to open.

2. Light without payment. Non-running of the meter portion has already been dealt with. If the P.P. mechanism is defective, then the fault may be one of the following—

(*a*) Tight gearing causing the meter to stop registering.

(*b*) Faulty bearings causing the P.P. wheels to jam and thus stop the meter.

(*c*) Sticking of the tripping device allowing the switch to remain closed.

The remedies in the above cases are quite clear, but it will be appreciated that above faults are not the only ones which occur. There are so many makes and types of P.P. meters that the faults are extremely varied. Many of the above faults are responsible for the common complaint of disagreement of indexes made by the meter reading department.

A good deal of trouble can be avoided if steps are taken to instruct consumers to insert coins when the credit is still respectably high. This will not only prevent unnecessary operations of the switch, but it will also save the consumer the annoyance of being put in darkness at inopportune times.

Prepayment Meter Rate Changes. When the price per unit is altered, there are several courses which may be taken by the meter department to pass the benefit or increment on to the prepayment consumer.

1. The premises visited and the price-change gear altered, leaving all the meter readings as they were on arrival. A note of the readings must be taken, together with particulars of the name of the consumer, etc. Special printed sheets with suitable columns are advisable (this also applies to the other methods) for this work, the addresses being transferred from the meter-reading records. If this procedure is adopted, a copy of the relevant figures should also be written on a suitable spot inside the meter to enable the tester to check the accuracy of the meter on any future complaint visit. It is only advisable, however, to use this method where an assisted wiring scheme is the cause of the P.P. meter being installed, and where the indication of completion of paying off the installation is determined from the total number of units consumed.

2. Readings taken, the consumer paid the amount of credit outstanding in hard cash, and all the meter dials then set to zero after altering the price-change gearing. This gives the meter a

complete new start and it enables the accuracy of the meter at any future date to be easily determined. A serious disadvantage of method 1 is that this calculation is rather involved.

3. If a price reduction is concerned, then the meters may be left undisturbed and the benefit handed on to the consumers by means of rebates at the times of emptying the coin boxes. The disadvantage of this method is that the benefit of the price reduction is not felt whilst the electricity is being used, and thus there is not the same incentive to increase consumption.

4. In the case of one or two makes of P.P. meter, the price-change does not require any special maintenance visit. The price change may be carried out by the coin collector on his first visit after the decision to alter the price per unit. (Refer to the description of the Smith P.P. meter.)

Which of the above courses should be taken will depend on the local circumstances and personal opinions; but, in general, it is preferable that after the rate change all the meter dials should be at zero, on the score of easy checking of the future agreement of the dials. Before making a decision, however, to change the meter gearing, the meter engineer must consider the various practical difficulties. The cost of a mechanical alteration is quite considerable, as one man can only do about fifteen meters per day even if he has little difficulty in obtaining access to premises. If there is much difficulty in this respect, the average daily number falls considerably, because of the time wasted in making ineffectual calls. It must be realized that the change of gearing is not always an easy matter on site, however simple it may appear in the test room, due to the awkward situations in which meters are often placed.

The change usually requires the meter-testing staff to be augmented if the time of change-over is to be kept reasonably short, say, four to six months. The temporary men may be borrowed from the meter manufacturers, or other sections of the undertaking, e.g. meter repairers. Before setting these men to work, however, they should be duly instructed in the method of obtaining access to premises which will cause the least offence to the consumer. There is quite an art in this matter. The various difficulties which may arise, and the method of overcoming them, should also be explained. In connection with this work of rate changing, notice should be taken of paragraph 3, page 134, dealing with the correct scaling of the credit index.

Passes. It is essential that all testing assistants should be provided with special passes, or warrants, to convince the consumer that the testing assistant is duly authorized to enter consumers' premises. It is not often necessary to show this pass, but one does occasionally meet obstreperous consumers.

METER REPORT

Work done at ..... *J. H. Jones, Ltd.*. .....
.. . . *14 Louisa St.,* .. ..
....*Barsonville* . .. ..

Date......... .. *21/7/35* ..

Reason for Visit .... . *1ϕ Total > 3ϕ Advance by 4%* ....

Date of Issue..... .. *7/4/26*.... . . . State of Seals .. . .*O.K.*

Load at Time of Visit .. *250 kW* .. ..

Situation	Red 1ϕ	Blue 1ϕ	3ϕ
Maker	X Y Z	X Y Z	X Y Z
Corp. No.	24101	24102	24103
Maker's No.	199888	199889	112112
Amperes	←—— 2 ×	50/5 A ——→	2 × 50/5A
Volts	6600/110	6600/110	6600/110
Phase	1	1	3
Wire	2	2	3
D.K.	10	10	10
D.I.K.	—	—	1
Initial Reading	089883 × 10	089993 × 10	61685 × 10 kWh
Max. Demand	—	—	300 × 1 kW
Time	2.30 p.m.		
Final Reading	089894 × 10	090004 × 10	61707 × 10 kWh
Max. Demand	—	—	0 × 1 kW
Time	3.45 p.m.		

Remarks. The 3ϕ meter found to be very dirty. The counter, bearings, and gaps were thoroughly cleaned. The jewel was found to be in good condition. The gasket was greased before replacing the cover.

The 1ϕ meters were found to be in good condition owing to well-fitting covers.

The M.D.I. was reset to zero.

Tester....... ... . . *I. Ryson*

FIG. 173. REPORT SHEET FOR WORK DONE ON CONSUMER'S PREMISES

Maintenance Outfit. A tester will require a kit of tools for carrying out maintenance work, and the following combination has been found very useful—

Leather attaché case, 12″ × 9″ × 4½″, with good safety-type clasps, containing: pinion driver, screwdriver, pliers, set of spanners, time-switch key, sealing pliers, tweezers, binding wire, seals, fuse wire, test lamp, one or two feathers, tube of seccotine, small tin of vaseline, emery paper, and essential spare parts (such as the commoner types of jewels, pivots, cover nuts, etc.) If working on D.C. meters, a pair of rubber overshoes is often necessary. The test lamp may with advantage be a neon lamp, since this lamp enables the live line to be detected even though no earth connection may be available. It also enables the tester to determine if a supply is D.C. or A.C. The testing assistant should also carry a stop-watch, to enable him to measure the consumer's load, or roughly check the meter accuracy, at the time of visit.

A special notebook must be kept for recording the data obtained on maintenance work. Full particulars of all meters on the consumers' premises should be taken at the time of visit, in order to avoid confusion when the test report is sent in to the office. A typical test report is shown in Fig. 173.

The tester must always notify a representative of the consumer before making any adjustments to the meter. This is particularly important in the case of M.D.I. meters, the readings of which must be checked by the representative before the tester removes the seals.

Periodic Changes. Experience has shown that a regular periodical test and/or change programme is most essential if the undertaking's revenue is to be maintained and the system losses are to be kept low. Large capacity meters should be tested once a year, whilst other meters should be changed at average intervals of three years for medium-sized power consumers, five years for P.P. meters or D.C. quarterly meters, and ten years for A.C. quarterly meters.

In the course of this work, opportunity is presented for doing other very valuable maintenance work on the service or consumer's installation. (Many old installations are in a deplorable state and ought to be brought up to date for the consumer's safety.)

Factory Act and Commissioners' Regulations. Before attempting any work on consumers' premises or in substations testers *must* carefully read the Factory Act Electricity Regulations and the 1937 Regulations of the Electricity Commissioners. They *must* also obey any local regulations of their undertaking.

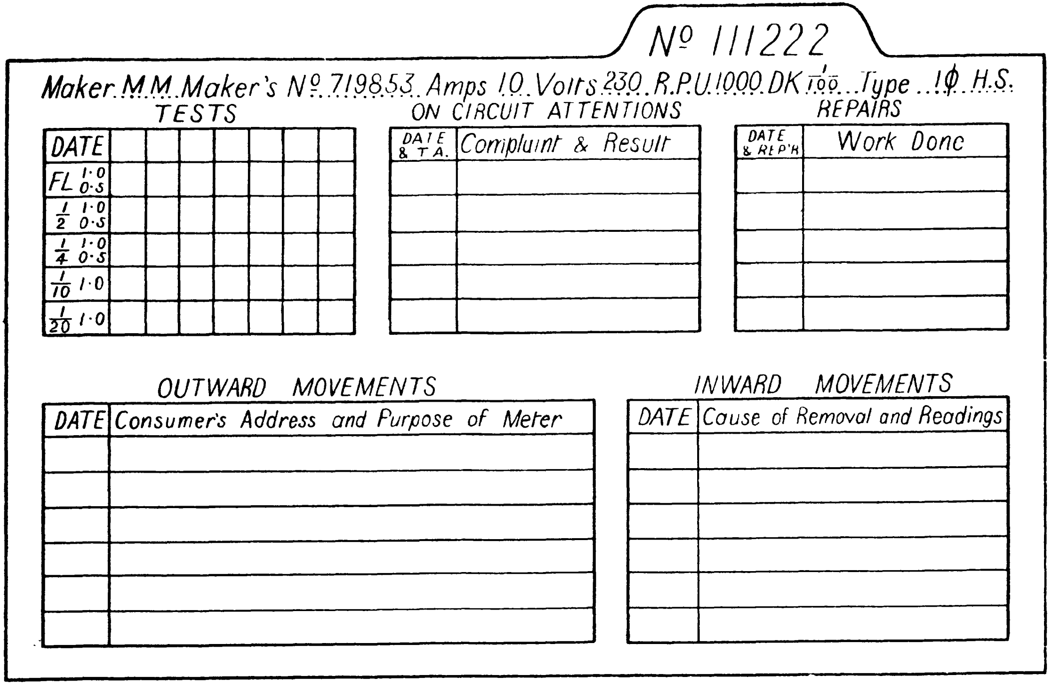
CHAPTER XX

METER DEPARTMENT OFFICE, STORES, AND WORKSHOP

IN this chapter we are going to consider the procedure which follows, or initiates, the work of the tester, the meter fixer, the meter reader, and the meter repairer. After a new meter has been tested, the test card is forwarded to the office, and a clerk transfers the essential data to a file card, as shown in Fig. 174. These file cards are kept in drawers in numerical order, and the cards are designed so that all the numbers (undertaking's numbers) are immediately readable. It is also necessary to have cards of different colours and phrasing to suit the different classes of meters.

Until recently it was the custom for testing departments to receive meters without special undertaking's numbers, and thus the first duty of the clerk, after entering up the file cards, was to issue meter cards and number plates to the stores attendant. The latter fixed the number plates and attached the meter cards to the appropriate meters. Nowadays, however, it is usual for the manufacturers to supply meters with suitable internal plates for the undertaking's numbers and also to supply the meters with numbers (allotted by the head clerk when ordering the meters) already engraved or stamped. This method has many advantages, the chief being that the meter need not be opened, after it has left the test room, until attention is required on circuit. The internal number plate also avoids a number being made indecipherable by corrosion or dirt. If the numbers are not engraved by the manufacturers, they are done on the engraving machine in the repair shop whilst the meters are being tested.

With the above system in operation, the work of the initial clerk is confined to issuing an outgoing meter card to the stores attendant for each new meter test card received, filling up the file card, and adding the meter number to a list of accepted meters, which is forwarded to the Financial Department for payment purposes. The meter test cards are stored for some time before they are destroyed, except in the case of special meters, for which all records are important. The outgoing meter card should be made of stiff paper, so as to avoid its being crumpled and the writing made illegible. Meters other than new are treated in a manner which will be apparent when the histories of an issued meter and an off-circuit meter are described.



No 111222

Maker M.M. Maker's No 719853 Amps 10 Volts 230 R.P.U. 1000 DK $\frac{1}{100}$ Type 1φ H.S.

TESTS

DATE							
FL 1·0 0·5							
$\frac{1}{2}$ 1·0 0·5							
$\frac{1}{4}$ 1·0 0·5							
$\frac{1}{10}$ 1·0							
$\frac{1}{20}$ 1·0							

ON CIRCUIT ATTENTIONS

DATE & T.A.	Complaint & Result

REPAIRS

DATE & REP'R	Work Done

OUTWARD MOVEMENTS

DATE	Consumer's Address and Purpose of Meter

INWARD MOVEMENTS

DATE	Cause of Removal and Readings

FIG. 174. METER FILE CARD

The stores are fitted with suitable racks and shelves to house the meters and the various accessories, and in the case of large capacity meters the arrangement should be such that each meter is immediately accessible. This enables any particular meter (if stored in capacity order) to be readily found and inspected or issued. Ordinary low capacity house service meters may be stored *en masse*, provided a scheme is arranged to issue the oldest tested meters first, since it is not necessary to lay hands on meters of particular numbers. The attendants issue meters on the receipt of an order from a responsible department, and it will be assumed for the purpose of this description that a new meter has been issued to a meter fixer. When the meter has been fixed, the fixer fills up the meter card as required (see Fig. 175) and returns the card to the office. The meter card information is entered up on the file card by a clerk, and a notification sent to the meter reading section that meter number XY has been fixed on a certain consumer's premises to measure a particular supply in a particular manner. The meter reading department should have two filing systems, one under consumers' names and the other under streets, owing to the frequent change of tenancy in many districts.

OUTGOING METER CARD

Maker........*A. B.*........ Maker's No.. ....*333141*....... ....

Undertaking's No. ....*99887* ....

Amperes........*50* ... Volts........*230* ... .. Type *Single-phase H.S.*

Meter installed at: ....*T. Jones* ....

...........*23 Adelaide St., Lowtown* .. ..

To measure ....*Total Supply on All-in System*...... ....

Fixed by.. ... *N. Caffery*........ Date ....*10/11/34*...... ....

N.B. The meter readings must be at zero when meter is installed.

FIG. 175. OUTGOING METER CARD

Suppose now that the meter has to be removed due to some cause or other. Before removing the meter, the fixer enters up an ingoing meter card, as shown in Fig. 176. When the meter is received in the stores, the reading is checked to see if it agrees with that written on the card, and the card is then sent to the office. A clerk enters up the necessary data on the file card and afterwards notifies the meter reading section of the alteration.

"Off-circuit" meters are investigated by the foreman in charge of the repair shop, and (if there is no scheme in force for determining the errors of O.C. meters) those which require attention are sent forthwith to the repair shop. The others are stored in special bins until they can be taken by the testing sections for testing purposes. In the case of special meters, the foreman would probably have the assistance of the testers concerned before making a decision. A report of the attention received by every meter handled by the repair shop is sent to the office to be entered up on the file card.

INGOING METER CARD

Maker *L. M.* Maker's No. *776819*
Undertaking's No. *34178*
Amperes *5* Volts *200* Type *D.C. Ampere-hour*
Meter removed from: *L. Thomason*
44 Bloom St., City
Meter measured: *Lighting supply*
Removed by: *R. Roping* Date *17/3/33*
Readings when removed: *1275 kWh*
Reason for removal: *Leaky mercury bath*

FIG. 176. INGOING METER CARD

The office will eventually receive a test card from the testing section in respect of all off-circuit meters, and the procedure regarding the outgoing meter card and file card is gone through again. Any special changes in the meter should be carefully noted on the file card.

The clerical procedure in respect of time switches, potential transformers, current transformers, and shunts is similar to that described above for meters. It is best for the undertaking to apply its own numbers to these components, as the maker's numbers are even more subject to disaster than those on meters, besides the danger of clashing.

Instead of the file card system, some undertakings prefer to use special ledgers, and in place of the test cards, special test books. Objections are sometimes raised against file cards that they are easily lost or misplaced in the filing box, whereas it is hardly possible to misplace a large ledger. On the other hand, only one person at a time can use a ledger, and this may interfere with the work of the clerks. Furthermore, it is an easy matter to replace a card when the old one is completely filled up. The test book has the advantage over test cards of ease of future reference, but it is not so convenient on the test bench. If the test card has to be filed, then it is usual to use a sheet of ruled paper to get the test results, and enter them on the test card on a writing desk for the sake of neatness.

CONSUMER'S COMPLAINT, No. 3451

Consumer:		*L. Williams*	
Address:		*15 Siddall St., Moor Park*	
Meter No.:		*44781*	*55623*
Amperes:		*5*	*20*
Volts:		*230*	*230*
Type:		*1ϕ.2w*	*1ϕ.2w*
Year of Issue:		*1926*	*1929*
Purpose:		*Lighting*	*Heating*
Last Reading:	*12/4/33*	*1261*	*9726* kWh
Prev. Reading:	*11/1/33*	*1201*	*9321* kWh

Complaint : Very large consumption, compared with last year, on lighting supply.

Corresponding consumption last year = 18 kWh.

Engineer's Report : Meters found to be in order. Increased consumption due to using a new wireless set on the lighting circuit, instead of the heating circuit. 28/4/33. J. L. F.

FIG. 177. CONSUMER'S COMPLAINT FORM

Another scheme which has been found very successful is to make out two file cards for each meter—one a Road Index Card and the other a Test Card. These two cards are filed separately, the Road Index Card going in the appropriate street drawer or stock drawer, and the Test Card going in the appropriate maker's drawer (in maker's number and size order, as an undertaking's number is not desirable in this scheme) or stock drawer. The cards are, of course, suitably coloured and number tagged on a definite pre-arranged code.

After the meters are tested, labels are made out and tied to them. The storekeeper issues the meters in the usual stores manner, and at the end of the day he receives back from the meter fixers the labels duly entered up with all fixing particulars. (These are cross-checked with the issues to see that no meters are lost.) From the particulars on each label, the meter clerk makes the necessary entries on the two index cards (the address goes on the Test Card, of course, as well) and in the Day Ledger. The file cards are then placed in the appropriate drawers, and (when a page is filled up) the Day Ledger sheet is torn out and forwarded to the Accounts Department. The Day Ledger contains a carbon copy of each sheet for cross-checking and statistical purposes. From the Ledger Sheets the Accounts Department make out the necessary reading sheets or reading sheet alterations, and also check up with other returns to ensure definitely that no error has occurred in the various bookings. It will be appreciated that a simple error of statement might have serious consequences, e.g. if the fixer marked the meter for lighting instead of power.

If a meter is removed from circuit, the meter fixer hands it to the storekeeper with a special Off-circuit Tag clearly describing the necessary particulars about the meter. The storekeeper or clerk checks the particulars written on the tag, and then enters up the two file cards in the appropriate manner. The two cards are then placed in the respective stock drawers, after entering in the Day Ledger the necessary information. Much clerical labour is saved if fixed and removed meters from the same address are placed adjacent to each other.

The advantages of the double file card systems are—

(1) A meter can be traced either from its number or the consumer's address. This overcomes certain disadvantages of the file card system, besides its inherent convenience.

(2) Only the Test Cards are taken away from the stock drawers into the Test Room and thus, even if a Test Card is lost, the clerk still has the Road Index Card to keep a track of the meter.

(3) If the ledger clerk makes a mistake, there are more chances of discovering the error.

(4) The complete card index system is a valuable insurance in case a disastrous fire should ruin the Accounts Department records.

(5) It is advisable to do periodical meter changes in street order, and the Road Index Files prove invaluable for this work.

On-circuit Test Reports. The majority of complaints and testing requests are first received by the office, and it is necessary for other sections who forward regular classes of complaints, etc., to use special printed forms for the purpose. An example of a form suitable for a consumer's complaint is given by Fig. 177, and the example shows how the information is sent to the meter department and how the engineer's report is entered up, after receiving the tester's personal report (see Fig. 173). The printed form is an advantage to the tester visiting the consumer's premises, owing to the stamp of authority which it conveys.

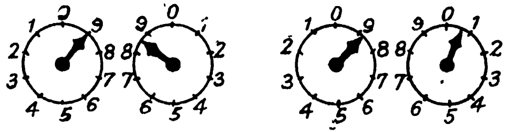
The office staff sort out the various complaints and testing requests, and issue them to the appropriate sections. When the tester's reports are received by the head of the testing section concerned, he enters up on the form the necessary comments, information, or instructions in the space provided. The form and report are then sent to the office, where the clerks forward the form to the appropriate department; give suitable instructions to other departments if so requested by the meter engineer; file away the testers' reports alphabetically; and if such a test affects the meter, then the necessary particulars are entered up on the meter file card. Also, the leading particulars of each testing request and its report are entered in a Day Book, in order to enable the amount of "on-circuit" work done in any period to be easily ascertained and analysed. An alternative method is to use duplicate books for the tester's reports, so that a copy is retained in the Test Room of all such reports. This method is very useful, since occasionally office boys do lose memos.

Meter Reading. The method of payment usually divides the consumers of an undertaking into the following groups—

1. Prepayment.
2. Weekly payment.
3. Monthly payment.
4. Quarterly payment.

Thus the scheme whereby the readings are taken will have to be divided into four sections and each treated on its own merits. Owing to their small number, the work of reading the meters for weekly and monthly consumers, and issuing bills, is relatively simple. The monthly consumers are often those equipped with M.D.I. meters, so it is preferable to keep this work in the hands of two or three reliable men who can be trusted to reset the D.I.'s and wind the time switches properly, as well as take accurate readings of check meters. If certain types of D.I.'s and time switches are not treated correctly, they are liable to give trouble. The monthly periods will not necessarily commence at the beginning of a calendar month for every consumer, of course.

In the case of quarterly consumers, many undertakings have now introduced special mechanized accounting systems which greatly reduce the amount of clerical work involved in issuing bills. Such systems are only profitable, however, to the larger undertakings, and the smaller ones must perforce still employ clerks to make out the bills from the meter reading books or file cards. It is usual to provide the meter readers with special books in which to put down the readings taken on the consumers' premises. The backs should be very stiff and should project over the leaves, which must be of high grade paper, by at least half an inch. Special pockets should be made in the meter readers' uniforms so that the books can be placed in a dry place during their journeys between premises. These precautions will reduce the danger of damage due to inclement weather. It is absolutely essential to make quite clear in these books the purpose of each meter and the tariff on which each supply is charged. The following points regarding the reading of meters will be of interest.



Reading equals 88, not 98. *Reading equals 90, not 80.*

FIG. 178. PRECAUTIONS DUE TO ECCENTRIC DIAL POINTERS

Meter Reading. The reading of a pointer type counter is a perfectly straightforward job if the following rules are obeyed—

1. If a pointer is between two numbers, read the lower one, except when the pointer is between 9 and 0, when the figure 9 is read.

2. Start the reading at the pointer which has the highest value.

3. Notice if the decimal position of a pointer between two numbers agrees with the number indicated by the following pointer. Sometimes it will be found that rule 1 has to be broken owing to the pointer being eccentric or twisted, and rule 3 will lead to a correct solution of the reading. This point is illustrated by Fig. 178.

4. The multiplier of the last (lowest) dial is noted, i.e. M_1. (Except in the case of dial testing, it is not usual to read the decimal placing of the last pointer, or below the units dial.)

5. If there is a further multiplier due to a special cause, that also must be noted. Let this be M_2.

6. The reading of the meter in the units being measured equals numerical reading $\times M_1 \times M_2$ units.

The numerical reading of a cyclometer type counter is obvious.

The work in connection with prepayment consumers is more difficult for the meter readers than in the case of quarterly consumers owing to the additional readings which have to be taken at each visit, the handling of money, and the issue of receipts. In some cases the reader also has to set up the fixed charge element, if a two-part tariff meter is employed. On the other hand, the clerical work is reduced, since, even though the amount of checking work is increased, no bills have to be issued.

Checking. As the work of making out consumers' bills and the checking of prepayment meter records proceeds, the clerks also look out for any special points, such as—

1. If the meter reading is still at zero, is this state of affairs in order?
2. If the advance during a period is zero, or very low compared with corresponding quarters, does it appear likely that the meter is faulty?
3. If the advance during a period shows a great increase, does it appear likely that the circuit is being overloaded, or that the consumer is using apparatus on the wrong supply, e.g. a radiator on a lighting supply?
4. Where duplicate meters are installed, are the advances within 3 per cent of each other?
5. If a meter has a number of sub-meters, does the sum of sub-meter advances equal the advance of the master meter within ± 3 per cent?

In some cases it is advisable for the meter reader to make a second visit, to see if the previous readings were correct, before forwarding a complaint to the testing section.

It will be realized, of course, that the above descriptions of clerical systems and routine are only given for the purpose of illustrating the needs and difficulties involved. Every undertaking has its own scheme already in existence which has been planned by the chief engineer or commercial manager to suit the requirements of the undertaking concerned. It is due to the widely varying local conditions that the system of meter clerical work is different in every undertaking. Every system has its weak point—usually the human element—and it is imperative that meter engineers should do their utmost to make their own particular system work satisfactorily by taking all possible precautions. For instance, a scheme might be made more watertight by insisting on each meter fixer keeping a Day Book recording every job done by him each day.

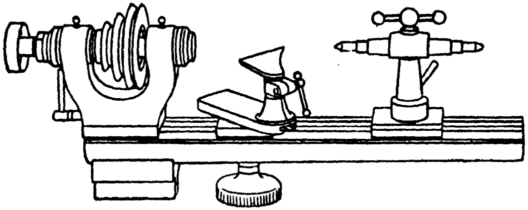
REPAIR SHOP

Although a description of the repair shop has been left until the end of the book, it must not be thought that it is of small importance compared with the other sections of meter work. In fact, it is the author's considered opinion that an efficient repair shop is vital to the well-being of the Meter Department, and it is to be regretted that there are fewer high-grade meter mechanics than there are high-grade testers. It is absolutely necessary to have at least one skilled craftsman in the repair shop if one expects to tackle successfully the numerous speciality jobs that continually occur in supply undertakings. In addition to purely meter work, the services of such a man are invaluable in assisting other departments out of difficulties.

FIG. 179. TYPICAL METER REPAIR SHOP

To be capable of any repair or conversion work on clocks, meters, relays, and instruments, the repair shop must be equipped with the proper machinery and tools as follows—

A 3-in. lathe, large and small drilling machines, emery wheel, grindstone, variable speed jeweller's chuck, one or more buffing spindles, air compressor, binocular microscope, full range of twist drills, range of strong adjustable spanners, special drills for jewel setting, disc trueing stands, airguns on each bench, adjustable meter stands, 3-in. bench vices, etc. The workmen will each possess their own kit of small tools, except cutting tools, which are provided by the department. An illustration of a typical repair shop is shown in Fig. 179, and the following points will be noted: (*a*) the meter stands; (*b*) the wide space allotted to each repairer; (*c*) the adjustable electric light fittings, which are necessary, even though the benches are placed near wide spacious windows, because there is no reasonable amount of daylight available for a large part of the year; and (*d*) the motor-driven buffing wheel and emery wheel.



(*R. Pringle & Son, Ltd.*)

FIG. 180A. JEWELLER'S CHUCK OR LATHE

Probably the chief routine work of the repair shop is that of overhauling the bearings of meter rotors and trains, and consequently before dealing with specific types of meters it will be advantageous to deal with this common factor.

It should be pointed out here, by the way, that a lot of money can be saved by living up to the name of the section, that is, by repairing meters and not merely fitting brand new components on every job.

Pivots. The treatment given will naturally depend on the condition of the pivot and the repairer's judgment, and the only rule that can be laid down is that when the pivot is finished its condition must be as good as new (sometimes better). By describing the treatment for a very bad pivot, the entire process will be laid bare and this will cover the detail requirements also.

The pivot is placed in the jeweller's chuck (see Fig. 180A) and checked for truth of running. By means of a fine oilstone, the pivot end is then reshaped to the desired contour. The pivot is then given a "lick" with a burnisher, but it is very important not to use the burnisher excessively, because such treatment tends to form a brittle skin on the pivot which will crack or flake under wear. The purpose of the burnisher is to make the pivot surface "flow" just sufficiently to get rid of the roughnesses left by the oil stone. The pivot is then given a final polish on a linen mop —fixed on a buffing spindle—which has just a trace of metal polish in it. The mop is, of course, prepared for this purpose by a tool which rips up the rim of the mop until it is soft and feathery. The pivot is oscillated in this soft portion (it is usually held in a pin vice) and not the more solid part of the mop. It is essential to clean the pivot thoroughly after polishing, in order to remove dirt and traces of metal polish. After this treatment, the pivot is inspected by means of the binocular microscope (see Fig. 180B). The radius of curvature of the pivot tip can be easily estimated when desired by comparing its size under the microscope with a steel ball or gauge of the correct radius. The ball is held in the field of view by means of a magnetized needle.

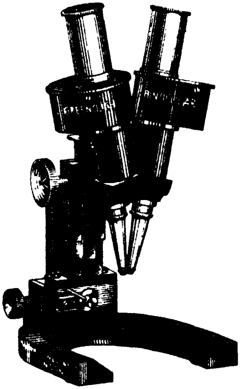


FIG. 180B. BINOCULAR MICROSCOPE

It is most essential for trainees or apprentices to be able to see that they have learned the correct method—and this can only be done by checking the results under the microscope, since the watchmaker's glass is not sufficiently powerful. If a little thought is given to the question of loss of revenue by bearing deterioration, it will be seen that a binocular microscope is a paying proposition for even the smallest undertaking.

As an average figure, the radius of curvature of the pivot may be taken as 0·025 in., but this figure varies considerably according to the make and type of meter.

The repaired pivot tip must be spherical, i.e. without flats, and it must be realized that the shape is controlled by the oilstone process. The burnishing and polishing processes cannot re-shape the tip, and their purpose is simply to get rid successively of the oilstone and burnisher score marks, so as to give the smooth highly polished surface which is essential for a long efficient life.

Other polishing mediums which are used are diamantine and rouge, but the pivot is not so easily cleaned after using these as it is with metal polish, nor is the polish obtained any better. Rouge or diamantine is usually applied by peg wood, after making it into a paste with oil, whilst the pivot is in the lathe.

Jewels. The jewels of meters under repair are carefully cleaned and then inspected under the binocular microscope. If the examination shows any serious signs of wear—such as pits, cracks, annular scores or deep wear rings—then the jewel is replaced by a fresh one.

There are two ways of doing this. One is simply to fit a new jewel plus setting supplied by the makers, and the other is to replace the faulty jewel by a new jewel. The jewels in the latter case may be supplied by the makers or purchased separately from the jewel manufacturers.

The question of long-life jewels has already been discussed on page 92, and it is clearly very advantageous to replace all faulty jewels by jewels having the correct cutting plane. In addition, it is usually much cheaper to fit a replacement jewel than it is to buy a complete spare. The argument that the original brass jewel setting will often not withstand this operation more than once is met by the fact that it is often easy to make new settings from brass rod or purchase the settings only. If a few special seat cutting tools (centred through the tailstock) are made, then the work of jewel resetting becomes very simple and accurate. The hardest part of the work is the care required not to put the jewel under strain when turning over the binding edge, or to leave brass wire at the binding. The jewel and pivot are, of course, lubricated during the process of assembly, for the reasons given on page 92. To prevent the oil creeping away from the pivot or jewel cup, certain engineers treat the surrounding metal surfaces with a special fluid (see page 93) but care should be taken to keep this varnish out of the working area.

Pintle Bearings. There is a tendency in many quarters to pay little regard to the top bearing, as it is considered to be only a guide. This attitude is quite wrong, however, since the presence of the recording train sets up a side thrust (as well as the unbalanced driving torque or mechanical out-of-balance of the rotor); consequently unwanted friction results if the pintle bearing is not in good order. It is essential therefore for the pin wire to be free from burrs (one make of top pin was actually issued with the end fresh from the cutting pliers) and nicely polished. The brass bush must also have a nice smooth hole in it to receive the pin wire, and it should be mentioned here that brass is a very uncertain material. Some bushes will last for many years, whilst others become rough in a very short time. If the round broaching of the bush makes the top pin a sloppy fit, it will be necessary to fit either a new pin or a new bush, whichever is the cheaper.

Trains. This work falls into two main categories: (*a*) trains in very bad condition and (*b*) trains in reasonable condition. The former type have to be taken completely down and thoroughly cleaned with petrol and rottenstone brushing—the bearing holes being afterwards cleaned out with peg wood. The wheels and spindles are treated similarly. Before re-assembly, any faulty spindle or bearing holes are repaired (e.g. badly worn holes are made round, then filled with a slightly taper plug driven tightly home, cut off flush with the plate, and then drilled for the new hole of the proper size).

The latter type usually receive a general petrol brushing, and possibly individual attention is given to one or two important bearings and spindles. For instance, even if a kWh train is in good general order, it is advisable to overhaul the first spindle bearing. It is desirable to put the train under an air blast after the petrol brushing in order to remove all trace of petrol.

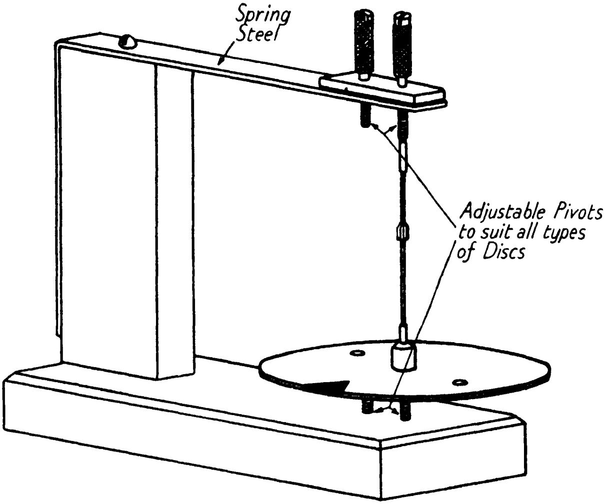


FIG. 181. DISC TRUEING DEVICE

Disc Trueing. An untrue disc not only looks bad, but it is also a serious practical defect. The gaps in electro-magnets and brake-magnets are kept to a minimum size for the sake of efficiency, and therefore disc clearances are small enough even in the perfect meter. If the disc is untrue, it means that all the parts have to be set "just so" in order to avoid any rubbing or catching of the disc. This means that there is no allowance left for any slight movements of the parts caused by transport or fixing, and that the narrow clearances cause the disc to be fouled by even a small particle of dirt or foreign matter.

Before re-assembling a motor meter, it is therefore necessary to true the disc very carefully. Although some repairers can manage certain types by hand spinning, it is easier to make and use an adjustable support (see Fig. 181). Any bending of the disc must not be done whilst in the support in order to prevent damage to the bearings. The art of disc trueing can only be acquired by practice, but a little experience soon guides the apprentice to the source of the erratic running.

Some discs are very easy to true up, but others have various defects, such as: (1) jewel setting out of true due to badly-cut thread; (2) disc loose on spindle (some collars become loose at the slightest strain); (3) jewel loose in seating; and (4) bent top pin, etc., which are not so immediately obvious as a buckled disc. The remedies are clear, although care and patience are required to carry them out.

Repairing D.C. Mercury Motor Meters. It was pointed out in the chapters on D.C. mercury meters how serious is the effect of friction on the error curve of such meters, since very few of them have friction compensators. Therefore it will not be surprising to find that the work of repairing a mercury meter involves dismantling the meter, cleaning all bearings, cleaning the magnet gaps and bath thoroughly, polishing the pivot (regrinding first if necessary), fitting a new jewel if the existing one is found to be faulty, polishing the top pin and its bush, and trueing the disc, if necessary, before again assembling the meter. Any special defects, such as a faulty insulator, leaky bath, etc. (for which the meter may have been reported), are rectified during the course of re-assembly. After assembly the bath is filled with clean mercury, and it will be of interest to give here two methods of cleaning mercury.

Cleaning Mercury. 1. Filter two or three times through filter paper funnel. This will remove the larger particles of dirt if the hole in the funnel end is kept small.

2. Squeeze through a chamois leather. This will remove the greater part of the finer dirt.

3. Wash in a dilute solution of nitric acid; one part of acid to five parts of water by volume.

4. Wash in water to remove the scum and most of the acid.

5. Wash in a very dilute solution of caustic soda to remove all trace of acid.

6. Wash in water to clear out the alkali thoroughly.

7. Dry in oven, care being taken to see that the oven is clean and will not deposit scale into the mercury. The mercury is now bottled ready for use.

The above method is not suited, of course, to cleaning large quantities at once, and certain meter departments have developed special devices to overcome this difficulty. These utilize either motor-driven washing paddles in cylindrical bowls, or a continuous process in which particles of mercury are allowed to fall through a series of jars containing the various required chemicals. It is important to note that the mechanical washer has to be very strongly made (of materials which are not affected by mercury or the various chemicals used) owing to the high density of mercury.

An alternative method is the distillation process, which gives far better results than the washing method, provided the mercury is rough cleaned and distilled before being passed through the final distillation process. The construction of such a plant should only be attempted by suitably qualified engineers. It is possible, however, to purchase an equipment of this type from Messrs. Baird & Tatlock (London), Ltd. (See *Electrical Review*, Vol. CXXII, page 119, July 22, 1938.)

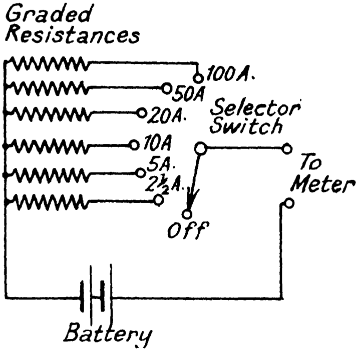


FIG.. 182. STARTING CURRENT TESTER FOR D.C. A.H.M.'S

Magnet Flashing. The mercury motor A.H.M. gives a very poor error curve if the driving magnet weakens appreciably, and it is therefore desirable to have some means of bringing a weakened magnet back to normal strength. As the magnet is usually encumbered with various meter parts (it is not advisable to remove the pole pieces of a magnet owing to the risk of seriously demagnetizing the magnet) it is not easy to use the method of winding the magnet with a number of turns and passing a heavy direct current (in the right direction) through the winding. To overcome this difficulty, it is possible to obtain special devices to enable magnets to be flashed with a minimum of trouble. These devices consist of divided solenoids in which the complete coil is obtained by inserting the bare wires of one-half into mercury pots fixed to the corresponding wire ends of the other half. The coil is shaped so as to suit the type of magnet being flashed, and naturally the mercury pot portion is the lower and stationary part of the device. If the flashing current is drawn from a low voltage battery, it is unnecessary to use a switch to make and break the circuit, as a pair of bare stiff wires is sufficient. If, however, the D.C. mains are used, it is necessary to employ a switch which is backed up by a circuit-breaker. As regards the number of ampere-turns required to flash a magnet, it is advisable to obtain the advice of the manufacturer.

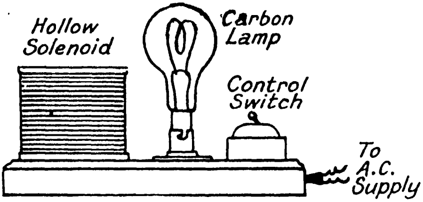


FIG. 183. DEMAGNETIZER

The lamp is in series with the solenoid and switch

Starting Current Test. The workman's criterion of a well-repaired D.C. ampere-hour meter is the lowness of the current required to keep the rotor in motion. It is therefore necessary to provide the workshop with the equipment outlined in Fig. 182. The various tappings give the starting current for the size of meter indicated. If the rotor runs satisfactorily on the appropriate starting current, the workman can feel that the amount of friction is not excessive, and that the meter will behave itself on test. If it is desired to test watt-hour meters in this manner, it is easy to provide the requisite D.C. pressure supply.

Owing to their being used near strong brake magnets, the tools become magnetized, which makes it difficult to handle iron screws, etc. The tools may be demagnetized by the device shown in Fig. 183.

Repairing Pendulum Meters. This type of meter is, fundamentally, a pair of pendulum clocks, and thus it is desirable that the meter mechanic entrusted with the repairs to these meters should have had clock repairing experience. He should also know how to repair switch contacts owing to the wear and tear on these parts.

Repairing Induction Meters. With the majority of A.C. induction meters, it is fortunately unnecessary to do more than dismantle the counter, the rotor, and the rotor bearings to effect

Prepayment Meters. The routine work of overhauling bearings and trains has already been discussed, so all that need be given here are a few hints on special points. Although the special construction of individual meters precludes any general statement of procedure, it is hoped that by these hints the reader will appreciate the purpose of the repair shop.

Departments using relatively old patterns of P.P. meters have found certain parts to be defective, and consequently these parts have to be replaced or repaired during the process of overhaul. In one meter, brass spindles running in steel plates were employed and, after service, the brass pivots were found to be badly worn. The two ways of repairing this fault are: (*a*) drilling the arbors and driving in steel (spoke wire) spindles, and then broaching the bearing holes to suit the new spindles; or (*b*) obtaining new steel spindles from the makers and transferring the brass wheels to them.

In another meter the contact springs of the electrical tripping mechanism are too strong to allow the contacts to close on very light loads, and these springs must be replaced by lighter ones.

Ratchet mechanisms are not correctly shaped on certain meters, and the pawls should therefore be filed to make their operation more precise and less liable to cause wear of the ratchet wheel.

Plated surfaces do not make good sliding surfaces, and meters incorporating such a feature require the plating removing if possible or, alternatively, a liberal dose of suitable lubricant.

On some meters the live switch parts are dangerously near the metal cover, but by careful adjustment they can be set back enough to avoid fuse blowing troubles.

Bakelite cases and covers for P.P. meters are rather expensive, and it is much cheaper to repair certain breakages than to buy new covers or cases. The procedure depends upon the breakage, but correctly placed tiny set screws and a dose of seccotine can work wonders.

One make of penny coin chute is subject to rather rapid wear, and to avoid future trouble it is necessary to braze metal risers on to the worn parts and recess the opposite riding plate.

CHAPTER XXI

EFFECT OF THE ELECTRICITY SUPPLY (METERS) ACT, 1936

THE law case of *Joseph* v. *East Ham Corporation* revealed that, with the exception of the London County Council, no electricity supply authority in Great Britain was strictly carrying out the provisions of the 1899 Act regarding electricity meters. In order to remedy this state of affairs, an Act was passed through Parliament giving the Electricity Commissioners extended powers over the construction of meters, the testing of meters, testing equipment, and the settling of cases where consumers dispute the meter accuracy or readings. The Act itself is rather vague, and the real law is to be found in the Regulations issued by the Electricity Commissioners in 1937 and later.

The problems before the Commissioners were not easy to solve, and in view of their magnitude and variety, it is not surprising that two years elapsed before the Minister of Transport was able to put the Act into full operation. There were also the difficulties that the sources of supply for equipment are very few, that the N.P.L. has only a limited capacity as regards the certifying of electrical sub-standards, and that a trained staff of Meter Examiners had to be organized and developed. Let us consider, therefore, the outstanding changes brought about by the Act and the Commissioners' regulations, leaving the reader to purchase the full series of regulations and memoranda published very cheaply by His Majesty's Stationery Office, if he desires detailed information.

Legal Error Limits. The Commissioners have superseded the old B.O.T. limits by one set of limits for all kinds of meters, viz. + 2½ per cent to − 3½ per cent, which is a great simplification. At the time of writing there are no "ifs" and buts" attached to these limits, except that they are applicable to mercury motor ampere-hour meters only at 59° F. or 15° C., and that the Commissioners do not expect meters to be offered for certification outside the limits + 2 per cent to − 3 per cent.

Ordinary Meters. The Act is only concerned with ordinary meters. Thus any consumers who are supplied under the terms of a special agreement do not come within the scope of the new regulations. Whilst this may seem very peculiar, it does not—or ought not to—create any concern, because any meter engineer worth his salt will already have taken steps to see that large consumers' meters are within closer error limits than the legal ones.

Maximum Demand Indicators. M.D.I.'s of any type do not rank as meters, and they are therefore outside the provisions of the regulations. Even if the M.D.I. is combined with a kWh meter, it still does not qualify in any way for certification. This again will not cause much concern, because in most undertakings all maximum demand consumers have special agreements.

Transition Period. As it would be quite impossible to have all existing meters certified in a short period after the Appointed Day, (1st July, 1938), the Act allows all meters in use on 1st July, 1938, to be treated as certified meters until they are first disconnected or until ten years have elapsed, whichever is the shorter period. This means that all undertakings will have to institute some scheme of periodical change in order to ensure that by ten years after the Appointed Day al lordinary meters will be certified meters of approved patterns. In budgeting for such a scheme, due allowance will no doubt be made for the large numbers of meters which are automatically changed due to change of consumer, change of tariff, increased loads, etc. The 1947 Electricity Supply Act extended the transition period to fifteen years after the Appointed Day.

Meter Examiners. The Government officials appointed to see that the terms of the Act are duly complied with are—

(1) The Chief Meter Examiner, who is directly responsible to the Electricity Commissioners;

(2) Area Meter Examiners stationed (initially) at Manchester, Leeds, Glasgow, North London and South London; and

(3) Assistant Meter Examiners.

Each Area Meter Examiner has allotted to him a number of Assistant Meter Examiners, who are stationed at convenient points in each area.

The first duty carried out by these Examiners was that of ensuring the adequacy of the testing equipment in every test room. To enable this work to be carried out smoothly, the majority of equipment was given a year's temporary approval, during which period the undertakings had to forward same to the N.P.L. to see if they complied with the requirements specified in the Regulations. If so, they were given a continuing certificate of approval by the Commissioners. Certain sub-standards not strictly complying with the Regulations in matters of small practical importance, or where the errors were only just outside the limits, were given a five-years' period of approval, provided they had been purchased before 1st June, 1937.

As wattmeters have not to be used below 40 per cent of full-scale reading, or R.S.S.'s below one-quarter load, the examiners also had to investigate all test benches to see if the testing circuits gave the necessary amount of control. Although the regulations say very little directly about the testing benches, quite a lot is said indirectly in the methods laid down for testing meters. For instance, although voltage control is not mentioned, the examiners will no doubt expect testing voltages to be within about 1 per cent of the specified testing voltage. In the past very little attention has been given to exactitude of voltage, and this will mean that many equipments will now have to have voltage controls added.

The next duty of the examiners was to work out the system of visiting meter departments for certifying meters. Owing to the varying outputs of meters, it was clear that some undertakings required more attention than others, even though no undertaking apparently justified the constant attendance of an Assistant Meter Examiner. The visits were worked out as well as possible, but it was clear from the start that meter departments would have to carry much larger stocks of meters owing to the dead period between the Examiner's visits, during which tested meters would be accumulated but could not be used.

As the Examiners obviously cannot test the entire output of meters, they simply rely on their entire freedom to make a random choice from the meters to be certified, to ensure that the quality of the meters is up to standard. The Act gives the Examiner full power, of course, to use any meter-testing equipment contained in a Meter Department. For each meter certified, the undertaking pays a fee (initially 3d.) to the Electricity Commission, and a set of special certification forms are used to obtain the Examiners' signature of acceptance and for ascertaining the total number certified. The certificates are retained by the Testing Department. The Examiners are not allowed to certify unapproved meters even if their errors are well within the legal limits, but this is not of great importance as the number of unapproved meters is now relatively small.

The other duty of the Examiners (if called upon to do so by the Supply Authority at the request of the consumer) is to investigate cases where the consumer disputes the accuracy of the meter. It is not anticipated that much work will result from this duty, but nevertheless the Examiners are now the deciding authority in the event of a dispute.

Sub-standards and Standardizing. Full details of the Commissioners' requirements for sub-standards are contained in the various regulation booklets, and the object of this section is to discuss reasons rather than technical details of instruments.

The national standards of current, voltage, and resistance are situated at the National Physical Laboratory, and there are three ways of comparing sub-standards with these legal standards (see Appendix V).

METHOD 1. Sending the sub-standards to the N.P.L. for certification.

METHOD 2. Comparing the sub-standards with an indicating instrument which has been certified by the N.P.L.

METHOD 3. Testing the sub-standards on a D.C. potentiometer equipment which has been certified at the N.P.L. This method is, of course, restricted to D.C. instruments, or instruments which are accurate on D.C. or A.C. of the declared frequency.

Method 3 was chosen as being the most suitable, and the Regulations require all Class A Testing Stations to be equipped with a D.C. potentiometer. The reasons for this choice are very interesting, and they are as follows—

(*a*) The legal units of electricity are phrased with respect to direct current only, and consequently both D.C. and A.C. instruments must be referred back to the fundamental D.C. units for standardizing purposes.

(*b*) Fortunately the D.C. potentiometer only requires sub-standard resistances and a sub-standard voltage for its operation; and, as these are easily reproduced with great accuracy and constancy, it constitutes a ready means of comparing instruments with the fundamental D.C. units.

(*c*) The potentiometer is a null-reading device which is capable of far greater accuracy than any indicating instrument.

(*d*) High accuracy of standardizing can only be obtained when the various currents and voltages are extremely steady. Therefore the potentiometer is obviously suited to standardizing work, since steady supplies are a necessary condition for its operation.

(*e*) The N.P.L. is clearly not large enough to deal with all the sub-standards in the country under Method 1.

(*f*) Method 2 did not meet with approval—except for rotating sub-standards—owing to the Commissioners' distrust of certain types of sub-standards or the manner in which they might be used.

(*g*) Since alternating current electrical units are not legally defined, it was felt necessary to confine A.C. indicating sub-standards to instruments which are accurate on both D.C. and A.C. to avoid complications.

The Regulations lay down definite time periods for the re-checking of sub-standards against the potentiometer, or against a wattmeter in the case of a R.S.S. They also specify the expected performance for all types of sub-standards. The requirements for R.S.S.'s have been made particularly stringent, and many manufacturers have developed special highly accurate models to suit the new conditions. This was very necessary on account of the numerous existing R.S.S.'s, which were merely ordinary house service meters placed in a polished wooden case.

DISADVANTAGES OF METHOD 3. Whilst the necessity for Method 3 is quite apparent from the above reasons, the meter engineer must not blind himself to the failings of the potentiometer as regards A.C. standardizing. These drawbacks are as follows—

(*a*) The D.C. potentiometer cannot detect phase angle or transformer effect errors in A.C. sub-standards. Therefore, before the mean of the two sets of D.C. errors can be taken as the A.C. error curve, it is essential to cross-check the instrument against another sub-standard on alternating current.

(*b*) The requirements of the Act make the use of C.T.'s almost inevitable on all A.C. test benches, and consequently it is impossible to use a D.C. potentiometer to standardize a wattmeter under its true working conditions. Now, whilst a C.T. is a very stable piece of apparatus, it is nevertheless still subject to internal and external faults which may cause serious errors. For example, a partial short circuit of the secondary due to two leads touching, causes a ratio error of about 1½ per cent, and it should be noted that errors of the 1 per cent order are far more difficult to detect than 10 per cent errors. It seems very necessary, therefore, for the sub-standard and C.T. to be tested together in their working positions, and this can only be done on A.C.

(*c*) The successful operation of a D.C. potentiometer depends on the tester's skill in avoiding harsh treatment of the standard cells, perseverance in cross-checking results, the steadiness of the battery supplies, and the good insulation of the various parts of the circuit.

In the author's opinion it is therefore essential to use Method 2 (or its equivalent) in addition to Method 3. Experience has shown that to be really satisfied with a test bench as a whole, one must connect a sub-standard where the meters are usually connected, and show that the error in that position is the sum of the C.T. and associated sub-standard errors. If the discrepancy is greater than 0·2 per cent, then one must investigate the trouble.

The use of Method 2 in addition to Method 3 is, of course, outside the legal requirements; but, as in many other walks of life, compliance with legal requirements does not remove the moral responsibility to avoid mistakes.

Standard clocks can be regulated by means of the Broadcast

Time Signals to such high accuracy that it was found unnecessary to send these to the N.P.L. for approval. All stop watches, however, had to be approved by the N.P.L. owing to the more stringent mechanical requirements of such devices. It is a pity that the regulations will not permit the dial to indicate more than 15 sec., because the author considers that the 30-sec. type is more reliable due to the reduced strain on the escapement. Mains-driven synchronous timing devices are not to be used for certification work, but the Commissioners are always prepared to consider the approval of any timing or testing method submitted to them which is satisfactory for its purpose.

Methods of Testing Motor Meters. Up to the time of writing, the Commissioners have approved only three methods for testing motor meters—

METHOD A. LONG-PERIOD DIAL TESTS USING SUB-STANDARD ROTATING METERS. The load on any sub-standard rotating meter to be not less than one-quarter of, or more than one and one-quarter times, its full load. The duration of any such test to correspond to not less than ten complete revolutions of the pointer of the last dial of the meter under test.

METHOD B. (*a*) TESTS (OTHER THAN LONG PERIOD DIAL TESTS) USING SUB-STANDARD ROTATING METERS. The load on any sub-standard rotating meter to be not less than one-quarter of, or more than one and one-quarter times, its full load. The duration of any such test to correspond to the number of complete revolutions of the disc of the meter under test ascertained as follows, namely, by multiplying 40 by the percentage of the marked current of the meter at which the test is being made and dividing by 100, provided that the duration of any test shall correspond to not less than five complete revolutions and need not be greater than a period corresponding to twenty-five complete revolutions.

(*b*) ONE LONG-PERIOD DIAL TEST. To be made in accordance with, and of duration not less than, that prescribed under Method A.

METHOD C. (*a*) TESTS BY SUB-STANDARD INDICATING INSTRUMENTS AND STOP WATCH. The load on any sub-standard indicating instrument to be such as to give a reading of not less than 40 per cent of its full-scale reading. The duration of any such test to correspond to not less than three complete revolutions of the disc of the meter under test, or not less than 100 sec., whichever be the longer period.

(*b*) ONE LONG-PERIOD DIAL TEST. In the case of alternating current meters—to be made in accordance with, and of a duration not less than, that prescribed under Method A.

In the case of direct-current motor meters—to be of a duration not less than that prescribed under Method A.

Actual Tests on Motor Meters. 1. Every motor meter to be tested—

(*a*) At 5 per cent of its marked current or, in the case of a direct-current meter having a marked current of less than 10 amperes, at 10 per cent of its marked current;

(*b*) At one intermediate load; and

(*c*) At 100 per cent of its marked current, or in the case of an alternating-current meter, at 100 or 125 per cent of its marked current.

Provided that in cases where the tests are carried out in accordance with Method B or Method C, the prescribed long-period dial test shall be at one of the loads specified for the three foregoing tests, and shall be additional to such tests.

Provided also that in testing any watt-hour meter, the voltage circuit of the meter and the voltage circuits of the sub-standard rotating instruments used for testing the meter must be energized for a period of at least one hour prior to the making of the actual test.

2. Every alternating-current meter also to be tested at its marked current and marked voltage at 0·5 power-factor (lagging), subject to a tolerance of plus or minus 10 per cent in the power factor.

3. Every watt-hour meter also to be tested for "creep," with its main circuit open, and with a voltage of 10 per cent in excess of its marked voltage applied to its voltage circuit.

4. (*a*) A 3-wire direct current, or single-phase alternating-current meter, may be tested as a 2-wire meter with the current circuits of the two elements of the meter in series and the voltage circuits in parallel.

(*b*) Every 3-wire direct current or single-phase alternating-current meter to be tested for balance of the elements (in the case of watt-hour meters with the voltage circuits energized at the marked voltage)—

(i) with the marked current flowing in either of the two current circuits of the meter and no current flowing in the other current circuit; and

(ii) with half the marked current flowing in both current circuits.

5. (*a*) Every polyphase meter to be tested as such on a circuit of the type for which the meter was designed.

Provided that polyphase meters for 3-phase 4-wire circuits may be tested as 3-phase 3-wire meters without current in the neutral wire.

(*b*) Every polyphase meter to be tested for balance of the elements with the voltage circuits of all the elements energized at the marked voltage, with the marked current flowing in the current circuit of one element and no current flowing in the other current circuit or circuits; such test to be carried out on each of the elements at unity power-factor, and also at 0·5 power-factor (lagging), subject in the latter case to a tolerance of plus or minus 10 per cent in the power-factor.

(*Note.* For testing polyphase meters for 3-phase 3-wire circuits, it will be permissible to use either one polyphase sub-standard wattmeter or sub-standard rotating meter, or two single-phase sub-standard instruments.

For testing polyphase meters for 3-phase 4-wire circuits, it will be permissible to use either one 3-element sub-standard wattmeter or sub-standard rotating meter or three single-phase sub-standard instruments. If the meter is tested as a 3-wire meter in accordance with paragraph 5 (*a*) above, it will be permissible to use either one 2-element sub-standard wattmeter or sub-standard rotating meter, or two single-phase sub-standard instruments.)

METERS OPERATED IN CONJUNCTION WITH TRANSFORMERS OR SHUNTS. Every meter intended for use with a transformer or shunt to be tested with such transformer or shunt, and with the connecting leads between the meter and such transformer or shunt.

METHOD OF TESTING ELECTROLYTIC AMPERE-HOUR METERS. To be tested against a sub-standard electrolytic meter, the load on the meter under test to be three-quarters of its full load. The duration of any test to be not less than 100 hours. The error (if any) after approximately 50 hours, and the error (if any) at the time of syphoning, also to be recorded.

Alternative Tests for Motor Meters. Methods A and C are quite clear, but it is necessary to indicate the alternatives under B (page 316), after pointing out the three patterns of R.S.S. which are available.

PATTERN 1. Fitted with kWh train only, and thus mainly of use for long period dial tests only.

PATTERN 2. Fitted with resetting dials only, and thus only of use for error curve testing.

PATTERN 3. Fitted with kWh train and resetting dials, and thus capable of carrying out any duty. This type is obviously preferable, in general, to the other two patterns.

FIRST ALTERNATIVE (B1). If it is desired to test one meter at a time, it is usual to let the meter under test run continuously and only allow the R.S.S. to run during the exact period in which the meter under test revolves a chosen number of revolutions (see also page 217). In this case, pattern (2) R.S.S. is required, or pattern (3).

SECOND ALTERNATIVE (B2). When doing routine batches of similar meters, it is desirable to test the meters simultaneously for the sake of economy. The procedure adopted, therefore, is to set all the meters and the R.S.S. to zero (as regards the disc spots or the resetting dials), and then run the R.S.S. for a number of revolutions which satisfies the regulations and the meter under test. The final positions of the disc spots of the meters under test will enable the errors to be determined (e.g. if the run was nominally 25 rev. and the disc spot was ¼ rev. fast, then the corresponding error would be + 1 per cent, assuming the R.S.S. to have zero error). The number of revolutions of the R.S.S. will not, in general, be the same as that of the meters under test.

It should be noted, though, that the legal requirements *only apply to the final tests for measuring the errors to be entered on the certificates.* During the process of calibration, the tester is free to choose any method or procedure he likes. It will also be appreciated that the second alternative above is not suitable for certain makes of meter on account of their variable cover effect. The clause regarding transformer- or shunt-operated meters is likely to be revised (owing to various practical objections), and the local Meter Examiner should be consulted on this point.

Undesirable Meters. The Commissioners have come to the conclusion that certain types of meters are not desirable, and have consequently decided not to certify such meters. Details of these meters, together with suggestions as to possible ways of utilizing instead of scrapping them, are given below.

(*a*) COMMUTATOR AH and WH METERS. The Commissioners have only approved a few of these meters, the remainder receiving ten years' grace.

(*b*) SINGLE-PHASE METERS FOR SINGLE-PHASE THREE-WIRE CIRCUITS. These can be converted to ordinary single-phase meters by suitable coil and gear changes, provided the meter is of an approved construction.

(*c*) SINGLE-PHASE METER FOR THREE-PHASE THREE-WIRE CIRCUITS. See comment under (*b*).

(*d*) DOUBLE CIRCUIT OR "POWER AND LIGHT" METERS. See comment under (*b*). This paragraph does not apply, of course, to the type of meter containing separate meters for the two circuits.

(*e*) TWO-ELEMENT THREE-PHASE FOUR-WIRE METERS. The Meter Examiners are allowed to certify existing meters of this pattern (provided they receive the usual type approval), but not meters purchased after September, 1937. Presumably the Commissioners hope to see a reduction of the number in use by the process of gradual elimination.

These meters can be converted to 3-wire meters very easily by simply changing the necessary coils and train wheels, or, on distribution systems taking all four wires into every consumer's premises, the meter may be used on two phases only, if so desired. As regards the testing of existing meters, no special rules have been laid down yet, but no doubt the Examiners will take steps to see that they are tested on a circuit where $V_r + V_y + V_b = 0$, which, of course, is the correct normal procedure irrespective of any regulations.

Sealing. The Commissioners have laid down a strict procedure regarding the sealing of meters, and have also prescribed the shape of the seal and the markings to be impressed thereon by the sealing pliers. The strictness is emphasized because the official in charge of the sealing will be usually the Meter Superintendent, and not the Meter Examiner. There are many reasons for trusting Meter Departments to do their own sealing, but the following three will indicate the difficulty of the situation—

(*a*) The physical task of sealing meters is so great that an enormous staff of assistant meter examiners would be required if they did the work.

(*b*) P.P. meters have to be attended on circuit for faults not due to the kWh meter, e.g. a bent coin stuck in coin slot, and—if it is already a certified meter—the meter mechanic has full power to break the seals and effect any repair which does not affect the kWh meter or its readings. The complaints men must therefore of necessity carry "Meters Act" sealing pliers.

(*c*) Electrolytic meters have to be periodically reset to zero, and again it is necessary for the meter reader or mechanic to have the approved sealing tackle with him.

In cases (*b*) and (*c*), the on-circuit attention is notified to the Commissioners on the special pink forms provided for that purpose. If the meter requiring attention has not already been certified, then it must be removed from circuit as soon as possible after the necessary attention has been given.

The present ruling is that once a kWh meter has been certified (meters being verified by an Examiner are, of course, not actually certified until he has finished his tests and reset the dials to zero) its working parts or dial readings must not be interfered with unless it is in the process of being re-submitted for certification. Even if a certified meter on circuit is found to be suffering from the most trivial defect of the kWh element, the seals must not be touched, and it will be necessary to change the meter. The complaints man must be very chary now of interfering with the new seals, owing to the fact that the consumer can now claim the attention of the district Meter Examiner if he desires (and is prepared to pay the expenses if the Examiner so decided) to dispute the meter readings.

Another important point is that the new seals cannot be used on existing uncertified meters, M.D.I.'s, terminal covers or apparatus other than kWh meters, and consequently it means that all complaints men will now have to carry two sets of sealing tackle, i.e. the new and the old.

Having dealt with the actual main points of the Act and Regulations, let us consider their general effect on meter testing departments.

General Effect of the Act on Meter Departments. To carry out the regulations will definitely increase the amount of work to be done, the stock to be held in the storeroom, and the space required. Thus there will be a general expansion of meter departments in equipment, space occupied, and staff employed. Many undertakings have already found it necessary to move the meter departments into new premises which are more compatible with the needs of to-day. These extensions make it even more necessary to consider the methods of testing to be employed.

Unfortunately, the problem is so bound up with the output of meters per week, the test-room space, the meters to be tested, etc., that it is impossible to lay down any general rules. Thus, although the dial-testing method (Method A) is positively the most economical of labour, it is not necessarily the most efficient method to employ in any particular test room (see page 171). Every meter superintendent has his own special set of circumstances, and he has to review the various methods in the light of his own particular requirements and test-room conditions. The table on page 322 may, however, be of assistance in arriving at a decision. It should be noted that it is assumed that the tester operates about four stop watches simultaneously when applying Method C to low loads, where no danger arises of missing a revolution.

Testing Equipment. The new regulations do not prescribe anything out of the ordinary as regards testing equipment, but experience suggests the following additions or modifications to the equipment described in Chapters XI and XIII.

1. SELECTOR SWITCHES. The multi-range C.T. (Class A.L.) should be combined with a rotary switch for selecting the ranges. Even if the maximum capacity is 1,000A, this still applies. In no case, of course, is it intended that the selector switch should make or break the current, and the range must only be altered when the current is zero.

The use of a rotary selector, and permanently C.T.-operated sub-standards, provides an outstanding convenience and a high safety factor. The saving in labour costs far outweighs the cost of the entire combined article, apart from the difference in cost between the rotary selector and ordinary links or knife switches. Fig. 185 also clearly shows how they can be neatly fitted into what would otherwise be redundant space.

A TIME COMPARISON OF THE VARIOUS METHODS OF TESTING

Type	Quarterly					Prepayment			Two-part Tariff		
Current Size	2½	5	10	10	25	5	5	5	25	25	25
Make	A	B	C	D	E	F	G	H	I	J	K
No. per Bench Side	48	40	48	40	48	36	26	26	26	30	26
R.P.U.	4000	2400	1000	1200	320	1200	1745	1200	240	450	300
Last Dial	1/100	1/100	1/10	1/100	1/10	1/100	1/10	1/100	1/10	1/10	1/100
Time for F.L. Dial Test in Minutes	100	50	250	25	100	50	500	50	100	100	10
R.P.M. at F.L. u.p.f.	40	48	40	48	32	24	35	24	24	45	30
Time for Basic Work in Hours	8	10	9	10	8	8	8	8	36	80	32
Time for Legal Tests by A in Hours	50	25	125	12½	50	25	250	25	50	50	5
,, ,, ,, B1 ,,	7½	5½	9½	5	10	7½	10½	5½	9	5	4½
,, ,, ,, C ,,	8	6	9½	5	9	6	10	4½	7	5	4
,, ,, ,, B1+C ,,	6½	4½	8½	4	7	5½	10	4½	7	4½	3
,, ,, ,, B2 ,,	5	3½	7	3	5	3½	9	3	4½	4½	2

Basic Work means connecting-up, cleaning, calibrating and disconnecting, plus the fixed charge element test in the case of two-part tariff meters. This work is very variable in labour requirements and the above times are only approximate. (Meters may be new, very old, difficult or easy to adjust, etc.)

In the last six lines the times refer to the meters per bench side in line 3.

2. Protection. The expense and trouble involved in getting equipment approved and standardized makes it all the more necessary to take steps to prevent any accident or maloperation from causing serious damage to the gear. As the dangers arise either from over-current or over-voltage, it is easy to insert instantaneous type relays at the desired points, set so as to close contacts and trip the main circuit-breaker whenever the current or voltage exceeds a predetermined figure.

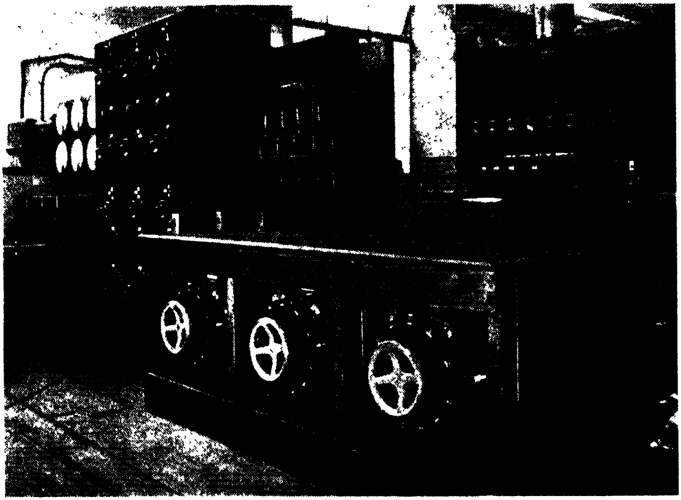


Fig. 185

An alternative method is to use fuses at the appropriate points, but this does not provide the complete protection offered by relays and a remote-operated circuit-breaker, particularly as regards the current transformers. (See also the next section.)

3. Higher Phantom Load Voltages. If the C.T. primary ranges go down to ½A or ¼A, then the voltage required in the phantom circuit may rise to as much as 60 V. Now the usual current loading transformer has, in the past, only been required to give from 6 V to 12 V, and consequently the new conditions call for some modification of the lay-out. One method of obtaining the higher voltages is shown in Fig. 186, where the current loading circuit may be fed from either the step-down transformer or from the auto-transformers. It is essential to interlock the change-over switch and the switches controlling the output of

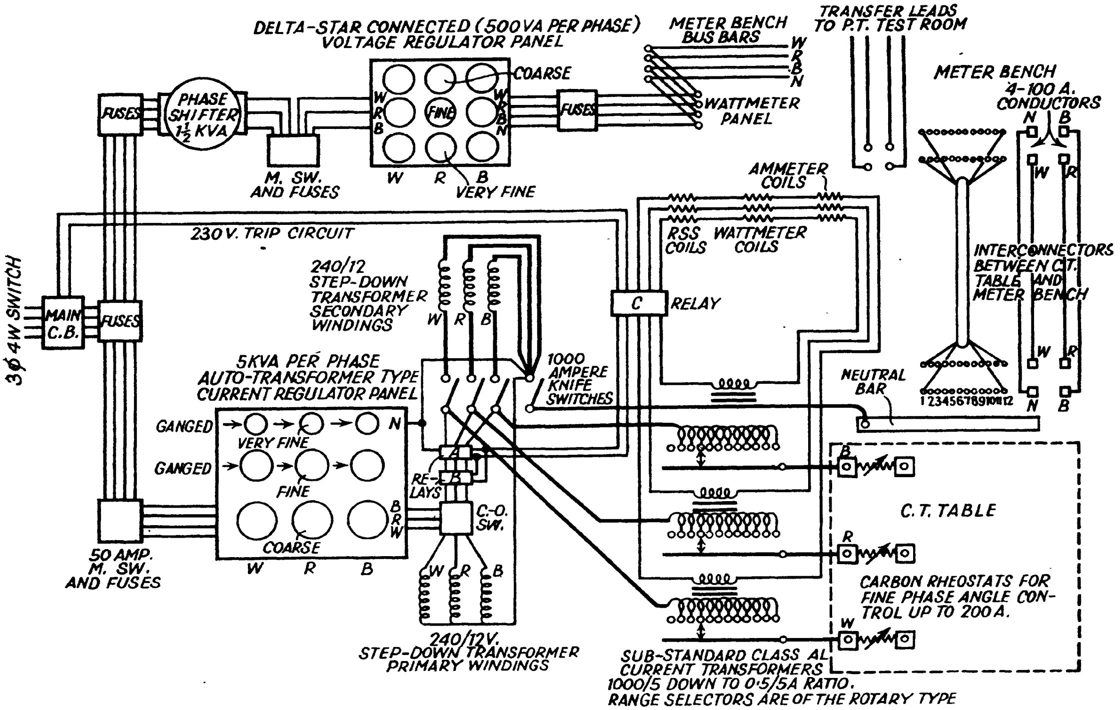
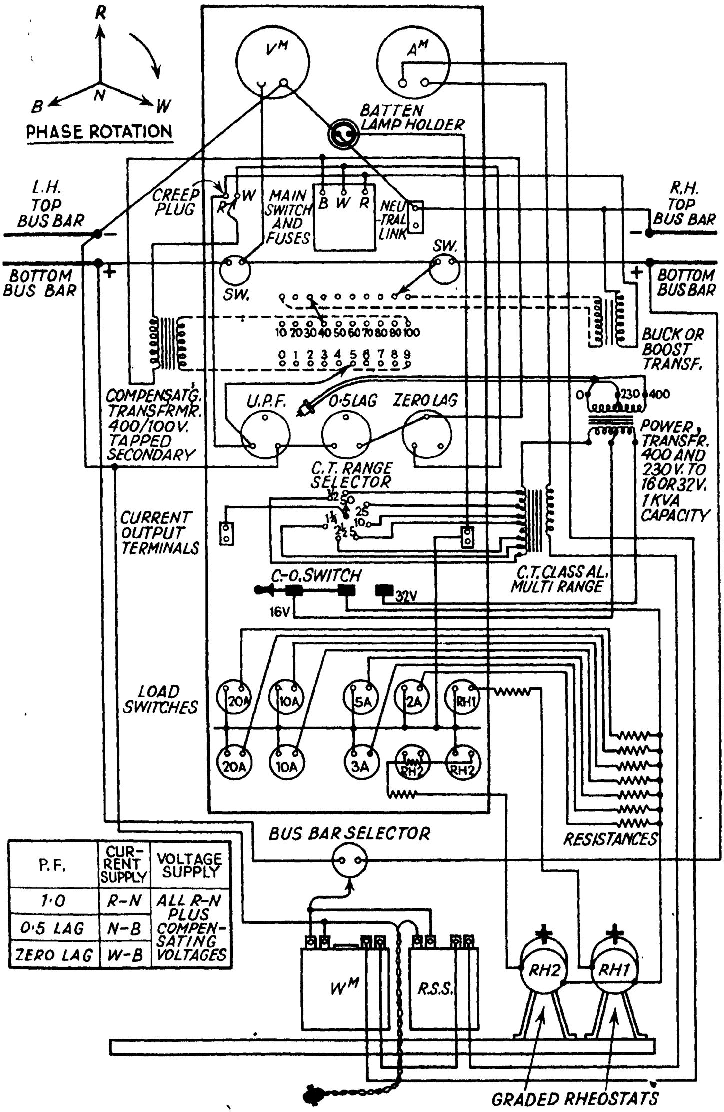


FIG. 186. POLYPHASE TESTING CIRCUIT TO SUIT THE METERS ACT (SEE ALSO FIG. 141)



P.F.	CURRENT SUPPLY	VOLTAGE SUPPLY
1·0	R-N	ALL R-N PLUS COMPENSATING VOLTAGES
0·5 LAG	N-B	
ZERO LAG	W-B	

FIG. 187. SINGLE-PHASE TESTING CIRCUIT TO SUIT THE METER'S ACT REQUIREMENTS

the step-down transformers in order to avoid trouble. Incidentally, Fig. 186 illustrates the use of protection (apart from the usual fuses) at four points: (1) interlocked *C-O* switch (see Fig. 185); (2) relay in each wattmeter current circuit which trips the breaker immediately the wattmeter current exceeds 6A; (3) relay in each auto-transformer output phase, when used direct, to prevent anyone trying to draw, say, 1,000A from it; (4) relay on each output phase, when used direct, to prevent the voltage on the C.T. circuit rising (in this case) above 40 volts.

For single-phase testing equipments, a simple method of obtaining the increased voltage is shown in Fig. 187. The double-throw knife switch constitutes the main current control switch as well as the voltage selector. Incidentally, the circuit shown in Fig. 187 provides all the control required by the Meter Examiners under the new Act. The two sets of injected voltages in the pressure supply to the meters provide (*a*) exact control of power-factor and (*b*) adjustment of the testing voltage within 1 volt of the stipulated figure. It is essential to use the tapped primary step-down current supply transformer in order to maintain the same output voltages on all power-factors. If the testing currents go up to 50A, this type of control is much better than that described in Method 5 (page 205). This equipment is capable of being entirely built up in the Meter Department from stock items if it is not desired to spend too much capital, or where many existing pieces of apparatus can be utilized.

Status of Meter Engineers. One of the most important results of the Act is to place British Meter Engineers on a definite footing in the industry. Whereas it was left in the past to local initiative to appreciate the merits of adequately treating the work of the meter department, it is now legally necessary for every undertaking to give meters their necessary consideration. This consideration demands the employment of trained men, which has automatically raised the status of the qualified meter engineer. Recognition of the services and requirements of meter engineers will, in return, prove to be of important financial benefit to supply undertakings, since it will, in general, result in increased revenue.

APPENDIX I

INTEGRATION

IF a product is supplied to a consumer at a constant rate, it is an easy matter to calculate how much has been supplied during a definite period. If, however, the rate of supply varies, it becomes more difficult to calculate the quantity supplied, and it is necessary to introduce the conception of infinitely small quantities. In the case of curve 1 (Fig. 188), the quantity supplied is clearly $M \times t$, i.e. the area under the curve if the unit of area is a rectangle measuring 1 unit of W by 1 unit of T. In the case of curve 2, the quantity supplied during a period δt equals $N \times \delta t$, if the quantity is constant at the value N for the stated period. The latter assumption becomes applicable to ordinary curves if the period δt becomes infinitely small, when it is denoted by the symbol dt. It must be remembered that dt is a symbol, and does not mean the product of d and t. Thus the area under curve 2 is the sum of all the little bits of area, such as $N \,.\, dt$, and this area is denoted by $\int_0^t W \,.\, dt$, since N is only a particular value of W. This area represents the quantity supplied if it is measured in the above units. The methods of evaluating the quantity $\int_0^t W \,.\, dt$, if the law connecting W and T is known, will be found in textbooks on the Calculus. If the law is not known, then graphical methods must be employed, such as (1) counting the squares; (2) weighing the cut-out area; (3) measuring equidistant

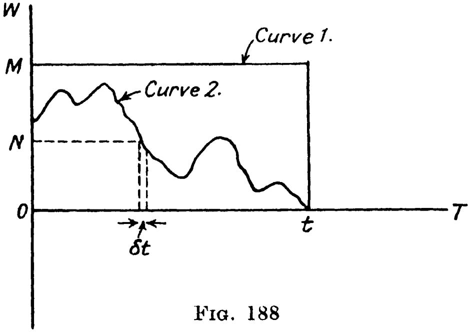


FIG. 188

mid-ordinates; or (4) applying Simpson's rule. The reader will be acquainted with one or other of these methods. If W contains a constant factor, then this factor can be taken outside the sign of integration, i.e. if $W = k \cdot Q$, then $\int_0^t W \cdot dt = k\int_0^t Q \cdot dt$. The reason for this should be clear to the reader, since the curve of Q is identical in form with the curve of W and only differs from it by the numerical ratio k in the heights of the corresponding ordinates.

The point that concerns us, however, is mechanical integration. If W represents the angular velocity of a spindle in revolutions per unit of time, then the above reasoning shows that $\int_0^t W \cdot dt$ represents the number of revolutions made in time t. If W is directly proportional to the rate of supply of some other quantity Z, then the number of revolutions is proportional to the amount of Z supplied in time t. It is shown in Chapter II how the number of revolutions of a spindle is counted and how, instead of marking the counter in terms of revolutions, it is marked in terms of Z, Z being ampere-hours, kWh, reactive kVA hours, or kVA hours.

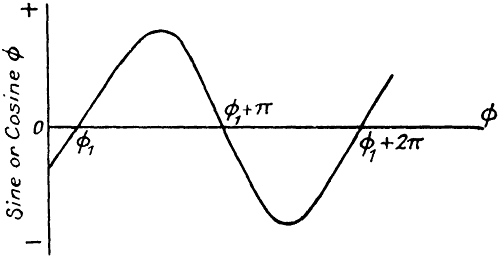


FIG. 189

Integrals of Zero Value. In Fig. 189 is shown the graph of a sine or cosine function, and it will be obvious to the reader that between the times ϕ_1 and $(\phi_1 + 2\pi)$ the numerical value of the positive portion of the area between the base line and the curve is exactly equal to the numerical value of the negative portion of the area. Consequently, $\int_{\phi_1}^{\phi_1 + 2\pi} \sin\phi \cdot d\phi$ equals zero and, similarly, $\int_{\phi_1}^{\phi_1 + 2\pi} \cos\phi \cdot d\phi$ is also zero. Clearly the integrals are also zero if the function passes through any whole number of complete cycles. This fact is very important when discussing the mean power and energy in A.C. circuits (see page 72).

APPENDIX II

VECTORS

A SOLITARY line AB has no significance except length (see Fig. 190). If, however, we also have another fixed line $-XOX$, then the line AB has another property, i.e. direction relative to $-XOX$. It is also usual to provide another fixed reference line $-YOY$ at right angles to $-XOX$, the meeting point O of these two lines being termed the origin. The lines $-XOX$ and $-YOY$ are drawn at right angles because of the many useful properties of the angle 90°.

Vectors may be used to express space relationships or time relationships, but care must be taken not to confuse the two on the same diagram. It is only in exceptional cases that a vector diagram can represent space and time relations simultaneously.

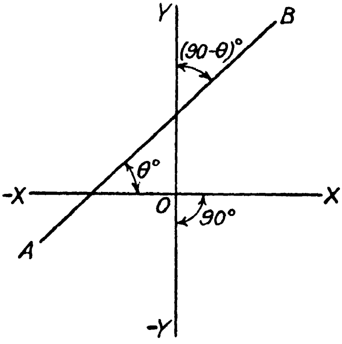


FIG. 190

When the vectors express space relations, the construction of the diagram should be fairly obvious to the reader, since the lengths of the vectors are proportional to the magnitudes of the corresponding quantities and the angles between the vectors are equal to those between the corresponding quantities. The method of summing or subtracting a number of vectors (i.e. finding the resultant) is shown in Fig. 191. For a proof of the laws of vector summation, the reader is referred to textbooks on mechanics.

A vector diagram can represent the time relations of a number

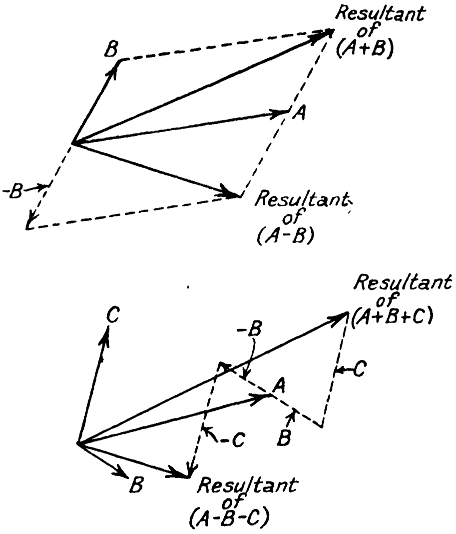


FIG. 191. METHOD OF SUMMING VECTORS

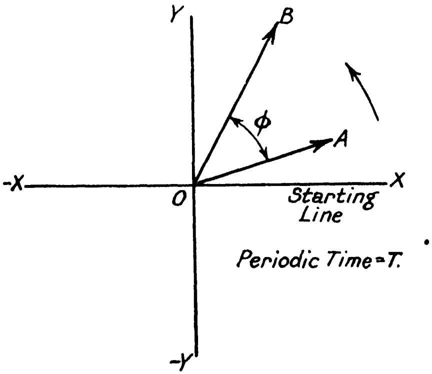


FIG. 192. TIME VECTORS

of quantities if a complete revolution of a vector at a certain constant angular velocity takes the definite time T. The counter-clockwise direction is usually taken as being the positive one. Thus the angle $\phi°$ in Fig. 192 corresponds to the time $\phi \,.\, T/360$ and vector OA is said to lag vector OB by this time, or vector OB is said to lead vector OA by this time (for the above positive direction of rotation). Provided the vectors represent the same type of quantity and these quantities occupy the same space, then they can be added or subtracted in the manner shown in Fig. 191, in order to obtain the resultant value of the quantity in the given space in phase and magnitude. "Phase" is a word used to express the time relation of one thing relative to another, although in A.C. work it is also employed to differentiate between different circuits. It must be remembered, of course, that vectors representing different types of quantities cannot be added or subtracted, e.g. a current vector cannot be added to a voltage vector.

APPENDIX III

USEFUL TRIGONOMETRICAL IDENTITIES

THE usual abbreviations are: sin = sine, cos = cosine, tan = tangent, sec = secant, cosec = cosecant, and cot = cotangent.

Consider Fig. 193, then

$$\sin\phi = AB/OA = CD/OC = 1/\operatorname{cosec}\phi$$

$$\cos\phi = OB/OA = OD/OC = 1/\sec\phi$$

$$\tan\phi = AB/OB = CD/OD = 1/\cot\phi = \frac{AB}{OA}\cdot\frac{OA}{OB} = \frac{\sin\phi}{\cos\phi}$$

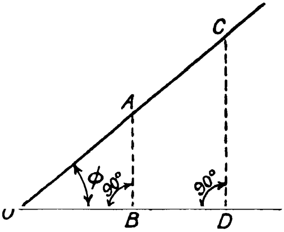


FIG. 193

Pythagoras's Theorem. This states that in a right-angled triangle the square on the hypotenuse equals the sum of the squares on the other two sides, i.e. $OA^2 = AB^2 + OB^2$. If we divide both sides of this equation by OA^2, we get

$$1 = AB^2/OA^2 + OB^2/OA^2$$

$$\therefore\ 1 = \sin^2\phi + \cos^2\phi,$$ from the above definitions of sine and cosine.

This identity is a very useful one in discussing alternating currents owing to the fact that if a sinusoidal current passes through a reactive circuit, then (1) the voltage drop across a capacitance lags the voltage drop across a resistance by 90°; (2) the voltage drop across an inductance leads the voltage drop across a resistance by 90°. The resistance voltage drop is, of course, in phase with the current.

Addition and Product Formulae.

$$\sin (A + B) = \sin A \,.\, \cos B + \cos A \,.\, \sin B$$

$$\sin (A - B) = \sin A \,.\, \cos B - \cos A \,.\, \sin B$$

$$\cos (A + B) = \cos A \,.\, \cos B - \sin A \,.\, \sin B$$

$$\cos (A - B) = \cos A \,.\, \cos B + \sin A \,.\, \sin B$$

$$\sin A + \sin B = 2 \,.\, \sin \frac{(A + B)}{2} \,.\, \cos \frac{(A - B)}{2}$$

$$\sin A - \sin B = 2 \,.\, \sin \frac{(A - B)}{2} \,.\, \cos \frac{(A + B)}{2}$$

$$\cos A + \cos B = 2 \,.\, \cos \frac{(A + B)}{2} \,.\, \cos \frac{(A - B)}{2}$$

$$\cos A - \cos B = -2 \,.\, \sin \frac{(A + B)}{2} \,.\, \sin \frac{(A - B)}{2}$$

$$\left.\begin{aligned} 2 \,.\, \sin A \,.\, \cos B &= \sin (\text{sum}) + \sin (\text{difference}) \\ 2 \,.\, \sin B \,.\, \cos A &= \sin (\text{sum}) - \sin (\text{difference}) \\ 2 \,.\, \cos A \,.\, \cos B &= \cos (\text{sum}) + \cos (\text{difference}) \\ 2 \,.\, \sin A \,.\, \sin B &= \cos (\text{difference}) - \cos (\text{sum}) \end{aligned}\right\} \begin{array}{l} \text{Sum} = A + B \\ \text{Difference} \\ \qquad = A - B \end{array}$$

Special cases of the above, which are useful when considering the power in an A.C. circuit, are

$$\sin^2 A = \frac{1 - \cos 2A}{2}, \text{ or } \cos 2A = 1 - 2 \,.\, \sin^2 A$$

$$\cos^2 A = \frac{1 + \cos 2A}{2}, \text{ or } \cos 2A = 2 \,.\, \cos^2 A - 1$$

THE VALUES OF THE FUNCTIONS OF 0°, 30°, 60°, AND 90°

	0°	30°	60°	90°
Sin ϕ . . .	0	0·5	0·866	1·0
Cos ϕ . . .	1·0	0·866	0·5	0
Tan ϕ . .	0	$1/\sqrt{3}$	$\sqrt{3}$	Infinity

APPENDIX IV

THE SLIDE RULE

The principle of the slide rule, which is an indispensable adjunct of the meter tester, depends on the law

$$\log M \,.\, N = \log M + \log N$$

If we represent a logarithm by a length, e.g. log 10, which equals 1, by 10″ and *pro rata*, then

$$\text{length}_{\log M \,.\, N} = \text{length}_{\log M} + \text{length}_{\log N}$$

Thus to multiply two numbers mechanically, we require two scales which are ruled off in accordance with the logarithms of the numbers marked on the scales. The two scales are mounted so that one can slide relatively to the other and so that the scale markings are adjacent. The scales are usually marked from 1 to 10, or 1 to 100, and most slide rules are provided with two of each, as shown in Fig. 194, for two reasons—

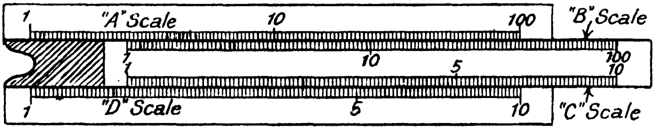


Fig. 194. Slide Rule, Arrangement of Scales

1. The 1 to 100 scales are more convenient for doing certain calculations than the 1 to 10 scales.
2. The square root of a number can be obtained directly by placing the cursor line on the given number on the *A* scale and reading off the corresponding number on the *D* scale. *Vice versa*, the square of a number is obtained by placing the cursor line on the given number on the *D* scale and reading off the corresponding number on the *A* scale.

Care must be taken when applying rule 2 if the numbers are outside the range of the initial scale. For instance, the square root of 333 is found by placing the cursor line on 3·33 on the *A* scale and multiplying the *D* scale reading by 10, whilst the square root of 0·333 is found by placing the cursor line on 33·3 on the *A* scale and dividing the *D* scale reading by 10. The square of 333 is found by placing the cursor line on 3·33 on the *D* scale and multiplying the *A* scale reading by 10,000, whilst the square of 0·333 is found by placing the cursor line on 3·33 and dividing the *A* scale reading by 100. The guiding rules should be obvious from these examples.

Division.

$$\log \frac{M}{N} = \log M - \log N$$

Thus we can find M/N mechanically by subtracting $\text{length}_{\log N}$ from $\text{length}_{\log M}$.

When applying the above rules for multiplication and division, the addition or subtraction must be done in such a way that the resulting length is measured from the point 1 on the scale and not from the 10, 100, or intermediate points.

Calculation of Percentage Errors. When a large number of errors have to be worked out for a definite constant, the scale *B* is placed so that the constant is opposite to 100 on the *A* scale. The cursor line is then placed over the number on the *B* scale equal or equivalent to the numerical difference between the constant and the meter figure, and the percentage error is read off from the *A* scale. The position of the decimal point is usually obvious.

In cases where the nearest figure is in doubt, e.g. if the error is in the neighbourhood of 0·35 per cent and it is desired to know if 0·3 or 0·4 is the nearer approximation, then the calculation is done on the *C* and *D* scales. The cursor line is placed on the number on the *D* scale corresponding to the constant, and the *C* scale is slid along until the number corresponding to the numerical difference is also under the cursor line. The percentage error is then given by the point on the *C* scale opposite to the 10 on the *D* scale. (In case the *C* scale is not opposite the 10 on the *D* scale, then the cursor line is slid along until it is over the 10 on the *C* scale and the *C* scale is then slid along until the 1 is under the cursor line. The point on the *C* scale now opposite the 10 on the *D* scale gives the required reading.)

If more accurate results are required than are given by the ordinary slide rule, then it is advisable to use the Fuller type of slide rule, which has a scale length of about 80 ft.

APPENDIX V

BRITISH LEGAL STANDARDS

By an Order in Council of 1910, the legal standards are defined as follows—

Standard of Electrical Resistance. A standard of electrical resistance, denominated 1 Ohm, agreeing in value within the limits of accuracy aforesaid with that of the International Ohm, and being the resistance between the copper terminals of the instrument marked "Board of Trade Ohm Standard verified 1894 and 1909," to the passage of an unvarying electrical current when the coil of insulated wire forming part of the aforesaid instrument and connected to the aforesaid terminals is in all parts at a temperature of 16·4° C.

Standard of Electrical Current. A standard of electrical current denominated one Ampere, agreeing in value within the limits of accuracy aforesaid with that of the International Ampere, and being the current which is passing in and through the coils of wire forming part of the instrument marked "Board of Trade Ampere Standard verified 1894 and 1909," when on reversing the current in the fixed coils the change in the forces acting upon the suspended coil in its sighted position is exactly balanced by the force exerted by gravity in Westminster upon the iridioplatinum weight marked *A* and forming part of the said instrument.

Standard of Electrical Pressure. A standard of electrical pressure denominated one Volt, agreeing in value within the limits of accuracy aforesaid with that of the International Volt, and being one-hundredth part of the pressure which, when applied between the terminals forming part of the instrument marked "Board of Trade Volt Standard verified 1894 and 1909," causes that rotation of the suspended portion of the instrument which is exactly measured by the coincidence of the sighting wire with the image of the fiducial mark *A* before and after application of the pressure, and with that of the fiducial mark *B* during the application of the pressure, these images being produced by the suspended mirror and observed by means of the eyepiece.

The limits of accuracy mentioned above are—

For the Ohm within one-hundredth part of 1 per cent.
For the Ampere within one-tenth part of 1 per cent.
For the Volt within one-tenth part of 1 per cent.

In spite of the existence of the legal standards it was the practice of the N.P.L. prior to 1st January, 1948, to state values in terms of the International units (see page 4) which were adopted in 1908.

Change in Electrical Units, 1st January, 1948. During 1947 the N.P.L. announced that on and after 1st January, 1948, values on N.P.L. Certificates would be stated in terms of the Absolute units, viz. the units derived from the centimetre, gramme, and second, in accordance with decisions taken by the International Committee of Weights and Measures at their meeting in Paris in October, 1946. On the 12th December, 1947, the Electricity Commissioners sent a letter to all authorized undertakers in England, Scotland, and Wales informing them that the international system of electrical units would be superseded by the absolute system of electrical units on 1st January, 1948.

The effects of this change are given by the following table—

One International ohm = 1·00049 Absolute ohm
,, ,, volt = 1·00034 ,, volt
,, ,, ampere = 0·99985 ,, ampere
,, ,, watt = 1·00019 ,, watts
,, ,, henry = 1·00049 ,, henry
,, ,, farad = 0·99951 ,, farad

Until the existing standards in Test Rooms are restandardized by the N.P.L. testers must make their own corrections as follows—

STANDARD CELLS: Add 0·00035 volt to the previous international value to obtain the new absolute value.

STANDARD RESISTANCES: Add 0·049 per cent to the previous international value to obtain the absolute value.

The Commissioners' Memorandum accompanying their letter provides detailed advice on the effects of the change and the procedure to be adopted in employing the various kinds of standardizing instruments and devices until they have been restandardized. The changes are so small that it is only in the work of standardizing instruments that they have a noticeable effect.

The Absolute Ampere is that current which flowing in a circle of 1 cm. radius creates at the centre a magnetic field of $2\pi/10$ gauss. It is $\frac{1}{10}$th of the E.M. Unit.

The Absolute Ohm is that resistance which produces one joule (10^7 ergs) when one Absolute Ampere passes through it for one second. It is equal to 10^9 E.M. Units.

The Absolute Volt is the potential difference which will drive one Absolute Ampere through one Absolute Ohm. It is equal to 10^8 E.M. Units.

APPENDIX VI

NOTES ON RECENT DEVELOPMENTS

ALTHOUGH there have been no epoch-making innovations in the meter industry since the publication of the third edition, it is, nevertheless, desirable to discuss the progress which has taken place in certain sections of meter engineering.

The Long-life Induction Meter. The ordinary induction meter was reduced to its elemental form some years ago, and the requirements of meter engineers now take the form of demanding superlative performance over a long life in addition to the other desiderata. In order to give point to these requirements let us consider the latest pattern Westinghouse meter, and note what has been done to try to achieve the desired end.

Minimization of Initial Friction and Growth of Friction.

(1) The teeth of gearwheels are cut on the involute principle so as to give rolling motion instead of a sliding motion.

(2) The first gear shaft of the kWh train has a polished steel pivot running on a jewelled bearing.

(3) The worm gear is placed in a slow speed stage.

(4) All gearwheels and pinions are given a gold finish so as to prevent corrosion, with the object of ensuring that friction will not alter with age.

(5) The bottom bearing consists of a chrome-steel ball between two jewels, the object being to provide rolling contact instead of a sliding contact. The chrome-steel ball has superseded the carbon-steel ball on account of its rust-proof qualities rendering the anti-rust coating of oil no longer necessary.

Permanence of Calibration. (1) The permanent magnets are integral with the full load adjuster and the U.P.F. temperature variation compensator so that they can be removed and replaced with little liability of alteration in the meter calibration.

(2) The electro-magnets are mounted on closed circuit laminations, and the low load adjuster and the inductive temperature variation compensator are integral with the electro-magnet so that their positions or effects are not altered by removing the electro-magnet from the case.

(3) The permanent magnets are given a copper coating, 0·015 in. thick, with a view to preventing demagnetization as a result of lightning surges.

Other manufacturers take similar or other steps towards the same ends, but the above list does give the reader an insight into the modern outlook on meter construction.

Jewelled Bearing Construction. Although the discovery of the influence of the optic axis (see page 92) on the resistance to wear of a jewel marked an immense step forward, research is still going on in respect of the jewelled bearing.

If it is desired to retain a pivot or ball of carbon-steel it is necessary to employ some means of preventing oxidation of the steel, and the problem is to produce a lubricant of sufficient stability to prevent the effects of deterioration or temperature being worse than the straightforward hazards. In this connection the reader must have a broad outlook, since meters have to be used in all parts of the world. It is on this account that efforts have been made to avoid the need for a lubricant by using a non-rusting type of pivot or ball, and all the American manufacturers now offer a bearing of this type. The materials at present favoured are chrome-steel, cobalt-tungsten, or Nobeloy.

An interesting light has been thrown on the wear and tear of jewelled bearings by the investigations of F. C. Holtz, of the American Sangamo Co. The results of the work are described by him in a paper to the A.I.E.E. (Vol. 59, Feb., 1940, page 116, *J.A.I.E.E.*). In brief, the paper shows that the motion of the bottom pivot of an induction meter is probably greater on no load than it is on full load; and in a particular case investigated the no load motion was about ten times the full load motion. It appears that the disc is subject to a figure-of-eight motion on no load due to the interaction of voltage flux eddy currents in the disc with the magnetic field of the permanent magnets. All meter engineers are aware of the state of excitement of an induction meter rotor on no load, but many will find it most illuminating to learn the nature and extent of the motion and its effect on bearing wear. The investigation gives a satisfactory answer to the problem of jewel wear taking place, even though the total disc revolutions may be only of a low order.

The no load motion is not, of course, all loss, because it is of much assistance to the meter rotor in overcoming the effects of stiction.

Although we are not concerned here with the effects of war-time restrictions on supplies, the reader is advised to read the 1941 Recommendations of the Electricity Commissioners' Meter Technical Committee on Meter Jewels, on account of the valuable information it contains on the use of microscopes and the treatment of jewel and pivot defects. For information on the art of repolishing jewel cups suffering from minor blemishes the reader is referred to a 1943 E.R.A. Technical Report.

Cleaning of Meter Parts by Chemicals. In recent years industrial concerns have been utilizing, to a greater degree, chemical methods of cleaning, and it is only natural that the methods employed are being taken up by meter engineers for meter repair work. The size of the repair shop is not an important factor, since small machines can be developed as well as large ones for this class of work. So far as the author is aware only one firm in this country (Messrs. Metropolitan-Vickers, Ltd.) markets a machine suitable for small meter parts, but this is a field in which the meter engineer can, if he desires, develop his own particular plant.

Different materials or components call for their own type of treatment in order to produce the best results, and it must not be thought that the use of a degreaser such as tetrachlorethylene is the simple answer to all cleaning problems. Some very useful information is contained in an article by W. A. Sturdevant in the *Electrical World* of 21st September, 1941, as regards the differing types of cleaning liquids and the methods to be employed for cleaning the bigger parts of meters, such as covers, bases, and terminal blocks, as well as the smaller parts.

The chemical method of cleaning has proved to be very successful in achieving the desired end, but, like all techniques involving chemical action, it has its limitations, which must be recognized. The important points are (1) that parts must not be exposed to the action of the wrong chemical (e.g. terminal blocks of fibre must not be treated with an alkali), and (2) that when the operations are complete there must be no residue of chemical left on the parts. Unless treatment is thorough and consistent the chemical method may result in disappointment.

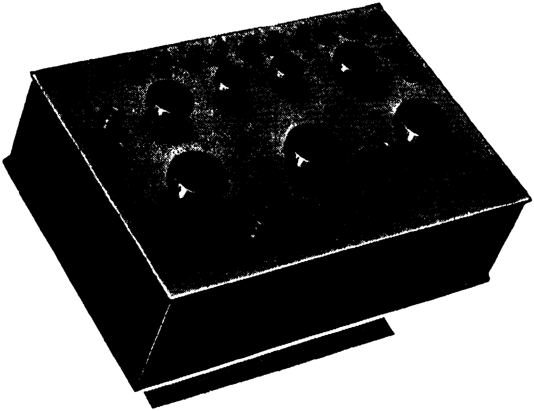
Automatic Load Holding and Testing. Constant thought and experiment are being devoted to this side of meter testing, and a number of devices have been described in the technical press which enable the load-holder to be done away with. These devices have not yet found wide acceptance because of their high cost if they are to be highly sensitive in their reaction to load changes. Further, they are restricted to the stop-watch method of testing, whilst, in addition, there is an element of doubt in the process which makes it uncertain that the method would be accepted for certifying meters.

Another interesting line of attack is to employ rotating sub-standards (one for each load) in combination with a starting and stopping arrangement operated by impulses derived from a suitable light spot on the rotor of the meter under test. In addition the switching on and off of the respective loads is done automatically, whilst the sub-standards are designed so as to project their reading (the scale is marked in terms of per cent error, since the sub-standard rotor always starts from zero and the number of revolutions is predetermined) on to an illuminated dial. Thus, at the end of an unattended testing run the error of the meter at each load is waiting for the tester to read on the respective dials. The importance of this method of approach is that it does not rely upon the steadiness of the load or the skill of the tester with a stop-watch. (It may be objected that the rotating sub-standard itself has to be tested with a stop-watch, but the answer to this is that whilst the timing periods for a sub-standard can be made long enough to minimize the stop-watch errors, the periods have to be kept as short as possible for the routine testing.) It should also be pointed out that rotating sub-standards can now be obtained which have a very high degree of stability, and this factor is far more important than the magnitude of the error. It will also be appreciated that if the reading of a rotating sub-standard can be obtained without having to use a mechanical device driven from the rotor, a further step in the direction of stability is achieved.

One can foresee a time when meter rooms will be handling a very small proportion of new meters, and when that time arrives it is quite feasible that the above apparatus will enable a meter repairer to test his meters as well as to repair them. Apart from the question of time saving, there is the possibility that such a combination might lead to the artisan taking a keener interest in his work, since there would be no divided responsibility as to the final state of the meter.

It is recognized that many of the older patterns of meter are not built in such a way as to facilitate the application of photo-electric revolution counting devices, but these types are now a decreasing percentage of the whole, whilst in any case there is nothing to prevent the meter engineer making certain cover alterations (with official sanction) to enable such devices to be utilized.

There is a fascination in the idea of being able to test a meter with a device which gives the error directly without continued eye-strain and nerve-strain, and the above discussion clearly shows that the art of meter testing has far from reached finality.



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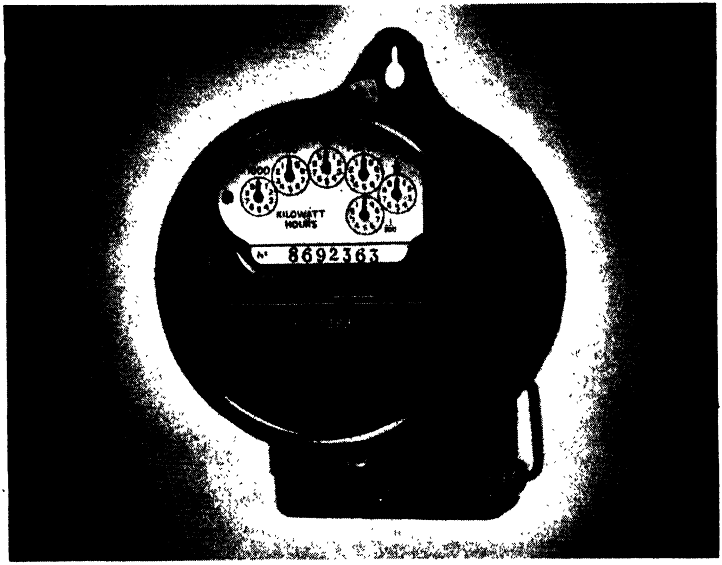
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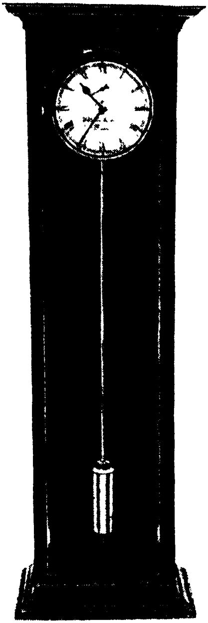

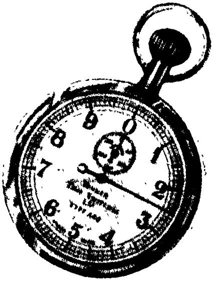

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