FACTORY INSTALLATION WORK

NEWNES' "ELECTRICAL ENGINEER" SERIES

General Editor: E. MOLLOY, *Editor of "Electrical Engineer."*

UNIFORM WITH THIS VOLUME

No. 1. *Electric Wiring: (Domestic)*
,, 2. *Practical Design of Small Motors and Transformers*
,, 3. *Installation and Maintenance of Electric Motors*
,, 4. *House Telephones, Bells and Signalling Systems*
,, 5. *Wiring Circuits for Lighting, Power and Industrial Control*
,, 6. *Testing Electrical Installations and Machines*
,, 7. *Factory Installation Work*
,, 8. *A.C. Motors and Control Gear*
,, 9. *Switchboard Instruments*
,, 10. *Cables and Wires: Selection, Jointing and Testing*
,, 11. *Power Transformers*
,, 12. *Electro-Plating and Anodising*
,, 13. *Power Rectifiers*
,, 14. *Electric Lifts*
,, 15. *Private Generating Plant*
,, 16. *Electric Relays*
,, 17. *Physics for Engineers*
,, 18. 101 *Electrical Examination Questions: With Model Answers*
,, 19. *Mathematics for Engineers*
,, 20. *Introduction to Electricity and Radio*
,, 21. *Chemistry for Engineers*
,, 22. *Mechanics for Engineers*
,, 23. *Diesel Electric Shunting Locomotives*

FACTORY INSTALLATION WORK

A Practical Work for Electrical Installation Engineers and Contractors, Plant Engineers and Works Electricians

BY

A. J. COKER

GENERAL EDITOR

E. MOLLOY

Editor of "Electrical Engineer"

WITH 107 DIAGRAMS AND PHOTOGRAPHS

LONDON

GEORGE NEWNES LIMITED

TOWER HOUSE, SOUTHAMPTON STREET

STRAND, W.C.2

First published . . 1940
Second Edition . . 1942
Third Edition 1945

PRINTED IN GREAT BRITAIN

PREFACE

DURING the past few years there has been an immense expansion in the use of electricity in industrial plant. The convenience of Grid supplies and the versatility of the electric motor are the two main factors which have brought about this striking development.

In nearly every large power-driven works or factory, electricity is purchased in bulk from the local supply authority. This supply enters the factory premises at a voltage much higher than would be suitable for use at the actual working points. It is necessary, therefore, in these cases to have on the premises, a factory sub-station which transforms this bulk supply down to the voltage which is required for operating the motors and for supplying the necessary lighting and heating services in the factory.

In the case of smaller plant, the electric supply may enter the premises after having first been suitably transformed at the supply company's sub-station. Whichever system obtains, an electrically driven factory will require to have suitable distribution switchgear, cable runs, motor control gear, and lighting and heating distribution circuits.

The present work has been compiled with the object of bringing together into a convenient form up-to-date and reliable information on these aspects of electrical work which are peculiar to factory installations.

Due attention has been paid to the question of Home Office Regulations (Factory and Workshops Acts).

The objects of a factory electrical installation may be described as (*a*) to ensure a safe and reliable supply of power lighting and heating, and (*b*) to ensure the maximum efficiency for the factory concerned. The last mentioned condition makes it necessary for the plant engineer or installation engineer, who is responsible for the electrical supply of the factory to consider the question of power factor, particularly where a large number of induction motors are to be used.

Electricity tariffs are almost invariably arranged in such a way that the industrial consumer, whose plant operates at a low power factor, has to pay considerably more for every unit of electricity used.

The engineer who is responsible for planning the electrical installation should, therefore, give due consideration to the necessity or otherwise of installing power factor correction equipment.

In this connection, the information given in Chapter VI will be found of special value.

In view of the modern tendency towards the use of high-rupturing capacity fuses, particularly as back-up protection for circuit breakers and motor control gear, special attention has been given to this subject in Chapter IV, under the heading "Excess Current Protection and Earthing".

This work is offered to electrical contractors, installation engineers and plant engineers in the belief that it will prove an unfailing and reliable source of reference upon any problem met with in up-to-date factory installation work.

A. J. C.
E. M.

CONTENTS

FACTORY INSTALLATION WORK

CHAPTER I

GENERAL SURVEY OF INSTALLATION REQUIREMENTS.

THE majority of new factories and a large proportion of those built within the last decade or so, are completely equipped with electrical installations supplied with power from the mains of towns or rural electricity corporations.

Older factories, originally equipped with mechanical power from gas, oil or steam engines, have in most cases converted or extended part of their plant so as to use electricity wherever convenient. When electricity supply was first introduced, in fact, before the electrical companies had done little more than install cables for lighting purposes, many industrial concerns put down machinery plant to generate their own electricity for the factory.

System First Adopted.

Low voltage direct current was then in general use, the plant mainly comprising steam engine driven dynamos for supplying arc lights, incandescent carbon lamps, and motors for driving shafting. Although most of these old-time installations have been superseded by direct supply, some are still in operation, capable of doing their bit when required, and have been retained chiefly as a stand-by for extra loads or emergency occasions.

With this object also, many concerns keep private equipment, capable of running vital sections of their manufacturing processes, particularly in cases where a temporary breakdown of supply would have really disastrous consequences.

Other factories, where steam boilers are essential for the industrial work, find it advantageous to retain steam heating for their shops and departments rather than turn over to electrical power for this purpose.

Ultimately no doubt with the improvements in transmission, distribution and tariffs forecast for the future, all factories will change over entirely to electrical supply, as there is no question that for industrial use electrical power is the most convenient, being cleaner, more adaptable and more easily controlled than other methods.

Scope for Electrical Equipment in Factory Installations.

In planning an industrial installation there are a number of items which have to be carefully considered, as the type and nature of the supply required will depend to a great extent upon the various forms in which electrical power is to be applied in the factory, and upon the maximum load likely to be necessary.

Electrical equipment can be adopted for a great variety of purposes, and has an enormous number of applications in general factory work. Lighting for all shops and offices; industrial heating for furnaces in metallurgical and chemical work; electro-deposition of

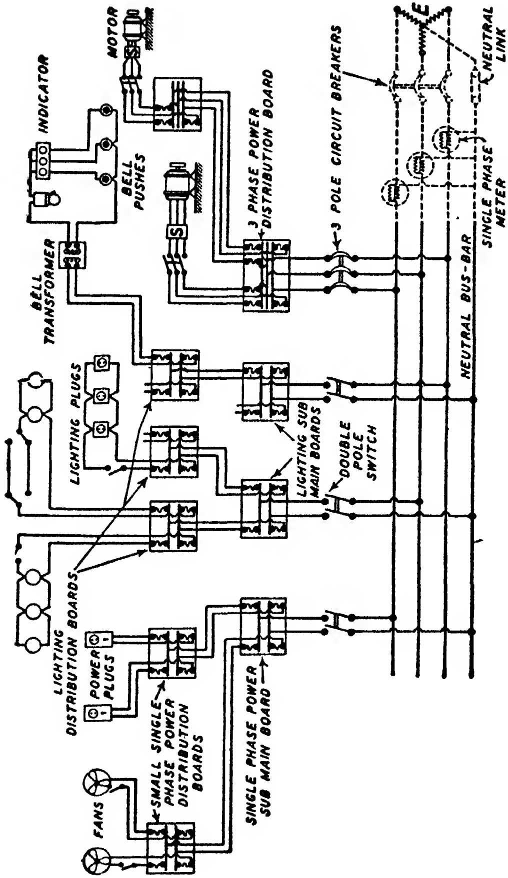


FIG. 1.—TYPICAL LOW-TENSION INTERNAL DISTRIBUTION FOR AC LIGHTING AND POWER.

For consumers taking loads of 50 kVA or over it is usual to bring a supply at high voltage into the actual building and to have step-down transformer equipment erected on the spot. The L.T. side of such equipment is shown above, with L.T. distribution taking place at 230 and 400 volts.

metals in plating processes; motors for all types of machinery drives in manufacture, for transport and traction within the factory—lifts, cranes, railways, trucks, etc., for pumping—air-conditioning and dust extraction, for communication and signalling devices such as telephones and bells.

Types of AC Supply Required.

In cases where electrical lighting and heating installations only are contemplated, the supply may be given by three-phase or single-phase low-tension alternating current, but where any large power equipment is concerned, a three-phase main supply at high voltage will be necessary, and a high-tension distribution actually within the factory may be advisable on the score of economy.

This will depend largely upon the number and situation of any high-power motors which have to be installed, since these will be less bulky and consume less current if wound for a higher voltage, say, 1,000 volts, than for 400 volts.

Smaller motors, however, are more economical at the lower voltage, so that it may be advantageous to carry out factory distribution at two different voltages.

Consideration of Maintenance Charges during Installation.

It must be borne in mind, however, that such a procedure increases maintenance charges, requires more spares, replacements and stores, and lessens the possibilities of interchange of equipment. It is essential, therefore, to take all these points into consideration before deciding upon the most economical voltage for distribution purposes.

Comparative costs of all the various items of electrical apparatus as supplied for at least two apparently suitable voltages, should be approximately worked out to give a general idea of the best scheme to adopt. The equipment costs must take into consideration all the factors relating to the supply, such as cables, switchboards, circuit breakers, measuring instruments, transformers, etc., in order that a true comparison may be made, since economies in regard to the size of motors may easily be counter-balanced by increased cost in relation to cables and switchgear.

The General Layout.

The general layout of the installation for a large factory will comprise a scheme of distribution usually from a central sub-station, in which the main supply cables will be housed, and from which the main feeders to the various manufacturing sections will radiate. Each section if sufficiently large, may have its own sub-station, from which sub-main cables will go to the various shops, where further distribution will take place to the separate items of electrical apparatus.

It is advisable to have a duplicate supply cable to the main distribution centres and to the most important manufacturing departments, and also a spare or duplicate transformer and switchgear cubicle, both for possible future extensions and also as a stand-by in emergency.

Choosing the Most Economical Sizes of Cable.

The type and size of cables required for supply to the various points will be determined by the voltage of distribution and the ultimate load which each

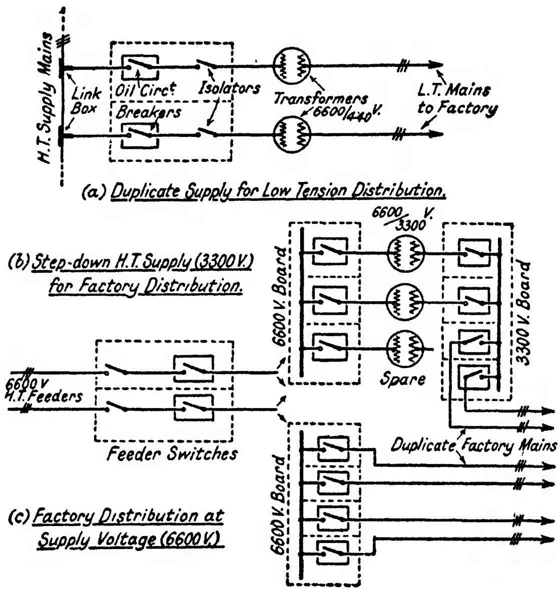


FIG. 2.—TYPES OF FACTORY MAIN SUPPLY.

The above are single line diagrams, each line representing the three-phases of the usual 50-cycle AC power supply.

separate cable will be called upon to bear; this will necessitate the calculation of the total current that may flow at each point of the installation network, and also a close estimate must be formed of the probable average current passing during the working day. From these figures the most economical sizes of cable required for the different sections of the lay-out can be ascertained that will give the necessary current without undue temperature rise or voltage drop.

Important Points of the Installation.

With regard to switchgear, the switches, circuit-breakers and fuses, erected at the various sub-stations and distribution centres, must be adequate in each case to meet the load demands which they are individually called upon to protect and control. In order, however, to be as safe as possible with regard to the prevention of fire from any possible explosion due to short-circuits, it is essential that each protecting fuse or circuit-breaker should in addition be capable of rupturing without damage, the full kVA of that part of the system which it controls.

The rupturing capacity at these various points in the installation must, therefore, be ascertained, and the switchgear designed to meet the necessary requirements. In laying out factory electrical installations, it is necessary to keep to certain well-defined requirements in order to get safe and satisfactory service. These various requirements can be stated somewhat as follows:—

Continuity of Service.

To maintain a general supply of power to the various sections in spite of the possible development of a fault in one or more parts of the system.

Safety Factor.

Allow a reasonable factor of safety by preventing as much as possible any defective work occurring, since any stoppage will cause loss of revenue.

Prevention of Fire.

Avoid explosions and possible fires by adequate protection and control of all electrical circuits, and to segregate such occurrences by the use of separate compartments lined with non-inflammable material.

Prevention of Shock.

To take necessary precautions in every way in order that any possible injury to employees may be avoided. The Factory and Workshop Acts embody the Government regulations for the protection of industrial workers and staff, and are explained by the Chief Inspector of Factories in a memorandum known as the Home Office Regulations.

Compliance with I.E.E. Regulations.

The actual erection work of the installation should, as far as possible, be carried out in accordance with the Wiring Rules of the Institution of Electrical Engineers—more recently entitled the Regulations for the Electrical Equipment of Buildings. Compliance with these sets of regulations will produce a high standard of work and allow of a good safety factor against possible breakdowns.

Primary Consideration when Obtaining Switchgear.

Regarding the various separate items of plant to be installed, these are usually manufactured to comply with certain specifications published by the British Standards Institution. A number of these specifications have been drawn up dealing with the various classes of electrical apparatus employed in any installation, with the object of avoiding any inferior design, workmanship or material in manufacture, so as to reassure the purchasers of such equipment that they are buying satisfactory apparatus of the best type to meet their particular requirements.

From these general observations regarding industrial electrical work, it will be seen that in planning the power and lighting system for a factory, there are certain special features which have to be carefully considered, and it is necessary to proceed step by step in dealing with the calculations of the installation requirements.

Main Points of the Lighting Installation.

The following list includes the main points which need to be studied in this respect.

Ascertain the amount of illumination necessary in the various departments, the number of points required and the total loading in kW—as an approximation for industrial lighting about one watt per square foot of illuminated surface can be assumed.

Heating Installation.

Determine the kW loading required for domestic and industrial heating purposes for which electrical energy is to be used—as an approximation use one watt per cubic foot of space for offices, canteens, recreation rooms, i.e., where domestic services are concerned.

Power Calculations.

Calculate the horse-power and determine the type for each motor to be erected, ascertain the most suitable type of drive and starting equipment necessary. Tabulate the various types under suitable headings, such as machinery drive, cranes, lifts, traction, pumps, etc., and work out the maximum, intermittent and probable average kVA required both at each distribution point and also the total overall demand.

Distribution.

Plan out the general supply system, determine the most economical voltage or voltages for the main and sub-stations; ascertain the size of main and secondary transformers required together with the necessary switchgear. Allow for extensions and stand-by plant.

Switchgear.

Determine the various types of switchboards necessary at the various distribution points, the rupturing capacity and continuous running load required at such positions, and where switches or fuses are to be installed—allow for spares.

Cables.

Calculate the size and type of cables required for main and sub-main circuits to carry the various loads without overheating or undue voltage drop. Determine the methods of laying to be adopted (the cable runs to be made as accessible as possible), nature of cable terminations, joints and draw-in pits. Allow for duplicate feed to all important supply points.

All the main electrical equipment—transformers, switchboards, motors, starters, heating apparatus and lighting points, together with cable runs—should be carefully noted and positioned on the various factory building plans.

Having broadly surveyed the general run of requirements in the factory installation, we can now proceed to deal in somewhat greater detail with the main items of the equipment.

Supply Sub-stations.

For an industrial installation of appreciable load, the supply will undoubtedly be given by three-phase alternating current at high voltage, probably 11,000 or 6,600 volts, and the power company will erect a sub-station, either within or just outside the factory, for the cable terminations and voltage transformation equipment. This gear will be entirely their responsibility and under their control and maintenance.

Advisability of Supply Duplication.

At least two main cables will be used to transmit the load, since it is very advisable to safeguard the continuity of supply in every possible way, so that duplication is essential in the most important apparatus. For very large concerns separate cables will be run from the nearest available sub-station, so that the factory installation is an independent unit of the distribution network—unconnected with other consumers, and therefore less liable to interference or other troubles from external sources.

The main supply cables will terminate in the sub-station at compound-filled end-boxes which will be connected to the busbars through oil switches and isolating links. Each cable will have a separate cubicle fitted with the necessary measuring instruments, such as voltmeters, ammeters and energy meters.

When Transformers are Employed.

In cases where the factory distribution takes place at low voltage, transformers will be installed, stepping down the mains to the required voltage, and these transformers will be supplied from the busbars through oil switches—a spare transformer and supply panel being incorporated as a stand-by provision. Cables from the low-tension side of these transformers will then run to the factory main station or sub-stations, depending upon the lay-out of the distribution system.

All oil switches in a supply station will be fitted with overload and no-volt release protection. In a similar way if high voltage distribution is required to the factory main station or sub-stations, transformers, stepping down to the required distribution voltage, will be placed in the supply sub-station, and will connect with busbars associated with the necessary panels to provide duplicate high-tension feeders to the various factory switchboards.

At these points the necessary stepdown transformers will be installed to supply low voltage for the power, heating and lighting equipment required for each particular section of the system.

Dispensing with Main Transformers.

In some cases high voltage distribution is arranged for at the main supply voltage, in which case transformers at the power company's sub-station are not required. The incoming mains supply, through circuit-breakers, the busbars. Connected to these are the requisite cables for feeding the various factory distribution centres.

All the main high-tension cables must be installed in separate compartments, made as fireproof and flame-proof as possible, and connected through isolating links to oil circuit-breakers which are protected by overload and no-volt release trips.

These main cables and connections are also often further protected by earth leakage trips set to operate when the earth current reaches a dangerous value, indicating a partial earth fault somewhere on the system.

One of the greatest dangers prevalent in electrical supply is that due to temporary short-circuits occurring, and as already mentioned, all main circuit-breakers must have sufficient rupturing capacity to be able to clear such a fault immediately without trouble.

Factors Governing Extent of Short-circuit Current

The short-circuit current that can flow in the mains depends upon the power of the generating station, the reactance and resistance of the cables, transformers, etc., in the circuit. The power of the short-circuit is determined by the short-circuit current and the normal voltage, and is usually expressed as short-circuit kVA.

Short-circuit Reactance of Transformers.

The short-circuit reactance of the transformers is expressed as a percentage of the voltage drop at normal full load, and the short-circuit kVA is obtained by dividing the normal kVA by this percentage value. Thus, a 5,000 kVA transformer with 5 per cent. short-circuit reactance would have

$$\frac{5{,}000 \times 100}{5} = 100{,}000 \text{ kVA (s.c.).}$$

The short-circuit current for a three-phase circuit under such conditions would be given by

$$\text{S.C. current} = \frac{\text{S.C. kVA.}}{\sqrt{3} \times \text{kV.}}$$

At 11,000-volt supply this would give 5,250 amperes S.C. current. The S.C. kVA at the main terminals must be ascertained and from this the corresponding values at various other parts of the system can be calculated.

As we proceed further from the main supply the S.C. kVA becomes less and less, on account of the division of the circuits and the increasing reactance of the cables and equipment interposed. Thus, starting with the main supply of say, 100,000 S.C. kVA rupturing capacity, that required at the three or four factory sub-stations would probably need to be about 75,000 kVA. From here to the sub-main distribution switchboards the rupturing capacity would drop to 25,000 kVA, and at the actual power supply boards would be 10,000 kVA or less.

Mechanical Stresses Set up by Short-circuits.

On the occurrence of a short, the heavy current flowing in the cables and busbar connections exerts an enormous force on the conductors, tending to distort them momentarily and strain the insulators and supports. Provision has to be made for this extraordinary strain in the design of the fittings, clamps and cable supports, so as to prevent fractures taking place. The force varies inversely as the distance apart of the conductors, so that as great a separation as possible, consistent with the other necessary requirements, must be allowed for in the switchboard construction.

Low-tension Main Distribution.

When the main factory distribution takes place at low-tension, supplied either direct from town mains or from H.T. supply transformed down at the company's sub-station, the feeder cables will usually be centralised at a main factory station from which they will radiate to the various sections of the works.

Supply Cables and Main Switchgear.

The incoming supply cables—two or more depending upon the load—one of which will be an emergency spare, will terminate in end-boxes connected by isolating links to a short length of common busbar, to which the oil circuit-breakers are connected. The other contacts of the breakers connect to common busbars supplying the feeder cables.

These busbars are in many cases totally enclosed in order to keep out dirt and vermin as much as possible, and the feeder cables are connected through oil circuit-breakers or oil switches and fuses—depending upon the capacity, each feeder having its own separate sectionalised compartment in order to decrease the dangers of fire and explosion.

Recording Instruments for Cables.

Each large feeder will also have recording instruments or kW-hr. meters, as will also the actual supply cables to the switchboard, so that the total energy is recorded and also the power used per feeder. The supply meters also have generally a maximum demand scale and pointer which operates on a time limit of half an hour, and readings are taken at stated intervals.

Electricity for an industrial concern is generally

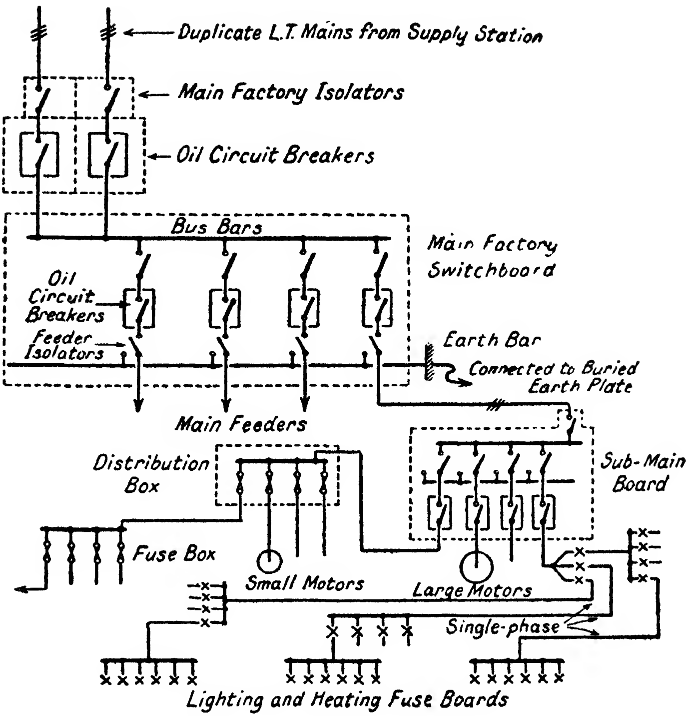


FIG. 3.—THREE-PHASE LOW-TENSION DISTRIBUTION IN A TYPICAL INDUSTRIAL INSTALLATION.

charged for on a two-part tariff, a fixed cost per kVA of the maximum demand over a definite period plus a small charge—a fraction of a penny—per unit consumed in this period. For this reason it is always necessary to keep an eye on the general maximum demand and to install recording meters on all important mains and sub-mains.

Advisability of Duplicate Feeders.

As already mentioned, the feeder cables radiate to the various sectional distribution centres where they terminate at a switchboard to which smaller feeder cables are connected, supplying power to the various shops and departments by means of other smaller distribution boards. It is advisable, wherever possible, that the most important feeders be duplicated or interconnected to some extent in order to safeguard the supply, so that a breakdown in most cases will only result in a short temporary shut-down of one section.

In using duplicate feeder cables, one may be entirely a spare, or both cables may share the load, provided they both have sufficient capacity to carry the total current independently in the event of one failing.

The Arrangement of Lighting and Heating Services.

If the three-phase L.T. supply voltage does not exceed 440 volts then it is usual for the lighting and heating services to be distributed between the separate phases, and this can be arranged either at the main or at the distribution centres by means of a separate L.T. switchboard control.

In the former case separate cables have to be run for lighting along with the power cables; this is sometimes advantageous, particularly when duplicate feeders are not employed, as a power breakdown may still leave the lighting equipment operating. Where spare feeder cables are laid, this matter is not so important, and the lighting can be taken from the power busbar through separate phase panels to the smaller distribution boards erected in the various workshops.

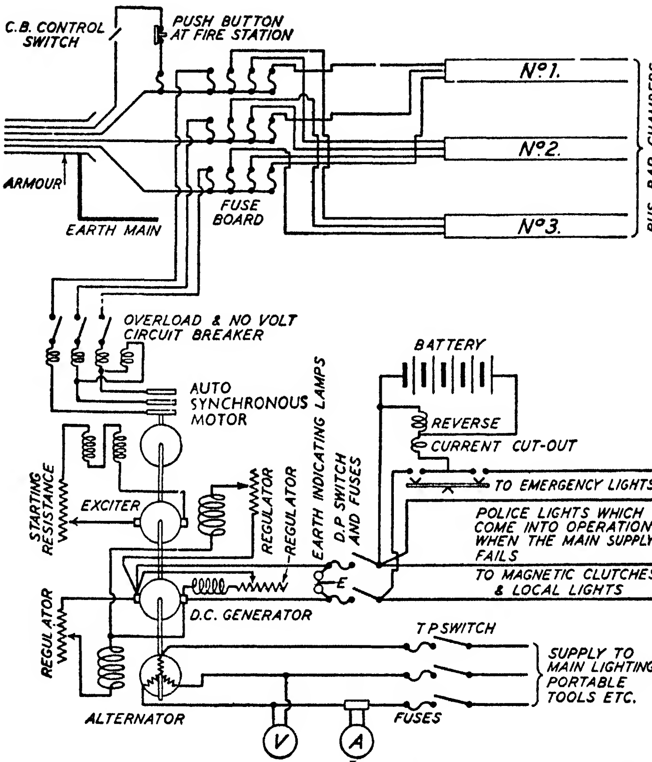


FIG. 4.—SCHEME FOR THE ELECTRICAL INSTALLATION IN AN ENGINEERING FACTORY.

The diagram shows a branch circuit supplying 440 volts, 3-phase, 50 cycles, for the motor drives. The machine tools, being in continuous rows, are conveniently supplied by an overhead busbar chamber system. A set comprising an alternator and DC generator driven by an auto-synchronous motor (with attendant exciter) gives a supply at other voltages (1) not exceeding 220 volts, 3-phase (130 volts to earth), of a periodicity to suit the equipment for the supply of main and individual lighting portable tools, and (2) a DC supply for use with magnetic clutches and emergency lighting, of 100 volts or less. The auto-synchronous set allows for adjustable power factor correction.

L.T. Supply exceeding 440 Volts.

With a L.T. supply voltage exceeding 440 for the power services, it is necessary to install additional step-down transformers for the lighting and heating equipment, and to keep the systems completely separated with independent switchboards and distribution cables.

Use of 100-120 Volts.

A lower voltage, 100–120 volts, is often made use of, both for lighting and heating services and also for small motors employed in workshops with automatic and semi-automatic mass-production processes. This lower voltage may be obtained by means of a transformer. An alternative is given in Fig. 4. Provided the low-tension supply is less than 135 volts, it need not be earthed; in fact it need not have a neutral at all, which has the advantage that unless there is an earth fault on one main, the potential to earth is negligible.

High-tension Factory Distribution.

When factory distribution takes place at high-tension an additional stage of transformation is necessary either in the supply company's sub-station or at the factory sub-stations, depending upon the nature of the lay-out.

Duplicate supply mains will be taken to these centres, or else the various sections will be interconnected by some form of ring main, so that there is supply available from more than a single source as a safeguard against breakdown. These main H.T. cables terminate in end-boxes connected to isolating links and through a

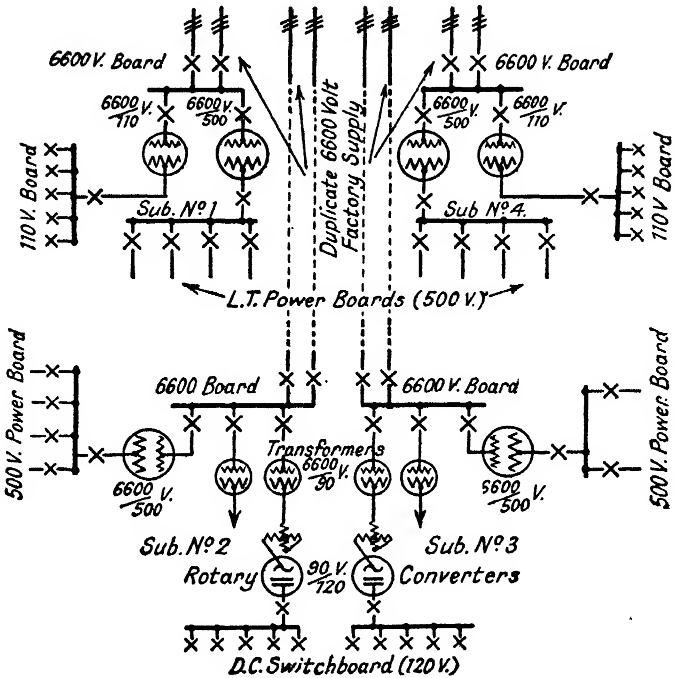


FIG. 5.—6,600-VOLT DISTRIBUTION WITH POWER SUPPLY AT 500 AND 110 VOLTS.

short length of busbar to oil circuit-breakers, all totally enclosed in separate cubicles or ironclad compartments.

Another set of busbars connected to the main circuit-breakers feed the step-down transformers through further isolators and oil circuit-breakers, one set for each transformer—also housed in separately screened compartments. Separate transformers may

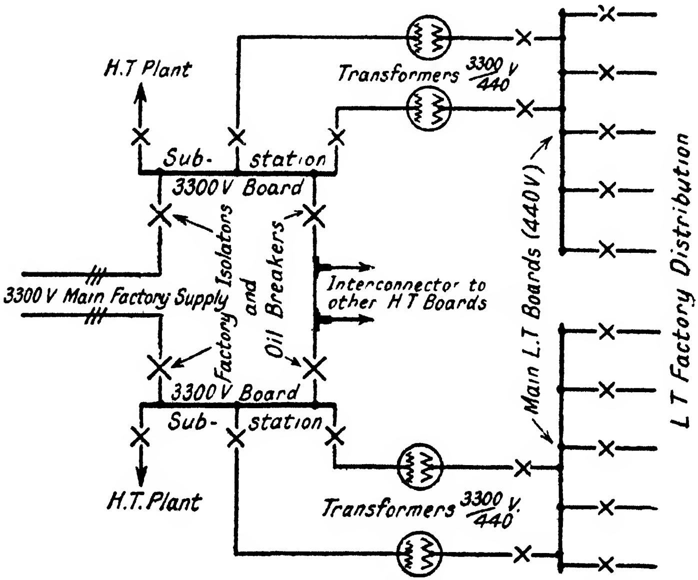


FIG 6.—STEP-DOWN 6,600–3,300-VOLT HIGH-TENSION DISTRIBUTION WITH POWER SUPPLY AT 440 VOLTS.

be installed for power and lighting, depending upon the low voltage adopted for both these services.

From the step-down transformers, cables are taken to the L.T. switchboard, and further distribution follows as already indicated earlier on in this article, when dealing with factory distribution at low tension. The main supply transformers are usually three-phase units, but may be made up of separate single-phase units connected together; the choice of equipment is concerned with the load to be supplied and also the accommodation space available for the erection of the plant.

When a D.C. Supply is Required.

Where direct current is required, motor generators, rectifiers or rotary converters supplied by step-down transformers can be installed.

Some of the usual methods of giving a main supply to industrial installations are shown by the single line diagrams in Fig. 2, and Fig. 3 illustrates the typical three-phase low-tension distribution lay-out in the factory. In Figs. 5 and 6 certain types of high-tension distribution are indicated, the low-tension power supply lay-out following in each case on the lines of Fig. 2.

Use of Higher Frequencies.

With a 50-cycle supply the choice of three-phase motor speed is very limited—while a speed of 3,000 r.p.m. can be obtained, 1,500 r.p.m. is the most convenient limit from a design point of view. However, for drives such as wood planers, moulders and routers, fine metal drills, portable tools, etc., higher speeds are advantageous, and are obtained by using a higher frequency current. A 200-cycle supply, for example, allows of a speed of 12,000 r.p.m. with a two-pole motor. The high frequencies required may be obtained by convertion from normal frequency by the use of frequency change sets, which are made for outputs from 1 to 100 kW at frequencies normally ranging between 75 and 450 cycles, giving motor speeds from 4,500 to 27,000 r.p.m.

In the case of new factories electrically equipped from the start, the installation can be properly planned with the sub-stations situated in the most suitable positions to meet the general requirements of the lay-out, section distribution, cable runs, etc., and with ample allowance for further extension.

When Sub-station Lay-out is Complicated.

Where factories have been in operation for years and electrification has been gradually introduced, the various sub-stations have in many cases had to be erected in situations most convenient to suit the main cable runs where sufficient space has been available, with the result that the lay-out becomes somewhat complicated and there is insufficient provision for expansion.

This is particularly the case with many of the oldest industrial concerns which originally had their own private plant, and as they expanded commenced to take power from the supply company's mains.

Factory Power Distribution.

As already indicated in the typical L.T. factory circuits shown in Fig. 3, the sub-main feeder cables from the sectional sub-stations connect to smaller switchboards situated in close proximity to the chief departments which they serve. These distribution boards are generally made up of a number of switches and fuses enclosed in foolproof ironclad boxes—one to each feeder cable; an energy meter is also connected in the circuit to measure the consumption in each department.

From these points further cables run to distribution fuse boards, from which the independent circuits for motor power or lighting are taken. Some of these circuits may still be further sub-divided for smaller equipment by means of other fuse boards, but the number of circuits which may be connected up in this way is definitely limited by the current taken by the various types of apparatus, and is given in the wiring rules for the electrical equipment of buildings.

Separate M.G. for Testing Plant.

In a testing plant equipment it is usual to install an independent motor generator to supply the necessary load, otherwise any surges set up, due to test breakdowns or sparkovers, are prone to get through back to the main switchboard, and have been known to bring out the H.T. breakers—shutting down a whole section of the installation.

Protective Fuses.

In order to increase the reliability of the plant and to avoid such contingencies as the shut-down of a feeder due to a temporary fault or excessive overload in one branch circuit, it is necessary to give very careful consideration to the matter of proper protection by fuses and circuit breakers.

TYPICAL ARRANGEMENT OF A LOW-TENSION INDUSTRIAL POWER-DISTRIBUTION SYSTEM

Fig. 7 shows a system of industrial power distribution commencing at the point at which an extra-high-tension bulk supply is received and finishing at the motors and lighting points, at which the low-tension (400–440-volt) power is used. The diagram is single-line, i.e., one line is employed to denote the three phases of the usual 50-cycle AC power supply.

The system shown is that for a large industrial plant receiving power at extra-high-tension voltage

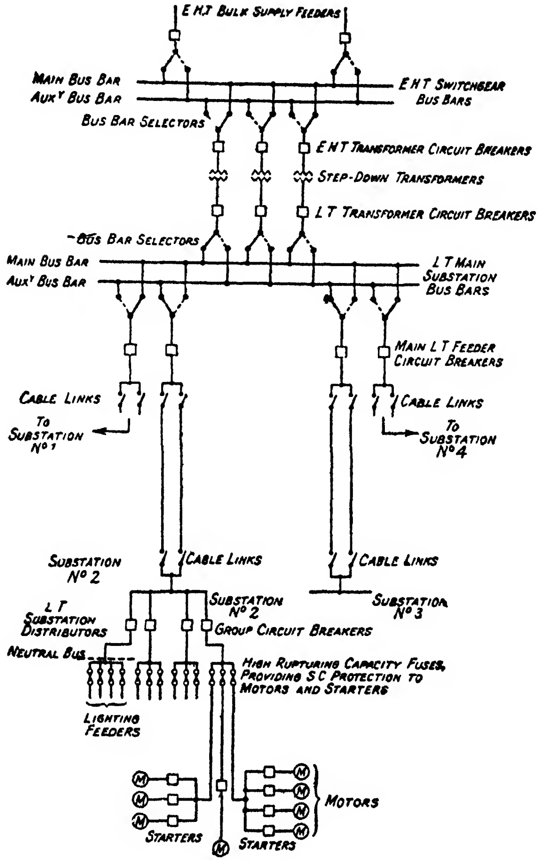


FIG 7—SINGLE-LINE DIAGRAM OF COMPREHENSIVE LOW-TENSION POWER SYSTEM DERIVED FROM E H.T. (EXTRA-HIGH-TENSION) SUPPLY.

from the local supply undertaking, transforming this power down to low voltage in a main sub-station, from which secondary sub-stations are fed. From the secondary sub-stations the power is distributed to the consuming points.

The study of such a comprehensive system provides the maximum of information, and the arrangement of a more simple scheme may be decided by utilising the relevant information.

Fig. 8 shows a layout for switchgear and transformers in the main sub-station.

The Extra-high-tension Switchgear.

The E.H.T. switchgear controlling the bulk supply may be either of the single-busbar type or of the duplicate-busbar type. If of the duplicate-busbar type, it will usually be sufficient for the switchgear to be of the type in which the circuit is transferred from one set of busbars to the other when the current is off, i.e., "off load". Duplicate-busbar switchgear provides additional switching flexibility, which is always desirable and results in maintaining a high standard of continuity of supply. Moreover, the provision of a reserve set of busbars enables one of the busbar systems of the switchgear to be cleaned and maintained without dislocation of supply. This necessary attention is often difficult to arrange on single-busbar gear in industrial plant where the power supply is continuous.

It may be convenient for the E.H.T. switchgear to be located as shown in Fig. 8, so that the main bulk-supply feeders can conveniently enter from the street If a high rupturing capacity is required on this switchboard some form of non-manual closing will be desirable and possibly even essential on the circuit-breakers. A convenient place for the push-button control panel

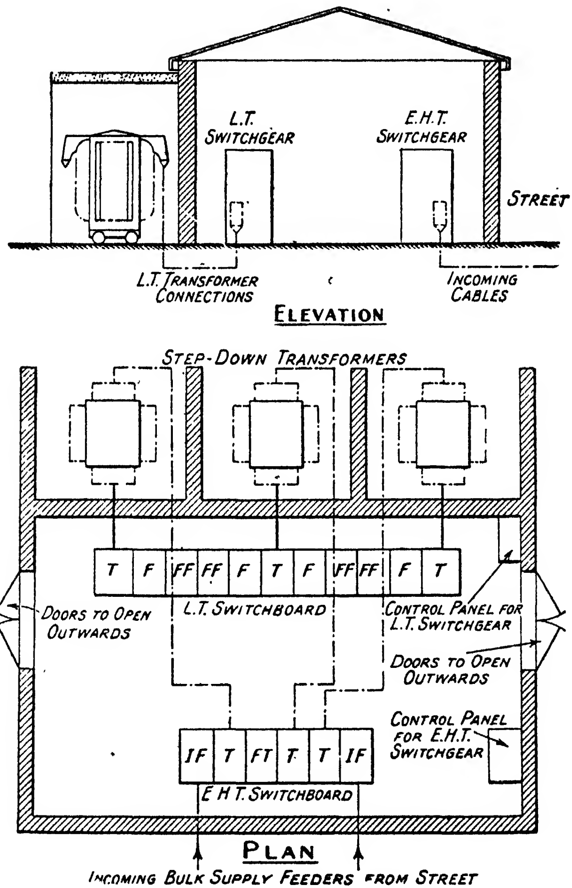


FIG. 8.—PLAN AND ELEVATION OF MAIN SUB-STATION FOR INDUSTRIAL POWER SYSTEM.

Key to lettering: T, transformer panel. FT, future transformer panel. F, feeder panel. FF, future feeder panel. IF, incoming feeder panel.

is close to the exit door and as far away from the switchgear as possible in order to provide the maximum security for the operator in the event of any switchgear trouble. This position is indicated in Fig. 8.

The power transformers should preferably be set apart from the switchgear, and a good position is that shown in Fig. 8, in which they are housed in masonry cells having one side open. This arrangement minimises the fire hazard to the switchgear and building arising from a possible failure of a power transformer, which may contain a large volume of oil. It is important to arrange that the distance from the transformer low-tension terminals to the low-tension transformer circuit-breaker should be approximately the same in all cases in order to ensure that the transformers will share the load proportionately when operating in parallel.

Main Low-tension Sub-station Switchgear.

The main low-tension sub-station switchgear may be of the single- or duplicate-busbar type. The advantages of the latter have been already discussed in a general way when referring to the E.H.T. switchgear. There is, however, a more vital reason for employing duplicate-busbar switchgear at this point of the system, particularly if the power transformers are of large capacity, say, 1,000 or 2,000 kVA each.

The usual value of the reactance of a 2,000-kVA transformer is of the order of five or six per cent., so that the short-circuit power which can be fed into a fault from each transformer would be approximately 40,000 kVA at the transformer terminals. Although the reactance of the main connections from transformer to switchgear will reduce the short-circuit kVA possibly to 30,000 kVA, it is clearly desirable to avoid grouping a number of such transformers on to a common busbar, as the short-circuit kVA would then be very high, and heavy rupturing capacity low-tension switchgear is extremely expensive and gives rise to technical difficulties in design and operation.

A double-busbar switchboard will enable sectionalisation to be conveniently effected, so that the short-circuit kVA on each section of the busbar system of the main L.T. board is limited and at the same time the use of duplicate busbars provides facility for the spare transformer to duplicate any one of the transformers in use in the event of failure or to meet temporary overload conditions.

Sectionalisation of an L.T. system to reduce the busbar short-circuit kVA is a most important step in the development of an industrial power scheme. A rupturing capacity of 30,000 kVA at 440 volts should be considered a maximum value.

The Circuit-breakers.

In view of the high value of short-circuit current which can be obtained on a low-voltage, heavy rupturing capacity switchboard, it is desirable for the oil circuit-breakers on the main switchboard to be non-manually operated. A convenient place for the push-button control is shown in Fig. 8, i.e., close to the exit door and as far away from the switchgear as possible, for reasons mentioned when referring to the H.T. switchgear in a preceding paragraph. As an example of the extremely high value of short-circuit current on a heavy rupturing capacity low-voltage installation, the following figures are interesting and impressive.

FIG. 9.—A TYPICAL LOW-TENSION INDUSTRIAL AIR INSULATED DRAW-OUT METAL-CLAD BOARD FOR FACTORY SERVICE

Showing two L T transformer circuit breakers and seven main feeder breakers

(1) Short-circuit kVA = 30,000.
(2) Pressure = 400 volts, 3-phase.
(3) Initial peak inrush current on which the circuit-breaker has to close when being operated on a fault = 110,000 amps.
(4) Short-circuit current to be interrupted = 43,500 amps.

An appreciation of what these currents mean may be gleaned from the fact that the same currents at 6,600 volts would mean a rupturing capacity of 500,000 kVA, which is the figure associated with super-power station main switchgear.

Feeders to Secondary Sub-stations.

From the main L.T. switchboard, feeders may be run to secondary sub-stations controlling sections of the factory or complete factory processes. These feeders may with advantage consist of multiple cables in parallel, each cable having a link at the transmitting and receiving ends. By this means it is possible for a single faulty cable to be isolated and supply maintained through the remainder, which will be sufficient to carry the load until such time as the faulty cable can be restored to service.

Discriminative Protective Gear.

The protective trip coils or relays on the L.T. feeder circuit-breakers on the main switchboard and the sub-station distributor feeder circuit-breakers must be so arranged that a fault on the sub-distribution circuits, i.e., on the motor or lighting circuits, trips the secondary sub-station distributor breaker before the feeder breaker on the main board can operate. This is important, since if the main-feeder breaker is tripped, the entire supply to that section of the factory or to that particular process will be interrupted. In other words, discriminative protective gear is required to ensure that the feeder circuit-breaker in the main sub-station is tripped only in the event of a fault on the main L.T. feeders.

Fig. 8 shows four main L.T. feeders, and for purposes of clarity the diagram shows only one secondary sub-station in detail.

The Secondary Sub-station.

The switchgear in the secondary sub-station will usually be of the single-busbar type, and if a feeder from the main sub-station is employed, a circuit-breaker is not necessary at the receiving end. If parallel feeders are employed it will be desirable to employ circuit-breakers at the receiving end in order to ensure that supply is maintained through the healthy feeder in the event of a fault occurring on one of the parallel feeders to that sub-station.

Outgoing Distributor Circuits.

The outgoing distributor circuits generally take the form of a number of feeder circuit-breakers, each circuit-breaker controlling a number of sub-circuits controlled by high rupturing capacity fuses. Each sub-circuit will control either a single motor or a group of small motors or a lighting distribution board.

Motor Sub-circuits and their Fuses.

Where the sub-circuit feeds motors, the motor starter gear will provide overload protection at the motor, but the high rupturing capacity fuses on the sub-station switchboard panel are installed to provide short-circuit protection during the starting and running conditions of the motors. These fuses would also provide back-up overload protection in the event of the motor starter failing to deal with the overload. The characteristics of high rupturing capacity fuses are such that in the event of a short-circuit occurring the current is inter-

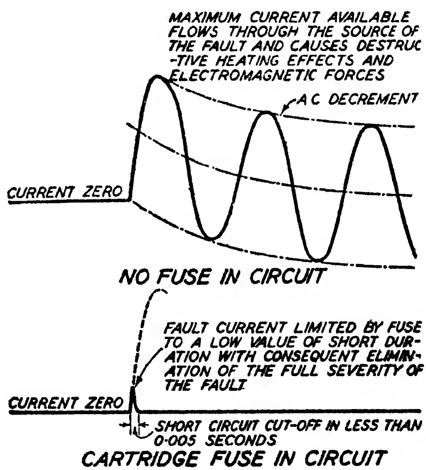


FIG. 9A.—SHOWING THE LIMITING EFFECT ON A SHORT CIRCUIT CURRENT BY MEANS OF A CARTRIDGE FUSE.

The fuse blows so rapidly that the maximum value of the fault current is not allowed to develop.

(*Lawson Beck Ltd.*)

rupted very quickly and before the short-circuit current has time to reach a very high maximum value. This relieves the duty on the contacts of the motor starter should it be called upon to close circuit with a short-circuit existing on the motor.

The L.T. breaker which controls the fuse ways on the secondary sub-station panels is provided, firstly, to afford means of sectionalising the system, and, secondly, as a last line of defence in the event of the fuses failing to deal with short-circuit or overload conditions.

Fuses with Direct-on Starters.

If the motors fed from the sub-circuits are controlled by means of direct-on starters, care must be taken that the fuse characteristics permit the passage of high starting currents prolonged for as long as thirty seconds without any deterioration such as would cause incorrect operation at some value of current lower than the fuse setting.

To sum up.

Summing up, the essential requirements of an L.T. industrial power-distribution system are:

(1) Sectionalisation of the main busbars to limit the short-circuit fault kVA on any section of busbar to a maximum of 30,000 kVA.

(2) Discrimination between the feeder circuit-breakers in the main sub-station, and those controlling sub-circuits in the secondary sub-stations in order to ensure that only the unhealthy sub-circuit is disconnected from the supply, which is then maintained on the rest of the system.

(3) Lay-out of main transformers in relation to switchgear to ensure correct sharing of load when paralleled on the L.T. side.

(4) Physical lay-out of switchgear and transformers to be such that the fire hazard is minimised, and also that the risk of injury to the operator arising from a switchgear or transformer failure is minimised.

(5) Duplication of busbars and main feeders to be considered with a view to maintaining continuity of supply.

(6) Where the rupturing capacity at the motor terminals is fairly high, high rupturing capacity fuses should be provided for back-up short-circuit protection of the motor starters.

Choice of Switchgear.

In choosing the switchgear the following factors should be carefully considered:

(1) Rupturing capacity.

(2) Whether hand or non-manual closing should be employed.

(3) Atmospheric conditions, i.e., whether damp or dusty or subjected to extreme temperature variations.

(4) The location of the gear, i.e., whether in the actual factory or in a place set apart.

Rupturing Capacity.

This will usually be determined by the capacity of the transformer or transformers feeding the busbar to which the circuit-breakers are connected. The theoretical short-circuit capacity at the L.T. terminals of the transformer may be calculated as shown by the example below:

Capacity of transformer = 1,000 kVA.

Reactance = 5 per cent.

$$\text{Short-circuit power} = \frac{1{,}000 \times 100}{5} = 20{,}000 \text{ kVA.}$$

Actually this short-circuit kVA would be realised only at the terminals of the transformer and also assuming an unlimited supply of power on the primary side of the step-down transformer.

The impedence of the connections from the L.T. side of the transformer to the L.T. switchboard busbars will reduce the short-circuit kVA available at the busbars, and the short-circuit kVA at any point on the outgoing feeders will be further reduced by the impedance of the feeder circuit-breakers and feeder cables.

The impedance of connections and cables can be calculated with reasonable accuracy and, as a very rough approximation, based on a typical sub-station lay-out the short-circuit kVA at the L.T. busbars may be taken as from sixty to seventy per cent. of the theoretical value, so that for example given above an L.T. rupturing capacity of 15,000 kVA would be a suitable rating for the switchgear.

Whether Hand or Non-manual Closing should be Employed.

It is interesting to consider the magnitude of the short-circuit currents for various typical L.T. rupturing capacities, assuming the worst fault conditions, i.e., a totally asymmetrical short-circuit and negligible fault resistance.

Voltage.	*Rupturing Capacity.* *kVA.*	*Current to be Interrupted.* *Amps.*	*Peak Inrush Current (or Making Current).* *Amps.*
440 . .	30,000	39,000	97,500
440 . .	15,000	19,500	48,750
440 . .	7,500	9,750	24,375

The last column indicates the current which has to

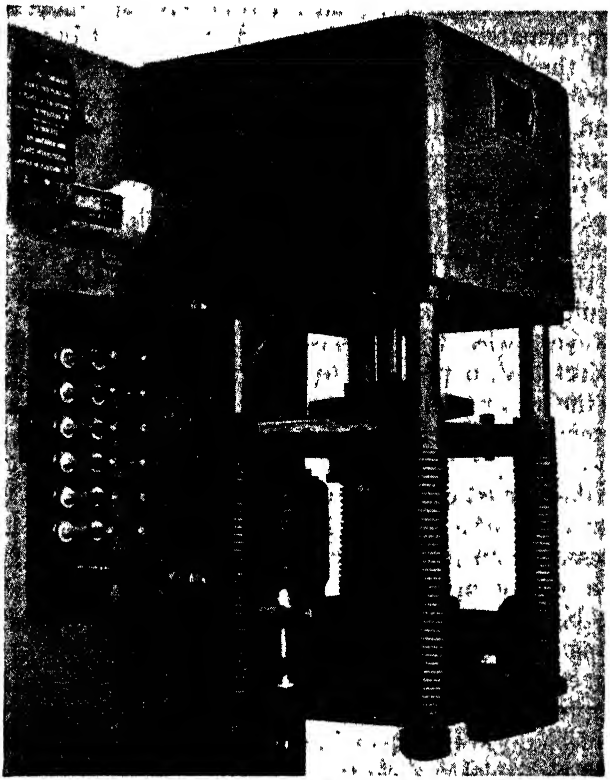


FIG. 10.—A TYPICAL SPRING-CLOSING MECHANISM FOR NON-MANUAL OPERATION OF OIL CIRCUIT-BREAKERS.

be made on the contacts of the circuit-breaker when closure is effected on a short-circuit. It will be appreciated that such high values of current would cause very strong repulsive forces acting on the contact bars of the circuit-breaker and on the closing-link gear due to the electro-magnetic forces developed by the loop formation of the conductors in the circuit-breaker.

If these high values of current are actually experienced it is doubtful whether the operator could, by hand, close the breaker with sufficient power and rapidity to ensure satisfactory closing in the case of the two higher rupturing capacities. Fortunately the impedance of an L.T. fault is usually sufficient to reduce these high values considerably, and in practice, except for rupturing capacities of 30,000 kVA and over, L.T. circuit-breakers are usually hand-operated. It is, however, wise to recognise the importance of this subject and, if possible, to supply non-manual closing for the main L.T. switchgear on a power-distribution system of large capacity as described in the previous article.

Non-manual closing has in the past been effected by means of motor or solenoid closing mechanisms which necessitate an independent supply of power, resulting in a costly arrangement. Non-manual closing can now be provided at a moderate cost by the choice of a spring closing mechanism as illustrated in Fig. 10. The energy for closing the breaker is stored up in compressed springs, and may be released either locally by mechanical trigger or from a remote point by means of an electrical push-button.

Heavy-current oil circuit-breakers are also difficult to close by hand even under normal current conditions, and non-manual closing considerably aids operations of such large breakers.

Atmospheric Conditions.

The atmospheric conditions, i.e., whether dusty or damp, or whether there is a considerable temperature variation, play an important part in the choice of switchgear.

Where the conditions are damp or extremely dusty it may be advisable to employ metal-clad switchgear of the compound-filled type in order to reduce to a minimum the insulating surfaces exposed to the collection of dust or moisture. Compound-filled switchgear is usually more expensive than air-insulated gear, and provided the design of the latter can be made reasonably dust-tight, air-insulated industrial-type metal-clad gear or air-insulated cubicle-type gear can be employed even in dusty atmospheres. The whole circumstances should, however, be reviewed and the design of the gear examined in order to determine its suitability for the atmospheric conditions.

Where temperature extremes are experienced, care must be taken to ensure that the characteristics of oil-dashpot time-lags are not affected to an extent which would cause maloperation. A high ambient temperature may also result in the temperature of the switchgear reaching an undesirably high level, and it may be necessary to arrange for the switchgear to be ventilated or for other steps to be taken to avoid a high final temperature.

Location of Switchgear.

If the switchgear is located in a sub-station, or, in official language, "in a place set apart," the switchgear may be of the non-interlocked cubicle-type or of the open flat-back type. Where, however, it is desired to locate the switchgear in the factory it is usual for fully interlocked draw-out type industrial metal-clad gear to be installed. This latter type is mistake-proof, compact, and robust, and the effective earthing of the metal-clad construction which encloses all live conductors prevents any possibility of electric shock to the operator. This class of gear also lends itself readily to sequence interlocking, which is often a requirement of many industrial processes.

Ensuring Continuity of Supply.

For the main sub-station, well-designed stationary cubicles, completely interlocked and adequately ventilated, can form a very reliable installation. With air-insulated gear of this type access to all components for maintenance can be obtained, and any temporary modifications to meet special circumstances or breakdown can be quickly made on site by the factory's maintenance staff.

Facility for inspecting circuit-breaker contacts conveniently and easily is desirable in maintaining the gear in sound condition, and this may be achieved effectively by mounting the circuit-breaker on a truck complete with mechanism to raise the circuit-breaker terminal contacts into engagement with the fixed portion of the gear. The main L.T. switchgear can therefore comprise either compound- or air-insulated equipment with a withdrawable circuit-breaker having these features. The use of a withdrawable breaker also aids in effecting continuity of supply by enabling a spare breaker equipment to be retained which can be immediately plugged into contact to replace a faulty equipment.

In choosing industrial metal-clad type gear for use in the factory either as motor-control gear or for sub-distribution switchboards, the essential requirements are:

(1) Good arrangement of contacts.
(2) Simple and reliable closing and tripping mechanism.
(3) Time-lag characteristics to meet working conditions.
(4) Compact, robust, and dust-tight construction.
(5) A simple and effective arrangement of interlocks and facility for conveniently arranging sequence interlocks.

CHAPTER II

THE FACTORY SUB-STATION

THE term "sub-station" is generally used to describe that place in a factory where the incoming supply enters the building and where the consumer's main switchgear is concentrated. It is in this broad sense that the word is used in this chapter.

It is proposed to review the accommodation that is desirable for this type of apparatus in the average factory and to discuss such arrangements as are necessary in the interests of safety and convenience.

Where to Locate the Sub-station.

The ideal situation for the sub-station, or for any distributing centre, is at the centre of gravity of the load it is to supply. Other considerations, however, often make the practical realisation of this impossible. The point chosen must be convenient for the incoming supply; and even if this condition be satisfied, a suitable site is not always available. The load concentration, however, must be the deciding factor, if full advantage is to be taken of a balanced distribution system. Any deviation from the ideal situation should preferably be towards the point of intake.

Type of Accommodation.

The consumer has a choice of two alternatives in deciding the type of accommodation to be provided:

first, an internal sub-station situated in part of a factory building used for other purposes; or an external sub-station entirely separate from otherwise occupied parts of the premises. The second course usually implies the provision of a special building.

Either type must be suitable to accommodate the supply company's apparatus in addition to the consumer's main distribution gear. When a medium pressure supply is being taken, the former usually is of the simplest, and comprises some form of main switch and the metering equipment.

If E.H.P. mains are brought in, the supply company will need to provide accommodation for E.H.P. switchgear and transformers as well. This will normally have to be housed separate from the consumer's gear, as it is unusual for him to have access to this equipment. In this case, it is usually most convenient to make the supply company's sub-station and the consumer's sub-station adjoin; although each must be distinct from the other.

Conditions in the average factory warrant the utmost care being taken to minimise the risk of injury or damage from electrical causes, and a big step in this direction is to restrict access to the key points in the distribution system. This is an important argument in favour of housing the electrical equipment in a special building, although the cost of this may be appreciable. When it is imperative to install such equipment in occupied parts of the factory, it should be placed beyond the reach of passers-by, and suitably enclosed. It is most essential that none but responsible persons have access to it.

It is not permitted to install open-type switchgear in situations where anyone may come into accidental contact with it; and with ironclad gear, of which the covers and cases have been properly earthed, there is little danger from accidental contact. Nevertheless, even ironclad gear is best protected if only to prevent interference with its satisfactory operation. Also, a point of the utmost importance where excessive values of fault kVA are to be expected, is that should the main switchgear fail to clear a heavy fault, the resulting disturbance may be disastrous if it is in an occupied part of the factory.

A further reason, which supports the case for installing large circuit breakers and the like as remote as possible from the factory buildings, is the risk of fire, which will be dealt with more fully later.

External Sub-stations.

The advantages of a special building for the sub-station are obvious, for it is easy to incorporate such special provisions as are necessary to ensure full safety, and the maximum of convenience in operating and installing the gear. This provision is most desirable whenever E.H.P. lines have to be brought into a factory, especially if the consumer himself be operating at E.H.P. Of course, the essential feature of the external sub-station is that it should be separated from other buildings by walls of fire resisting material, and that unauthorised access to it should be impossible.

The Fire Risk.

The risk of fire is perhaps the governing feature in the design of sub-stations where oil-filled apparatus is to be used. This risk is mainly centred in the possibility of igniting the oil used in the tanks of circuit breakers, and for cooling transformers and similar apparatus. When a circuit breaker clears a fault, some of the oil is vaporised by the arc. This vapour, which can form an explosive mixture when mixed with air, may be ignited by subsequent racing. Similarly, the oil in transformers can be ignited by open faults in the windings.

Notwithstanding that every care is taken in modern designs to reduce this risk as far as possible, the real danger lies in the possibility of the burning oil escaping from its tank, and starting an oil fire which rapidly becomes uncontrollable.

Therefore, in any situation where equipment containing a large quantity of oil is installed, means to prevent its unrestricted flow are desirable. This can be done by providing a drainage sump under each piece of gear, or, alternatively ducts leading to a common sump outside the building. When only small quantities of oil are concerned, a concrete sill cast round the base of the apparatus may be sufficient.

Obviously, the constructional materials used in the building itself contribute much to the risk from fire. Inflammable materials such as wood should be used sparingly, brick and concrete being preferable from all points of view.

Floor of Sub-station.

The floor of the sub-station needs the most careful consideration. If, as is usually the case, this is of concrete, served with a waterproof dressing, provision for foundations, cable trenches, and the like must be made before the floor itself is laid This renders it difficult to convert an existing building with an established floor.

Foundation bolts are not usually provided for heavy equipment, such as transformers; but heavy gear generally is best provided with some form of foundation, to prevent localised stress on the floor and to avoid damaging it when the equipment is installed or moved. The usual way to deal with this is to provide "H" or channel section girders in the floor and slightly above floor level. The gear can then be run in and stand on these, as is shown in Fig. 11.

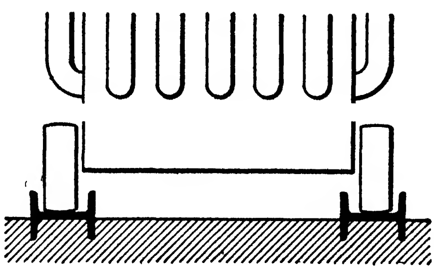


FIG. 11.—FOUNDATION FOR TRANSFORMER.
The usual method—an "H" or channel section girders in the floor of the sub-station.

Switchgear, on the other hand, usually needs foundation bolts and holes, for these must be left when the floor is made so that the bolts can be grouted in during erection. When a long switchboard is being installed, it may be carried on girders set in the floor as shown in Fig. 12. This will prevent the gear being stressed by inequalities in the level of the floor, and the web of the girder itself can be drilled and tapped to receive the holding-down bolts.

Cable Trenches.

The arrangement of the cable trenches deserves special consideration. They should be deep enough to allow a gentle sweep on the biggest cable being used, large enough to accommodate the cables without untidy bunching, and so positioned that they can be laid in the trenches and give the jointers ample room in which to work. Sharp bends should be avoided, and cable racks or cleats to hold the cables in position when laid are most desirable.

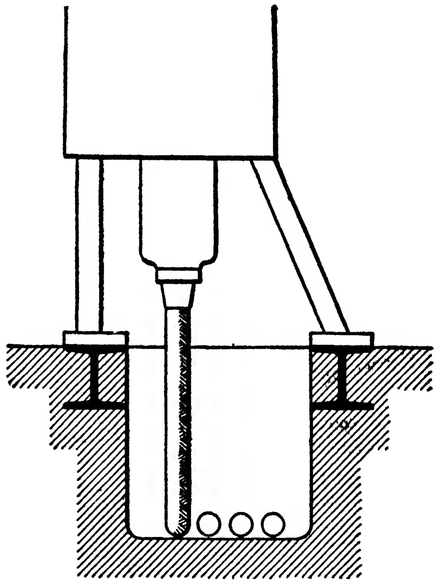


FIG. 12.—METHOD OF CARRYING A LONG SWITCHBOARD.
The girder webs can be drilled and tapped to receive the holding down bolts.

The common fault with cable trenches is that they are too narrow, because they usually have to pass beneath switchgear, and the width is therefore limited by the span of the legs of the switchboard. This can be overcome by the arrangement shown in Fig. 13. This arrangement suffers from the disadvantage that the girders pass across the trench, and prevent the cables being laid in position; moreover, the space for jointing is rather restricted. On the whole, the layout

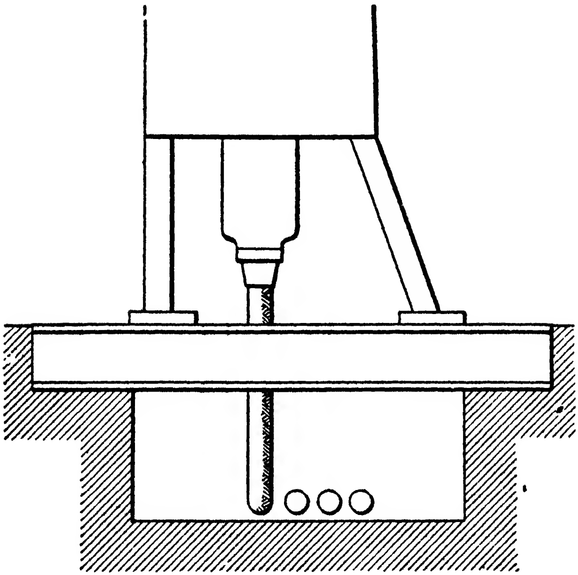


FIG. 13.—ARRANGEMENT OF CABLE TRENCH BENEATH SWITCHBOARD.

shown in Fig. 14 is to be preferred, although its cost may be somewhat greater. Here the cable trench proper lies behind the switchboard, which is carried on girders set in the floor, and cantilevered from the front of the trench.

Free ventilation for the sub-station is most necessary, and the maximum of natural lighting is also desirable. Some form of artificial heating will prevent the condensation of moisture during the winter months; although, when power transformers are included in the equipment they will usually supply this need.

Another point to be mentioned is the necessity of

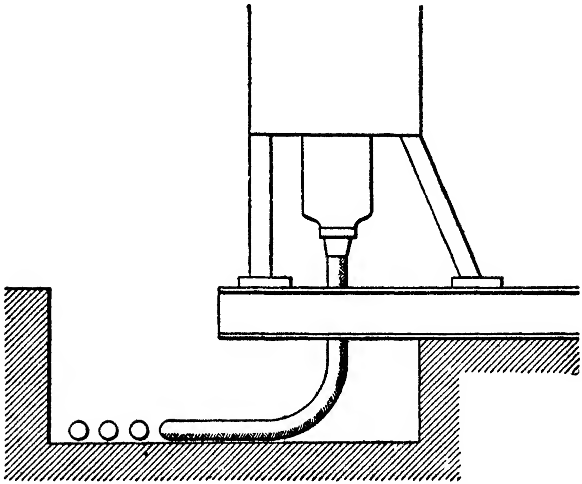


FIG. 14.—CABLE TRENCH ARRANGED BEHIND THE SWITCHBOARD.

providing some form of lifting gear for the heavier equipment, not only during erection, but as a permanent fitting to facilitate regular maintenance. This may involve strengthening the roof structure to support it.

Safety.

The most effective safety measure that can be taken is to see that unauthorised persons have no access to the sub-station. Therefore, provision for locking the doors of all switchrooms is necessary, together with full supervision of the keys.

Doors.

An emergency door, in addition to the main door of the sub-station, should also be provided; and the former should preferably be made to open outwards, and be fitted with panic bolts on the inside. The main door, of course, must be large enough to pass the largest single piece of apparatus that may have to be installed in the sub-station; and valuable space can often be saved by making this door of the roller or folding type.

As is to be expected, the type of equipment used by consumers follows closely the established practice of the supply companies. In fact, it is often possible for a consumer to effect considerable economies in the cost of his equipment by making it of a type that will line up with that installed by the supply company. For example, if the supply company's main switches can be incorporated in the consumer's main switchboard, as the incoming units, this will avoid the necessity of the consumer duplicating these.

E.H.P. SWITCHGEAR

The choice, as regards E.H.P. switchgear, lies between two main types: air-insulated gear, and gear with compound-filled, or oil-filled busbar chambers. This distinction applies only to the method of insulating the busbars and connections therefrom, as the use of oil-immersed switches is universal at these pressures.

The fixed cubicle, and the truck, are typical of the air-insulated construction. In the fixed cubicle, the circuit-breaker is fixed in position; and some form of mechanically operated isolating switch is provided so that the breaker can be made dead for inspection. With a truck, on the other hand, meters, current and potential transformers, and the like, are mounted with the circuit-breaker on a truck which can be removed bodily from the switchboard. The connections to the circuit-breaker are made through plug contacts, which are so shrouded when the truck is withdrawn, that there is no danger of accidental contact. With this type of gear, therefore, maintenance and major repairs can be carried out with relative ease; and, moreover, trucks of the same size are usually interchangeable.

Filled gear is usually slightly more expensive than air-insulated gear; but it gives the maximum of safety, and allows a slightly more compact construction. This design is somewhat less accessible than truck gear, however, as all the fixed connections and busbars are embedded either in compound or in insulating oil. The circuit-breaker is isolated and withdrawn by a horizontal or vertical movement, or occasionally by a combination of the two, which results in a reduction of the space required to accommodate the gear. Plug contacts of a type similar to that used in trucks are provided, and all live metal is carefully shrouded and shielded from accidental contact when the breaker is withdrawn.

Transformers.

Of the various types of transformer available, the oil-immersed, self-cooled type is the most suitable and is universally used for secondary sub-stations. The chief point of interest to a consumer, is the number of transformers that should be installed to give, if possible, stand-by protection. With transformers of medium size—say, up to 1,000 kVA.—one transformer is much cheaper in first cost than two of half the size; and similarly, two are much cheaper than three of the same total capacity. This divergence in cost is increased when allowance is made for the attendant switchgear, and the increased accommodation necessary. Nevertheless, the advantage of not being entirely dependent on one unit is obvious; and in this matter the laws of economics are not so strictly applicable to the industrial user, whose total output depends on the maintenance of the electrical service, as is the case with, for instance, a supply company who are faced merely with a loss in revenue, and who, in any case, usually have means whereby an emergency supply can be given.

It is most desirable that at least two transformers should be installed, either of which is capable of maintaining all services essential to production should the other fail. The transformers themselves have an overload capacity of fifty per cent. for thirty minutes, and this can be taken into account when the emergency rating of the equipment is determined. Thus, it is possible to load a two-transformer sub-station up to seventy-five per cent. of its nominal capacity, and still retain full output with one transformer out of service for a limited period.

Similarly, a three-transformer sub-station can be loaded up to 100 per cent. of its nominal capacity in the same conditions.

In deciding the technical characteristics of the transformers to be installed, consideration should be given to the value of reactance, which should be sufficiently high to limit the fault kVA on the medium pressure side to reasonable proportions.

MEDIUM PRESSURE SWITCHGEAR

It is common practice for supply companies to provide only simple links and open type fuses for the control of medium pressure feeders. The consumer, however, will find it to his advantage to provide in his own sub-station ironclad switches, either circuit-breakers or switch-fuses, which can be opened and closed on load, and which operate simultaneously on all phases

Modern medium pressure switchgear is built up on lines generally similar to metalclad E.H.P. gear, except, of course, that compound or oil-filled busbar chambers are not necessary at the lower pressures. When oil circuit-breakers are used, these may be of the fixed or of the withdrawable pattern; but when

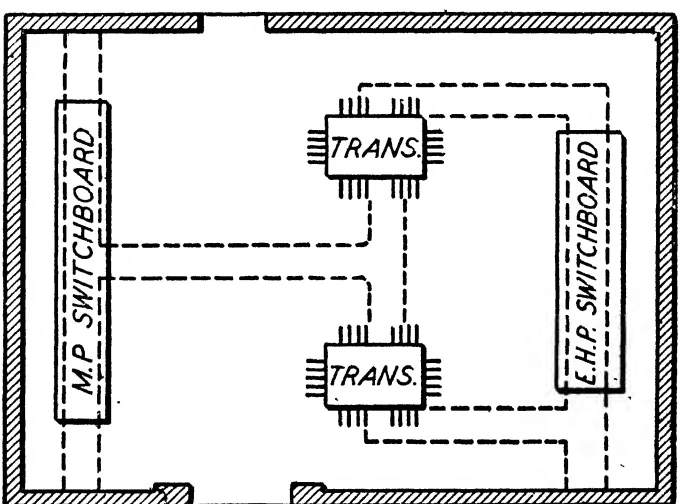


FIG. 15.—A CONVENIENT GENERAL LAY-OUT OF EQUIPMENT, SEPARATING E.H.P. AND M.P. APPARATUS.

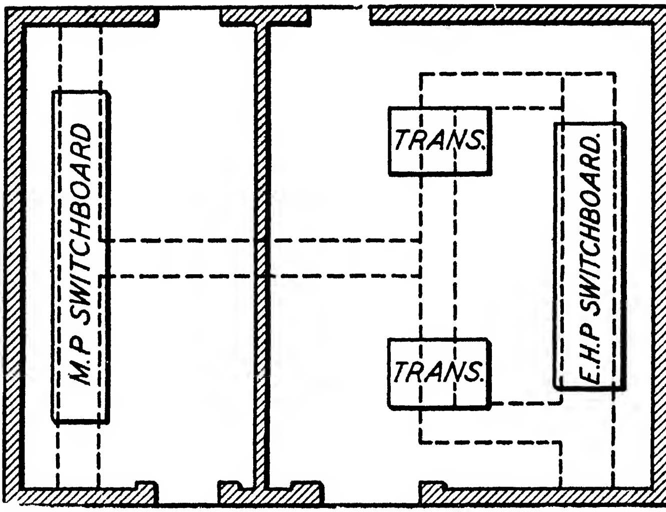


FIG. 16.—ARRANGEMENT WHEN SUPPLY CO. OWN AND CONTROL THE E.H.P. SWITCHGEAR AND TRANSFORMERS.

breakers of the fixed type are used, some form of isolating switch for each circuit-breaker is desirable.

As an alternative to circuit-breakers, ironclad switches with high rupturing capacity fuses can be used.

LAY-OUT OF EQUIPMENT

Probably the most convenient shape for a sub-station is a rectangular one; although it is often necessary to depart from the ideal shape when a sub-station has to be established in an existing building.

The most convenient general lay-out is one on the lines shown in Fig. 15. This has the advantage of separating E.H.P. and M.P. apparatus; and also keeps to the minimum the length of the interconnections

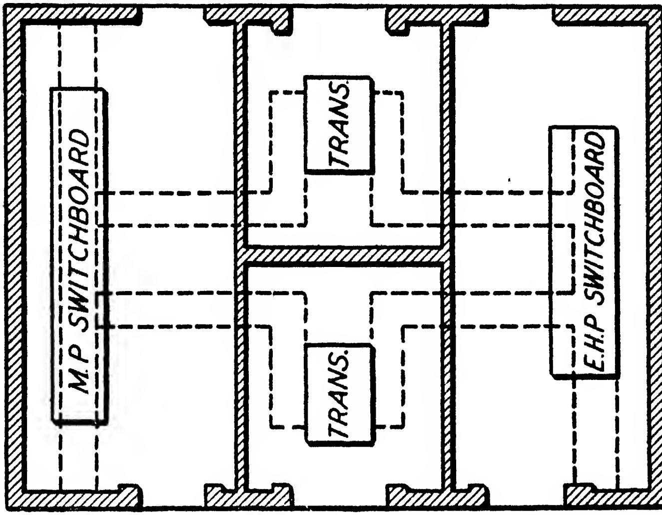


FIG. 17.—WHEN EACH MAJOR PART OF THE EQUIPMENT IS HOUSED IN A SEPARATE COMPARTMENT, MAXIMUM SAFETY IS OBTAINED.

between the switchgear and the transformers. A point of practical interest is to see that there is free access round all the gear. This is particularly important in the case of the switchboards, because access to the back of the boards does much to facilitate erection and maintenance.

When the supply company own and control the E.H.P. switchgear and transformers, an arrangement similar to that shown in Fig. 16 can be adopted. In this the sub-station is divided into two, the consumer only having access to that part in which the M.P. apparatus is installed.

The maximum of safety is obtained when each major part of the equipment is housed in a separate compartment, as is shown in Fig. 17. In this way all danger of mistakes or accidental contact while repairs are being carried out is avoided; and also, the danger of fire spreading from one piece of apparatus to another is much reduced.

Interconnections.

For obvious reasons, the cable runs inside the sub-station should be as direct and as short as possible; and for the sake of safety as well as of appearance, the cables should either run in trenches, or be cleated in position on the walls or roof of the sub-station.

E.H.P. interconnections will usually be carried out in multi-core paper insulated, lead covered cable; armouring will usually be unnecessary inside the sub-station.

Short runs of M.P. cable, especially those of moderate current carrying capacity, are best in single core V.I.R. cable.

Interconnections of large capacity, such as the incoming feed to the medium pressure switchboard, can often be made with bare copper strip, carried overhead on insulators, and protected, where necessary by screens of expanded metal.

Metering Equipment.

The run of the interconnections may be decided by the fact that the supply company's meters have to be inserted between their main switch and the consumer's installation. Thus, when a medium pressure supply is taken, provision has to be made for current transformers in the connections to the consumer's main switchboard. Often these transformers, which are the property of the supply company, are mounted on the wall in some position convenient for the reception of the meter panel, and the connections to the switchboard run through them; but by far the best arrangement is to provide a meter cubicle at the incoming end of the switchboard, and constructed as an integral part of the board. In this way, the transformers can be connected solidly in the run of the busbars, and be totally enclosed. The face of the cubicle can be used to accommodate the instruments themselves.

Interlocks.

Interlocks are one of the safeguards provided for those who have to handle the equipment in the sub-station; but it must be remembered that the purpose of an interlock is to remind the operator when an action he wishes to take may be dangerous, not to prevent him taking that action in any circumstances. It may prove necessary on occasion to defeat an interlock; and any attempt to make it proof against intentional attempts to defeat it often seriously hampers the elasticity with which the gear can be operated.

The most useful type of commercial interlock is that which ensures a correct sequence of operations; such as, for example, the correct operation of isolating switches and the like, and to prevent access to live metal until the appropriate switch has been opened to make it dead. And for such purposes as these, a simple and robust mechanical interlock is the most serviceable.

The use of padlocks at all points where casual access to live metal is possible is most desirable.

Similarly, provision should be made for locking all isolators and circuit-breakers in the "On" and "Off" positions. For this purpose, it is essential that the keys of such locks should not be interchangeable, so that anyone working on a switch or any apparatus connected to it can be certain that no one can interfere as long as the appropriate key is in his possession.

It is not abnormal, of course, for maintenance to have to be carried out while the plant is still alive, and to facilitate this, special equipment such as rubber mats, rubber gloves, and special tools with insulated handles is desirable.

Fire Fighting Equipment.

It is common practice to supplement the precautions against fire already mentioned in these notes, with one of the recognised automatic fire fighting services specially designed to cope with oil fires. This is particularly important in internal-substations, where the risk of an oil fire spreading assumes perhaps greater significance than is the case with an isolated building.

The action of these systems is entirely automatic, and they are operated by fire detectors placed in strategic points over the equipment.

CHAPTER III

DISTRIBUTION SWITCHGEAR

THIS chapter deals only with distribution switchgear as used for factory and industrial purposes. Such switchgear includes the main switchboard controlling the low tension side of transformers, or the main L.T. supply from the mains, and feeders to sections or bays of the factory or industrial plant, and smaller switchboards at the end of these feeders, controlling the supply to motors, lighting circuits, etc. It does not include switchgear for the control of generating plant, small fuseboards which form a part of the lighting installation, or motor control gear.

Function of Switchgear.

The function of switchgear is to control and protect electrical circuits, and, incidentally, to measure or indicate the amount of power used. It may not be called upon to operate for months, or perhaps years, yet should be capable at any time of interrupting faults such as overloads or short circuits. Hence suitable design, reliable construction and care in maintenance are of the greatest importance.

Electricity Regulations.

The type of switchgear to be installed for any particular use is governed very considerably by the

Home Office Regulations (Factory and Workshops Acts). Some of the requirements of these regulations, in brief, are:—

(1) Switchboards having bare conductors exposed so that they may be touched must be located in a room or enclosure set apart for the purpose, to which only authorised persons have access.

(2) Where bare conductors are exposed, there must be a clear passageway of three feet from conductors to wall (four feet six inches if conductors are exposed on both sides) and seven feet from floor to conductors overhead. (These distances refer to systems not exceeding 650 volts between phases).

(3) When work has to be done on a switchboard, either it must be made dead, or the section on which work has to be carried out must be made dead and screened from adjoining live conductors.

It will be seen that these clauses practically prohibit the use of open type switchboards, except when they are located in proper switch rooms, and require that switchboards and the distribution system in general must be planned so that any section of any board can be made dead (by operating isolating switches, for example) for cleaning.

TYPES OF SWITCHBOARDS

Industrial distribution switchgear may be divided into four broad classifications:—

(*a*) Flat-back or open type switchboards, consisting of knife switches, fuses, circuit-breakers, etc., mounted on slate, marble or insulated steel panels.

(*b*) Cubicle type boards, of the fixed or truck type.

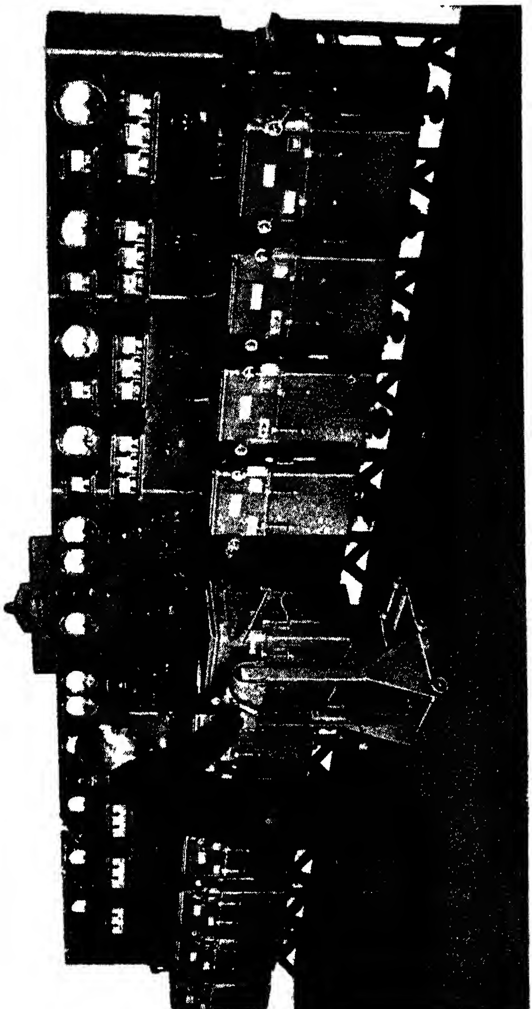


FIG. 18.—SWITCH UNIT BEING REMOVED FROM TRUCK TYPE OIL CIRCUIT-BREAKER BOARD.
(M. & C Switchgear Ltd.)

(*c*) Ironclad oil break switchgear, with isolating features of various kinds.
(*d*) Ironclad switch and fuse gear.

Flat-back Switchboards.

The flat-back board must be housed in a proper switch room or suitably enclosed. If the front has no live metal exposed, and the back is closed by a wall, expanded metal doors and screens at the end form sufficient enclosure. Unless it is possible to make the whole board dead for inspection (which may be possible at weekends for routine inspection, but may be very inconvenient in case of a breakdown), isolating switches between the busbars and the other apparatus are necessary, together with means for screening other circuits (fixed or temporary divisions) from the one on which work has to be carried out.

Boards of this type are low in first cost, particularly for heavy currents (500 amps. and above) and when equipment a little out of the ordinary is required. They occupy rather a large amount of room, the required depth back to front, with passage-way and operating space, being about eight feet, and they are not suitable for dusty situations. Their chief use is for the control of the main supply and distribution cables when housed in a proper switch room, which may be combined with the transformer room.

Cubicle and Truck Type Switchgear.

Cubicle type boards have all live gear enclosed, and therefore need no enclosure. They are dearer than flat-back boards, occupy about the same amount of room, and are not entirely suitable for really dusty

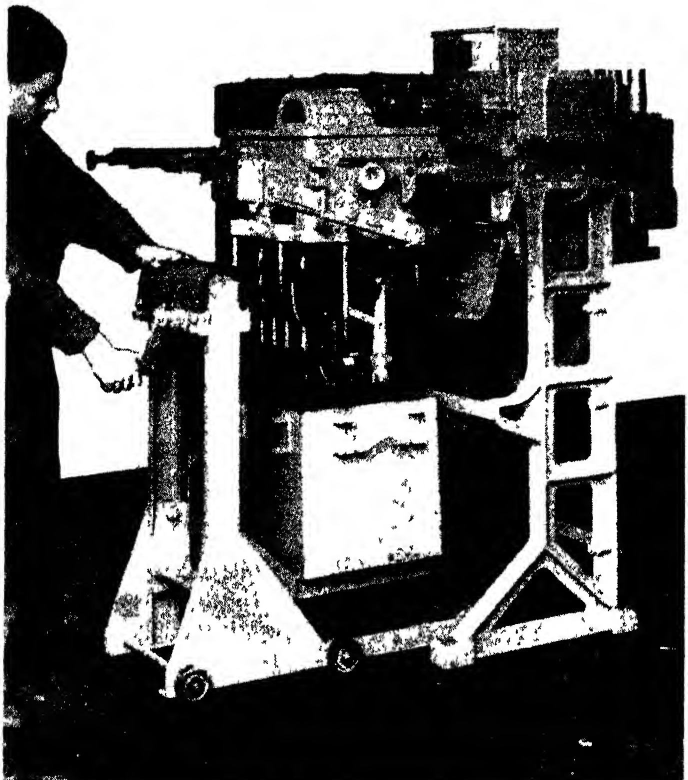


FIG. 19 —TANK LOWERING AND SWITCH REMOVAL TRUCK—
SHOWING METHOD OF USE

The special type of tank lowering and switch removal truck illustrated in this and the preceding illustration facilitates the transportation, inspection and maintenance of oil break switchgear.

(*M & C Switchgear Ltd*)

situations or similar severe conditions. Both the fixed and the draw-out type (the former when provided with interlocks) are safer than open type boards, and the latter are particularly easy to overhaul, since all parts needing examination are mounted on a truck portion, which can be withdrawn. Fixed cubicle boards are made which can stand with the back against a wall, but for easy jointing of cables and any necessary repairs a passageway at the back, even if rather narrow, is invaluable.

Ironclad Switchgear.

The majority of industrial switchgear requirements are met by oil-break ironclad gear, either of the draw-out or drop-down type (Fig. 19), in which the complete breaker unit can be isolated and removed if necessary for overhaul, or the simpler type with or without some device for isolating the main parts from the busbars. This type of gear is compact, safe in operation, even by semi-skilled attendants, is suitable for very damp and dusty situations and can be made suitable for use in fiery mines.

Ironclad switchboards built up of ironclad air-break switches and fuses are very suitable for secondary distribution boards in large installations, or the main board in a small factory. Where there is one incoming feeder of larger capacity, this may be controlled by an oil-break unit connected to the air-break switchboard (Fig. 20).

Owing to the improvement in recent years of high rupturing capacity fuses, there is a growing tendency to use them throughout factory distribution systems, that is from the main L.T. busbars in the sub-station to the final sub-circuit boards.

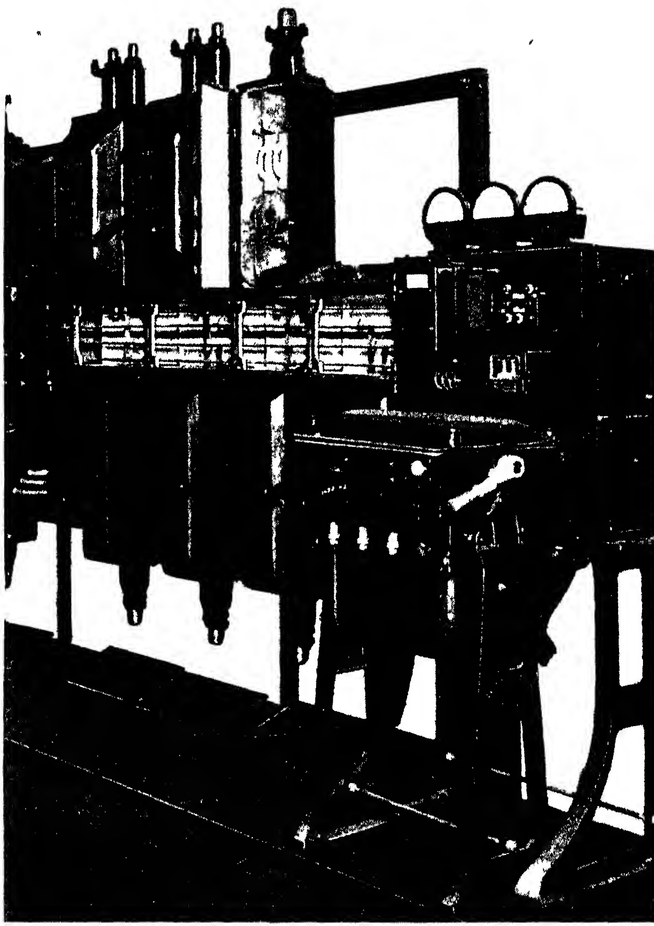


FIG 20 — AN IRONCLAD SWITCHBOARD

This consists of ironclad oil circuit breaker (fitted with three ammeters and watthour meter) for the incoming feeder and ironclad switches and fuses for the outgoing circuits mounted above and below the busbar chamber

(Johnson & Phillips Ltd)

EQUIPMENT OF SWITCHBOARDS

The following recommendations are based on average requirements. When cost permits, the fuller equipment scheduled should be chosen.

Main Incoming L.T. Feeder or Control of L.T. Side of Transformer.

(1) Automatic oil circuit-breaker, with isolating switches or isolating device on incoming side (and on busbar side unless there is not and is unlikely to be any other incoming supply). Neutral link if a four-wire circuit.

(2) Automatic device consisting of overload tripcoil with time-lag on each phase, or, preferably, Merz Price or similar protection for a transformer.

(3) Instruments.

(*a*) Ammeter on each phase, or one ammeter with switch for reading current on each phase.

(*b*) Voltmeter, with switch for reading voltage between each phase and/or from each phase to neutral.

(*c*) Watthour meter (as a check on the supply company's meters), with maximum demand indicator if desired.

(*d*) Indicating wattmeter (a "luxury" extra).

(*e*) Power factor indicator (always useful where there is a large motor load, and practically essential if the supply company gives a bonus [in the form of reduced terms] for high-power factor).

Feeder to Secondary Switchboard or Large Motor.

(1) Automatic oil switch with two time limit over loads and one earth leakage tripcoil. No-volt

trip optional. Isolating switch on busbar side. Neutral link if a four-wire feeder.

(2) Ammeter (with switch to read in each phase if there is any single-phase load which may not be balanced).

(3) Power factor indicator for power circuit if desired.

Feeder to Lighting Distribution Board.

(1) Either automatic oil switch with overload trip-coils or ironclad fuses. Isolating switches on busbar side (or ironclad knife switch) and neutral link.

(2) Ammeter in each phase (preferable) or one ammeter with switch to read current in each phase.

Essential Accessories.

The above equipments do not list essential accessories supplied by the switchboard maker (such as current transformers, voltmeter fuses, etc.) or necessary cable boxes or conduit fittings to suit the cables.

Spares.

It is recommended that a small stock of spares be kept, including:—

Complete set of sparking contacts for each size of circuit-breaker.

Spare fuse handle of each size.

A few time limit fuses.

Reels of fuse wire of useful sizes.

More complete stocks for larger installations may include, in addition to the above:—

Complete set of contacts for the most important size of breaker.

A few porcelains or busbar insulators with clamps.
Drum of switch oil.
No-volt tripcoil (if fitted).
Voltmeter complete with resistances.

ERECTION OF SWITCHGEAR

Flat-back Switchboards.

These will probably be delivered in complete panels, possibly with large oil circuit-breakers removed. The instruments will be packed separately and naturally the busbars and any connections between panels will be dismantled. The sub-base of angle or channel iron, on which the board is fixed at the base, should be laid in the required position (carefully measuring the distance from the wall as shown on the erection diagram) and firmly fixed to the floor by means of coach screws, if the floor is of wood, or rag-bolts grouted into the floor if the latter is of concrete. Now carefully mark out and make any necessary holes in the wall for the wall stays. If the latter are fixed to an angle iron, which in turn is bolted to the wall, this angle may be fixed temporarily in position, but it is safer not to grout in the wall bolts with cement in case the measurements are a little out, as otherwise new holes might have to be drilled in the angle iron.

Using Lifting Tackle.

Next take one end panel and bolt to the sub-base. For this, lifting tackle may be needed if the panels are of marble or slate. Secure the panel temporarily by means of stays or a rope from the ceiling, and bolt on the end wall stay. If this accurately fits the hole in the angel iron bolted to the wall, the latter may now be fixed permanently.

Use a plumb-line to get the panels vertical, drawing the holes in the wall stays oval with a file if necessary for adjustment.

Now, in turn, erect the remaining panels, and when all are erected go over all bolts and finally tighten up.

When to Complete Fine Wiring.

Before the busbars and other connections are assembled, any fine wiring for the instruments should be completed. This may include a common earth wire or bar which has to be cleated along the whole length of the back of the board. The wiring diagram will indicate any connections of this nature, which cross from panel to panel. Also mount the instruments, taking care to get them in the right positions, which should be indicated by numbers on the backs of the instruments corresponding with numbers on the board in the positions they are to occupy.

Fitting Busbars.

Next fit busbar insulators and busbars, and main connections to the isolating switches or other apparatus on the panels. In clamping up the copper connections, see that the faces are perfectly clean. If the contact surfaces have not been tinned by the switchboard maker, it is worth while to do this by dipping in a pot of solder. The tinned surface, being softer than copper, ensures close contact between the faces when bolted together.

When erection has been completed, carefully attend to the following points.

Oil Switches.

Fill tanks with switchgear oil (transformer oil is of the same kind) to the required level, having first cleaned out the tanks and made sure that they are dry. Try the levergear and tripping mechanism for easy action. Most tripcoils can be tried by pushing up the plunger with the finger or end of a pencil; quite a light push should suffice to trip the switch, and if it does not, examine for dirt or rust.

Set the Tripcoils.

The overload coils should be adjusted, all coils on the same switch being set to the same mark. Methods of setting vary somewhat with the make of switch; usually adjustment is made by screwing up or down a nut on the plunger, locking the nut when the required position is reached (Fig. 21).

The overload settings to be made will depend on the circuit controlled. A setting of fifty per cent. above normal should be enough for a transformer unless the load fluctuates violently or allowance has to be made for the starting of a large motor, in which case a longer time lag would be preferable to a very much higher overload setting than fifty per cent.; power feeders from fifty per cent. when they supply a number of small motors to 150 per cent. (two and a half times normal load) in the case of a feeder controlling one large motor taking a heavy starting current. In general, the settings should be as low as possible without involving frequent tripping at starting or on normal overloads.

FIG. 21.—SETTING TRIPCOILS OF CIRCUIT-BREAKER.

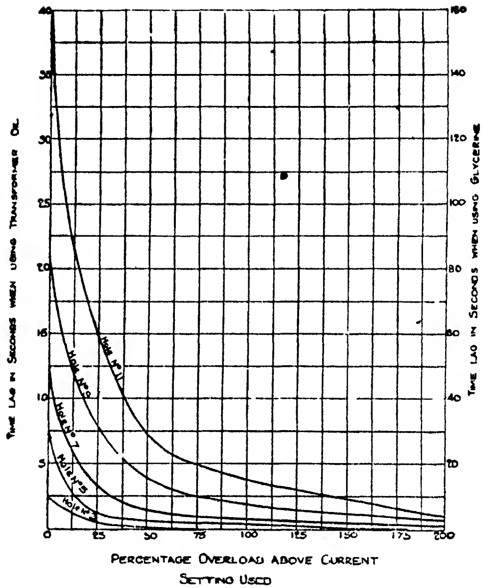


FIG. 22.—TYPICAL CALIBRATION CURVES FOR OIL DASHPOTS.

Adjust the Time-lags.

Time-lags should next be adjusted. If of the oil dashpot type the setting will probably be made by fixing a screwed pin in numbered holes. Adjustment can also be made by altering the variety of oil with which they are filled. Fig. 22 shows the settings obtainable with one common type. Here again the setting will be settled by the time taken to start the largest motors on the circuit. Referring to this diagram, if the overload coil is set to trip at fifty per cent. overload, and the setting of the time-lag is No. 9

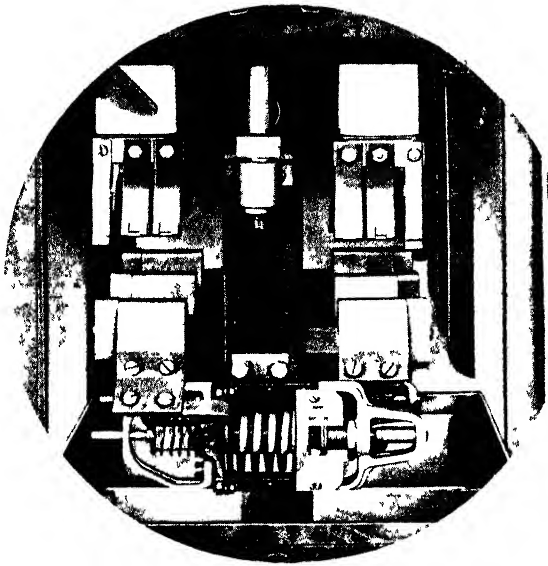


FIG. 23.—A SERIES TYPE OF TRIPCOIL.

This is shown mounted under the moving cross-bar of the oil circuit-breaker Note the calibration plate.

(*Crompton Parkinson Ltd*)

(transformer oil used), a further fifty per cent. overload, making 150 per cent. plus fifty per cent, equals 225 per cent. normal load, will trip the switch after about four seconds.

Examine Relays.

It is not likely that delicate relays will be used on industrial gear, but they may be installed possibly on the main switchboard. Examine carefully, see that any cords in relays of the weight-winding type are free, the trip switch or contacts operating properly, and if there are any mercury contacts, fill the cups with mercury. Instructions for any setting required will probably be given on a label or instruction plate under the cover.

Wire the Fuses.

The various small instrument fuses should be wired before the board is dispatched by the makers. Power fuses may also be wired, but the gauge of wire should be checked with the requirements of the circuit. The following table gives approximate normal maximum current ratings of tinned copper wire when used in an ordinary porcelain-handle fuse.

TABLE I—APPROXIMATE FUSING CURRENT FOR COPPER WIRE.

Current Rating in Amps.	S.W.G. of Wire	Current Rating in Amps	S.W.G. of Wire
3	38	30	21
5	35	37	19
8.5	30	46	18
10	29	53	18
15	25	60	17
17	24	64	17
20	23	83	15
24	22	100	14

(*From I.E.E. Regulations*)

When two or more wires are used in parallel they should not be twisted together, or the fusing current will be altered.

There are many forms of cartridge fuse in use which cannot be rewired with ordinary fuse wire and for which spare elements or complete cartridges must be carried.

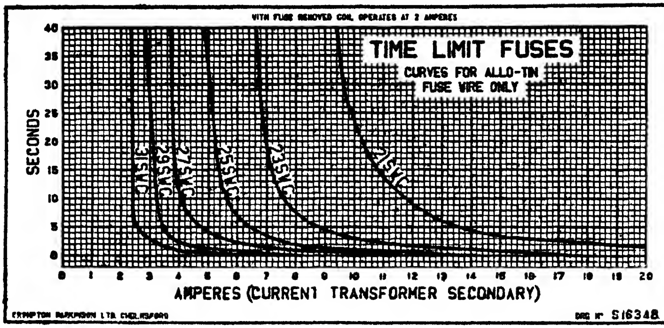


FIG. 24.—CALIBRATION CURVES FOR TIME LIMIT FUSES.

SWITCHBOARD INSULATION TESTS

After erecting any switchboard, and before making it alive, carry out the following tests with a "Megger" Insulation Tester or similar instrument:—

Checking Resistance of Busbars to Earth.

(1) Close all isolating switches and oil switches. Temporarily join the three busbars with a piece of bare copper wire. Connect the earth lead from the "Megger" Tester to the framework of the board and the other to one of the busbars and test. This measures the insulation resistance of all bars together to earth.

Resistance between Busbars.

Then remove the wire joining the busbars and measure the resistance between pairs of busbars—A to B, A to C, B to C. These tests can be done in two measurements, as follows:

Connect the busbar A to earth and busbars B and C together and test between A and B. Then connect B to earth and A to C and again test between A and B. It will be seen that this checks the insulations between all busbars and earth, and between any two busbars.

All the above readings should be twenty megohms or more, except perhaps for slate boards consisting of a large number of panels.

Causes of Low Readings.

If very low readings are obtained, open the isolating switches and check each panel in turn, when the cause of the low reading may be found.

A general poor insulation may be caused by damp; keeping the switch room dry and warm for a day or two will probably improve matters.

Other possible causes of low readings, apart from short circuits, which should be easy to trace by careful visual examination, are: faulty insulating washers and bushes on knife switch or fuse stems, cracked or very dirty insulators, copper filings or metallic dust partly bridging insulation material, etc.

Testing Secondary Wiring to Earth.

(2) Before testing secondary wiring to instruments, tripcoils, etc., first study the wiring diagram. It may be found that certain parts of the wiring are connected to earth, and these connections must be temporarily broken before the insulation resistance to earth can be measured. Such points include one terminal of the secondary windings of current and potential transformers, voltmeters reading phase to earth voltage, leakage indicators, etc. When all such earth connections have been

removed, test the wiring on each panel in turn to the earth bar or switchboard framework. Make sure that the whole of the secondary wiring is included, if necessary making temporary connections between phases at convenient points such as the connection stems of instruments.

These precautions in regard to disconnecting earth connections apply to tests under (1) when the voltmeters, etc., are connected direct to the main circuit and are not operated through potential transformers.

It is difficult to quote an average figure for the insulation resistance of secondary wiring to earth. On a panel with a large number of instruments and a lot of wiring it may be as low as one or two meghoms. If a short-circuit reading is obtained, first look for accidental shorts; if none is found, disconnect the wiring and test each instrument, tripcoil, etc., in turn until the trouble is found.

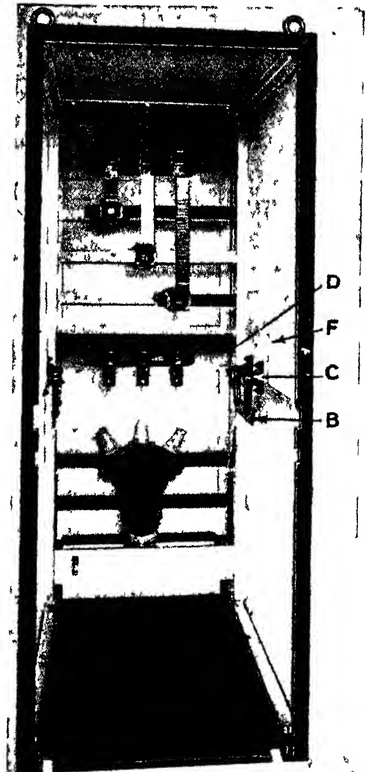
ERECTING CUBICLE TYPE SWITCHBOARDS

Cubicles of the stationary type will be delivered as complete cubicles, only the busbars and possibly the instruments being dismantled.

Erection of the board on a level prepared floor (preferably concrete) should be carried out by lifting the cubicles into position side by side in the correct order and levelling by means of wedges until holes for the bolts securing adjacent cubicles coincide, then bolting up. It is hardly necessary to bolt boards of this type to the floor, but compensation may be made for any irregularities in the floor level by running fluid concrete round the foundation frame members, wood battens cut to suitable lengths being laid on the floor, Fig 25.—Cubicle Type Switchgear.

When cubicle-type switchgear is used, interlocking mechanism is invariably fitted to prevent the withdrawal of the switch while in the closed position This can be clearly seen on the two facing illustrations The roller A on the switch truck engages with the bar B in the cubicle which is swung on the pivots C and raises or lowers the shutters at the rear of the cubicle thus protecting the operator from accidental contact with the sockets and busbars when the switch truck is withdrawn In addition the lug E on the switch engages with the angle plate F when the switch is closed, thus effectively preventing the withdrawal of the truck in this position of the switch Similar interlocks are incorporated on withdrawable pillar switchgear

(*General Electric Co, Ltd*)

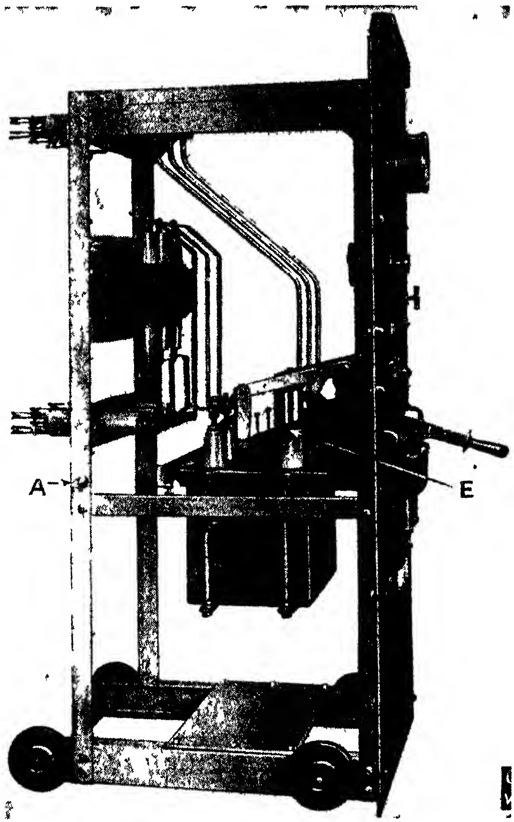


Interior of Cubicle.

spaced about half an inch from the framework, to hold the concrete until it sets.

Fitting Busbars.

Busbars should be slipped into position from one end of the board, the end plate being detached for this



TRUCK FOR CUBICLE SWITCHBOARD.

purpose. Bolt up the busbars very securely, for once the board is alive it is unlikely that many opportunities will occur for examination of these connections.

Next mount the instruments, fill the switches with oil, attend to tripcoils, etc., as detailed for flat-back boards, and make an insulation test before putting the board into commission.

Cover Cable Trenches.

With cubicle type boards, both fixed and truck type, the cables usually drop down into a trench which runs the length of the board. To prevent rats gaining access to the switch *via* this trench, it should be completely covered with $\frac{1}{8}$-inch sheet steel plates fitted with wood bushes accurately fitting the cables. Rats have caused many short circuits on switchboard terminals, particularly on high tension gear, and this precaution is well worth the time involved in making and cutting holes in the sheet steel plates. On some types of cubicle switchboards it will be found that screens are fitted to prevent rats getting from the trench to live gear; in such cases, of course, any extra trench coverings are unnecessary.

Truck Type Cubicles.

The erection of the fixed portions or housings of truck type cubicles is very similar to that of stationary cubicles, but particular care must be taken not to distort the framework by careless handling or erection on an uneven floor, or it may be difficult to insert the truck carriages.

When the housings are erected, assemble the busbars by slipping them in from one end. If there is a passage-way behind the board, it may be convenient to remove the back sheets of the housings to facilitate bolting up the bars; but usually this can be managed by temporarily wedging open the shutters which cover the holes in the screen plates in front of the busbars, and putting a hand through these holes to get at the bolts.

The trucks should wheel into the housings easily. If much force has to be used, bad alignment may be suspected. This can probably be cured by loosening framework bolts and inserting wedges underneath until the truck will push into position.

To facilitate running the trucks in and out, it is a good plan to lay down on the floor runways of flat iron, about two or three inches wide, to form rails for the truck wheels.

When all trucks can be inserted, remove them to allow the cables to be connected, and while they are out go over the tripcoils, fill switch tanks, etc. Make an insulation test, before the end plate of the busbar chamber has been replaced, as already described. If it is desired to test the secondary wiring, this must be done for each truck in turn with the truck out.

ERECTION OF IRONCLAD SWITCHGEAR

If the units are of the draw-out type, first remove the carriage portions, to facilitate handling. Next assemble the pedestal portions in the correct order, loosely bolt together and insert holding-down bolts, engaging the nuts, but leaving sufficient thread for tightening up later. Align the units accurately by means of wedges and tighten the various bolts which fasten the units together. Next run liquid concrete round the feet and into the holes in which the holding-down bolts have been inserted, if necessary covering any holes made in the floor for cables to prevent them being cemented up.

Assembling the Busbars.

If possible, wait for the cement to set before proceeding with erection. The next step consists of assembling the busbars. To do this, remove the busbar chamber end plate and also the top covers, thread in the bars from one end, and bolt up securely.

Making the Cable Connections.

Cable connections may now be made. If the board is erected against a wall, it may be convenient to mark off the cable to the length required, detach the cable boxes, and draw the cable forward between the two sides of the pedestal or feet so that the bonding of the lead sheath may be done in a less cramped position; after these operations the cable and cable box can be drawn back and the box bolted into position, one half of the box being left off until the lugs on the cable cores have been bolted to the connecting stems, which pass into the switchgear. The procedure is not possible with all designs, particularly those in which the cable cores have to be taken right through to the switch terminals.

Test All Phases Together to Earth.

After the cables have been connected, make "Megger" tests of the insulation of all phases together to earth, temporarily bridging the busbars with a piece of wire for this test, and from each phase to earth. If these tests are satisfactory—and they should show readings of twenty megohms to infinity—the cable boxes may be filled with compound, and also the busbar chambers in gear of the compound-filled type. Pouring in the compound should be done gradually, to allow any imprisoned air to bubble to the top. The compound may be heated in any clean pail over a coke brazier or a gas ring if available, the pail being kept covered to exclude dirt. A proper compound bucket, with pouring spout, is preferable if one is to hand. The compound should be heated until it is sufficiently fluid to flow easily and should not be overheated.

The busbar chamber covers may now be replaced, all bolts (including holding-down bolts) finally tightened, the carriage portions of draw-out type gear lifted into positions on the rails, and the gear is ready for commission after the setting of tripcoils, time-lags, etc.

AIR-BREAK CIRCUIT-BREAKERS

Air-break circuit-breakers are nowadays generally confined to

(1) DC circuits—where they are used in preference to oil-break gear on account of the greater risk of oil deterioration by carbonisation and sludging than with AC—and

(2) to small single-phase domestic-type breakers up to thirty amps. capacity.

They are generally of the open type, for mounting on switchboards, but occasionally one may meet iron-clad types for special service such as marine work, in damp situations, or in flameproof enclosures for mine work.

Overload devices on air-break gear are almost universally magnetic, with oil or air dashpots when fitted.

When pillar-mounted air-break gear is specified practice almost invariably follows oil-break design, but with unfilled oil tanks.

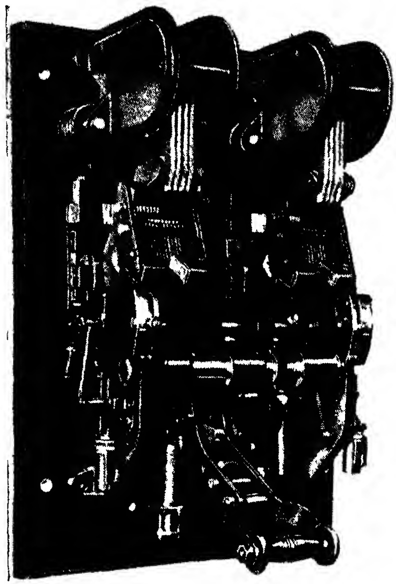


Fig. 26.—A Double-pole Panel Mounting Air-break Circuit-breaker Rated at 4,000 Amps.
(*General Electric Co, Ltd*)

Air-break gear is generally fitted with butt contacts with carbon or copper sparking tips, and laminated copper brushes are invariably used for the higher current ratings Magnetic blow-out coils are standard practice.

Erection.

It will generally be found that the moving parts have been tied up with string in the closed position for safety in transport, and possibly the dashpots or parts of the tripping mechanism have been dismantled and packed separately.

To erect air-break gear, the instructions having been studied, the string is cut and removed and the switch bolted in position on the panel. It is perhaps obvious to point out that the switch should be carefully lined up on account of appearance, in addition to which some circuit-breakers will have their tripping calibration upset unless mounted truly vertical.

After erection the cables should be connected up and the breaker operated once or twice by hand in order to check that there is no binding on bearings or pivots, after which the dashpots should be carefully filled with the grade of oil specified by the makers and screwed into position. The tripping mechanism should then be lightly operated to ascertain that the dashpots are exercising the required degree of drag and, finally, the tripping adjustment set to the desired figure. The breaker is now ready for load tests.

Maintenance.

With air circuit-breakers this is generally confined to cleaning up or renewing sparking tips, replacing arc chutes or arc-chute linings where these have been damaged by interruption of heavy short-circuits, and to occasional oiling of pivots and bearings. As the majority of air circuit-breakers are open to the atmosphere and dust, such oiling should be carefully done and any accumulation of oil-and-dust sludge removed before applying fresh oil.

OPERATION OF SWITCHGEAR

There are a few precautions in the routine operation of switchgear which are worth noting.

Operate all switches and circuit breakers smartly and cleanly, without hesitation and without undue force. Closing switches slowly and with hesitation leads to damage of contacts through sparking and may set up disturbances in the system resulting in damage to machine windings, particularly transformers.

Never open or close a circuit on load by means of a fuse or slow break knife switch if it can possibly be avoided, and never open or close an isolating switch unless the circuit-breaker on the same circuit is open.

If a breaker trips repeatedly or a fuse blows on load, try to find the cause before setting the trips higher or using heavier fuses.

Watch ammeter readings, remember the full load of each circuit and investigate the cause of persistent or often-repeated over-loads.

Cleaning.

Before carrying out any cleaning or overhaul work make the apparatus dead, and take any precautions necessary to prevent any other person switching on while work is carried out. If such a possibility exists, as an added precaution fix temporary earthing connections from the cable terminals to the earth bar.

An exception may be made in the case of surface cleaning of low tension flat-back boards, if the floor is dry and the cleaner uses one hand only for the work so that he cannot easily make contact across poles or phases.

Keep the surface of all switchgear clean by wiping regularly with clean waste *very* slightly moistened with paraffin (too much paraffin causes rust). All exposed insulators should be kept free from dust and damp, and the backs of flat-back boards should not be overlooked.

Occasionally go round with an oil-can and drop a spot or two of oil on all operating mechanism, link gear, slide rails of draw-out units, etc. If necessary, use a blower to get dust out of the operating mechanism of oil switches, or it may accumulate and prevent tripping on overload.

The sliding contact surfaces of knife switches and air-break circuit-breakers may be cleaned occasionally

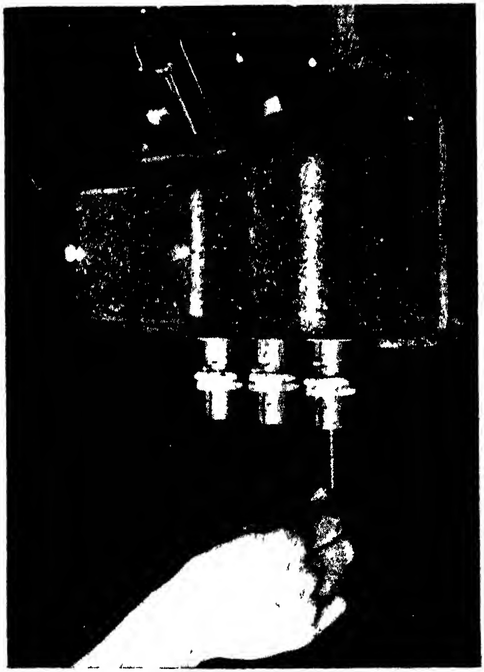


FIG. 27.—TESTING THE TRIPPING MECHANISM OF AN OIL CIRCUIT-BREAKER BY LIFTING TRIPCOIL PLUNGERS.

with a clean rag and a trace of vaseline, which helps to secure low resistance contacts. The same applies to isolating plug contacts of draw-out type gear.

MAINTENANCE

Oil Circuit Breakers.

The most important item of equipment is the oil circuit-breaker. Regularly test the freedom of the operating mechanism, tripping if possible by lifting one of the tripcoil plungers by means of a pencil, as illustrated (Fig. 27). If the breaker is often called upon to open on overload, every few months (and as soon as possible after it has operated on any severe fault) drop the tank and examine the contacts.

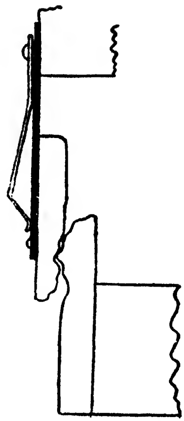


FIG. 28. — BADLY BURNT ARCING FINGERS.
Showing "blobs" of molten metal likely to catch and prevent the breaker opening.

Cleaning Arcing Fingers and Plates.

The arcing fingers and plates should be smooth and free from pitting. Slight pitting may be cleaned up with a file; if the burning has been so severe that much metal has to be removed to secure a smooth surface, fit new fingers and plates. The arcing fingers should make circuit before, and break circuit after, the main contacts; if they do not, it is a sign that they have been badly burnt or distorted. Blobs of molten metal on the arcing contacts may catch and prevent the switch tripping (see Fig. 28).

If the arcing fingers are in good condition, the main contacts should need no attention. After a switch has been on full load for a few hours the tank should be comfortably warm; a higher temperature rise than, say, thirty to forty degrees C. measured at the hottest part is a sign of bad contacts unless the full load has been exceeded.

Renewing Fuses.

If the breaker trips on slight overloads, it may be that the time-lags, if of the fuse type, need renewing. These fuses shunt the tripcoils so that normally the fuses carry the current. On overload the fuses blow after an interval of a few seconds, the current then passing through the tripcoils and tripping the switch. Even if they do not fuse owing to overload, the fuse wire of which they are composed may deteriorate in time and fuse at less than their rated current. If the fuses have not been changed during the year, it is a good plan to renew them annually if of the rewirable type; the sealed type fuses should not require renewal. All fuse type time-lags are used in conjunction with current transformer operated tripcoils, normal full load in the main circuit corresponding to five amps. in the tripcoil circuit.

Examine the Oil.

The condition of the oil in the tank should be examined. If dirty and sludged, due to repeated operation of the breaker on load or high operating temperatures, it should be renewed, using proper switch or transformer oil.

The other parts of switchgear needing attention call only for straightforward mechanical examination. Occasionally go over all nuts, particularly on switch and breaker terminals, and tighten when necessary. Contact surfaces such as those on isolating plugs and sockets may be examined; usually the state of the contacts can be judged from the appearance of the metal, which will be lighter in colour than ordinary copper which has not been in rubbing contact with another copper surface. In conjunction with no-volt and some other tripcoils there may be a small auxiliary switch mounted near or on the oil switch, and the contacts of this should be examined and cleaned and adjusted if necessary; often the contacts are not too substantial and the spring fingers soon take a permanent set.

When to Renew Tube of Asbestos in Power Fuses.

Power fuses of the porcelain handle type usually have a tube of asbestos or similar material which encloses the fuse wire.

This may be damaged when the fuse blows on a heavy overload and should be renewed when necessary. If fuses are badly damaged or shattered by a short circuit, it is clear that they are unsuitable for the large amount of power to be broken, and should be replaced by an oil switch unit.

When overhauling switchgear, the insulation resistance should be measured in the manner already described.

CONNECTIONS FOR SWITCHBOARD INSTRUMENTS, ETC.

The accompanying diagrams illustrate the connections of various commonly used instruments, tripcoils, etc.

Simple Draw-out Type Unit.

Fig. 29 shows a simple draw-out type unit fitted with two series-operated overload tripcoils, an ammeter connected direct in the circuit, and a no-volt coil

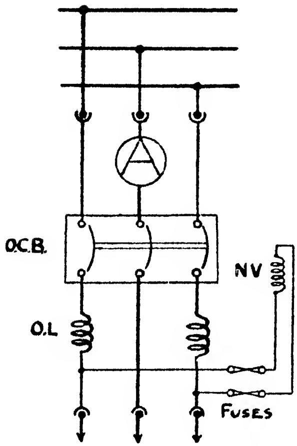


FIG. 29.—A SIMPLE DRAW-OUT TYPE OF UNIT.

Fitted with two series-operated overload tripcoils, an ammeter connected direct in the circuit and a no-volt coil connected on the load side of the switch and protected by fuses.

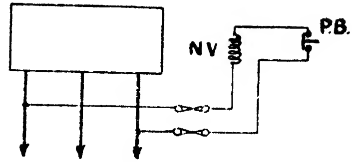


FIG. 30.—ARRANGEMENT FOR DISTANT PUSH-BUTTON TRIP (1).

Here the connection is taken from one of the tripcoil fuses through the distant push-button and back to the no-volt tripcoil.

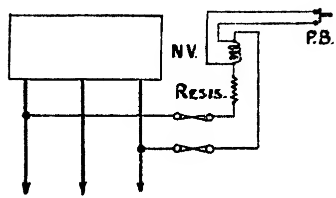


FIG. 31.—ARRANGEMENT FOR DISTANT PUSH-BUTTON TRIP (2).

Here the push-button is of the normal type and short-circuits the coil when the push-button is operated.

connected on the load side of the switch and protected by fuses. With this arrangement the no-volt trip must be held by hand while the switch is closed. If connected on the supply side, it will act as a no-volt, no-close trip, and will usually be fitted with an auxiliary switch which is open when the switch is off, but closes before the switch to allow the coil to attract the plunger away from the tripping position.

Two Ways of Arranging a Distant Push-button Trip.

A distant push-button trip can be arranged in two ways. One is to take the connection from one of the

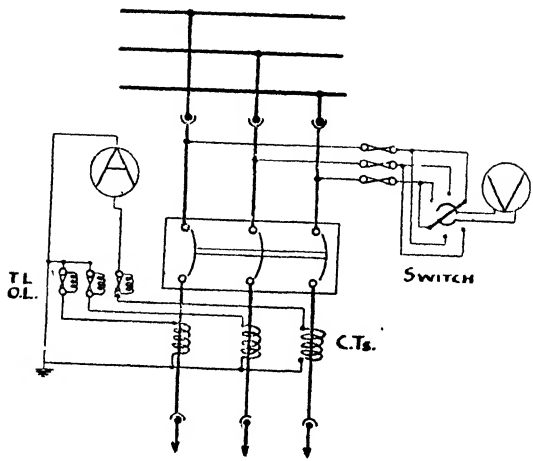


FIG. 32.—OPERATING THREE TRIPCOILS FROM THE SECONDARIES OF CURRENT TRANSFORMERS.

These transformers are arranged so that full load in the primary corresponds to 5 amps. in the secondary.

tripcoil fuses through the distant push-button (which must be of the "push to open circuit" pattern, and insulated for the working voltage) back to the no-volt tripcoil (Fig. 30). The second method is shown in Fig. 31. Here the push-button is of the normal type and short circuits the coil when the push-button is operated. This method can only be used when the resistance is provided, with coil wound to suit, by the makers.

Operating Three Tripcoils from the Secondaries of Current Transformers.

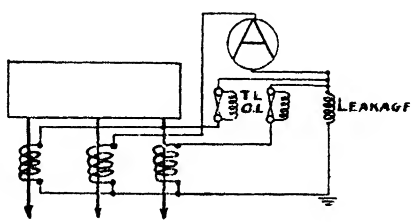
Fig. 32 shows a similar unit, but with ammeter and three tripcoils operated from the secondaries of current transformers. These transformers are arranged so that full load in the primary corresponds to five amps. in the secondary. The advantage of current transformers is that all instruments, etc., operated from them are at low voltage, whatever the voltage of the main circuit, and coils can be standardised for five amps., being calibrated and marked, however, in amperes in the main circuit. One terminal of the secondary winding of current transformers should be earthed.

The unit in this diagram has a voltmeter, with switch to read the voltage between phases. The tripcoils are fitted with time-limit fuses.

Connections for Overload and Leakage Protection.

Fig. 33 shows the connections for overload and leakage protection. The leakage coil can be set low,

FIG. 33.
CONNECTIONS FOR OVERLOAD AND LEAKAGE PROTECTION.



to operate at as little as ten to twenty-five per cent. of full load (or even lower in conjunction with a relay) and will only operate on earth faults, not ordinary overloads. If the ammeter shown in this diagram is not required, complete the wire which is shown connected to its terminals.

One instrument which may give a little trouble is the power factor meter. Owing to differences in phase rotation, the meter may read on the wrong half of the scale or quite incorrectly.

Checking Connections of Meter.

It is usually known what the approximate power factor of a load may be. An industrial motor load, for instance, will be something between .6 lag and unity With this as a basis, the connections of the type o' meter most often used may be checked as shown in Fig. 34.

Disconnect the voltage leads. With not less than

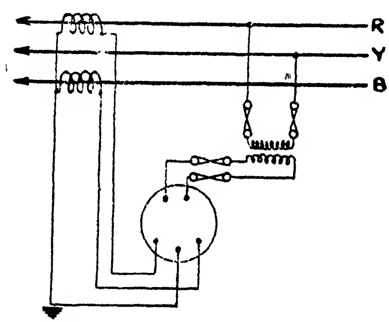


Fig. 34.—Checking Connections of the Type of Power Factor Most Often Used.

half full load in the current transformers the pointer should rotate in a clockwise direction; if it rotates in the opposite direction interchange the right and middle current connections (as viewed from the back).

Reconnect voltage leads. If the pointer indicates on the wrong half of the scale, i.e., motoring instead of generating, reverse the potential leads.

If the above tests fail to give correct indications and the instrument transformer polarities are correct and the wiring made to diagram, the fault will probably be found to be due to non-standard phase rotation.

Use of Potential Transformer.

On high tension circuits all potential coils of instruments, no-volt coils, etc., will be operated from the secondary of potential transformers. The primary of a potential transformer is connected to the main circuit through H.T. fuses. Connections from the secondary side are taken through L.T. fuses and the terminals are then regarded for the purpose of instrument connections as the phases of the main circuit.

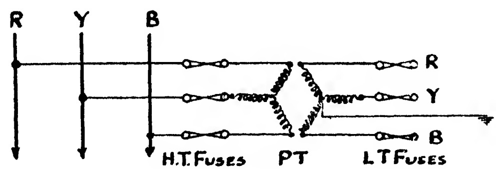


FIG. 35.—USE OF POTENTIAL TRANSFORMER.
The normal pressure on the secondary side is 110 volts between phases.

The neutral point of three-phase instrument transformers, or one pole of a single-phase transformer, is earthed. The normal pressure on the secondary side is 110 volts between phases (see Fig. 35). Inaccurate reading of potential instruments on H.T. circuits may be due to a blown H.T. fuse, but this is almost invariably caused by a fault in the potential transformer.

CHAPTER IV

EXCESS CURRENT PROTECTION AND EARTHING

PROTECTION has to be given to cables, transformers and other apparatus in the distribution system, with the object of controlling and minimising the effects of an electrical breakdown, and to prevent such breakdowns as far as possible.

Excess Current Protection.

More often than not, the only form of protection provided in factory distribution systems is that against excess currents. This is done by the provision of fuses or circuit-breakers at various points, so that these devices interrupt the current before it so exceeds the working rate as to involve danger to cables, etc. The fuses or circuit-breakers must protect the whole length of the cable in the installation, and it is therefore necessary that they be inserted at the origin of every branch circuit where the conductors forming that branch are smaller than the conductors supplying the branch.

The fuses or circuit-breakers must open the circuit without fail if the current exceeds the rated value for the cable for a time long enough to be dangerous. In other words it is the size of cable which should determine the size of the fuse.

The question as to whether circuit-breakers or

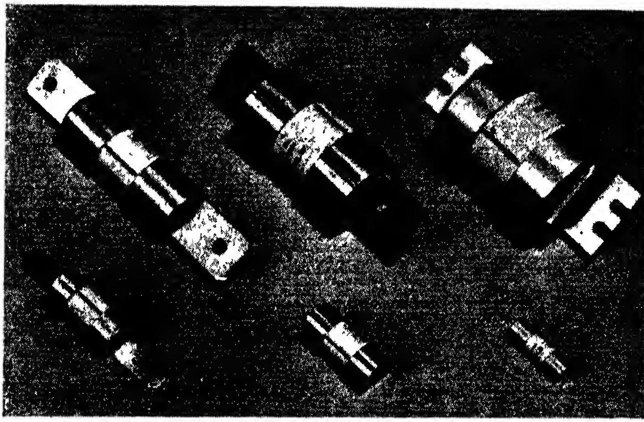


FIG. 36.—HIGH-RUPTURING CAPACITY FUSE-LINKS FITTED WITH VARIOUS TYPES OF END CONNECTIONS.
(Lawson Beck Ltd.)

switches with fuses shall be employed at particular points of the installation depends upon the type of network and distribution scheme adopted and upon the maximum load and possible short-circuit current that may occur.

Types of Fuses.

The simplest and cheapest form of protection against excess current, due to overload or short-circuit, is the fuse. Two types of fuse are in use:—

(1) The semi-enclosed type, comprising removable porcelain holder with handle through which the fuse-wire passes.

(2) The totally enclosed or cartridge type fuse in which the fuse itself is enclosed by a cylinder of hard, noncombustible material having metal capped ends,

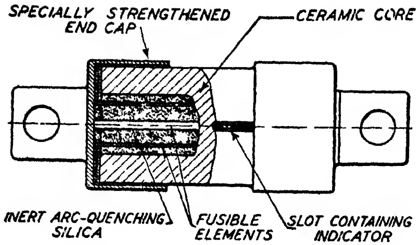


FIG. 36A
CONSTRUCTIONAL DETAILS OF AN H R C CARTRIDGE FUSE
(*Lawson Beck Ltd.*

which is filled with a special non-inflammable powder, or other special material

During recent years, the use of the cartridge type of fuse has become general as the fuses do not deteriorate in service and are designed to rupture the very severe fault currents which are available in modern plant, without external arching or explosion.

Semi-enclosed Type Fuses.

The semi-enclosed type fuse, though the most convenient for rewiring, is disadvantageous in many respects. The fuse deteriorates with continual heating, due to oxidation, and there is always risk of damage or fire when blowing on heavy fault, owing to the external flame produced and consequent possibility of spark-over at the contacts. On this account, and because

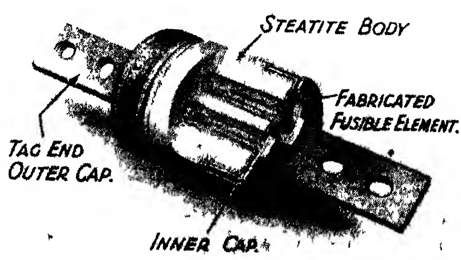


FIG 36B
400-AMP 660-VOLT HIGH-RUPTURING CAPACITY CARTRIDGE FUSE
(*English Electric Co., Ltd*)

of the time-lag occurring in operation, these fuses have a low rupturing capacity and are usually restricted in practice for use with voltages up to 600 having a maximum short-circuit kVA not much above 5,000, maximum rating of current 200 amps.

H.R.C. Cartridge Type Fuses.

Low-tension cartridge type fuses are available for voltages up to 660, in sizes from 2 to 800 amps. carrying capacity, with rupturing capacities capable of dealing with any value of fault kVA likely to be met with.

Other important advantages of correctly-designed high-rupturing capacity fuses are:—

Discrimination.—The fuse nearest the fault will operate, thus ensuring that only the faulty circuit is isolated and healthy circuits are unaffected. This discriminating property is inherent in cartridge type fuses, as a glance at the current-fusing time curves for different sizes of fuse in Fig. 37 will show. It will be seen that the speed of operation for any particular value of overload or fault current increases as the fuse gets smaller. This is bound up with another property of H.R.C. fuses—non-deterioration.

Non-deterioration.—This property is valuable because it ensures that the characteristics already mentioned are maintained throughout the life of the fuse.

High speed of rupture on short circuit.—This property enables H.R.C. fuses to be used for the back-up protection of motor starters and low rupturing capacity circuit-breakers. For such purposes high rupturing capacity in itself is not sufficient. The speed of operation of the fuses used for back-up protection must be faster than the speed of operation of the

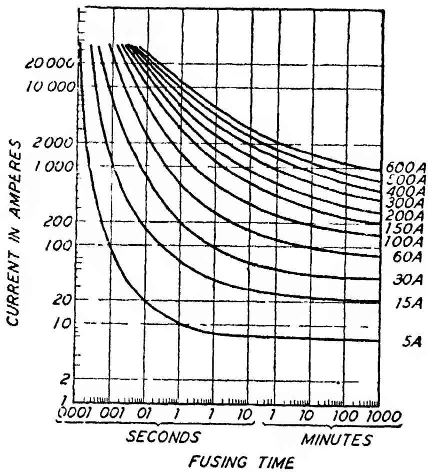


FIG 37
CURRENT-FUSING TIME CURVES FOR TYPICAL CARTRIDGE FUSES
(*Lawson Beck Ltd*)

motor starter or circuit-breaker to be protected; otherwise the apparatus under protection would be damaged or destroyed before the fuses had time to act.

Selection of Fuses.

When selecting suitable fuses for any particular situation the following factors should be considered:—

(1) *The rupturing capacity of the fuse* should be sufficient to clear the estimated short-circuit current in the conductor. If fuses of inadequate rupturing capacity are used and they are called upon to clear a short-circuit in excess of the value with which they can safely deal, the fuses and metal clad enclosures may be completely destroyed.

(2) *The current rating of the fuse.*—This is the maximum current which the fuse will carry continuously without deterioration. The current rating of the fuse should not be more than the normal full load current

rating of the conductor in which the fuse is to be used. An exception to this is the case of motor circuits which are dealt with in paragraph (4). Suitable sizes of tinned copper wire for rewirable fuses are given on page 74. H.R.C. cartridge fuses are marked.

(3) *The minimum fusing current of the fuse.*—This is the least current which can definitely be stated to blow the fuse. The minimum fusing current should correspond with the degree of overcurrent protection required. Commercial fuses, wired with tinned copper fuse wire, will blow at currents 170 per cent normal up to 60 amps., and 200 per cent for the larger sizes, whilst cartridge fuses are usually arranged to blow at lower percentages of normal current, e.g. 160 per cent. It is possible to obtain H.R.C. fuses that will blow with accuracy at currents as low as 120 per cent normal.

Another way of conveying this property of a fuse is referred to as the fusing factor—this is the minimum fusing current divided by the current rating, thus 170 per cent normal current corresponds to a fusing factor of 1.7.

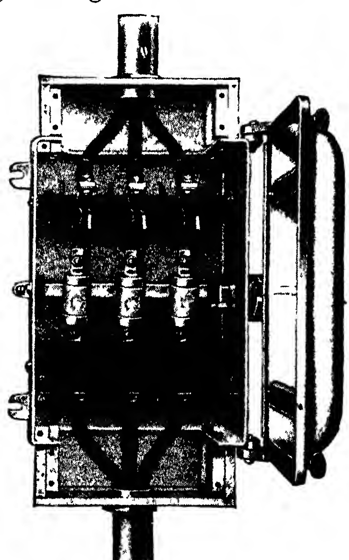


FIG. 38.—A TRIPLE-POLE FUSE-SWITCH WITH H.R.C. FUSES. (*Bill Switchgear Ltd.*)

(4) *When fusing for motor circuits*, the rating of the fuse selected

should be such that all overloads (as distinct from electrical faults) within the capacity of the starter should be dealt with by the starter. It is obviously undesirable that the fuses should operate on overloads when a motor starter is available for this purpose. When the thermal or magnetic overload device in the starter deals with an overload, the operator can restart the motor after having removed the cause of the overload. If, however, the fuse is also arranged to operate on similar overloads, considerable trouble would result.

In selecting the current rating of fuses for a given motor circuit, it is necessary to take into account the starting current, which may be considerably in excess of the normal full load current of the motor, depending on the type of motor and method of starting. It is permitted (by the I.E.E. Regulations) to use a fuse 50 per cent larger than that required for the protection of the cable, so that there is less chance of the fuse blowing prematurely on heavy starting currents. The situation can be further eased by installing cables having a rated capacity somewhat in excess of the motor load, so that the fuse sizes are considerably greater than the rated current of the motors.

When selecting H.R.C. fuses for motor circuits, the required ratings can be obtained from the tables published by the fuse manufacturer. If, owing to special conditions, there is any doubt, the question should be referred to the makers of the fuse concerned.

DISTRIBUTION FUSE GEAR

It is convenient to divide distribution fuse gear into three distinct types: (1) Sub-station boards, (2)

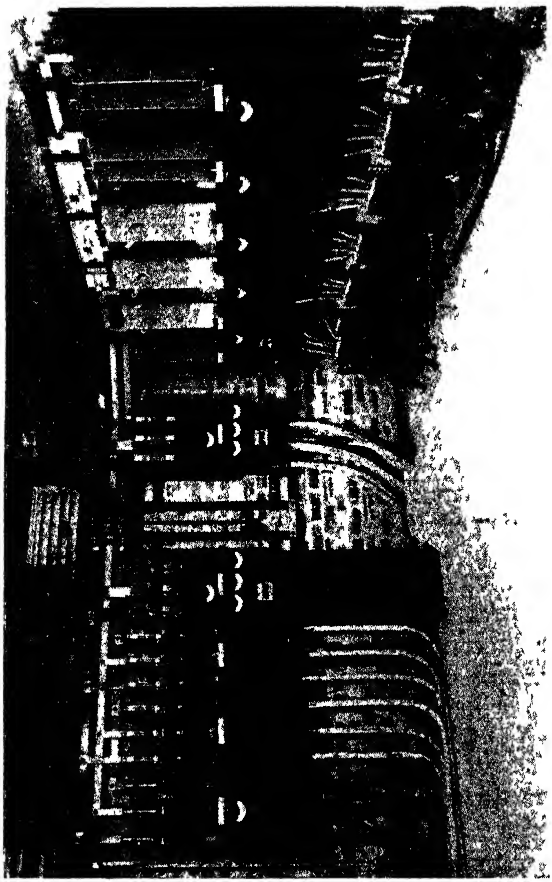


Fig 39.—Sub-station Skeleton Type Fuseboard consisting of Two 1,500-ampere Transformer Circuits, Three 800-ampere and Six 500-ampere Distributor Circuits

The installation includes a 1,500 ampere bus coupler and angle type cable boxes All fuses have a rupturing capacity of 40,000 kVA

English Electric Co., Ltd.

Unit-type switchboards, and (3) Distribution fuse boards.

Sub-station Boards.

Sub-station boards are confined to special stations or switch rooms set aside for the purpose and accessible only to authorised electricians. In these cases the board can consist of exposed busbar systems feeding each outgoing cable through open, unshrouded switches and fuses. Some precautions are necessary to ensure safety, and the method of handling the switches and fuses must be such that a man with some electrical knowledge is in no danger of receiving a shock. For this reason the fuse contacts and bridges may be shrouded, or in some cases the provision of isolating switches on both sides of the fuse renders the latter completely disconnected from the circuit before handling, so that shrouding is unnecessary. To minimise the possibility of accident a clear passageway not less than 3 ft. 6 in. wide having an insulated floor or mat must be provided in front of the board to act as an operating platform. This type of board is usually supplied direct from the transformer, either through isolating links or a main switch, and each outgoing way will be a main feeder supplying a unit-type switchboard of a distribution fuse board.

Unit-type Switchboards.

Unit-type boards are advisable at all the important main distribution points in a factory system. They consist of a totally enclosed busbar chamber supported on pedestals or a framework, on which outgoing combined switches and fuses or fuse-switches are mounted

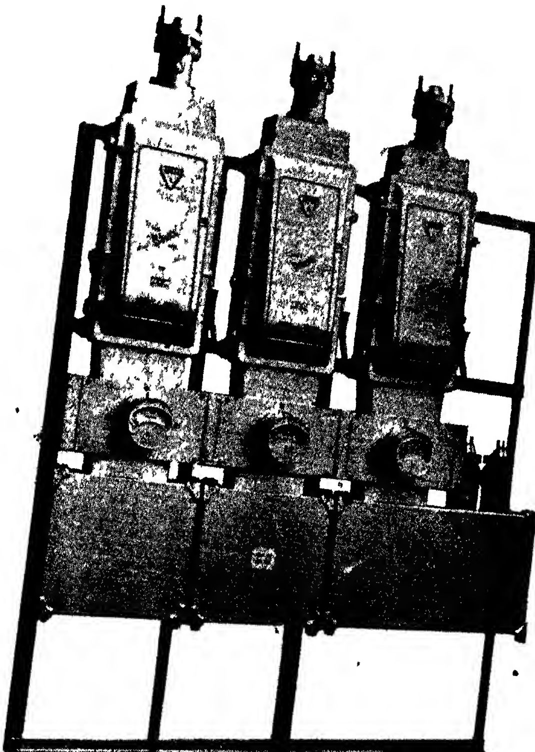


Fig 40—300 ampere Distribution Panels.
The main cables are arranged to drop down from above, into the cable glands above the busbar chamber
(Bill Switchgear Ltd)

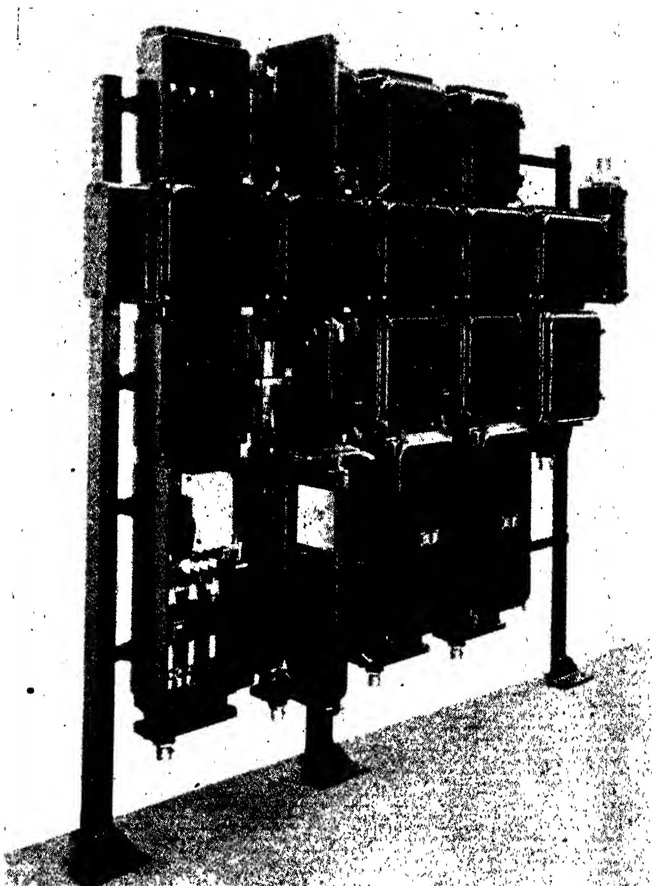


FIG. 41.—DISTRIBUTION BOARD COMPRISING TRIPLE-POLE ELECTRICALLY HELD-ON CONTACTORS IN SERIES WITH HEAVY-DUTY CARTRIDGE FUSES, MOUNTED ON A BUSBAR CHAMBER.

(*A. Reyrolle & Co., Ltd.*).

and internally connected to the busbars. Each outgoing fuse-switch is fitted with a cable gland or conduit, and all the connections and the current-carrying parts are contained in earthed metal enclosures so that no access thereto is possible. These boards must be such that it is safe for a completely untrained workman to handle them, as they are situated in the open shop within reach of all. To prevent illicit tampering, however, it is quite common to have the switches fitted with padlocks so that the lids may not be opened except by the qualified staff.

Like the sub-station boards, the feeders from the unit-type boards will usually pass to distribution fuse boards, although in some cases the unit-type board is used as the final distribution board and the outgoing cables pass direct to the motors, etc.

Distribution Fuse Boards.

Distribution fuse boards form the final protection for the distributors which carry a supply to the various consumption points—lighting, heating, and small motors. Fuse boards consist of a number of sets of fuses, each connected to a short length of common busbar for the protection of the various branch circuits. They are constructed for single- or three-phase requirements and may be fitted with separate switches if necessary.

Various standard patterns are in general use and are designed to meet the Home Office regulations for this type of equipment. The sets of busbars must be separated by partitions of incombustible material, fuses of standard type must be used so that replacements can be easily effected, and the fuse carrier must hold the fuse in such a manner that no damage can occur to the hand should the fuse blow while being inserted in the contacts. The majority of fuse boards are totally enclosed in metal-clad boxes lined with asbestos to prevent damage from the effects of arcing.

Fuses of both semi-enclosed or cartridge types are used somewhat indiscriminately in these smaller boards; the semi-enclosed type have the advantage of being easily and cheaply replaced. There is, however, the possibility of improper-size wire being fitted inadvertently in replacements—particularly if attended to by unskilled labour—whereas the cartridge fuses are all definitely sized and labelled for their respective duties, but necessitate the keeping of a supply of assorted spares in stock.

THE AUTOMATIC CIRCUIT-BREAKER

The alternative to fuses is the automatic circuit-breaker, usually oil-immersed for use on AC circuits. While basically more expensive than fusegear, these switches trip simultaneously on all lines, and can be equipped with a variety of release coils, either direct acting, or operated by relays.

Overload Releases.

The simplest automatic release used is the direct acting over-current coil, which is a solenoid energised by the current passing through the switch, and calibrated to operate when this reaches a predetermined value. The trip setting is adjustable, usually from normal full load current up to about 200/250 per cent normal, and therefore a setting as near as is desired to

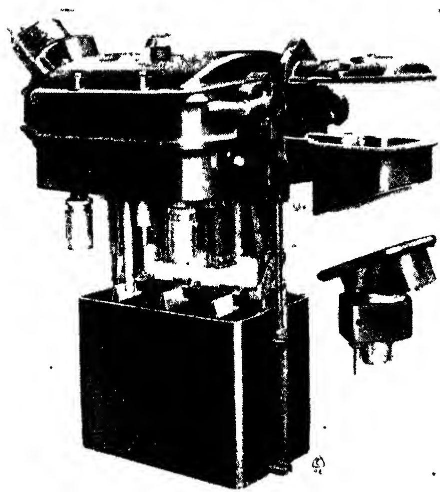


FIG. 42.—OIL-BREAK CIRCUIT-BREAKER WITH DIVIDING FITTINGS FOR ARMOURED CABLE.

Time lag cover removed and oil tank lowered to show construction.

(*George Ellison Ltd*)

FIG. 42A.—OIL DASH-POT TIME LAG.

With calibration tube.

(*George Ellison Ltd.*)

full load current can be obtained. On a three-phase insulated system, coils in two phases will give full protection, since any fault must involve two phases; but with an earthed system, release coils must be provided in all three phases, unless leakage protection is also provided, when two overcurrent coils will again suffice. In small current sizes it is usual to make the overcurrent coils direct series connected; but in larger sizes the coils are often operated from current transformers.

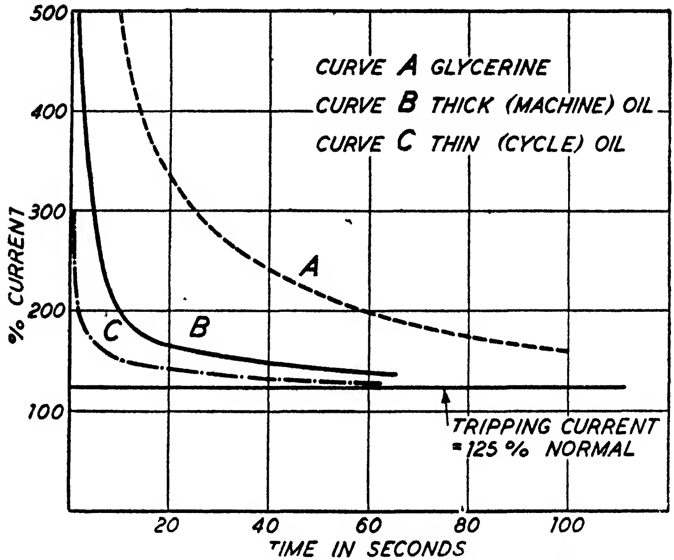


FIG. 43.—CHARACTERISTIC FOR SERIES TRIP COIL WITH OIL DASH-POT.

Time Lags.

If full advantage is to be taken of the facility to obtain close overcurrent settings that is offered by circuit-breakers, some form of restraining device is necessary to retard the action of the releases, as this is normally instantaneous. This retarding device, or time lag, usually takes the form of a piston and dash-pot. Its purpose is to delay the action of the trips so as to allow for sudden fluctuations in the load, and also to give a measure of discrimination. In practice, a characteristic closely resembling that of a fuse is obtained; and a typical characteristic for an oil dash-pot time lag—perhaps the most common type in general use—is given in Fig. 43.

Use of Time-limit Fuses.

When the overcurrent coils are transformer operated, it is possible to use a shunt fuse in place of the mechanical retarder. These fuses are designed to short-circuit the trip coils, which therefore, cannot operate until the fuse has blown. The fuse itself is usually of silver, or some other non-deteriorating metal, and is accurately calibrated as regards blowing current. When time limit fuses are used, no advantage is to be gained by making the release coils themselves adjustable; and alternative trip settings are obtained by varying the blowing current of the fuses.

It is difficult, if not impossible, to obtain with commercial overcurrent releases and fuses a grading of tripping times which is theoretically satisfactory. Such discrimination can be readily obtained with currents up to perhaps four or five times normal; but when very heavy currents flow, all discriminating action disappears.

Discrimination when Circuit-breakers and Fuses are in Series.

It is especially difficult to get discrimination when fuses and circuit-breakers are used in series. With a circuit-breaker, a certain time must elapse between the operation of the tripping mechanism and the actual breaking of the current; and with commercial types of breaker this time is usually of the order of 0.1 sec. On the other hand, a high rupturing capacity fuse is capable of clearing a very heavy fault in less than half a cycle; and, therefore, it will operate in these conditions long before a breaker has had time even to start the opening operation.

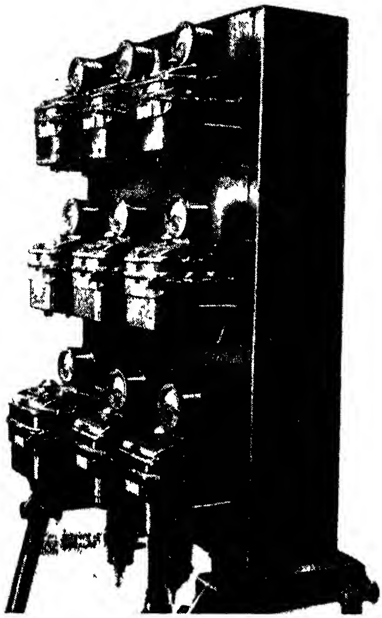


FIG. 44.—A 3-TIER SWITCHBOARD INCORPORATING EIGHT 20-AMP. AND ONE 40-AMP. CIRCUIT-BREAKERS.

(*George Ellison Ltd.*)

As will be seen from Figs. 37 and 43, an opposite characteristic is obtained with moderate excess currents, and between 100 per cent and 200 per cent normal current, a circuit-breaker will clear long before a fuse. Therefore, while a circuit-breaker will always clear before a fuse on relatively small values of excess current, the fuse will always clear first on anything approaching fault conditions.

Use of Induction Pattern Relay.

If true discrimination is desired over the whole range of possible currents, it is necessary to use a relay having a definite minimum time setting, such as the induction pattern relay. This relay, which is used in conjunction with an automatic circuit-breaker, replaces the conventional overcurrent trips and time lags. It has a definite minimum time of operation, which can be adjusted.

Therefore, it is possible to grade the tripping times on a series of breakers so that they will trip in any desired order; and this discrimination will remain sensibly unaffected throughout the whole current range. This arrangement has the disadvantage that the most severe faults, those near the source of supply, will be maintained for the longest periods before they are cleared, since the nearer the source of supply, the greater must be the delay before the breaker is allowed to trip.

Of course, there is not the need for accurate discrimination in factory distribution that there is in the network of an electricity supply company; and since, in any case, a severe fault represents a major disturbance, the balance of argument is in favour of realising discrimination on moderate values of excess current, rather than attempt to cover all possible circumstances.

EARTHING

An important feature of the installation is the earthing system, due regard to which ensures that proper precautions are taken against the dangers of shock and fire.

Earthing refers to the connection of the non-current-carrying metalwork in the installation to the general mass of earth, so that, in the event of such metal becoming alive due to the failure of insulation or other cause, the following things happen:—

(1) The earthing leads will convey the fault current to earth without danger of fire or shock.

(2) The circuit of the defective apparatus will be

opened. The usual method of achieving this will be for the metalwork to be solidly earthed, the resistance of the earth electrode being low enough to pass sufficient fault current to blow the fuses or operate the circuit-breaker of the defective apparatus. Where it is not economically possible to achieve a low enough earth electrode resistance, opening the defective circuit must be obtained with the assistance of earth leakage protection devices.

The necessity for earthing framework and metalwork derives from the fact that the neutral point of any low-voltage or medium voltage distribution system is now almost invariably earthed. This means that a voltage exists between earth and the other pole or poles of the supply system.

Bonding.

The metal casings of all the electrical apparatus in an installation to be solidly earthed should be bonded together. Conduit should be electrically continuous. The sheaths of metal-sheathed cable, where employed, should also be bonded together at junction boxes, or the earth-continuity conductors inside the metal sheaths bonded together, where provided.

Conduit armouring and other metal covering of cables must be mechanically connected to the metal cases of fuseboards, switches, starters, motors, etc.

Earthed bars should be fitted to all switchboards, to which the lead sheathing and armour of all supply cables can be rigidly connected, and a system of bare earth strips should be run in suitable positions to which all the metal parts of the electrical equipment—casings, screens, cover plates, etc.—can be connected.

All building steelwork, pipes, etc., should be bolted to an earthed metal strip, care being taken to clean off the paint at the connecting bolts in order to obtain a good contact.

The Earth Continuity Conductor.

Earth connections are usually made by means of tinned-copper conductors, and must be kept continuous throughout, any joints being carefully protected against the possibilities of corrosion. Periodical tests for continuity and resistance must be carried out on the various parts of the earth system so that any faults such as bad joints, broken connections and loose contacts can be attended to as quickly as possible.

The I.E.E. Regulations require that the earth continuity conductor shall have a resistance of not more than one ohm when measured between the connection to the earth electrode and any other point of the installation. This requirement is usually fairly easy to fulfil. Where solid earthing is used each fixed continuity conductor should be of a size not less than 0.0045 sq. in. cross sectional area, and not less than half the size of each current carrying conductor to be protected, but no earth conductor need be more than 0.1 sq. in. section.

The Earth Resistance.

The I.E.E. Regulations also require that every effort shall be made to render the consumer's earth resistance (defined as the sum of the earth electrode resistance plus the resistance of the earthing conductors) low enough to allow sufficient current to pass to operate the overload trips or melt the fuses in the event of a fault. It is comparatively easy to achieve this in the case of a small motor. Considering a 2 h.p. three-phase motor fed from 400 volt supply with earthed neutral (230 volts to earth), with fuses arranged to melt at, say, 12 amps.—if we neglect any resistance other than consumer's earth resistance this may have a maximum value of $\frac{230}{12}=19.16$ ohms, which can usually be maintained much less.

In the case of a 200 h.p. 400 volt motor with overload releases set to operate at, say, 400 amps., the maximum permissible consumer's earth resistance would be $\frac{230}{400}=0.575$ ohm, which might be difficult to obtain or maintain. With this motor, suppose that a faulty joint introduced an additional 0.01 ohm, then the heating at this joint might be in the region of $400^2 \times 0.01$ watts $=1.6$ kW. (Losses $=I^2R$ watts.) The heating of the joint might introduce the risk of fire and the necessity for keeping the resistance low enough to ensure operation of the overload releases, with solid earthing is evident.

When Solid Earthing is Used.

The maximum possible earth leakage current is assumed to be the voltage to earth of the supply divided by the consumer's earth resistance. The I.E.E. accept solid earthing protection where the earth resistance can be proved low enough to allow of the overload releases being operated (or the fuses melted)—that is, where the overload setting is lower than the voltage to earth divided by the consumer's earth resistance.

Solid earthing is also accepted for a circuit up to 100 amps. rating, where the metal work is earthed to an urban system of underground metallic water mains with metal-to-metal joints In this case, the earth connection must be made to the pipe of entry of the water service into the building or, if it is taken to another part of the pipe, this must have efficient metal to metal joints and the resistance of the pipe must be low enough to ensure that the potential difference between any two points along the pipe cannot exceed 40 volts. That is, the resistance of the pipe multiplied by the overload setting (or melting current of the fuse), must not exceed 40.

When Earth Leakage Circuit-breakers are Used.

Where the conditions specified above cannot be complied with, the I.E.E. Regulations require the use of an earth leakage protection device capable of disconnecting the live conductors when the potential between the metal framework, etc. and earth exceeds 40 volts. The earth leakage protection device can be provided in place of, or in addition to, solid earthing, and the device can be fitted to the main or individual circuits.

Fig. 46 indicates how a leakage breaker can be used to give sensitive earth-leakage protection to any air or oil circuit-breaker provided with a no-volt coil, or any contactor or direct-to-line starter. Note that the leakage breaker is connected so as to interrupt the circuit of the no-volt or hold-on coil. In this manner installations or motors of any size can be efficiently and safely protected at little extra cost. The small single-pole, 15-amp. size of earth leakage breaker is generally large enough for this purpose.

FIG. 45.—ALL-INSULATED EARTH LEAKAGE CIRCUIT-BREAKER.
(*G.E.C.*).

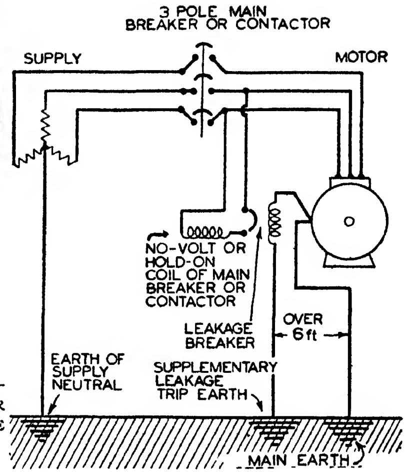


FIG. 46.—METHOD OF OPERATING MAIN CIRCUIT-BREAKER OR CONTACTOR BY LEAKAGE CIRCUIT-BREAKER.
(*G.E.C.*)

For factory installations, the double-earth system, as shown in Fig. 46, is recommended, owing to the fact that the combined normal leakage plus capacity current might cause unnecessary tripping with only a single earth connection. With the double-earth system, any leakage current is divided between the main earth and the supplementary earth, and the breaker does not function unless the voltage of the motor frame reaches the amount necessary to operate the trip.

To ensure that a fault on one section of the installation does not cause the leakage breakers to operate elsewhere, it will be necessary to split the earth circuit into sections, insulating one section from another.

With earth leakage protection care should be taken that the leakage trip coil cannot become short-circuited due to the lead between trip coil and the earth connection coming into contact with other parts of the metal framework, etc., of the consumer's apparatus or with earthed metal. Insulation of the earthing lead will probably be desirable.

A 6-ft. driven rod will be a quite satisfactory earth electrode for earth leakage circuit-breakers, provided the resistance is not more than 500 ohms. If the resistance is greater a special earth leakage circuit-breaker must be used.

Earthing Requirements of Portable Tools.

All portable plant should be efficiently earthed. Usually connection to earth is by means of an extra core in the trailing cable. This is not ideal, as a broken core in a light trailing cable, while not a common occurrence, is not easily detected. Where the tools are being used in a damp situation, further protection is necessary. This protection should prevent

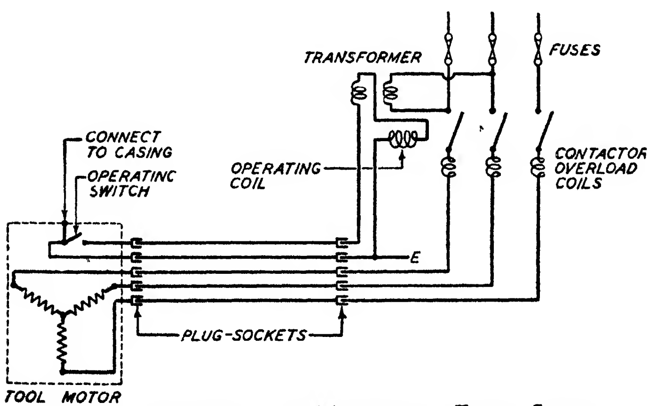


Fig. 47.—Portable Tool Motor with Earth Circuit Protection.

current reaching the motor unless the frame of the tool is connected to earth. Such an arrangement of connections is as shown in Fig. 47.

A triple-pole circuit-breaker is fitted at each plug point and the trailing cable will have, in addition to the three cores, two pilot wires, one earthed and connected to the frame of the machine. The other pilot is a control wire which is connected to one pole of a control switch, the other pole being connected to the frame. In this way the operating coil of the circuit-breaker can only be energised through a small transformer when the earth connection is complete. Where the portable tool is on wheels, a triple pole emergency switch connected in the line wires is very desirable.

As these tools are easily overloaded, the circuit-breaker should be fitted with overload release protection while triple pole fuses should be fitted which will be ruptured in the event of an earth at the motor.

Selecting Earth Electrode.

In selecting the type of electrode best suited to a job, the primary consideration is that of low resistance. To achieve this result it may be necessary to have large electrodes or, preferably, several electrodes connected in parallel, and the choice is therefore largely governed by the space available and by the specific resistance of the soil. Copper is the most useful material, being the least liable to corrosion.

Plate or Pipe Earths.

Where space is restricted, an earth consisting of a rectangular or circular metal plate or a large diameter pipe buried in the ground is often used. Such plates, although relatively costly to install, have the advantage of a high current carrying capacity and may give a sufficiently low resistance provided the specific resistance of the soil is not too high.

Fig. 48 gives an idea of the relative resistance values of different sizes of earth electrode buried in soil having

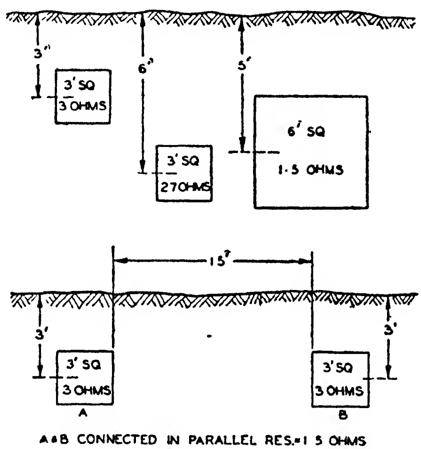


FIG. 48.—SKETCH SHOWING RELATIVE RESISTANCE VALUES OF VARIOUS SIZES OF EARTH PLATE BURIED AT DIFFERENT DEPTHS.

Soil resistivity 1,000 ohms per cm. square.

(*Evershed and Vignoles, Ltd.*)

a specific resistance of 1,000 ohms per centimetre cube. It will be seen that a 3-foot square plate buried on edge with its centre 3 feet below the surface has a resistance of 3 ohms, and that by increasing the depth to 6 feet the resistance is only reduced to 2.7 ohms. If, however, two such plates 15 feet apart, are connected in parallel, the resistance is reduced to 1.5 ohms and is equivalent to a single plate 6 feet square with its centre at a depth of 5 feet below the surface.

Driven Rod Earths.

Where space is not restricted, an earth consisting of a number of driven rods or pipes of small diameter,

FIG. 49.—DRIVING EARTH ROD BY MEANS OF SPECIAL ELECTRIC HAMMER ("KANGO").
(*Mansion Motors Ltd.*)

connected in parallel, has much to commend it. This type of earth is used to a great extent in the United States of America and is rapidly finding favour in this country, particularly on account of its cheapness and ease of installation.

In England, tubes of 1-in. bore or rods of ¾-in.

diameter are commonly used, whereas in the United States of America longer rods of smaller diameter are employed, the rods being driven into the soil by means of electric or pneumatic hammers. A special electric hammer, which will drive ½-in. rods down as far as 40 feet when necessary, is admirable for this purpose.

In general, the length of rod is more important than its diameter and, moreover, by using long rods it may be possible to penetrate to a depth where the soil has a low specific resistance. Whether it is more advantageous to use a smaller number of long rods or a larger number of shorter rods will depend on the specific resistance of the subsoil at different depths and this can only be ascertained by observing the changes in resistance as a rod is driven in with an earth tester, such as the "Bridge-Megger" Testing Set, or by measuring the specific resistance of the soil at different depths. Under good conditions one rod six feet long will usually be quite satisfactory.

Spacing of Multiple Rod or Plate Earths.

There is one condition of paramount importance in connection with electrodes consisting of a number of rods or plates in parallel, and that is that the individual rods or plates must be sufficiently far apart so that their respective resistance areas do not overlap. If two rods, for instance, are too close together, the nett resistance of the two in parallel will be considerably greater than if they were adequately spaced. Rods should, were possible be spaced not less than four feet apart. Plates should be placed, say, twenty feet apart.

Metal Strip or Conductor Earths.

This type of electrode consists of a copper strip, many yards long, buried in a trench. It is capable of giving a very low resistance, but may have to occupy a large area and is not particularly cheap to install. It is of advantage where the specific resistance of the soil is high, or where rocks come very near to the surface.

Connections of Earth Lead.

Where possible, the connections between the earth lead and the earth electrode should be made above ground so that it may be accessible to inspection. Where this is not possible, as in the case of a buried plate, precautions should be taken so as to eliminate as far as possible the effects of corrosion. Joints involving dissimilar metals should, for instance, be avoided as likely to promote electrolytic action, and all joints should be treated with bitumen. Even slight corrosion at the joint may considerably increase the resistance of the earth circuit and the importance, therefore, of periodic testing, cannot be over-emphasied.

Artificial Treatment of Earths.

The practice of surrounding earth plates with coke is only of value if the specific resistance of the surrounding soil is high compared with that of the coke. Under these conditions, coke has the effect of extending the apparent dimensions of the electrode. Where the electrode is of copper, however, coke is not to be recommended, as certain types of coke corrode copper.

It is also quite a common practice to treat earths with salt. In the case of a rod, the procedure is usually to excavate a hemispherical hole round the top of the rod, fill this with salt and cover it up again with soil. The effect, however, is not permanent, as the salt is gradually washed away and requires replenishing at intervals. The salt, moreover, is liable to cause corrosion.

Main Earths.

Main earths should preferably be in duplicate or divided into two sections, each section being connected to the earthing cable by means of a removable bolted link. It is then possible, by removing each link in turn, to test each section without losing the protection of the earth connection. To give the lowest possible resistance the two sections should be sufficiently far apart so that their respective resistance areas do not overlap.

Specific Resistance of Soils.

Some values of specific resistance are set out in the table, p. 126. The very wide variation in values is due mainly to moisture content. The specific resistance of any particular kind of soil cannot be forecast with any degree of accuracy, and it is therefore of the utmost importance to test the resistance of any earth electrode when it is first laid down and thereafter at periodic intervals.

TABLE II—SPECIFIC RESISTANCE OF SOILS.

Material.	*Specific resistance in ohm-cms.*	*Source of information.*
Ashes	350	Higgs
Coke	20–800	—
Peat	4,500–20,000	—
Garden earth—50% moisture ..	1,400	Ruppel
,, ,, —20% moisture ..	4,800	,,
Clay soil—40% moistrue	770	,,
,, ,, —20% moisture	3,300	,,
London clay	400–2,000	—
Very dry clay	5,000–15,000	—
Sand—90% moisture	13,000	Ruppel
,, —normal moisture	300,000–800,000	—
Chalk	5,000–15,000	—
Consolidated sedimentary rocks ..	1,000–50,000	Broughton Edge & Laby

(*By courtesy of Evershed & Vignoles Ltd.*)

CHAPTER V

MOTORS AND CONTROL GEAR

BEFORE a new motor, or its control gear can be ordered, the following points must be considered—

1. *Enclosure and protection.* Which of the many types of enclosure should be selected? This depends on site conditions and affects reliability, first cost, running and maintenance costs as well as installation charges to a certain extent.

2. *Horse-power and time rating.* What output will be demanded by the driven machine, in horse-power, and will this be required all day or only for short periods? Affects size, first cost, and, to a limited extent, running charges.

3. *Speed and speed control.* What speed will be most suitable and should this be constant or variable, and, if the latter, to what extent? This concerns installation costs, first cost and running charges and affects efficiency and ease of operation.

4. *Starting conditions.* Will the motor be required to start up against a heavy load and which method of starting will be most efficient and satisfactory? Upon this depends convenience and ease of operation and it also affects the first cost to a large extent.

5. *Temperature rating.* What temperature rise is allowable in the motor? This decides the probable life of the motor, its reliability, and affects the first cost.

6. *Special fittings.* What special fittings are essential to meet the conditions, and are these available in standard machines, if required? Affects first cost and maintenance charges as well as running and installation costs in some instances.

ENCLOSURE AND PROTECTION

The method of protecting the motor against adverse site conditions is of supreme importance and manufacturers have developed certain standard methods of accomplishing this. Open type motors should be employed only in situations which are clean, dry and cool, and inaccessible to unauthorised persons, as the windings and current-carrying parts are either unprotected or only lightly guarded; further, the ingress of dust and dirt into the machine is not controlled in any way, and neither is the drip of water or condensed steam prevented from falling on the windings, commutator, or slip rings.

Protected or Screen Protected Motors.

Industrial motors are generally of the protected or screen-protected types.

Here again, the motor should be installed in a clean and dry situation, except that, as all the live parts and windings are protected from accidental or careless contact, machines of the screen-protected type having wire mesh or screen guards are suitable for use in workshops and rooms where workpeople are present, and, since the protecting covers do not obstruct the ventilation of the motor to any large extent, the size and cost are low.

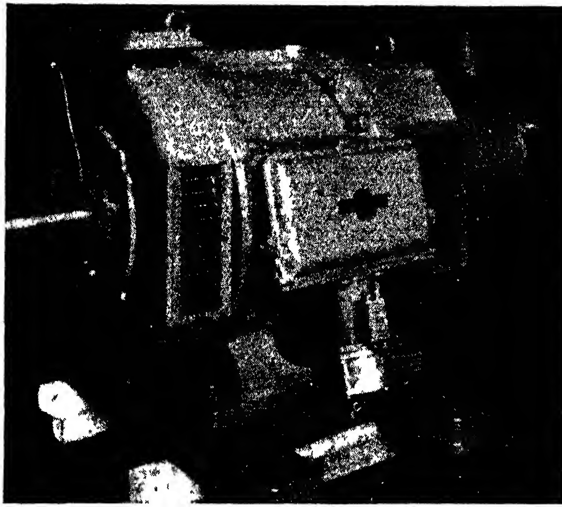


FIG. 50.—SCREEN-PROTECTED SYNCHRONOUS INDUCTION MOTOR.

Both the motor and its exciter is of the screen-protected type of enclosure. Observe the canopy over the top opening at the driving end and the solid covers in the same position at the other end and on the exciter. This is a good feature, although not essentially a part of the screen-protected enclosure. Note the cable fittings on the terminal box and the slidebase.

(*Metropolitan-Vickers.*

Drip-proof Motors.

Where dripping water (as condensed steam) or falling matter is to be encountered, a drip-proof type of motor is indicated. This, as its name implies, is suitably protected to withstand such conditions, and it is also well protected against contact with live parts. The site conditions must still be clean and cool however.

An open machine is sometimes fitted with a canopy to render it drip-proof, especially in marine service, but in this case it is still subject to the limitations of its lack of protection of live parts and might be more correctly termed "open drip-proof."

The industrial motor of drip-proof type may be regarded as somewhat more protected than the screen-protected variety, and it is the second most popular type at the present day.

Pipe Ventilated Motor.

When the temperature of the atmosphere the motor works in exceeds forty degrees C. (104 degrees F.), or where the air is dirty, as with flying dust, and in cases

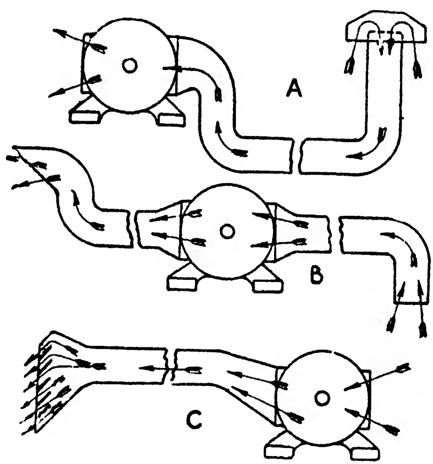


FIG. 51.—THREE ALTERNATIVE ARRANGEMENTS OF DUCTING FOR A PIPE-VENTILATED MOTOR.

In all cases the total length of the ducting should not exceed 40 to 50 ft., while the cross-section should not be less than 150 per cent of the area of the opening on the motor to which the pipe is attached, and the number of bends should not exceed 3 or 4. In "A" we have a motor with pipe in only, the inlet end of the pipe being protected by a cowl. "B" shows a pipe-in-and-out case, protection of the inlet being effected by downcasting, while the outlet is cut off at an angle with the opening facing downwards. In "C" is a case with pipe outlet only and louvre protection.

where both these adverse conditions exist together, a pipe-ventilated motor is probably the best solution. This can be applied only when it is possible to carry a pipe or duct to a position where the air is clean and cool. Pipe-ventilated motors (see Fig. 51) may have (*a*) inlet duct only, exhausting direct into the local atmosphere and cleansing and cooling it to some extent; (*b*) both inlet and exhaust ducts where it would be objectionable to exhaust into the local air; for instance, where the local air contains corrosive fumes which would penetrate into the motor through the exhaust ports when the machine was not running; or (*c*) exhaust duct only, when the local air is both clean and cool for motor ventilation but the heated exhaust air would be objectionable.

Totally Enclosed.

When the site conditions are cool but dirty and it is impossible to run a pipe to a source of clean air, it is necessary to use a totally enclosed machine.

This enclosure may be made in many variations, such as (*a*) plain totally enclosed, usually made only for small outputs and entirely at the mercy of the local air conditions for cooling, but nevertheless completely protected and supremely reliable under adverse conditions. Alternatives are (*b*) totally enclosed, fan-cooled, a plain totally enclosed motor with a fan blowing air over the outside, cooling surface of the motor; or (*c*) totally enclosed closed-air circuit, which type usually employs radiators with internal and external fans further to augment the cooling and reduce the size.

The choice between (*a*), (*b*) and (*c*) is usually one of

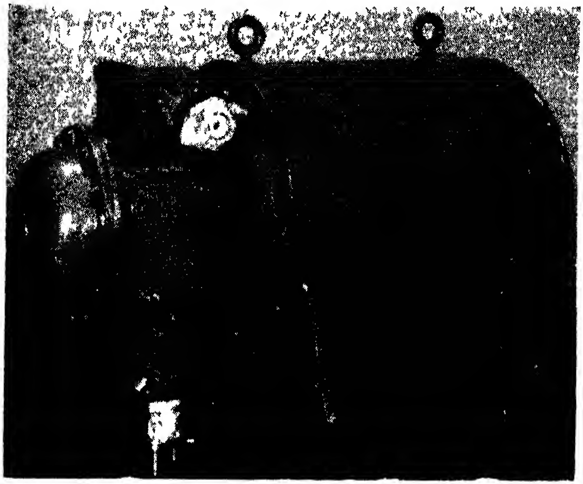


FIG 52.—A FLAMEPROOF T E C A C (TOTALLY ENCLOSED CLOSED-AIR-CIRCUIT) MOTOR

The ducts for the motor-cooling air may be seen around the outer circumference at the left-hand end of the motor On this machine note the cable fittings, the cup washers beneath the hexagon nuts and bolt heads to prevent their removal except by a proper box spanner, and the wide joints of the flameproof covers.

(*Metropolitan Vickers*)

horse-power, speed, and time-rating specified, and manufacturers will offer the correct type if a totally enclosed motor is specified in the inquiry.

Special Conditions.

These three types are suitable only for cool site conditions as specified above; when total enclosure is essential from considerations of dirty conditions and in addition a hot atmosphere has to be contended with, it becomes necessary to consider such alternatives as totally enclosed, water-cooled motors, while for cases where the site atmosphere is explosive, as in fiery mines, petrol stores, etc., a totally enclosed, flameproof motor is called for.

From the considerations given, it will be possible to select a standard type to satisfy the site conditions in almost every case, remembering that additional protection may always be given if considered desirable in the form of rails, a roof or a shield against driving rain.

It is, of course, *most essential* that any additional protection shall not obstruct the motor ventilation in

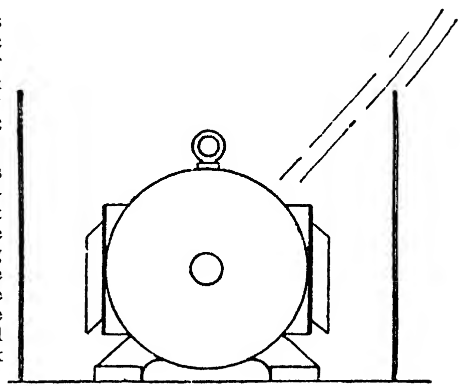


FIG. 53.—THIS SHOWS HOW SHIELDS MAY BE ERECTED TO PROTECT A DRIP-PROOF MOTOR AGAINST DRIVING RAIN AND MAKE IT SUITABLE FOR OUTDOOR USE.

Note that the shields should stand sufficiently high to prevent rain driving into the tops of the ventilating openings. If there are any openings at the top of the machine they should be closed by means of blank plates.

any way, and for this reason shields erected around drip-proof machines when they are installed out of doors (to oppose driving rain) should always be well away from the ventilating openings, so as to allow free flow to the motor ventilating air, while no top canopy should be employed since it will be unnecessary with a drip-proof motor. (See Fig. 53.)

In the event of the site conditions appearing somewhat special or onerous, it is advisable to mention the fact when inquiring for a price for the motor, asking the manufacturer to quote for his standard type and to give an alternative or additional price for special features to meet the conditions described.

THE HORSE-POWER OF THE MOTOR.

When individual drive is adopted, i.e. when the motor is to drive one machine only, the horse-power required is best obtained from the maker of the machine to be driven. In the case of pumps, compressors, generators, alternators, boosters, centrifugal separators, fans, etc., this should always be done since the horse-power required depends on the efficiency of the driven machine and this can only be estimated by its manufacturers.

In the case of machine tools a great deal depends on the class of work and the cuts to be taken, and in estimating the horse-power required one should remember to allow for the heaviest work likely to be undertaken which must be accomplished without overloading the motor to any large extent.

Some Typical Figures.

The following figures may be taken as a guide for average work; they must be increased for heavy duty, and rapid production, and they may be reduced when only light work is the rule. These figures may be used for preliminary estimates and are representative values, but it is much better and safer to ask the machine-maker what horse-power is required or to obtain it from a similar machine on the same class of duty.

Lathes.

	Centre Height.
A	4 to 6 inches
B	6 to 8 ,,
C	8 to 12 ,,
D	12 to 15 ,,
E	15 to 20 ,,
F	6 ,,
G	8 ,,
H	12 ,,

H.P. required, average duty.

A	1	Ordinary machine-shop centre lathes, without special high production features.
B	2	
C	5	
D	$7\frac{1}{2}$ to 10	
E	15 to 20	
F	1	Wood-turning or pattern-makers' lathes.
G	$1\frac{1}{2}$	
H	2	

Drilling Machines.

Sensitive drills of capacity up to about half inch in steel require approximately half h.p. For radial drills we can take roughly one horse-power per foot of radial arm for ordinary average duty, i.e.

3 feet arm ..	$2\frac{1}{2}$ H.P.
4 ,, ,, ..	3 ,,
5 ,, ,, ..	5 ,,
6 ,, ,, ..	6 ,,

FIG 54 —SLIP-RING MOTOR DRIVING A HOT SAW

This slip-ring motor drives through double belts and is mounted on the swinging frame of the saw The control gear may be clearly seen on the right and is of the rotor resistance type to which the motor connections are carried through conduits

(Metropolitan Vickers Electrical Co , Ltd)

Boring Mills.

Table diameter.	*H.P. required, average duty.*
3 feet	6
4 ,,	8
6 ,,	12

Or, roughly, two horse-power per foot of table diameter.

Saws.

For circular saws for wood, horse-power may be taken as equivalent to saw diameter divided by three, i.e.:

12 inches diameter	..	4 horse-power.
18 ,, ,,	..	6 ,,
24 ,, ,,	..	8 ,,

A bandsaw, on woodwork, with thirty-six inches diameter wheel will require about three H.P.

Rotary Wood Planers.

18 inch knives	..	6 horse-power.
24 ,, ,,	..	8 ,,

Cranes, Hoists and Winches.

In these cases, the horse-power may easily be obtained from the maximum weight and speed of lift, assuming an efficiency of about seventy per cent. for the mechanical parts, if worm or spur gearing, or a combination of both is employed throughout the transmission, or, if a stage of friction gearing is incorporated, as in a friction hoist, the figure should be about sixty-five per cent. The horse-power required will then be:—

$$\text{H.P.} = \frac{\text{Pounds lifted} \times \text{lifting speed in ft. per min.} \times 1.4}{33{,}000}$$

(For spur or worm gears)

$$\text{or H.P.} = \frac{\text{Pounds lifted} \times \text{lifting speed in ft. per min.} \times 1.5}{33{,}000}$$

(For friction gears).

The figures of seventy and sixty-five per cent. are good average figures which may be exceeded in certain favourable cases; on the other hand, the efficiencies may easily be less than these, requiring more horse-power if the gear train consists of many stages or if it is badly cut or worn or if cast gears are employed.

Group Drives.

As has been stated above, the figures given are for individual drive. If, however, the motor is to drive a lineshaft which in turn is belted to a group of machines, it may be taken that the horse-power required in the motor will seldom exceed half the sum of the requirements of the driven machines. This is because the maximum requirements never occur together when the driven machines are hand controlled or fed, and when there are pauses during which no work is being done, such as for setting up.

If these conditions do not apply, as in cases where the driven machines are on full capacity work all the time, being probably automatically controlled, then it will be necessary to install a larger motor, and the same will apply where there are only a few—say, less than six—driven machines on the lineshaft, when the diversity factor of the load may make fifty per cent. of the aggregate horse-power insufficient.

THE TIME RATING

In service a motor may be required to run for a series of short periods on full load, say a few minutes at a time, or it may have to carry full load all day. Since it is impossible to reproduce the service conditions on test for the vast majority of applications it has become general practice, recognised in all the usual specifications, to apply a "time rating," that is to say, the manufacturer guarantees that the motor will not exceed a certain temperature after being run on full load for a certain length of time. We will deal with the temperature value later when we consider "temperature rating."

These time ratings have, by accumulated experience, come to be regarded as being suitable for certain definite duties and have become fairly definitely standardised as continuous, one hour and half-hour ratings.

Continuous Rating.

A motor with continuous rating will not exceed the specified temperature rise if it is run for ever. In practice it is found that all except the very largest machines have reached a constant temperature in less than six hours full load run, while small motors attain their final temperature in a still shorter time, so that temperature tests of continuously rated machines are usually taken for six hours, or less for small horsepowers, and the term "six hours' rating" is often used to describe continuous rating.

The continuous rating is employed for most individual cutting motions, and group drives of machine tools, for pumps, conveyors, compressors, motor-generator sets, looms and textile machinery generally, for forging hammers, wire drawing and woodworking machinery, mine haulages and, in fact, for the great majority of applications. Its capacity for carrying overloads for short but appreciable periods—see B.S.S. 168/36—makes this rating invaluable for most industrial applications, although special forms of rating have been worked out for metal planers and a "continuous conveyor rating" is used for mining conveyors.

In considering an installation it must never be forgotten that although a shorter rating than continuous might appear suitable, a sudden influx of work, or a new process of manufacture, may cause the use of the driven machine to be greatly increased so that a short time rated motor will be unable to cope with it. In this respect each case must be considered on its merits.

One Hour Rating.

This rating is employed for cranes, hoists, winches, capstans, lifts, etc., which are in use all day on heavy or maximum duty. A one hour rated motor will operate all day without excessive heating, running on full load for one minute and standing (i.e. not revolving) for two minutes, that is not carrying current for more than one-third of the time. Conditions of this type apply on the duties mentioned above but rarely do conditions arise where the maximum load is lifted every time, and for this reason it has been found that the half-hour rating is sufficient for most general purpose cases. It is regularly applied to all motions of workshop, harbour and stockyard cranes, to dock and shunting capstans and warehouse hoists as well as to those motions on machine tools which do not involve more than infrequent operations. This rating is equivalent to all day operation running one minute and standing four minutes (i.e. one in five) without injurious heating.

Composite Ratings.

There are also various composite ratings which may be obtained, especially on D.C. machines, such as continuous no-load running with one hour or half-hour loaded periods. Such special ratings will be offered by the manufacturers if necessary if the conditions are described when inquiring the price of a motor.

SPEED AND SPEED CONTROL

The speeds available in A.C. induction motors are fixed from fundamental considerations depending on the frequency of supply and the number of poles in the winding of the stator. With the now standard fifty cycle supply, speeds of approximately 2,900, 1,450, 960, 720, 570, 480, 410, 360 r.p.m. as well as smaller values in certain cases, are available in most sizes. These values are the full load speeds, the no-load figures being some three to four per cent. greater; beyond this small change of speed with load, however, induction motors are not capable of speed variation except in the case of slip-ring motors where resistance may be used in the rotor circuit to reduce the speed.

This speed reduction by rotor resistance control is wasteful because of the power dissipated in the resistance resulting in a low overall efficiency, and, further, any change of load when running on a given setting of the controller will result in a change of speed. This is objectionable in certain cases of variable loading and, combined with the low efficiency confines this method to cases where the running time at reduced speed is only a small proportion of the total running time. The speed may be reduced to about one-third of full load speed (i.e. 1,450 to, say, 500 r.p.m.) by this method.

Pole-changing.

By means of special pole-changing windings on the stator, in the case of squirrel-cage motors, and upon both stator and rotor of slip-ring machines, certain definite alternative speeds may be obtained. Two speed motors are common, but above this number of speeds the technical difficulties increase rapidly so that motors with three or more speeds are costly and comparatively rare.

Where speed control is essential with an A.C. circuit, two-speed squirrel-cage motors should be used if possible as the cheapest and smallest alternative. The speeds of pole-changing motors will be fixed, as for ordinary machines, at values decided by the frequency, and with certain reservations where the combination is fundamentally impossible, any two of the speeds given above may be obtained on a two-speed fifty-cycle motor. Special control gear is necessary to change the connections to obtain the different speeds, but certain manufacturers can offer motors which operate as slip-ring motors at one speed and as squirrel-cage machines at the other speed and this helps to simplify the control gear to some extent.

Gradual Speed Variation.

Obtaining gradual speed variation is costly on A.C. supplies, but it may be obtained if required by installing commutator motors or by converting to D.C. and employing shunt field or Ward-Leonard control. It is wise to consult the manufacturers when speed variation is required on A.C. supplies, mentioning especially the type of load to be driven and the variations necessary, keeping to two definite speeds if possible, with no variation in between. The type of load is most important, since it affects the size of equipment to an enormous extent.

Speed Variation with D.C. Supplies.

We must now refer to motors on D.C. supplies. In these cases there is no difficulty in obtaining speed control with gradual variation and high efficiency, since by adopting shunt field control stable speed ranges up to three to one or more may be obtained with motors of standard construction, while this range may be extended by comparatively cheap and simple modifications to the design. In addition to this it is possible to obtain speed variation down to zero against any load by adopting Ward-Leonard control, this necessitating a motor-generator set and being equally applicable, as noted above, to A.C. supplies, converting same to D.C. for the motor connected to the driven machine.

STARTING AND CONTROL GEAR

Dealing with A.C. motors first, we find that the starting gear is mainly decided by the conditions and load against which the motor is to start. It is advisable before deciding definitely on the type of control gear, to ascertain the rules imposed by the supply authority since these may have a definitely over-ruling effect as compared with purely technical considerations.

For instance, many authorities will not permit direct starting of squirrel-cage motors of sizes larger than five h.p. or squirrel-cage motors at all if larger than thirty to fifty h.p., and, in addition, they specify in some cases how many overload trips are to be incorporated in the starter, together with other details of protective features.

All starters are, of course, fitted with some form of protection, either magnetic overloads with or without time lags, or thermal overloads which need no time lags, as well as no-volt protection to return the starter to "off" in the event of failure of the supply.

Direct Starting.

In the direct starting method the motor is simply switched directly on to the line, and with normal machines of high and medium speed a starting torque of some one to one-and-a-quarter times full load torque is obtained while drawing some four to six times full load current from the line. This torque is generally ample for most loads, but it can be increased at a small extra cost by the employment of a special type of squirrel-cage rotor which will give up to about twice full load torque for the same starting current.

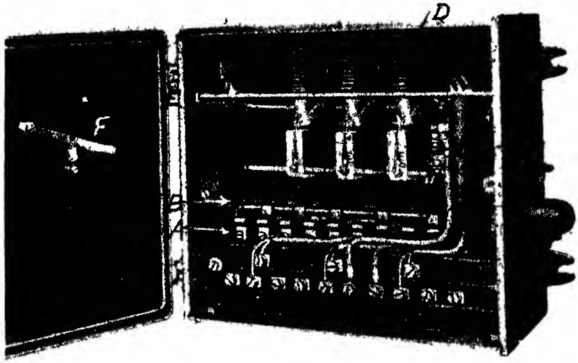
FIG. 55. DIRECT-ON-LINE AUTOMATIC STARTER FOR SQUIRREL-CAGE MOTORS UP TO 2 H P.
(Igranic Electric Co, Ltd)

This special squirrel-cage rotor is termed the high-torque type and it may also be employed to give the same starting torque as the ordinary machine but with less starting current.

Star-Delta Starting.

In star-delta starting the stator is firstly connected to the line in star connection and the motor allowed to attain a certain speed. The stator connection is then changed to delta, which is the arrangement for running. Motors for star-delta starting must be specified thus, since the stator connections and terminal arrangements may be different from standard machines not required for this method of control.

Ordinary squirrel-cage motors give about thirty to forty per cent. full-load torque, taking one-and-a-quarter to two times full-load current, when star-delta started, and this is usually sufficient for short line



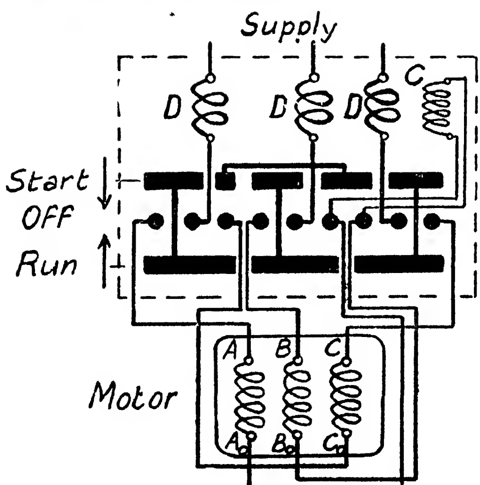


FIG. 56. HAND-OPERATED STAR DELTA STARTER AND ITS CONNECTIONS

A, fingers, B, drum. The drum has spring return to off position, and is retained in run position by magnetic catch C, the operating coil of which forms an under-voltage release. The catch may also be tripped automatically by the action of any of the over-current solenoid releases D, the plungers, of which, when lifted, engage the tripping bar, E. This bar is connected with the catch.

shafts with the driven machines on fast-and-loose pulleys, or for motor generator sets, and most individual drives which can be started up light. If this torque is insufficient a high-torque machine will give about fifty-five to sixty-five per cent. of full-load torque for a similar order of starting current, and this degree of torque usually suffices for most lineshafts started up with the machines on the loose pulleys.

Auto-transformer Starting.

In the case of auto-transformer starting an auto-

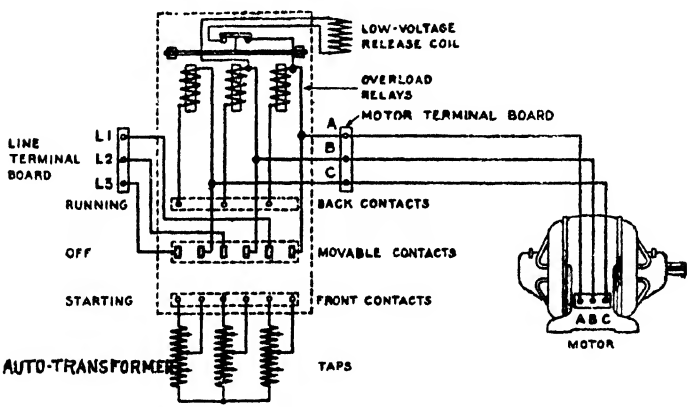


FIG. 57.—CONNECTIONS OF AUTO-TRANSFORMER STARTER.
The changeover-switch is of the lever type. It puts the transformer in circuit at starting.

transformer is employed to reduce the voltage across the motor terminals at starting, so as to limit the starting current. A special switch, incorporating the protective devices, puts the auto-transformer in circuit at starting and cuts it out again after some speed has been attained.

The auto-transformer is usually provided with about three tappings, giving fifty, sixty and seventy-five per cent. of line volts at starting, the corresponding torque and current figures being as shown in Table I. The seventy-five per cent. tapping is usually ample for all normal drives, especially if used in conjunction with a high-torque machine.

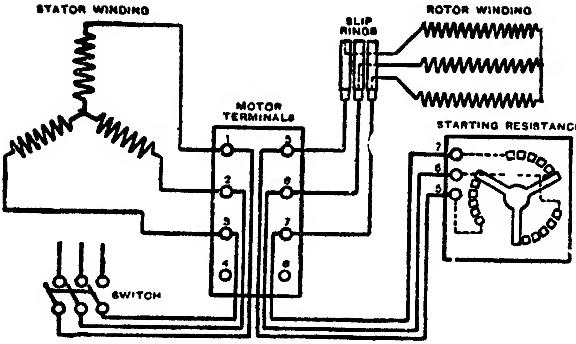
Starting Slip-ring Motors.

Slip-ring motor starting is accomplished by means of a stator switch embodying the protective devices and a rotor resistance controller which brings the motor up to speed gradually by cutting resistance out of the rotor circuit. This resistance is also used, and should be rated for, any speed variation which is proposed, and in certain cases it consists of a liquid resistance which is cut out gradually and finally shorted, while in other cases contactors are used to make all changes of connections, thus permitting automatic operation. The torque obtainable is approximately one and three-quarter to two times full-load torque for two to two and a half times full-load current, this being sufficient for everything except the heaviest duty where special equipment would be needed in any case.

The slip-ring motor is employed for duties where smooth starting is essential, such as the lifting motion of cranes, where smooth lifting and careful handling of the load is required, although for other crane motions and where this care is not necessary a high torque squirrel-cage motor suffices.

Single-phase Motors.

Single-phase motors are only employed in small sizes and are then best obtained complete with starting



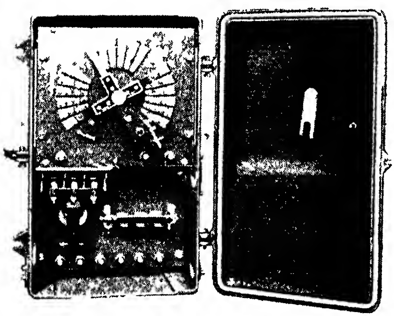


FIG 58A (*above*). CONNECTIONS OF ROTOR STARTER FOR THREE-PHASE MOTOR.

FIG. 58 (*left*) COMBINED STATOR AND ROTOR STARTER. The stator switch takes the form of a triple-pole contactor, as shown

(*Airedale Electrical & Manufacturing Co, Ltd*)

gear. In general, the starting characteristics are much inferior to those of three-phase machines, except in the very small sizes, where special types and designs have been developed to improve this feature. The supply authority rules must always be referred to and the manufacturers should be consulted on all single-phase power problems.

D.C. Machines.

No very serious problems arise with D.C. machines, it being possible to design for very large starting efforts with quite reasonable starting currents, while the gear may be either manual or automatic as required. No great difficulties need be anticipated in D.C. starting, but any special features should be mentioned to the manufacturers.

Summary of Three-phase Starting.

For average, medium speed, fifty-cycle machines, Table III gives the approximate starting figures expressed as percentages of the full load values. Where any doubt is felt as to the starting torque required, the maker of the driven machine should be consulted.

TABLE III.—STARTING TORQUE AND CURRENT FOR A.C. MOTORS.

	Squirrel-cage.	*High torque squirrel-cage.*	*Slip-ring.*
Direct started, Torque ..	100/125	200 max.	—
„ „ Current ..	400/600	450/600	—
Star-delta, Torque ..	30/40	55/65	—
„ „ Current ..	125/200	150/200	—
Auto-transformer—			
50 per cent. tapping,			
Torque	25/30	50/55	—
Current	100/150	110/150	—
60 per cent. tapping,			
Torque ..	35/45	65/75	—
Current ..	150/220	160/220	—
75 per cent. tapping,			
Torque ..	55/75	100/125	—
Current ..	225/350	250/350	—
Rotor resistance starting—			
Torque	—	—	175/200
Current	—	—	200/250

THE TEMPERATURE RATING

The necessity for specifying the temperature which a machine will not exceed at the end of its time rating, arises from the fact that the windings are insulated with a material which must not exceed a certain temperature or it becomes permanently damaged. For this reason it is necessary to lay down a temperature which is below the value at which injury will occur, and it is usual to specify this in the form of a certain temperature rise above the surrounding atmosphere.

For most industrial machines, which are insulated with "Class A" material (see B.S.S. 168/36), the maximum continuous operating temperature must not exceed ninety degrees C. if damage is to be avoided, and from this must be subtracted a margin to allow for sustained overloads, so that it may be taken that the maximum temperature which is allowable on industrial machines insulated with ordinary materials, is seventy-five degrees C. after normal full load for the period of the time rating.

Temperature Rise.

This seventy-five degrees C. is the total temperature as measured by thermometer, and it is clear that for any given motor the measured temperature will vary with the atmospheric temperature at the time of test; in other words, if we have a machine which gives seventy-five degrees C. total temperature in an air temperature of twenty-five degrees C., we would find on repeating the test on a day when the air temperature was only fifteen degrees C. that the total temperature would be only sixty-five degrees C., i.e. the difference between machine temperature and air temperature remains fifty degrees C. whatever the air temperature. This fifty degrees C. is the temperature rise.

Therefore, it is usual to specify the temperature rating of a motor by saying that its temperature rise must not exceed a certain figure above atmospheric temperature, and in order to keep within safe limits it is necessary to subtract the maximum atmospheric temperature from the seventy-five degrees C. mentioned above. By general consent the maximum atmospheric temperature in this country is assumed to be thirty-five degrees C., so that for normally insulated, ventilated industrial motors the temperature *rise* is 75° C. – 35° C. = 40° C., while for totally enclosed motors, where because of design limitations sustained overloads cannot be carried, the total temperature is taken as eighty-five degrees C., giving 85° C. – 35° C. = 50° C. temperature *rise*.

For Hot Atmospheres.

It is clear from the above that if damage is to be avoided, the allowable temperature rise must be reduced when the atmospheric temperature may be high so as to maintain the figure of seventy-five degrees C. total maximum. For instance, in a tropical country (or a works location where great heat is to be encountered such as a steel works), where the atmosphere might reach forty-five degrees C., the maximum allowable temperature rise would be 75° C. – 45° C. = 30° C.

An alternative method to these special low temperature rise motors would be to install machines having mica and asbestos insulation which will withstand much greater heat and thus permit of higher temperature rises. For further information on this matter the reader should consult B.S.S. 168/36, which gives full details regarding both temperatures and insulations.

SPECIAL FITTINGS

There are many fittings which may be added to standard machines in order to protect them against site conditions, to make maintenance more simple or

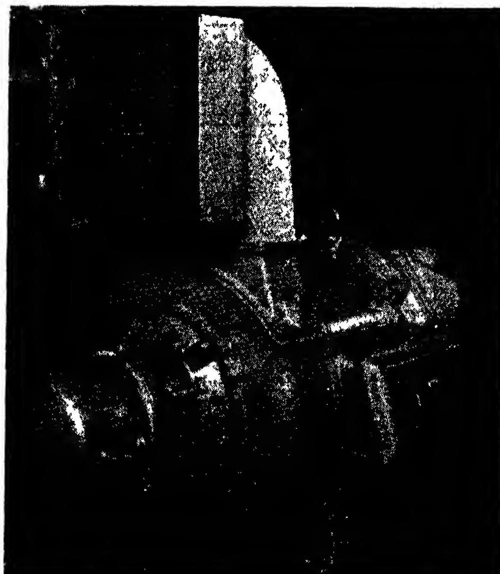


FIG 59 MOTOR WITH INLET AIR FILTER

This slip-ring motor is equipped with an inlet air filter to cleanse the motor-cooling air, the outlets being screen protected The quick-release catches on the filter to release it for cleaning should be noted

(*Metropolitan-Vickers*)

to conduce to a safe and efficient drive, and most manufacturers are prepared to modify their standard designs in certain respects to cover these cases.

Among these usually easily available additions we may note inlet air filters for use when the local air is dusty and a pipe cannot be run conveniently to permit a pipe-ventilated motor to be employed; cable fittings and glands which are suitable for bonding and sealing any type of cable, including armour clamps and plumbing cones, as well as trifurcating boxes for multi-core cables and plain conduit adaptors for use when screwed conduit is employed.

In addition to these, various types of slipring brush-gear are available for induction motors, including continuous running brushgear, continuously rated brushes with short-circuiting arrangements, and equipment for lifting the brushes from the rings and simultaneously short-circuiting the rings when the motor is up to speed. These last two types are commonly fitted with interlocks to prevent attempts at starting up when the slip-rings are short-circuited.

Drive Equipment.

Drive equipment includes, besides such obvious things as sliderails and slidebases, all types of coupling, pulleys and pinions, bedplates, outboard pedestal bearings and jackshafts, while in certain cases alternatives of ball and roller or sleeve-type bearings are available. Very often D.C. machines can be completely split horizontally, if this is considered advisable from a maintenance viewpoint.

INSTALLATION

There are many pitfalls for the unwary in the installation of electric motors, but if properly carried out little attention should be necessary over many years. These notes are intended to point out how mistakes may be avoided.

Check up Name-plate Details.

Let us begin at the beginning. The first duty of the installation engineer, assuming that the motor has been delivered, is to check up details on name-plate as regards voltage, speed, and system of supply. Even motor manufacturers have been known to make mistakes and, if these particulars are taken for granted, serious damage may result.

Protecting Motor during Installation.

In many instances, where motors are being installed, building operations in progress cause dust and grit in the atmosphere. It is important that the motor, after being examined, should be well protected by packing to prevent entrance of abrasive dust to its interior. This packing should be retained until the motor is ready to run, and when finally removed the machine should be carefully examined to make certain that it is quite clean inside. This applies particularly to commutators and brushes of DC machines, and slip-rings and brushes of slip-ring machines.

Fitting on Pulley.

If a pulley or half-coupling has to be fitted, special care should be taken. Never attempt to hammer a tight pulley on, as you may shear the set-screw holding the bearing bush or fracture the cast-iron housing.

Slide-rails.

Where the drive between motor and machine is by means of a belt, the motor will be fitted, of course, on slide-rails. Make quite certain that all four feet of the motor stand evenly on the slide-rails before

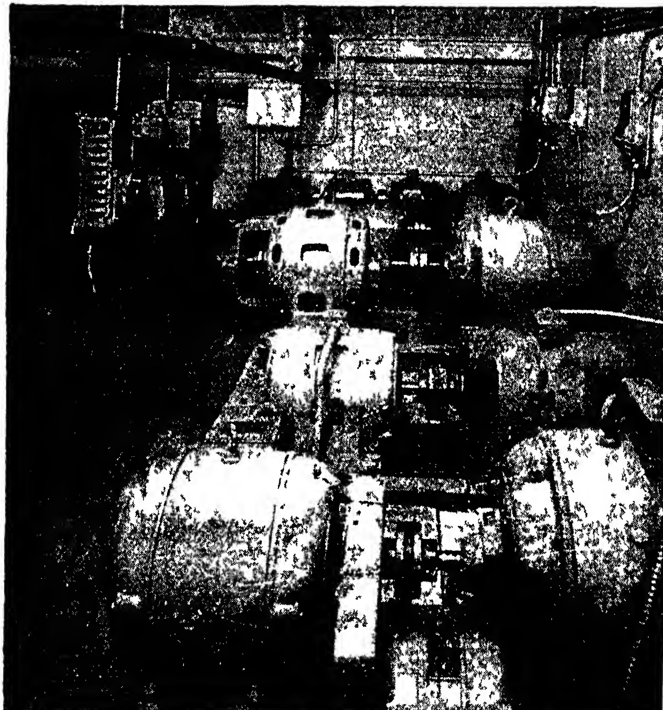


FIG 60—A COMPLETED INSTALLATION OF SMALL MOTOR-GENERATOR SETS

tightening up, as the feet are usually made of cast iron and will easily break

Lubrication.

If the motor is fitted with ball and roller bearings, these will be filled with grease before they leave the works, and require no attention for some months. Be sure to obtain the same grease as used by the makers as, if different kinds of grease are mixed, the lubricating properties of both may be destroyed.

When the motor is fitted with sleeve bearings, these must be filled to the correct level with the grade of oil specified by the makers. Here again it is important to use the correct grade of oil; for example, too heavy an oil may prevent the oil rings from revolving freely.

After filling with oil revolve the motor by hand, and ascertain that all oil rings are revolving and bringing oil up to the bearing bushes. Allow any surplus oil to drain off before starting up the machine.

Position of the Starter.

The starter will, of course, be fixed in the most convenient position. It should be placed so that the operator can see the motor during the starting operation.

If the starter is fitted at a distance from the motor (for instance, on another floor) it is necessary to fit an emergency stop-button or isolating switch near the motor so that the latter can be stopped in emergency. The Home Office Regulation No. 11 demands that "efficient means, suitably placed" shall be provided for cutting off all pressure from any electric motor *and its control gear.*

Position of Isolating Switch.

In the case of automatic starters not provided with an internal isolator, it is necessary to fit an isolating switch near the starter. Ordinary starters which have a definite off-position need not be so fitted, provided that the distribution board is suitably placed,

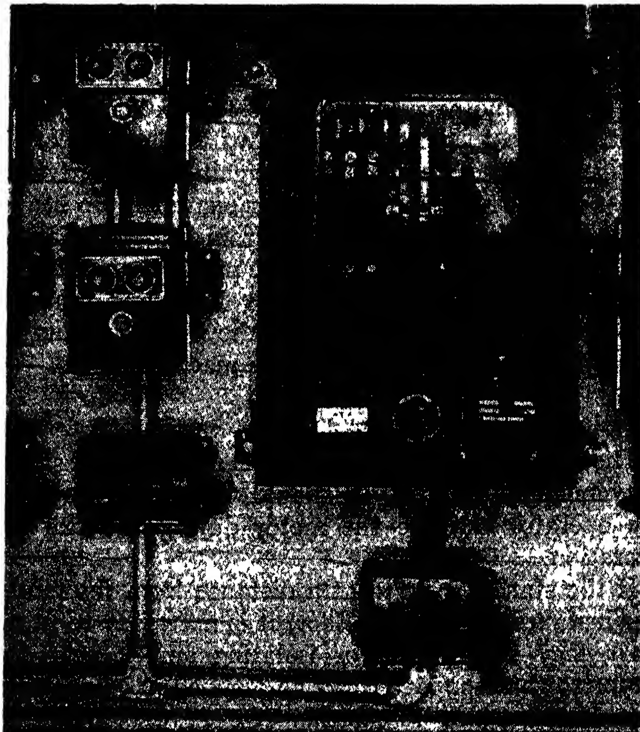


FIG. 61.—AUTOMATIC STARTERS WITH ISOLATING SWITCHES FITTED BELOW.
(*Dubilier Condenser Co., Ltd.*)

i.e. near the starter; otherwise an isolating switch must be supplied. This should preferably be mounted on a panel adjacent to the starter.

Mounting and Fixing Starters.

The fixing-lugs of starters are usually so arranged that the back of the starter is spaced from the wall on which it is fixed. But it is always advisable to mount the starter, with its isolating switch, on channel iron, to provide ample ventilating space behind. This especially applies to starters embodying resistances.

When starters or motors are fixed in close proximity to woodwork or other combustible material, protection with non-combustible material should be arranged in accordance with I.E.E. Regulations 702 (c) and 706.

How to Examine Starter before Operating for First Time.

After fixing the starter, examine it carefully and see that all contacts are perfectly clean, and that moving parts work freely. Sometimes moving parts, such as contactors, are tied up for protection during transit.

If dash-pot time-lags are fitted, see that these are filled with the oil supplied with the starter. Check up on the settings of the overloads (generally set correctly before leaving the works) and keep them set as low as possible. It is very important that these should operate before any fuses.

See that Motors are Correctly Fused.

It is of utmost importance that circuits controlling motors should be correctly fused. Avoid confusion between fusing current and carrying capacity of fuse wires. Fuse wires should always be periodically examined to see that they have not been heating up, and are not mechanically damaged. A three-phase motor can easily be burnt out by one fuse blowing, causing the motor to continue running on two phases. Under these conditions the windings may be burnt out before the remaining fuses blow.

WIRING AND CONNECTING UP

Every motor should be controlled by a separate set of fuses or a circuit breaker. Each distribution board controlling motors should be provided with a chart showing the motors and circuits it controls.

Colours for Wiring.

Wherever possible colours should be used to distinguish phases and polarity, especially on Busbar chambers, circuit breakers, distribution boards, etc. I.E.E. Regulation No. 310 specifies the following :—

DC 2-wire system . .	Red, positive. Black, negative.
DC 3-wire system . .	Red, positive. Black, middle wire. White, negative.
AC 2-wire . . .	Red, phase wire. Black, neutral.
AC 3-phase . . .	Red, White, Green, } Phases. Black, neutral.

In a three-phase four-wire system of wiring it is permissible to use parti (red/white or red/natural) instead of green for impregnated-paper-insulated conductors otherwise in conformity with British Standard Specification No. 480.

System of Wiring.

Wiring to motors should preferably be carried out with armoured cables or heavy-gauge screwed conduit. Lead-covered cable may be used if properly protected.

Bonding Conduit.

For all pressures over 250 volts (medium pressure), all circuits must be enclosed in metal casing for the whole of their length, and therefore connections to fuse-boards, starters, and motors must not be made by bare VIR cable entering the terminal entries, but the conduit or other metal covering must be mechanically connected to the cases of the starters or motors.

Flexible Metallic Tubing Connections.

Connections to motors mounted on slide-rails should be made by means of flexible metallic tubing and suitable adaptors.

It is better to use the watertight quality of flexible tubing, as it will stand up to hard wear and tear in exposed positions and pays in the long run, although it costs about fifty per cent. more than the ordinary kind. Where appearance is important polished brass adaptors should be used, otherwise the cast brass or malleable iron type is quite as efficient and much cheaper.

The flexible tubing must not be relied upon for earthing the motor; a copper earth wire of ample capacity, with a substantial earth clip and sweating sockets, should be provided so as to effect a reliable earth connection between the conduit system and the frame of the motor.

Earthing the Motors.

Unfortunately, most motor makers do not provide a suitable means for earthing their motors, and it is usually left for the earth wire to be connected to the holding down-bolt or terminal box cover screw. This

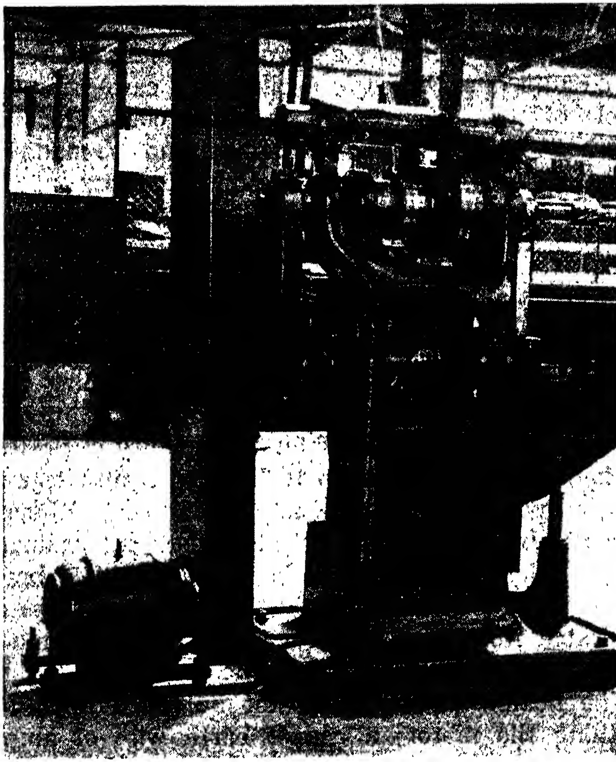


FIG. 62.—3-CORE ARMOURED CABLE FEEDING PUSH-BUTTON STARTER AND 2-H.P. MOTOR.

Note that cable crosses floor in tubing and is impervious to water and oil, and will withstand rough usage.

(*Dubilier Condenser Co., Ltd.*)

method is very unsatisfactory, as it is not always possible to obtain a reliable electrical contact by this method. Furthermore, there is every likelihood of the holding-down bolt becoming loosened or the terminal box cover screw removed at some future time and the earth wire not properly replaced.

It is therefore always best to drill and tap the side of the terminal box or the base of the motor and fit a brass stud and sweating socket.

Starter makers almost invariably fit earthing studs to the cases of their starters, but usually these are not necessary as the conduit forms a reliable earth connection where it enters the case of the starter.

Connections to Slip-ring Motor.

When installing slip-ring motors always make sure of the rotor current of the motor before running the conduit for the rotor cables, as some of these motors are wound with a low-voltage rotor with a resultant high-rotor current. The rotor current of a motor may be as much as four times the line current. If this detail is not given on the name-plate, the makers should be consulted.

Always keep the rotor cables on the large size if the motor is not fitted with brush-lifting and short-circuiting gear. If the starter is a long distance from the motor it controls, special care must be taken to avoid voltage drop in these cables, as this might appreciably affect the speed of the motor. The resistance of a low-voltage rotor is fairly low, and even a low external resistance will materially restrict the current in that circuit. Many mysterious cases of a slip-ring motor running at under its rated speed have been traced to this cause.

When the control of a slip-ring motor *must* be from a distance it is always best to provide an automatic starter fitted as near to the motor as possible, with

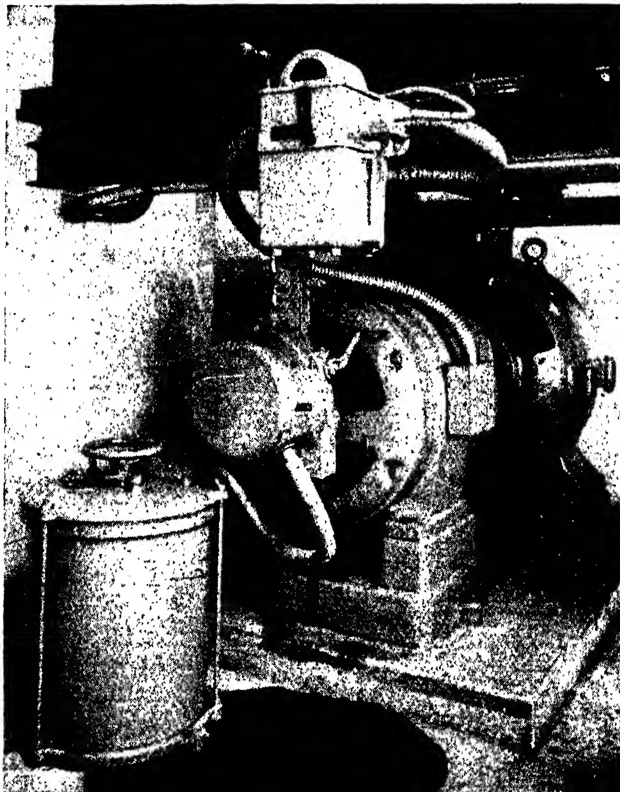


FIG. 63.—MOTOR-GENERATOR SET, SHOWING FLEXIBLE TUBING CONNECTIONS TO CONTROL GEAR.

The stator circuit-breaker is at the top and the rotor starter on the floor.

(Dubilier Condenser Co., Ltd.)

push-button control from any desired position. Local "start" and "stop" push-buttons should also be fitted on the starter, and this affords ample protection in cases of emergency.

Conduit Runs.

It is best to run a separate conduit from the distribution board to each motor Avoid bunching circuits if possible

Cables carrying AC currents must always be arranged

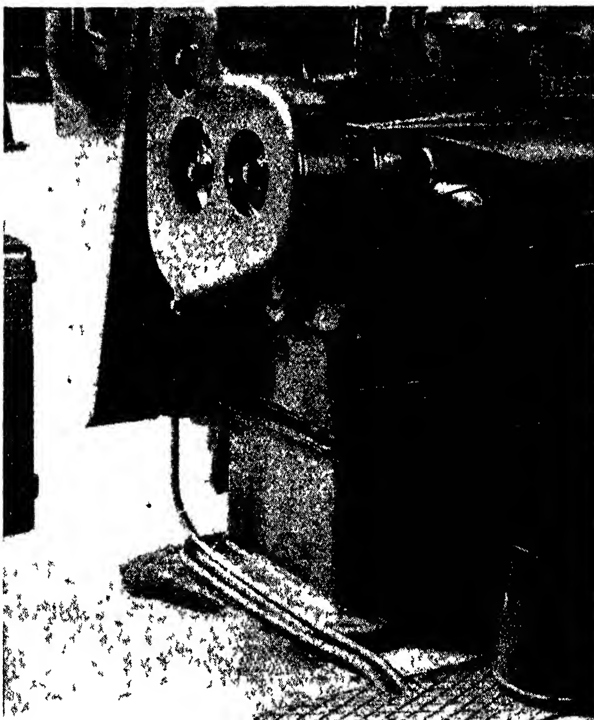


FIG 64—3 CORE ARMOURED CABLES USED FOR STATOR AND ROTOR LEADS TO MOTOR

The cable is run in a duct under the floor Note that conduit run in the above position would not be so satisfactory

(*Dubilier Condenser Co, Ltd*)

so that the outgoing and return cables are in one conduit, otherwise the induced currents which will be set up will have a far-reaching effect on the efficiency of the circuit, and where heavy currents are flowing will cause the conduit to heat up and cause serious damage.

Conduit runs from the starter to the motor often present a difficulty, as in many cases it means running down a wall, across a floor, and then up to the terminal box of the motor.

This is never very satisfactory, as there is always the possibility of condensation collecting in the trap formed by the conduit. If this is unavoidable always drill a small hole in the under side of the conduit at the lowest point to allow any moisture to drain away.

One method, which is sometimes preferable, is to run the conduit overhead. This is not perhaps so neat but it is certainly more serviceable.

Use of Armoured Multicore Cable.

Some cable makers supply a small lead-covered, armoured, and served multicore cable as small as 3.029; this can be run in a duct under the floor and is impervious to all water, oil, and rough usage. It can be connected to the starter and motor terminal box by means of a neat sealing gland, and once installed will last almost indefinitely.

It is not much more expensive than screwed conduit, and is certainly worth the slight extra cost.

Mounting for Motors which Saves Space.

If possible it is best to mount the motors on an iron framework about six feet from the ground, and

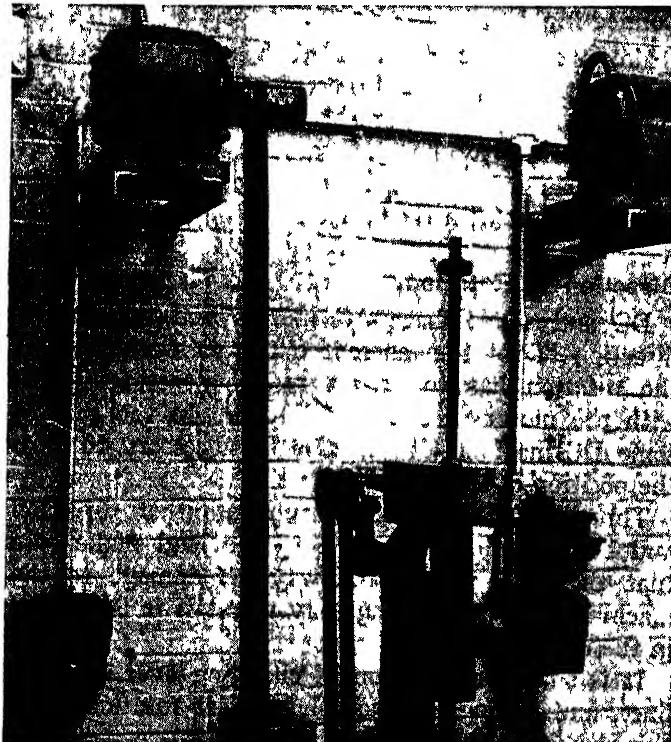


Fig. 65—Small Motors Mounted on Wall to Conserve Floor Space

Starters are mounted underneath This arrangement also keeps motors away from any water, oil, etc, which may collect on floor

(Dubilier Condenser Co Ltd)

the starters underneath This conserves floor space and also keeps the motors away from water, oil, and other injurious matter which generally collects on the floor, and may be drawn into the motor by the fan.

Connecting Up.

Motors are generally provided with wiring diagrams, and connecting up should present no difficulty. If the motor and starter are purchased from different sources a little care may be necessary, as the diagram of connections provided with the motor may not coincide with that sent with the starter.

Direction of Rotation.

DC and single-phase AC motors will run in the direction of rotation as sent out from works, but if the rotation has to be reversed instructions given with the motor should be followed. In the case of some DC machines it will also be necessary to alter the position of the brush rockers.

Three-phase motors may run in either direction and before connecting these to the load make sure that they run the correct way, as damage to the machine they are driving may result if it is rotated in the reverse direction.

It is simply a question of changing over any two lines, and having obtained the correct rotation mark this clearly on the motor.

If you have to change the direction of rotation of a three-phase squirrel-cage motor, make sure and change over two phases at the isolating switch, or at the line terminals of the starter. On no account change over wires between the motor and the starter or you may get two halves of any phase winding opposing one another, and unless you are prepared to trace the connections out afresh you may have considerable difficulty in getting the wires back in the correct positions again.

Testing.

Having got the motor running it should be tested under its normal load, and an ammeter should be inserted in series with one phase to see what current it is taking.

A record should be made of this reading, and also of the insulation resistance of the cables and the motor windings.

These records will be valuable, as periodical tests can be taken from time to time and any variations in the readings obtained may give an indication of trouble developing which can be investigated before a breakdown occurs.

AC motors are not very efficient, and have a low power factor unless they are well loaded, and ammeter tests will assist in distributing the various loads on to the motors which will best take them, and also avoid overloading.

Power Factor.

If the cost of electric current is based upon the power factor of the installation, steps should be taken to test this, and if necessary, condensers be installed to bring this up as near to unity as possible.

Reputable condenser manufacturers will be pleased to make tests and advise whether it will pay to install condensers, and if so what saving can be effected. In many cases the capital cost of the condensers can be saved within twelve months, which shows a very high return on capital invested in this way.

Temperature Rise.

Tests of temperature rise of bearings and windings should be taken. Temperature rise which originates at one of the bearings may indicate lack of lubrication, foreign matter in the bearing, too much belt tension, or that the machine is out of alignment.

Temperature rise which originates from the windings need give no concern providing it is not excessive. If a motor is fully loaded there should be some temperature rise when the carcass is felt with the hand, and it should be borne in mind that B.S.S. No. 168 permits a rise of forty degrees C. for open-type machines.

If there is no temperature rise in the windings of a machine it can generally be assumed that it is underloaded.

Finally, much may depend upon the manner in which the work is carried out. A loose connection might have the effect of shutting down a whole factory. Unless it is unavoidable, never make a temporary job with the idea of completing it later on when you have more time, as the chances are that you will never find time until a breakdown occurs

CHAPTER VI

POWER FACTOR IMPROVEMENT

What is Power Factor?

THE simplest and most practical definition of power factor is "the proportion of the current in an electrical circuit doing useful work." From the purely academic viewpoint this may not be strictly correct, in as much as heating and windage losses in motors for example cannot be considered as "useful work." Such losses are, however, registered as kilowatt-hours on the supply meters, which are the best judges of what is and what is not "useful work" in the electrical sense.

For example, if in a circuit having a power factor of 0.5 the current is ten amps. at a voltage of 250, the watts output of the circuit, as registered on the watt-hour meters, is not 2.5 kW, but 0.5 × 2.5, or 1.25 kW. That is to say, only five amps. of the current are doing useful work.

What is happening to the other five amps.? They are definitely present, since the ammeter records them, and in addition, should the cable carrying the load be designed for five amps. only, it will get hot.

Let us, then, examine the nature of the load.

The first thing that we notice is that only apparatus incorporating electro-magnets show a low power factor. When the load consists of lamps, radiators, or other appliances without electro-magnets. then all the current does useful work. In other words, the power factor is unity.

The second thing that we notice is that with DC supplies the power factor is always unity, regardless of whether the load comprises electro-magnets or not.

Cause of Poor Power Factor.

Poor power factor, then, is a phenomenon relating solely to electro-magnetic appliances on AC supplies

When you switch the current on to an electro-magnet there is a slight delay before the current reaches its peak value, during which period the iron core becomes magnetised. When the current is switched off there is another short period, during which a current is

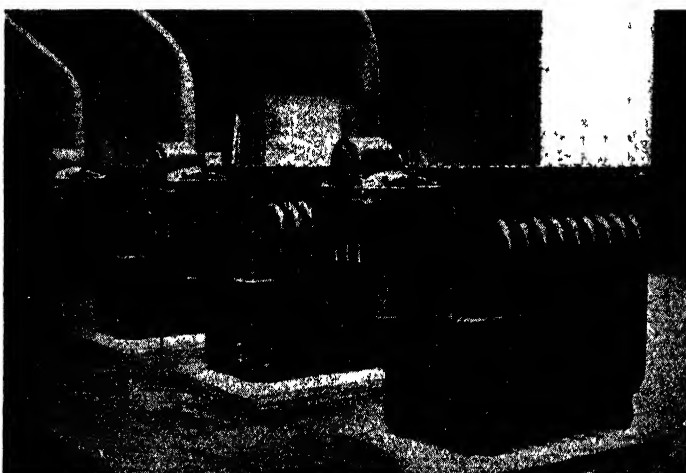


FIG 66 —INDUSTRIAL CONDENSER INSTALLATION

Three 175 kVAr, 500v, 3-phase, 50-cycle condensers, complete with controlling oil circuit-breakers mounted on the ends of the tanks

(Johnston & Phillips, Ltd)

"induced" in the windings by the core as it becomes demagnetised.

In a DC circuit this happens only at the moment of switching on and switching off, the energy stored in the iron being dissipated in the comparatively destructive inductive spark at the switch contacts as they part, but in an AC circuit, where the current is reversed several times a second, it happens each time, the generator supplying the magnetising current during the first half of each cycle and the demagnetising iron core pumping the current back through the generator during the succeeding half-cycle.

Therefore, in addition to the current doing useful work, there is a see-saw flow of current doing nothing but magnetising the iron cores of the motors and generators in turn and which is always lagging behind the current doing the useful work.

Since this is really the same small amount of electrical energy see-sawing backwards and forwards it imposes no load on the machine driving the generator, but the current nevertheless has the effect of heating up the conducting cables. This loss has to be made up by the generator, but it is small compared to the magnetising current itself.

It is this current that is so frequently referred to as "wattless" current, and it cannot be truly wattless, in that it does heat up the cables, but the name is derived from the fact that at one point in each cycle a current is flowing that has no potential behind it, and a current with no volts can be said to have no watts. In actual fact, however, the voltage that is responsible for the flow of magnetising current is the voltage of self-induction across the electro-magnet, and this is in step with the magnetising current and lags behind the supply voltage by exactly the same amount and in the same way as does the magnetising current behind the useful current.

How to measure Power Factor.

The power factor of a circuit can be determined by dividing the actual kilowatts, as measured by a wattmeter or calculated from efficiency figures, by the product of the supply voltage and current in kVA.

With regard to the term kVA, we know that the product of volts and amperes in a circuit is watts, but in an AC circuit we apparently have two distinct lots of watts in the one circuit, one doing useful work and the equivalent wattage of the magnetising current. In order to prevent confusion it has become the custom to refer to the useful load as watts or kilowatts and the total load including the magnetising current as volt-amperes or kilovolt amperes (kVA).

In any circuit it will be found that the square of the total kVA will be equal to the sum of the squares of the "useful" kilowatts and the "magnetising" kilowatts.

To determine the kilowatt load of the circuit use either an indicating wattmeter or time a number of revolutions of a kilowatt-hour meter, which is usually installed by the supply company, and calculate the kilowatts from the equation—

$$kW = \frac{3\,600 \times n}{t \times k}$$

where n = the number of revolutions timed, t = the duration of the test in seconds, k = the meter constant in revolutions per kilowatt-hour as engraved on the nameplate, and kW = the test load in kilowatts.

To determine the kVA, measure the current in each phase with an ammeter—a "tong" instrument is very convenient for this purpose—and apply the necessary equation as follows:—

(1) For single-phase, kVA = volts × amperes/1000.
(2) For two-phase circuits, kVA = volts × amperes × 2/1000.
(3) For three-phase balanced circuits, kVA = volts × amperes × 1.73/1000.
(4) For two-phase unbalanced circuits, kVA = the sum of volts × amperes in each phase/1000.
(5) For three-phase unbalanced circuits, kVA = the sum of line/neutral volts × amperes in each phase.

Except where otherwise stated, the voltage referred to is the voltage between phases.

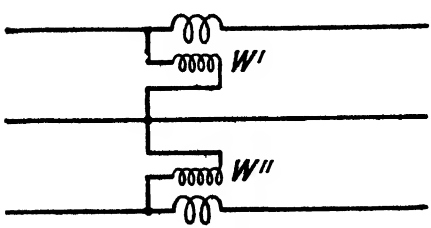


FIG. 67. TWO-WATTMETER METHOD OF MEASURING POWER IN THREE-PHASE CIRCUIT. Diagram of connections.

Alternatively, the power factor can be determined from the two readings of wattmeters connected as in Fig. 67, the necessary equation being—

$$PFI = 1.732 \times \frac{W' - W''}{W' + W''}$$

where PFI = the power-factor indicator and W′ and W″ are the wattmeter readings. The power-factor indicators and their equivalent power factors are

TABLE IV.—TWO-WATTMETER METHOD OF MEASURING POWER FACTOR

Table of Power-Factor Indicators and their Equivalent Power Factors

Power Factor Indicator.	*Equivalent Power Factor.*	*Power Factor Indicator.*	*Equivalent Power Factor*
0·1441	0·99	0·9110	0·74
0·2035	0·98	0·9363	0·73
0·2512	0·97	0·9640	0·72
0·2892	0·96	0·9919	0·71
0·3288	0·95	1·0200	0·70
0·3630	0·94	1·0489	0·69
0·3952	0·93	1·0780	0·68
0·4279	0·92	1·1080	0·67
0·4557	0·91	1·1133	0·66
0·4841	0·90	1·1695	0·65
0·5146	0·89	1·2002	0·64
0·5395	0·88	1·2327	0·63
0·5670	0·87	1·2654	0·62
0·5934	0·86	1·2985	0·61
0·6200	0·85	1·3333	0·60
0·6461	0·84	1·3679	0·59
0·6720	0·83	1·4045	0·58
0·6937	0·82	1·4415	0·57
0·7239	0·81	1·4788	0·56
0·7499	0·80	1·5158	0·55
0·7762	0·79	1·5587	0·54
0·8021	0·78	1·6003	0·53
0·8283	0·77	1·6426	0·52
0·8551	0·76	1·6867	0·51
0·8816	0·75	1·7321	0·50

given in Table IV, the indicators being merely the tangents of the angle of lag of the current behind the supply voltage. The cosine of this angle is, of course, equivalent to the power factor.

This method is suitable only for balanced three-phase loads.

Improvement of Power Factor with Condensers.

There are several ways in which the power factor of a circuit may be improved or corrected. By correction is meant the process of bypassing the magnetising current as near to the appliance with the low power factor as possible, so as to relieve the cables and generating plant, while by improvement is meant the reduction of the magnetising current by bypassing a portion of it in a similar way. The most usual method of improving the power factor is by means of condensers.

The effect of connecting a condenser to the line is to add to the load an appliance having a leading power factor. That is to say, in a condenser, when the current is switched on, the first rush of current rises to a considerable value, the equivalent resistance of an uncharged condenser being zero. As the condenser becomes charged the current drops, until it ceases to flow when the condenser is fully charged. Then, as the voltage across the condenser falls off with a decrease in the applied voltage, the condenser discharges back into the mains, the cycle being exactly the opposite to that in an electro-magnet.

Calculating the Size of a Condenser.

To correct the power factor of a given load a condenser having a reactive kVA capacity equal to the kVA of magnetisation will be required. Table V gives data for calculating the size of condenser for a required correction. This Table is also compiled for improvement, the kilowatt load in this case being multiplied by the factor under the heading corresponding to the required final power factor. If a different final power factor is required, then the factor is obtained from the difference between the factors in the last column corresponding to the initial and required power factors.

For example, the factor for improvement from 0.50 to 0.96 would be 1.732 − 0.292, or 1.44. The reactive capacity of a condenser for this degree of correction with a load of 60 kW would therefore be 60 × 1.44, or 86.4 kVA.

For a motor, the horse-power, efficiency, and initial power factor of which are known, the reactive capacity can be calculated from the formula—

$$kVA = \frac{HP \times 0.746 \times k}{\mu}$$

where kVA = the reactive capacity of the condenser
HP = the full load of the motor in horse-power
k = the constant from the Table
and μ = the efficiency of the motor

It is a characteristic of the majority of motors that at a power factor of 0.96 or thereabouts the power factor remains constant at all loads, whereas at other power factors it varies with the load. It is therefore general to improve the power factor of all motors to this figure for best results: k should therefore be taken from the 0.96 column.

The relationship between condenser capacity in microfarads and reactive capacity is given by the equation—

$$kVA = \frac{E^2 \times 2 \times 3.1416 \times f \times C}{1,000,000,000}$$

TABLE V.—CALCULATING SIZES OF CONDENSERS FOR GIVEN DEGREE OF POWER-FACTOR CORRECTION

Initial Power Factor	*Correction to*				
	0·85	0·90	0·95	0·98	*Unity*
0·40	1·668	1·805	1·959	2·085	2·288
0·41	1·605	1·742	1·896	2·021	2·225
0·42	1·544	1·681	1·836	1·961	2·164
0·43	1·487	1·624	1·778	1·903	2·107
0·44	1·421	1·558	1·712	1·837	2·041
0·45	1·360	1·501	1·659	1·784	1·988
0·46	1·309	1·446	1·600	1·725	1·929
0·47	1·260	1·397	1·532	1·677	1·881
0·48	1·206	1·343	1·497	1·623	1·826
0·49	1·160	1·297	1·453	1·578	1·782
0·50	1·112	1·248	1·403	1·529	1·732
0·51	1·066	1·202	1·357	1·483	1·686
0·52	1·024	1·160	1·315	1·441	1·644
0·53	0·980	1·116	1·271	1·397	1·600
0·54	0·939	1·075	1·230	1·356	1·559
0·55	0·899	1·035	1·190	1·316	1·519
0·56	0·860	0·996	1·151	1·277	1·480
0·57	0·822	0·958	1·113	1·239	1·442
0·58	0·785	0·921	1·076	1·202	1·405
0·59	0·748	0·884	1·039	1·165	1·368
0·60	0·714	0·849	1·005	1·131	1·334
0·61	0·679	0·815	0·970	1·096	1·299
0·62	0·645	0·781	0·936	1·062	1·265
0·63	0·613	0·749	0·904	1·030	1·233
0·64	0·580	0·716	0·871	0·997	1·200
0·65	0·549	0·685	0·840	0·966	1·169
0.66	0·518	0·654	0·809	0·935	1·138
0.67	0·488	0·624	0·779	0·905	1·108
0.68	0·459	0·595	0·750	0·876	1·079
0.69	0·429	0·565	0·720	0·840	1·049
0·70	0·400	0·536	0·691	0·811	1·020
0·71	0·372	0·508	0·663	0·783	0·992
0·72	0·343	0·479	0·634	0·754	0·963
0·73	0·316	0·452	0·607	0·727	0·936
0·74	0·289	0·425	0·580	0·700	0·909
0·75	0·262	0·398	0·553	0·673	0·882
0·76	0·235	0·371	0·526	0·652	0·855

TABLE V.—*continued.*

Initial Power Factor	*Correction to*				
	0·85	0·90	0.95	0·98	*Unity*
0·77	0·209	0·345	0·500	0·620	0·829
0·78	0·183	0·319	0·474	0·594	0·803
0·79	0·156	0·292	0·447	0·567	0·776
0·80	0·130	0·266	0·421	0·541	0·750
0·81	0·104	0·240	0·395	0·515	0·724
0·82	0·078	0·214	0·369	0·489	0·698
0·83	0·052	0·188	0·343	0·463	0·672
0·84	0·026	0·162	0·317	0·437	0·645
0·85	—	0·136	0·291	0·417	0·620
0·86	—	0·109	0·264	0·390	0·593
0·87	—	0·083	0·238	0·364	0·567
0·88	—	0·054	0·209	0·335	0·538
0·89	—	0·028	0·183	0·309	0·512
0·90	—	—	0·155	0·281	0·484
0·91	—	—	0·124	0·250	0·453
0·92	—	—	0·097	0·223	0·426
0·93	—	—	0·066	0·192	0·395
0·94	—	—	0·031	0·160	0·363
0·95	—	—	—	0·126	0·329
0·96	—	—	—	0·089	0·292
0·97	—	—	—	0·047	0·250
0·98	—	—	—	—	0·203
0·99	—	—	—	—	0·143

where kVA = the reactive capacity of the condenser
E = the applied voltage
f = the frequency
and C = the capacity in microfarads

This can, however, be simplified by remembering that a 400-volt, 20-mfd. condenser has a reactive capacity of 1 kVA at 50 cycles, the standard frequency in this country, using the information to place correctly the decimal point when applying the formula—

$$kVA = \frac{C \times E^2}{32}$$

Other Types of P.F. Correction Apparatus.

It frequently happens that by using special types of motors, which give a leading power factor, one piece of apparatus can be made to perform two functions—namely, providing motive power for a portion of the works or factory, and at the same time, providing a leading current which serves to maintain the overall power factor of the installation at a figure close to unity. Among these special types of motors are: synchronous and synchronous induction motors, compensated induction-commutator motors.

INSTALLATION OF POWER FACTOR CONDENSERS.

Installations on the Main Supply.

Let us first consider the question of installing a condenser as a line unit across the main supply from an outside source such as the supply company or authorised distributor of electrical energy. It is assumed that the installation of the condenser is for the purpose of effecting a reduction in the M.D., either to lower the annual charges for M.D. kVA or to earn discounts for prescribed minimum power factor in accordance with the conditions of supply.

It is essential that all such line condensers should be fitted with controlling switchgear and protective apparatus and, since such switchgear will in all probability need fairly frequent inspection and possible replacement of sparking tips, the switchgear should be connected to the busbars on the consumer's side of the main switch which thus acts as an isolator for such purposes of inspection. If such a procedure is impossible or inadvisable, then suitable isolating gear should be provided in addition to the switchgear.

For condensers of not more than thirty amps. line current, air break ironclad switch-fuses of not less than sixty amps. capacity may be fitted, provided that such

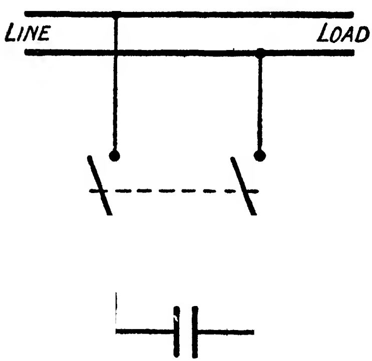


FIG. 67A.—SINGLE-PHASE LINE CONDENSER AND SWITCH.

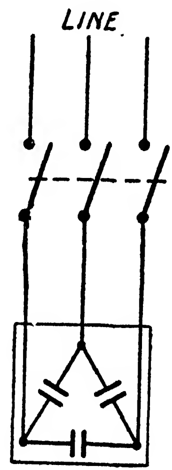


FIG. 67B. THREE-PHASE LINE CONDENSER AND SWITCH.

switchgear is of the quick make and break type and of reputable and rugged construction. Condensers above thirty amps. per phase line current should always be controlled by well designed oil circuit-breakers fitted with overload release trips and time-lags.

All air break switches should be mounted in the vertical position for which they were designed or trouble will eventually be experienced due to the arc set up on breaking circuit not travelling away from the blades as intended but actually "hanging" on to the blades causing burning and pitting.

Oil Circuit-Breakers for Condensers.

Oil circuit-breakers, when used in connection with condensers, must be of special design or operation will in the long run be detrimental to the circuit-breaker and condenser alike. The points to watch for are (*a*) liberally rated sparking tips and main contacts, (*b*) complete freedom from contact bounce on making contact, and (*c*) good even pressure along the contact faces.

When the breaker has been installed and before the main switch is closed, the breaker should be closed and the alignment of the contacts be tested with a feeler gauge. It will occasionally be found that the contacts are not seating properly and adjustments will have to be made.

If, subsequently, the switch tends to get warm to the touch, it should be immediately examined for this fault and, if this is in order, the connections to the switch terminals should be closely inspected. Loose terminals have been the cause of the almost total destruction of more than one excellent circuit-breaker. It is hardly necessary to add that the cables must be of adequate cross section and the following V.I R. and P.I.L.C. cable current capacity tables may be useful in this respect.

TABLE VI.—CURRENT CARRYING CAPACITY OF CABLES

Stranding.	*Area. ins.*	*Current rating subject to stranding.*	
		V.I.R. Cables.	*P.I.L.C. Cables.*
		amps.	
3/·029	0·002	7·8	—
3/·036	0·003	12	—
7/·029	0·0045	18·2	—
7/·036	0·007	24	22
7/·044	0·010	31	34
7/·052	0·0145	37	46
7/·064	0·0225	46	60
19/·044	0·03	53	70
19/·052	0·04	64	83
19/·064	0·06	83	108
19/·072	0·075	97	126
19/·083	0·100	118	153
37/·064	0·12	130	168
37/·072	0·15	152	197
37/·083	0·20	184	237
37/·093	0·25	214	274
37/·103	0·30	240	308

NOTE.—The above figures apply to three-core cables.

Line Condensers.

From the point of view of economy in first cost line condensers seem to be particularly favourable but there are limitations that must be considered. If the line condenser is of exceptionally large capacity, it may cause the supply company untold trouble if left on the line when the plant is shut down, and will certainly cost them a large amount in I^2R losses in the supply mains.

If the supply to the plant is through a transformer, then excessive capacity under light load conditions may seriously impair voltage regulation and will, in all probability, cause high voltages which will shorten the life of voltage-sensitive apparatus—such as metal filament lamps, etc.—which happens to be on at the same time. It is therefore good practice to switch off line condensers of any great size when the associated plant is shut down, but it is also wise to take precautions to avoid the possibility of the plant being started up without the condenser in circuit. A suitable method is shown in Fig. 68. When installing line condensers, then, it is always advisable to ask the supply company if the reactive capacity which it is

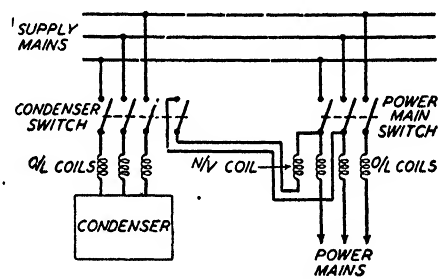


Fig. 68. Three-phase Line Condenser and Interlock with Power Main Switch.

proposed to install will have any undesirable effect on their mains if left on load without the associated plant.

Installations on Private Generating Plant.

The installation of condensers on apparatus fed from a private generating plant will not result in any monetary saving in fuel but it may, nevertheless, be necessary in order to permit the plant to be used to its full kilowatt capacity if the load is much below the prescribed power factor for which the alternator was designed. It is, perhaps, not necessary to point out that if the full kilowatt load be applied to the alternator with a power factor lower than that inscribed on the nameplate, then overheating of the alternator windings will result with detrimental effect.

On the other hand, assuming that the alternator and prime mover have a reasonable overload capacity, although this capacity is only intended as an intermittent one, by improving the power factor to a point well above that prescribed it is possible to run the plant continuously on overload without detriment, providing that the current taken from the alternator is not in excess of that on the nameplate.

If the power factor of the load is exceptionally low—such as would be the case with welding equipment—it may be necessary to install a condenser having a total reactive capacity in excess of that of the alternator. Under these conditions very great care must be taken as the result of overloading the alternator with leading reactive capacity on light kilowatt load conditions will inevitably result in the development of a high output voltage which may damage the condenser irreparably.

It is not easy to give a general rule as to the size of a condenser that may be connected across a lightly loaded alternator without excessive interference to the voltage regulation since so much depends upon the actual design of the alternator but, generally speaking, it is inadvisable to allow a condenser having a reactive capacity in excess of twenty per cent. of the rated kVA output of the alternator across the line under no load conditions.

Condensers Across Motor Terminals.

By far the best method of installing condensers is

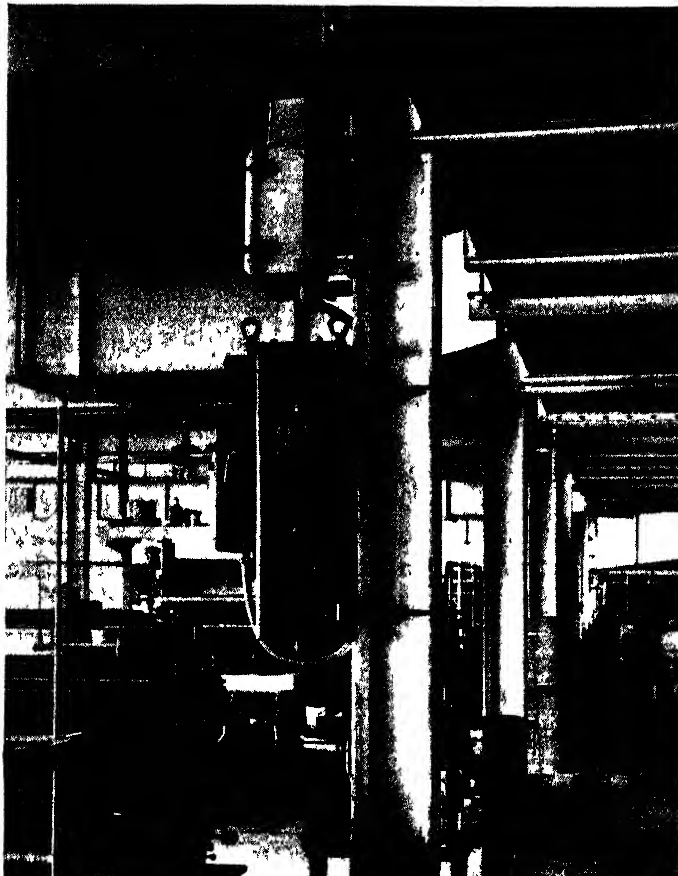


FIG 69—POWER FACTOR CONDENSER CONNECTED ACROSS DISTRIBUTION BOARD

No floor space is occupied (*British Insulated Cables, Ltd*)

to connect small units of the required reactive capacity directly across the terminals of each motor or appliance contributing to the low power factor, since the total capacity on the line becomes automatically regulated as the plant goes into or comes out of commission. The disadvantage of this method obviously lies in the fact that the total reactive capacity must be in excess of that which would be connected as a line condenser, since no account of diversity is taken.

A compromise is often reached by installing condensers across those motors which are most generally in full use, leaving the lesser used motors uncorrected and dependent upon the diversity for their share of the condenser current. This compromise can also be taken a stage further by increasing the capacity of the units on the largest motors to take care of the magnetisation current of some of the smaller motors even though the latter are fairly constantly in use, since the prime cost of a single high capacity condenser is naturally somewhat lower than that of two separate units of equivalent capacity, particularly if the size of the smaller condenser is only one or two kVA.

Single-Phase Motors.

Single-phase motors are generally of the "split-phase," "capacitor start-induction running" or plain "capacitor" type. In the latter two types a single phase condenser is used in series with one of the two windings in order to give the necessary phase displacement, the only difference being that in the capacitor start type the condenser winding is only in circuit during the run up to speed afterwards being cut out by a centrifugal switch. Sometimes the condenser unit is automatically connected across the running winding to serve the purpose of power factor correction in addition to acting as part of the starting winding.

Capacitor motors in their modern form have the condenser in series with the second winding and in circuit as long as the motor is running. Since the size of this condenser is chosen to give the required starting torque it is quite possible that the overall power factor of the motor may require further correction to conform to the desired standard for the factory. Split-phase motors obtain the phase displacement by adjusting the respective resistance and impedance of the two windings so that there is a reasonable phase displacement between them, which

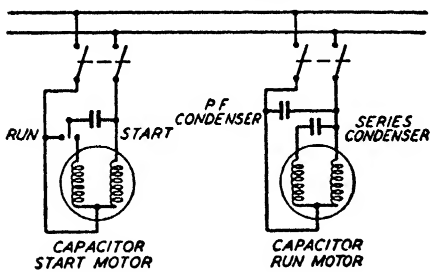


FIG. 70.
SINGLE-PHASE
MOTOR CONDENSER
CONNECTIONS.

can be used to produce a rotating field necessary for the starting of A.C. motors.

The starting torque of these motors is usually rather poor and the power factor is also generally low, so condensers will almost invariably be found to be necessary for single-phase motor installations of this type.

Connections for single-phase motor condensers are given in Fig. 70.

Two-Phase Motors.

There are still one or two undertakings where two-phase supply is still in use so diagrams of connections for two-phase motor-connected and line-connected condensers are given in Figs. 71 and 72.

Three-Phase Motors.

There are a variety of types of three-phase motors ranging from the simple squirrel cage motors, to the rather complicated but extremely efficient high power factor motors with self-contained phase advancing

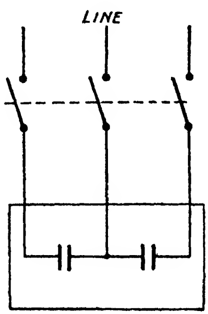
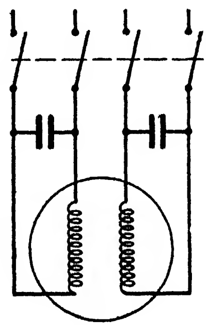


FIG. 71 (*left*).—TWO-PHASE THREE-WIRE LINE CONDENSER.

FIG. 72 (*right*).—TWO-PHASE FOUR-WIRE MOTOR CONDENSER.



equipment. These latter, needless to say, do not require condensers but connection diagrams for squirrel cage motors and slip-ring motors are given in Figs. 73–76. It should be noted that condensers are never connected across the rotor terminals of slip-ring motors but always across the stator windings.

When dealing with exceptionally large motors it is sometimes found that the controlling switchgear of the motor is in itself of insufficient capacity to stand the charging current of the condenser and the initial surge of the motor, since the former may be two or three times the latter in magnitude. Under these circumstances it is advisable to control the condenser

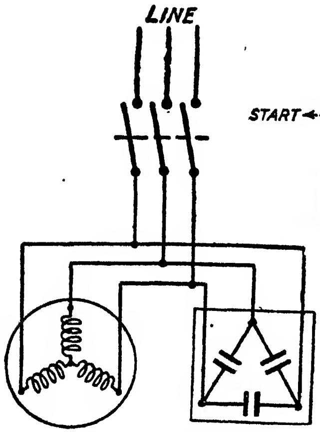


FIG. 73.—DIRECT-START THREE-PHASE MOTOR.

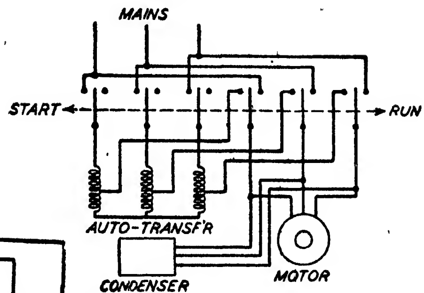


FIG. 75.—AUTO-TRANSFORMER START THREE-PHASE MOTOR.

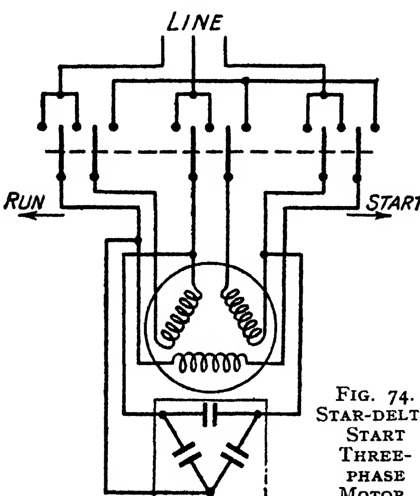


FIG. 74. STAR-DELTA START THREE-PHASE MOTOR.

by means of a separate switch electrically interlocked with the starting switch of the motor as shown in Fig. 77.

Auto-transformer Condensers.

Where motors are started up by auto-transformers the same conditions may apply in relation to condensers connected across the motor terminals but since the transformers are

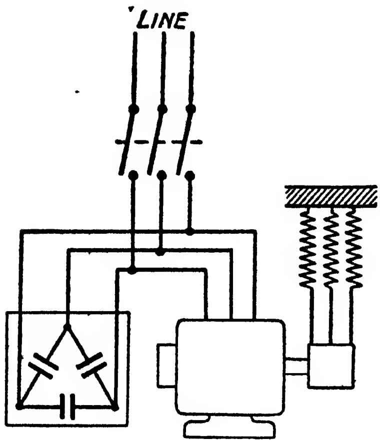


FIG. 76.—SLIP-RING THREE-PHASE MOTOR.

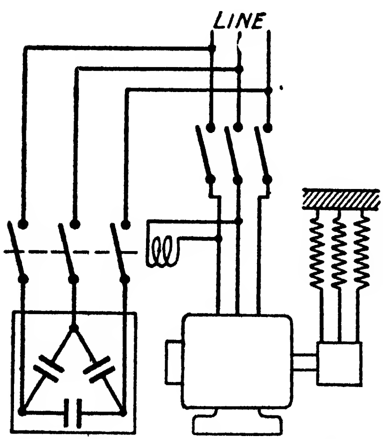


FIG. 77.—SLIP-RING THREE-PHASE MOTOR WITH SEPARATE CONDENSER SWITCH.

only in circuit for a very short time the risk is comparatively slight. Nevertheless, if the necessary reactive capacity is high, due to exceptional conditions, it is as well to arrange the condenser so that it does not come into circuit until after the transformer is disconnected from the motor circuit. Connection diagrams are shown in Figs. 79 and 80.

Automatic Condenser Banks.

Conditions occasionally arise where it is not possible to install motor-connected condensers and the risk of excessive line capacity must be avoided at all costs. Under these circumstances an automatic condenser bank is the

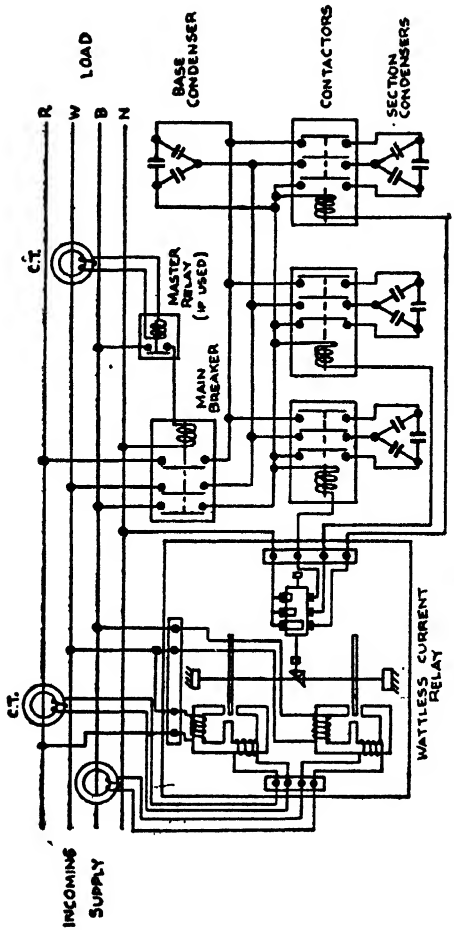


FIG. 78.—SCHEMATIC DIAGRAM OF AUTOMATIC POWER FACTOR CONDENSER APPARATUS.
(Dubilier Condenser Co., Ltd.)

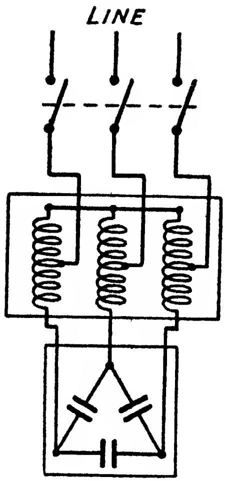


FIG. 79.—THREE-PHASE AUTO-TRANSFORMER LINE CONDENSER.

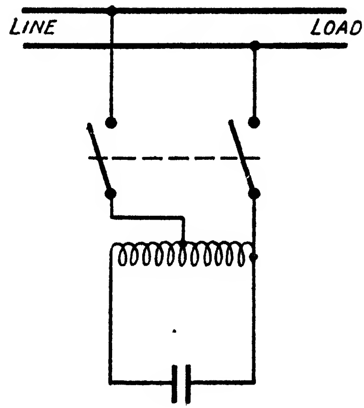


FIG. 80.—SINGLE-PHASE AUTO-TRANSFORMER LINE CONDENSER.

only alternative to the rotary equipment. Automatic condenser banks comprise a condenser split up into a number of sections each controlled by a suitable oil-immersed contactor which are in turn operated by a special relay which limits the reactive current—whether leading or lagging—to a predetermined value by adjusting the proportion of the bank in circuit.

The connections of such an equipment are shown in Fig. 79 the relay and contactors being represented by simple rectangular outlines for the sake of clarity.

Welding Equipment and Discharge Lamps.

A.C. welding equipment and gaseous discharge lamps all have a poor power factor partly on account of the chokes and transformers which are a necessary part of the apparatus, and partly on account of what is known as the form factor of the appliance.

It will be appreciated that wherever the circuit is in the form of an electric arc there is a minimum voltage at which the arc will strike and also another voltage, slightly below the striking voltage which is the minimum to maintain the arc. Since in an A.C. circuit the voltage varies between zero and a maximum several times a second, it can be seen that for that portion at the beginning of each cycle until the voltage rises to the striking voltage of the arc, no current flows and it ceases as soon as the voltage falls below the maintaining voltage.

Since current does not flow continuously in a sinusoidal manner, it follows that the R.M.S. value of the equivalent sinusoidal wave form of the actual current is less than the R.M.S. value of a sinusoidal current and the relationship of these two values is referred to as the form factor. This represents the maximum value to which the power factor can be corrected. It will be appreciated that since the striking and maintaining voltages are constant for a given set of electrodes or a given gas vapour, the higher the supply voltage the better will be the form factor. Thus gaseous discharge lamps on the higher voltages can be improved to about 0.95 while only 0.85 to 0.9 can be attained with lower service voltages. For welding sets it is rarely possible to better 0.8 power factor while the essentially poor regulation of the transformers for the conditions of the particular job is responsible for the exceptionally low initial power factor over the whole equipment—often as low as 0.35.

CHAPTER VII

FOUNDATIONS FOR ELECTRICAL MACHINES

ONE of the chief merits of the electrical machine is its adaptability to circumstances. To some degree this is the result of its even torque and the comparative absence of vibration. It is therefore often quite a simple matter to provide a suitable foundation for a motor or for a direct-coupled set such as a motor-generator.

A small set on its own bedplate often requires no more foundations than an ordinary floor, reasonably level and flat, on which it can be laid either directly or on cushioning material such as felt, cocoa-matting, etc. But it must be remembered that in many cases the electrical machine is only a small part of some more complex structure, its function being to drive or to be driven by some other part. It frequently happens that the nature of this other part, or of the connecting drive, greatly alters the type of foundation required.

A few examples may help to make this clear: in the case of an electric motor driving line-shafting or of a generator driven by belting, there is a pull on the foundation due to the tension of the belt and this pull must be allowed for in the design of a suitable foundation; also in the case of an electrically-driven ram-pump, loads and vibrations are set up by the pump similar to those of a slow speed horizontal steam engine and these loads and vibrations must be respectively counteracted and "damped out" by the foundation. Thus it will be appreciated that in very few cases is the design of a suitable foundation a simple matter.

The Purpose of Machine Foundations.

Some or all of the following requirements must be fulfilled by a foundation:

1. A foundation is required to maintain the machinery fast in position and level, with all parts in true alignment. In very small machines the bed or base plate may be relied on to ensure this.
2. A foundation is required to transmit the dead weight of the machine to the ground or other supporting medium, in such a manner that the safe bearing pressure of the ground or supporting medium is not exceeded.
3. A foundation may be required to transmit the "live" load of the machine to the ground or other supporting medium, i.e., to transmit the reaction for a belt, gearing or other type of drive, or in the case of steam, oil or gas engine, the thrust on the crank pin. These forces may act in any direction at right angles to the crank shaft or motor shaft; in the case of electrical machines with belt or gearing drive the direction and value of these forces will be constant for uniform conditions of operation, but in the case of reciprocating engines they will vary in both direction and value depending on the position of the crank in its cycle.
4. A foundation is required to absorb as far as possible vibrations set up by the machinery so as

to transmit as little as possible of this vibration to the surrounding ground.

According to the type of machine and the nature of the ground under consideration one cr other of the above requirements will assume primary importance. Thus in the case of an electric motor-generator, levelling and alignment are of more importance than absorption of vibration (except at very high speeds, say over 3,000 r.p.m.); a lighter foundation could therefore be used, then, in the case of, say, a generator driven by a diesel engine, which latter machine will set up vibrations, necessitating a heavy foundation mass to absorb them.

Location and the nature of the ground must be taken into account in deciding on the suitability of a foundation, because in certain situations even the smallest amount of vibration is prohibitive, whilst in others the only limit is that which the machine itself will withstand without injury.

Rotational Machines.

The foundation problem depends largely upon whether the machines to be supported are purely rotational (e.g. electric motor or steam turbine), or reciprocating (e.g. oil engine or pump); also on the nature of the ground. As an example of the points to be considered, the requirements of a motor foundation may be examined. The motor is supposed to be driving a line-shaft by means of a belt.

An Example.

Fig. 81 shows the typical case of an electric motor driving a line shaft. The motor weighs W_m pounds,

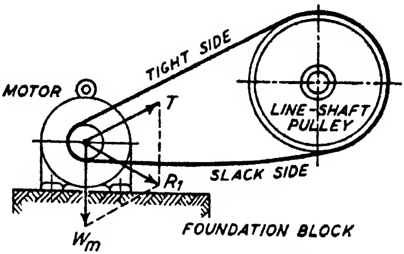
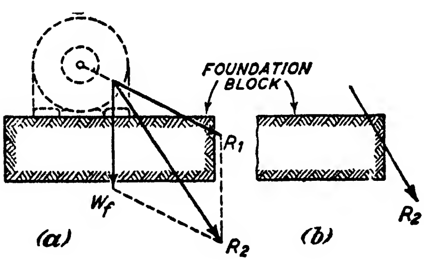


FIG. 81.—FORCES ON A MOTOR DRIVING A LINE-SHAFT PULLEY.

and the belt pull results in a load of T pounds being put on the motor shaft. Although T is strictly the resultant of the pulls of the tight and slack sides of the belt, it is usually sufficiently accurate to assume that T is equal to the tension on the tight side and is parallel to that side of the belt.

The resultant R_1 of W_m and T is obtained by applying the principle of the "parallelogram of forces," treating W_m and T as vectors and finding their vector resultant R_1.



FIGS. 82 & 83.—FORCES ON THE FOUNDATION BLOCK.

(a) Resultant reaction on the ground due to a motor and its foundation block.

(b) The reaction must not fall outside the base line.

Forces on the Foundation Block.

We now have the conditions described by Figs. 82 and 83: a foundation-block weight of W acting vertically downwards through its mass-centre, the block at the same time supporting a resultant load R_1 acting at an angle to the vertical, Fig. 83 (*a*). The two forces W_f and R_1 are now combined to give the resultant R_2.

The line of action of R_2 must lie within the base of the foundation block, and preferably within the middle third of the ground line. If the line of action of R_2 is outside the ground line (Fig. 83 (*b*)) there is clearly a force available tending to overturn the foundation block.

Ground Pressures.

It is now necessary to calculate the pressures on the ground, for the ground must finally be relied upon for supporting the whole structure. The weight W_f of the foundation block itself acts vertically through the mass-centre of the block. The resultant R_2 cuts the ground at a distance a away (see Fig. 84 (*a*)). The total downward load on the ground is a force W_r and a couple $W_r \times a$, while the horizontal load on the ground (tending to slide the foundation horizontally to the right) is F_r.

If the foundation block is rectangular in plan with dimensions b, c (Fig. 84), the downward pressure will have an average value of W_r/bc, with a further pressure due to the turning moment of W_r about a which increases the total pressure

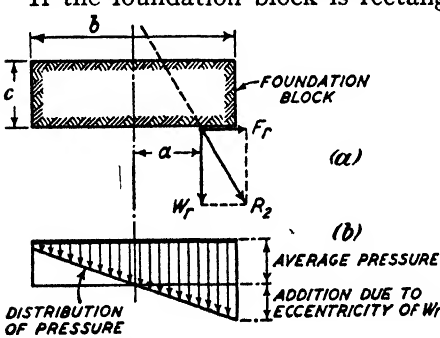


Fig. 84.—Forces Acting on the Bottom Surface of the Foundation Block.

at one end and decreases it at the other by the amount $6W_r a/cb_2$. The *maximum* downward pressure is consequently

$$\frac{W_r}{bc} + \frac{6W_r a}{cb_2} \text{ per unit area.}$$

The horizontal shearing pressure per unit area is F_r/bc. The dimension c is the width of the foundation block at right angles to the plane of the drawing in Fig. 84 (*a*). The bearing surface of the block is the product bc.

Permissible Values.

The horizontal shear should never exceed a few pounds per square foot. If the calculated value exceeds about one-tenth of the maximum downward pressure, the foundation must be sunk and the ground tightly packed in front of the block to provide an additional resistance to sliding. In this connection it is always desirable to sink a foundation below the top soil at a level unaffected by frost. In Britain a depth of three to four feet is sufficient.

The maximum downward pressure must not exceed about two-thirds of the values given in Table VII.

Belt Overhang.

It is tacitly assumed in the foregoing that the resultant R_1 acted centrally to that block. Actually one of its components, the belt pull T, acts eccentrically since it is usual for the pulley of the motor to be overhung. The foundation has therefore to resist an additional overturning moment equal to the product of the distance from the pulley centre to the centre of

TABLE VII.—TYPICAL LIMITS OF PRESSURE FOR VARIOUS TYPES OF GROUND.

Material.	*Max. Safe Pressure in Tons per sq. ft.*
Alluvial soil and quicksand	less than ½
Chalk—soft	„ ¾
„ hard	„ 3
Sand—dry	„ 1
„ fine and very compact	„ 3
„ firm sand enclosed by sheet piling	„ 6
Clay—moist, soft	„ ¾
„ yellow clay, dry	„ 2
„ London Blue clay	„ 4
„ Boulder clay, dry in thick beds	„ 5
„ Wet, in thin layers, inclined	„ 0
Gravel—ordinary	„ 3
„ compact	„ 4
Rock—soft; sandstone, limestone, etc.	„ 2
„ medium; yorkstone, gritstone, blue limestone, etc.	„ 8
„ hard in thick layers; granite, etc.	in exceptional cases up to 75; usually not more than 30.

the armature and the vertical component of T. It is easy to check this and in most cases (except perhaps where the line shaft is more or less vertically above the motor) it will be found that the foundation as calculated will be sufficient to carry the additional forces without modification.

"Braked" Machines.

A machine with a heavy rotor which may be suddenly stopped in service will produce further overturning forces, which must be taken into account. This is a somewhat more difficult mechanical problem.

Vibration.

Foundations carrying only electrical machines will rarely be called upon to sustain any serious vibrational stresses, since the even turning moment of all (except single-phase) machines keeps vibration to a minimum. In the design of foundations in these cases it is not necessary to make any addition for vibration.

Typical Values.

Table VIII, based on data from "Foundations and Machinery Fixings," by F. H. Davies, gives typical figures for some foundations for rotary electrical machinery. It will be observed that there is a decided reduction in the ratio of foundation weight to machine weight in the case of the synchronous-converters, due to the absence of belt-pull or gear-thrust.

The ground pressures, on the other hand, are normal, for this is determined by how much the ground will stand. The convertor foundations will thus be less

TABLE VIII.—TYPICAL FIGURES FOR SOME FOUNDATIONS FOR ROTARY ELECTRICAL MACHINERY.

MACHINE.		*Ratio of Foundation Weight to Machine Weight.*	*Total Pressure on ground, Tons per sq. ft.*
Description.	*Speed, r.p.m.*		
75 kW belt-driven generator	850	2·1	0·34
100 kW belt-driven generator	625	3·6	0·51
20 h.p. belt-drive motor ..	775	5·1	0·32
45 h.p. belt-drive motor ..	950	4·7	0·37
500 kW synchronous convertor	500	0·51	0·29
900 kW synchronous convertor	250	0·67	0·35

thick but of much the same surface area compared with a belt-driven machine of similar size.

Reciprocating Machinery.

It is not a simple problem to calculate foundations for reciprocating engines such as steam, gas or oil engines and ram pumps, on account of the cyclically varying forces and out-of-balance vibrations. Experience has given a basis for empirical methods of design, such as the following (Table IX), which gives a suitable weight ratio for the foundation in terms of the weight of the machinery mounted on it.

TABLE IX.—SUITABLE WEIGHT RATIOS FOR THE FOUNDATION IN TERMS OF THE WEIGHT OF THE MACHINERY MOUNTED ON IT.

MACHINERY.	*Typical ratio Foundation Weight to Machine Weight.*
Vertical steam engine, single-cyl. ..	4
Vertical gas engine, 4-cyl.	2·5
8-cyl.	2
Vertical diesel engine, 4-cyl.	2·4
8-cyl.	1·9
Horizontal steam engine, cross-compound	3·75
Horizontal gas engine, 2-cyl.	3·4
4-cyl.	2·75

The depth of the foundation block may be obtained from (six times the cylinder bore, or four times the piston stroke, whichever is the greater), average values of bore and stroke being used in the case of multi-cylinder steam engines.

Turbo-Generators.

Up to about 1,000 r.p.m., turbo-generators may be given foundations three to four times the weight of the machinery. But for the large turbo-alternators running at 1,500 to 3,000 r.p.m. and themselves weighing some hundreds of tons, these ratios have to be greatly increased. In any case, these machines are very highly specialised and the design of the foundation is an intricate job for a specialist.

Types of Ground.

The ground on which machinery may have to be erected may vary from hard igneous rock to quicksand. It is obvious that the first step is to discover the nature of the ground. This may be obvious, or deductible from the stability of other structures in the locality, or it may have to be investigated by (*a*) probing with hollow steel tubes, (*b*) digging test pits and shafts, (*c*) percussive borings, (*d*) rotary borings, or (*e*) test piles, the handling of which is a matter for an experienced civil engineer.

Table I gives typical limits of pressure for various types of ground. Of all foundation materials clay is the most treacherous. If dry and in thick beds it forms a good foundation, but if wet it becomes lubricated and plastic, having little bearing value and less shear value. It is particularly dangerous if alternately wet and dry, as it shrinks considerably on drying; in such circumstances it should never be relied upon as a foundation material.

Rock.

As would be expected, rock will carry with safety a very heavy load, but as a foundation it may possess two disadvantages:—

(*a*) it may be too solid, i.e. it may not possess sufficient resilience to "cushion" the machinery, resulting in harsh running, breaking of foundation bolts or cracking of the foundation block.

(*b*) it frequently possesses the property of transmitting vibrations along a vein to a great distance. In this connection F. H. Davis quotes the following case. In a power station "four exactly similar vertical engines were installed, one of which happened to be placed on a vein of bed rock. Three of the sets have never given cause for complaint, but the fourth, which was situated on the vein, was for a long time a continual source of trouble and expense, and it was only as a result of considerable structural alterations that an improvement was secured. The vibration set up by this engine was sensible all along the run of the vein to a great distance and to such an extent that litigation was threatened by the property-owners affected."

These difficulties may be partly overcome by placing a layer of soft and resilient material between foundation block and the rock. Materials frequently used are: five-inch layer of fine sand; two-inch layer of cork, rubber or other patent material. Fig. 85 shows a foundation suitable for a situation in which the transmission of vibration is to be expected.

Wet Clay and Mud.

Wet clay and mud, particularly if overlaid by a firm stratum, may give rise to trouble due to the transmission of vibration. The same author quotes the case of the Manchester Square generating station

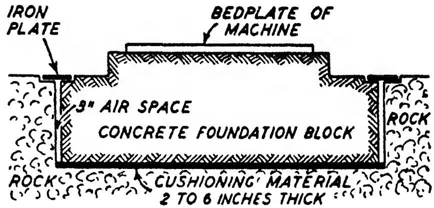


FIG. 85.
FOUNDATION WITH CUSHIONING LAYER TO MINIMISE THE TRANSMISSION OF VIBRATION.

of the Metropolitan Electric Supply Co., Ltd., London. The case may be termed classic, and it is often quoted to show the enormous difficulties which may arise in the operation of an engine plant in a central position. It shows further that even the most drastic and comprehensive remedies are at times inadequate to overcome vibration trouble.

A Classic Case.

"Manchester Square station, which is now shut down and converted into a sub-station of the Borough Council Electricity Department, was assumed originally to stand upon solid ground, but when vibration trouble arose it was ascertained that about ten to twelve feet below the floor of the engine room there was a stratum of spongy clay or mud which extended to a depth of twenty-three feet resting on the solid London clay. The stratum of soft clay was subject to an influx of water after periods of heavy rain and it was at such times that complaints of vibration were most frequent.

"The original foundation was laid on top of this stratum and consisted of a block of concrete measuring eighty-eight feet by twenty-four feet by seven feet thick and weighing about 800 tons. It rested upon a concrete floor with a layer of felt and lead intervening and was free of the walls all round. On this bed were installed ten 200 H.P. two-line Willans control central valve engines coupled direct to alternators and running at approximately 350 r.p.m.

"For some years there appear to have been few complaints and it is stated on good authority that, to a person standing on the foundation, no vibration of any sort was perceptible, but apparently as the load on the station increased complaints became frequent, culminating in a searching inquiry by experts and an application for an injunction against the company. In the meantime every effort had been made to improve conditions. At a cost of approximately £2,000 large cast iron columns filled with concrete were placed under the original concrete bed, one between every two engines, and they extended for a depth of some twenty-three feet right down to solid clay.

"It was thought that this would overcome the difficulty, but vibration was still sensible to a considerable extent in neighbouring premises; it was then seen that, solid as these pillars were, they yielded to a certain extent in a horizontal direction, moving in the manner of an inverted pendulum. To remedy this, slanting struts were placed against the tops of the columns, but disturbances were still marked. In the resulting court proceedings it was proved beyond doubt that many of the complaints of adjacent householders were well founded, and ultimately the company removed the reciprocating engines and replaced them by steam turbines on the same foundations."

General Principles.

Machinery foundations should be separate from those of buildings in order to minimise the transmission of vibrations to the structure; coupled, geared or belted machines should, if possible, be mounted on the same foundations in order to eliminate the shear stress on the ground.

It is bad practice to "step" a foundation on the under side. It should be of uniform thickness. Steps are a source of weakness in concrete. Portland-cement concrete in a mixture of one part cement, two parts sand and four parts broken stone is a usual material. Its weight can be taken as about 130 lbs. per cubic foot. Where a foundation is more than two feet thick, layers of old rails may be used for reinforcement. These can sometimes be employed to anchor foundation bolts.

As a general rule, it can be said of foundations that "the heavier the better."

Foundation Bolts.

Foundation bolts, for holding machine beds down on to the foundation block, may be of the rag or Lewis type. If steel reinforcement members are embedded in the block, it is good practice to anchor foundation bolts to these by some simple means such as by passing the bolt through a hole in the web of a short length of channel iron which in turn bears on the underside of the rails or joists. It is practically impossible to pull such a bolt out of the foundation. For this reason it is not advisable to use the method for bolts subject to shock or vibration, for in the event of breakage great trouble will be experienced in replacing it. The method is admirable for bolts taking a steady upward pull.

CHAPTER VIII

LIGHTING AND HEATING

THE initial cost of a first-class lighting job, while probably more than that of a mediocre one, is justified by the benefits it secures. In actual fact it may eventually work out cheaper, inasmuch as additions and alterations are usually necessary to a badly planned installation. The specification of a number of points of a certain wattage is insufficient to ensure an effective lighting installation. Many features must be studied to secure first-class illumination.

Deciding on Required Intensity of Lighting.

The first consideration must be the intensity of light required to enable the work to be carried out satisfactorily and without giving rise to eyestrain. Given sufficient and suitable artificial lighting, production after dark compares favourably with that in daylight in quantity and quality. Schedules published by the Illuminating Engineering Society and by the E.L.M.A. Lighting Service Bureau give guidance on this point for a great variety of industrial processes. Statutory minimum illumination values which must be provided in the darkest spots irrespective of whether work is carried on there or not, are specified in the 1937 Factories Act and these requirements must also be met. They are unlikely to be infringed in production areas where the general illumination is based on the recommendations referred to above but may, unless care is taken, be infringed in such places as gangways, passages, staircases and stores.

Height and Spacing of Fittings.

Having decided upon the intensity, the method of application must be settled. In the great majority of cases a regular system of lamps mounted at a good height, in suitable reflectors and giving an even, general light over the whole area, is preferable. Where, however, particularly high intensity is required at specific points or in directions in which a general overhead system cannot serve, supplementary local lighting may be necessary. Local lighting does not, however, affect the necessity of continuing the general lighting system throughout. Heavy contrast between small highly illuminated areas and practically dark surroundings are undesirable.

Where the machinery is large, or where the bulk of the work requires directional lighting, it may be desirable to locate the lighting points in relation to the machines or surfaces where the extra illumination is required. Such a localised system of lighting may involve nothing more than the intelligent placing of the rows of lighting units in a general system. It does, though, make a great difference to the illumination on the work.

In bays where overhead lighting fittings must be mounted high for crane clearance, it is usually preferable to rely on the overhead lighting for only part of the illumination. It should be supplemented by side lighting from angle type fittings mounted on the walls below crane level. The Home Office now requires these to be used at a height of sixteen feet or more from floor level in order to avoid glare.

Switching Arrangement.

The arrangement of control is important particularly where some sections may be working at night after others have closed down. Though, obviously, some lights must be switched off, switching for each point is seldom desirable. In any lighting system, a single light or a very small number of lights cannot provide the full intensity at any particular point. An essential of good general illumination is that light must reach the work in roughly equal volume, from several directions, so avoiding hard shadows. A single lamp will provide less than fifty per cent. of the illumination which would be available directly under it were the whole shop lit up. At least two, and usually more, lamps can therefore be controlled by each switch without involving unjustifiable electricity consumption where only a portion of the shop is working.

In very small shops the control switches may, with economy, be situated in one position near the entrance, but in larger areas it is generally considered more satisfactory and economical to locate switches in small groups on stanchion or wall near the lamps they control. At the same time, opinion is divided on this point, some preferring centralised control at the shop foreman's desk or office for the whole of the lighting. This avoids waste due to operatives neglecting to switch off unnecessary lights, but is likely to prove more costly in wiring, particularly if the shop is a large one.

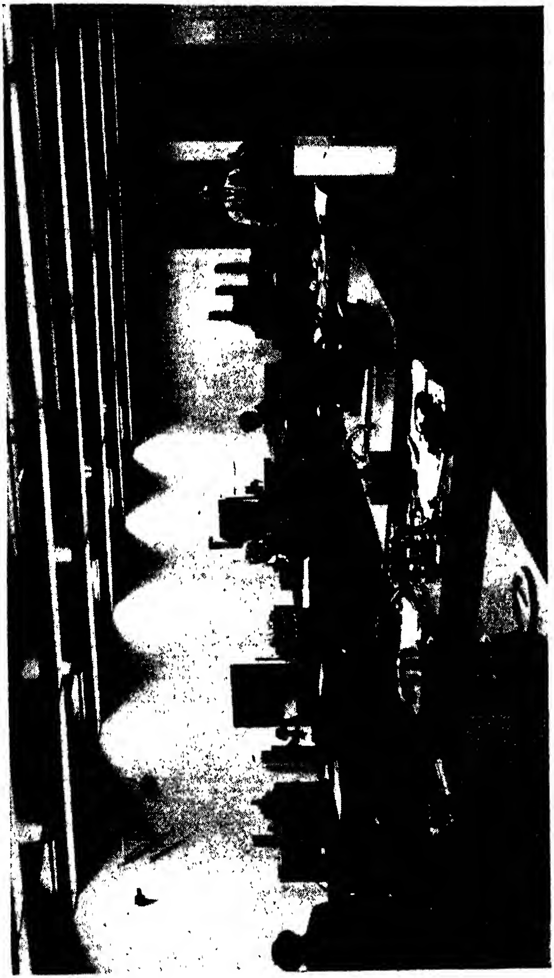


FIG. 86.—STANDARDS ROOM AT ENGINEERING WORKS.

Precision measurements and the reading of engraved scales calls for high intensities, high diffusion, and large areas of moderate brightness reflected from the object. This is achieved by providing 25-ft. candles of light from open top continuous reflectors which produce a light ceiling, and in addition provide well-graded shadows to show form.

(*Crompton Parkinson, Ltd.*)

Pilot Lighting.

In the larger shops it is desirable to have one or two pilot lights switched from the entrance for the use of night watchmen. While these can form part of the general lighting system it is an advantage if they are supplied from a different source, or at least through a different fuse board from the remainder of the lighting so that in the event of a failure of supply to the main lighting board the pilot lights remain on.

Type of Light Source.

The type of lamp to be used depends upon various factors. While satisfactory illumination for most purposes can be obtained by the use of tungsten filament lamps, they are not necessarily the most suitable nor the most economical type for any individual case. Mercury discharge lamps have proved their reliability in all kinds of factories. They provide excellent light in comparison with which the light from tungsten lamps appears almost dingy. Colours, though slightly distorted in some cases, are sufficiently natural for most discriminations, particularly if the fluorescent mercury discharge lamp is employed. In this the deficiency of red in the mercury spectrum is largely made up by light from fluorescent coating on the inside of the bulb.

On the score of efficiency, mercury discharge lamps of either type constitute a great advance over tungsten lamps. For a given wattage roughly three times the light output of the tungsten lamp is obtained. Their cost is higher than that of the tungsten lamp, but this is partly offset by their having at least a fifty per cent. longer useful life. Except where electricity is very cheap, or where lamps of small light output are necessary, the total running cost (electricity plus lamps) for a given volume of light over a given period shows a saving in favour of mercury discharge.

Sodium vapour lamps have been used for factory lighting, but in spite of the somewhat higher efficiency they have certain limitations. Their colour distortion is somewhat pronounced; they require a high striking voltage, take some time to reach full brilliance and are not available in a size comparable with that of the 400-watt mercury lamps in light output. Thus for installations where the latter lamp would be suitable about twice as many sodium lamps would be necessary.

The latest development in factory lighting is the fluorescent tube. This may be regarded as a modification of the original mercury discharge lamp. In its standard form it consists of a glass tube, 5 ft. long and about 2 in. diameter, coated on the inside with a fluorescent compound and having heater filaments, which act as electrodes fused into each end of the tube. The usual 5 ft. fluorescent tube has a rating of 80 watts.

Owing to the fact that an 80-watt fluorescent tube has a surface area of about 2 sq. ft., the surface brightness of the light source is greatly reduced, whilst at the same time the total illumination provided is very much greater than could be provided by metallic filament lamps of similar rating. Thus an 80-watt fluorescent tube gives approximately the same amount of light as a 200-watt tungsten lamp. This light emanates from the surface of the tube which has an area of approximately 2 sq. ft. as compared with an area of 3 sq. ft. in the case of 200-watt tungsten lamp (providing the latter is an opal or pearl lamp). It will be seen that the surface brightness in the case of the fluorescent tube is approximately one-sixth that of the older form of lamp. If the comparison is made with the clear glass metallic filament lamp, the light source in the latter case, shows a very much greater brilliance as compared with the fluorescent tube. It will be readily appreciated that fluorescent tube lighting affords great possibilities for effecting improvements in the technique of works and factory lighting.

The stroboscopic effect which is sometimes noticeable with mercury discharge lamps can be entirely eliminated by using the tubes in pairs and arranging the respective circuits so that there is a large phase difference (approximating to 90°) between the currents in the two tubes. Details of this circuit are given on page 219.

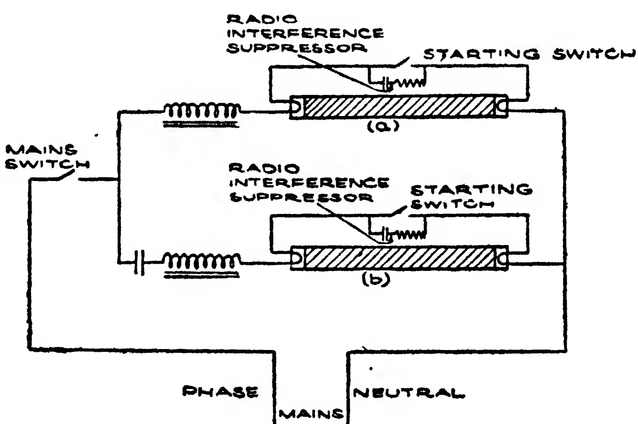


FIG. 87.—DIAGRAM OF THE T.T. CIRCUIT.
(*G.E.C. Ltd.*)

Construction of the Fluorescent Tube.

As has already been mentioned, the fluorescent tubes used in this country consist essentially of a 5-ft. length of tubing coated inside with fluorescent powder and having heater filaments (which also act as electrodes) fused into the end of the tube. The interior of the tube is filled with mercury vapour and argon at low pressure. The elements of a fluorescent tube circuit are shown in Figs. 88 and 89. It should be particularly observed that the glow starting switch in the diagram is not the main control switch for the lamp. The operation of the circuit is as follows.

Action of Glow Starting Switch.

As soon as the main lamp switch is closed, the full mains voltage is applied across the electrodes of the glow starting switch. The voltage is sufficient to cause glow discharge in the starting switch bulb. This has the effect of warming up the bi-metallic strips on which the switch contacts are mounted. The heating of these bi-metallic strips causes them to bend towards each other until the contacts touch. The glow discharge in the starter switch then disappears. The heater elements which form the electrodes in the fluorescent tubes are heated by the current which now passes through them. In the meantime the bi-metallic strips not being heated by the glow-discharge cool down and spring away from each other. This sudden interruption of the circuit which contains a choke, causes a voltage surge across the fluorescent lamp electrodes. It is this voltage surge which takes place in the opening of the starter switch contacts, that starts the discharge in the fluorescent lamps.

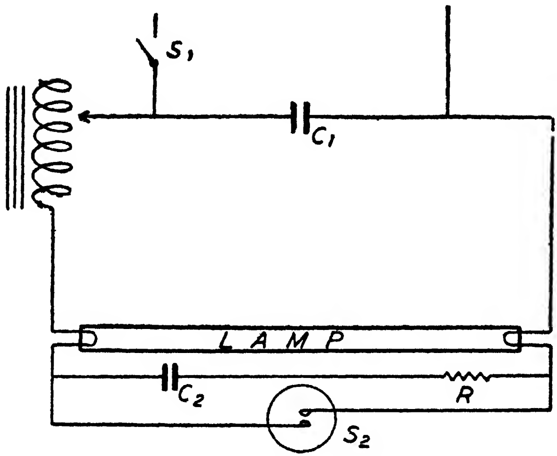


FIG. 88.—CIRCUIT DIAGRAM OF GLOW TYPE STARTER SWITCH.

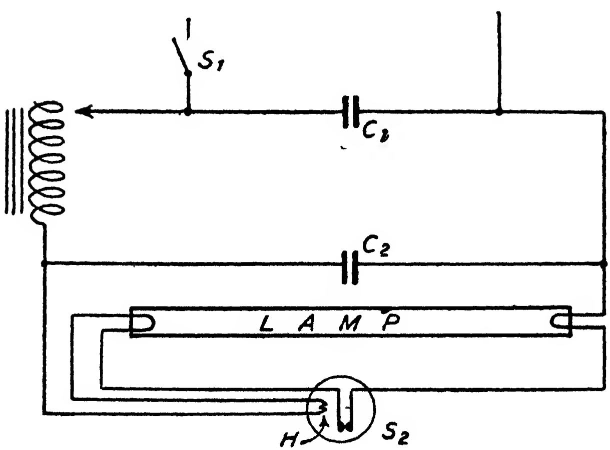


FIG. 89.—CIRCUIT DIAGRAM FOR THERMAL TYPE STARTER SWITCH.

Action of Thermal Type Starter Switch.

Fig. 89 shows an alternative type of starter switch. It will be seen that the starter switch contains two contacts mounted on bi-metallic strips, the contacts being closed when the main lamp is not switched on.

When the lamp switch is closed, current passes through the choke, the thermal switch heater, the main lamp electrode heaters and the bi-metallic switch contacts. After a short interval the heating of the bi-metallic strips causes them to spring apart. This sudden interruption of the circuit causes a voltage surge across the electrodes This initiates the discharge.

The Twin Tube Circuit.

The arrangement illustrated in Fig. 87 enables two lamps to be used in such a way that the instant of partial extinction of one lamp coincides with the instant of maximum brightness of the other lamp. Thus the two lamps, providing they are arranged reasonably close together, will give almost flickerless lighting.

Reflectors.

The use of suitable reflectors is essential to the success of the installation, for on them depends the correct distribution of the light and the elimination of glare. The Home Office requires a direct light cut-off angle twenty degrees below the horizontal for all open reflectors used less than sixteen feet above floor level. The most generally used unit made to comply with this requirement is the dispersive type of reflector, the best makes of which comply also with B.S.S. 232.

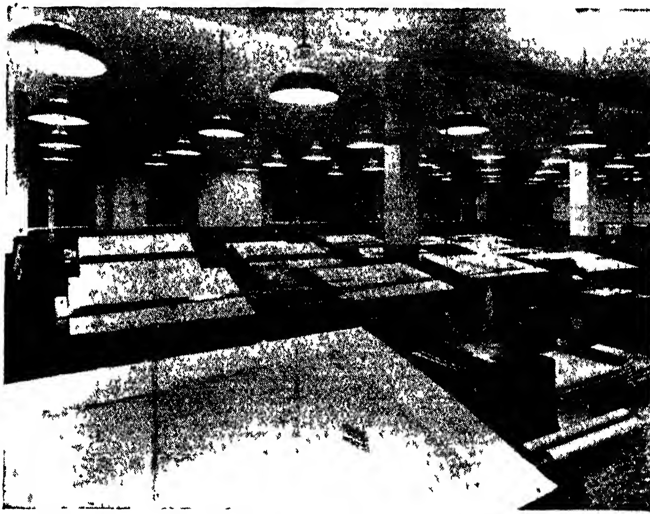


FIG 90—DRAWING OFFICE LIGHTING WITH GLASS STEEL REFLECTORS
(*G E C Ltd*)

While the dispersive type of reflector is generally applicable to the majority of industrial purposes, others may be preferable in certain cases. For high mounting in relatively narrow shops concentrating types are applicable while angle reflectors have already been mentioned for use on the side walls of such shops.

Where a more diffused light than that provided by the dispersive type is required, as for instance with polished articles, such as cutlery and plated goods, Glassteel Diffuser fittings are admirable. These incorporate an opal glass diffusing glove inside the reflector.

For local lighting near eye level the reflector must be deep enough to shield the whole of the lamp from the eyes of the operative. Home Office regulations now prohibit the installation of bare lamps or shallow conical or shell type shades in such situations.

Owing to the special shape and lighting characteristics of fluorescent tubes the question of suitable reflectors is of primary importance if it is desired to obtain the most efficient service from this new type of lighting. For factory work the light is required chiefly on the horizontal plane with a certain proportion of the light reflected sideways to give reasonable illumination on the vertical plane. Trough fittings have been designed to meet these requirements. The following general notes, which are extracted by permission from *Fluorescent Lighting* (Atkinson), will serve as a guide to the factory engineer who wishes to select fittings to suit the particular requirements of his factory.

Open-Top Fittings.

In order to make a trough fitting as compact as possible the lamp is fixed in a position well inside the trough, where it naturally obstructs some of the light being reflected from the surface above it. The loss is not of great importance, since only about one quarter of the light intercepted by the lamp is absorbed. Many industrial trough reflectors are available with a partly open top, i.e. a long open slot, perhaps an inch wide, is cut in the reflector immediately above the lamp, so that the light previously reflected and trapped is allowed free exit in an upward direction. The appearance of the room is thus improved, since the ceiling becomes lighter, while the downward illumination is reduced very slightly if at all, as the small amount of light now escaping upwards may be compensated for by the better ventilation of the fitting, reducing lamp temperature and increasing the efficiency of light generation.

Continuous Lines of Light.

In situations where the illumination level is to be of a high order, it is preferable, if possible, to employ continuous lines of light running from end to end or from side to side of the interior, rather than to use large numbers of individual fittings. Not only is the whole installation much neater, but the number of suspensory chains, tubes or brackets may be greatly reduced, since considerable lengths of continuous troughing can be installed with only one support at each end. In certain designs of continuous troughing, wiring may also be simplified.

The illumination over an area served by a number of lamps will generally be reasonably even *if the fittings are spaced at a distance apart not greater than 1½ times the mounting height above the plane of work. This spacing applies to both the longitudinal and transverse directions. In most cases, however, this maximum spacing will not be used, a lesser one being either more convenient for installation work, or necessary in order to provide sufficient illumination on the work; a lesser

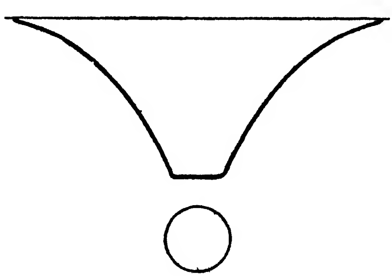


Fig. 91.—Section Through Distributing Type Reflector.

* Minimum illumination not less than 70% of the maximum.

spacing of course improves the uniformity of illumination.

Multi-Lamp Fittings.

Fittings housing two or three lamps may be used either to provide extra high illumination levels at low mounting heights, or (provided the available height is sufficient) to reduce the number of fittings it is necessary to use to provide moderate illumination. The necessity to avoid such fittings being unduly large, the obstruction which each lamp offers to the light from the other lamps, and the extra heat developed in a multi-lamp fitting all tend to reduce the efficiency compared with an equivalent number of single-lamp fittings. The degree of loss naturally depends on the design of the reflectors, particularly as regards the spacing of the lamps, their distance from the reflector surfaces, and the angle of "cut-off" from the lip of the reflector to the lowest point of the farthest lamp. Individual makes of multi-lamp reflectors therefore vary in efficiency according to the value the manufacturers attach to angle of cut-off, compactness, etc. It is quite possible to make a 3-lamp fitting almost equally as efficient as a well-designed single-lamp fitting, but the relatively high efficiency will probably be obtained only with a fitting which is unduly large or has the cut-off angle (usually about 20° below the horizontal for a single-lamp fitting) reduced so that the lamps become more visible at normal angles of view. If the cut-off angle of a 3-lamp fitting is retained at 20° the efficiency of a compact 3-lamp fitting of good design will fall by about 15 per cent, and that of a 2-lamp fitting by about 10 per cent. Greater losses are to be expected in fittings which are made too small, or where the lamps are crowded together too closely.

In interiors with low ceilings the *distributing* type of fitting may be preferred (Fig. 91). This type will not give so much downward light as the inverted trough, but a proportion of the light goes in an upward direction and, with the help of the reflector, is spread over the adjacent ceiling. For efficient utilisation the ceiling must, of course, be white or off-white, in order to reflect the light down again and to ensure that the lamp is not seen against too dark a background.

Finally, it must be remembered that the best of reflectors cannot evenly distribute light over an area larger than that which they are designed to cover, so for a given mounting height it is important not to exceed a given spacing between adjacent units. Thus an attempt to economise on the number of fittings by adopting a wider spacing to height ratio than the maximum recommended by the makers is bound to give rise to uneven illumination. Such an installation does not give all the operatives equal opportunity of producing good work, for some will be working in a better light than others and none will have as good illumination as if the correct spacing was adopted.

LOW VOLTAGE LIGHTING

Increasing use is being made of low-voltage lighting units for local lighting under industrial conditions.

(1) to eliminate risk of electric shock, and

(2) to provide a robust lamp filament which will withstand vibration on machines.

It is also convenient for some special lighting problems where space does not allow of the use of mains-voltage lamps and for preventing pilfering of lamps.

On A.C. the low-voltage is simply obtained with a transformer. For D.C. supplies a motor-generator is required, and this is naturally a more expensive method.

The choice of voltage is important. The susceptibility of individuals to shock varies considerably, and although it is usually accepted that a pressure not exceeding 25 volts to earth is safe, it is better practice to limit this to about 12 volts. It is thus possible by earthing the mid point of the transformer secondary to use 25-volt lamps, or even 50 volts in exceptional cases.

Choice of Lamps for Low-Voltage Lighting.

Where there is vibration, it is preferable to use 12-

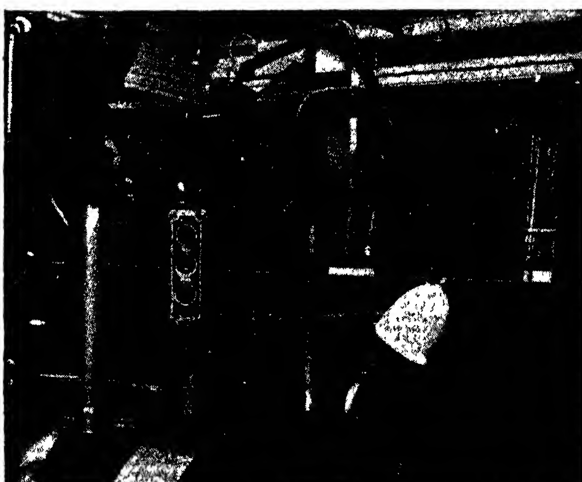


FIG. 92.—"LO-VO-LITE" LOW VOLTAGE TRANSFORMER SWITCH-FUSE EQUIPMENT MOUNTED ON TURRET LATHE.
(Igranic Electric Co., Ltd.)

volt lamps on account of their robust filaments, and this voltage has the advantage that it is standard for motor-bus lighting, so that lamps are easily obtainable. The standard interior lighting lamp is 12 watts and this is sufficient for most purposes, owing to the concentration of the light on a comparatively small area by the reflector. They are made either of pearl or clear, with alternative sizes of bulb (38 mm. and 50 mm.), the larger size being the cheaper.

Distinction should be made between motor-bus and motor-car lamps, as the former are rated at 1,000 hours' life, whereas motor-car lamps are rated at only about 500 hours, and where they are required for continuous use the cost of replacements would be heavy.

For special purposes, motor-car headlamp bulbs are available in 24-, 36-, 48-, and 60-watt sizes, but it is preferable to use the motor-bus type, which is available in 24- and 36-watt sizes. The motor-bus type are rated at 13.5 volts, but owing to their high lumen/watt ratio they will still give far more light on 12 volts than would be expected from experience with mains-voltage lamps of the same wattage, and at the same time their life should be about 1,000 hours.

Except where considerations of space make their use essential, the small bayonet cap (S.B.C.) should be avoided, as the lamp-holders are in general not so robustly made as the standard 22-mm. bayonet cap (B.C.) size, and trouble is often experienced with the very small screws and other parts, as well as with overheating of the plunger springs. Further disadvantages are that they are not readily available with a switch incorporated and also that in some cases there may be pilferage of lamps. A disadvantage of the B.C. lamps, on the other hand, is that there is a risk that they may be accidentally inserted in lamp-holders connected to mains voltage, and this may be avoided by using 3-slot lamp-holders and lamps with caps to suit.

Wiring Low-Voltage Lamps.

It is, of course, unnecessary to earth lighting units used on low-voltage provided that suitable transformers are employed, and no connection box in the base of the unit is required, although they are often used in order to make a neat arrangement of wiring.

For use on machine tools, the lighting units are sometimes mounted directly on the top of the transformers, but owing to the difficulty on most machines of finding a possible mounting position even for the small base of a lighting unit, it is preferable to mount the transformer in any suitable position on the frame of the machine where it will not impede the operator and choose the position for the lighting unit independently. As the wiring between the two is at low-voltage there is no danger from this, and the wiring can easily be given mechanical protection by flexible metallic tubing if necessary.

Fig. 90 shows a typical wiring diagram for an installation in which the transformers for the 12-volt lighting are fed from a lighting distribution board, and if desired the same circuits may also be used to supply mains-voltage lamps. The 230-volt portion of the wiring requires no comment, but it is important to remember that on the 12-volt circuits the size of conductor required is much greater than would be usual for lamps of the same wattage on normal supply voltages.

In the installation shown, the maximum load on

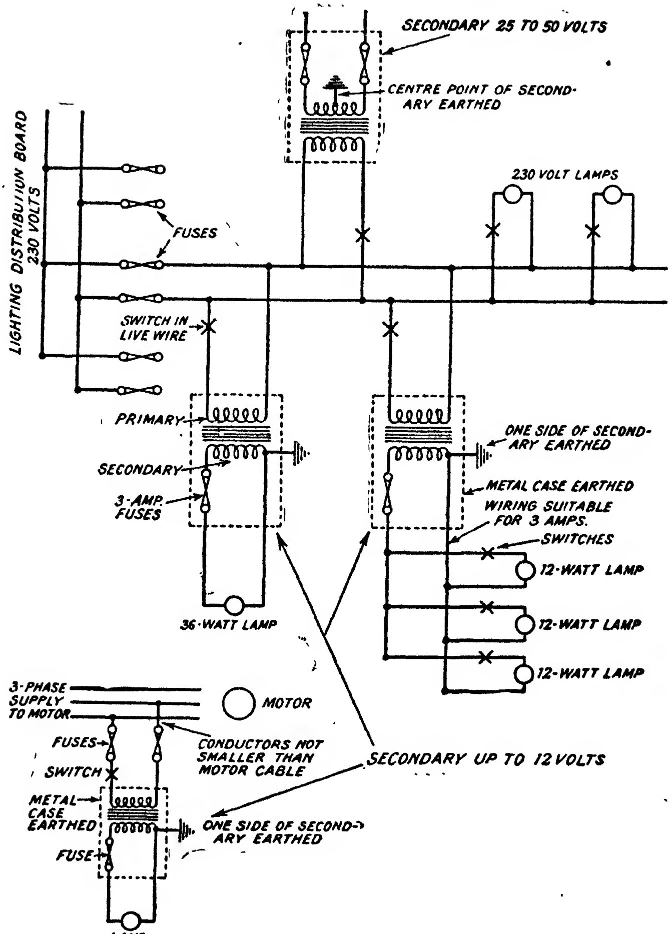


FIG. 93.—TYPICAL WIRING DIAGRAMS FOR LOW-VOLTAGE INSTALLATIONS FROM 230-VOLT A.C. SUPPLY AND 400-VOLT 3-PHASE SUPPLY.
(*Mek-Elek.*)

each 12-volt circuit is 3 amps., and for this the fixed wiring should not be less than 1/.036 in. and the flexibles 23/.0076 in., but if it were desired to use larger transformers it would be either necessary to split their output between a number of circuits, each with 3-amp. fuses, or to use heavier wiring.

Fuses for Low-Voltage.

Under short-circuit conditions the current in the low-voltage wiring may be very high compared to the normal load (about 25 amps. with a 12-volt 36 VA transformer), and in order to avoid risk of fire or burns from handling the low-tension wiring, fuses are essential. For low-tension voltages up to 12 volts one end of the winding would be earthed, so that only one fuse per circuit is required, but if a higher voltage is employed, the mid point of the winding would be earthed and fuses would be required on each pole, as shown in Fig. 93.

These fuses need not be of the shock-proof type, but must be constructed so that they are safe in operation; for example, it must not be possible for hot metal to be expelled when they blow. They should preferably be of the usual rewireable type, using ordinary fuse wire rather than the cartridge type, with a view to ease of renewal.

Small transformers of this sort are sometimes provided with a pair of rewireable-type fuses on the high-tension side in place of fuses on the low-tension side. The primary short-circuit current corresponding to the 25 amps. in the secondary mentioned above would, however, only be about 1.5 amps., which is below the continuous rating of the smallest fuse wire normally employed in such fuses, and they do not therefore afford protection against short-circuits on the secondary side.

It is, however, now possible to obtain reliable cartridge fuses of very small sizes, and if they are employed some protection is given to the transformer winding as well as to the secondary wiring. They should have sufficient capacity to withstand current surges due to switching, and the reactance of the transformer should be low enough for the short-circuit current to blow them. The use of fuses on the low-tension side is to be preferred.

Earthing.

It will be noticed from the typical wiring diagrams shown in Fig. 93 that both the metal case of the transformer and also the secondary winding of each transformer should be earthed.

These points are of particular importance in a low-voltage installation because one of the main reasons for the adoption of such a system of lighting is to minimise the danger of electric shock. It will be appreciated that if the transformer casing became live through a breakdown of insulation on the high-tension side of the transformer the advantage of the low-voltage on the output side would be neutralised.

Taking Supply off Three-phase Motor Circuit.

On machines with individual-motor drive it is usual where the supply company's tariffs allow, to take the supply for the transformer off the motor circuit (Fig. 93). In such cases fuses are necessary on the high-tension side as well, the fuses of the motor circuit normally being too large to afford protection to the high-tension connections and transformer winding. These fuses should be located where there is a change in the section of conductor, and if they are built into the transformer case the wiring to it should be the same size as that supplying the motor. They must, of course, be rated for the motor voltage, normally 400 or 415 volts.

Particular attention should be paid to voltage regulation, since an over-voltage of only five per cent.

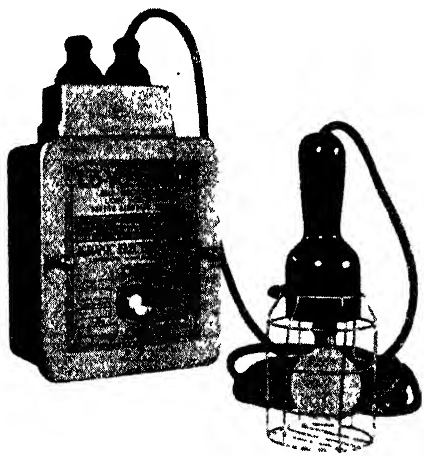


FIG. 94. — 48-WATT LOW VOLTAGE LIGHTING UNIT WITH TWO FLAT PIN PLUGS AND HANDLAMP.
(*Igranic Electric Co., Ltd.*)

halves the life of the lamps, whereas with five per cent. under-voltage the light output is only about eighty per cent. of the rated figure. In making the calculations the permissible variations in the supply voltage of plus or minus six per cent. must be allowed for, together with the voltage drop in both high- and low-voltage circuits and the voltage drop in the transformer itself, and for this reason transformers with high reactance are undesirable.

From this aspect the best arrangement would be to supply only one lamp from each transformer, but for reasons of economy several lamps are usually grouped together where it is possible to do so without long runs of 12-volt wiring.

It is usual except where the lighting is of a purely temporary character, to take any long runs of cable in conduit and to use cab-tyre cable for the lighting units themselves. An installation of this sort is naturally higher in first cost than one of a temporary kind, but the difference is soon made up by saving in maintenance wages and lost time of operators due to light failures.

TUBULAR HEATING INSTALLATIONS

The robust design of tubular heaters renders them particularly suitable for factories and workshops. Frequently it is desirable to heat areas around benches only, as to attempt to warm the whole shop would result in a heavy load and entirely uneconomic unit consumption.

Local Heating.

For some measure of comfort for bench workers it is essential that the hands and feet be kept warm. Often the arrangement shown in Fig. 92 is used. While this scheme, in which heaters are fitted above benches but below windows, is of great assistance in off-setting the cooling effect of solid windows, it does little towards providing local heating. Air currents are induced in the direction shown by the arrows and it is seen that the lower parts of a bench worker are in a stream of cool air.

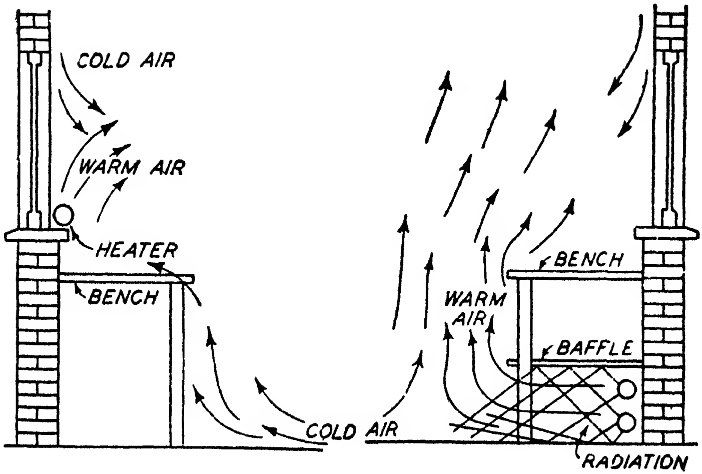


FIG. 95. FIG. 96.

FIGS. 95 AND 96.—TUBULAR HEATING ARRANGEMENTS IN THE WORKSHOP.

The arrangement shown in Fig. 96 gives far better results for a standing worker and can be more effective still if stools are provided. This arrangement often involves fitting a baffle below the bench, the effect of which is to give air currents as shown. Tubular heaters with higher loadings than the standard 60 watts per foot run should be used, for the temperature of the warm air stream is directly proportional to the surface temperature of the heater; it does not, however, approach very closely to the temperature of the tube surface.

Where tube temperatures of, say, 300° F. are used, the radiation component is appreciably increased.

This is seen from Fig. 96. Some of the radiation is, of course, absorbed by the wall fabric, but full fifty per cent. of this is reflected by the surrounding surfaces to the workers' feet.

Overhead Tubular Heaters.

One of the most fruitful causes of coldness in works with north lights in a "saw tooth roof" is down draughts. This can be cured by a tubular heater at the base of and along the window. The load required for the elimination of down draughts for temperature extremes of 55° inside to 30° F. outside, is approximately 8 watts per square foot of window area, but on account of downward air velocity it is desirable that tubes extend along the whole window. In factories this generally means a rather higher load than is obtained upon a window area basis.

Where low level space is limited tubes are often fitted along or across roof trusses. This may be convenient but it is inefficient. Such an arrangement results in a high temperature at roof level. The heating effect of tubes in this position is reduced by about thirty per cent. but by the addition of a canopy this loss may be largely reduced.

A wood canopy, over the tube, tends to reduce the upward convection loss, thus raising the temperature of the canopy itself and also the tube. The temperature rise of the canopy increases the radiating surface directing heat down to the floor.

In either case, where overhead tubes are used, a load of about fifteen per cent above the load required by tubes in the floor position is required to obtain the same results.

Flameproof Tubes.

Many situations where there are inflammable gases demand the use of flameproof tubes.

No heater may be described as flameproof unless the design is covered by a Buxton Certificate. This certificate covers a design in which terminals must be housed in a chamber separated from the element chambers and no flange or joint be less than 1 in. wide. It also covers, in the case of heating for cellulose paint rooms, the surface temperature. For this purpose no tube must exceed a load of 28 watts per foot length.

For petrol stations the standard loading of 60 watts per foot may be used, but the construction must conform to the Buxton certified construction.

INSTALLATION OF UNIT HEATERS

The "unit heater"—which is the name given to the type of heating appliance which incorporates a motor-driven propeller fan to drive air across electric, steam, or hot water heating elements—can be floor mounted or suspended from roof trusses. The roof position is particularly attractive for workshops and factories where floor space is always at a premium.

Range of the Heater.

The effective range of unit heaters depends entirely upon the velocity of the air leaving the heater. When discharging in a horizontal direction the range in feet may be taken as approximately .06 of the air velocity per minute when leaving the heater. The initial velocity of the air is, of course, obtained by dividing the total volume of air handled by the fan per minute by the area of the heater. Some ten per cent should be deducted from this area value to allow for the space occupied by the heating elements.

Where air is delivered downwards at an angle of, say, 30° to 45°, the effective range is reduced considerably, the value being approximately .04 of the initial velocity.

Air Velocities.

As very high air velocites are needed at the heater outlet, high velocities may result at the working levels. These would, of course, be objectionable. Air velocites at the working levels, that is to say, about three feet above the floor, should not exceed about 150 feet per minute. In exceptional cases, however, a value of about 100 feet per minute should not be exceeded, as some people are susceptible to the higher air velocities. If, however, the criterion of floor velocity is only that it shall not disturb dust, then velocities of up to 10 feet per minute may be used.

The final velocity at the working level will necessarily depend upon the initial air velocity at the heater outlet and the following may be taken as a guide for initial velocites:—

Heaters fixed 10 to 12 feet up, about 1,500 feet per minute; 7 to 8 feet high, 800 feet per minute; at floor level, 150 to 200 feet per minute.

Heating Elements.

In the hot water or steam types of unit heater the heating elements—or battery as they are more generally called—consist of vertical tubes with radial gills. When fitted with flameproof motors this type of heater is most suitable and economic for installation in so-called explosive atmospheres. Heating capacities for these types can usually be obtained from manufacturers' catalogues. For the electric types the elements may be of the open coil type mounted upon porcelain cleats or flat mica wound strips. Occasionally totally enclosed tubular elements are used.

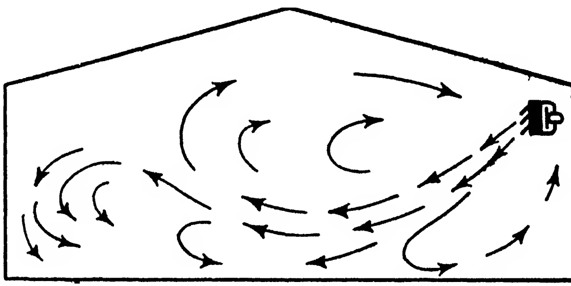


FIG. 97.—HEATING BY UNIT HEATER.

In front of the heating element adjustable louvres are fitted to deflect the warmed air in a downward direction. The approximate path of air currents from a unit heater is shown in Fig. 97.

Heating Load.

To calculate the heating load required it is first necessary to know the volume of air being passed, which is the velocity × the surface area. This value is expressed in cubic feet per minute. The load may then be calculated from the formula

$$kW = \frac{t \times \text{cubic feet per minute}}{2{,}800}$$

where $t =$ temperature rise in °F. To the value so calculated some ten per cent should be added to compensate for losses by radiation.

There will, of course, be a certain temperature drop between heaters and working level due to induced air currents and diffusion, but as this will not be great, even for heaters fixed at a 12-foot level, the air temperature value of the outlet should not exceed about 90° F., depending upon the temperature required at the lower levels.

Wiring Unit Heaters.

Where the unit is entirely electric—that is, having the usual electric motor and also electric heating elements—the problem of control is important.

The heating elements may have a load of up to 20 kW, and be for either single- or three-phase connection. This load on a 230-volt three-phase circuit requires about 30 amps., but the fan motor will seldom need more than about 1 amp., or up to 1 h.p.

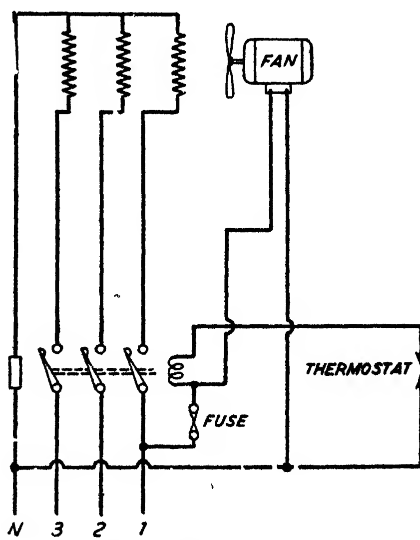


FIG. 98.—WIRING UNIT-HEATER

The temperature of the heating elements is, of course, proportional to the air velocity and will rise rapidly if the fan fails. Because of this it is essential that should the fan fail the supply of energy to the elements must be interrupted. On the other hand, it is necessary that the fan motor should have more protection than simply looping the two circuits through the one set of 30 amp. fuses.

One method adopted is to provide an additional set of fuses for the motor on the outgoing side of the main fuses. This method is not entirely satisfactory, but if the fuse gear is inspected regularly no accidents should result. As an additional protection thermal trips or fusible cutouts can be fitted close to the heating elements.

Automatic Control.

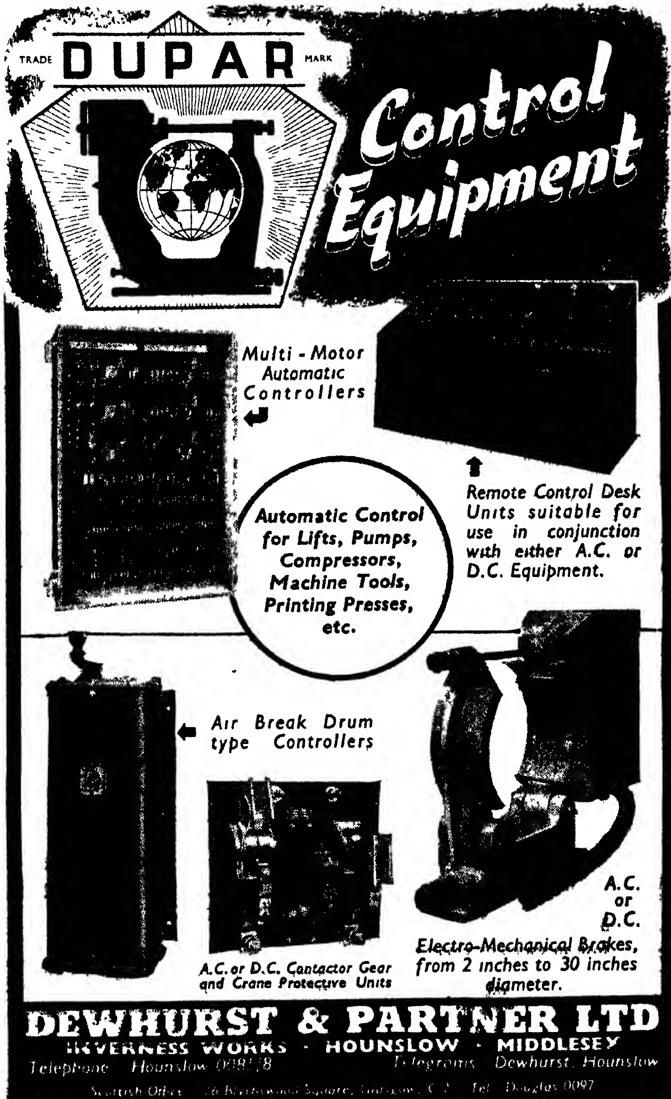
Unit heaters can be controlled by thermostats, as can any other type of heating plant. Where this is desirable, contactors are used. With this arrangement, ample protection can be afforded to fan and heaters by inserting a fuse in the contactor coil circuit and using this fuse for the fan motor, as in Fig. 98.

Fan Motors.

Fan motors for unit heaters may be either single- or three-phase and do not as a rule require any controls other than a direct-to-line starter. Generally, of course, for the sizes used it is uneconomic to wire for three-phase motors only when the heating is either steam, hot water or gas. Where the heating is by electricty, with loads of 10 kW and over, three-phase wiring may be a necessity.

INDEX

Printed in Great Britain by Wyman & Sons, Ltd., London, Fakenham and Reading.


TRADE DUPAR MARK
Control Equipment
Multi - Motor Automatic Controllers
Remote Control Desk Units suitable for use in conjunction with either A.C. or D.C. Equipment.
Automatic Control for Lifts, Pumps, Compressors, Machine Tools, Printing Presses, etc.
Air Break Drum type Controllers
A.C. or D.C. Contactor Gear and Crane Protective Units
A.C. or D.C.
Electro-Mechanical Brakes, from 2 inches to 30 inches diameter.
DEWHURST & PARTNER LTD
INVERNESS WORKS · HOUNSLOW · MIDDLESEX
Telegrams Dewhurst, Hounslow
Tel. Douglas 0097