BATTERY-ELECTRIC VEHICLES

BATTERY-ELECTRIC VEHICLES

Dealing with the Construction and Operation
of all types of Battery-operated Electric
Vehicles and Accessory Equipment

By
STANLEY M. HILLS
A.M.I.E.E.

WITH 135 ILLUSTRATIONS AND MANY USEFUL
TABLES AND CHARTS

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PREFACE

BY the outbreak of the war in 1939 it was evident that the electric-vehicle industry had definitely established itself, and the output for that year was nearly four times the output of 1936, sufficient indication that real and solid progress was being made. Unfortunately, the restriction of steel supplies has led to an inevitable slowing down in production, though a greater number of delivery electrics on the road would have been a godsend when petrol became in short supply.

Despite the progress made in the last decade, there seem to be many electrical engineers who fail to realise the extent of the industry, the variety of models on the market, and the real service that electric vehicles can render in towns and urban districts, and it is hoped that to them this volume may prove to be of assistance.

With the modern tendency towards what may be described as big business, firms are operating mixed fleets to provide for the needs of branches or depots in towns and in urban and rural districts, so that the transport manager is interested in the use of electrics.

Again, both in the electrical and the transport industries there is the younger engineer or student who desires to obtain a basic knowledge of this subject.

This volume may therefore be said to have been prepared to interest essentially the electrical engineer, the transport manager, and the student, while there must also be a number of prospective users or owners of small fleets who would be able to gain advantage by reading its pages.

As it is not altogether advantageous to study a subject without knowing what has gone before, some historical matter is included, while in the second part of Chapter III a review of present types of vehicle has been presented in order that the reader may obtain an impression of the current trend of manufacture.

Likewise a chapter on batteries has been included, because there are differences that affect the design and utility of traction batteries which do not apply to the stationary battery or accumulator, and the chapter on battery charging, together with one on maintenance of vehicles, it is hoped will be of value to the transport manager or user as well as to the student.

Transport is not, however, confined to working on the road, and consequently battery-electric trucks and locomotives have been given some reference, so that the industrial field might not be neglected, and the subject of battery-electric transport covered as a whole.

The literature on the subject, so far as the author is aware and as the bibliography shows, is confined to two books, both first published more than twenty years ago, and a number of papers read before technical institutions, together with articles published on the subject in electrical and transport journals.

There is one monthly journal on the subject—*Electric Vehicles*, published by Electrical Press, Ltd.—with which the author has been associated in an editorial capacity for some eighteen years and to the publishers of which he is greatly indebted for permission to use material from that journal. He is also indebted to various manufacturers (acknowledged in the text) for the loan of drawings or photographs and supplying information concerning their products. Lastly, but by no means least, he acknowledges his indebtedness to his friend and colleague, Mr. F. W. Rogers, for many helpful suggestions, and for reading the manuscript and proof pages.

STANLEY M. HILLS, A.M.I.E.E.

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BATTERY-ELECTRIC VEHICLES

Chapter I

EARLY HISTORY AND DEVELOPMENT

THE history of the battery-electric vehicle is largely bound up with that of the accumulator. The electric primary battery held the field for a long period, and although Gaston Planté discovered the accumulator in 1860, it largely remained a piece of laboratory apparatus. Planté, however, was able to make use of his invention in the pursuit of his theoretical researches, and installed in his laboratory a bank of 800 cells capable of giving a pressure of 1,600 volts, these batteries being recharged from Bunsen primary batteries. Planté used this equipment to investigate the phenomena of the electric current in heat and light, which he described in his work *Recherches sur l' Electricité*, published in 1879.

The invention of the Gramme dynamo in 1869 commenced the industrial applications of electricity, to be later definitely marked by The International Exhibition in Paris in 1881. This date also marked a distinctive point in the evolution of the accumulator ; for Planté was then unable to delay longer his efforts to perfect it, because in that year Camille Faure described to the French Academy of Science his own and new ideas. Broadly speaking, while Planté used pure lead for his plates or electrodes, Faure used plates covered with oxide of lead. This founded the idea of the pasted plate, which is more economical and gives greater capacity.

Actually, the application of secondary batteries or accumulators to electric traction took place before batteries were used in conjunction with dynamos for the distribution of electricity. An early installation of dynamos and batteries was at the Paris Theatre of Varieties in October 1882, while in April 1881 a tricycle was driven in Paris by means of Planté cells, and a battery-electric tramcar using Faure accumulators underwent trials in May and June of the same year. One of Faure's associates, Julien, produced the Julien electric street car, which at Antwerp in 1885, after six months' competition with other cars using steam or compressed air, was awarded first prize by a jury of experts. The same car was also tried out in Hamburg and in Eighth Avenue, New York. In a paper on " Secondary Batteries for Light and Power," read before the American Institution of Electrical Engineers, by A. H. Bauer, the author said that in 1885 " a battery consisting of forty-nine four-plate cells, having a capacity of 100 ampere-hours, was taken to Daft electric railway station near Baltimore, placed on one of the motor-cars used in that

Fig. 1.—AN EARLY ELECTRIC TAXI-CAB

Photographed in 1927 when it was 24 years old and had travelled over 180,000 miles. It attained a speed of 28 miles per hour, and did 45 miles on one charge. It was fitted with D.P. Kathanode batteries.

system, and connected to the motor and switches in the usual way—an extra switch being used, however, to vary the e.m.f. by adding or subtracting a number of cells." The total weight of car, motor, batteries, etc., was about 5½ tons. Three trips of about one mile each were made. The author also described a trial made with a 20-ft. car borrowed from one of the Baltimore railway companies and run over a specially laid track one-eighth of a mile in length. In this test the current was regulated by varying the resistance of the motor, instead of cutting cells in and out. The weight of the car, 60-cell battery, motor, etc., was 12,623 lb. or about 5½ tons.

In 1892 trials were made of a battery locomotive by the Northern Railway of France, but no serious development ensued. Road transport by battery vehicles next received attention, and about the year 1900 battery-driven taxi-cabs appeared on the streets of Paris. On the Dresden tramways in 1896 trials of battery-driven cars were carried out over a period of several months. The test car, containing forty-eight persons and hauling another containing thirty-two persons, had a single 250-volt motor, and carried a battery of 144 cells weighing over 2 tons. It travelled on occasions 130 miles with one charge, developing 68·8 kWh.

Fig. 2.—An early Ransomes "Orwell" vehicle
Used for local deliveries by a railway company. The drive was on the front wheels.

The battery was charged on the vehicle without removing, at the rate of 60 amps., and the amount paid to the city's electricity works was a fraction over 9*s*. for a full charge, which worked out at 0·84*d*. per mile as power cost for the traction of two cars with about eighty passengers. The power vehicle weighed 12 tons when loaded, the trailer 5½ tons. The battery was a new type, at that time known as the Marschner accumulator, its patent consisting in the composition of the paste. The plates seem to have stood up to unexpected strains pretty well.

In 1905 a Krieger vehicle travelled without recharge from Paris to Trouville at a stated average speed of 40 Km. per hour.

The first battery vehicle to run in England was built in London in 1889, and Mr. Frank Crawter, of the Chloride Electrical Storage Co., Ltd., makers of Exide batteries, drove it from Kentish Town to Oxford Street. To do this Mr. Crawter had to obtain a special permit from Scotland Yard, because at that time 2 miles per hour was the regulation speed in this country for mechanically propelled vehicles and a man carrying a red flag had to walk in front of them!

Electric Road Vehicles

An electric brougham, also built by Krieger, was delivered to this country in 1907 and in 1912 was purchased by a Mr. Scott of London.

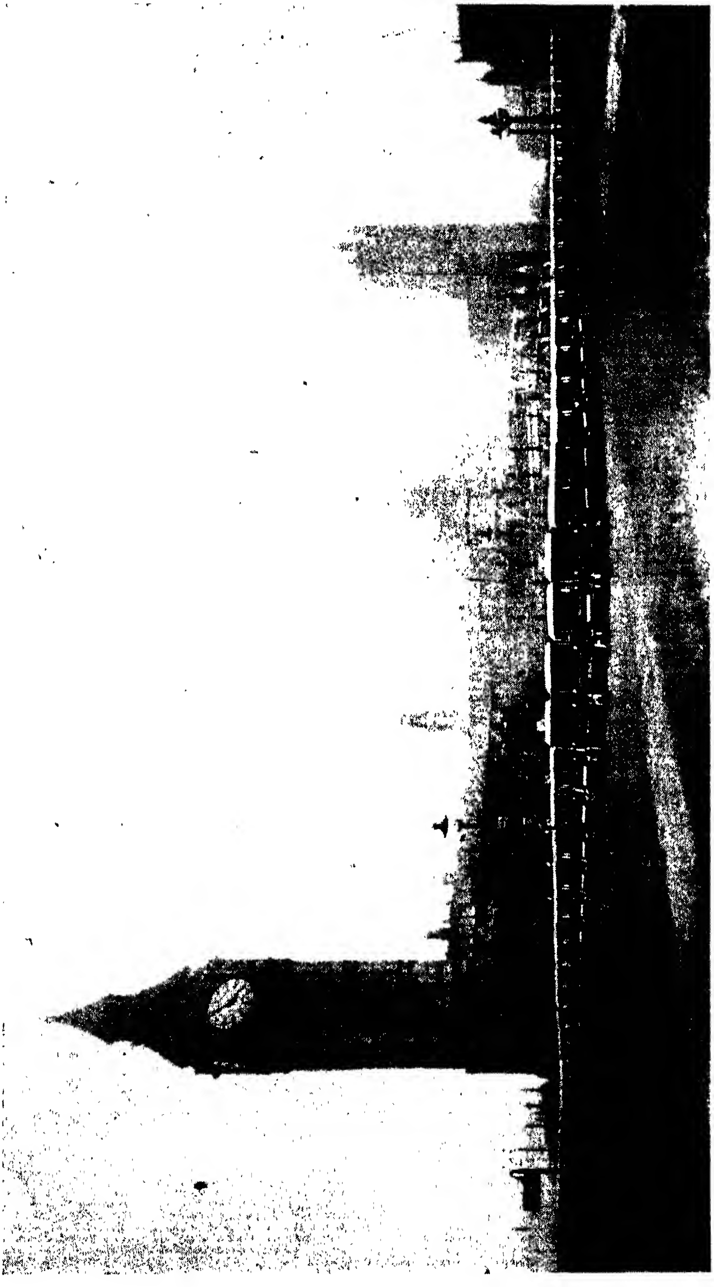


Fig. 3.—EARLY FLEET OF ELECTRIC VEHICLES USED BY MESSRS. HARRODS LTD.

This fleet has now been renewed and enlarged. Edison steel batteries have been used throughout.

It was still in running order in 1932, when the author lost track of it. When last seen it had covered some 130,000 miles and was working as well as it did in 1912. It had two motors, and was rated at 6 horse-power. The controller gave six forward speeds and one in reverse, while there were two brakes, one electric, giving regenerative control, and one hand brake. The average running speed was 15 to 20 miles per hour, and the vehicle would travel 45 to 50 miles on one charge ; but in ordinary use it was not called upon to do more than 25, being used purely as a town runabout. The battery was a 48 K 13 D.P. Kathanode, having a capacity of 168 ampere-hours at the five-hour rate. A similar battery ran the car 28,000 miles and lasted over five and a quarter years. The total weight of the vehicle, including the battery, was 1 ton 15 cwt. The driver sat in the front, as in the case of a horse-drawn brougham, and steering was then by wheel. Inside the cab was room for two passengers. A distinctive feature was the comparatively low loading line, seeing that the tendency in those days was to follow horse vehicles in body design. Thus one stepped up to gain access to cabs, buses, etc.

In 1913 a battery-electric coupé travelled from Dumfries to London, a distance of 362 miles. At this time battery-electric vehicles were attracting attention, as was also the Edison battery, the first of the alkali or nickel-iron batteries, so called in contradistinction to the lead-acid battery. In that year the Incorporated Municipal Electrical Association held their Annual Convention in London, at which Messrs. Seabrook, Watson, and Mitchell read papers on battery-electric vehicles, and a parade of vehicles was arranged at Kingston-on-Thames. One of these vehicles was an Edison Arrol-Johnston coupé, the car at the time of the Convention being at the Arrol-Johnston Works, and it was decided to bring it to London by road instead of by train. Mr. Maurice E. Fox, then chief engineer of Edison Accumulators, Ltd., was in charge of the vehicle, and Mr. W. E. Warrilow, then on the editorial staff of *The Electrician*, travelled as observer. The run was successfully carried out in two and a half days, this time including resting for one night and a number of stops for battery charging. The battery was a 60-cell A 4-type Edison of 150 ampere-hours capacity, thirty-six of the cells being placed under the bonnet and twenty-four cells under the rear seat. This vehicle operated in London for a number of years, and then spent the last five of a useful life of fifteen years as a milk-delivery float in Southport.

Municipal Service

The next stage after the application of batteries to passenger cars was that of municipal service for refuse collection, to which conditions during the war period of 1914–18 gave some encouragement. Compared with to-day, some of these vehicles look somewhat grotesque, with their comparatively high loading line and lack of protection against their contents being blown about the roads. The pioneer firms in this con-

Fig. 4.—AN ELECTRICAR TRUCK-TYPE LORRY
A start toward the lightweight vehicle.

nection were Electricars, Ltd., The General Vehicle Co., Ltd., and Ransomes, Sims & Jefferies, Ltd. In this period the drive was generally by means of chains, and in a short while the electric was by no means that silent vehicle which one sees on the streets to-day.

None the less, considerable development took place. The Cleansing Superintendents in the towns and boroughs that pioneered the use of electrics in this field, among which were Birmingham, Glasgow, Wallasey, Blackpool, Enfield, Leyton, Sheffield, and Nottingham, co-operated with manufacturers, and modern designs, as is revealed in later pages in this book, bear little comparison with those of the early days.

Delivery Work

Contemporarily, development also took place in the use of battery-electric vehicles for delivery service in large towns, a field which was developed to a very marked extent in the United States of America. Among firms who were early users of these vehicles in this country were Harrod's, Selfridge's, Carter Paterson, Whitbread's and Meux the brewers, and some of the railway companies.

In the post-1914-war period the Commercial Motor Vehicle Users Association helped development by providing classes for electrics in their annual parades, and during the later years one found veteran electrics which had run over 100,000 miles and were over ten years old

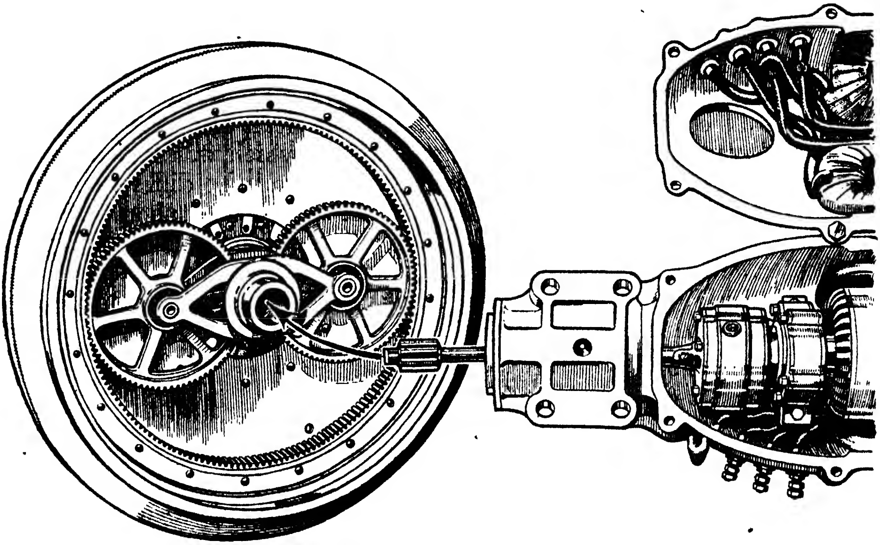


Fig. 5.—The Walker balanced drive

winning prizes and proving the long life of this class of vehicle to the consternation of some petrol enthusiasts.

Then came the development, by Morrison and Electricars (who have since been taken over by Crompton Parkinson, Ltd.), of the lightweight electric, the half-tonner, for the small retail tradesman. This class of vehicle opened up the field for the use of electrics by dairies, bakers, co-operative societies, etc. A contributory factor towards further development was the extension of the period of guarantee given by battery manufacturers of from two years to three years for the life of the battery.

Since 1934 there has been a renaissance period for electrics, and but for the outbreak of the present hostilities great developments, for which the stage was already set, would have taken place. Between 1934 and 1939, the number of electrics in use increased by three and a half times, showing that the retail tradesman was beginning to appreciate the value of this class of vehicle for local delivery service ; the Bristol Co-operative Society, to mention one concern, were using 300 electrics at the outbreak of the present war.

Design

The design of vehicles in the early period, i.e. 1908–1918, bore considerable evidence of American origin. Generally the difference between various makes lay in the design of transmission, many employing chain drive to the rear wheels, using either one or two motors. There were then but few designs in which shaft transmission, and worm and worm-wheel reduction, to the back axles was employed. This was possibly partly due to the difficulty at that time of obtaining a sufficiently rigid rear-axle casing for a heavy vehicle, and the electric was then not only heavy in design of body, but there was of course the dead weight of the battery to be considered. One vehicle of American origin very successfully employed a unique type of transmission, which was known as the Walker " balanced drive." In this the motor and the differential were housed in the back axle, and the drive to the wheels was taken through a pinion wheel and two idler wheels to an internal toothed wheel (Fig. 5).

Bodies, generally speaking, were ugly, and the loading line followed that of horse-vehicle practice, such important points as kerbside control, ease of exit from and access to the driving seat, or the provision of special bodies to suit particular trades, belonging to the past decade.

Speed

The modern design of electrics does provide for a slightly increased speed over that of the early days, but speed, as is pointed out elsewhere, is not an essential factor of the electric. It is not intended to compete with petrol or steam vehicles for carrying large loads over great distances at a high average speed.

Its proper sphere is in the transport of goods and material over comparatively short distances in congested town and urban areas where stops and starts are frequent. Most of the prejudices created against electrics in the early days arose from misconceived ideas concerning their proper field of use, and from an attempt by some to reduce prices by cutting down the battery capacity to too fine a limit.

The modern electric can be relied upon to give good service in its proper field and will prove to be more economical than either horses or petrol; while, though no startling development has taken place in battery design, there has been a gradual but sure improvement in the production and servicing of traction-type batteries by the various battery manufacturers.

A further important factor has been the development of the grid, bringing in its train an almost universal A.C. supply, so that with the development of rectifiers, battery charging is not the complicated and retarding factor it once was. In fact, it can now be an almost automatic process, and in cases where the extra dead weight can be carried conveniently, the charger can be accommodated on the vehicle.

Chapter II

THE FIELD FOR THE ELECTRIC VEHICLE

THE employment of the battery-electric vehicle is practically limited to what may be described as short-distance frequent-stop service, i.e. delivery work, or refuse collection, in urban and suburban areas within a radius of 12 to 15 miles from the base.

This limitation is obviously due to the fact that the energy for propelling the vehicle is drawn from an accumulator, commonly termed the battery, carried on the chassis. The quantity of electrical energy given out on discharge from the battery, and consequently the mileage per charge, obviously depend upon the size of the battery, i.e. its rated capacity. The size, and therefore rated capacity, are in turn controlled by the economic dead weight of battery that can be carried. In other words, increasing the battery size will increase the mileage range, but will in turn reduce both the weight and space available for the load to be carried.

On good road surfaces, and in a district having only moderate gradients, the permissible mileage per charge varies from about 50 miles in the case of a lightweight delivery van to 35 miles in the case of a 5-ton lorry.

Speed

The electric is a moderate-speed machine, the speed obtainable being 20 to 25 miles per hour for a van, and 8 to 12 miles per hour for a lorry.

Actually this speed limitation is not such a disadvantage as at first thought in this age of speed it might appear to be, because the electric has one advantage over the petrol vehicle or the horse, viz. rapid acceleration from rest. Consequently, when the electric is used in its correct field, which is for short-run frequent-stop service, this advantage of rapid acceleration enables it to compete, so far as journey time is concerned, with both horse and petrol. (See Fig. 7.)

Mr. J. A. Priestley, when Cleansing Superintendent of the City of Sheffield, carried out some interesting tests in this connection. Three types of vehicle were employed—a horse-drawn vehicle, a petrol wagon, and an electric. Each was run over a measured mile, making a definite number of stops.

The first test comprised a stop every 10 yards and the second covered a stop every 20 yards. The results, as shown in Table I, were in favour of the electric and heavily against the horse.

The effect of doubling the number of stops is to increase the total time: horse-drawn by 3·5 per cent.; petrol by 36·4 per cent., and the

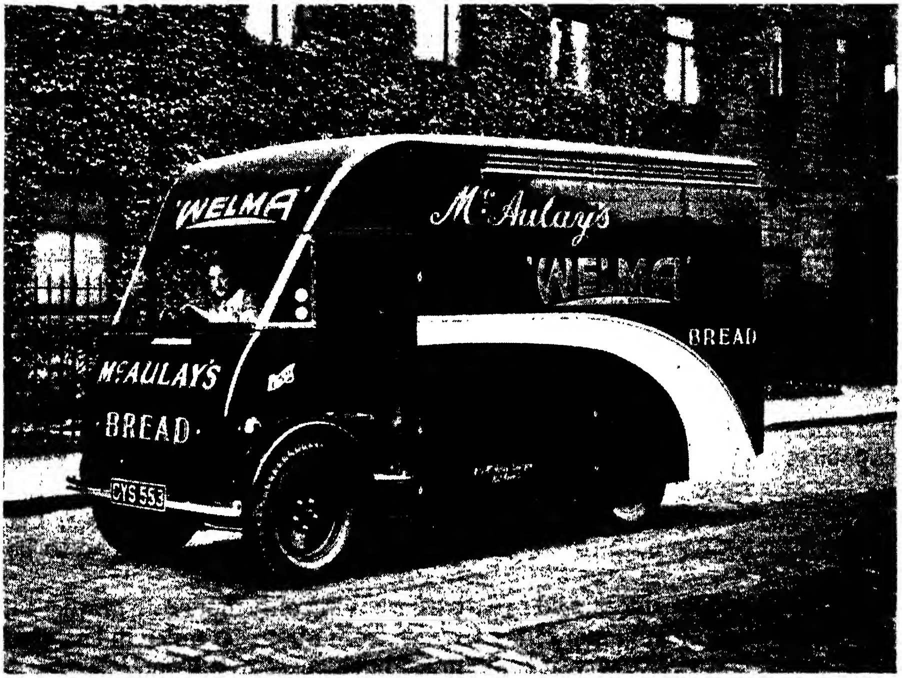


Fig. 6.—A MODERN LIGHTWEIGHT DELIVERY VEHICLE
For retail delivery in towns and urban districts. (*Midland Vehicles, Ltd.*)

TABLE I.—TIME TESTS FOR THREE TYPES OF VEHICLE OVER A MEASURED MILE

Vehicle	*Time in Minutes*	
	Stopping every 10 *yds.*	*Stopping every* 20 *yds.*
Horse-drawn	33·52	32·40
Petrol (2-tonner)	14·80	10·85
Electric (2-tonner)	11·33	9·33

electric only 21·4 per cent.—a clear tribute to the rapid start-stop characteristics of the latter.

Advantages over Petrol

In comparison with petrol vehicles, the even torque or turning power of the electric motor, together with the fact that no gear change is involved, enables the electric vehicle to accelerate more quickly than the petrol vehicle ; consequently, on routes such as are often met with in towns and cities that involve many stops, the electric has proved the best type of transport, despite the fact that its speed does not exceed 20 to 25 miles per hour, while the petrol vehicle is capable of a higher speed than this. It is seldom, however, that in town work the petrol vehicle can travel at this higher speed for any considerable length of road.

Another factor of advantage in the electric vehicle is that it does not consume power while standing. Traffic congestion, and traffic regulation, particularly in towns and cities, involve many stops and slow downs, apart from the actual stoppages when deliveries have to be made. Where the vehicle slows down or stops to await a traffic signal, or to make a delivery, both affect the running cost, and for this reason many city routes, that possibly do not occur among delivery stops, nevertheless involve frequent traffic stops, and on such routes the electric vehicle, in comparison with the petrol vehicle, can operate at lower cost, and even travel more quickly over the whole journey.

In comparison with the horse-drawn vehicle the electric vehicle will also prove economical. The haulage for which a horse now finds itself fitted is mainly that in which the volume of goods handled is so small that the necessary capital outlay for one electric vehicle would not be warranted, or in distinctly country districts.

In operating the electric vehicle the driver has only the steering wheel, brakes, and speed control to become familar with ; consequently, many firms have found it an easy matter to change over from horse-drawn to electric vehicles, and to employ their old horse drivers for the work. Quite often it has happened, in the case of changing over from horse to petrol vehicles, that whereas the horse drivers were good drivers and good salesmen, they could not successfully drive a petrol vehicle in crowded areas.

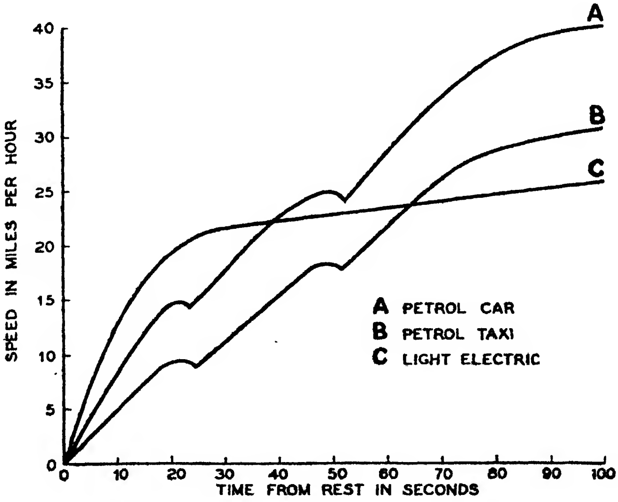


Fig. 7.—Typical acceleration curves for a petrol car, petrol taxi, and a lightweight electric vehicle. (*L. Murphy.*)

The advantages of the electric vehicle may be summarised as follows :

(1) On suitable routes the running cost per ton, per mile, per day, or per package is most economical.

(2) Economy can be obtained on routes up to 40 miles in length under most circumstances so far as town and city work is concerned, and the 40-mile limit need not apply if facilities for recharging or obtaining an exchange of battery are available on the route.

(3) Shows greatest economy where stops are most frequent, either because of deliveries or traffic congestion.

(4) Saves space ; ten electrics can be accommodated in the space required for five horses and vans.

(5) By quick acceleration obviates traffic congestion.

(6) Simple to drive.

It has generally been found that the most extensive use of electric vehicles has occurred in instances where one vehicle only was purchased in the first place, and, this vehicle having proved its superiority for short-run frequent-stop work, led to the addition of further vehicles to the owners' transport fleet.

In making comparison of costs for various types of transport, it is essential that all the actual costs of the three types of vehicles should be taken into consideration. A comparison of the cost of different types of vehicles means little unless all are operated under similar conditions of route, load, and size, but if it does more work, either by carrying larger loads or by hauling the same load a greater distance, it may cost less per package, per ton, or per mile.

Another important advantage of the electric is its cleanliness, and an electric-vehicle garage can much more easily be kept clean than a petrol-vehicle garage, and there is, of course, no comparison between the electric-vehicle garage and the horse stable. Both the driver and the electric vehicle can be maintained in a clean manner, a factor of considerable sales value where delivery or transport of foodstuffs is concerned, and of most particular advantage where the driver of the vehicle acts also as a salesman, as in the case of milk and bread delivery.

Maintenance Costs and Life

The lower costs with electric vehicles for repairs are due mainly to the fact that speed control is a simple matter, and that the operating mechanism contains but few moving parts. The petrol vehicle contains somewhere in the neighbourhood of 1,000 moving parts ; the engine alone contains several hundred, for example, the piston, valves, shafts, dynamos, etc., which are in constant and rapid motion whenever the engine is running, whether the vehicle be moving or not. Then, as accessories to the engine, there are cooling systems, ignition parts, etc. ; hence there is a very much greater liability to wear and breakdown in the petrol vehicle than there is in the electric vehicle, which contains

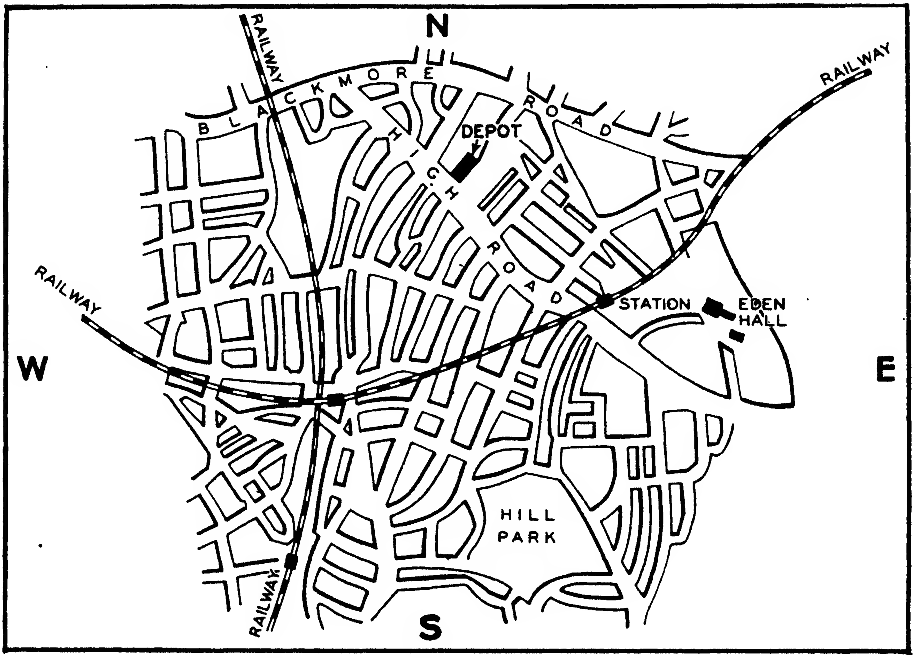


Fig. 8.—A TYPICAL TOWN DELIVERY AREA

only an electric motor and mechanical means of power transmission to the wheels. The greater reliability of the electric vehicle means that it is out of service for repair for only a very short time, and that breakdowns on the road are infrequent.

The average life of a petrol vehicle may be said to be six years, but the life of an electric is much more difficult to determine, and many examples of vehicles lasting twenty years have been known, while lives of ten and fifteen years upwards are frequent.

Planning the Work

The electric delivery vehicle has proved its suitability for bakers, dairies, laundries, and such-like types of retail delivery service. Retail tradesmen are discovering that delivery can be a costly item, and it is worth while to study economy in this direction. What is wanted is twenty or more customers per road, not per mile. It was the industrial insurance companies that planned what became known as the " block " system to guard against time wasted in making long journeys between calls. The same idea is exactly suited to delivery by electric vehicle.

Thus, consider the typical area shown by the map in Fig. 8. The head shop or depot is considered to be in the High Road, at the point marked by a large black rectangle. Assuming that the rounds warrant the employment of four vehicles, the one driver can be allotted to the area bounded by Blackmore Road and the two railway lines ; another to the Hill Park area between the railways, Eden Hall, and a suitable boundary on the southern side ; while others may be allotted the areas lying to the west of the railway running north to south.

The electric van being ideally suitable for the driver-salesman, each driver has the opportunity of developing new customers on his routes, and each route, so far as mileage is concerned, falls within the capabilities of the vehicle. Thus business can be developed and transport costs reduced.

It does not seem to be so generally realised as it should be that in many businesses transport and delivery cost absorbs a large proportion of the gross revenue, and that very careful organisation provides great opportunities for affecting increased net profits. There are many people engaged in business to-day who do not realise what their transport does cost, and these are probably among the most difficult to approach on behalf of any new method of transport. They are the ones who do not know what is expended on providing spare horses to replace horses on the sick list, or what is the rental value of space occupied by harness, fodder, etc. They do not even know that frequently misleading piece of information, the cost per mile or the cost per ton, though actually they are really concerned with the delivery cost per package or per customer.

Seeing that haulage cost represents a very serious outlay for the business man, and in some businesses one of the largest items of expense, it would be anticipated that greater attention would be given to investigating possible means of reducing transport cost than seems to be the case in many instances. Thus, if a company has a gross annual income of £20,000 and expenses on deliveries amount to £4,000, the net profit of the concern being £1,000 per annum, a saving of only 1 per cent., or £40, in delivery cost would provide an additional sum equivalent to 4 per cent. of the net profits.

Chapter III

LIGHTWEIGHT ELECTRIC VEHICLES

A. TECHNICAL CONSIDERATIONS

AS has been explained in previous chapters, the field for the electric vehicle is the short-run frequent-stop service. In this field it is a direct alternative to the horse, and one electric can replace two or three horses. The introduction of the lightweight vehicle, i.e. the vehicle ranging between 7-cwt. and 20-cwt. payload, opened up a new era in electric-vehicle development, by exactly meeting the needs of the retail tradesman. Previously electrics of a heavier type had been used for similar work by large stores, co-operative societies, brewers, and carriers.

What the tradesman requires is a lightweight vehicle, in some cases only a truck fitted with a body, which will enable him to move goods at the highest speed that conditions of the round permit. Factors which affect the situation are the time taken to approach and leave the customers' premises, the time required for the removal of goods, and the time required to drive the vehicle between stops at customers' premises. There is actually more effort involved in operating a petrol vehicle than at first thought appears to be the case, so used have people become to driving such vehicles. With an electric, all the driver has to do is to get in, apply the power, drive the required distance, operating the controller and brakes as required, switch off, apply brakes, and get out.

On the other hand, with a petrol vehicle the driver, after getting in, has to test gear lever for neutral, switch on, operate starter and choke, accelerate engine, declutch, engage first gear, let in clutch and accelerate, declutch, engage second gear, let clutch in and accelerate, declutch, engage top gear, drive to position required. Then declutch, put top gear to neutral, brake, switch off, and get out. The difference between the two in regard to time taken, skill required, and wear and tear on parts is considerable. Also in town areas, where traffic congestion causes many stops, the petrol vehicle wastes petrol while idling over, but the electric vehicle consumes no electrical energy when standing in traffic. Essentially the electric vehicle consists of a chassis of similar design to that employed on petrol vehicles, but the engine and gearbox are replaced by an electric motor and controller, the motor drawing power in the form of electrical energy from the battery, the latter in a sense representing the petrol tank. The motor takes much less space than the engine, clutch, and gearbox, and no radiator is needed, while the lubricating system, apart from the bearings of the armature, is confined to the mechanical parts of the chassis. The designer has therefore greater space at his disposal, the motor being mounted below floor level, and the driving

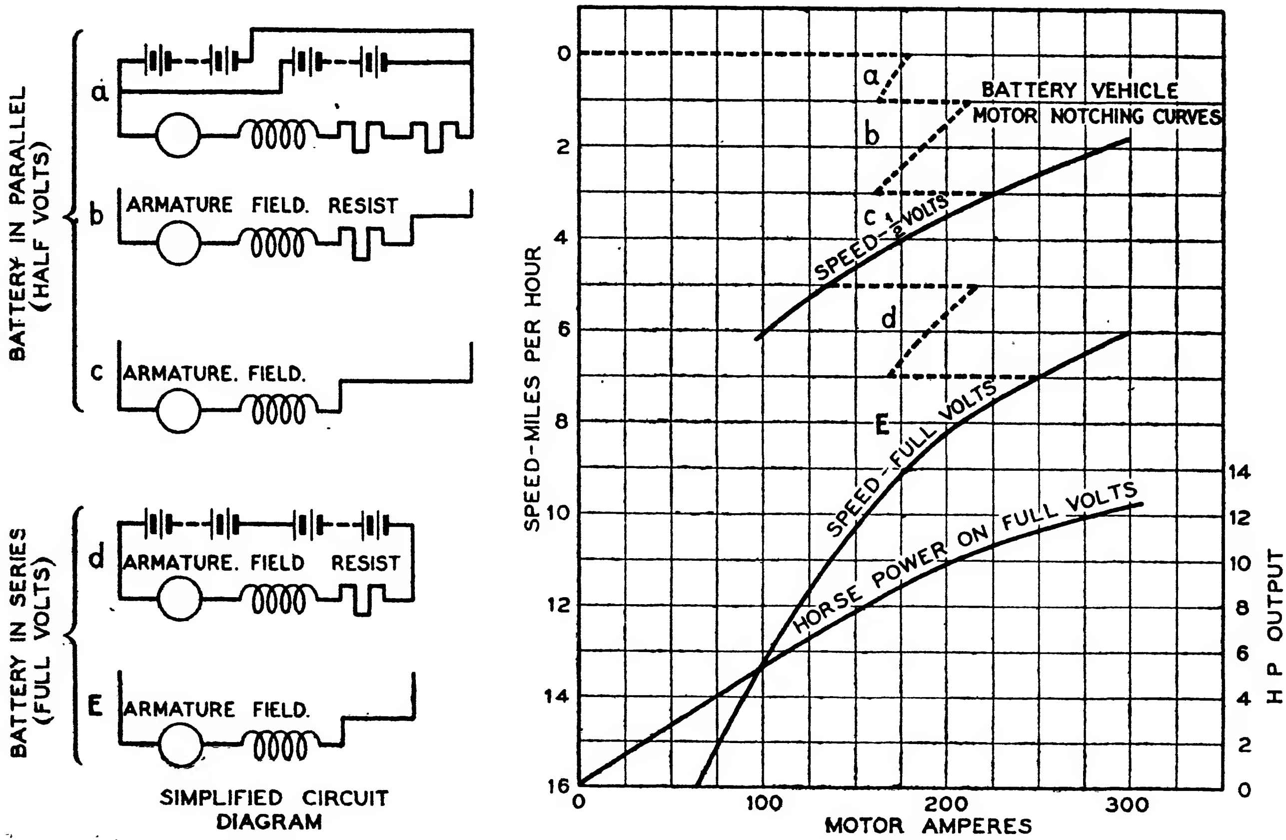


Fig. 9.—Series-parallel battery control for an electric vehicle. (*J. H. Cansdale.*)

position brought right to the front of the vehicle. The battery being heavy, and more bulky than the petrol tank, sometimes causes some changes in chassis design. The drive from the motor to the rear wheels generally follows conventional petrol design, being effected by means of a shaft and bevel or worm gears, a differential being housed in the back-axle casing. The use of chain drives has now, practically speaking, been dropped but for a few exceptional cases, such as tri-cars.

The back-axle ratio is usually higher in the case of an electric vehicle than with the petrol vehicle. The characteristics of the power unit are quite different. The petrol engine develops maximum torque at its rated speed, and the torque diminishes rapidly as the speed declines. It also diminishes as the speed rises ; hence, a gearbox and clutch are necessary to prevent stalling of the engine.

The electric motor, on the other hand, has the opposite characteristic. Its torque increases as the speed decreases, and reaches its maximum as the speed approaches zero. The limiting factor is the ability of the windings to carry the increased current. In other words, the electric motor exerts power to overcome an overload, and at a point, according to the design, the motor will burn out. The petrol motor on the contrary will stall on an overload.

The Motor

The motor generally employed is the series traction-type motor, having Class B-type insulation, specially designed to withstand heavy overloads, the windings being liberally rated so as to withstand high temperatures without damage or deterioration. The torque, as has been stated, increases very rapidly as the current increases, the torque being proportional to the product of armature current and field-flux values.

As an approximate guide the values in Table II show the size of motor required for vehicles of various payloads, but it is only approximate, because sizes vary between makers, and of course with the type, i.e. weight of body used.

TABLE II

Rated Payload of Vehicle in Cwt.	*Rated Size of Motor in Horse-power*
10–15	3·5–4·5
20	4·5–5·5
40	6–8
60	8–10
Tri-car 5–10 cwt.	1·5–3·5

If the field flux increased in arithmetical proportion to the current over an indefinitely great range, then twice any given current (within the range of the motor) would entail an increase of torque of four times, and so on. In other words, the torque would vary as the square of the current. But iron will not magnetise in this convenient way, and therefore a point is reached where " saturation " begins, and hence further increase of current does not render a proportionate increase in magnetic-field strength. On switching on the current to the first notch (fields in series and all resistance units in circuit) a current flows, the value of which depends on the applied voltage, and inversely upon the series resistance of the battery and motor. The motor exerts torque and, being as yet unloaded, it increases in speed until the torque is balanced by the forces of road resistance, wind pressure, and so on, reacting on the vehicle. On moving the controller to a " higher-speed " notch (i.e. as by cutting out resistance and finally bringing the fields into parallel), a new state of out-of-balance is reached, since the fields are now more heavily loaded, as also are the armature windings. The increase in current accelerates the armature, which, rotating in a stiffened field, causes the generation of a higher value of counter electromotive force in the armature than was in operation previously. This counter E.M.F. sets a limit on the increase in speed which can occur, and will attain such a value that a balance exists between the tractive resistance (motor torque), speed, and current flowing in the motor circuit, every internal condition remaining constant until some change occurs in the total forces acting on the vehicle, causing its effective tractive resistance to increase or decrease. If a hill be approached, this will increase tractive resistance, which will cause the

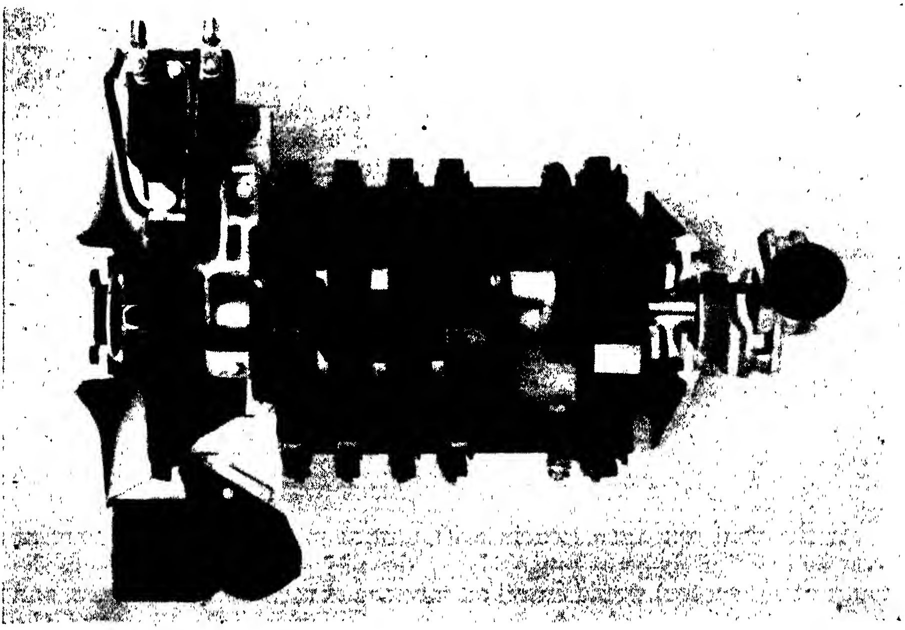


Fig. 10.—The " Metrovick " controller

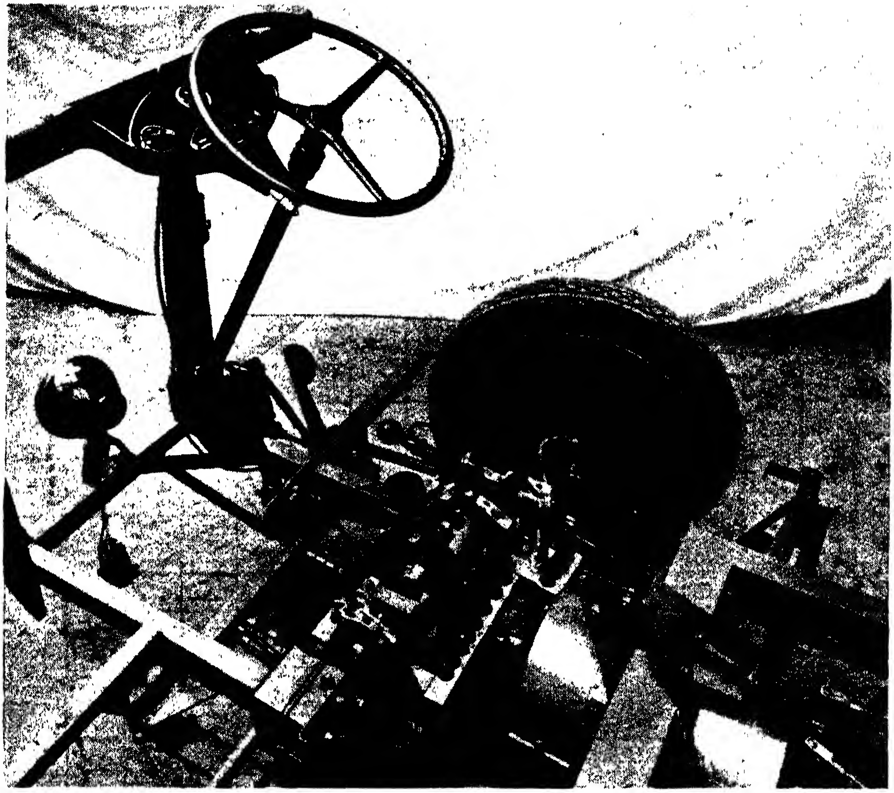


Fig. 11.—Chassis view of a "Metrovick" electric, showing the control gear

armature to slow down, reducing the counter E.M.F., thereby increasing the current, which increases the torque and stabilises all the conflicting forces again, but at a lower speed. On running over the top of a hill the force of gravity is acting to reduce the tractive resistance, and the armature is speeded up, increasing the counter E.M.F., and reducing both the current flowing in the circuit and the field strength, hence reducing the torque. This process is limited in the case of a series motor by the fact that with increase of speed a double process is proceeding, i.e. the counter E.M.F. increasing, not only reduces the current, but also the field produced by it. Hence, to produce the condition in which the motor would be just floating on the line is impossible at any safe speed on a battery electric, and in practice the driver pulls back his controller handle to neutral.

This may suggest to some readers that it might be possible to provide a self-energising electric brake on an electric vehicle, and indeed it can be easily done by several methods, the utility of which, however, is open

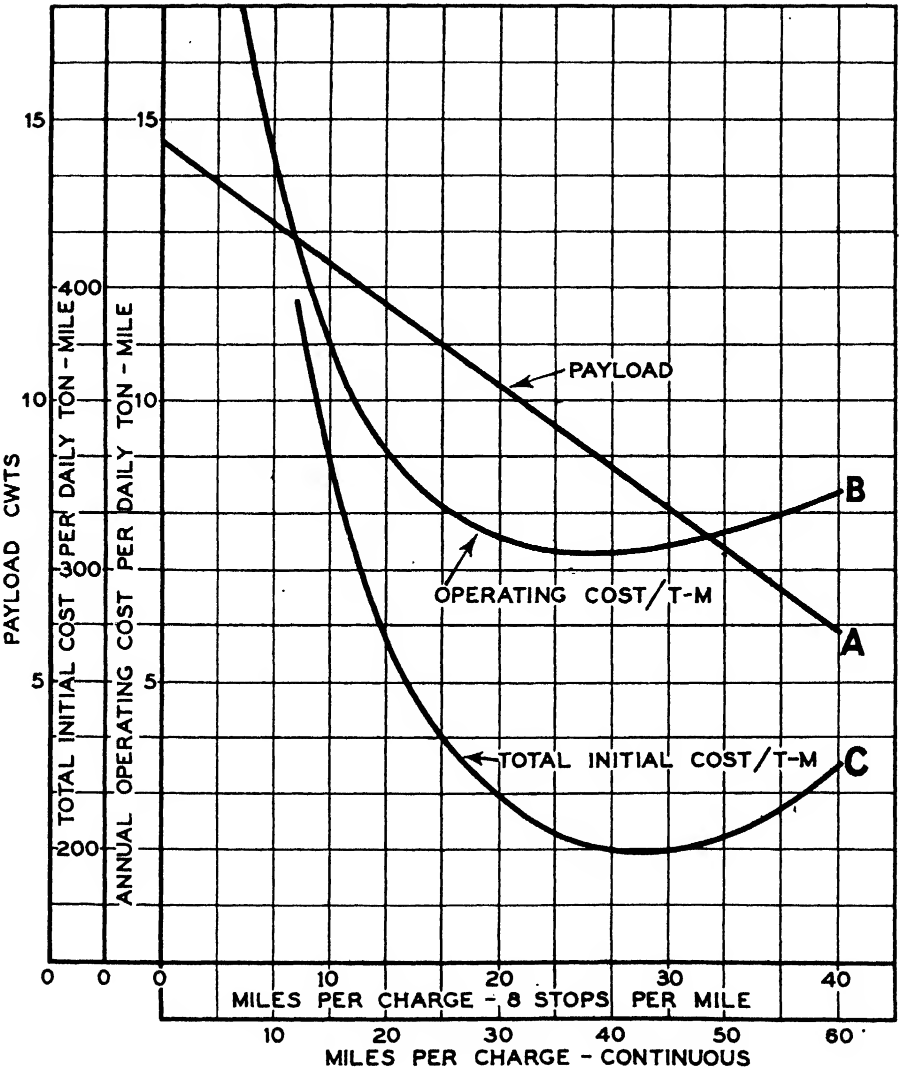


Fig. 12.—Operating data for a 7/9-cwt. electric vehicle. (*Metropolitan-Vickers Electrical Co. Ltd.*)

A. Payload in cwt.
B. Annual operating cost per daily ton-mile.
C. Total initial cost per daily ton-mile. Plotted against daily miles per charge.

to question on a road vehicle. In every case, the principle of electric braking is to provide a field of such " direction " or magnitude that the counter E.M.F. is high enough to overcome that of the battery supplying

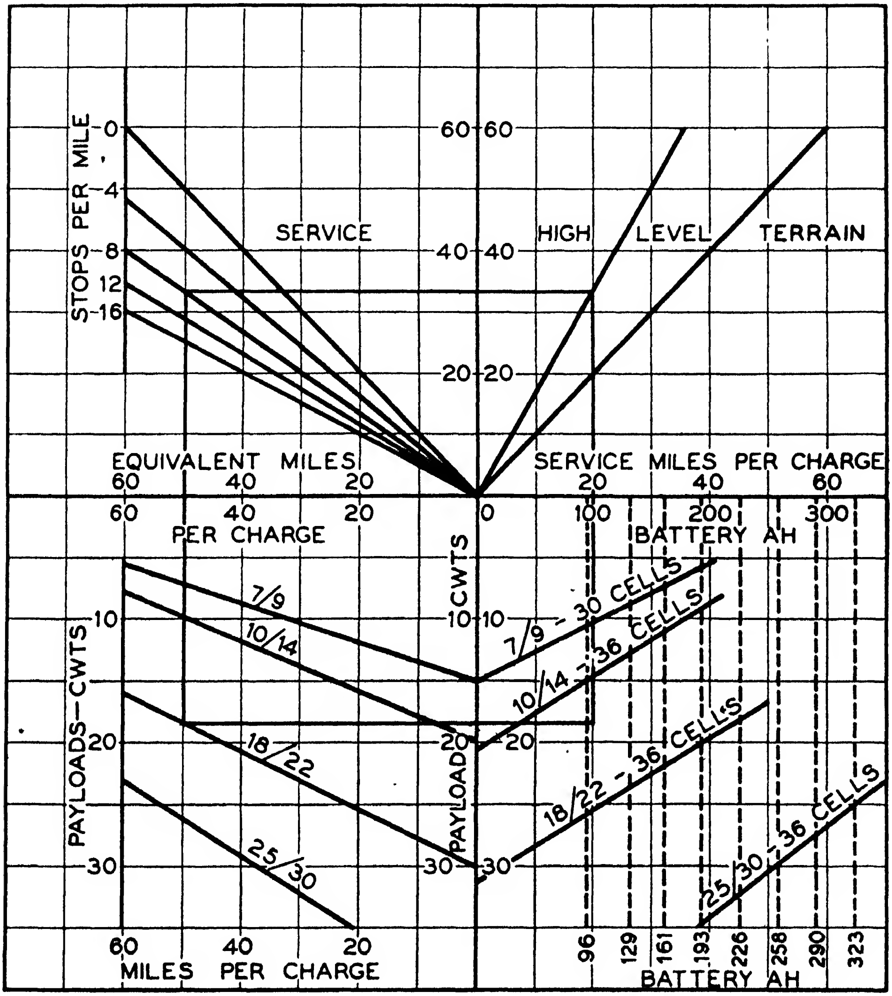


Fig. 13.—General performance curves for "Metrovick" battery vehicles. These are rated at 7/9, 10/14, 18/22 and 25/30 cwt. respectively. (*Metropolitan-Vickers Electrical Co. Ltd.*)

the motor. One method of arranging matters is to shunt the field coils by a resistance above a certain speed downhill (i.e. when gravity is pulling) which gives a braking effect, and hence a charging current above the critical speed related to the value of the shunt. In other words, a brake of this type will not bring the vehicle to rest, but acts as a maximum speed limiter.

Speed Control

The simplest and probably the most obvious method of providing speed control is by placing resistances in series with the battery and the motor, these resistances, commonly called starting resistances, being cut out of circuit in steps by means of a controller, the final position being one in which the motor is running at full battery voltage. This is, however, to a degree a wasteful proposition, so vehicle manufacturers modify this to obtain more than one economic running position.

One method is to employ series-parallel control, as is done in the case of trams and trains. That is, the motor is started up with a strong field, which reduces the starting current, and when the motor is up to running speed the field is weakened either by diverting part of the field current through a resistance, or by connecting the field coils first in series and then in parallel.

A second method may be termed series-parallel battery control. This gives the advantage that an economical running position can be obtained at about half normal speed. The diagram in Fig. 9 shows the effect produced, and refers to a 15-cwt. vehicle. It was prepared by Mr. J. H. Cansdale, A.M.I.E.E., and published in *Electric Vehicles*, vol. XXIV, p. 136. The diagram may be described in words as follows : On the first point (*a*) the battery is connected with its two halves in parallel and with two steps of resistance in series with the motor. When switching on, a current of about 180 amp. flows which drops to 160 amp. as the vehicle speeds up to 1 m.p.h. At this speed the second step (*b*) is taken and one section of resistance cut out. The current increases to 215 amp., falling again to 160 amp. at 3 m.p.h., when the third step (*c*) is taken. On this step the motor is connected directly across the two sections of battery at half volts, and

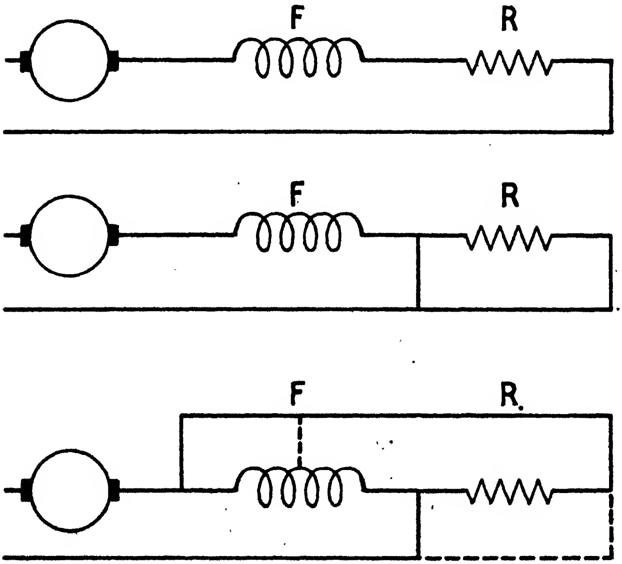


Fig. 14.—Small series resistance as first step, and after normal speed is attained a portion of the field current is shunted for slow-speed running this point can be held as long as required. For further increase of speed the battery sections are then connected in series and one step of resistance reinserted to give the fourth point (*d*). This notch is taken at 5 m.p.h., and the final notch on to the full running speed at 7 m.p.h. Assuming that the vehicle is accelerating at the rate of 2 m.p.h. per second, the second step would be taken after ½ second and the subsequent steps at 1-second intervals. It can also be seen from the diagram that the motor output increases as the speed falls.

This allowance of time can of course be made by the driver, as is done in changing gear with a petrol vehicle, but as (with the electric) the controller could be operated without an allowance of time, some makers provide an automatic means of preventing this, and introduce a dashpot action which ensures that the necessary time intervals are provided between the steps. It may be pointed out that this precaution of providing a time interval is called for only when the vehicle is starting from rest, as when the vehicle is running at speed, with the power off, the controller might be operated without any delay when it is desired to reapply the power.

Figs. 9, 14, 15, and 16 refer to connections for methods of control.

The actual type of controller varies according to the maker, and of course to a degree affects the price, and falls into three main divisions: (*a*) a simple drum-type controller; (*b*) a cam-operated contactor-type controller; (*c*) a master controller and separate contactors electro-mechanically operated.

Speed control can be by hand or

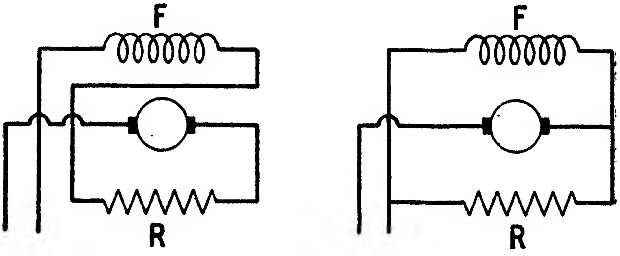


Fig. 15.—SERIES-PARALLEL FIELD CONTROL

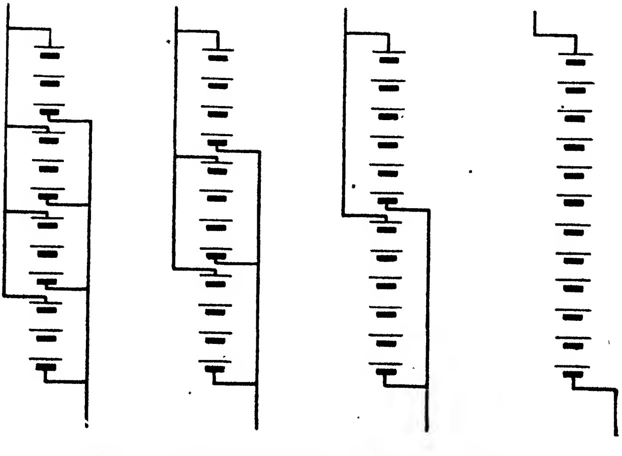


Fig. 16.—SERIES-PARALLEL BATTERY CONTROL by means of a foot pedal; with the latter arrangement, of course, the driver's hands are left entirely free for driving, steering, and signalling.

The following description of the controller fitted to the 10/14-cwt. " Metrovick " electric provides an example of modern practice (Figs. 10 and 11). This controller is foot-pedal operated, and provides six speed steps, from a very low first through easy speed gradations up to the maximum, thus minimising transmission stresses and reducing wear and tear on the transmission and tyres, as well as helping to keep down the peak loads on the battery. These six steps are divided into two sets, giving three steps with parallel battery, and three more with series connection. This reduces losses in artificial resistance, thereby conserving battery capacity and further protecting the battery against peak loads on frequent stops and starts.

The controller also provides a continuous torque throughout its six steps (there being no break as the controller passes from one speed position to the next) and an economical running position at half-speed with no resistance in circuit, permitting traffic conditions to be negotiated without waste of power.

These six steps on the controller are not traversed with one stroke of the pedal. The first three steps, with parallel battery, are obtained by the first stroke of the pedal, which then has to be allowed to return part of the way, after which a further depression enables the next three steps, with series battery, to be ob-

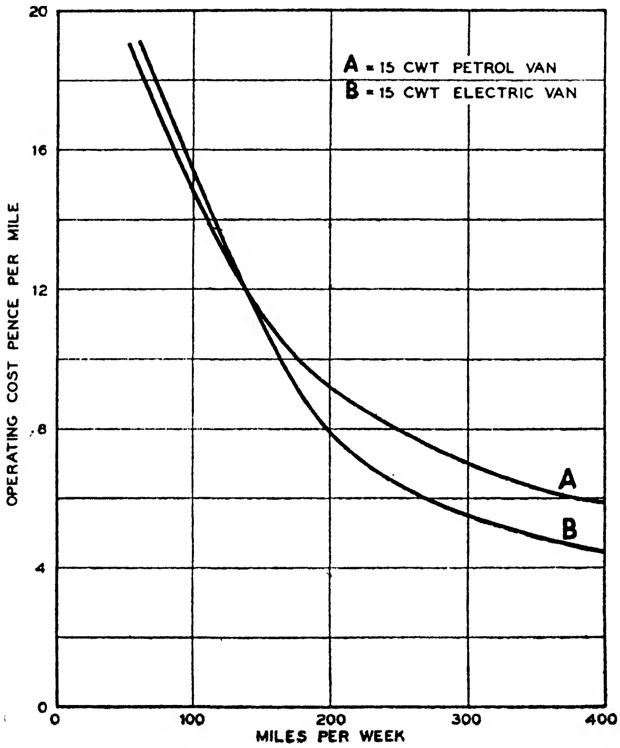


Fig. 17.—GRAPHS SHOWING COMPARATIVE RUNNING COSTS FOR 15-CWT. PETROL AND ELECTRIC VANS

(From a Paper read by J. M. Steele, before The Institute of Fuel, 1941.)

tained. This arrangement prevents the driver from advancing the controller to full speed too suddenly, while leaving him a reasonable measure of control over his rate of acceleration in an emergency.

When the pedal is released from any position, the controller automatically returns to the neutral position, so that the vehicle cannot be started in any speed but the first, and provision is also made to prevent the driver changing from forward to reverse or vice versa, without first returning to neutral.

Tractive Effort

The assessment of the tractive effort required for an electric vehicle is not an entirely simple matter owing to the number of variables involved, as for example road resistance, which involves questions of the rolling resistance or drag between the wheels and the road, the tractive resistance which varies with the road surface and gradient, and the tractive resistance created by wind pressure which varies with the area of resistance offered by the body of the vehicle. The rolling resistance is dependent upon wheel diameter, tyre structure, and road surface. Obviously a hard and smooth road surface offers a minimum value of rolling resistance. The author is indebted to Mr. R. J. Mitchell, M.I.E.E., for the value of rolling resistance given in Table III :

TABLE III.—VALUES OF ROLLING RESISTANCE

Character of Road Surface	*Rolling Resistance in lb. per Ton*
Straight Railway Track	5–10
Straight Tramway Track	30
New Asphalt	15
Worn Asphalt	22–29
Good Wood Paving	30
Unworn Granite Sets	35
Good Tarred Macadam Road	30–40
Concrete Road	30–40

In the opinion of the same authority, in considering tractive effort, so far as Great Britain is concerned and from a design point of view, it is safe to take a figure of 35 lb. per ton as the value of rolling resistance (R).

Streamlining of bodies will undoubtedly develop as the electric-vehicle industry develops, but actually wind pressure is not a very serious item at low or moderate speeds. The expression for calculating wind pressure is $0{\cdot}0032\ AS^2$, where A is the projected frontal area of the vehicle in square feet and S is the speed of the vehicle in miles per hour.

For example, for a vehicle having a projected frontal area of 25 square feet and running at 20 miles per hour in still air, the head resistance due to air pressure would amount to only 32 lb. (projected frontal area is of course the front presented by a flat surface moving at right angles to direction of motion, or actual area × cos ϕ where ϕ = angle of slope of front to the vertical). Streamlining would probably reduce this to two-thirds or one-half, i.e. to 22 or 16 lb.

Battery Capacity

Just as several entities enter into consideration of the tractive effort required, so do various factors affect the question of battery capacity. The number of stops per mile and the type of district, i.e. whether hilly or not, vitally affect the question. There is also the type of work to be considered. Many delivery vehicles go out full and return empty, the load decreasing gradually towards the last call. A milk vehicle, on the other hand, goes out fully laden with full bottles, but returns with at least an equivalent number of empties, so that the saving in load as the journey proceeds is a matter of the weight of the milk—about half the load.

For calculating the power required from the battery the following formula and method may be used :

Let W = Gross vehicle weight in tons.
R = Tractive road resistance in lb. per ton.
S = Speed in m.p.h.
G = Transmission efficiency as a percentage.
M = Motor efficiency as a percentage.
E = Energy per hour in watts (1 watt = 1 amp. × 1 volt)

$$\text{Then } E = \frac{W \times 2R \times S}{GM}$$

In the above, wind pressure is considered to be negligible in amount, in view of a number of unknown variables which affect the question more.

In practice it is usual to select a battery size so that it will discharge for three hours at a rate corresponding to full speed on a good hard level road. The energy capacity Q of the battery required will then be :

$$Q = 3\left(\frac{W \times 2R \times S}{GM}\right)$$

The capacity of the battery is stated in ampere-hours, and the voltage of the individual cells may be taken as 1·9, so that if a battery of 40 cells is decided upon, the ampere-hour capacity of the battery required will be approximately equal to

$$\frac{Q}{1{\cdot}9 \times 40}$$

For calculation purposes, too, R may be taken as being 35, G as 95 per cent., and M as 80 per cent.

Actually, however, in practice a very great deal depends upon experience and the class of work the vehicle has to perform, while, as already stated, the nature of the routes on which it is to be employed also enters into the question. The vehicle makers and the battery manufacturers have now gained considerable knowledge and experience of the battery sizes best suited to vehicles employed in a number of different trades, and in many districts in the United Kingdom, and their guidance in this matter may be relied upon. To show how the duty and such like conditions affect the matter it may be pointed out that the ampere-hour capacity of the battery may vary as shown by the approximate figures given in Table IV.

TABLE IV.—VEHICLE-BATTERY CAPACITIES

Type of Vehicle	*Payload in Cwt.*	*Mileage per Charge*	*Battery Capacity in Ampere-hours*	*Max. Speed per Hour*
Three-wheeler	5–6	25	100–112	10–12
Four-wheeler	10–15	30–35	96–258	18–25
Four-wheeler	20	25–30	160–200	12–20
Four-wheeler	40	20–30	160–288	15–18

Of course, to an extent one is limited to sizes of batteries made by the battery manufacturers, and the nearest standard battery to the considered requirements is selected. The greater the ampere-hour capacity of the battery, the greater its cost and the greater is the dead weight to be carried. It does not, however, pay to purchase too small a battery. A point to bear in mind is that the ampere-hour capacity of a battery decreases with age, being perhaps only 80 per cent. in the third year of life of a lead-acid battery. Therefore, if there is just enough capacity for a normal journey at the start, then after a year or so "tow-homes" may become frequent. A useful and approximate guide to vehicle performance can be obtained by remembering that a tractive pull of 1 lb. over a distance of 1 mile, i.e. 5,280 ft.-lb. of work, is practically equal to 2 watt-hours.

As an example, supposing that for a certain vehicle weighing 1 ton gross the draw-bar pull required to drag it on the level is 50 lb., then the minimum quantity of electrical energy required to propel under road conditions will be 50 × 2, i.e. 100 watt-hours, increased by an amount to make up for losses in the motor, transmission gear, etc. Thus, if the motor efficiency is taken as being 80 per cent. (many are better than this), the efficiency of the power-transmission system is taken as being 92 per cent. and the rolling or tractive resistance on the level amounts to 35 lb. per ton, then the least amount of energy which the 1 ton total weight of the vehicle will require for every mile travelled on a dead-level road at constant speed will be $\frac{1 \times 35 \times 2}{0{\cdot}80 \times 0{\cdot}92}$ watt-hours per gross ton-mile. This works out at 95 watt-hours per ton-mile. Under favourable conditions this figure can be obtained, but for normal use a figure of 130 to 140 watt-hours per gross ton-mile is a safer figure to allow, and requires to be increased considerably when stops are numerous or when the route is hilly, and of course a still higher figure is required when both these factors are encountered.

Battery capacity is generally referred to in ampere-hours at either the 3-, 5-, or 10-hour rate, the 5-hour rate being the most general. For instance, a battery of a capacity of 258 ampere-hours at the 5-hour rate would be discharged in five hours at a discharge current of 51·6 amps. Of course, the actual discharge rate under running conditions is never constant. Starting calls for a heavy current, and this falls comparatively rapidly as the vehicle travels at an increased speed, i.e. as it accelerates. The effect of increasing or decreasing the number of hours for discharge is to lower or decrease the capacity. Thus a battery of 258 ampere-hours capacity at the 5-hour rate would have a capacity of about 90 per cent. of that amount at the 3-hour rate, and about 112 per cent. at the 10-hour rate.

The power output of the battery in watt-hours is obtained by multiplying the ampere-hour capacity by the mean discharge voltage. The mean discharge voltage may be taken as 1·9 volts per cell. Therefore, a 20-cell battery of 258 ampere-hours capacity would have a power output

$$\frac{258 \times 20 \times 1\cdot 9}{1000}$$

= 9·8 kWh (kilowatt-hours), or 9,800 watt-hours. By using 30 cells for say 160 ampere-hours capacity, the figure becomes

$$\frac{160 \times 30 \times 1\cdot 9}{1000}$$

$$= 9\cdot 12 \text{ kWh}$$

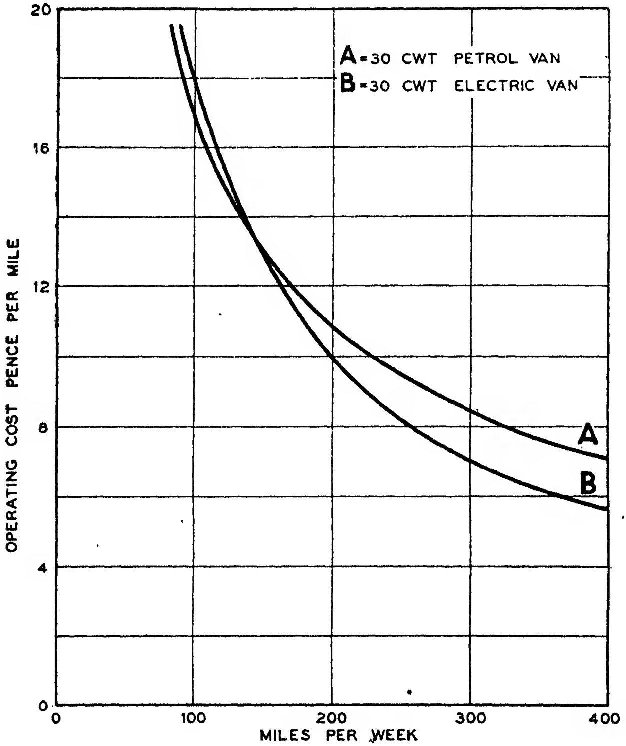


Fig. 18.—GRAPHS SHOWING COMPARATIVE RUNNING COSTS OF 30-CWT. PETROL AND ELECTRIC VANS

(From a Paper read by J. M. Steele before The Institute of Fuel, 1941.)

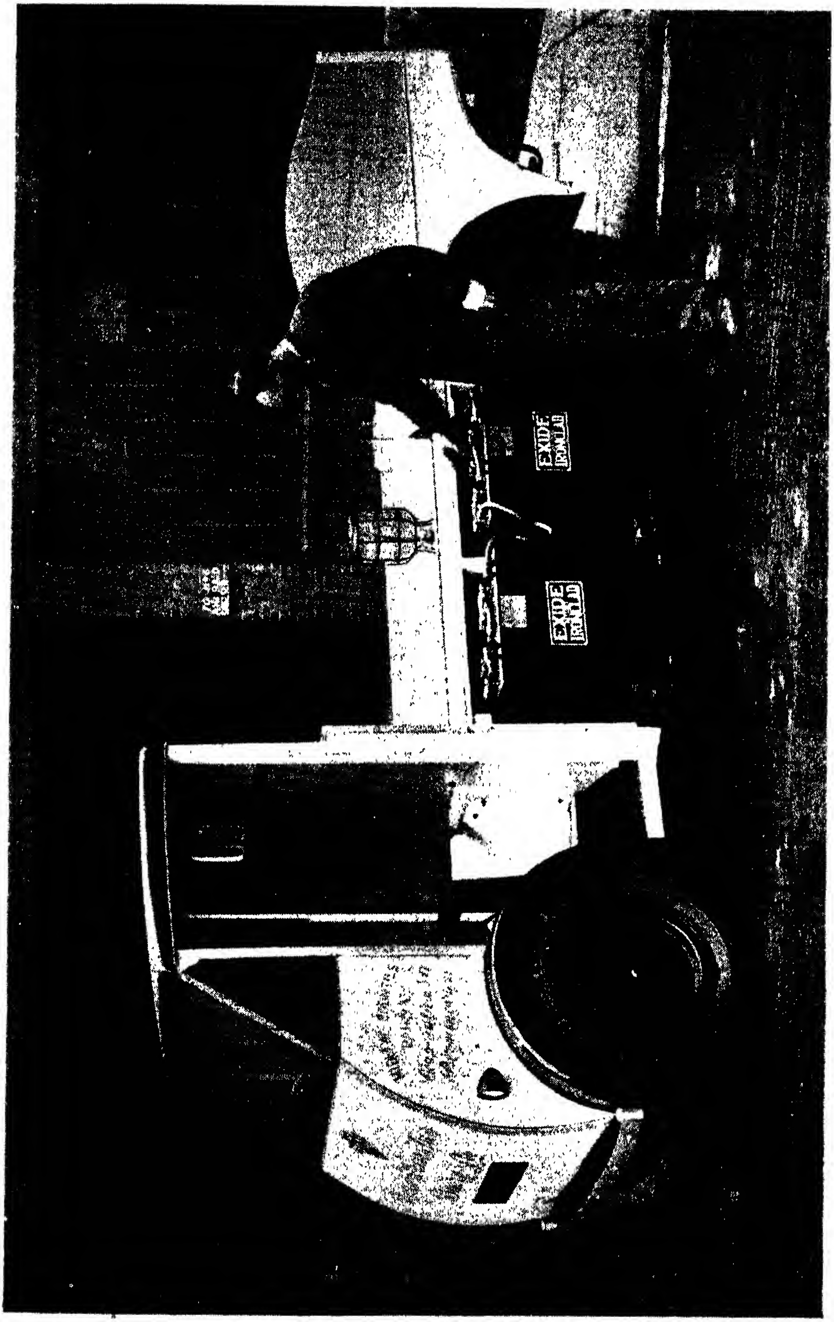


Fig. 19.—MIDLAND ELECTRIC VEHICLE
Showing method provided for obtaining access to batteries.

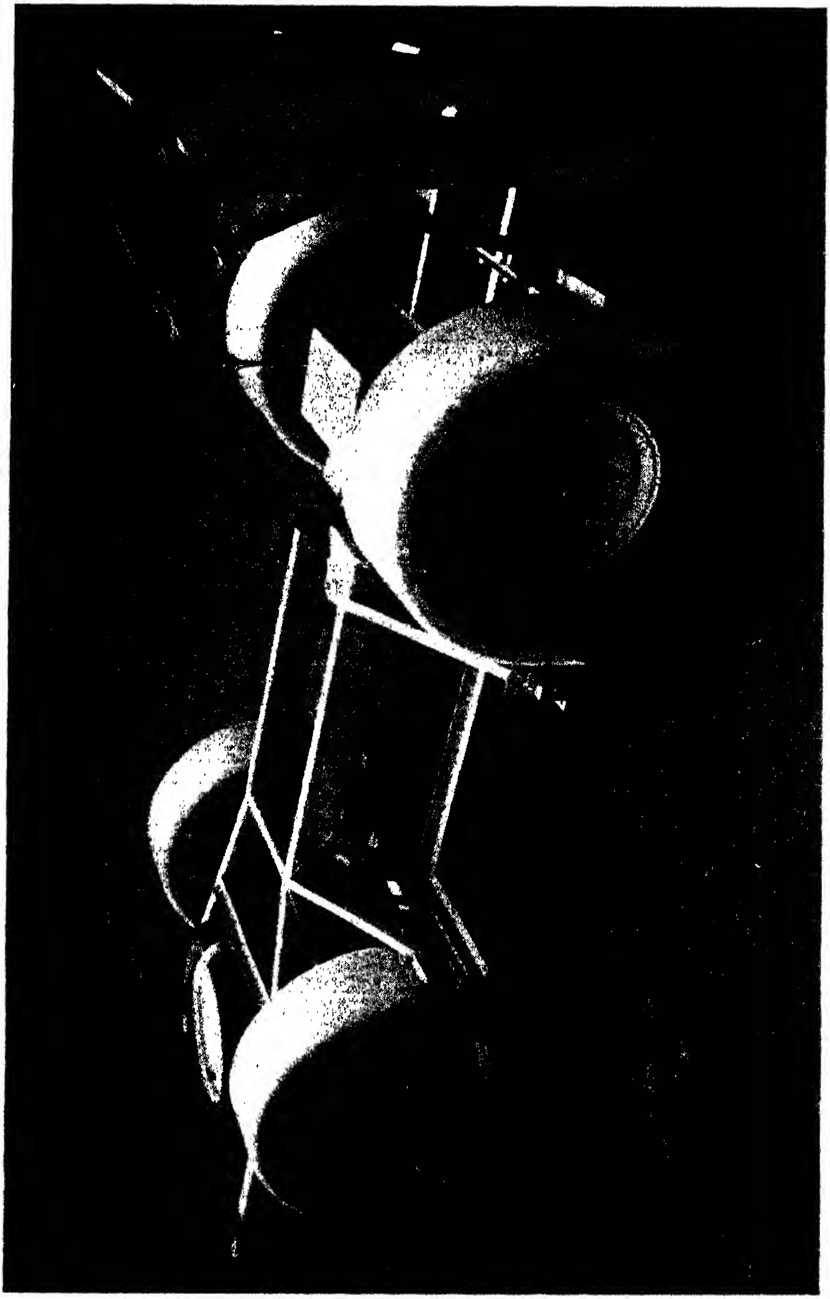


Fig. 20.—Chassis of 30-cwt. "Metrovick" electric i.e. approximately the same, and the weights of the two batteries will be nearly the same, but if the same motor is used, the 30-cell battery will provide for higher speed, but for a shorter time.

As has been stated, the battery represents dead weight to be carried on the vehicle, and the loading of the vehicle stated in the maker's lists is the load to be carried. The weight of the vehicle itself is given in lists as the weight of vehicle and body (unloaded) excluding the weight of the battery. This is done for taxation purposes. Actually, of course, the weight to be propelled is the weight of the chassis and body, plus the weight of the battery and the load. Thus, if the total weight the vehicle is designed for is 1¾ tons, i.e. 35 cwt., and the battery intended to be used weighs 20 cwt., the maximum payload that can be carried will be 15 cwt. A larger battery to give increased speed might weigh 25 cwt., and then the maximum payload would be reduced to 10 cwt.

Range is dependent upon battery capacity, and upon the number of stops per mile, and the length of the stops makes comparatively little difference except that during a really lengthy stop the battery recovers a little. Weight carried also affects the range to a degree, and in estimating range it is general to consider that for delivery service the average load carried is half the permitted payload. Very bad weather, e.g. snow-covered roads, will of course reduce the range.

From the foregoing it can be seen that there are many variables to be taken into account, and experience has to be relied upon in choosing battery capacity, or alternatively, a trial run over the route may be arranged for.

Generally speaking the optimum range for delivery work, taking into consideration first cost and economical operation, is about 25 to 30 miles, assuming that there will not be more than an average of eight stops and starts per mile. The charts in Figs. 12 and 13 relate to " Metrovick " electric vehicles, and were prepared in connection with an article by Mr. G. H. Fletcher, M.I.E.E., published in *Electric Vehicles* (vol. XXV, p. 98).

Fig. 13 illustrates the effect of various service conditions on the range obtainable from a given vehicle, or, conversely, enables the correct vehicle to be determined for given conditions. For instance, if a vehicle is required for a daily mileage of 20, in a hilly district, on bread delivery involving 150 delivery stops, the initial load being 17 cwt., the vehicle required is the 18/22-cwt. model, with a 36-cell, 226 ampere-hour battery. This is deduced as follows :

The daily mileage of 20 is read off along axis OX and the equivalent level mileage of 34 read off from the " hilly " line along the vertical axis, from which it is transferred direct to the " service " quadrant. Here the correction for stops per mile, assuming eight stops per mile, i.e. 160 total per day, is applied, giving a range of 50 miles on the horizontal axis. Proceeding along this ordinate to the third quadrant, a payload of 17 cwt.

lies between 10/14 and 18/22, and hence the 18/22 model is required. The rated payload at 50 miles is shown as 18·5 cwt., and this weight, transferred to the fourth quadrant, shows a battery capacity of 220 ampere-hours, or, to take the next larger battery size, 226 ampere-hours.

Fig. 12 shows the variation against daily miles per charge of (*a*) payload, (*b*) annual operating cost per daily ton-mile, and (*c*) total initial cost per daily ton-mile, in curves A, B, and C respectively. While the actual values given in curves B and C are to some extent arbitrary, their general form may be accepted, and it will be seen that in each case a minimum value is shown at approximately 40 miles per charge continuous running. This corresponds to the range of about 25 miles at eight stops per mile, required for average service conditions, a result which confirms the suitability of the vehicle for the work for which it is designed.

Use of Gears

As far back as 1925, in a paper read before a gathering of gas and electricity producers for South-West France, M. M. Thouvenin put forward the argument that a speed-reduction gear on an electric vehicle was veritably "an extra horse" on a difficult bit of road, because it provided assistance in climbing hills. He further argued that when from any cause—insufficient charging, too long a journey, a mistake in the route, etc.—a driver found his battery suddenly weakening, and a moment came when it would not surmount the least slope or bad patch of road, then with the help of a reduction gear the strain on the battery would be reduced, and probably the vehicle would be able to get home, if only very slowly. Some French vehicles were produced on this idea; but in this country preference ruled for the simplicity obtainable by not using reduction gears. In 1940, however, the Lancaster Electrical Co. produced the Lecar, in which a mechanical gearbox was employed, giving three speeds, and the makers claimed that the introduction of this gave an increase of 25 per cent. in range. Against the direct drive, or fixed gear, the designer pointed out that the motor has to pull very hard on an up grade, and may even be overloaded; it is, at all events, drawing a heavy current from the battery. On a down gradient, it is turning over very fast, and it limits the level-road speed. Thus, when climbing a hill, a change to a lower-gear ratio enables the motor to run faster, thus reducing the load on it and the current drain on the battery. Second gear in the gearbox is the ratio used for normal running, comprising starting and stopping on reasonably level ground, and top gear is intended to be used only where a fairly long run is possible on level ground, or when descending a hill, when a speed of 25 to 30 miles per hour becomes possible. The gearbox used is a standard model as employed on a well-known make of light petrol car.

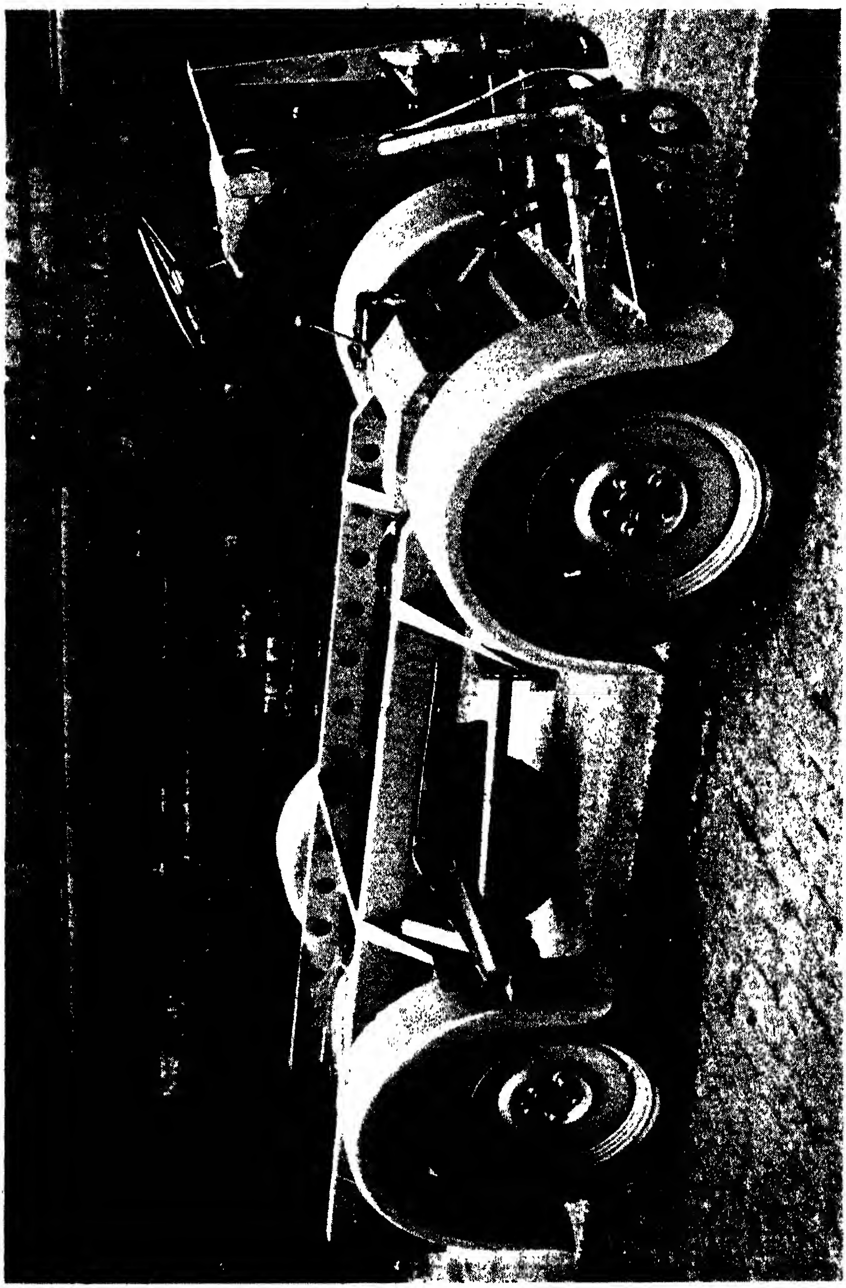


Fig. 21.—Chassis of 7/9-cwt. "Metrovick" electric

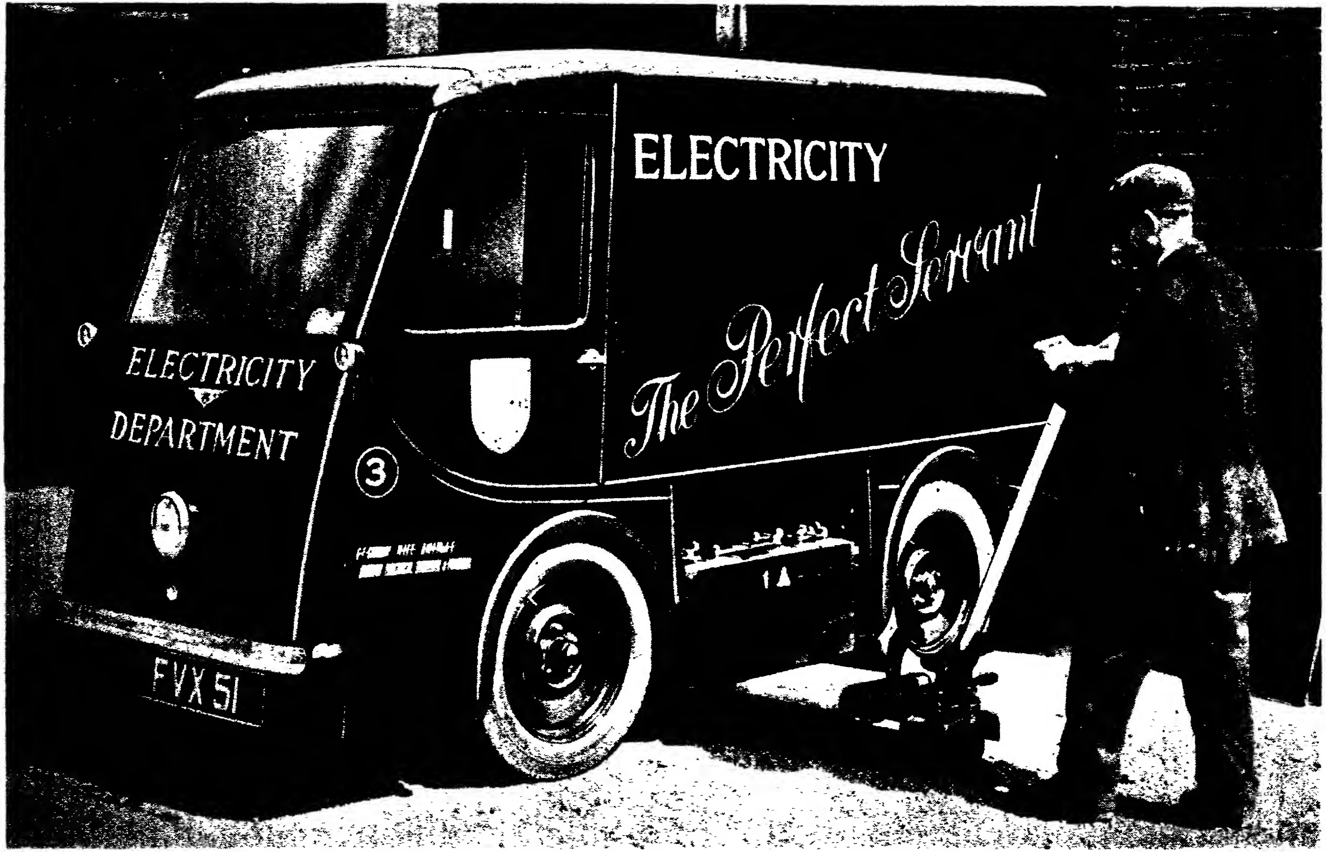


Fig. 22.—METHOD OF EXCHANGING A BATTERY BY USING A HAND TRUCK ("METROVICK")

Meters

The use of an ampere-hour meter mounted on the vehicle and permanently connected in the battery circuit greatly helps towards efficient operation of the vehicle and guarding against stalling due to the battery becoming discharged on a journey. Such a meter can be provided with a movable indicating hand (red) which should be placed at the point where it is desirable that the battery should be recharged. By this means the driver or person responsible for the condition of the battery can always tell, by comparing the position of the ordinary moving black hand of the meter and the stationary red hand, what remaining capacity is available before the battery must be put on charge.

In some meters the regulation is on the "slow on charge" basis, i.e. when the battery is placed on charge the direction of the current through the meter is opposite to the direction when discharging is taking place, and a resistor element is provided which causes the meter to run slow when the battery is on charge. In this way an overcharge is automatically given to the battery, the percentage being indicated by the position of the small hand on the resistor scale. The more modern practice is to use a meter with a setting based on "excess charge over discharge." If it happens that both types are in use on vehicles in the same garage, it is important to remember that they do not both require the same setting. Actually 20 per cent. "slow on charge" is identical with 25 per cent. "excess charge over discharge."

It is generally arranged that when the meter hand reaches the full-charge point a contact is made in the train mechanism which trips a circuit breaker in the main charging circuit, thereby terminating the charge at the proper time. This protects the battery against premature deterioration due to excessive gassing and heating which accompanies continued or repeated overcharging. It also provides a saving in man-hour attendance, because there is no need for an operator to be on watch to take voltage and specific-gravity readings.

It should be borne in mind that sudden increases of current rate due to acceleration of the vehicle will not be measured fully because of the lag or retarded pick-up of the rotating parts of the meter. Another cause of some inaccuracy is the lag in the moving parts occasioned by the increased friction in the bearings when the vehicle is tilted or ascends a gradient. Therefore in cases where the vehicle service calls for frequent acceleration or negotiation of gradients, compensation for meter inaccuracies must be provided for by allowing a greater per cent. excess charge over discharge, owing to the fact that the ampere-hour meter will not have registered all the ampere-hours taken out of the battery.

Operating Costs

The costs of operation of an electric vehicle naturally vary between operators, and to some extent between the classes of work that

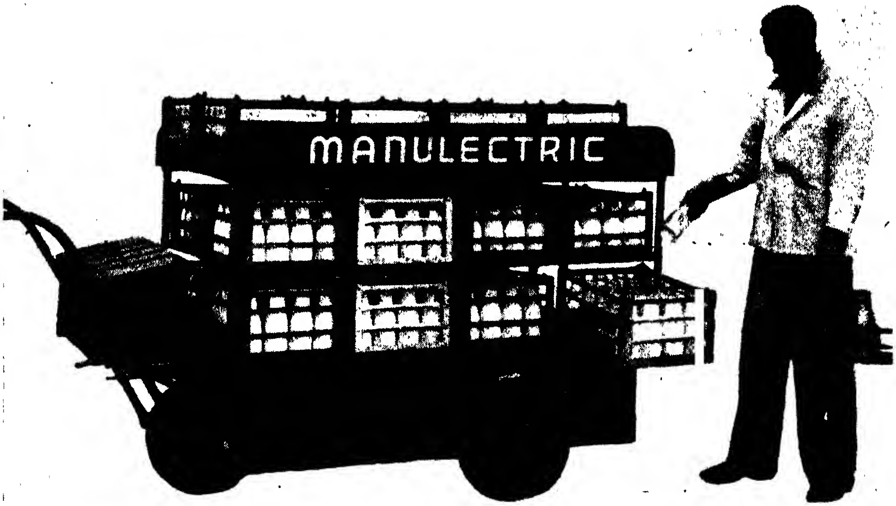


Fig. 23.—A BATTERY-ASSISTED MILK PRAM (*Sidney Holes*)

lightweight battery electric vehicles are called upon to perform. It is also difficult to provide comparative costs between one kind of transport and another because the conditions are rarely exactly alike.

At various times, costs for all kinds of operation have been published, but perhaps the most independent and most fair method, so far as a book is concerned, is to use the figures given in a paper on "The Electric Battery Vehicle," read before the Institute of Fuel in 1941 by Mr. J. M. Steele. He based his statement of comparative costs upon figures drawn up by "S. T. R." and published in the *Commercial Motor* and from them developed the curves shown in Figs. 17 and 18. These refer to two types of vehicle of 15- and 30-cwt. carrying capacity respectively, curves being given for both electric and petrol vehicles.

The data upon which the curves are based are given in Table V. The cost of electrical energy has been taken as being 1*d.* per unit, and depreciation on the electric allows for battery renewals every three years. Naturally, the operating cost in pence per mile is less as the mileage is increased, but on delivery work in towns, 300 miles per week may be considered to be the reasonable limit for a compact area where daily deliveries are made to regular customers. From the curves it will be seen that within this limit the electric is cheaper than the petrol in both cases.

It is interesting to notice that though the electric vehicle is the cheaper to operate, its standing charges are the higher, due largely to the cost of battery renewals.

TABLE V.—COMPARATIVE OPERATING COSTS

Class of Vehicle :	15 *Cwt.*		30 *Cwt.*	
Type of Vehicle :	*Petrol*	*Electric*	*Petrol*	*Electric*
Standing charges (per week) in shillings :	*shillings*	*shillings*	*shillings*	*shillings*
Licences	8·0	4·0	10·0	6·0
Wages	68·0	68·0	73·6	73·6
Rent and rates	5·0	4·6	6·0	6·0
Insurance	6·10	5·2	7·6	7·3
Interest	3·3	5·0	3·6	7·3
Maintenance	—	6·4	—	12·9
Depreciation	—	26·6	—	35·6
Total standing charge per week	91·1	119·6	100·6	148·3
Running costs in pence per mile (based on 300 miles per week) :	*pence*	*pence*	*pence*	*pence*
Fuel	1·3	0·42	1·9	0·60
Lubricating	0·08	—	0·09	—
Tyres	0·32	0·35	0·42	0·50
Maintenance (routine)	0·47	—	0·53	—
Maintenance (repairs and overhaul)	0·36	—	0·63	—
Depreciation	1·15	—	1·25	—
Total running cost in pence per mile	3·68	0·77	4·82	1·10

B. TYPES AVAILABLE

As is to be expected with an industry that has been growing rapidly in recent years, there are, under peace conditions, a number of types available ranging from propelled hand barrows, through tri-cars to the lightweight four-wheeled van with a body designed to suit a particular trade. There are also several makers, among which may be mentioned Morrison, "Metrovick," Midland, Murphy (Auto-electric), Cleco, Tomlinson, Wilson, and Tumilty. Each of these produces more than one type, and to describe every one in detail would be wearisome to the reader and would increase the size of this volume beyond reasonable limits. It will probably be of interest and value to the average reader to have a brief description covering each make.

Tri-cars

Three-wheel electric vehicles, being light in weight and enjoying low taxation, have proved very popular with smaller retailers, particularly dairies. In general the foregoing comments on technical points apply, but while in the four-wheeler the drive is invariably on the rear wheels, for a three-wheeler it can be either front or back, and the single wheel can be either front or back. With front-wheel drive there is a tendency to wheel slip on greasy roads and on gradients. Slip on gradients is always present, and is due to the fact that when climbing a hill there is a natural tendency for the front of the machine to lighten and for wheel-road adhesion to be reduced. With rear-wheel drive and front-wheel steering, the tendency when cornering at speed is for the stress to become greatest on the near and offside front, causing considerable strain on the steering head. A double front wheel, with drive on the back wheel, obviates these difficulties. The drive is generally arranged by means of a chain from the motor, which is mounted amidships. The payload for these vehicles ranges from 5 to 7 cwt. No three-wheeler is as stable under all conditions as a four-wheeler, but it has to be remembered that the speed of the electric need not be high. A maximum speed of 10 miles per hour is all that is usually wanted for a tri-car, which is really justified for use, in preference to a four-wheeler, only where it initially replaces the hand barrow of the dairyman and baker. The field for the three-wheeler is the compact delivery area in a town, as against the more widely distributed area of an urban district, where a four-wheeler should always be used.

Battery-assisted Prams or Barrows

The man-propelled milk pram or baker's barrow is still a familiar sight in the streets of towns, despite the strain that is placed upon the delivery man, especially in hilly districts. A year or so prior to the 1939 war, battery-electric prams or barrows were attracting attention. Generally they were three-wheel vehicles and virtually speaking a tri-car in miniature (except that the operator walked with the vehicle instead of being carried), and the speed provided for was about 3 miles per hour, the operator only having to guide the vehicle. The advantages are, of course, saving of fatigue for the delivery man, and a saving of time on the round.

A co-operative society tested out a milk pram of this type in 1938 over a period of three days on a 3-mile round involving ninety-six stops. On the first day 24 gallons were taken out on the early morning round and twenty minutes were saved. Thirteen gallons went out on the second delivery and forty-five minutes were saved. On the second day 24½ gallons went out on the first round and thirty minutes were saved, while on the second round 14 gallons went out and the saving was forty-five minutes. On the last day the loads were about the same, but thirty-five minutes were saved in the morning and 105 minutes on the afternoon found.

This type of vehicle should prove very advantageous to the smaller dairyman or baker having a compact round in the neighbourhood of the shop, and as an auxiliary in the fleet of the large firm for handling the near-the-depot routes.

The time saved is a definite advantage, in that the delivery man can endeavour to obtain new customers without extending his working hours or reducing the number of calls.

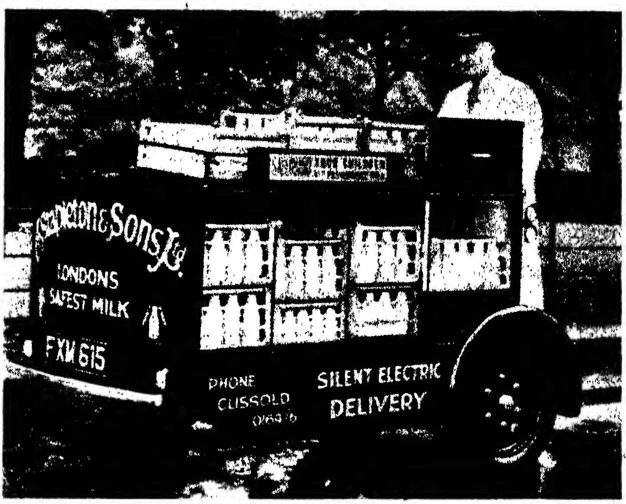


Fig. 24.—A MURPHY THREE-WHEEL SERVITOR USED FOR MILK DELIVERY

Three-wheelers

The next stage from the battery-assisted pram or barrow is the three-wheel vehicle or tri-car. These vehicles have the advantage of very low taxation, and as they can be provided with comparatively large storage capacity, they serve a very useful purpose where the load to be carried is limited and the delivery field is reasonably compact. The driver does not get weather protection, but he does get reasonably comfortable riding, and he is of course much better off than in the case where he has to operate a manual barrow.

One example is the *Nelco* three-wheeler, Type M.P.3, which is intended for rounds about 10 miles in length and has a full-load range of 35 miles per charge. All the wheels are sprung and fitted with large-section tyres to provide comfortable riding. The motor is rated at 1½ b.h.p., and is capable of withstanding overloads of 300 and 400 per cent. for short periods. The motor is mounted integral with the rear axle, driving through a silent, high-efficiency worm gear and differential. Steering is by means of the Nelco patent combined two-handled tiller, which embodies speed control. Four forward and two reverse speeds are provided for. A foot-operated brake is fitted together with a scotching brake, which has a separate hand lever. The overall length is 7 ft. 4 in., width 3 ft. 11 in., height 4 ft. 2 in., the track being 3 ft. 3 in. The body space measures 5 ft. 9 in. in length, 3 ft. 9 in. in width, and 2 ft. 7 in. in depth. The weight unladen including battery is 11 cwt., and the load capacity is 10 cwt., the speed on the level being 12 miles per hour. It is mainly intended for dairymen, and the body will accommodate 210 pint and 42 quart bottles.

The *Morrison* "*Trilec*" is an example of a chain-driven model. The single wheel is at the rear and the motor is carried amidships, driving the rear wheel through a heavy chain. The batteries are mounted on

Fig. 25.—A FLEET OF MORRISON-ELECTRIC VEHICLES USED BY BERTRAM HUGHES, LTD., OF BELFAST

either side of the main chassis members. A standard type of controller as fitted to the Morrison four-wheeler is provided, which gives four speeds by means of series-parallel connections. A " dead-man " control is used, consisting of a solenoid-operated main switch with magnetic blowout, the switch being foot operated against a spring. No matter what position the controller is in, the vehicle cannot move until the foot switch is depressed. Lifting the foot from the pedal switches off the motor, and the hands are free for steering and signalling. Steering is by wheel. Bendix-Servo brakes are applied to all three wheels. Heavy-type wheels are fitted, and the rear wheel is easily detachable without interfering with the drive. This vehicle, also, is intended mainly for use by dairymen. It is designed for a load of 7 cwt., but will handle 10 cwt. if necessary on occasion, and the body will accommodate 35 to 40 gallons in bottles, the body being fitted inside with steel rails to hold 15 to 20 crates of bottles.

There is also the *Murphy Servitor*, designed as an 8-cwt. quick-service vehicle, which can be fitted with a body for either milk or bread delivery. The motor is a 1½-h.p. traction type, and control is by a foot pedal, combined with tiller steering. The vehicle is fitted with Bendix brakes. Transmission is by totally enclosed worm gear and a robust parallel pinion differential. The range is 25–30 miles with 300 to 400 stops, and

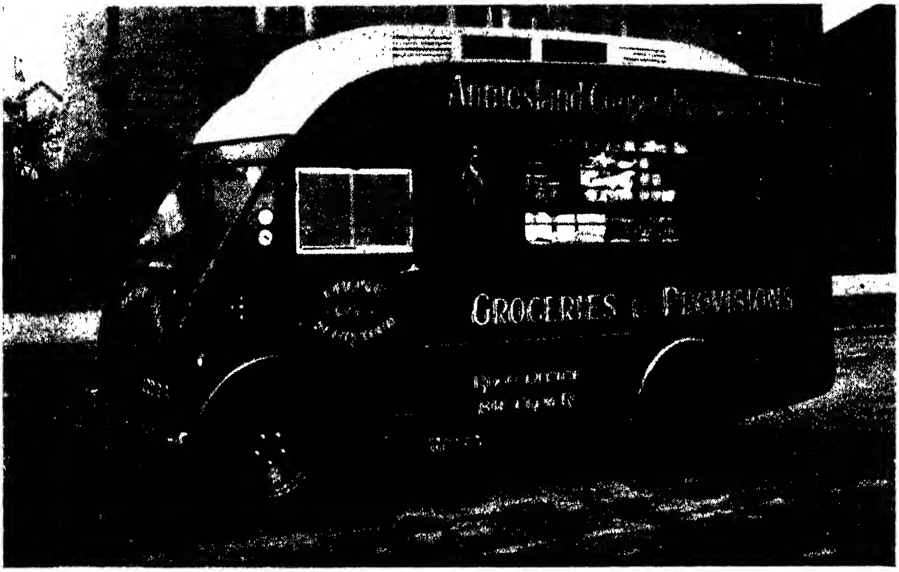


Fig. 26.—A MIDLAND ELECTRIC—WITH "SHOP WINDOW" IN SIDE OF BODY

an average speed of 12 m.p.h. The bread body will carry 100 quartern loaves and the milk body 180 pint bottles in standard crates.

The *Lewis* pram was designed specially to provide for conditions where hand prams had to be used in hilly districts. One speed only, 4 miles per hour, is provided for, the control equipment comprising a hand-operated contactor worked by means of rods attached to the handle bar. An interlocking arrangement is provided which comes into action when the parking brake is applied. The front axle is of one piece, banjo construction employing a spiral bevel reduction gear. The motor is of the series traction type, and the battery has a capacity of 144 ampere-hours, which is enough for a 10-mile journey and a load of 6 cwt.

The *Graisley* barrow, in common with the others, is a three-wheeler, has a $\frac{3}{4}$-h.p. motor, and is designed for a speed of 3 miles per hour. It can be obtained fitted with a flat platform body, an open-type body designed for the dairyman, and a closed-type box body for bakers, the daily mileage per charge being from 8 to 10 miles. The power unit consists of the motor, automatic clutch, and gearbox mounted on a platform securely bolted to the fork plates which house the driving and steering wheel. The contactor switch and steering head are also bolted to the fork plates, so that the whole forms a complete power and balanced steering unit, fitted to the head bracket by means of a king-pin. The final drive is by means of a chain. Power is applied by operating a control lever fitted to the steering handle, the lever being connected by rods and roller joints to the contactor switch.

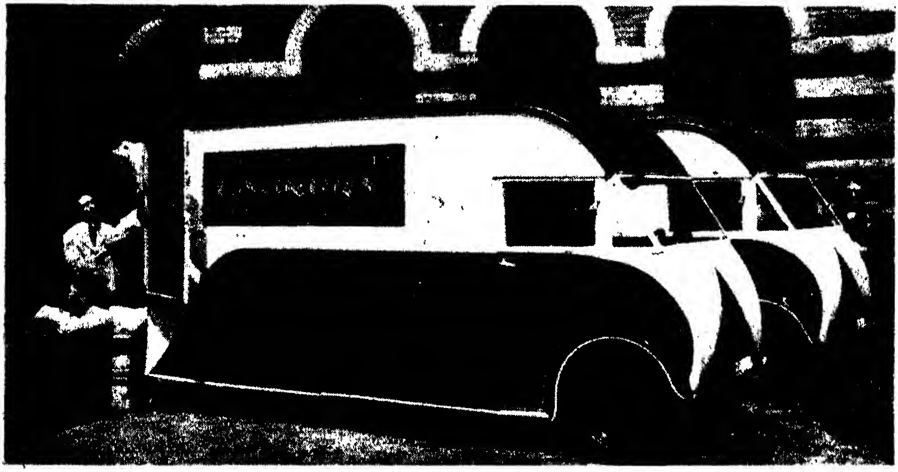


Fig. 27.—MIDLAND ELECTRIC FOR LAUNDRY DELIVERY
The body has a capacity of 250 cubic feet.

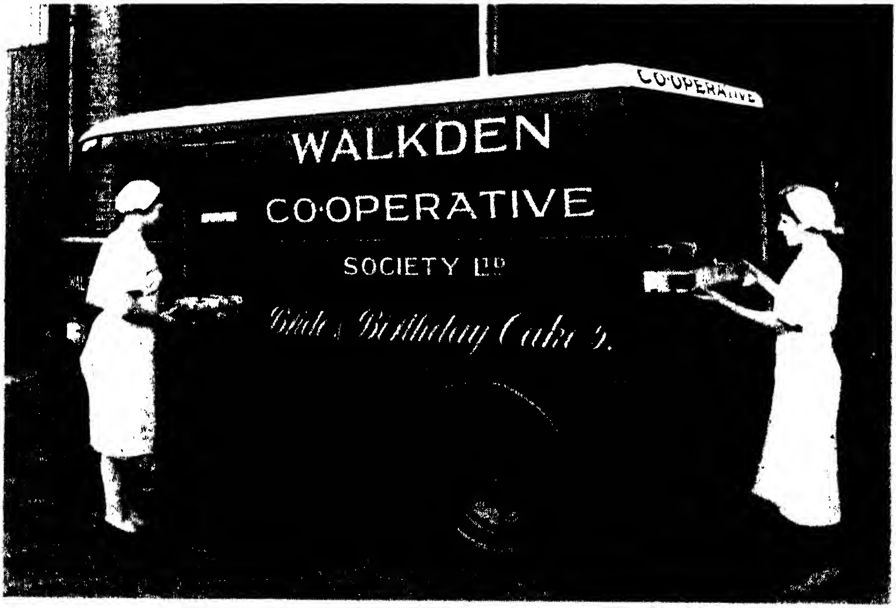


Fig. 28.—A " METROVICK " ELECTRIC FOR BAKERS
Note the separate compartments for cakes and pastries at the side. Bread is loaded from the rear.

There is also in this class the *Sidney Hole* "*Manulectric*," which has an open-type body specially intended for use by dairymen. It is designed to carry 16 standard crates inside and 8 on the top, making a total of 480 bottles. The range is 10 miles per charge. A series motor is used, but the particular point is the method of control, which is effected by a handle, the movement backward and forward of which engages the brakes on the motor, the control being by springs. These springs are compressed by the forward movement of the control handle, and the motor starts. When the initial inertia of the vehicle has been overcome on a level road, the motor switch automatically switches off and the vehicle coasts on its free wheels, the motor automatically switching on again when the vehicle reaches a gradient.

Four-wheelers

The *Morrison-Electric* was standardised into three types in 1941. These are rated respectively at 10 cwt., 20 cwt., and 40 cwt. The frames in each case are built up from pressed steel and the front axles are of the Akerman type, with roller-bearing hubs. The motors are of the series traction type. The rear axles are of the special bevel type, taper roller bearings being fitted to the first two models, roller-bearing hubs to the 40-cwt. model. The controllers are of the solenoid contactor type, giving three speeds, reversing being arranged through a hand-operated reverse switch. The foot controller has an automatic delayed action. Four-wheel brakes are used with all models, Lockheed hydraulic being used for the 10-cwt. and 40-cwt. vehicles and Bendix for the 20-cwt. model. A removable key operates a safety switch to guard against the vehicle being set in motion when left unattended. The performance for the 10-cwt. and 20-cwt. vehicles is 30 to 35 miles per charge on the basis of average half-load with approximately 100 stops and starts. Both the 10-cwt. and 20-cwt. vehicles are intended for use as utility delivery vans, and the standard body sizes are 6 ft. 4 in. length, 4 ft. 3 in. width, 3 ft. 7 in. height; and 9 ft. 6 in. length, 5 ft. 1 in. width, 4 ft. 5 in. height, respectively. The cab is of the open type, but can be fitted with doors, and the rear door is of the sliding shutter pattern. The 40-cwt. model has a flat deck which measures 12 ft. 9 in. in length by 6 ft. 4 in. in width.

There are five models of the *Midland* electric, B12, BA12, B20, B25, and B30, the payloads being 10/12, 12/15, 18/22, 25/28, and 30/35 cwt. respectively, and the B20, B25, and B30 models are supplied as either vans or lorries. The motors are of the series type and the motor is so mounted that the commutator projects into the driver's cab to provide for easy inspection. The controller is pedal operated, with an air delay action, and quick make and break contactor-type control fingers operate with magnetic blowouts (Fig. 38). The frame is specially designed to give a combination of low entrance behind the front wheels and a low centre of gravity, together with facilities for quick withdrawal of the batteries.

Steering gear is of the Marles-Weller cam and lever type, and a foot brake acts on all four wheels, while the hand brake operates on the rear wheels only. The propeller shaft is of the Layrub type.

The standard body dimensions are as follows, the figures being given in the order of length, width, and height: B12—7 ft. × 4 ft. 9 in. × 4 ft.; BA12—the same; B20—9 ft. × 5 ft. 4 in. × 4 ft. 4 in.; B25—9 ft. × 5 ft. 4 in. × 4 ft. 4 in.; B30—9 ft. 6 in. × 5 ft. 6 in. × 5 ft. 6 in. The platform of the lorries measures practically the same as the floor of the vans.

The *Cleco* electric has several interesting features. In the first place, a mercury controller is used in place of the usual type, and this is sealed, it being claimed that no maintenance is necessary. In the second place, the chassis is an electrically welded unit, no bolts being employed, and the front end is dropped to give a low floor to the driving cab; and in the third place, it employs a battery of the light-plate type. The mercury control system employed gives speeds of 14, 24, and 30 m.p.h. by means of a preselected hand lever, and it is impossible to run the motor in intermediate positions for more than 1 or 2 seconds. At the intermediate positions resistances are incorporated to ensure smooth application of torque at the preselected speeds, and they are in use for such a short time that losses are very small. The first speed is obtained by placing two 32-volt batteries in parallel, the second by placing them in series, while the top speed is attained with the batteries in series but with the motor field current partly diverted. Whenever the foot is taken off the switch the controller automatically returns to the starting position for the speed preselected, in readiness for application of power again by the foot. A hand control is provided for use when manœuvring or driving under icy road conditions. The motor is of the traction type, the drive being transmitted to the rear axle by an open propeller shaft incorporating a Hardy-Spicer needle-roller universal joint. The rear axle is of the heavy-duty semi-floating pattern, with helical bevel crown wheel and pinion incorporating thrust-cancelling double-reduction gear. Bendix-Servo "Single Anchor" brakes are fitted operating on all four wheels, independently by foot pedal or hand lever. Two models are made, "A" and "B," being rated at 5/10 and 12/20 cwt. respectively. The range (with a standard Cleco 60-volt 140-ampere-hour battery for smaller and a 50-volt 200 ampere-hour battery for the larger model) is 25 to 43 miles when operating on house-to-house delivery. The closed van body for the "A" model measures 3 ft. 7 in. in height, 3 ft. 9 in. in width, and 8 ft. 5 in. in length, while the dimensions for the "B" model are 3 ft. 9 in., 4 ft. 10 in., and 9 ft. 7 in. There is also a dairy body.

"*Metrovick*" electrics are built in four sizes, 7/9, 10/14, 18/22, and 25/30 cwt. The motor is of the series-wound traction type, designed to give high overload capacity. The controller is a foot-operated drum, which in two strokes of the pedal accelerates the vehicle from rest to full

Fig. 29.—A SUNBEAM ELECTRIC FITTED WITH A VAN BODY

Roller-shutter doors are placed on either side in addition to full-width doors at the rear.

Fig. 30.—A MIDLAND ELECTRIC MODEL B20, 18/22-CWT. PAYLOAD

With platform-type body for coal delivery.

Fig. 31.—A SUNBEAM ELECTRIC
With body specially designed for milk delivery. This vehicle is one of a fleet supplied to the Wolverhampton and District Co-operative Society.

Fig. 32.—A 10/12-CWT. VICTOR ELECTRIC
The open doorway saves time in leaving and mounting the vehicle.

speed through six continuous torque stages. An economical running speed, corresponding to half full speed, is provided at the end of the first (pedal) stroke to enable the driver to proceed at reduced speed in traffic or in fog, without running with resistances in circuit. This is done by means of battery connections reducing the voltage applied to the motor and of course the speed. The controller pedal, upon being allowed to return fully to the commencement of either the first or second stroke, automatically results in the main drum returning to the " off " position. This automatic trip is supplemented by another tripping device actuated by the foot-brake pedal, which cuts off the power when the brakes are applied by the foot pedal, and makes it impossible to drive the vehicle under power with the foot brakes applied. A cam-actuated contactor with a magnetic blowout system works in conjunction with the controller drum, to reduce sparking when stopping and starting. A forward-reverse switch is provided which will act as an emergency switch for breaking the power circuit. The chassis frame members are of all-welded box section dropped at the front to give access to the driving seat. A Layrub propeller shaft is used, and the rear axle is of one-piece banjo construction employing helical first-reduction and spiral bevel final-reduction gears. On the 25/30-cwt. chassis the axle is of the fully floating type, and on the other models is of semi-floating design. Lockheed hydraulic brakes are applied on all wheels, and the hand brake operates on the rear wheels. A number of standard bodies are available : general purpose, open dairy, semi-closed dairy, bakery, streamline, and open lorry. As an example of sizes and capacities, the general-purpose van body measures, in the order of height, length, and width : 3 ft. 8½ in. × 6 ft. 7 in. × 4 ft. ; 3 ft. 10 in. × 7 ft. 3 in. × 4 ft. 7 in. ; 4 ft. 2½ in. × 7 ft. 9 in. × 5 ft. 1 in. ; 4 ft. 9 in. × 9 ft. 11½ in. × 5 ft. 5 in. respectively for the four models 7/9, 10/14, 18/22 and 25/30 cwt. Each model is obtained in a number of variations so far as battery capacity and number of cells are concerned, to suit various payloads, and the range of travel per battery charge varies accordingly.

So far as the lightweight electric vehicle is concerned, which for the purpose of this chapter has been taken as being vehicles up to 40 cwt. payload, *Wilson* electrics are made in four models : as 7/10, 15, and 18/25 cwt. delivery vehicles, and a 40-cwt. lorry. Series traction-type motors with Class B insulation are used in all cases. Likewise Bendix brakes are used in all models. The controller for the smallest type, i.e. 7/10-cwt. van, is of the drum pattern, and has a constant delay-action controller, the other vehicles are fitted with a fluid foot controller. The drum controller effects speed control by series-parallel connection of the motor-field circuit, the actual making and breaking of the circuit being done by an interlocked contactor and not by the drum itself, the contactor being fitted with a magnetic blowout. The contactor is foot-pedal operated. A key switch switches off the pedal circuit, and removal of the key gives security against unauthorised operation. The Wilson fluid automatic controller comprises a set of resistances, two double-pole contactors (one for forward and one reverse), and three single-pole contactors for cutting out resistance in steps, together with a relay mechanism with foot-pedal control (Fig. 37). A forward-reverse push-button switch is mounted on the dashboard. The Wilson constant delay-action speed controller has four contactors, which are operated mechanically by depression of a foot pedal, which rotates a camshaft and brings them into circuit successively (Fig. 36). Release of the pedal restores them all to the off position, and too rapid operation is prevented by a hydraulic pressure unit, which restricts the rate of rotation of the camshaft. On the smallest model, transmission is by a hollow steel propeller shaft, with Hardy-Spicer flexible couplings to a spiral-bevel rear-axle gear. On the intermediate models and the lorry, transmission is direct from the motor to an overslung worm-drive back axle through a propeller shaft fitted with Hardy-Spicer needle-roller joints. There is also a lorry with a tipping body designed for a payload of 30 cwt. The Wilson-Scammell electric horse is dealt with in another chapter. The body dimensions of the 7/10-cwt. model are : length 7 ft. 3 in., width 3 ft. 9¾ in., height 3 ft. 3 in. The bodies for the 15-cwt. models measure : length 7 ft. 3 in., width 4 ft. 8 in., height 2 ft. 11¼ in., and those of the 18/25-cwt. model are : length 8 ft., width 4 ft. 7 in., height 3 ft. 3 in.

The *Sunbeam* electric is rated at 12/15 cwt., and is fitted with a series traction-type motor, controlled by a bar-type accelerator pedal which actuates a master controller. The master-controller switch consists of a number of contacts of the interlock type which bring into operation magnetic contactors, the master controller carrying only sufficient current to operate the solenoids on the main contactors, which are electro-magnetically controlled. Resistance is placed in circuit on the first two points of control. A reverser switch is mounted on the contactor panel. The front axle is of the reversed Elliott type, with an I-section beam, the hubs being mounted on taper roller bearings. The rear axle is of the double-reduction spiral-bevel gear-driven pattern, the main section being in the form of a pressed-steel banjo, and the differential unit can be quickly withdrawn as one piece. The transmission consists of a short tubular shaft from the motor to the rear axle, with a Hardy-Spicer needle-roller universal joint at each end. The main frame is built up from high-tensile-steel pressings. Bendix brakes are fitted to all wheels, and the foot and hand brakes operate on all wheels. Body dimensions vary with the type, but the platform space behind the driver's cab measures 8 ft. in length by 4 ft. 11¼ in. in width. A long-chassis model is also available giving a platform length of 9 ft., and there is a short-chassis model which has a platform length of 7 ft. 3¼ in.

Victor electrics in the lightweight range comprise five models rated as 8/12, 12/15, 15/20, 20/27, 30/40 cwt. The motors and controllers are

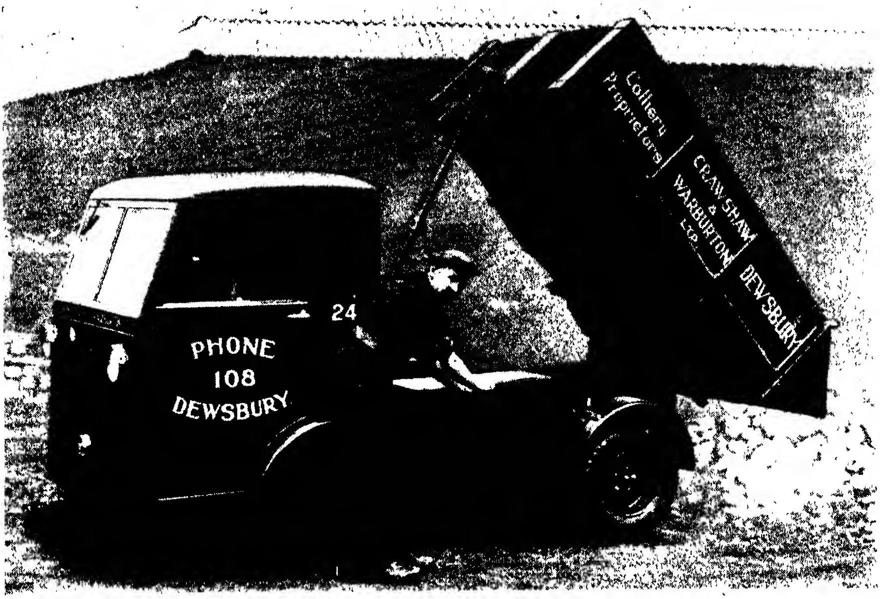


Fig. 33.—PARTRIDGE WILSON ELECTRIC
With tipping body for delivery of coal.

Fig. 34.—AN 8/10-CWT. MURPHY ELECTRIC
With body designed for the delivery of dairy produce.

Fig. 35.—MORRISON-ELECTRICS USED BY A DYER AND CLEANER

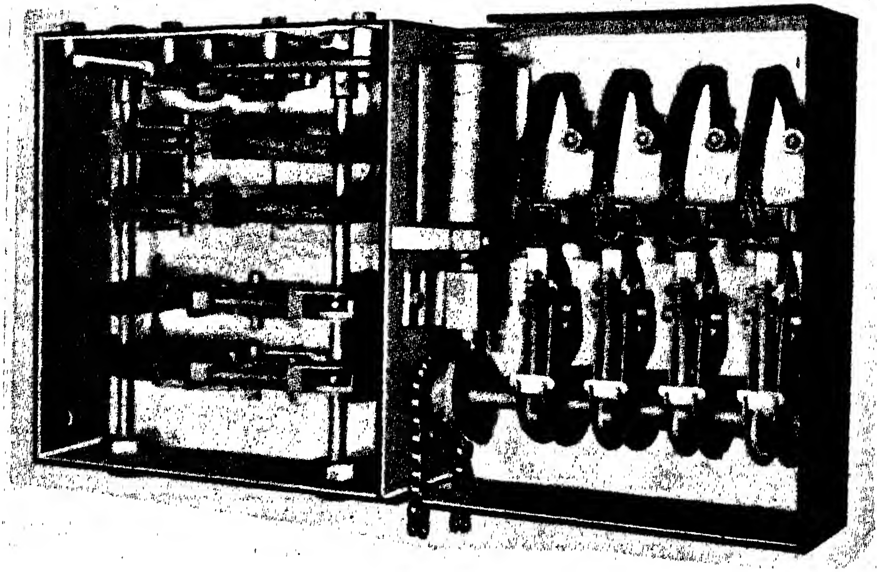


Fig. 36.—CONSTANT DELAY-ACTION SPEED CONTROLLER
(*Partridge Wilson & Co., Ltd.*)

of Victor manufacture, the controllers being available for either hand or foot operation. The usual top speed is 15 to 17 m.p.h., controlled in three or four stages, but 20 m.p.h. can be provided for if required. The brakes operate on all four wheels. The 15/20 and 20/27 models are fitted with Bendix brakes. Batteries of 60 volts are standard; battery capacity varies with the mileage range required. The body dimensions of the various models are as follows: 8/12 cwt.—length 6 ft. 6 in., width 4 ft. 2 in., height 3 ft. 6 in.; 12/15 cwt.—length 7 ft. 6 in., width 4 ft. 6 in., height 3 ft. 6 in.; 15/20 cwt.—length 8 ft., width 5 ft., height 4 ft.; 20/27 cwt.—length 8 ft. 3 in., width 5 ft. 3 in., height 4 ft. 6 in.; and 30/40 cwt.—length 9 ft. 3 in., width 5 ft. 6 in., height 4 ft. 6 in.

The *Tumilty* electric is designed for a payload of 10 cwt. and is intended for use as a low-loader delivery van. The chassis is built up from channel steel with electrically welded joints, the front being dropped to give a low entrance to the cab. The front axle is a drop forging arranged for forward control by Marles-Weller steering. Transmission is by a tubular shaft direct from the motor through Hardy-Spicer needle-bearing universal joints to a spiral-bevel final drive, in the rear axle, there being no double-reduction gearing. The brakes are Bendix cable, operated with a Bendix compensator centrally disposed in the chassis, operating on all four wheels. A slow-speed totally enclosed motor is used, designed for correct road speed when directly coupled. Four speeds are obtainable by direct switching through a foot-operated mechanical delay unit. In operation the foot pedal can be fully depressed, leaving the delay unit to maintain a predetermined rate of acceleration, which can be adjusted to suit various classes of duty. The control unit operates a master contactor panel to avoid sparking on the controller fingers. Starting resistances are not employed, and it is claimed

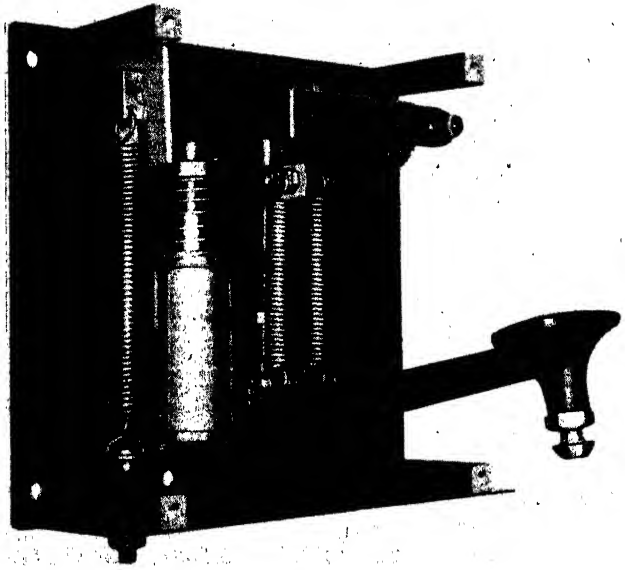


Fig. 37.—AUTOMATIC FLUID CONTROL DEVICE FOR BATTERY VEHICLES (*Partridge Wilson & Co., Ltd.*)

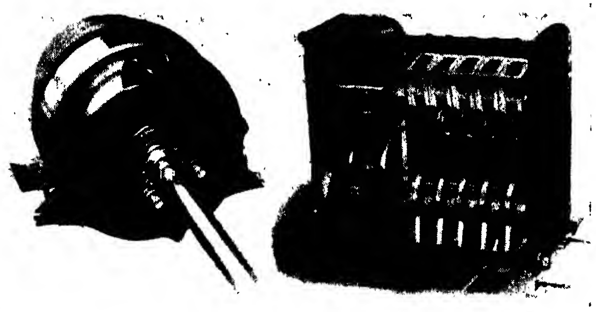


Fig. 38.—Motor and controller for Midland vehicle

that as a result, together with the care taken to reduce electrical and mechanical losses generally, consumption is low, and the 24-cell 162 ampere-hour capacity battery, fitted as standard, will give a range of 35 to 40 miles per charge. with a speed range of 18 to 20 m.p.h. on average service.

The *Murphy* electrics, known as Auto-electrics, have several distinctive features. The drive is direct on to the rear axle through a single-reduction double-helical gearing, no universal joints or propeller shaft being employed. The power unit is a Nelco totally enclosed series traction-type motor, specially designed, not only to give high efficiency, but to operate as a totally enclosed machine without overheating and without special ventilation. Thus the utmost protection against dust and dirt can be provided.

The battery containers are made of aluminium instead of the more usual wood, thus obtaining better protection against fire, and freedom from deterioration from soaking by acid. The controller is of simple design, and provides for a continuous torque, the circuit not being broken between speeds. A series-parallel main battery switch, fitted with a removable key, gives a choice of two ranges of speed by placing the battery sections in parallel or series. The chassis, instead of following the usual private-car design, is patterned on the lines of a heavy-duty vehicle, large-diameter tubular cross members being employed to resist torsional stresses.

Bodies

As will be inferred from the foregoing descriptions, a number of types of bodies can be fitted to lightweight electric vehicles, and, to suit customers' requirements, special types such as those designed as travelling shops, or specially large bodies for carrying light but bulky loads, etc. The general user is a retail trader, and the majority are dairymen, bakers, stores, co-operative societies, etc. It is not possible, within the limits of a volume such as this, to include particulars of every type of body fitted by every maker, so the accompanying diagrams, which relate to "Metrovick" electrics, have been chosen as being generally representative of the trend in standard body design. Some of the photographs included indicate a number of special models by various makers.

The "Metrovick" diagrams (Fig. 40) refer to six types, the general description being as follows :

Type 1 (Open Dairy).—The load space is roofed over, but both sides are open from the floor sills to the roof cant rail, while a fixed steel panel containing a reversing window completely closes the back. A partition extending the full width and height of the body separates the cab from the load space, and a window gives the driver a clear view rearwards through the body. The cab has half-length doors.

Type 2 (Semi-closed Dairy).—Similar to Type 1. The fixed rear panel is omitted and the sides are enclosed, except for an opening on each side at the forward end.

Type 3 (Bakery).—This is a simple box-type van, with a separate forward end for confectionery, access to which is obtained through either sliding or hinged doors. This compartment has six equally spaced rows of angle-iron tray supports, and the width can be made to fit any size of tray. The rear compartment has a shelf at mid-height running the full length and width of the compartment. Two hinged rear doors are fitted, each having a window and ventilating louvre. The cab has half-length doors.

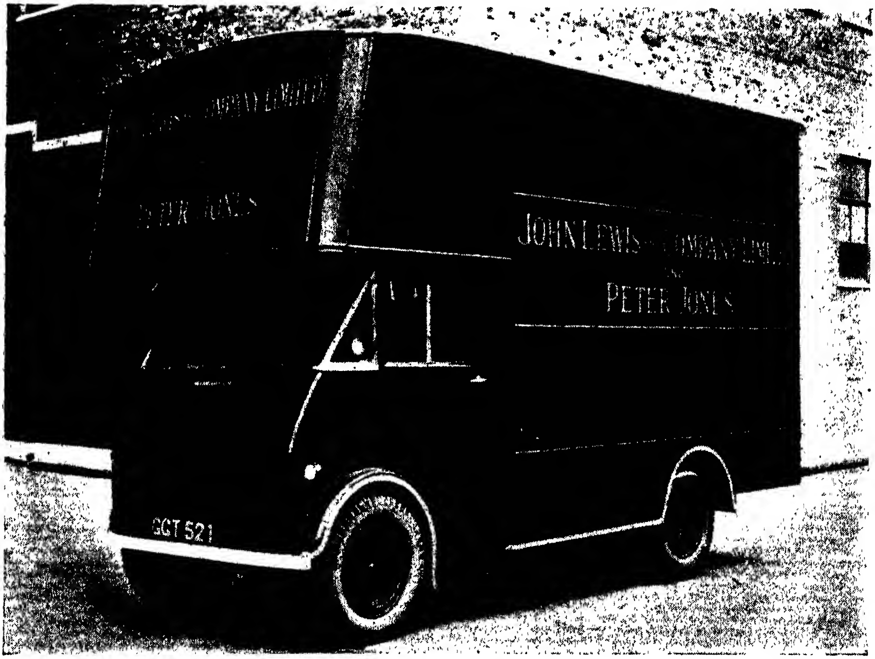
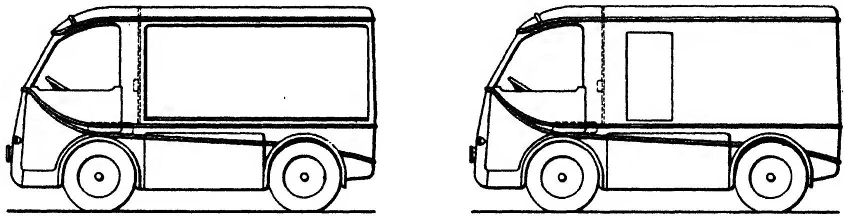
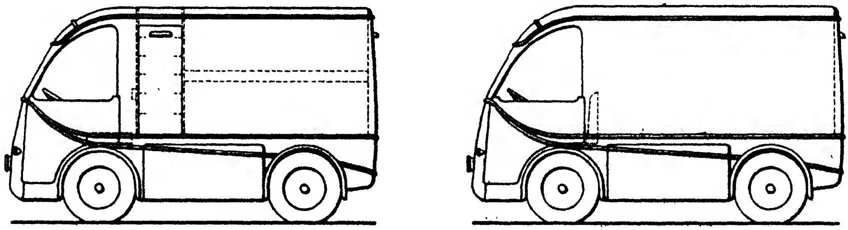


Fig. 39.—A Midland electric
With special body to take bulky loads, such as carpets, lino, etc.



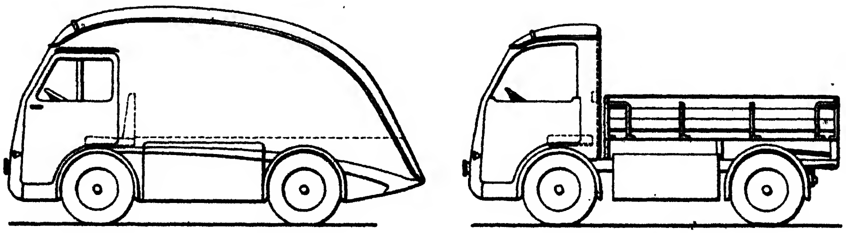
TYPE 1. OPEN DAIRY

TYPE 2. SEMI-CLOSED DAIRY



TYPE 3. BAKERY VAN

TYPE 4. GENERAL PURPOSE VAN.



TYPE 5. STREAMLINE VAN.

TYPE 6., OPEN LORRY.

Fig. 40.—Outline body designs ("Metrovick")

TYPE 4 (GENERAL PURPOSE OR UTILITY VAN).—A simple box-type van body without any interior partitions or fittings, but otherwise similar to Type 3.

TYPE 5 (STREAMLINE VAN).—An attractive body having publicity value and a very general application as a delivery vehicle. The entrance to the load space is by means of a sliding roof, which can be fastened in any raised position, and a drop-down hinged rear door, which is easily detachable to enable lengthy articles such as ladders, carpets, lino, or conduit, etc., to be carried. The drop-down door has two reversing windows of safety glass and a built-in step which facilitates entry to the load space when the door is lowered. When the body is fully opened up, heavy articles can be loaded directly into the vehicle by crane. Full-length doors are fitted to the cab.

TYPE 6 (OPEN LORRY).—A plain, non-tipping-type lorry with drop-down sides and tailboards. The cab has half-length doors, while the window in the cab wall is protected by iron bars, and iron wearing strips are suitable placed on the floor. Similar bodies can be arranged to have either hand screw or hydraulic tipping gear.

An interesting point in connection with vehicles for dairymen was brought out by Mr. H. G. Wilson, A.I.E.E., M.Inst.P.I., in an article in *Electric Vehicles* (vol. XXII, p. 315) which he wrote after visiting the Dairy Exhibition in 1938. At that exhibition he noticed the " Satona " machine for packing milk in cartons, the machine being designed to make the waxed-paper cartons and also fill them with milk. Three gallons of carton-packed milk, housed in light wooden crates, weigh 35 lb., as against 78 lb. for a similar quantity in bottles. This gives a weight ratio of 1:2·2. There is also a saving in accommodation, i.e. space. The advantage is that not only does the milkman save the loss occasioned by broken bottles, but he is enabled to use the smallest and least expensive electric vehicle of the 7/8-cwt. class to accommodate 70 to 80 gallons of milk. There is also the point that with cartons the load is gradually decreasing as the round is being completed, while with bottles the empties have to be carried back to the depot.

Vehicles for Postal Services

Considerable use is made on the continent of electric vehicles for both the postal and telegraph services, but in this country progress has been slower in this connection, though experiments have been made at various times over a period of years. Toward the end of 1942, a fleet of " Metrovick " electrics were put into operation by the G.P.O. in a northern provincial town and replaced some light petrol vans. The vehicles were the equivalent of the " Metrovick " standard 10/14-cwt. chassis, modified where necessary to suit body requirements, which called for a shortening of the longitudinal chassis members at the rear.

The vehicles were designed for a payload of 8 cwt., in addition to a crew of two, and are capable of running 42 miles on a charge with full-rated battery capacity, average payload of 4 cwt. (and crew of two), in a reasonably level district with eight stops a mile. They will attain a speed of 20 m.p.h. on the level and 8 m.p.h. up a gradient of 1 in 10, with average load of 4 cwt. in addition to the crew of two. They are intended for a service involving a scheduled daily mileage of 30 for six days per week, and are driven by women drivers.

The chassis frame is of all-welded box section rigidly braced by transverse members carrying the batteries and equipment. Transmission is effected by a Layrub propeller shaft which, owing to the absence of mechanical joints, requires no lubrication. The road springs, fitted with Silentbloc bushes, are of the orthodox semi-elliptic type. The semi-floating rear axle employs helical first reduction and spiral-bevel first drive. The steering gear is of the Burman-Douglas pattern, which gives a light and positive action. The Lockheed hydraulic brakes are fitted on all four wheels, the hand brake operating mechanically on the rear wheels only.

The bodywork consists of ash framing and steel-faced plywood panels built on ordinary electric-vehicle lines, but designed with short overall length to conform with G.P.O. practice. Advantage was taken in the body design of the opportunity to introduce electric-vehicle methods of light yet robust construction, without omitting any of the essential features of the standard G.P.O. design, which is the result of very extensive experience under operating conditions in all parts of the country.

The motor is of the series-wound traction type. The controller is of the drum type and is pedal-operated. It is combined with a change-over switch with hand lever for forward or reverse running.

The controller connects the battery halves successively in parallel and in series, thereby giving two economical running speeds and keeping resistance losses to a minimum. One full depression of the pedal takes the controller through two resistance stages to the half-speed position with the batteries connected in parallel. Allowing the pedal to return about three-quarters of its stroke and depressing again to the full extent, progress continues through two resistance stages with battery sections in series to the full-speed position. These six steps, with continuous torque transmission, enable smooth and rapid acceleration to be obtained under all conditions, the economic half-speed being very useful for working in fog or dense traffic.

Chapter IV

VEHICLES IN MUNICIPAL SERVICE AND FOR HEAVY DUTIES

ELECTRIC vehicles in this country, so far as use in numbers is concerned, date from the 1911 to 1914 era, that is, from just before the European War of 1914–18, and it was during that war that considerable development first took place in connection with the use of these vehicles for municipal service, which in the main was related to the work of cleansing departments. There were, during that period, heavy vehicles, i.e. 2- to 3-tonners, in use by electricity supply authorities, notable among which was West Ham, but in general it was refuse collection that constituted the largest field of application.

Vehicle design at that time had not progressed to the present stage, and the really lightweight vehicle, i.e. the 7/9- or 10/14-cwt. vehicle, was not thought of, and when progress continued during the early post-war (1919) period, the electric delivery vehicles generally employed by such firms as Whiteley's, Harrod's, Carter Paterson, etc., were 1- and 2-tonners, while a number of 2-, 2½-, and 3-tonners were used by a few coal merchants for retail delivery.

It must be remembered that the petrol lorry had not been developed to the standardised, mass-production, low-price stage that it has to-day, and the electric was the direct competitor of the horse. The old horse-drawn dust cart is mostly, and should be completely, a relic of the Victorian days, when many long petticoats were worn presumably to harbour dust.

It was then, so far as electrics are concerned, a new field, and while experience was being gained every year, the maker was largely subject to the whim of the municipal officer who ordered the vehicle. Each vehicle was the subject of a specification and in those days represented a considerable expenditure. They won their way, however, and ultimately proved that a life of twenty or more years, so far as the vehicles were concerned, was not unusual, though of course batteries had to be replaced. In the early days batteries were only guaranteed for two years, and the extension to three, which rules at the present time, with a probable life of four years, helped development very materially. The battery was a comparatively costly item, and it was by no means easy to justify this cost to the minds of the City Fathers, even though it was virtually petrol purchased in advance.

Pioneer Work

Great credit is due to the early pioneer manufacturers—Electricars, Ltd., the General Vehicle Co., Ltd., and Ransomes, Sims and Jefferies,

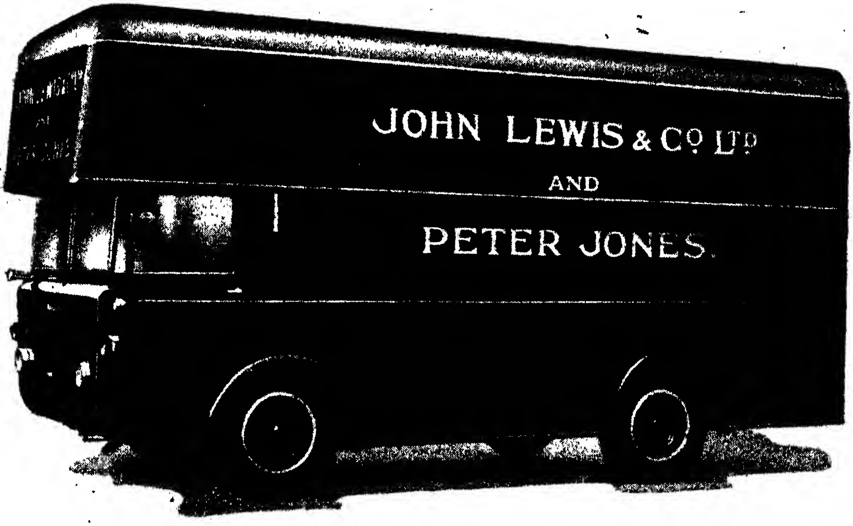


Fig. 41.—50-CWT. MORRISON-ELECTRICAR VAN

Ltd., who sank much capital in the venture. At a later date Richard Garrett & Sons entered the field and supplied a number of vehicles to Glasgow and other local authorities. They were, in basis, mainly lorries fitted with hand- or power-operated tipping gear, and the only protection against dust blowing about the streets was often a poorly tied tarpaulin. As development took place, special bodies were built with the aim of obviating this disadvantage, and the refuse collector of this pre-war period, i.e. 1939, bears but little resemblance, so far as the exterior is concerned, to its pioneer predecessor of the 1915–20 period.

Refuse Collection

Cleansing work in towns is of course ideally suited to the electric vehicle, as it entails a call at defined intervals upon every occupied building or house in the area. This is definitely frequent-stop-and-start working which so largely increases both running and maintenance charges for petrol vehicles. In addition, in some towns, Glasgow being an example, the refuse is burned, and in burning is used to generate electrical energy in a power station, the output from which is partly used for charging the batteries of electric vehicles, which of course leads to very economical operation.

For example, in the year before the war, i.e. the year ending March 31st, 1939, the report of the Director of Cleansing for the City of Glasgow showed that at the Govan works, where the refuse is burned in the generation of electricity, a total of 159,743 tons of refuse was dealt with, the electrical energy generated therefrom amounting to nearly 39,000,000 units, the whole of which, less the amount required by the Cleansing Department, was sold to the Corporation Electricity Department, thus, of course, reducing the cost of cleansing and refuse collection.

A mixed fleet was operated and the streets to be covered amounted to 768 miles. The number of electrics in use was 67, and although, because Glasgow was a pioneer, many are very old, they were worked on a double shift, and collected 62 per cent. of the bulk of refuse conveyed by the department's vehicles.

Birmingham provides another example. In this town a large fleet of electrics is employed, Electricars being the type favoured. In 1935, electrics collected 224,000 tons, which amounted to 91·6 per cent. of the total refuse transported. The total fleet of electrics then numbered 148. This is equivalent to the work that would be done by about 320 to 350 horses and carts of the type that the original electrics displaced.

Wallasey and Grimsby provide other provincial examples, while Blackpool is a good instance of the use of electrics in a seaside resort which takes great care to ensure that, despite seasonal tripper activity, the town always presents a clean appearance.

Several of the London Metropolitan boroughs use these vehicles, and a

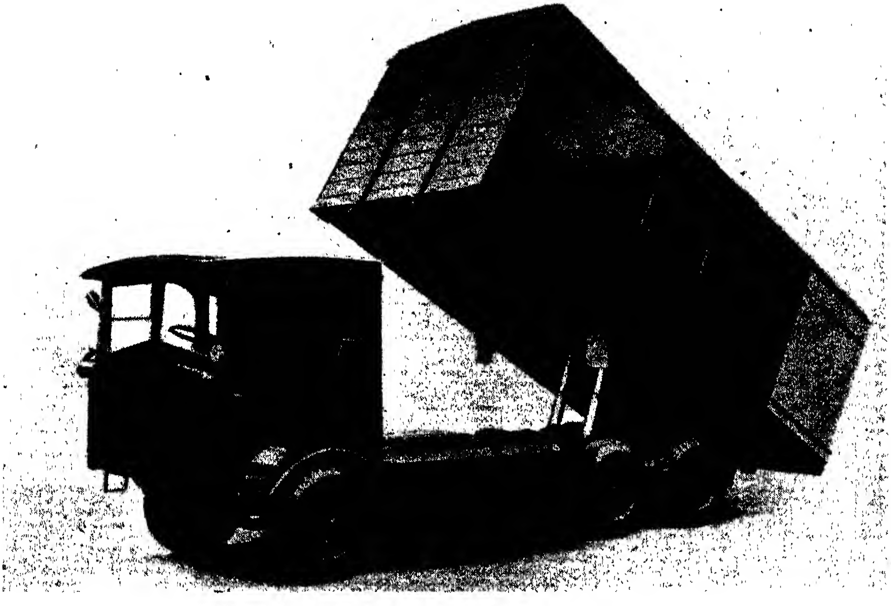


Fig. 42.—A G.V. ELECTRIC
With dustproof tipping body for refuse collection.

Fig. 43.—A 2½-TON ELECTRIC VEHICLE
Used for heavy deliveries (*Tilling-Stevens, Ltd.*)

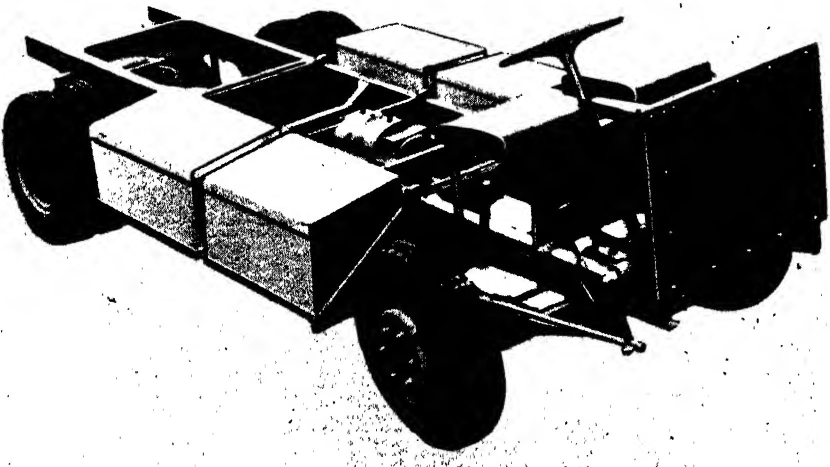


***Fig.* 44.—Chassis of a Tilling-Stevens 3-ton electric vehicle**
(*Tilling-Stevens, Ltd.*)

good example of the latest modern practice is provided by the City of Westminster, which possesses one of the most comprehensive public cleansing services in existence. The Director of Public Cleansing, Mr. H. Arden, M.B.E., A.M.I.Mech.E., has had very extensive experience in the use of electrics in the cleansing service, and they are a distinctive feature at Westminster.

The work to be done includes the provision of a sanitary service for large blocks of flats, hotels, shops, offices, fruit markets, etc., involving 100 miles of streets ; and calling for the collection of between 300 and 400 tons of refuse before 9 a.m. each day which has to be disposed of, and in addition the street-cleansing service has to be maintained.

After about 1920, more and more attention was given to the design of bodies so as to cater for the collection of bulky refuse and to prevent the nuisance of dust blowing about as the vehicles travelled from street to street, or street to depot. This tended to efficiency, not only in regard to cleanliness, but also in regard to the fact that a light bulky load could fill a lorry but did not load it to its full rated payload. Enclosed-type bodies with shutter windows then came into use, and a number of loaders worked with each vehicle.

Trailer Operation

The next stage was the introduction of large trailer containers drawn by a " mechanical " horse, and in the case of electrics it was an electrically operated appliance. By this means work could be staggered, that is, an empty container could be left in a street for the loaders to fill, in cases where the length of carry was not large, e.g. blocks of flats, while the tractor took a full container back to the depot. Where carries were longer, the vehicle could operate as an ordinary lorry, but provided more carrying space.

The use of a tractor or " electric horse " also enabled an electric to be used for more than one purpose, i.e. the trailer unit could be a refuse collector, water sprinkler, or gully emptier, whereas previously these were generally separate vehicles possessing their own motive power —petrol or electric.

Westminster as an Example

Returning to Westminster as the example,[1] a mixed fleet is employed, petrol and electric, the electrics being twenty-six Electricar tractors for hauling two-wheel trailer units fitted with automatic couplings. The trailer units are in the form of refuse collectors, street sprinklers, washers, and gully emptiers. In addition, the department used a 10-cwt. and a 25-cwt. electric van.

The Electricar horse carries the loaders and the batteries, as well as

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[1] *Electric Vehicles*, vol. XXIII, pp. 229 and 252—" Public Health," by Frank Slade, A.M.I.Mech.E.

the driver, and was specially designed, not being an adaptation of an existing mechanical tractor. The front wheel has a taper-roller thrust bearing to provide for easy steering, and the rear axle has fully floating hubs and twin tyres, interchangeable with the tyres of the trailers (Fig. 47).

As Westminster operates a mixed fleet, to avoid the risk of any confusion arising, all controls, with the exception of the electric controller, are similarly arranged. The electric controller is of the cam-operated contactor type, giving five speeds forward, and reverse by a separate reversing switch.

Power transmission from the motor is by direct coupling to a Hardy-Spicer propeller shaft to a double-reduction bevel and spur differential-drive axle. In order that the tractor may be used as a source of power for driving motor-driven pumps on a gully emptier, two heavy contacts are placed at the rear which, on coupling up with the trailer, engage with two similar contacts on the gully emptier. The cab allows for staggered seating for five persons, and is fully enclosed to provide adequate weather protection.

Each battery is divided into two sections, the sections being connected in parallel on the first three speeds, giving half-voltage, and in series giving full voltage on the last two speeds. Only with the first speed is the use of a starting resistance involved, series-parallel motor field control being employed for the four other speeds.

The motors are of the series-wound heavy-duty traction type, and are rated at 19·3 h.p. at the one-hour rate, and are capable of producing 45 h.p. for short periods. With a fully loaded trailer the normal speed on the level is 11 to 12 miles per hour.

The batteries consist of forty-four cells, and are rated at 405 ampere-hours at the five-hour rate of discharge, and are so mounted that they can be readily taken out for charging, or exchanged for a fully charged battery. Charging is done by means of mercury-arc rectifiers, starting at 80 amperes and tapering off as the charge proceeds.

A trained attendant looks after the batteries and a very efficient log is kept. Two spare sets of batteries are maintained, making twenty-eight in all.

The Nevelin mercury-arc rectifier units are designed for an input of 400 volts, 3 phase, 50 cycles, and an output of 140 volts 80 amps., but are capable of giving 100 amps. for two hours if required. Externally operated tapping switches enable a choice of charging rates to be obtained. Each equipment is self-contained and entirely automatic in action, it being only necessary to plug in the battery connection and to switch on the A.C. supply.

The refuse-collector trailers are of the box-van type, but the interesting and important feature is that they are fitted with a mechanically operated compression apparatus which, when applied, compresses the

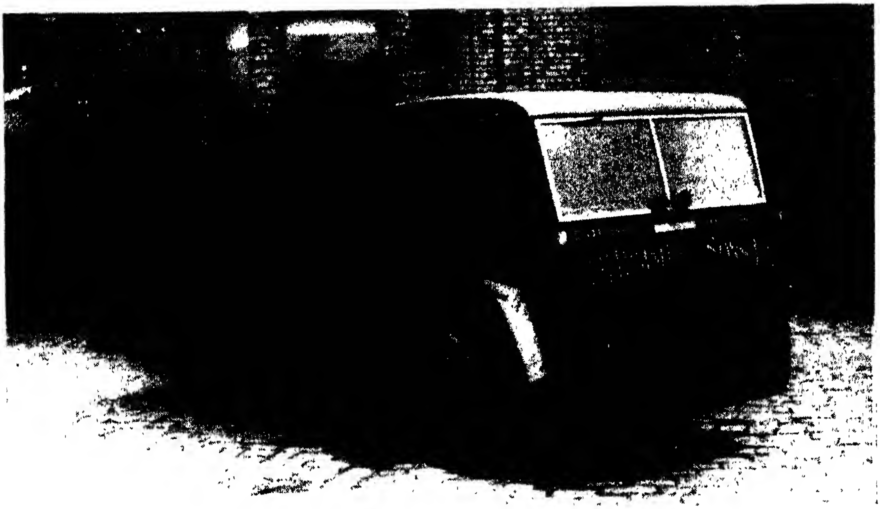

Fig. 45.—A 3-TON LOW-LOADING VICTOR ELECTRIC

Fig. 46.—ELECTRICAR 4-TON REFUSE COLLECTOR AS SUPPLIED TO THE CITY OF BIRMINGHAM

Fig. 47.—Electricar mechanical horses at the City of Westminster

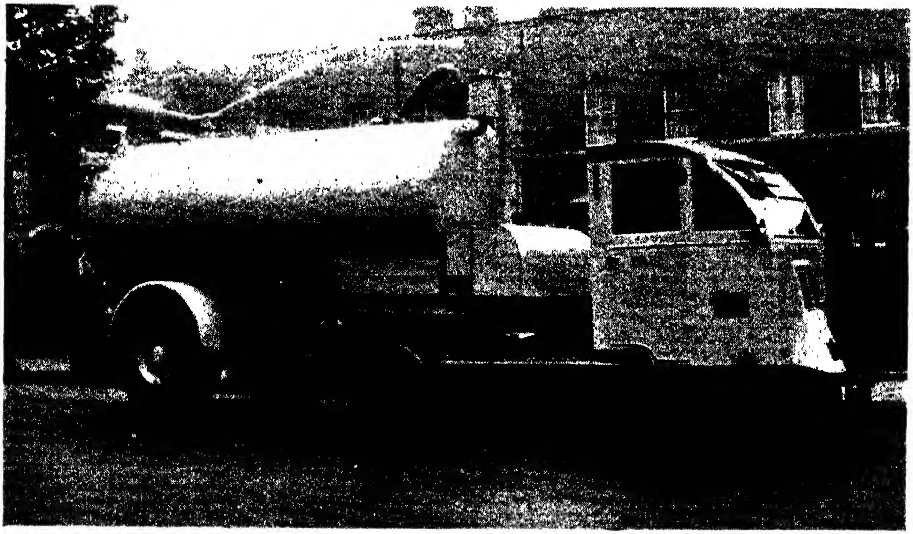

Fig. 48.—Electricar mechanical horse Model T.V.—with gully emptier, used by the City of Westminster load, thereby reducing the space occupied and increasing the weight per cubic foot of space occupied, which of course decreases the cost per ton collected.

The bodies are designed for rear loading, which minimises the offence to passers-by. The method of applying compression to the load is by means of the rear door, which is connected by a trolley to a double-acting hydraulic ram, actuated by an electric motor and pump set, controlled by a push-button switch. The ram operates at a pressure of 800 lb. per square inch, pressure control being effected by means of an electrical contactor. The motor is rated at 88 volts and 11 horse-power. The total unloaded weight of the trailer is 4 ton 16 cwt.

The water-tank trailers used for street cleansing have a capacity of 1,200 gallons. The unladen weight of the trailer is 2 tons 4 cwt. and the fully loaded weight is 8 tons 15 cwt.

The laden weight of the refuse container is less, but it has to be borne in mind that it operates in the reverse way, that is, the load gradually increases as refuse is collected, but with street cleaning it decreases, because as the journey proceeds, less water remains in the tank. Most of the work is done at night, and in general the men book on at 12.30 a.m., commencing collection duties about 1 a.m. and returning to the depot for a meal at 4 a.m.; at 5 a.m. the vehicles go out on duty again and return to the depot at midday, when the batteries are put on charge.

Of course, if twenty-four-hour operation was considered necessary, this could be arranged by having duplicate sets of batteries, a charged one being exchanged at the depot for an uncharged one. The range of these vehicles is considered to be 32 miles, but of course this is liable to variation with both the amount of refuse collected and the number of starts and stops.

The law of averages applies very well on the whole to refuse-collection work. Unless a town is developing at a very rapid rate, statistics of past performance can be applied to the determination of future schedules. That is, the loads to be collected generally compare closely, season by season, i.e. spring, autumn, winter, and summer. Those responsible know within a little what work will have to be done, and can therefore plan the operation of a mixed fleet to a close degree of efficiency, using electrics for the closely packed areas near the centre of the town, and petrol for the outlying distances, where much larger runs are involved. The best performance can then be obtained from both types.

One great advantage of electrics in an area like Westminster, or in any area where a number of people are sleeping at night, is silence in operation. Gully cleansing, with a petrol vehicle, is, for example, a very noisy business, and in areas like Westminster would probably have to be done by day, unless an electrically conveyed gully-cleansing unit was used.

Of the two lightweight vans already mentioned, which are Electricars, the 10-cwt. one is used for general duties, such as the delivery and collection of stores, while the 25-cwt. Electricar was put into service in 1939, and has a special body, so that the Public Health Department can use it in connection with disinfection.

The fleet of vehicles is housed in a specially built depot, which covers an area of 60,000 sq. ft., and is noteworthy for the equipment installed for the handling of collected refuse and the maintenance of the fleet.

Sheffield Corporation Practice

Another example of the use of electric tractors for refuse collection is provided at Sheffield, which Corporation in 1931 purchased an Electricar tractor for drawing a Cable-Eagle refuse-collecting trailer unit. This tractor had a wheelbase of 5 ft. 2 in. and a track 5 ft. 9 in. in the front and 5 ft. 3 in. in the rear, the battery being carried under the bonnet. It was designed for a load of 7 tons at a speed of 10½ m.p.h. on the level, with a cruising range of 35 miles per charge. It would ascend a gradient of 1 in 10 with ease. The same authority also purchased an Electricar tractor for use with an Eagle-Newey refuse body and one for a Faun body. The Eagle-Newey body is designed to rotate in order to pack and reduce the bulk of the load. The Faun body is loaded at the rear into a separate hopper, which is tilted vertically, discharging the contents into the main body, and at the same time packing and thereby increasing the effective capacity of the vehicle (Figs. 49 and 50).

A 24-ton Unit

The limitation of load, so far as tractor-trailer units are concerned, is governed by the space available within vehicle-track limits, and by the weight of the greatest load encountered sufficiently often to justify the use of a very heavy vehicle. An example of a really large tractor-trailer unit was provided in the U.S.A., when the Golden State Milk Products Company put into operation a 24-ton unit, consisting of a six-wheel tractor and a six-wheel trailer both carrying load, and both carrying batteries, a flexible cable being run between the tractor and trailer to give connection to the battery in the trailer. This unit operated on a round trip of 25 miles, being rated for a load of 24 tons.

The Question of Vehicle Capacity

The commencement of the development of electric refuse collectors from comparatively small to large units can probably best be illustrated by the following quotation from a paper which Mr. James Jackson, Cleansing Superintendent of Birmingham, delivered before the Public Works, Roads, and Transport Congress in 1924 :

" Up to February, 1921, thirty-two vehicles were put into commission, one being a 3½-tonner with a capacity of 5·14 cu. yds., and the remainder being 2½-tonners of 5½ cu. yds. capacity. Our experience with these

Fig. 49.—AN ELECTRICAR TRACTOR

With Eagle-Newey refuse-collecting body. (*D.P. Battery Co., Ltd.*)

Fig. 50.—AN ELECTRICAR TRACTOR

With special refuse collector, at Sheffield. (*D.P. Battery Co., Ltd.*)

vehicles led us to believe that bigger vehicles could be used with advantage, and in 1921 two 3½-tonners of 9 cu. yds. capacity were purchased. In 1922 three 3½-tonners and three 4-tonners were acquired, and this year we have bought sixteen 5-ton vehicles, with carrying capacities varying from 10½ to 13 cu. yds.

" I do not regret the purchase of the first 2½-ton electrics. It was the only size available at that time, and to-day our organisation enables us to ' place ' each one to full advantage.

" I do not believe in sudden or radical changes and prefer a continued evolution of our transport. We must, however, have some vision and courage to carry out our ideas. I would not dare to lay down a hard rule that only big-capacity vehicles give the best results. There are too many complications. We have districts where a 5-tonner could not work, and where the time available will only allow of a small vehicle being used economically, on account of the distances to be travelled, for it is no use running a larger vehicle than you can fill. Results prove, however, that the larger vehicles, if correctly placed, can be run to advantage, and in Birmingham the cost in selected districts, 3 miles from the depot, has been brought down to the level of that of the horse working within a radius of 1¼ miles. There is now being constructed for my department the first auto-electric trailer built in this country. The trailer is, in effect, an electric vehicle which can be towed out to the collecting area by an ordinary electric vehicle. It will be moved from house to house under its own power, and filled with refuse by the loaders of the towing vehicle whilst that vehicle has gone to discharge its load. It will then be attached to the towing vehicle after or whilst the latter is being filled with its second load, and, finally, will be towed back loaded to the place of disposal.

" The trailer, designed to carry a 2–3 tons load, will have a hand-tipping body of 5 cu. yds. capacity, and be fitted, like all our electrics, with spring-roller canvas covers. The transmission is automatically declutched when the draw bar is lifted for connection to tractor."

Another development in the same year was a Garrett six-wheel unit delivered to the Public Health Department of Norwich. In general design and construction this was a shortened Garrett 5-ton chassis on four wheels, mechanically coupled to a two-wheeled trailer body. The motor was an 11-h.p. series-wound machine, and the battery had forty-four Exide cells, twelve being mounted under the bonnet, and a section of sixteen cells mounted on either side of the tractor amidships. The tipping mechanism was operated by a 1-h.p. electric motor, and was made by Bromilow and Edwards. A novelty in connection with this vehicle was kerbside control, it being arranged that the steering wheel could be removed from the main steering column and fixed at the end of a shaft projecting from the side of the vehicle, thus enabling steering to be done from the kerbside without getting into the driving cab and enabling the driver to act as a driver-loader. Adjacent to the wheel were placed hand

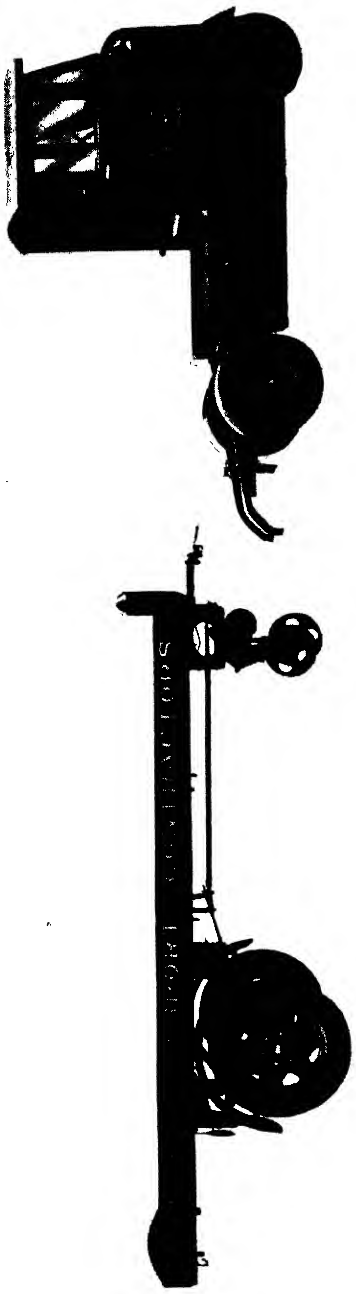

Fig. 51.—Wilson-Scammell Electric Horse

levers for operating the controller and brake. The length was 25 ft. overall, and the radius of operation about 30 miles per battery charge at a speed of 8 to 10 miles per hour.

Typical Modern Vehicles

In 1937, *Tilling Stevens, Ltd.*, produced a 2/3-ton three-wheeled electric tractor, and a 2/3-ton four-wheeler, the latter being able to be fitted with a special body for refuse-collection work, or a long-type body for coal delivery or other transport work.

The tractor had a wheelbase of 8 ft. 8 in., with a track of 4 ft. 6⅝ in., and an overall length of 13 ft. 2 in. The overall width was 6 ft. 2⅜ in., with a ground clearance of 5 in., and the vehicle could turn in an 18-ft. circle.

The frame was of channel-section pressed steel, bolted throughout and well braced by gusseted cross members. Side members were upswept at the front end and connected by a double-angle cross member of deep section to withstand steering and loading stresses. Steering was by worm and wheel, the box being mounted in the head of the fork that carried the front wheel. The steering head was fitted with an adjustable lock stop, the maximum lock available being 160°.

The rear axle was of spiral bevel and pinion type, with a four-star differential in a pressed-steel casing. The axle shafts were fully floating.

The brakes were of the internal expanding type acting on the rear wheels, the hand-brake lever operating separate shoes in the single wide drums. The trailer brakes were operated independently of the tractor brakes, by a separate lever in the driver's cab.

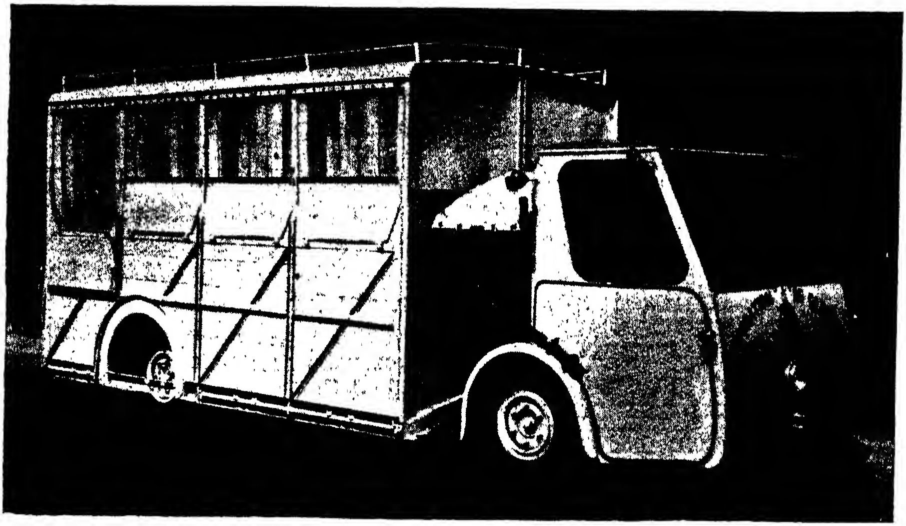

Fig. 52.—A "METROVICK" ELECTRIC REFUSE COLLECTOR
This type of vehicle, equipped with Tudor batteries, is used in the service of the Glasgow Corporation Cleansing Department.

Springing was by underslung semi-elliptics rearwardly, a helical coil enclosed within the steering fork taking care of the front of the tractor.

Transmission was by tubular propeller shaft with needle-roller universal joints, and the wheels were of the steel-disc type with 23 × 5-in. tyres, twin rear.

Special automatically locking coupling gear was provided for use with the semi-trailer, coupling and uncoupling being effected without the driver leaving his seat, while the coach-built cab had high-sided doors and a double windscreen, a deep cowl covering the front wheel and resistance unit.

The Tilling-Stevens four-wheeled vehicle has a pressed-steel channel-section frame of 36-ton tensile steel, rigidly braced and gusseted. The motor, which is of the series-wound, traction type, is capable of heavy overloads without overheating. Full access to the commutator and brush gear is made possible through large openings, fitted with easily-removable covers.

The front axle is of high-tensile steel, " I " section, with hubs running on large-diameter taper-roller bearings. The rear axle is of the full-floating type. A spiral-bevel drive, with bevel differential gear mounted in drop-stamped steel casing, is employed. The whole of the drive assembly can easily be taken from the axle casing in one unit. The banjo case is a 35-ton steel casing. The hubs run on large-diameter taper-roller bearings.

The battery is arranged in four blocks on slide-out trays, mounted between the wheels, and is easily accessible and interchangeable. No trap doors are necessary in floor of body, and any make of battery can be fitted to order.

The starting resistance is of the unbreableka grid or expanded-metal type.

Silico-manganese semi-elliptic laminated springs are fitted to front and rear, and the brakes are of the cam-and-lever type, designed to give exceptionally easy steering.

The electrical specification was common to both types of vehicles, and comprised a Tilling-Stevens enclosed-ventilated traction motor, capable of withstanding heavy overloads. The armature was ball-bearing mounted, and the machine was designed with a light shunt winding to prevent the vehicle attaining too high a speed downhill when laden. A pedal-operated controller was fitted, incorporating a patented switch mechanism, so arranged that the rate of acceleration of the vehicle was controlled independently and could not exceed a predetermined rate even when the pedal was depressed quickly to its fullest extent. The direction lever, which was hand operated, was connected to a drum-type switch with three positions, and was interlocked with the controller. The charging plug could only be inserted when the lever was in the " off " position, between " forward " and " reverse."

The capacity of the battery was 350 ampere-hours at the five-hour rate of discharge. The battery was supported from the side members

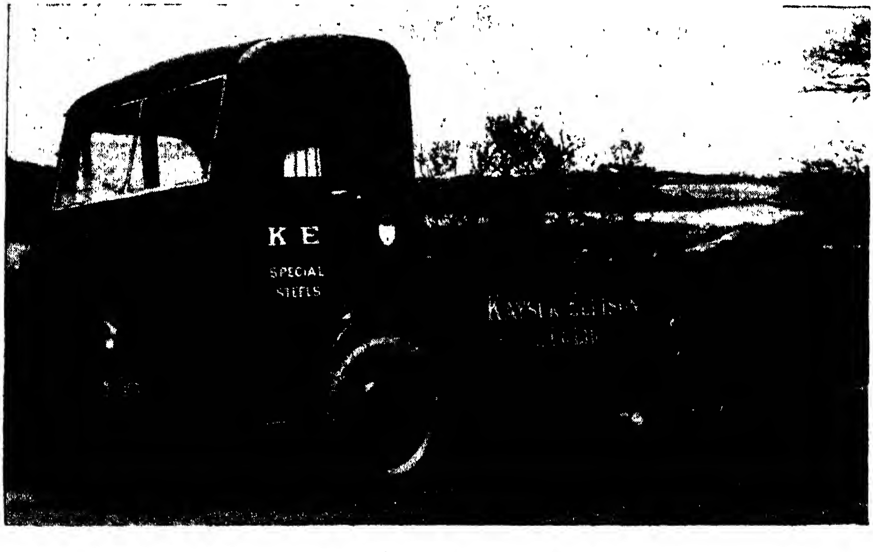

Fig. 53.—A 2½-ton Electricar lorry.

of the chassis by strong angle framework, and slide-out trays for easy access to batteries were fitted. The lighting current was taken at 12 volts, distributed as far as possible over the battery to equalise the discharge.

Dimensions of this vehicle were as follows:

Wheelbase, 9 ft. 8 in. Track, 5 ft. 0$\frac{11}{16}$ in. (front), 4 ft. 11$\frac{3}{4}$ in. (rear).

Overall length, 16 ft. 8 in. Overall width, 6 ft. 6 in.

Ground clearance, 7 in. Turning circle, 42 ft. Body space, back of cab to end of frame, 10 ft. 11$\frac{1}{2}$ in.

Partridge, Wilson & Co., Ltd., have produced the *Wilson-Scammell* electric horse, which is a three-wheel tractor for coupling up to a two-wheel flat lorry or carrier, which, of course, could be fitted with another type of body if desired. As it is, it provides a very manœuvrable unit for service with heavy loads. It is rated for a payload of 4 tons on the basis of five stops per mile, when it will give a total mileage per battery charge of 28·5. The speed *en route* when fully laden is 10 miles per hour. The battery consists of thirty-two cells, hung pannier fashion on each side of the vehicle, and ten cells housed under the driving seat. The motor, of the series type, is rated at 85 volts 100 amps. 1,400 r.p.m. on the one-hour rating. Transmission is direct by a tubular propeller shaft and Hardy-Spicer needle-roller-bearing joints.

The driving axle has a double-reduction gear incorporating a four-pinion differential. The axle shaft is of the three-quarter floating type. The brakes are of the internal expanding type, and the carrier brake is operated by a separate hand lever connected to a pin passing through the centre of the turntable and actuated by a bell-crank lever on the motive unit. The brake is automatically engaged or disengaged on coupling or uncoupling the carrier. The front portion of the carrier is fitted with a turntable to which is attached a retractable undercarriage, carrying two wheels to support the carrier when detached. The locking device consists of two steel claws engaging rollers on an oscillating beam on the carrier turntable. Withdrawal is effected by a hand lever in the driver's cab. Coupling or uncoupling is a matter of great simplicity and can be effected in a few seconds. The speed controller was specially designed, and is fully mechanical, there being no electro-magnetic contactors. The selection of the four speeds is made by a cam action operated by a pedal through a chain and sprocket wheel. The delay action is provided by a hydraulic unit, in which Lockheed fluid is used, and it is thus unaffected by temperature. The whole assembly, including a reversing and isolating switch, is housed in a single box, and any one of the eight contactors can be quickly and easily dismantled, adjusted, and re-assembled.

In what may be termed the heavy class, there is the *Wilson* H.W.-type 2-tonner, which also has the Wilson constant delay-action speed controller, giving four speeds forward and reverse. A Hardy-Spicer

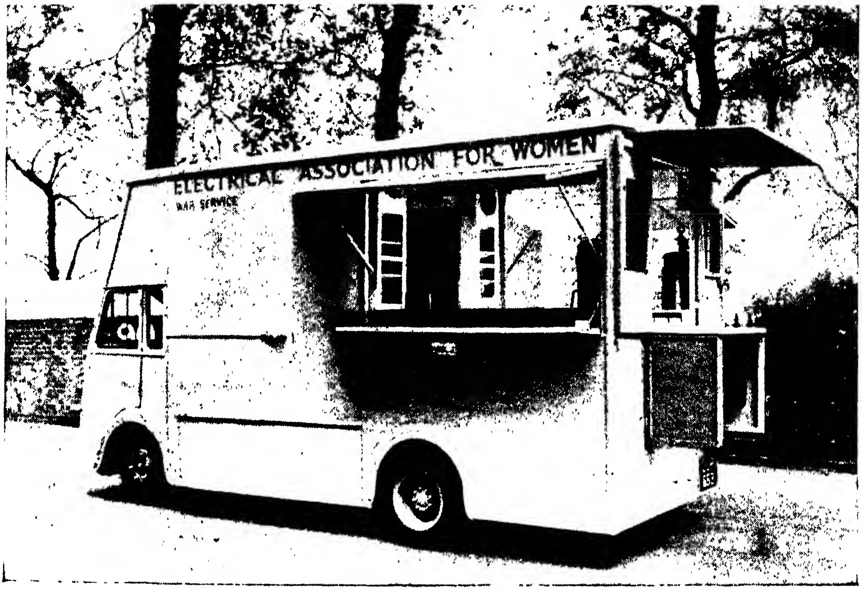

Fig. 54.—A BATTERY-ELECTRIC TRAVELLING CANTEEN

transmission is again used, and the rear axle is of the overslung fully floating type with a heavy-duty high-efficiency worm drive. Brakes are Bendix and cable operated. The length of the body platform is 9 ft. 8 in., width 6 ft. 4 in., the loading height being 2 ft. 10 in. The battery has a capacity of 240 ampere-hours and is carried amidships. The motor is of the series-traction type.

There is also the *Electricar* 2½-tonner which comes into the heavy-vehicle class. The standard model has a flat deck but, of course, other types of body can be fitted. The front axle is of the Ackerman pattern and has roller-bearing hubs. Transmission from the series traction-type motor is by means of a Layrub propeller shaft, and the rear axle has an overhead worm drive and roller-bearing hubs. The controller is of the contactor type, giving three speeds, the foot controller having an automatic delayed action, and there is a hand-operated reverse switch. Four-wheel Lockheed hydraulic brakes are fitted. A removable key to a safety switch guards against unauthorised operation. A forty-cell Young battery is supplied of 297 ampere-hour capacity, which gives a range of 30 to 35 miles per charge on an average of half-load with about one hundred starts and stops.

In many respects, of course, heavy-weight vehicles are similar to the lightweight ones, the same general underlying principles being involved. They are larger and heavier and built to carry heavier loads, but generally speaking, except in the case of refuse collection, do not have to make so many stops.

Further Fields of Use

The main field in this country has lain in connection with public health service, i.e. refuse collection, and also for conveying heavy appliances or materials by electricity supply authorities and building contractors, and for the delivery of coal. In the U.S.A. their use has been extended to furniture removal, ambulances, large-scale conveyance of milk products, and as fire engines in the Holland Tunnel.

One field which lies open, at any rate for the larger vehicle of the 4–5-ton type chassis, is that of a refrigerator van. A vehicle of this type would probably call for a battery having an output of 40 kilowatt-hours at the five-hour rate of discharge, and would weigh, when carrying a payload of 3 tons, perhaps 9 to 10 tons. The body would have corkboard or other form of insulated walls, and would be designed for carrying meat, butter, bacon, etc. Technically, the requirement with average foodstuffs is that they be maintained at a temperature round about 40° Fahrenheit. Under such conditions milk, cream, etc., will keep fresh for many days, whereas under hot-weather conditions their life is measured in hours. The refrigerating apparatus would call for only 500 to 750 watts, and could be designed on compact lines and provided with automatic control, so that when the temperature rose or fell outside of fixed limits the refrigerator was brought in or out of operation. Probably only about 5 units (5 kilowatt-hours) would be required every twenty-four hours for the operation of the refrigerator unit.

In towns also there is much opportunity for development in the use of electric ambulances, as they can be designed to give extreme comfort and are silent running. Much ambulance work in towns is not connected with accident service, but is booked service for maternity cases, future operations, etc., and patients returning to their homes. This service does not call for great speed, but does require smooth running, and it is a short-run service suited to the electrics.

Chapter V

ELECTRICS IN THE ELECTRICITY SUPPLY INDUSTRY

ELECTRICITY Supply Authorities have at hand in the electric vehicle both an ideal advertising medium and also an ideal load. It is altogether an anachronism in these days to see domestic apparatus delivered to consumers by means of a petrol vehicle bearing on its sides the slogan " Use more electricity." The load is ideal, because battery charging can be done at night during " off peak " hours, when load is desired to fill in the valleys of the twenty-four-hour load curve.

What electrics mean in the way of load can be computed approximately as follows. Assume that the average vehicle battery has a rated capacity of 200 ampere-hours and a voltage of 60, then about 12 kWh. will be required by the vehicle per day, assuming that a spare battery is not used as a means of lengthening the daily available mileage of the battery. At the outbreak of the 1939 war there were some 5,000 electric road vehicles (excluding trucks) licensed, the majority of which were in use six days a week. The nightly load for battery charging for these vehicles would amount to 75,000 units, assuming a discharge/charge ratio of 80 per cent. Allowing fourteen days per annum for each of the vehicles being out of commission on account of painting or repairs, which is a liberal allowance, the annual load would amount to $75,000 \times 6 \times 50 = 22,500,000$ units, which at the low rate of ·5*d.* per unit (a very usual rate in 1939) represents £46,875 (Fig. 55).

Given really good support, however, from supply authorities, backed by the efforts of the Electric Vehicle Association of Great Britain in popularising the use of electric vehicles, there is no doubt but that the 1939 figure of vehicles on the road could be readily increased to 20,000, with a corresponding increase in the load for supply authorities.

Of course, so far as the delivery of meters, cookers, and domestic equipment is concerned, the lightweight electric, the half-tonner, which has proved so popular for retail deliveries in general, and which has already been described in Chapter III, is ideally suited to the purpose so far as town and urban districts are concerned.

There are, however, other uses to which electrics may be applied in the electricity supply industry. The battery-electric vehicle is a source of power on wheels, and can therefore be applied to testing purposes, using the battery, and if necessary a larger battery than normal, as the means of providing power. Emergency lighting supplies, for instance, can be arranged for in this manner.

An Articulated Vehicle for Mains Work

Some ten years ago the Manchester Corporation Electricity Department placed in service a 10-ton articulated electric for the conveyance of cable drums and other heavy material and appliances. It was specially built for the purpose by the General Vehicle Co., Ltd., and handled cable drums weighing from 1 to 7 tons. The vehicle was designed with a low platform measuring 16 ft. in length and 7 ft. in width, and an electric winch, obtaining power from the battery, was provided for hauling the cable drums on to the platform, a hinged flap at the rear of the vehicle being dropped down to provide a sloping platform up which the cable drums were hauled. The vehicle had six wheels, four being employed for the tractor portion, i.e. the propelling unit or "electric horse," and two for the platform or carrying portion of the vehicle. The batteries were carried on the tractor and were mounted behind the driver's cab.

Tower Wagons

The use of centrally suspended lanterns for street lighting, and also the increase in height of street-lighting posts, created a need, so far as maintenance was concerned, for mobile tower wagons, as tramways did not operate in all thoroughfares where electricity was used for street lighting. Following upon the use by a few tramway authorities of battery-electric tower wagons for overhead-line maintenance, some supply authorities used similar vehicles in connection with work on street-lighting equipment.

An early example was that of Liverpool, where the City Lighting Engineer put into operation a G.V. electric fitted with a ladder which could be extended in height from 12 to 35 ft. by means of an electric motor. The drive to this motor, as with the motor for propelling the vehicle, was by means of roller chains and sprockets. The motor was of the totally enclosed type, the operating switch being fitted in a small locker placed at the side of the tower. A swivelling platform was arranged to be operated from the platform itself by means of a gear and pinion, provision being made for it to be mechanically locked in any desired position. Collapsible guard rails were fitted to the top platform, which measured 4 ft. 6 in. by 2 ft. The tower and vehicle body was mounted on a 2-ton G.V. low-loader chassis, having an overall length of 14 ft. 6 in. and width of 6 ft. 6 in. The wheelbase measured 8 ft. 3 in. and the vehicle had a turning radius of 16 ft. The steering gear was of the enclosed worm-and-wheel type, and the chassis frame was built up from pressed-steel channels. A single totally enclosed motor was employed for driving the vehicle, the controller giving five forward and two reverse speeds. A sixty-cell A6-type Edison battery was employed.

For some time battery-electric tower wagons continued to be of the heavy type, i.e. to be built on a 1½-or 2-ton chassis. In 1939, however, a new type of lightweight vehicle was developed by Associated Electric

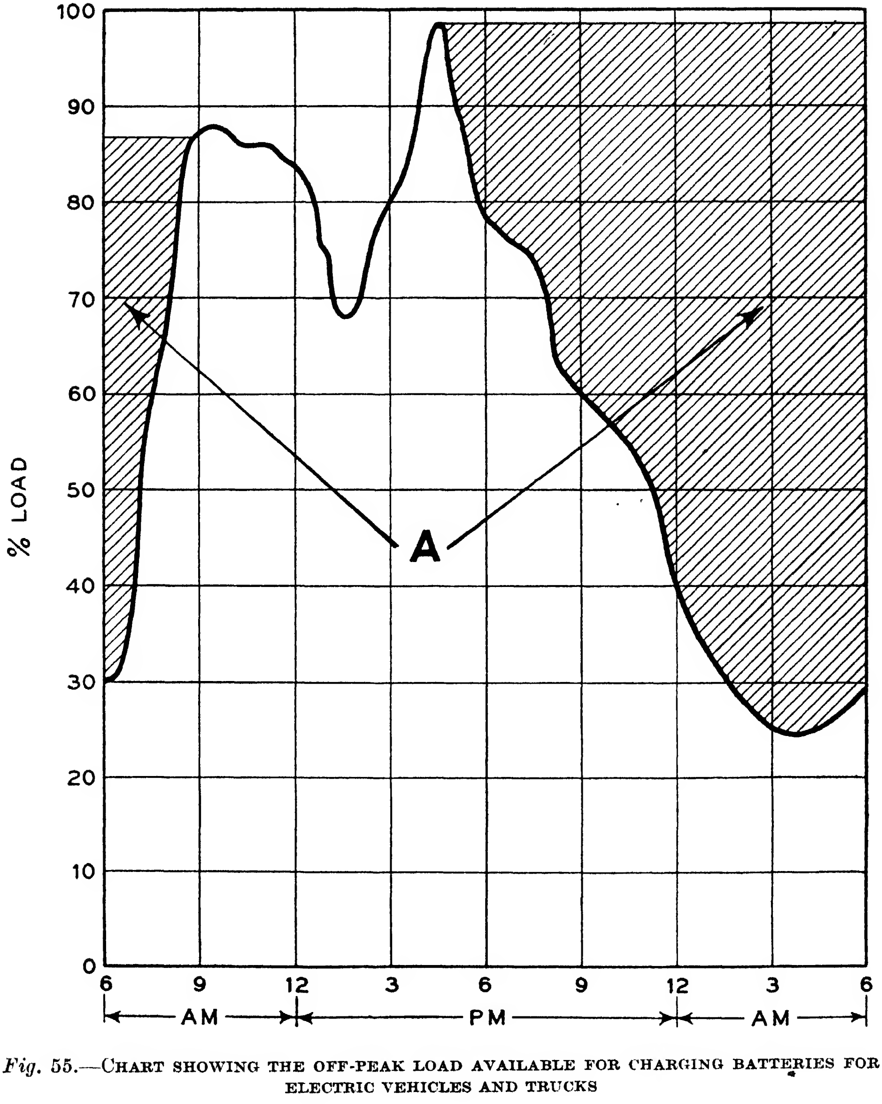

Fig. 55.—CHART SHOWING THE OFF-PEAK LOAD AVAILABLE FOR CHARGING BATTERIES FOR ELECTRIC VEHICLES AND TRUCKS

Vehicle Manufacturers, Ltd., who have since been absorbed by Crompton Parkinson, Ltd. The Warrington Corporation Electricity Department was one of the first supply authorities to employ this form of vehicle. This had been specially developed to provide a vehicle reasonable in price to meet the need for a mobile tower which could be used for the maintenance of high-power mercury-vapour lamps used for street lighting.

The vehicle had a standard 12-cwt. Morrison chassis of the F60 type having a three-speed contactor controller with pneumatic foot operation, and used a thirty-cell SATH 9 Young traction battery of 160 ampere-hours capacity, providing a range of 30 miles. The vehicle was fitted with Bendix brakes. An observation window was provided in the roof so that the driver could observe what was happening on the tower platform. The tower was a Rawlinson of three-section type constructed of seasoned oak, the sliding faces being steel plated. Extension of the tower was provided for by means of a one-man operated winch and counter balance. The tower could be extended to its full height of 20 ft. 6 in. in 10 seconds. Stabilising jacks were provided as standard equipment to enable the tower to be set in a perpendicular position when the vehicle was standing on a cambered road surface.

A Midland tower wagon was built for the Borough of Hampstead Electricity Department in 1939, for use in maintaining street-lighting equipment. The chassis was designed on particularly robust lines, with a very low centre of gravity. The batteries were mounted on the Midland withdrawable system, being divided into four sections, each section being on a withdrawable subframe enabling the battery to be withdrawn by hand, the frame being self-supporting when in the withdrawn position. The chassis had a long wheelbase and twin wheels were fitted to the rear axle, stabilising jacks being built into the chassis at the rear. The tower was of the Rawlinson counter-balanced type, giving a platform height of 25 ft. The platform was of the revolving type and provided space for three men to work on it. Elevation of the tower was by electric motor, the current being drawn from the battery. The tower could also be elevated by hand.

Lockers for tools and equipment were provided behind the driver's cab and at the rear of the vehicle, while a third locker at the rear housed the switch buttons for controlling the tower elevator. The wheelbase measured 8 ft. 4 in. and the turning radius was 31 ft., giving really good manœuvrability.

An interesting feature was that in addition to the foot-operated delayed-action controller, series-parallel switching of the battery was provided for, so that when travelling short distances and manœuvring, the battery voltage was halved and the capacity therefore increased proportionately. Ten speeds forward were provided for, ranging from an almost imperceptible movement to 15 m.p.h. The same range of speeds was also available in reverse.

Fitted in the roof of the driver's cab was a window, glazed with safety glass, which could be opened by the driver when he desired to communicate with the men on the platform. A mirror in the cab also enabled the driver to see what was happening on the platform. The driver was therefore able both to observe and receive instructions without leaving his cab.

Fig. 56.—A VICTOR ELECTRIC 2-TON DELIVERY VEHICLE

Fig. 57.—A STREAMLINED " METROVICK " ELECTRIC FOR LIGHT SHOWROOM DELIVERIES

Fig. 58.—A Midland electric tower wagon with ladder closed

The batteries were D.P. "Kathanode," having a capacity of 210 ampere-hours, giving a range of about 25 miles with 50 to 60 cycles of tower elevation. An interlocking device was provided on the series-parallel switch, which prevented the batteries being charged unless they were connected in series with the appropriate voltage.

Demonstration Vans

Although towns and urban districts are to-day served with electricity showrooms, or halls are available in which cooking and other demonstrations can be staged, in rural areas it has often proved to be necessary to use a specially built van or trailer van for this purpose, as the small villages have no suitable hall available and of course the population does not justify the establishment of a showroom. Believing that a supply authority should show confidence in its own product, the West Gloucestershire Power Co., Ltd., decided to employ an electric vehicle for this purpose. The interest that this vehicle aroused when visiting villages indicates that there should be considerable opportunity for further development in this direction after the war.

The chassis of this particular van is a four-wheel Electricar model V.C.55B, having an especially short wheelbase measuring 10 ft. 9 in. in length. The track is 6 ft. 10 in. front and rear, and full use of this width is made in the design of the body, the wings forming only slight projections.

The interior of the body which provides the demonstration room measures 15 ft. in length and 7 ft. 2 in. in width, the height being 6 ft. 4 in. The entrance door and steps are placed at the rear and are electrically operated. Pressing the button to open the door and place the steps in position is a "curtain-raiser" that can always be guaranteed to intrigue the audience.

Dual control is fitted for this feature, so that the door may be opened from the inside in case of emergency. The battery is mounted in two sections between the axles, the rated capacity being 355 ampere-hours.

Fig. 59.—A MIDLAND ELECTRIC TOWER WAGON WITH LADDER EXTENDED

The motor is rated at 6 b.h.p., and gives a road speed of about 12 miles per hour on the level, and the vehicle will ascend gradients of 1 in 7 at 4 miles per hour, the mileage on the road per charge being about 55. Charging is effected by means of a Westinghouse static-type charger mounted in the driver's cab, and cables are provided so that the batteries may be on charge from a convenient public supply while a demonstration is in progress. Naturally there is considerable standing time with a vehicle of this character, and therefore in a sense the vehicle charges itself *en route*.

In the driver's cabin are the usual speed and brake controls, an ampere-hour meter with auto-cutout, battery charger and control switchboard, direction indicators, etc. The switches and controls for connecting the demonstration circuits to the supply point in the village are also mounted in the driver's cab, as is a pump for operating the hydraulic jacks. The jacks are so arranged that each may be operated separately in order that the van floor may be levelled in accordance with the undulation or camber of the road surface.

An electric exhaust fan provides for ventilation, as there are no windows in the side or rear of the van body. Specially designed shadowless lighting is provided in the demonstration part of the vehicle, and a battery clock and indicating unit meter are mounted in full view of the audience, while metal-framed chairs are provided for seating purposes.

The total weight of the vehicle is 5¼ tons.

Locos and Trucks

In the main, battery-electric locos are described in another chapter. It may be pointed out here, however, that with the larger power stations, battery-electric locos can well be used for conveying coal trucks around the yard, and in sidings. Battery-electric locos are used for this purpose at Glasgow, Stourport, and Luton, to mention only three instances. Similar remarks apply to trucks, as in and about power stations and stores there are heavy parts and equipment to be transported which can be moved more quickly and efficiently by these handy vehicles than by hand-drawn trucks or trolleys, and their use provides an example for industrial consumers to see and profit by.

Chapter VI

BATTERY-ELECTRIC TRUCKS AND TRACTORS

NOT so very many years ago, if one wanted an example of real factory planning and production of goods "along the line," as it is popularly termed, one had to go to the U.S.A. or to a firm in this country of American origin. To a large extent the progress of mass production in the motor-car industry changed the position, but even in 1942 there were countless firms still using old-fashioned man-handling methods.

It has, in fact, been said that we as a nation are lazy and work-shy, but in so far as that criticism applies to a growing disinclination to waste effort in needlessly man-handling bulky packages and heavy materials, there seems little to be ashamed of. After all, man was not intended as a pure beast of burden, and it is not to the general advantage of employers that he should be used as such, for as a beast of burden at present rates of wages he is by no means cheap. There are a number of battery-electric trucks available which have been designed to enable such work to be done more economically, more rapidly, and more efficiently. One of these trucks will perform as much carrying work as can be done by six labourers, and many instances are known where the initial cost of the truck has been saved by reduced working costs within twelve months from the time the truck was placed in service.

That is not the whole story, however. Other incidental savings also result, because the factory aisles, stores, and yard become less congested owing to the more rapid handling of materials and parts, resulting in less loss by damage and a general speeding up in output.

Another point is that the electric truck has no complicated mechanism such as a clutch, gearbox, or carburettor, and the simplicity of the mechanism ensures low maintenance costs. Running cost is also low, amounting to about ¾*d.* or 1*d.* a mile with electricity at, say, ¾*d.* a unit. No energy is consumed while the truck is standing, and no noxious fumes are emitted. Most important, however, is the fact that electricity is home produced, while petrol has to be imported.

These handy little vehicles are very sturdily constructed and simple to operate, a factor of some importance, because it obviates the necessity of keeping one or more men to act especially as truck drivers. An hour or so of instruction and practice is all that is needed to enable any intelligent workman to drive a battery-electric truck, and women have proved to be quite apt at the task. It is a comparatively easy matter, therefore, to provide for a number of drivers to be available, as occasion demands.

The ordinary form of battery-electric truck is very useful for conveying goods around a factory yard, or for conveying trailer trucks from place to place within the factory.

Types of Trucks

On considering the matter it becomes obvious that goods have to be lifted as well as carried, and after being carried they have to be deposited or stacked somewhere, and it is therefore necessary to carry out as much of this work as possible by means of the truck, even though there is distinct labour saving in transportation only. Briefly the types may be enumerated as follows, although there may be subdivisions, or combinations of each :

1. The simple-platform truck.
2. End- or side-tipping trucks.
3. The crane truck, i.e. a truck with a crane, hand or power operated, fixed to it.
4. The elevating-platform truck.
5. The lifting or tiering truck.
6. High-lifting or stacking truck.
7. Non-elevating tilting frame or fork truck.
8. Electric tractors and trailers (non-electric).

Many of the above are again divided into three- or four-wheel models, and of course rated at varying capacities.

Applications

Practically any kind of manufacturing works provides opportunity for the use of battery-electric trucks, but the engineering and allied trades are an exceedingly good example.

Mechanical handling in a foundry, for example, can be arranged so that each man does his particular job without acting as a labourer.

Firstly, it is generally planned to have the foundry separated as much as possible from the rest of the works, so that dust and dirt may be kept away from finished work. Therefore, patterns have to be conveyed from stores, the materials, such as sand mould, and then the castings have to be conveyed, etc. All this can be much more quickly done by an electric truck.

A plain-platform truck will do the conveying, but the general transport system can be speeded up and made more economical by the use of an elevating-platform truck and packing the loads on stillages. Special stillages are made to suit particular classes of work, such as stillages for scrap material from the machine shop, where the scrap bin is mounted on the stillage ; then stillages for the malleable foundry are made to enable castings to be conveyed between the annealing ovens and the store without touching the floor. In this case, as the castings are drawn from the pots, they are placed in the stillages and conveyed to the rumbling barrels, trimmers, sandblasts, and stores, obviating man-handling

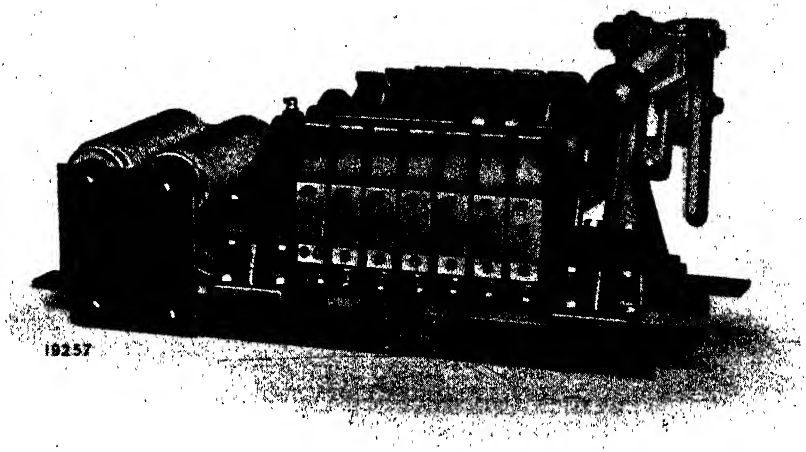

Fig. 60.—CONTROLLER FOR A RANSOMES TRUCK

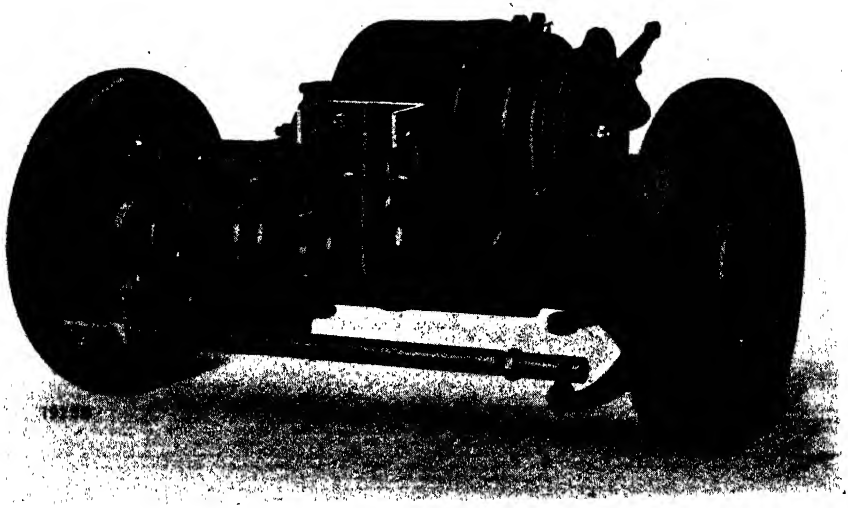

Fig. 61.—TRUCK DRIVING AXLE. (*Ransomes.*)

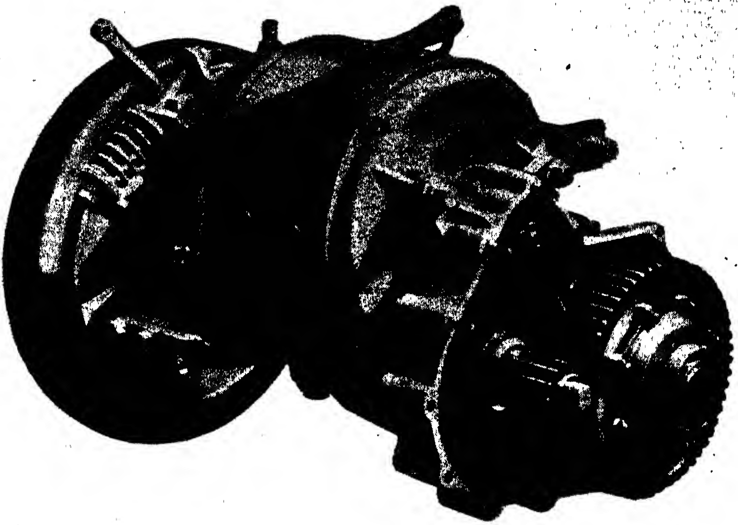

Fig. 62.—Truck driving unit with half of gear cover removed

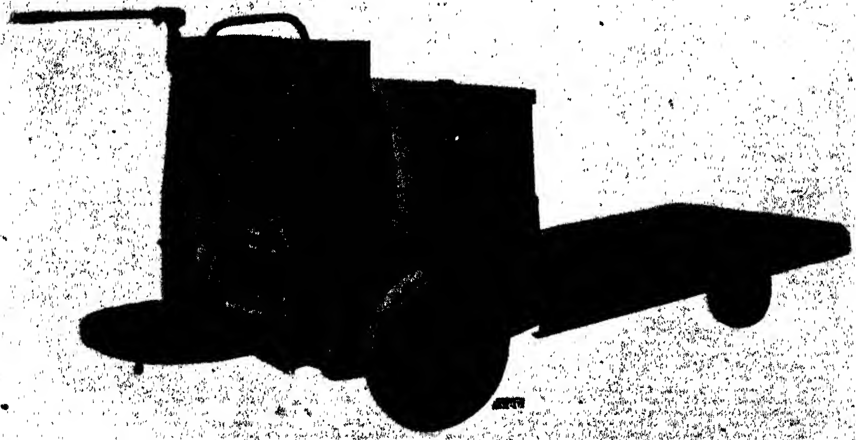

Fig. 63.—Low-loading fixed-platform truck. (*Ransomes.*)

between one process and another. Other stillages are specially made to suit the output of the machine shops, assembly shops, etc., but they are designed with feet that raise the bottom of them a certain height from the floor. The platform of the truck is driven underneath, then elevated, and the truck again set in motion to convey the load to the desired destination, where the stillage is deposited and the truck proceeds on the next journey. Thus, the use of the elevating platform and stillages keeps a truck constantly in service, no time being wasted on loading or unloading operations.

The electric crane truck provides a very helpful means of transporting goods that are too heavy to be man-handled, off an electric truck or stillage, on to the truck or stillage, where lifting equipment, such as an overhead crane runway, is not available. There is also the question of loading and unloading parts or goods at different levels; for example, to and from railway wagons, from floor level to a higher shelf level, etc. This is done by means of a tiering truck. The platform of the truck is elevated by electric power, and an automatic cutout mechanism operates when the platform reaches the extreme position. The high-lift truck or stacker is a similar appliance for lifting the load to a height of 15 ft. or so for stacking on shelves.

There are also a number of special purposes for which a truck may be designed; for example, handling heavy cable drums, offset platform trucks for carrying girders, bar-tiering trucks for carrying wire reels, etc.

Trucks in the Production Line

A good example of the use of battery trucks in connection with straight-line production in an engineering works is provided by the plant of the Kearney and Trecker Corporation, where Milwaukee milling machines are made.[1] This works, operating on a twenty-four hours a day working schedule, employs a fleet of battery industrial trucks to serve the production of more than 3,000 small parts, including 2,000 different gears, as well as delivery to the main production and assembly line.

The general plan of the production lines is shown in Fig. 64, the main line of flow is represented by thick black lines and is served by overhead cranes, and comprises the flow of beds, saddles, knees, etc., which form the main part of a milling machine; the thin arrow-headed lines which converge into the main line show the small-parts routes, i.e. gears, etc., which are served by battery-electric trucks.

The small parts, consisting originally of forgings and castings, are put on skid platforms, boxes, or racks, immediately upon receipt, and are handled by battery-electric trucks in the same type of unit used during the journey through the milling, grinding, and finishing shops, to inspection and final assembly. In the various finishing operations, the work is taken from one skid load and deposited in another as the operation is completed.

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[1] *Edison's Storage Battery Power*, vol. II, No. 6, p. 3 (1941).

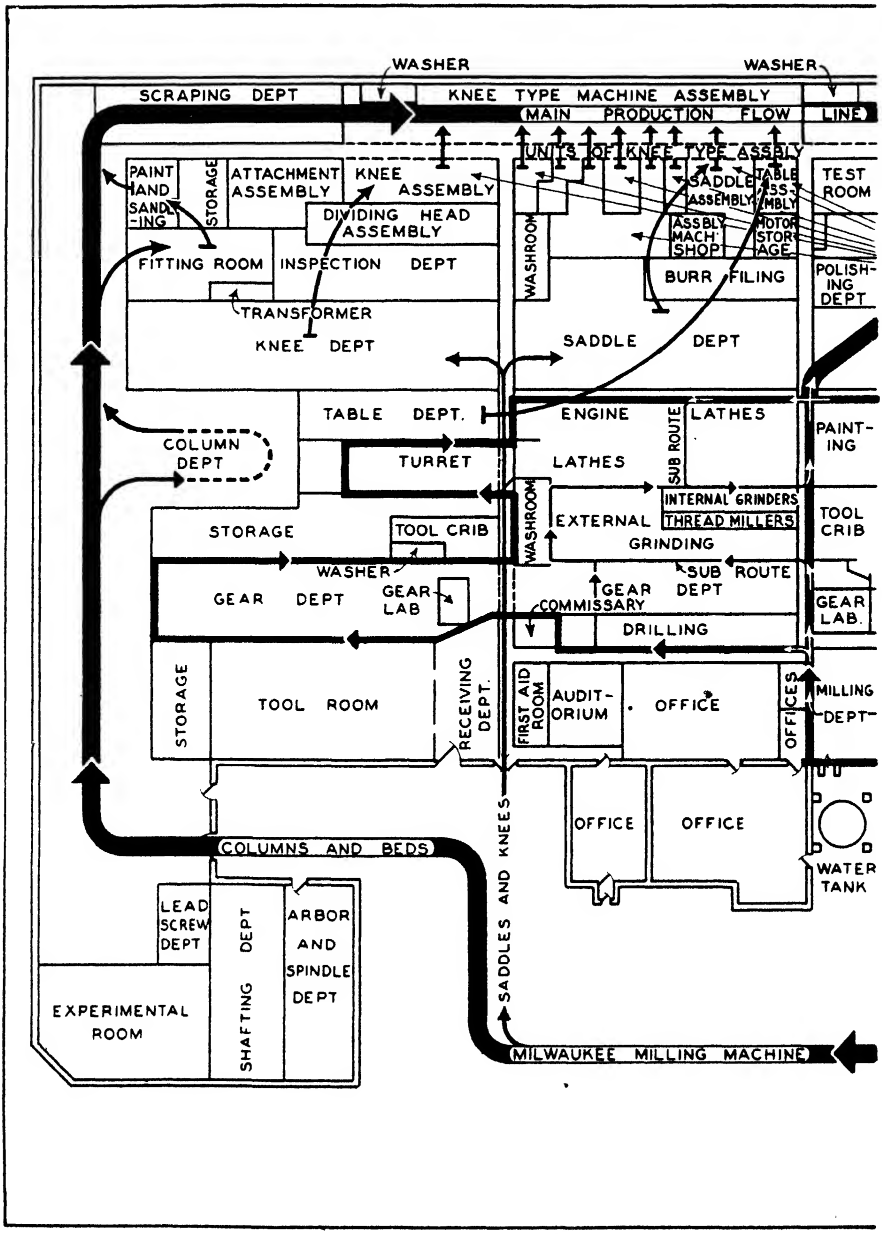
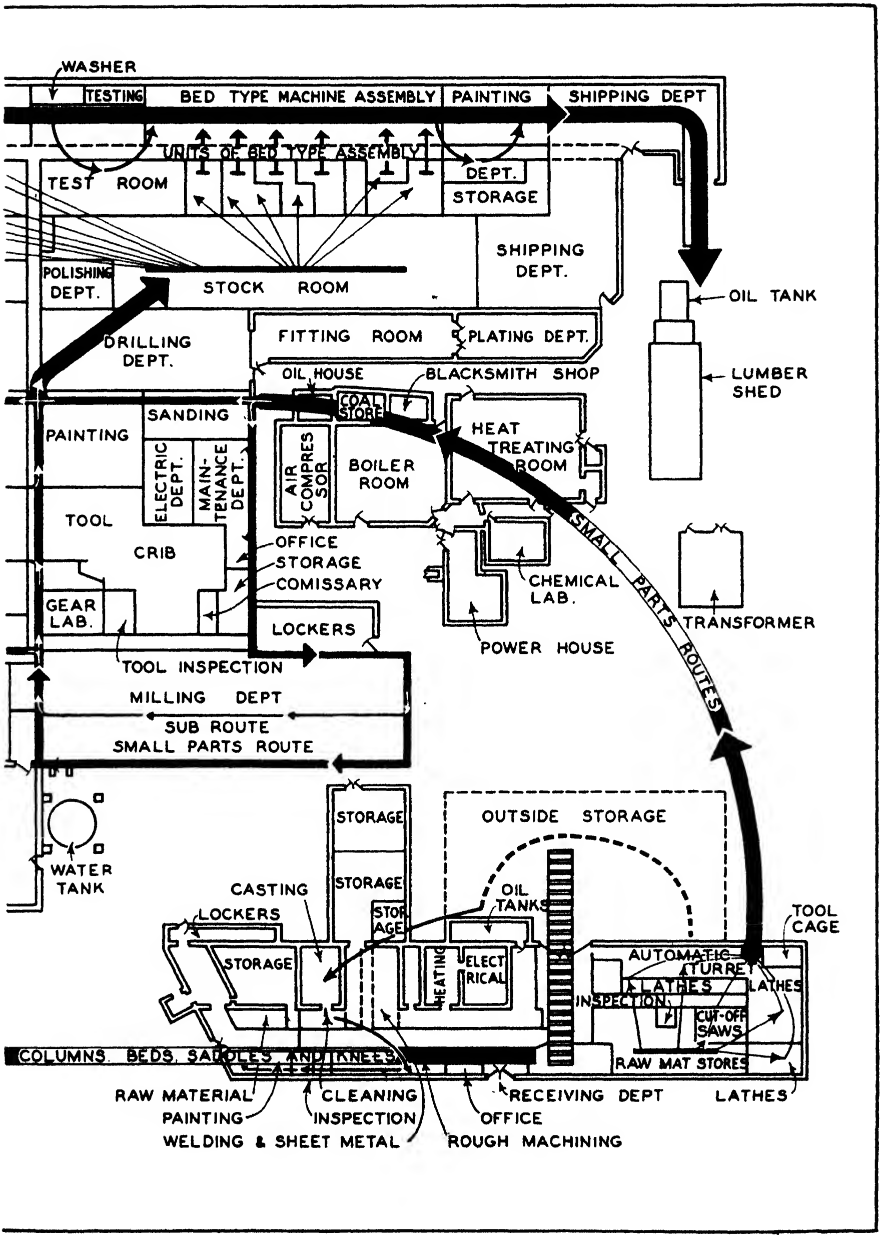


Fig. 64.—THE "FLOW" OF PRODUCTION AT



KEARNEY AND TRECKER CORPORATION

4

In all departments, aisles are plainly marked by yellow boundary lines painted on the floors, while machines are arranged, for the most part, with the operator's position on the side facing the aisle and spaced to allow room for at least two skid units placed at his right and left, both to minimise handling by the machine operator and to facilitate delivery and pick up of loads from the aisle.

Skid racks are employed for gears, skid boxes for relatively small parts such as levers, pulley wheels, pins, and small shafts ; and skid platforms for relatively large parts such as knees, saddles, columns, and the like. To pick up the larger parts, set them up in the machine and lower to the outgoing skid platform, overhead equipment is employed. The small, light parts are, of course, set up by hand. The same is true at final assembly.

Although only one stock room is indicated by the diagram—for finished parts—there are numerous temporary storage points for rough and semi-finished parts in virtually every department. They consist merely of skid units beside the aisles, tiered two or three high as necessary to equalise variations in the rates of successive operations.

The skid-lift-truck system, by its high flexibility, aids greatly in accomplishing this result, while the tiering of loads at these points of temporary intermediate storage plays an important part in obtaining maximum production from the available plant facilities. This was provided by the addition of a high-lift truck to the company's existing fleet of low-lift trucks.

Although the call system of the plant can be used to summon trucks where needed, this is rarely necessary. The trucks operate constantly along their established routes, passing each point frequently throughout the twenty-four-hour day.

Care is taken to maintain the floors in good condition, which permits of using ampere-hour meters on the trucks. Edison alkali batteries are used throughout. Trucks are taken to the electrical department and batteries exchanged either according to the discharge indication of the meter or when completion of charge of other batteries makes charging facilities available. Like the plant itself, the charging equipment works twenty-four hours a day and its full capacity is almost constantly required.

The trucks, including batteries, are making a record of close to 100 per cent. availability for duty, despite the twenty-four-hour working schedules. Hand-lift trucks are also employed in nearly all departments for convenience in shifting skid loads short distances when power trucks are not immediately to hand ; but all of the actual flow of small parts between departments plus most of it between operations is maintained by battery lift trucks.

It can thus be seen that battery-electric trucks increase the efficiency of straight-line flow production by filling in the gaps where it is not possible or is not economic to provide for overhead crane transport.

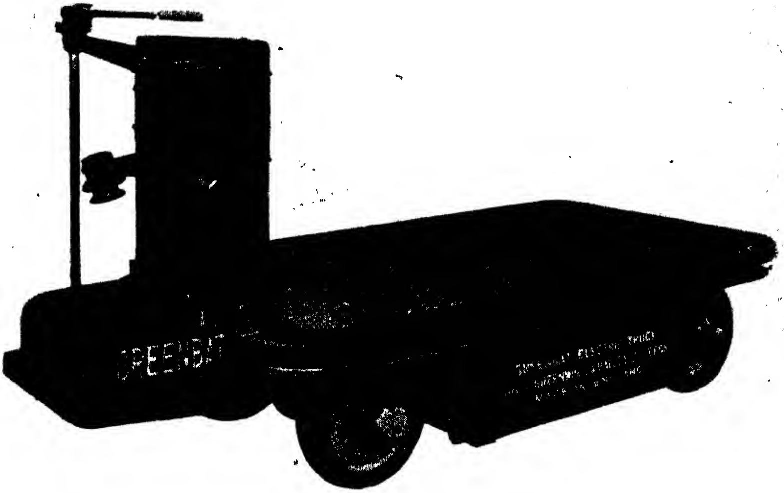


Fig. 65.—A FLAT PLATFORM TRUCK. (*Greenwood & Batley, Ltd.*)

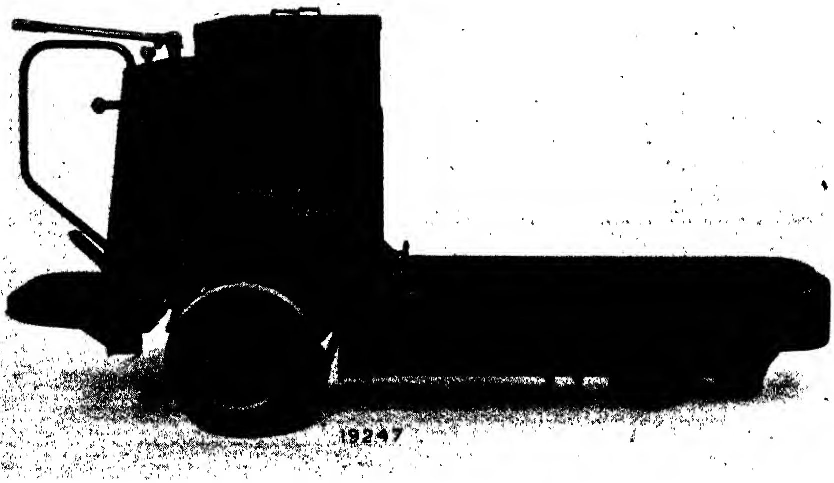


Fig. 66.—TWO-TON LOW ELEVATING PLATFORM TRUCK. (*Ransomes.*)

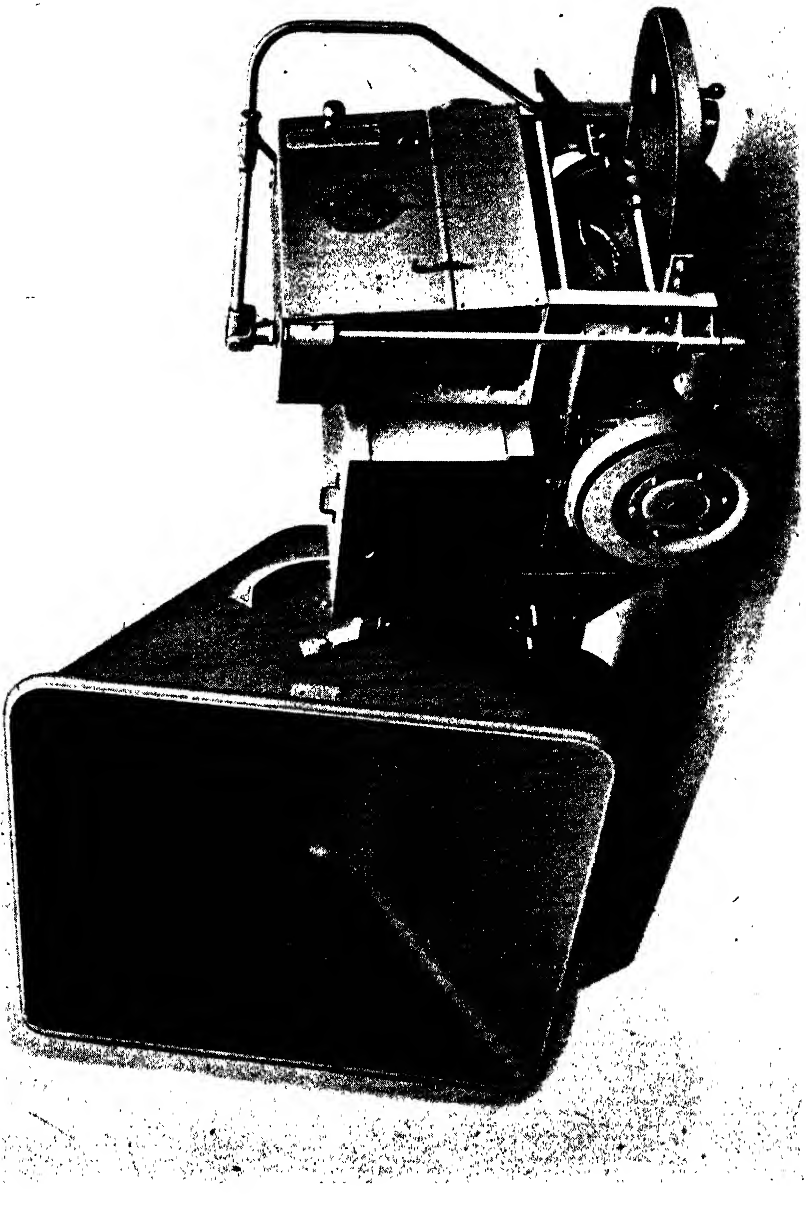


Fig. 67.—TIPPING TRUCK FOR HANDLING SAND, GRAVEL, ASHES, ETC. (*Ransomes.*)

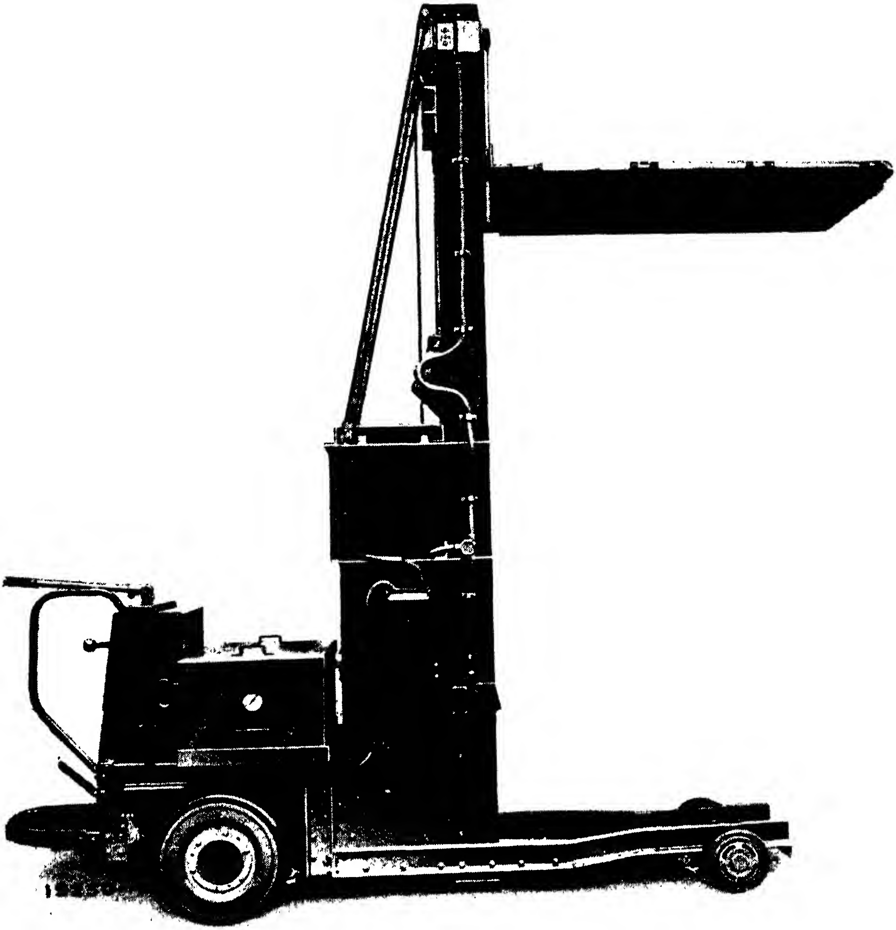


Fig. 68.—BATTERY-OPERATED ELECTRIC STACKING TRUCK. (*Ransomes.*)

Tractors and Trailers

A tractor is virtually a truck, adapted in the form of a power unit and provided with a drawbar connection for conveying a number of trailer trucks. They can be designed to suit various industrial conditions, and for operation on floors or in yards, or alternatively can be fitted with flanged wheels for operation on rails. In the latter case they are frequently employed in connection with building operations, the trailer trucks carrying cement, ballast, etc., or excavated material. The brake and control levers are placed on the side to the left hand of the driver,

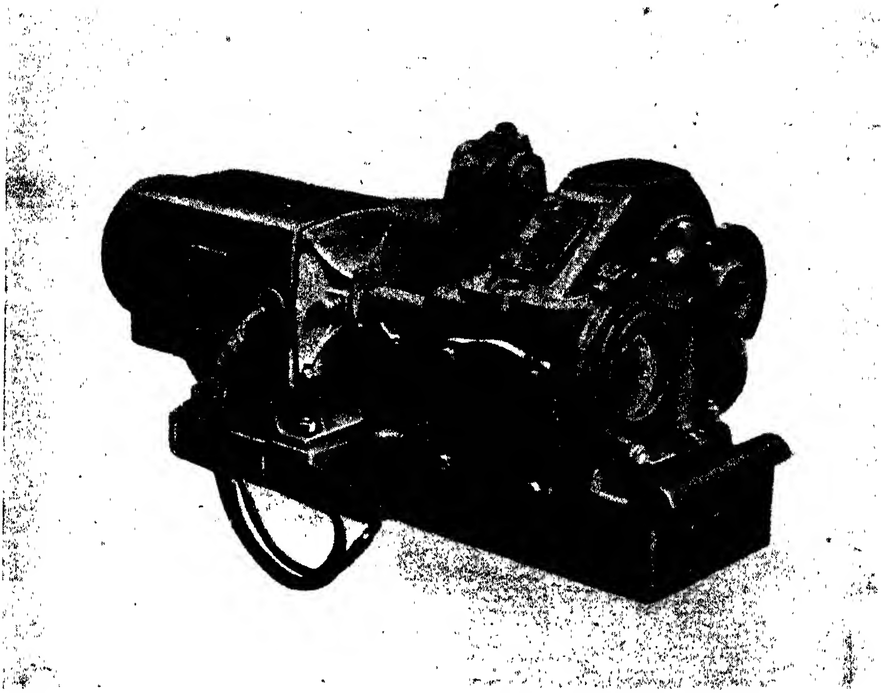


Fig. 69.—TRUCK ELEVATING GEAR. (*Ransomes.*)

and the driver's seat is arranged to spring up to one side so that it can be interlocked to ensure that the driver must be in a seated position with the controller handle in the neutral position before the truck can move under power. Two-wheel steering on the front wheels gives good operating stability and provides for manœuvrability in congested quarters. For heavy-duty work they sometimes have to drive on all four wheels. Three-wheel tractors are also made, steering being by the front wheel and the drive on the rear wheels.

With care it is possible of course to trail any four-wheel truck or trucks behind a tractor by coupling up, but there are makes of trailer designed for the purpose, the Yale being an example. In these, steering is accomplished by a suitable arrangement of levers and connecting rods mounted beneath the platform, which automatically produce the correct steering angle for each wheel of the truck. In operation, the trailers are connected to the tractor and to each other by the steering mechanism through a drawbar inserted in the steering yoke. This drawbar is coupled either to the rear of the tractor or to another truck. By this means it is ensured that each trailer in the train steers through the same angle and on the same track as the other trailers.

Motors

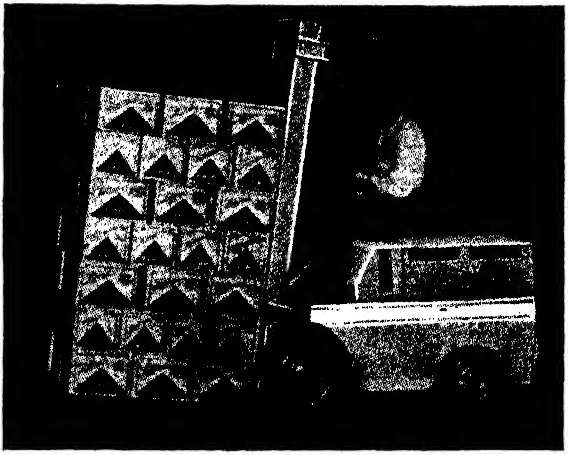


Fig. 70.—Battery-electric fork for handling bulky packages. (*Storage Battery Power.*)

The motors used for battery-electric trucks are of the series-traction type similar to those used for vehicles. For driving purposes trucks may have either a single or a double motor drive, but the single motor drive using reduction gearing and differential is most generally employed. A lifting truck will have a motor for travel and another for lifting, while the fork-type truck has three, one for travel, one for elevating, and one for tilting. In each case all the motors derive power from the one battery.

Power Required

A useful idea of the relative quantities involved in truck design may be gained by considering a random example. This is a purely hypothetical case, and should not be taken as a rule-of-thumb method to follow in actual commercial designing.

Fig. 71.—Method of using stillage with an elevating platform truck. (*Ransomes.*)

Fig. 72.—METHOD OF USING A TIERING TRUCK IN CONJUNCTION WITH A STILLAGE. (*Ransomes.*)

Assume, for a start, that a truck of unladen weight (including battery) of 1 ton has to deliver a load of 2 tons at a distance of ½ mile and return empty. To add interest, let the outgoing journey be a climb of 1 in 120. It will take, say, eight minutes to load and the same time to unload the truck, assuming also that it is a flat platform truck and the load is therefore not on a stillage. (This equality may be unlikely, but it does not matter, as it is the total standing time that counts). Handling time is therefore sixteen minutes per journey. The truck is operated for eight hours a day, making sixteen complete journeys in that time and on one charge.

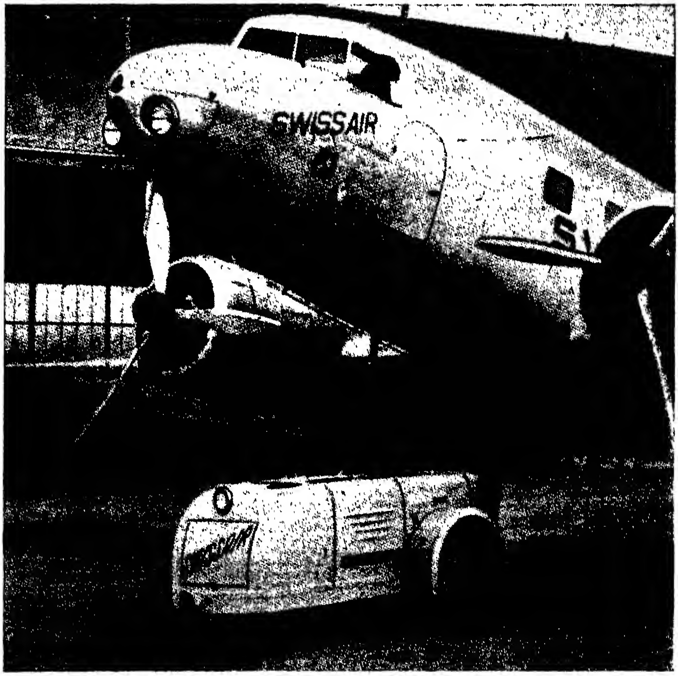


Fig. 73.—A BATTERY-ELECTRIC TRACTOR AT AN AERODROME IN SWITZERLAND

It can be shown that, on the average, a drawbar pull of 50 lb. is required for every ton of load pulled on level ground. In this case, maximum load $= 1 + 2 = 3$ tons, and lever pull required $= 3 \times 50 = 150$ lb. Extra effort on account of the incline on the outward journey will be in proportion to the incline; i.e. $3 \times 2240 \times$

$\frac{1}{120} = 56$ lb. Total maximum drawbar pull therefore equals 56 + 150 = 206 lb.

The speed at maximum load must be known in order to calculate horse-power required. In the working period of eight hours, sixteen complete journeys and 16 × 16 = 256 minutes of "load and unload" time must be allowed for. Journey time obviously is 480 — 256 = 224 minutes.

$$\therefore \text{Speed} = \frac{16 \times 60}{224} = 4\tfrac{1}{4} \text{ m.p.h. (say).}$$

A climbing speed of 2½ m.p.h. and a return speed of 6 m.p.h. will give this average.

From the well-known formula, the horse-power required will be :

$$\frac{206 \times 2\cdot5 \times 88}{33000} = 1\cdot37 \text{ or, say, } 1\tfrac{1}{2} \text{ h.p.}$$

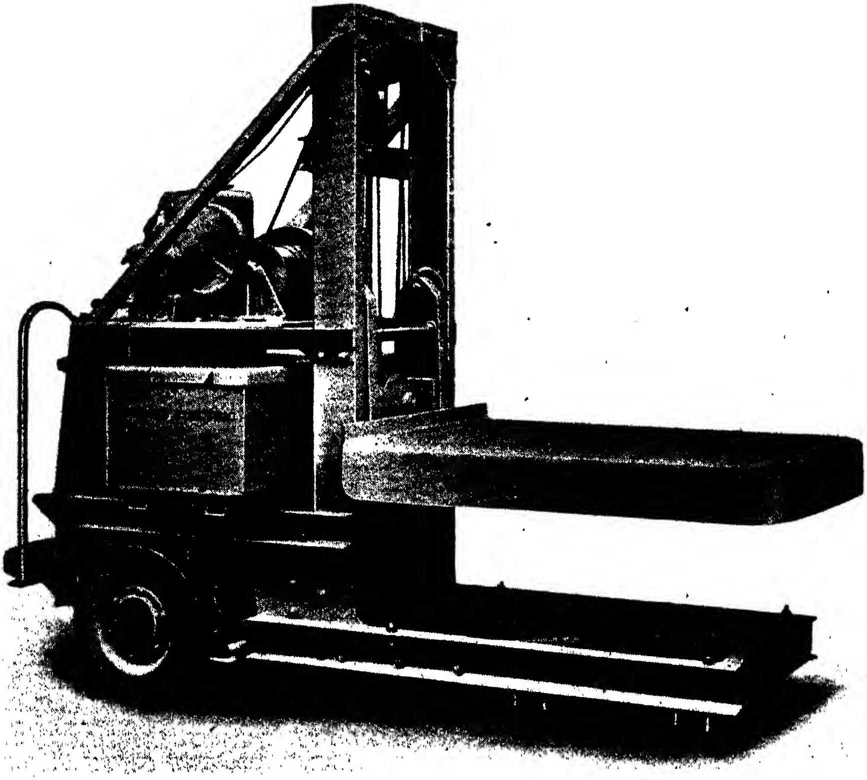


Fig. 74.—ELECTRIC TIERING TRUCK. (*Ransomes.*)

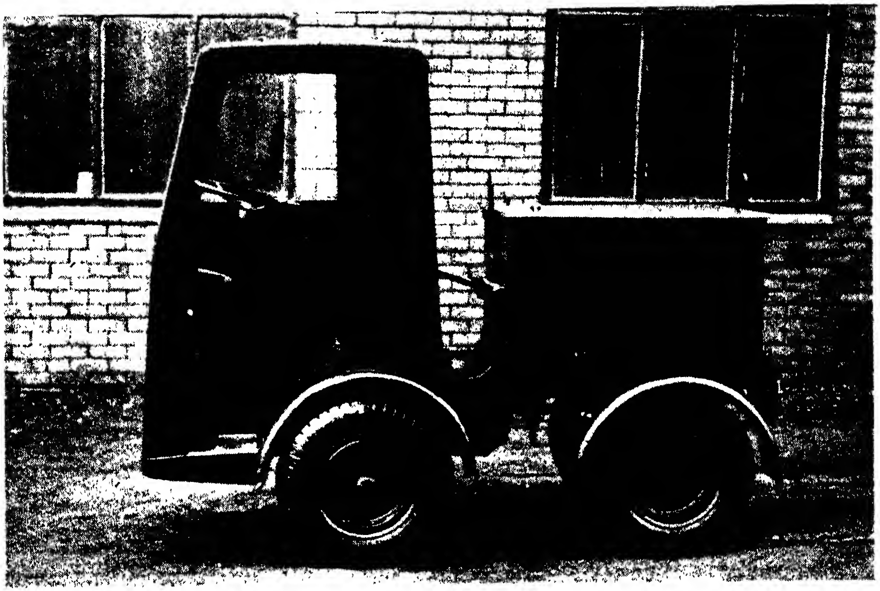


Fig. 75.—VICTOR ELECTRIC 8-TON E-TYPE TRACTOR

Ampere-hour Consumption

Assume a 40-volt battery is to be used. Then a $1\frac{1}{2}$-h.p. motor, *allowing an efficiency of* 75 *per cent.*, will take :

$$\frac{1\cdot5 \times 746 \times 100}{40 \times 75} = 37 \text{ amps.}$$

At a speed of $2\frac{1}{2}$ m.p.h. the uphill journey time will be 12 mins.
Total uphill going time ∴ = 16 × 12 = 192 mins.

$$\text{and ampere-hours (uphill)} = \frac{192 \times 37}{60} = 118 \text{ ampere-hours} \ldots 1$$

Going downhill, the motor horse-power required will be less than the level effort by an amount proportional to the gradient. Remember that the return load is 1 ton only. The decrease therefore =

$$1 \times 2240 \times \frac{1}{120} = 18\cdot6 \text{ lb.}$$

Drawbar pull of 1-ton load on level = 50 × 1 = 50 lb.
Drawbar pull of 1-ton load (downhill) = 50 − 18·6 = 31·4 lb.
At downhill speed (assumed) of 6 m.p.h. :

$$\text{Horse-power} = \frac{31\cdot4 \times 6 \times 88}{33000} = 0\cdot5 \text{ h.p.}$$

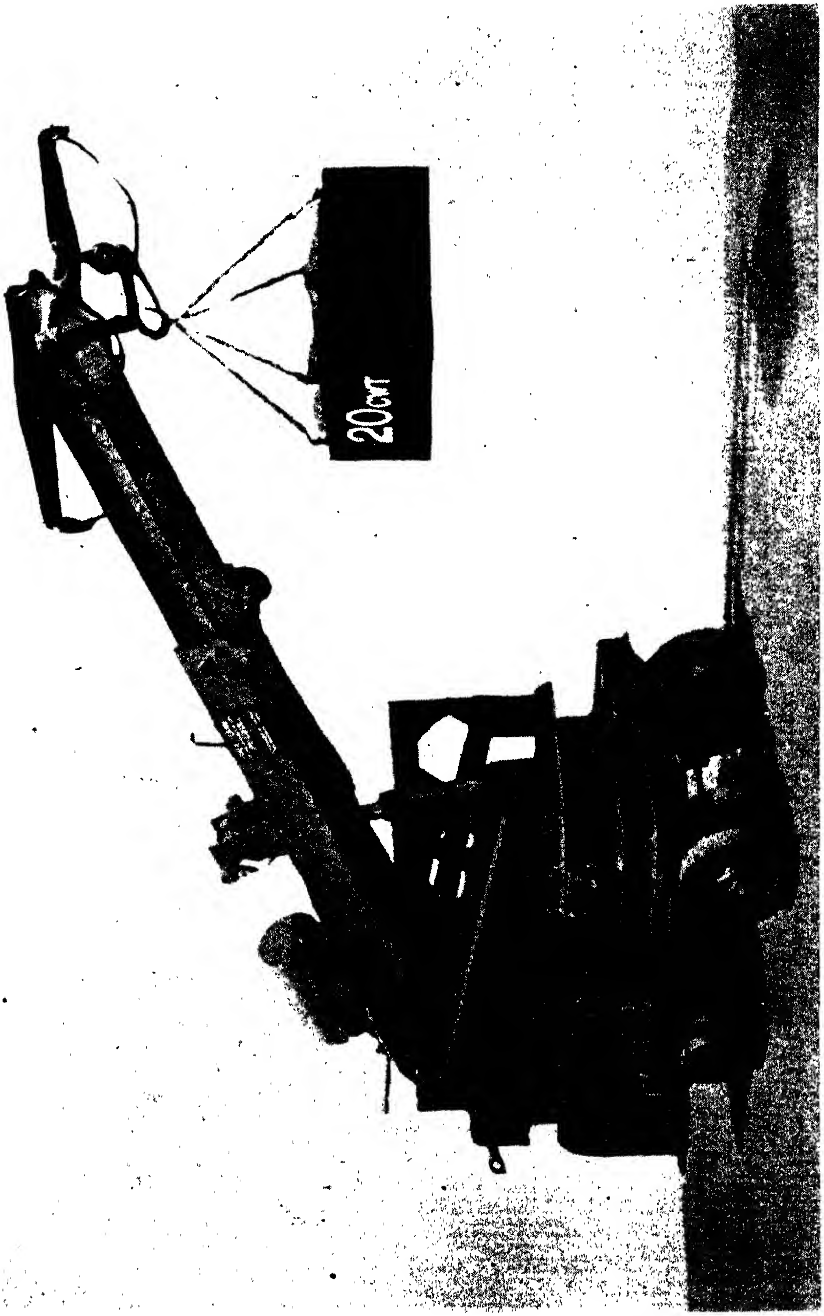


Fig. 76.—ELECTRICAR BATTERY-ELECTRIC CRANE TRUCK

With hydraulic lifting gear.

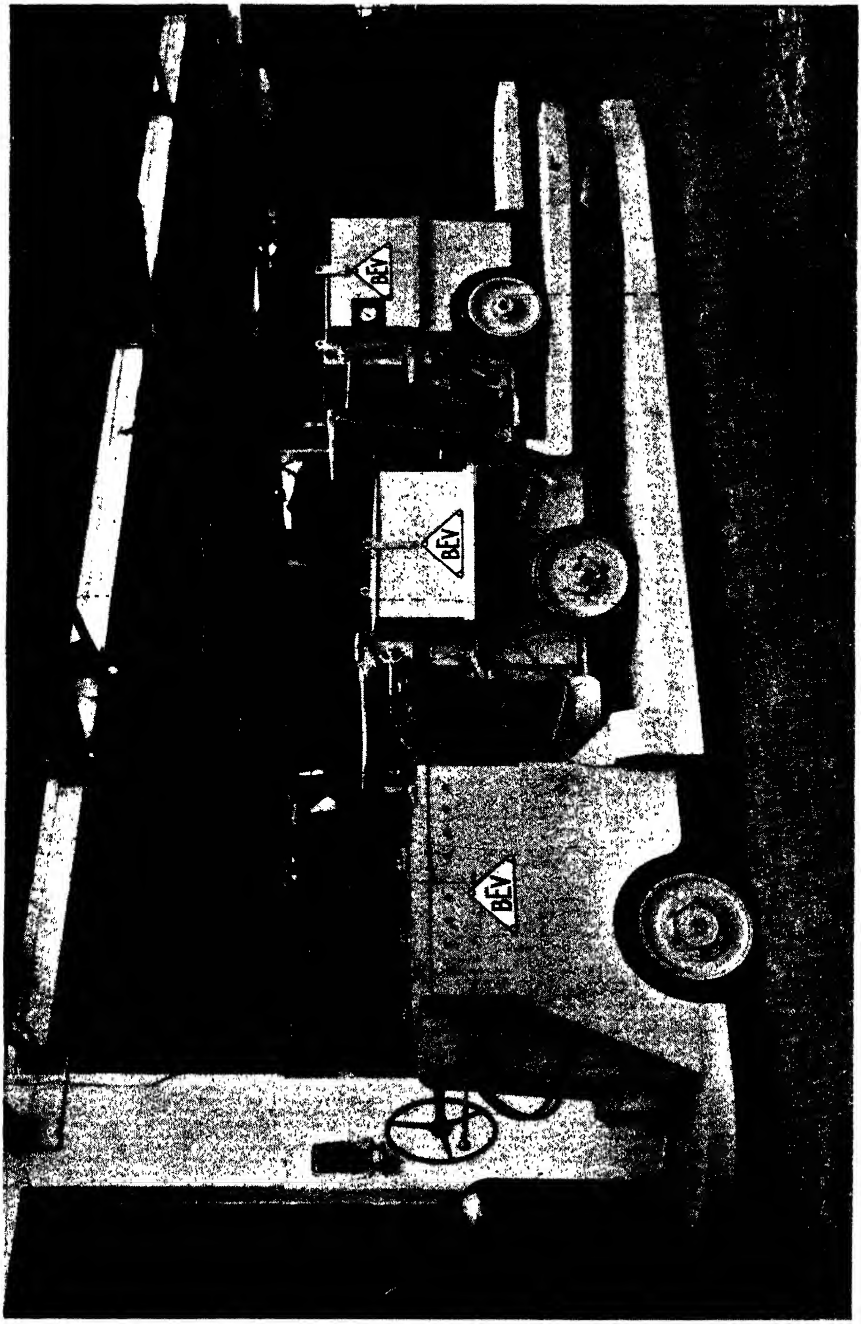


Fig. 77.—GROUP OF THREE B.E.V. TRUCKS. (*Wingrove & Rogers, Ltd.*)

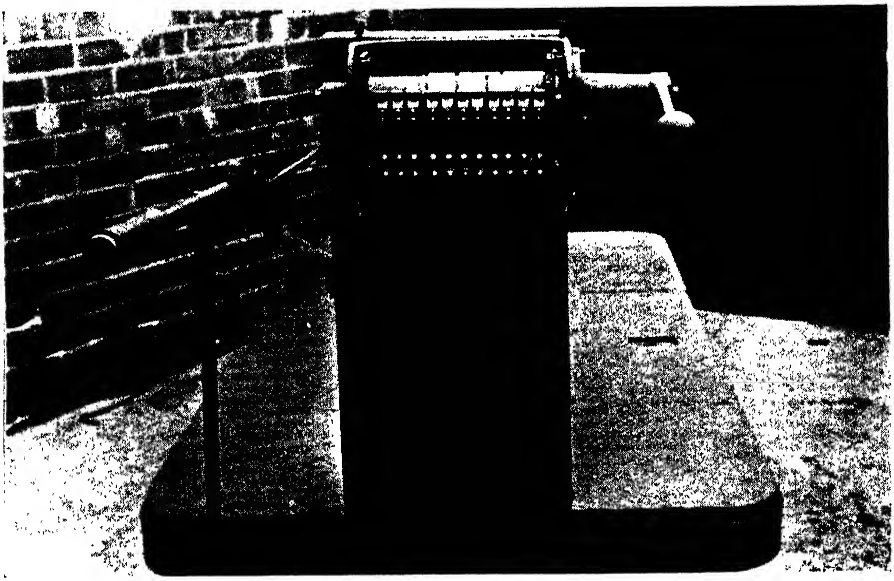


Fig. 78.—TU.20 Electricar one-ton fixed-platform truck
Control-column cover removed, showing drum controlled. (*Crompton-Parkinson, Ltd.*)

Assuming that the motor and transmission efficiency remains constant at 75 per cent.

Then the current consumption $= \frac{0 \cdot 5 \times 746}{40} = 9 \cdot 35$ amps.

At 6 m.p.h. the journey time will be 5 mins.
and total journey time = 5 × 16 = 80 mins.

The consumption $= \frac{9 \cdot 35 \times 80}{60} = 12 \cdot 4$ ampere-hours 2

From 1 and 2 the total ampere-hour capacity required is :

$118 + 12 \cdot 4 = 130 \cdot 4$ ampere-hours.

To prevent the battery from being discharged flat out, a capacity of about 180 ampere-hours should be allowed in such a case. Thus 180 ampere-hours with a lead-acid battery would be $\frac{180 \times 100}{80}$, i.e. 225, and with an alkali battery $\frac{180 \times 100}{95}$ or 189, the nearest standard maker's rates to those figures being chosen.

Batteries and Battery Charging

As with electric vehicles, the choice for batteries lies between the lead-acid and the alkali types, but whereas lead-acid are the more

Fig. 79.—B.E.V. ELECTRIC CRANE TRUCK. (*Wingrove & Rogers, Ltd.*)

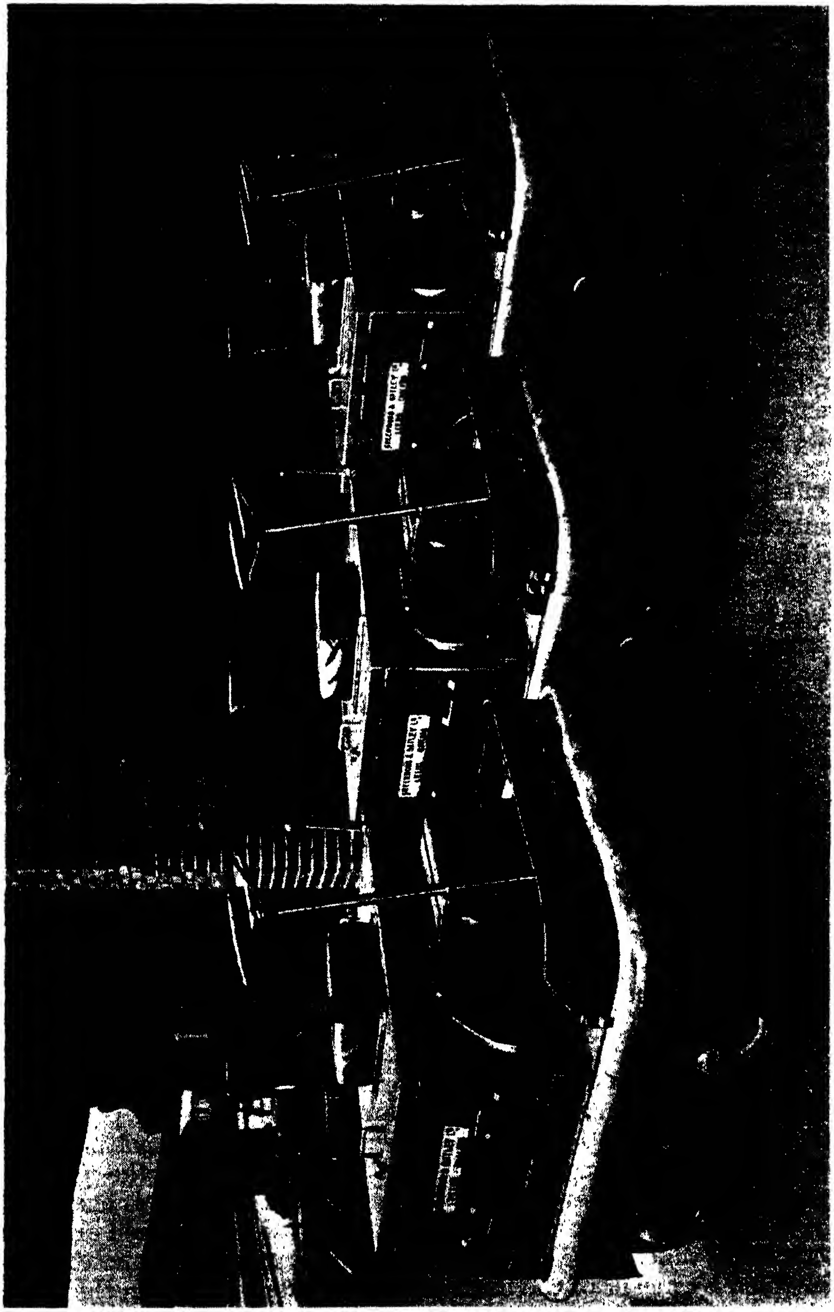


Fig. 80.—BATTERY-ELECTRIC TRACTORS AT A MAIN RAILWAY STATION

These are used for drawing trailer units containing luggage, etc. (*Greenwood & Batley, Ltd.*)

generally used for vehicles, a number of trucks are fitted with alkali batteries. Charging is generally effected by means of rectifier-charging or motor-generator equipment as referred to in another chapter. The average truck is fitted with a battery which will provide for eight to twelve hours' operation, and where longer hours of operation are required, a discharged battery is exchanged for a charged one at the truck depot or charging station on the works of the firm.

As an approximate guide, a 2-ton truck using a 20-cell 129-ampere-hour battery will operate for a distance of 7 miles when loaded, and 11 miles assuming an average load of 50 per cent., but it depends upon floor or road conditions and the number of stops and starts. The above would represent an ordinary working day of eight hours, and of course, if necessary a boost charge could be arranged for during the lunch hour. Generally speaking the batteries for trucks consist of a number of cells up to twenty for lead-acid and thirty-two for alkali types, the voltage being 40 volts in each case.

Controllers

Controllers are generally arranged so that the handle must first be placed in the neutral position before the direction of travel can be reversed, which gives the motor time to come to a stop, and undue strain on the windings is thereby avoided. It is also arranged that the truck cannot be started unless the handle is first returned to the neutral position. Further, by means of a pedal-contactor control the driver can leave the truck stationary with the controller handle in one of the moving positions, because the pedal operates to cut off the power, and on releasing the foot off the pedal the brakes are applied. This provides for a very safe means of operation, and acts as a "dead man's handle" as on a tramcar, an essential point where vehicles like trucks are driven in narrow gangways adjacent to which men are working.

It is essential that the controller should be of robust construction both mechanically and in regard to current-carrying capacity, as the duty placed on the controller is heavy. It should also be constructed and mounted so that inspection is an easy matter, and that access to the contact fingers can be gained readily. A good method is to arrange that the circuit is broken by a trip mechanism actuated either mechanically or electrically, so that arcing is confined to one or two of the controller fingers only. The trip mechanism is operated by a cam mounted on the controller-drum shaft, and when this cam is in the neutral position it presses a solenoid on to a plate behind which is mounted a solenoid coil. No current passes through the solenoid coil until the brake pedal is depressed, when a secondary circuit is closed and the magnet is energised.

The solenoid is then held to the magnet, and to the solenoid are fixed contact fingers which close the main circuit; movement of the drum of the controller by means of the handle causes current to flow in the motor

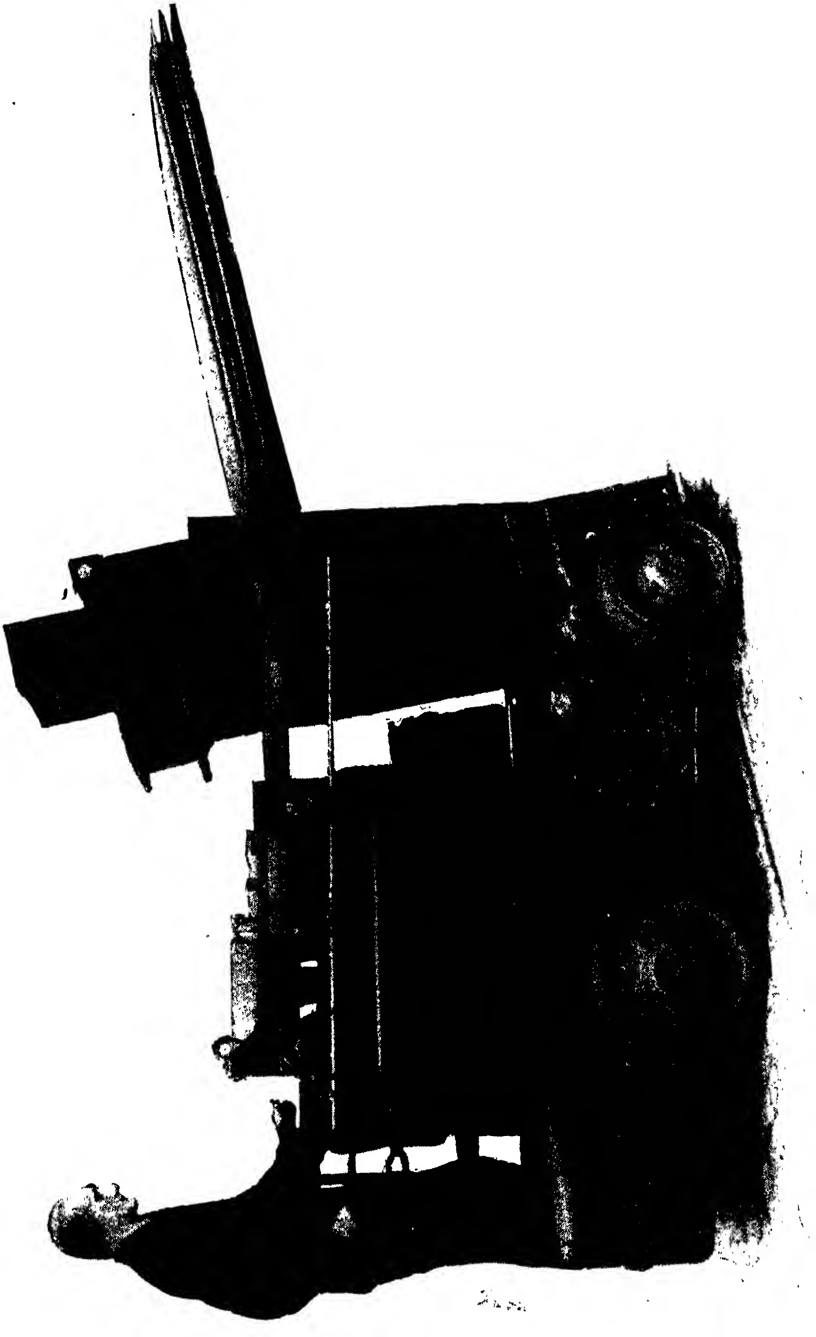


Fig. 81.—A TILTING AND TIERING TRUCK. (*Greenwood & Batley, Ltd.*)

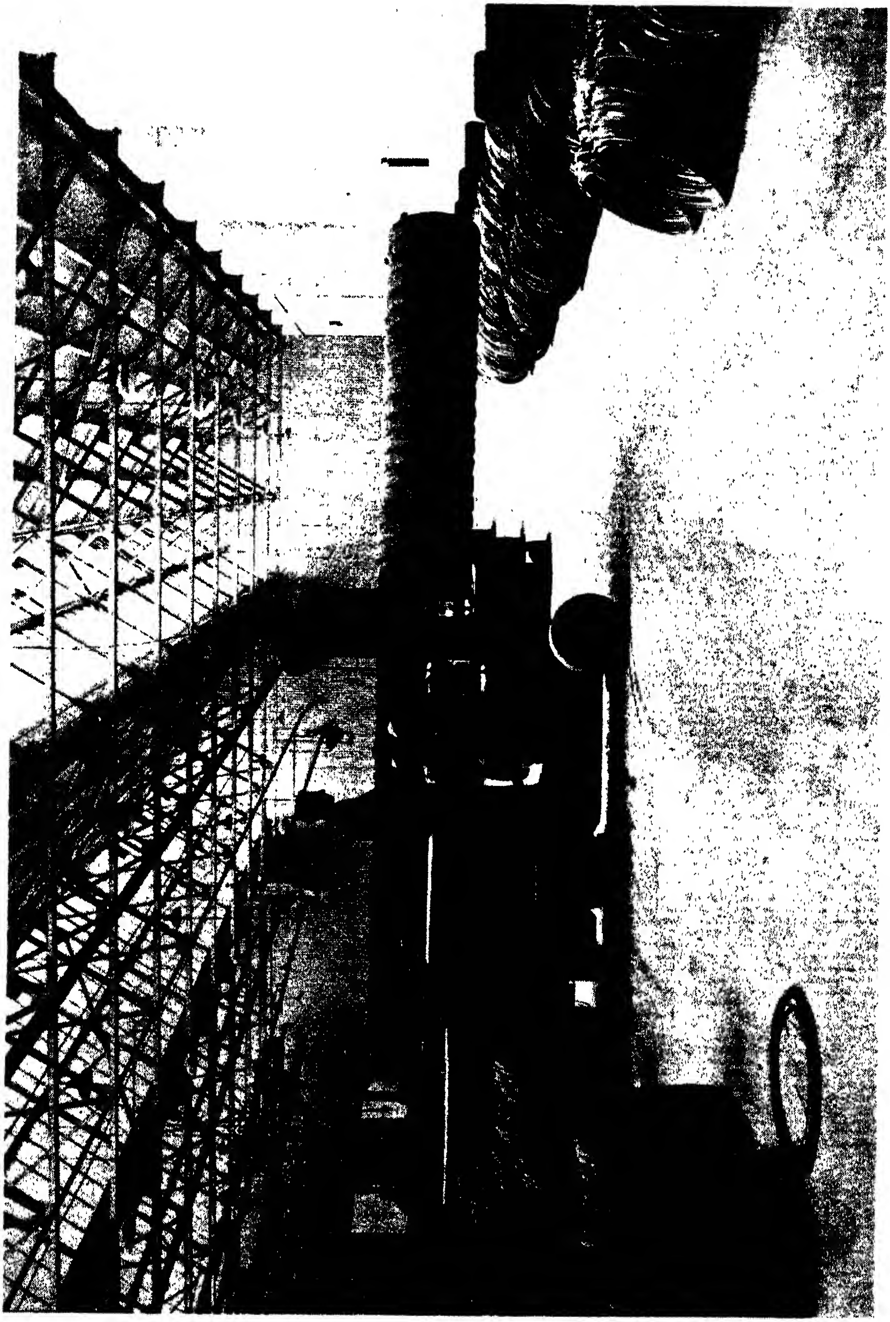


Fig. 82.—A BAR TIERING TRUCK. (*Greenwood & Batley, Ltd.*)

circuit and the truck therefore moves. When the brake pedal is partially released, the secondary circuit is broken, and the solenoid flies out, breaking the main circuit by means of the fingers attached to it. The solenoid flies out beyond the range of magnetic attraction, and cannot be influenced by the secondary circuit unless the controller drum is brought into the neutral position, so that the cam on the drum shaft can close the circuit again. That is, unless the driver is standing on his pedal, no current can pass through the main circuit.

Speed Control

Speed control is generally effected by means of resistances, the various connections being brought about by contacts on the controller. Speed is lower than that of a road vehicle, and generally three speeds are provided for, resistance occupying but one stop. On the starting position current flows through the resistance and the field coils and armature in series. The next stop cuts out the resistance, and the last stop connects the fields in parallel with each other and in series with the armature.

An alternative is to arrange the fields in parallel and connect them in series with the armature, to provide a number of stops on the controller which connect with a similar number of tappings on the resistances, by which means on the first stop all the resistance is in series with motor connections and at each successive stop the amount, i.e. number of resistance coils, in circuit is reduced. With this method a series-parallel switch could be employed, and the number of speeds in each direction could be doubled by incorporating the first method as well. Reversing can be arranged for by changing the armature lead connections, i.e. crossing them, which can be arranged for either through the controller or by means of a separate switch. Slow speed only can of course be provided for in the controller, but if a range of speeds is available for both reverse and forward, trucks can be driven either way, i.e. forwards or backwards, as desired, the driver standing on the driving platform, but reversing his own position. That is, the truck acts like a tank-engine.

A point worthy of note, in connection with the starting and speed-control arrangements of both trucks and electric vehicles, is that, up to the present, no attempt seems to have been made by the makers to dispense entirely with the use of the wasteful starting resistance, except in the case of the early Headland vehicle of 1900, the electrical equipment of which comprised forty Headland accumulators, arranged in four groups, and a single 4-h.p. series-wound motor. The axle of the motor, placed longitudinally, carried a bevel wheel driving a phosphor-bronze bevel wheel on the rear-wheel axle, a differential gear being used.

There were no resistances in the electrical circuit, speed regulation being effected by various groupings of the four sets of cells ; at starting they were all in parallel, and from this passed through two groups in series and two groups in parallel to all in series.

It will be appreciated that, where motors are being supplied from mains supply, some form of resistance is essential to limit the current flowing through the armature before the latter has attained the speed necessary to generate a back E.M.F.

With a battery-driven motor, the same result can be obtained by applying the voltage gradually, that is to say, the motor could be connected to a low-voltage tapping at the moment of switching on, and the voltage gradually increased by moving the control over tappings from the battery until the full voltage was applied as the motor attained its normal speed. Such an arrangement would dispense with the need for a starting resistance.

There would be a certain unevenness in the demands made upon different cells in the battery, though, no doubt, this could be taken care of by a change-over arrangement enabling groups of cells to be used alternately for starting purposes, thus keeping the load on the battery as a whole even. Of course, the starting resistance is only in circuit for a short period, and probably that is why parallel and series connection of cells, as referred to in Chapter III, has been considered to be sufficient.

Chapter VII

BATTERY-ELECTRIC LOCOMOTIVES

THE battery-electric loco is a natural development out of the battery-electric tractor; but while the latter is confined to use in and around factories, sometimes used as a road vehicle, sometimes on light rails, the former serves in the industrial, mining, tunnelling, and railway fields. While its principles of operation are the same, it is heavier in design to fulfil the more arduous conditions which are called for.

Civil Engineering and Contracting

The smaller type of battery locomotive for hauling a load of from 5 to 20 tons may be considered to fall within this field. In the construction of tunnels for tube railways, tunnels for roads or railways, tunnels for sewers, etc., this type of traction unit has proved to be eminently satisfactory. The conditions are generally arduous, and the track is often very rough, so that even if space and conditions permit the use of an overhead trolley or third-rail system, track conditions do not tend to efficient operation with them.

They are more flexible as power units, emit no fumes, and are, generally speaking, safer in operation than any other type of motive power.

Their use to a considerable extent in this country dates back to the construction of the Tube railway extensions between 1921 and 1926, and in connection with the construction of the L.C.C. surface relief sewers during the same period. Time is generally the element of such contracts, and the equipment is in use both day and night, with perhaps a break of twenty-four hours at the week-end.

The use of battery locomotives in connection with the above led to their use by the Sydney Metropolitan Water, Sewerage, and Drainage Board[1] in connection with a pressure tunnel constructed for the purpose of increasing the water supply in Sydney. This tunnel was 10 miles in length and ran in a perfectly straight line, and in its construction seventeen shafts were sunk at an average distance of 300 ft. The tunnel was driven through solid sandstone formation. Each loco drew a train of about six loaded skips, the aggregate weight being 10 tons. The track ran from the working face to the shaft. Near the shaft the track was divided into two, one line leading into a cage. The locomotive with its loaded skips ran on one side and continued through the cage, leaving the end skip of the train in the cage ready for being raised to the surface.

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[1] *Storage Battery Locomotives*, by N. E. Bayliff (Association of Mining Electrical Engineers, 1931).

At the surface the skip was emptied by an automatic tipler, the remaining skips being detached from the locomotive and left on the siding to await their turn for conveyance to the surface in the cage, the locomotive being shunted and returned by the other line, again passing through the cage and collecting the empty skips. The empty skips were then pushed to the working face by the locomotive to await refilling.

The above may be considered to be a typical example of using battery-electric locos for this class of work. The locomotives also come into use in connection with concreting, the concrete being mixed at the surface by a mixer and run direct into a side-tipping truck standing in the cage on the surface. The cage is then lowered to the tunnel and the locomotive either draws or pushes it to the place where it is to be used.

Battery-charging requirements vary with the conditions of working, e.g. length of run to working face, number of runs per day, etc., and also the ampere-hour capacity of battery used.

Where the run is long, i.e. over 1,000 ft., daily charging will probably prove necessary. The process is quite simple, the battery being moved off the locomotive on to a plain-platform trolley and lifted to the charging station on the surface, a ready-charged battery for exchange having already been brought down in the cage, which is slid from a trolley into the battery compartment of the locomotive.

In the Sydney case the locomotive had a drawbar pull of 300 lb. and was capable of exerting a pull of 1,100 lb. for short periods. The average speed on the level under full-load conditions was between 3 and 4 miles per hour. The wheelbase was 2 ft. 4 in. and the locomotive would negotiate curves of 11-ft. radius. All four wheels were driven through spur gearing by a single totally enclosed series motor of the traction type. The batteries were nickel-iron, 40 cells, 215 ampere-hour.

Another example of the use of battery-electric locomotives was the Mersey Tunnel. These were designed for loads of 5–7 tons, and the gradients were about 1 in 30, while a further one was the water-drainage scheme of the Halklyn district of North Wales. In the latter case one locomotive did the work formerly done by ten ponies and ten men, and showed a saving in working cost of about £20 a week.

Design of Light-type Locomotive

The drawbar pull of a locomotive is affected by the action of wheel slip, which in turn is related to the condition of the track. The maximum drawbar pull on the level is also reduced when climbing a gradient, because part is required to raise the weight of the locomotive itself up the gradient (see Chapter III A). Under conditions of track met with in connection with civil engineering work, the maximum drawbar pull on the level may be taken as being 20–25 per cent. of the weight of the locomotive.

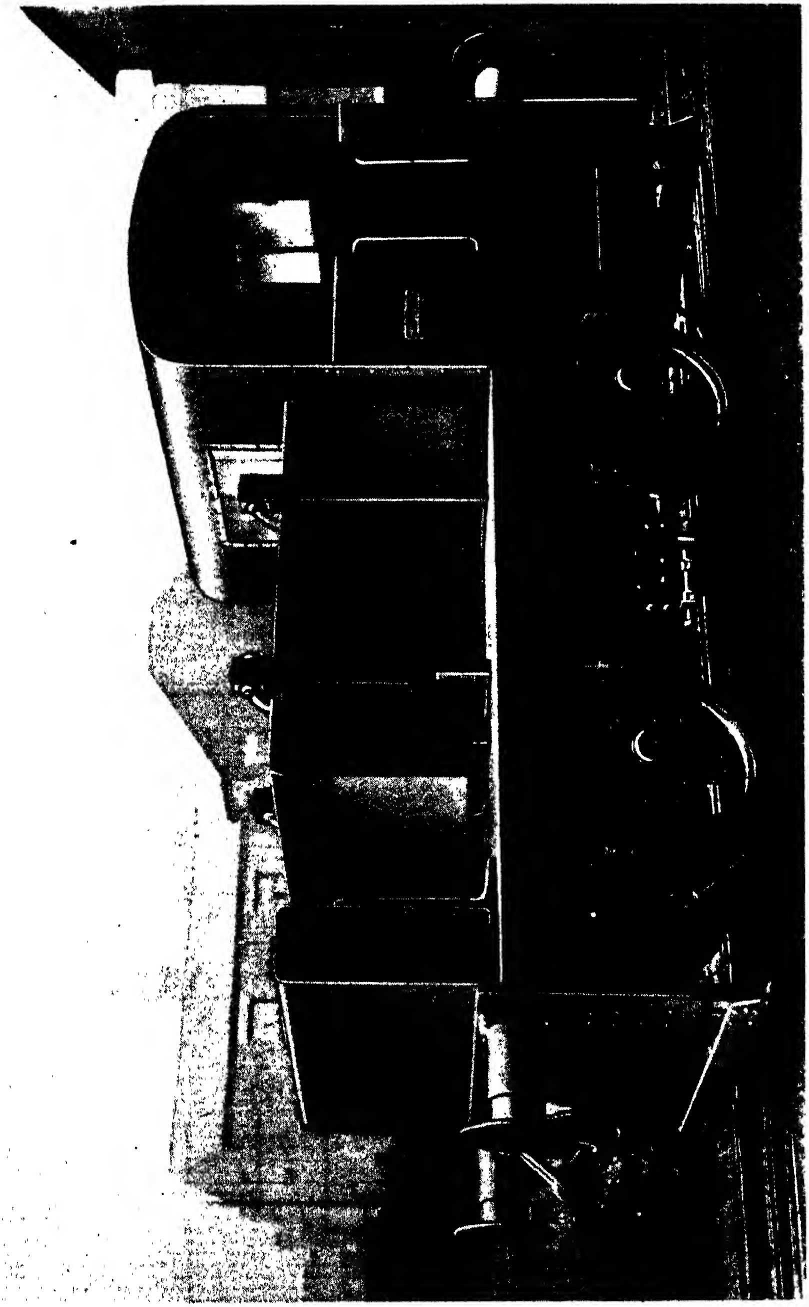

Fig. 83.—Two-axle battery-electric shunting locomotive

Trains up to 150 tons weight are handled at a speed of 5 m.p.h. by this locomotive. (*Metropolitan-Vickers Electrical Co., Ltd.*)

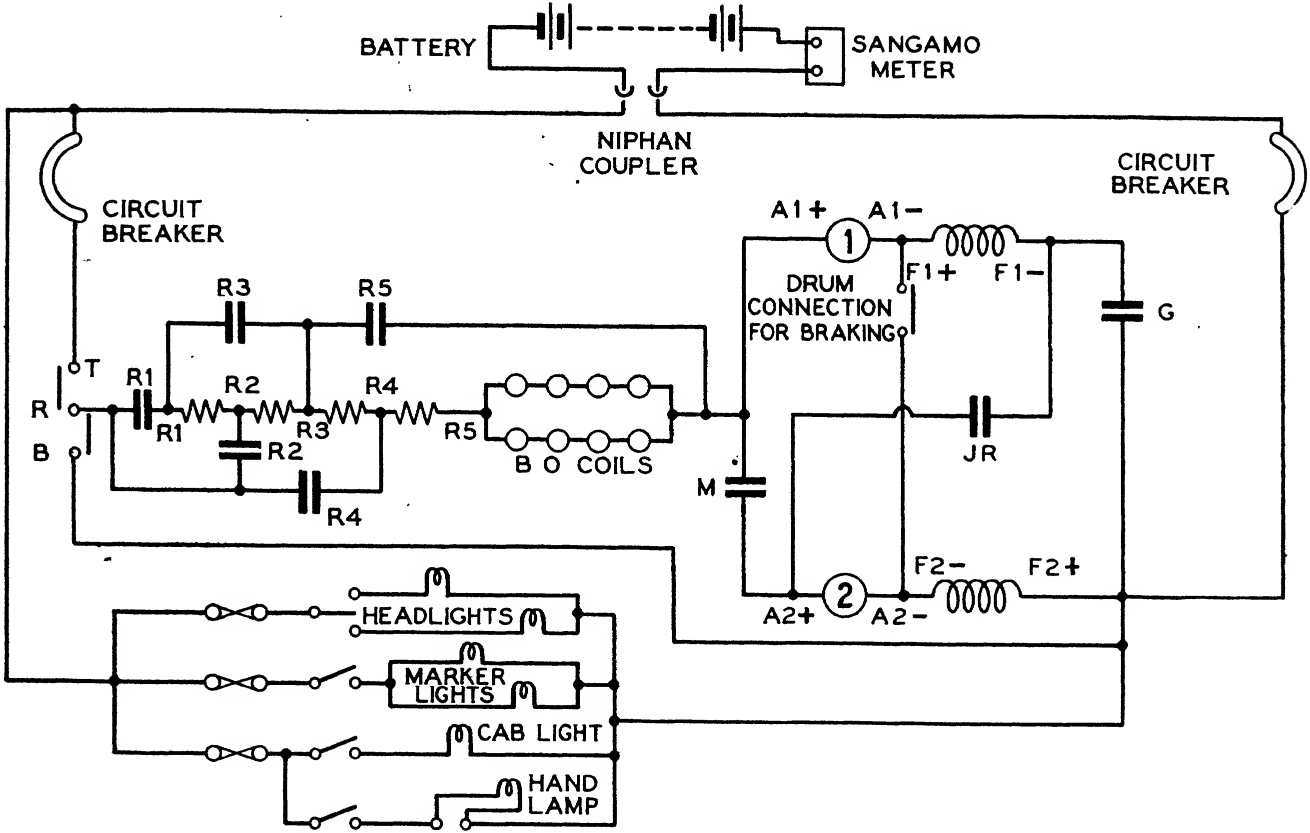

Fig. 84.—Schematic diagram of connections for Metropolitan-Vickers battery-electric locomotive

As a means of approximately determining battery capacity, Mr. N. E. Bayliff gave, in his paper before the Institution of Mining Electrical Engineers, the formula :

Watt-hours required = 3 × total effort × distance in miles.

Speed control of the motor follows the usual lines by means of a controller which gives series-parallel control of the motor fields. Either lead-acid or alkali batteries are used, the latter sometimes being preferred, in cases where the locomotives are liable to lie idle for some time between contracts.

The drive from the motor may be either by means of worm or spur gear or chain. The two first each have advocates, but the latter is generally used only for locomotives of the very light type, i.e. up to 1 ton weight.

The frame is of steel plate, and outside frame construction is generally adopted because it gives the best protection from accidental damage, and obviates the risk of workers' clothing being caught in the wheels. Sprung axle boxes are generally employed, and also spring buffers, which in this class of locomotive are generally of the central type, as such are of advantage in negotiating curves of small radius.

Locomotives for Mining

Mention of mining in this country immediately suggests coal-mining, and calls to mind the risks occasioned by the possible presence of inflammable gases. Very considerable use has been made of battery-electric locomotives in mines and quarries in other countries, however, the United States of America being a particularly good example. In 1928, the United States Bureau of Mines made the statement that :

" The Bureau of Mines, from the first, has looked upon the permissible type of storage-battery locomotive with favour because of its inherent safety advantages. That its energy is self-contained and limited to the immediate zone of the locomotive is a factor of safety of great importance."

Before that, however, in this country the late Mr. Charles Markham, who died in 1926, was very interested in improving mining conditions, and offered, through the Ministry of Mines, a prize of £1,000 for the best locomotive built to a specification issued in connection with the competition. The specification, briefly, called for a locomotive designed to run on a 2-ft. gauge and able to turn through an angle of 90° on a circle with a radius of 13 ft. measured from the middle of the track without overlapping the rail more than 12 in. The overall dimensions were limited to 38 in. in width and 42 in. in height above the top of the rail, the length being left unspecified. The weight was limited to 5,600 lb. as an upper limit, and the duty was specified in terms of drawbar pull, speed, and time for each complete change of battery, the figures being 600 lb., $3\frac{1}{2}$ m.p.h., and $1\frac{3}{4}$ hours respectively; the minimum battery capacity was specified

	Sequence of Switches								
	Step	JR	M	G	R1	R2	R3	R4	R5
Series	1	●			●				
	2	●			●		●		
	3	●			●		●	●	
	4	●			●		●	●	●
Transition		●						●	
		●		●				●	
				●				●	
Parallel	5		●	●				●	
	6		●	●				●	●
	7		●	●		●	●	●	●
	8		●	●	●	●	●	●	●
Brake	1		●	●	●				
	2		●	●	●	●			
	3		●	●	●	●	●		
	4		●	●	◓		●	●	
	5		●	●			●	●	●
	6		●	●		●	●	●	●
	7		●	●	●	●	●	●	●

Fig. 85.—SEQUENCE DIAGRAM FOR METROPOLITAN-VICKERS BATTERY-ELECTRIC LOCOMOTIVE

at 12 kWh. at the one-hour rate and 18 kWh. at the five-hour rate of discharge. The comparatively large battery capacity was called for to ensure ample margin of reserve for emergency duty.

The winning locomotive was designed and made by Booth Bros. and was of the two-axle type with a single 8-h.p. motor coupled to one axle by a worm reduction gear, the driving axle and second axle being coupled by connecting rods. Owing to the well-designed single motor and other features, the test duty which was planned to represent the average work of a shift required only one-third of the capacity of the battery, or 38 per cent. of the duty as originally specified, which was somewhat greater than the duty of the actual test.

The outer frame of the locomotive was spring supported from the inner frame and hence from the wheels by six helical springs. This frame carried the battery, the controller, and the switchgear, and the two frames with their equipment could be separated without disturbing any internal electrical connections. The battery receptacle was divided into two groups of boxes, each group consisting of a pair of steel boxes carried on the same base and so arranged that each group could be rolled in and out of the receptacle after removing one of its sides. A battery could be replaced in about three minutes. All connecting cables between parts of the equipment were carried in stout metal tubes, and provision was made by means of spring-loaded valves in the battery-box covers for relief of gaseous pressure, the actual openings being protected by nickel gauze.

The maximum speed drawing a 5-ton load up 1 in 24·8 gradient was 5½ miles per hour, and on the level was 5·68 miles per hour ; the average speed in the duty cycle test was 4 miles per hour. The maximum speed of the locomotive running unloaded on the level was 8·95 miles per hour.

In a paper read before the Institution of Electrical Engineers, Mr. L. Miller, A.M.I.E.E., the author, in referring to the design of storage-battery locomotives for use in coal-mines, laid down the following conditions :

" The design of the locomotive must be such that it can be taken down in the cage either in pieces or as a whole, run over the main haulage roads to the gate roads, and be able to clear all the obstructions which exist on the main haulage road. The locomotive must also be capable of giving sufficient adhesion to pull at least a load of 5 tons on a grade of 1 in 20 and have a speed on the level of about 3½ miles per hour when pulling the same load. The wheelbase of the locomotive must be such that the locomotive is capable of going round a curve of about 12-ft. radius. The overhang when negotiating the curves must be such as not to foul the sides of the gate road.

" The whole of the electrical equipment must, of course, be flame-proof and of a type which it is safe to operate near the coal face. It must, in addition, be capable of being worked in the open air with rain falling and of being operated through a considerable depth of water without permanently affecting in any way the sanding gear or the electrical equipment.

" It must be possible to change the battery quickly.

" The choice of drive lies between the single motor of Booth's design, which proved very efficient, i.e. mounting a single motor which drives one axle, the second being connected by connecting rods, or a cardan shaft and worm drive, and using two motors, one on each axle, connected through gearing. The latter method, by connection of the motor fields and armatures in series-parallel, makes it possible to do away entirely with resistances for speed control, which leads to economy in current consumption. This becomes particularly apparent in the performance of marshalling duties, which has to be done at low speed, but the advant-

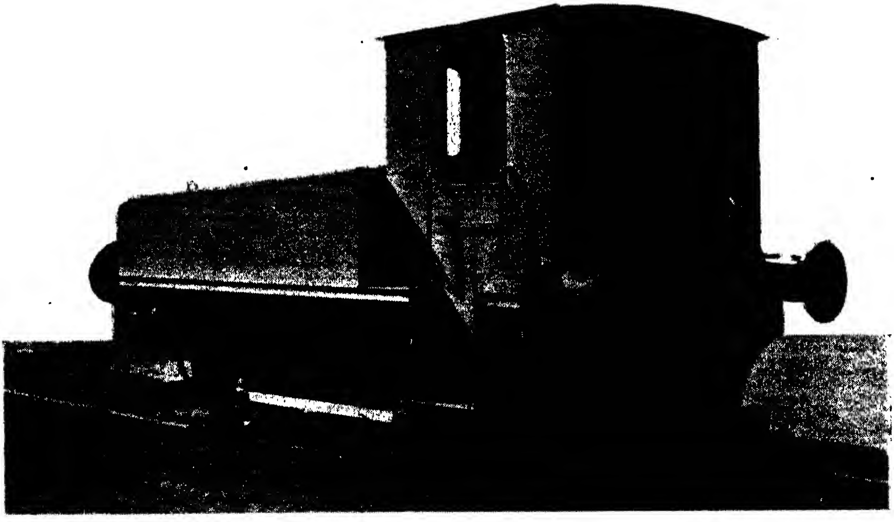

Fig. 86.—INDUSTRIAL-TYPE BATTERY-ELECTRIC LOCOMOTIVE. (*British Thomson-Houston Co., Ltd.*)

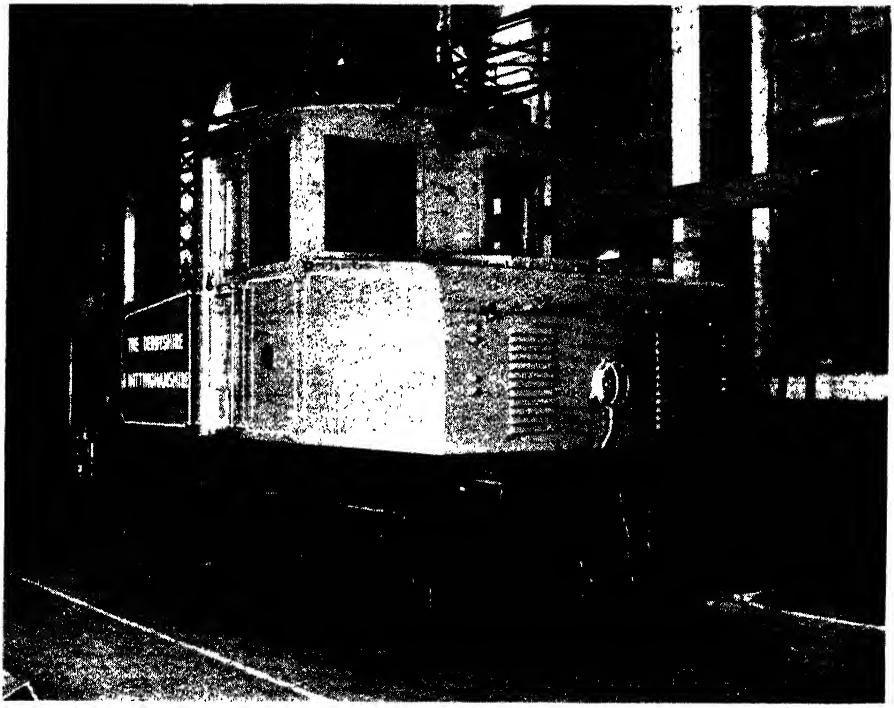

Fig. 87.—Combined battery and trolley locomotive. (*English Electric Co., Ltd.*)

age is not so apparent on long straight runs. The two-motor arrangement is generally favoured in the United States of America.

"As the duty is what may be termed heavy service, the controller should be of the contactor type. Roller bearings for the axles of the locomotives and tubs lead to considerable saving in power over ball bearings, and in some cases this saving has amounted to as much as 40 per cent. of the power required to overcome friction, while the use of ball bearings on the motor not only helps in obtaining a flame-proof design, but enables the length between bearings to be reduced. The enclosure of all electrical apparatus used on the locomotive must comply with the British Standard Specification for flame-proof enclosure for use in mines."

Industrial Locomotives

Many large industrial works have their own sidings where goods trucks have to be marshalled and shunted, or coal trucks dealt with in similar manner. This is a field where a battery-electric locomotive of the light-railway class can often be used with advantage, and particularly

Fig. 88.—20-TON BATTERY-ELECTRIC LOCOMOTIVE. (*English Electric Co., Ltd.*)

Fig. 89.—A 50-TON DOUBLE-BOGIE CENTRAL CAB TYPE BATTERY SHUNTING LOCOMOTIVE

Used by the Bombay, Baroda, and Central India Railway, Bombay. (*English Electric Co., Ltd.*)

so in the case of large electricity generating stations where rail-borne coal has to be handled.

A Greenwood and Batley locomotive is used, for example, at the Luton generating station for shunting purposes and for hauling a gross load of 100 tons on the level on a full-gauge track. The locomotive weighs approximately 10 tons, Edison alkali-type batteries being fitted. Other examples are to be found at Glasgow and Stourport.

During 1942, the English Steel Corporation put into service a 13-ton two-axle type battery-electric shunting locomotive, built by the Metropolitan Vickers Electrical Co., Ltd., for use in shunting operations in the works. Trains up to 150 tons weight are handled at a speed up to 5 miles per hour (Fig. 83).

The construction follows the robust lines of established railway practice, and all the materials used were in conformity with the appropriate B.S. specification. The structure is built on two plate side frames braced together by cross stays at each end for the drawgear and at the centre for carrying the motors. The top edges of the side frames are covered by a stiff plate, which ties the structure together and forms the platform for the battery chamber. The driver's cab is at the end, and is provided with a seat conveniently placed for manipulating the controller and the brake wheel. The buffer and drawgear are arranged for working with standard railway wagons. Hand-operated sanding can be applied to all the wheels. A chamber mounted at the left of the battery serves the dual purpose of accommodating the sand and protecting the battery from the heat emitted by hot ingot wagons being trailed. Incidentally, this sand chamber improves the weight distribution of the locomotive. The locomotive has a wheelbase of 6 ft.; its overall dimensions are 17 ft. 9 in. length, 9 ft. height, and 7 ft. 6 in. width.

A lead-acid battery of 90 cells of Exide type TL11, supplied by the Chloride Electrical Storage Co., Ltd., is used. This battery, which constitutes about 18 per cent. of the weight of the complete locomotive, has a rated capacity of 240 ampere-hours at the five-hour discharge rate and an average pressure of 180 volts. The locomotive operates on a 24-hour-day service, and duplicate batteries are provided to alternate with each other—one being on charge while the other is at work. Each battery is housed in a stout fabricated box which can be easily disconnected and removed by crane in a matter of a few minutes. The battery boxes are painted on the inside with acid-resisting paint, in the usual manner. Connecting and disconnecting are readily effected by convenient plug and socket jumpers. To warn the driver when the battery is reaching its discharged condition, a Sangamo meter is mounted in the cab and indicates, with a red pointer, the stage at which the batteries should be changed over. The setting, initially fixed at 150 ampere-hours, can be adjusted in the light of experience on the particular duty being performed.

The drive consists of two standard axle-mounted tramway motors transmitting through single helical single-reduction gearing. The motors are " Metrovick " type MV116AY, with an hourly rating of 60 h.p. each at the normal tramway voltage of 500 volts. Working on the battery averaging 180 volts, the speed is reduced so that the nominal rating of each becomes 15 h.p. The motor is furnished with Class B insulation. Special roller bearings are used so that the armature can be withdrawn with ease for any overhauls required.

The road-wheel diameter chosen was 37 in. to permit of a satisfactory clearance above rail level and a gear ratio of 13/76 was adopted to suit the speeds contemplated.

The control arrangements can be gathered from the schematic diagram of connections in Fig. 84 amplified by the sequence diagram in Fig. 85. The two motors are operated in series-parallel so that economical running is possible at two different speeds. In addition, three other speeds can be obtained in both combinations with some resistance in circuit.

When running, braking is normally applied rheostatically by switching the controller over to the braking side and using the energy of the moving train to drive the motors as generators and load on to the resistances. Seven degrees of rheostatic braking are available. For final standstill and holding at rest, ordinary hand mechanical braking with brake blocks on the wheels is resorted to, and a hand-wheel for that purpose is installed by the driver's seat.

The controller itself is a " Metrovick " cam-operated contactor-type OK48B tramcar controller, in which all breaking of circuits is carried out on quick-operating contactors, each of which has its own powerful blow-out.

As an example of alternative design, the battery-electric locomotive supplied by the British Thomson-Houston Co., Ltd., for an important industrial works may be quoted. This locomotive replaced a Diesel locomotive, and was the 0—4—0 type weighing 10½ tons. It was driven by a single-traction motor geared to one of the two coupled axles. The single motor had roller bearings for the armature. The motor was rated at 20 h.p. on 150–200 volts and was operated from a 380 ampere-hour NI–FE alkali battery of 124 cells. The controller was of the drum-type tramway pattern modified for single-motor operation. The spare contacts on the reversing cylinder of the controller were utilised to effect the change-over in the head and tail lights, in accordance with the position of the reversing handle, and consequently the direction of the locomotive. The locomotive was provided with rheostatic braking and hand brakes acting on all four wheels, and would haul a load of 75 tons on the level (Fig. 86).

The English Electric Co., Ltd., have built a number of utility-type industrial standard-gauge two-axle type locomotives with a central cab. They are equipped with two standard-series traction-type motors driving

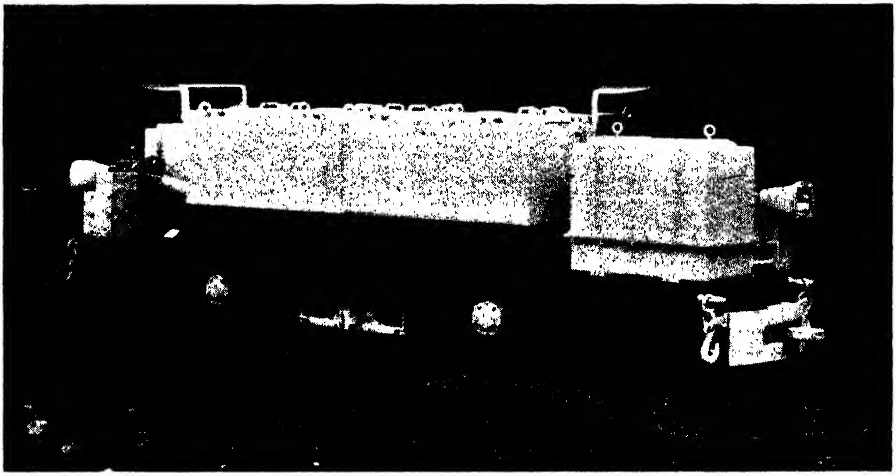

Fig. 90A.—ONE OF THREE 10-TON FLAMEPROOF BATTERY SHUNTING LOCOMOTIVES FOR COAL MINES. ("*Metrovick.*")

***Fig.* 90B.—B.E.V. BATTERY LOCOMOTIVE**

Capable of hauling 15 tons at 4 miles per hour on level track. (*Wingrove and Rogers, Ltd.*)

through a single-reduction gear, one motor driving each axle. Control is effected by means of a hand-operated drum-type controller in the cab which gives series-parallel operation of the motors. One supplied to an electric power company, for example, had a weight of 20 tons, a maximum tractive effort of 11,000 lb., and the horse-power was 68. The battery voltage was 220 and the ampere-hour capacity 294 at the five-hour rate.

This locomotive was fitted with overhead gear so that it could work also as a trolley locomotive.

Similar locomotives, also supplied to electricity supply authorities, but working purely as battery-electric locomotives, had a weight of 20 and 14 tons, the battery voltages 250 volts and 200 volts, and ampere-hour capacities 252 and 224, respectively. The respective horse-powers were 54 and 31, and tractive efforts 11,000 and 7,500 lb.

In all cases mechanical brakes are fitted, operated by a handwheel inside the cab. In addition, the controller is arranged to provide electric rheostatic braking, which is useful in cases where the locomotive must hold a heavy train when running down a gradient.

A Flameproof Battery Locomotive

Fig. 90A shows one of three 10-ton battery shunting locomotives with flameproof enclosure, supplied for hauling man-riding trucks below ground. The drive consists of two D.C. motors, each rated at 29·5 h.p., 165 volts for half-hour, transmitting through worm gears of ratio 9·33 to 1. Power is supplied from a lead-acid battery of ninety cells. The control arrangements provide series-parallel combinations giving two economical running speeds and eight resistance notches. Magnetic track brakes were fitted for emergency and coasting braking.

Railway Locomotives

Post-war conditions may bring very extensive developments in connection with the electrification of railways, and in this connection the battery-electric locomotive can solve one of the most difficult problems, i.e. the complication and cost created in electrifying goods and shunting yards, whether the electric system adopted is overhead trolley wire or third rail.

Shunting and marshalling in railway goods yards calls for a large tractive effort, but only moderate speed, which is a condition exactly suited to the battery-electric power unit. Actually during the course of a normal day's work the time when the maximum output is required is small, and the demand is intermittent. Consequently it is wasteful to employ a steam locomotive on such work, because steam has to be kept up all the time.

Some years back the Bombay, Baroda, and Central India Railway employed in the Carnac Bridge shunting yards two 50-ton battery-

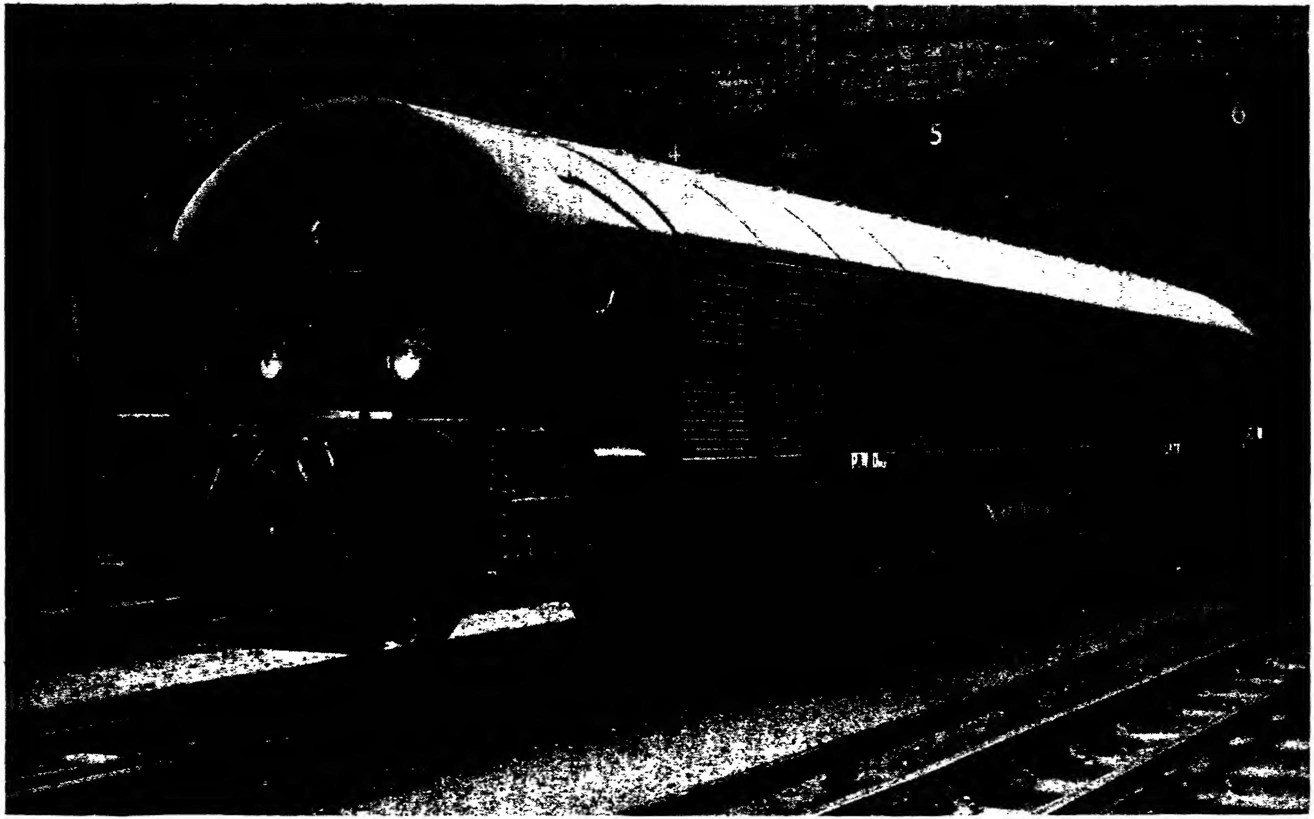

Fig. 91.—Battery-electric locomotive
Used by the London Passenger Transport Board.

electric locomotives (Fig. 89). These locomotives were built by the English Electric Co., Ltd., and were of the double-bogie central-cab type, with the batteries mounted in the two end compartments, and weighed 50 tons each, being fitted with four 60-h.p. motors. The normal battery voltage was 440 volts, and at the continuous rating of the motors the locomotives gave a tractive effort at the tread of the wheels of 7,600 lb. at a speed of 9 miles per hour, and exerted a maximum tractive effort at starting of 256,000 lb.

Each battery was rated at 400 amp.-hours at the one-hour rate of discharge, equivalent to about 750 amp.-hours at the five-hour rate of discharge, and consisted of 238 cells in series of the Kathanode type, supplied by the D.P. Battery Company. The battery was mounted in halves in the two end compartments, which had louvres in the end walls and large ventilators in the cover. The covers and sides of these compartments were double, with large air spaces between, and the covers for the ventilation apertures were also double. By means of this method of construction a free flow of air was ensured through, under, and over the battery, and the double walls of the container and lid gave considerable protection from the direct rays of the sun.

A special type of controller was designed for these locomotives owing to the large currents that had to be dealt with. It was operated on the camshaft principle, and consisted of two camshafts arranged vertically and geared together, with the reverser drum, which was of the ordinary tramway type, mounted between them. A handwheel was provided in place of the usual crank handle. Six series speeds, five parallel speeds, and six electric-brake notches were provided, and a notch at the end of the electric-brake group applied the air brake.

When first put into service each locomotive was used for a twelve-hour shift, the second one receiving a battery charge while the first one was in service, but the drivers, shunters, and yard staff worked in three eight-hour shifts as before.

After a period it was found that the increased speed of movement obtained enabled the time required for shunting to be reduced considerably, and as a result the authorities were able to arrange for the whole of the shunting to be handled comfortably in two eight-hour shifts. This naturally led to very considerable economies in working being effected, and also, apart from the reduction in stand-by losses inherent in working with steam locomotives, the cost of the yard operating staff was reduced materially.

It was found that the control and operation of the locomotives was such a simple matter that it was not necessary to employ trained steam drivers, and a number of firemen were promoted to a grade of shunting drivers, and an equal number of steam drivers were thus released for other work.

A recent example of a large battery-electric locomotive is provided

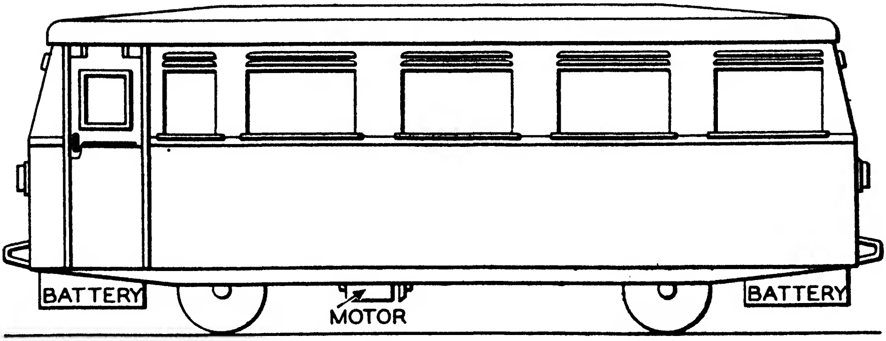

Fig. 92.—CONTINENTAL-TYPE RAILCAR

by one put into operation by the London Passenger Transport Board for the transport of materials on the underground railway in connection with extensions (Fig. 91).

The question of transport of materials is a difficult one, for while it is easy to move rails, sleepers, and so on, either on the roads or on existing tracks, the point is reached where the electrified track ceases, and where roads are some distance from the site of the new track.

The problem was surmounted by the construction of battery-electric locomotives, which can run over temporary track hauling goods wagons. The locomotive is 54 ft. 4½ in. long over the coupler faces, 31 ft. between bogie centres, has a 7-ft. bogie wheelbase, and weighs 56 tons.

Practically the whole of the interior of the locomotive is taken up with the 160 cells of the type LKA49 D.P. battery, which is of 768 ampere-hours capacity at the five-hour rate, and which weighs about 13 tons.

This, the first battery locomotive to be built by London Transport, was equipped with Metadyne control by Metropolitan Vickers Electrical Co., Ltd.

Battery charging is accomplished by means of the Metadyne, and the charging current is 200 amperes until the voltage per cell is 2·4 volts. A potential relay then operates, which reduces the charging rate to 70 amperes.

There are four traction motors to each locomotive, with a one-hour rating of 150 h.p. at 600 volts, this voltage being, of course, that used on the system for ordinary traction purposes, and supplied by means of the live rails. The equipment includes switchgear which makes it possible for the loco to run either from the conductor rails or from the battery power. In all, nine vehicles were decided upon for this work, three having Metadyne control by Metropolitan-Vickers, and six having General Electric Company resistance control and a series, series-parallel, and parallel motor combination.

Battery-electric Railcars

The railcar, propelled by a diesel- or steam-engine, was introduced into railway service for working on branch lines, or as a shuttle service, where traffic was small. With extensions in electric traction it may well be that there will be developments in this connection in this country, as their suitability for the purpose has already been proved in New Zealand and on the Continent.

Trials, on the German State Railways, prior to 1937, showed that while some cars travelled for 250 miles non-stop at 25 m.p.h., half that distance could be covered at 40 m.p.h.

In the first case the power consumption was 18 watt-hours per ton-mile and 26 watt-hours per ton-mile in the second case.

With later cars the maximum economical speed was generally speaking 37–47 m.p.h. In 1938 there were 170 cars on the German State Railways. During 1935, these cars travelled approximately 7,700,000 miles over 5,300 miles of line ; thus the average yearly car mileage was 38,500. The maximum car mileage was 56,000 and the average power consumption 37 watt-hours per ton-mile. On the Polish State Railway and on several French secondary lines, twenty storage-battery cars are run, and in the north of Italy, forty cars, mostly of the double-bogie type, are in service on tramways and suburban lines. The latest Italian cars weigh between 28·5 and 34 tons. These use 800–950 ampere-hour 300-volt batteries, weighing 8·8 and 11·4 tons respectively.

Each car carries 70–100 passengers, and has four motors developing a total horse-power of between 165 and 195, with tractive efforts at these two limits of 4,000 and 5,300 lb. The maximum speed is usually 31 m.p.h., and loads up to 70 tons, consisting of four trailers, are handled over gradients up to 1 in 28·3 ; in exceptional cases the speed has been increased to 47 m.p.h. The consumption is about 45 watt-hours per ton-mile and the yearly car mileage is about 31,000 miles. Positive battery plates are replaced about every 21,500 miles and negative plates at intervals corresponding to twice that mileage.

A car of this type was placed in service by the Zschornewitzer secondary railway, owned by the Electroworks Company of Golpa-Zschornewitz, to connect the town of Oraneinbaum with the Berlin-Halle main line at Burgkemnitz. Power is supplied by a 300-volt battery, which which gives a mileage of 94 under normal conditions ; this constitutes a day's work.

This battery supplies a 70-h.p. axle-hung motor. The control is camshaft operated and has seven contacts, one of which is a weak-field contact that reduces the motor field by half. The car is of the centre-entrance type, and carries 87 passengers. Luggage is carried at the rear driver's compartment. The car develops a maximum speed of 37 m.p.h.

Smaller battery cars have also been placed in service on some Continental railways. These vehicles carry 36 seated and 14 standing

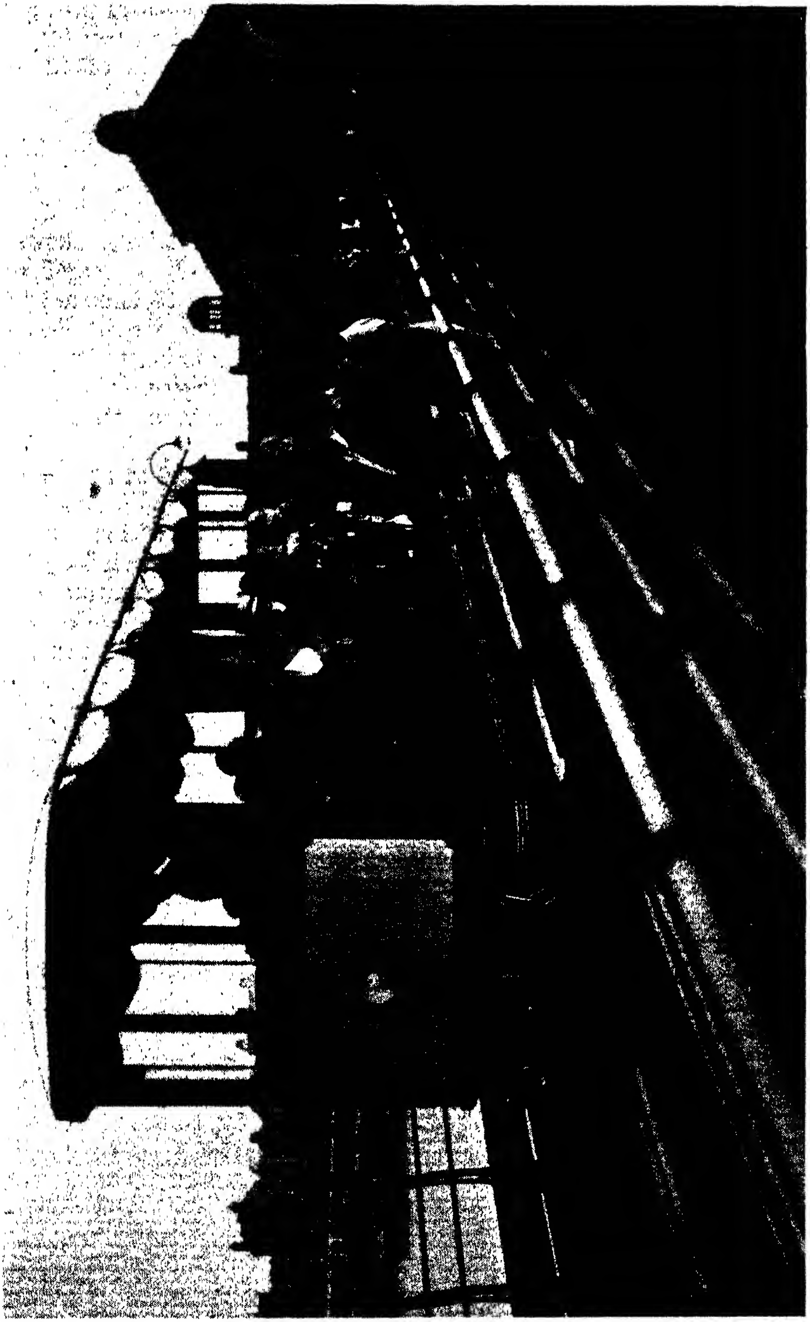

Fig. 93.—BATTERY-ELECTRIC TRAM

On the pier of a health resort. (*D.P. Battery Co., Ltd.*)

passengers and are designed for a maximum speed of 31 m.p.h.; the battery ensures a service for 125 miles. The car is powered by a 37-h.p. motor and weighs a total of 17,200 lb. with a battery weight of 4,900 lb. This compares well with modern diesel units of similar capacity.

The modern battery locomotive is a product of nearly thirty years' slow but continuous development both electrically and mechanically. In its design a variety of technical improvements in such different branches of engineering as ball and roller bearings, manufacture of alloy steel, and improved methods of cutting gears and finishing them by grinding, can all find direct and useful application. To be successful the machine must be the product of a high-grade shop used to the manufacture of heavy rolling stock. From the very nature of the service entailed in their day-to-day use, it follows that rough handling is inevitable—and hence, not only must these machines be robust in their general construction, but also their detail design and construction must be first rate in every way.

Granting these premises, the field for the successful use of the battery locomotive is a large one, and in the author's view could be extended by scrapping considerable numbers of old steam locomotives which are to be found dotted about the map of Great Britain, in works both large and small. The summarised advantages of the battery type against steam include a definite superiority in regard to drawbar pull at starting, economy of operation, non-necessity for boiler upkeep or cleaning, much simpler operation, greater safety in respect of fire risk, total absence of grit and smoke, and instant readiness for service after a period of non-use. Practically any labourer or yard man could drive an electric locomotive, and a very small amount of instruction will suffice to enable a conscientious man to deal with the problems incidental to battery maintenance. The alkaline type of accumulator finds a specially favourable application in this service on account of its immunity from damage due to shunting bumps. The very high rates of charging permissible in emergency are of further advantage, together with the relatively light weight which permits of specially robust construction of the locomotive underframe without any undue sacrifice in relation to a reasonably favourable power-weight ratio of the complete machine.

Chapter VIII

THE BATTERY-ELECTRIC BUS

THE advantages of the electric vehicle for short-run frequent-stop service, already referred to in previous chapters, are of course equally applicable to passenger-vehicle service, such as short bus routes in towns, the trial development and extension of routes for trams or trolley buses, conveyance of passengers and luggage between railway termini, or taking visitors from the station to large works, or driving them and staff around works which are spread over a large area.

One of the early examples in this country was the use of battery-electric buses in the old-world town of Lancaster in 1916, where they were applied to develop routes on the north side of the town not covered by the existing tramway service. Here two services were maintained, one from Market Square to Skerton, a distance of 1·4 miles, and the other from Market Square to Marsh, a run of 1·5 miles. In addition, there were special services on workmen's routes, morning and evening, from the centre of the town to Mills, a run of about 2 miles (Fig. 94).

The chassis of the buses were supplied by Edison Accumulators, Ltd., and the bodies were built by the Brush Electrical Engineering Co., Ltd. Seating capacity was provided for 22 passengers, the seats being partly on a longitudinal and partly on a transverse basis. The front entrance was fitted with a double hinged door, under the control of the driver, so that the vehicle could be operated on a pay-as-you-enter basis. The batteries were the Edison nickel-steel A8 type, 300 ampere-hours capacity.

A five-hour charge was given to the batteries at night and a number of boosting charges were provided at the termini according to the mileage the bus had travelled. Charging was effected at the bus depot by placing four charging plugs in series, across the 460-volt D.C. supply busbars, with the provision of the usual series variable resistance, ammeter, voltmeter, and watt-hour meter. The resistance could be adjusted to give a charging rate of 60 amps. When the four batteries were on charge at the same time, very little resistance was required in circuit, and usually, after the first hour, the batteries were placed direct on to the busbars. If only three batteries were on charge, the fourth plug was put into a short-circuited socket, and the resistance was suitably adjusted. This entailed, of course, a corresponding loss in efficiency of 25 per cent., but this did not compare too unfavourably with the loss entailed in running a motor generator at only three-quarter load, and obviated the necessity of employing running machinery in the charging station.

For adults there was a universal fare of 1½*d.*, and 1*d.* was charged for children. The fleet consisted of five vehicles, four of which were in operation every weekday, and it was a very rare thing for a trip to be missed owing to a mechanical or electrical fault.

Cost statistics in connection with these vehicles are still of interest, because, although twenty years old, they show the relative position of petrol and electric vehicles at that time, so far as running cost was concerned. They were originally published in *Electric Vehicles*, vol. IX, p. 15, by courtesy of Mr. J. B. Patterson, who was then engineer and manager of the Lancaster Corporation Tramways.

Each of these buses provided a revenue for the electricity department of £200 per annum. Petrol buses would have occasioned an expenditure of some £300 a year for petrol, which expenditure would largely have gone abroad, instead of benefiting the English miner and others concerned with the production of electricity energy. The running expenses of these buses are fully set out in Tables VII and VIII.

TABLE VI.—LANCASTER ELECTRIC BUSES (1923–24)

Month	*Receipts*			*Mileage*	*Passengers Carried*	*Receipts per Bus-mile*
	£	*s.*	*d.*			*d.*
April	217	19	3	4,849	36,191	10·73
May	228	8	3½	5,198	37,934	10·57
June	224	17	5½	5,051	37,309	10·70
July	254	18	9	5,117	42,299	11·98
August	262	10	2	5,267	43,975	11·97
September	245	1	1	4,933	40,639	11·94
October	251	16	11½	5,324	41,842	11·70
November	242	11	5	5,143	40,167	11·62
December	245	17	9	4,891	40,884	10·98
January	244	12	4½	5,161	40,516	11·41
February	216	9	7	4,991	35,859	10·40
March	226	4	5	5,180	37,273	10·48
	£2,861	7	6	61,107	473,988	11·27
Special Receipts	6	8	2			
	£2,867	15	8	61,107	473,988	11·29

The factor as to whether a profit or loss is made on a bus service does not, of course, entirely depend upon the mode of power adopted. Traffic conditions, fares charged, etc., largely influence the question. Total working costs per bus-mile are perhaps a better guide for comparative purposes than profit or loss, and Table VIII shows total working cost per bus-mile for nine other towns where petrol buses were employed, these figures being taken from the abstracts of accounts of the various under-

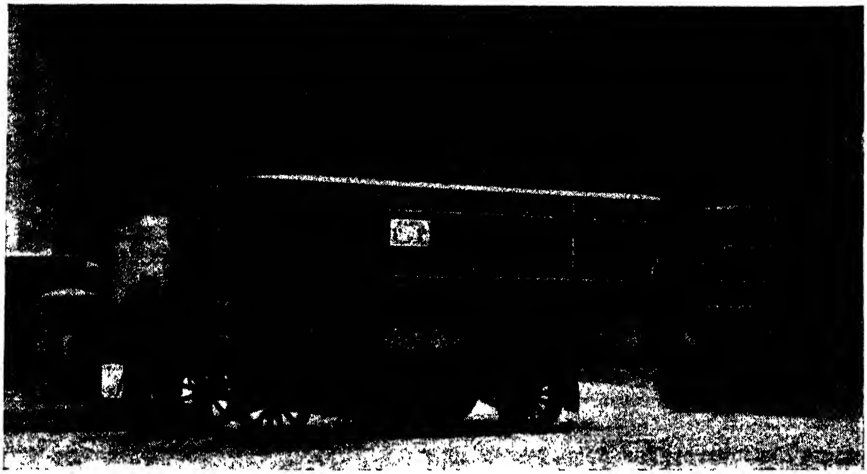

Fig. 94.—One of the buses at Lancaster being charged in Market Square

takings. It will be seen from this table that the average total cost per bus-mile for these nine undertakings amounts to 16·50*d.*, and the average cost of petrol per bus-mile to 4·07*d.*, whilst the Lancaster electric buses involved a total cost per bus-mile of only 12·62*d.*, and a cost of 2·93*d.* per bus-mile for electrical energy.

The journeys allotted to these vehicles were mainly through narrow and winding streets, with stops every quarter of a mile, and a maximum run of 3 or 4 miles. A vehicle capable of a higher average running speed of 8 or 9 miles per hour was not therefore called for, particularly as the electric has a marked characteristic of rapid acceleration from rest.

In 1925 a similar type of pay-as-you-enter vehicle was put into service at Liverpool to act as a feeder to a tramway route. It had a 2-ton Walker chassis fitted with a twenty-five-seater bus body, and was powered by a 42-cell Exide Ironclad battery. The route was 4 miles in length, of an undulating character, but not involving very steep gradients. The average speed was 9 miles per hour, although the chassis was standard and not specially designed for a passenger-carrying vehicle.

The next experiment was at Southend-on-Sea in 1926, where Clayton Wagons, Ltd., supplied a vehicle to the Corporation.

The chassis frame was constructed of mild-steel pressings strongly cross-braced, and set down at the rear end to provide for carrying a drop platform. The front axle was of high-grade steel, and supported two laminated springs designed to provide easy carriage for the body. The steerage pivots and stub axles were of specially heat-treated steel, and steerage was arranged for by means of Ackerman-type steering gear.

The rear axle was of the worm-driven type, working in a dustproof

TABLE VII.—ANALYSIS OF WORKING EXPENSES OF LANCASTER BUSES (1924)

	£	s.	d.	Cost per Bus-mile d.
Check Clerk	26	8	8	0·10
Traffic Expenses	956	13	6	3·76
Power	654	10	10	2·57
Accident Insurance (third party claims)	142	8	4	0·58
Repairs and Maintenance	988	9	0	3·89
Cleaning	92	16	5	0·36
Miscellaneous Expenses	90	10	0	0·36
Uniforms	9	3	9	0·03
Inland Revenue Licences	204	0	0	0·80
	£3,165	0	6	12·45

	d.	d.
Working Expenses per Bus-mile	12·45	
Interest and Debt Redemption	2·69	
Total Expenses per Bus-mile		15·14
Income per Bus-mile		11·83
Balance, being Net Loss		3·31

		£	s.	d.
Traffic Revenue		2,867	15	8
Total Revenue		3,008	11	11
Working Expenses		3,165	0	6
Interest on Loans		37	17	5
Sinking Fund		34	4	3
Balance	Net Loss	839	14	2
Bus-miles		61,107		
Passengers Carried		473,988		
Total Number of Units used		104,720		
Number of Units per Bus-mile		1·71		
Average Number of Buses in use for 14-hour Day		3·50		
Percentage of Working Expenses to Receipts		105		
Average Bus-miles per Day per Bus		57		
Average Speed per Hour		8 miles		
Average Bus Hours per Day		14		
Average Fare per Passenger		1·46*d.*		
Average Number of Passengers per Mile		7·77		
Number of Buses in Stock		5		

oil bath. The worm was of nickel-chrome steel, and gears had a phosphor-bronze worm wheel, the worm wheel carrying the differential gear. The axles were of nickel-chrome steel.

Flanged brake drums were bolted to each of the rear-wheel hubs, duplex brake expanding shoes lined with Ferodo being provided. The brakes could be instantaneously applied by either hand or pedal.

A special traction-type motor, series wound, suitable for 100 volts, and capable of carrying a 300 per cent. overload for short periods, was designed for this vehicle. The usual drum-type controller was mounted

TABLE VIII.—COMPARATIVE WORKING COSTS OF PETROL AND ELECTRIC BUSES

(*Figures extracted from the Abstracts of Accounts of the various undertakings for year ended March,* 1923)

A. Petrol Buses

Town	*Total Working Cost per Bus-mile*	*Cost of Petrol per Bus-mile*
	d.	*d.*
Preston	16·05	4·29
Cardiff	17·12	4·45
Reading	18·56	3·91
Stockport	13·29	4·80
Manchester	15·27	3·01
Lincoln	17·79	5·10
Wolverhampton	13·57	3·56
Walsall	16·48	3·46
Coventry	15·94	4·17
Average	16·50	4·07
B. Electric Buses		
Lancaster	12·62	2·93

near the driver's seat, and provided for five forward and two reverse speeds. An interconnection with the brake automatically cut off the current when this brake was applied.

Power was obtained from an Exide Ironclad battery consisting of 50 cells, I.M.V.13, having a capacity of 419 ampere-hours. The battery was housed in two containers carried at the side of the vehicle. At the bottom of the battery containers rollers were fitted to permit easy changing of batteries.

The body was designed to carry 34 passengers, including the driver, a main entrance being provided at the rear, and a driver's entrance on the offside toward the front of the vehicle. The clerestory roof and pleasing lines of the body gave the vehicle a very smart appearance. Balanced windows were fitted to each side of the bus, and the windows could be adjusted to and held in any desired position.

The electrical interior lighting of the bus was controlled by switches fixed to the dashboard in the driver's cab. The chassis without battery weighed 3¾ tons, the battery adding another 2 tons to the dead weight. Pneumatic tyres were fitted to both front and rear wheels. On the level the vehicle, loaded with passengers, attained a speed of 14 miles per hour, on an incline of 1 in 20, 7 miles per hour, and could climb a hill of 1 in 12 at 5 miles per hour. The overall length was 27 ft. 11⅜ in., width 7 ft. 6 in., and turning radius 30 ft.

It will be seen that this vehicle was far more in accordance with

Fig. 95.—THE LECAR SMALL BATTERY-ELECTRIC BUS

modern ideas in passenger-vehicle design, and it gave good results. The reason that these vehicles went out of service was largely the fact that these routes were ultimately embraced within extended petrol or trolley-bus routes, and as they were operated by municipal bodies, there was a boundary limit beyond which they could not be used. They did, however, show that battery-electric passenger vehicles were a practical proposition and a serviceable type within their field of operation.

Continental Practice

A good modern example from the Continent is that of the City of Lyons, which with its suburban areas had in 1938 a population of 77,000 inhabitants, and had been operating battery-electric buses since 1925. At the beginning of 1938 there were fifty-two of these buses in service, and although the early vehicles had been in operation for more than twelve years, and had travelled about 300,000 kilometres each, the chassis were still good for many years' service, though the bodies were naturally out-of-date. The vehicles were of three types, De Dion, Renault, and Vetra, the latter having been put into service in 1933, and in 1938 were used much more than the older vehicles. They were designed to compete with petrol vehicles, and therefore particulars of the 1933 models are of interest, and are given in Table IX.

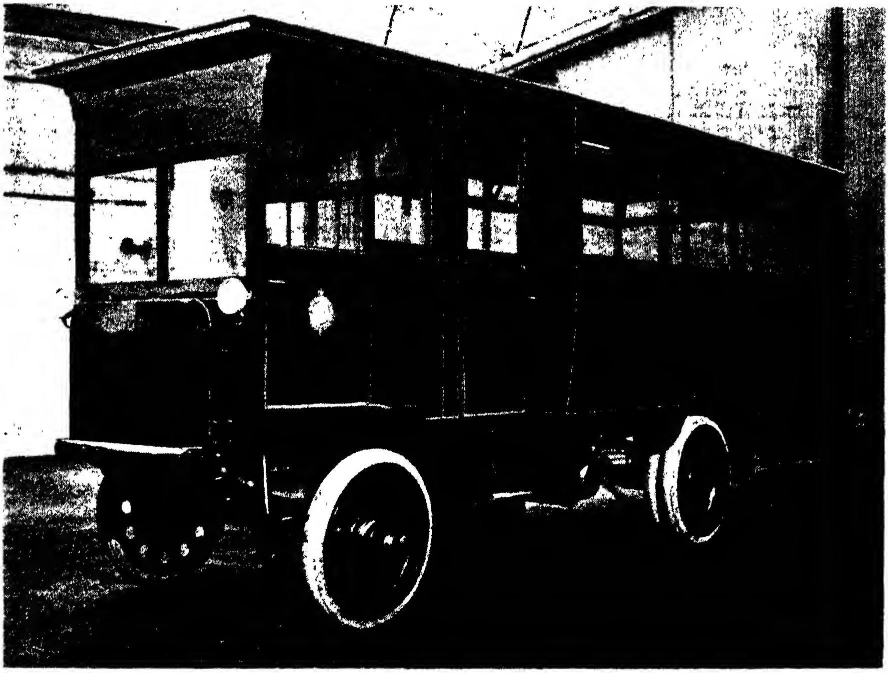

Fig. 96.—An early-type 40-seater bus on a $3\frac{1}{2}$-ton Ransomes "Orwell" electric chassis

The batteries were arranged in three different ways. On the De Dion vehicles the battery consisted of one crate of forty cells fitted between the longitudinals of the chassis and the axles. The wooden crate was provided with iron reinforcements and with two pulleys for the winch, four wheels for manœuvring on the floor, and six double links for suspension on the chassis.

On the Renault vehicles there were eighty cells arranged in four crates, and on the Vetra there were forty-two cells arranged in four crates. In the latter type of vehicle a special arrangement enabled the crates to be lowered and brought out from the coach body, so that they could be examined without having to remove the battery.

The average energy consumption was about 120 watt-hours per ton-mile, rising to 140 or even 160 watt-hours per ton-mile during rush hours, when the congestion of traffic called for much braking and the stops and starts were very numerous.

For battery buses in continuous municipal service, it is necessary, owing to the limited mileage obtained on one charge from a battery of reasonable size, to have more than one battery per bus, involving exchange of batteries once or even several times a day.

TABLE IX.—VETRA ELECTRIC BUS, 1933 MODEL

Chassis :	
Dimensions :	*In.*
Front Width	68
Back Width	67
Base	179
Total Length	299
	Tons
Weight (excluding body and battery)	3·7
Weight of Body	1·8
Weight of Useful Load, viz., 39 Passengers and 2 Attendants, say	2·9
Weight of Vehicle completely equipped without Passengers	8·5
Electric Motor :	
Number	1
Excitation	Compound
Rating (1-hour)	34 h.p.
Position	Axial
Battery :	
No. of Cells	42
Capacity	800 ampere-hours
Weight	2·9 tons
Brakes : Provided on all four wheels and regenerative braking	

Trailer Vehicles

In a contribution to *Electric Vehicles* (vol. XXII, p. 318), Mr. E. C. McKinnon, Chief Engineer of the Chloride Electrical Storage Co., Ltd., suggested employing for municipal service buses of a type which could be used without alteration for either battery or trolley propulsion by having a battery mounted on a trailer behind the vehicle. This would, of course, make the matter of changing batteries a very simple matter.

The figures in Table X show that it is impracticable to provide a battery large enough to do anything like the daily mileage required on a standard schedule, which may be 180 to 240 miles per day. The scheme would therefore require several batteries for each bus, using a large number of small batteries or a smaller number of large batteries, the former being more efficient but the latter requiring less frequent changing over.

Increasing the size of battery does not increase the mileage per charge in proportion owing to the greater weight of battery to be carried about in the trailer. Working on these lines, a continuous service could be maintained having no more than either two or three batteries for each bus, each battery being recharged whilst the others are in use, the batteries being actually used in rotation.

On these lines battery propulsion is definitely feasible for certain restricted services. Partial recharging during the day with two or three batteries per bus may in certain cases prove a really commercial proposition for regular services.

Using a Gearbox

A development in the present war was the Lecar bus, by the Lancaster Electrical Company, the vehicle having been produced for a well-known

Fig. 97.—THE CHASSIS OF THE LECAR

Showing battery, gearbox with long bent lever, and electric motor. The control has not been assembled.

TABLE X.—PERFORMANCE TABLE FOR 32-SEATER SINGLE-DECKER BUS PROPELLED BY BATTERY MOUNTED ON TRAILER

Average weight of bus assumed to be 7 tons 10 cwt., representing load comprising driver, conductor, and 22 passengers

Battery Capacity at 5-hour Rate (180 *cells*)	*Battery Dimensions*			*Battery Weight*	*Weight of Battery plus Trailer* (*assumed*)	*Propulsion Distance in Miles per Charge*	
	Length	*Width*	*Height*			*Assuming* 200 *Watt-hours Consumption per Ton-mile and* 15 *m.p.h. Average Speed* (30 *m.p.h. max.*)	*Assuming* 150 *Watt-hours Consumption per Ton-mile and* 10 *m.p.h. Average Speed* (20 *m.p.h. max.*)
Amp.-hrs.	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Tons*	*Tons*		
96	5 1	5 7	1 10½	2·12	2·7	9·0	14·5
144	6 5¼	5 7	1 10½	2·97	3·7	13·5	22·5
	7 8⅝	5 7¾	1 10¾	3·82	4·8	17·5	30·0
-	9 7½	5 7¾	1 10¾	4·7	5·9	21·5	37·0
	10 10½	5 7¾	1 10¾	5·65	7·1	25·0	42·0

film company for the conveyance of staff. The chassis was that of a well-known make of lightweight petrol vehicle, the engine and body having been scrapped, and the chassis reconditioned and fitted with new bearings and the springs fitted with extra leaves. Cross-bracing members were fitted to support the motor (Figs. 95 and 97).

The motor is mechanically connected directly to the shaft of the mechanical gearbox, which is itself connected by universal joint to the propeller-shaft and back axle in the normal manner. The controller gear is of the automatic type, the contacts being brought into action by trip-switches through the medium of a dashpot-controlled cam mechanism. Full depression of the accelerator pedal, when the vehicle is stationary, results in the contactors functioning at suitable predetermined time intervals.

The lighting is of the trolley-bus type, the side, tail, and interior lights being supplied in series direct from the battery instead of only from the end cells, which permits of economy in current consumption. The battery is a 60-volt Ediswan and the motor, which is of the semi-enclosed type, is rated at 4½ h.p. The range per battery charge is about 40 miles, and the vehicle can attain a speed of 35 m.p.h. on the level, while the three-speed gearbox greatly aids hill climbing. It also increases the mileage range of the vehicle, because the motor has to pull hard on an upgrade, and therefore draws heavily on the battery, while on a down gradient the motor turns over at a very fast rate. Thus the gearbox allows the vehicle to travel faster when climbing, and reduces the current consumption. Second gear is used for normal running and top gear only when there is opportunity for a fairly long run on the level on a clear road. Consumption tests taken over a 20-mile circular route in fairly hilly country showed a consumption of about 3 ampere-hours per mile. Accommodation is provided in the form of bucket seats for five passengers and the driver.

A similar development, i.e. the production of a lightweight bus for transporting staff and visitors from, in, and around works, or to and from railway stations, was carried out by the Metropolitan-Vickers Electrical Co., Ltd., in 1940. This vehicle had a 7–9-cwt. "Metrovick" chassis provided with a special saloon-type body, giving accommodation for six passengers seated face to face in a longitudinal direction, access to the passenger compartment being through a door at the rear.

Chapter IX

THE BATTERY-ELECTRIC PASSENGER CAR

As has been shown in the opening chapter, the passenger electric vehicle is not a new idea, and in fact dates back to the commencement of the electric-vehicle industry. As a competitor to the horse-drawn brougham for use in towns it proved superior, and at one time a considerable number were to be seen in London, but ultimately the petrol vehicle won the day—with the petrol vehicle, people grew out of the idea of having a town vehicle and used one car for all purposes. Difficulties connected with the present war have revived interest again, and it may well be that the value of an electric vehicle for short-run service, such as shopping, office to town, and doctor's rounds, will be fully realised as a result of petrol rationing. The roads outside London and other towns for a radius of 10–15 miles are sufficiently crowded with traffic under normal conditions to restrict speed of travel considerably, and the electric possesses the advantage of good acceleration from rest, so can compete under such conditions, where traffic stops and traffic lights render a fast, continuous run impossible.

It is also quite practicable to use electrics for journeys between towns 30 miles apart, as will be shown later.

Another point to be considered by the electricity supply industry is that of load development, and the vehicle charging load is a most valuable one, because it can be mainly an off-peak load. Having progressed remarkably in the past decade, electricity supply authorities will be facing the problem in the future of reducing prices still more and no doubt solving it by filling in the valleys in the load curve, thus improving load factor; and an active development scheme for electric vehicles would be a great help toward this end.

This was referred to some ten years ago by Mr. B. H. Leeson, in his address as Chairman to the North-Eastern Centre of the Institution of Electrical Engineers : " At the present time," he asked, " are we making any real efforts to deserve progress in this direction ? "—and suggested that we were not. " Instead of adopting this apathetic attitude, should we not organise a co-ordinated effort intensively directed to the aim of producing an electric passenger vehicle by the time it is required to sustain progress in the electrical industry, which "—as he had suggested—" would be in the vicinity of 1940 ? " The war altered things so far as concerned the date he gave of 1940, but it has only postponed the matter. Mr. Leeson's idea of an electric passenger vehicle was an electrical equipment applied to a modern form of chassis and light body construction, which he pictured as shown in Fig. 98.

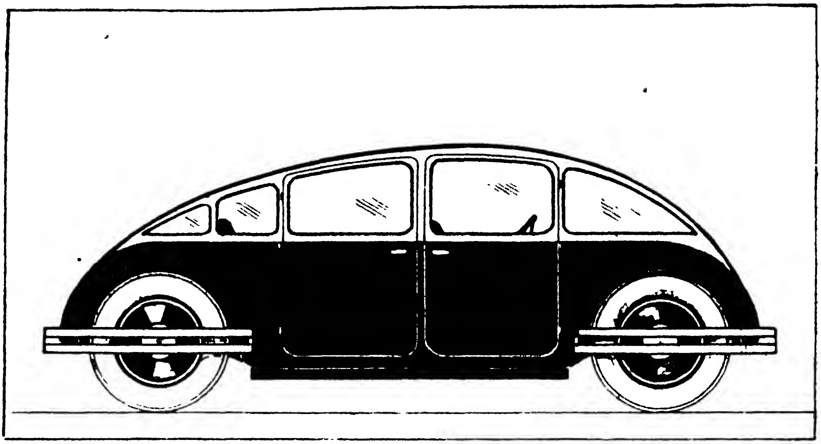

Fig. 98.—An impression of the battery-electric passenger car of the future

The absence of fumes, good road adhesion, adequate body protection by the four-sided bumpers, and accommodation for luggage, render this an ideal car for town use. Further, its easy starting and control, coupled with the ease and speed with which the even contour of its body can be washed, cleaned, and polished, make an instant appeal to the owner-driver, and especially the woman driver. In Mr. Leeson's words: " The light, powerful, high-speed motor, directly geared to each of its four separately sprung wheels, ensures rapid acceleration, perfect suspension, and uniformity of wear on tyres. Its underslung battery gives a low centre of gravity and uniformity of weight on each wheel, which ensures easy cornering and road adhesion when the car is rapidly brought to rest by its powerful four-wheel regenerative-hydraulic brakes. Wind resistance is reduced to a minimum, giving a quiet glide at its cruising speed of 40 miles an hour with a low electricity consumption. The regenerative control allows the battery to be capable of driving the car on an average of 500 miles. It may be recharged in your garage, or it can be readily charged in ten minutes or replaced at any service depot."

That, of course, was a mental picture, and cannot to-day, a decade after, be realised in practice, particularly in so far as the range and charging time are concerned, but the town vehicle does not need to have a range of 500 miles or a charge in ten minutes.

Battery vehicles can be designed to travel at 40 miles an hour, and by the use of interchangeable batteries almost any mileage could be obtained in a day, but such a scheme would call for the batteries to be changed very frequently, and an immense capital expenditure to be borne by someone in installing interchangeable batteries at service stations throughout the country.

What does the average user of a town car need, however ? Nothing like a range of 500 miles. The occasional week-end run probably does not usually involve more than 100 miles.[1] To ascertain this point an interesting test was made in 1941, with a Murphy " Trader " vehicle rated at 10 cwt. fitted with a van-type delivery body, the editor of *Electric Vehicles* travelling as observer.

The car was taken over at the Maidenhead works of Murphy Cars and Trucks, Ltd., at 11.10 a.m., and with one passenger was driven via Bracknell and Bagshot to Guildford, and so on to the other works of the Company at Shalford, Surrey. This journey of 29 miles was carried out comfortably in an hour and fifteen minutes, showing an average speed of 23 m.p.h., inclusive of a few brief stops for traffic. During the journey a test was made of the running speed over a clear measured mile, which was practically level and free from traffic. This test gave a speed of 24½ m.p.h. which, although the vehicle was carrying very little load, showed that the makers' estimate of 20 m.p.h. with a 10-cwt. load was well within its actual performance. It was also interesting to observe how closely the average speed for the whole journey compared with the speed over a measured mile—a common experience with those used to the operation of electrics.

This run of 29 miles took 89 ampere-hours out of the battery, so it was safe to assume that on its rated battery capacity of 189 ampere-hours, the vehicle would have covered over 60 miles before charging would again become essential. The makers stated that, in fact, the vehicle had covered between 60 and 65 miles on a single charge in this condition of light load, so that here again the rating of 45 miles per charge with a 10-cwt. load would seem to be well within the capacity of the vehicle under reasonable conditions.

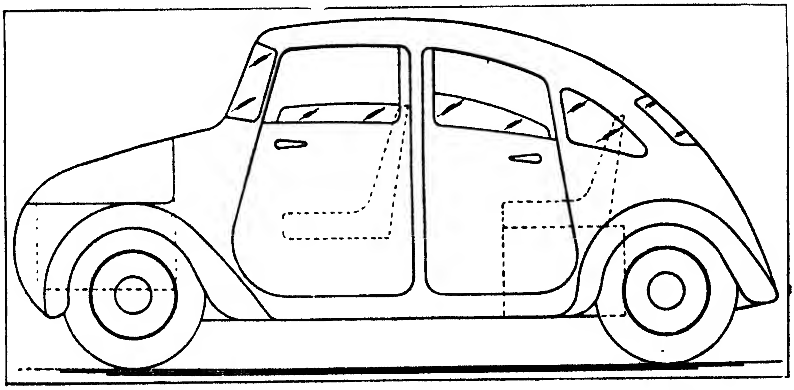

Fig. 99.—AN OUTLINE OF A STREAMLINE DESIGN FOR A LIGHT FOUR-SEATER CAR. (*Murphy.*)

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[1] *Electric Vehicles*, vol. XXVI, p. 172.

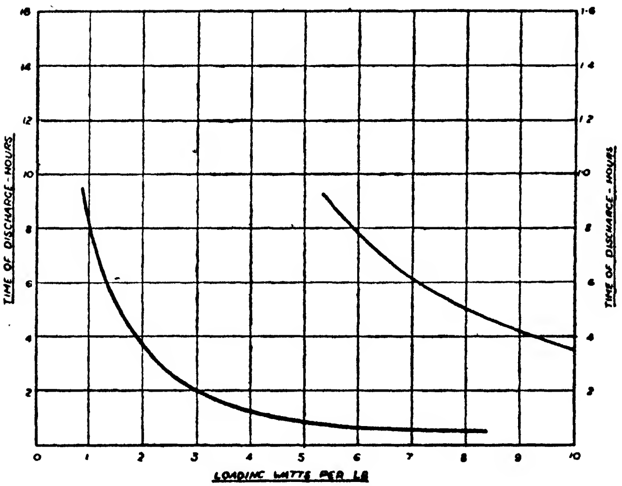

Fig. 100.—CURVE SHOWING RELATIONSHIP OF TIME OF DISCHARGE TO LOADING IN WATTS PER LB. (*L. Murphy.*)

On arrival at Shalford, the vehicle was put on charge at a rate of 30 amperes, and a break was made for lunch. A restart was made at 3.30 p.m., when it was observed that the ampere-hour meter indicated only 24 ampere-hours from the fully charged state instead of 89, as at the time of arrival. The route now taken was via Chilworth, turning in the village up Great Halfpenny Lane. This is a narrow country lane with a steep gradient leading up to the historic St. Martha's Church, on top of the Downs, where the Pilgrims' Way crosses this part of the country. The climb is about a mile long and has a maximum gradient of 1 in 5 or 6. For the greater part of the distance, the speed did not fall below 18 m.p.h. except at the steepest part, where the speedometer dropped momentarily to 12 m.p.h., rising again immediately the gradient eased. The speed, incidentally, was about as fast as would be comfortable in any car of the dimensions of this one on this particular road.

A stop was made on the Downs for about an hour and a half. No charging was available during this stop. At Merrow it was seen that 5½ miles had been covered from Shalford, and by previous arrangement a load of 5½ cwt. was put into the car, thus imitating a condition of carrying six persons, including the driver. The car was now driven back to Guildford and Bagshot, then on to Ascot, through the Windsor Great Park and Eton, and so into Slough, where approximately half the load was discharged. With the remainder of the load the vehicle was then driven back to the original starting-point at the works of the manufacturers in Maidenhead, giving a total distance of 41 miles from Shalford to Maidenhead, and including some quite appreciable hills.

The finishing reading of the ampere-hour meter (162 out) left 27 ampere-hours still available, and actually there was hardly any diminution of speed such as would occur if the battery was in danger of an early run out. The consumption was, therefore, 138 ampere hours for the 41 miles from Shalford via Merrow, Ascot, and Slough into Maidenhead, including the hill-climbing test and the load-carrying described.

At all points throughout the journey the vehicle was driven without any consideration of possible damage due to overspeeding of the motor, this point having been made a bogey at times in connection with the electric type by its critics. The highest speed shown on the speedometer was 43 m.p.h., but on many occasions on down grades, speeds of approximately 40 m.p.h. were obtained. At this speed the motor rotates at 6,250 r.p.m., which, it must be admitted, is a very high speed for a motor which is capable of exerting a continuous 4 h.p. There was no discernible vibration from the running mechanism at any time.

At the conclusion of the run the motor and controller were examined, and no signs of any overheating or mechanical damage could be discovered. It was particuarly noticed that the motor commutator was in the same bright, new-looking condition as at the commencement of the run.

The total distance covered on the trip was 71 miles, and the actual time seated in the car was 3 hours 10 minutes, giving an average working speed throughout of 22½ m.p.h.

The total ampere-hours employed from the battery were 227, being the 162 shown as actual discharge at the finish, plus 65 which had been replaced at Shalford.

Assuming that the battery was increased, say, from 189 to 240 ampere-hours and assuming that a higher speed, say 30 m.p.h. average, were adopted, it should easily be possible to obtain 70 miles without recharging with a car otherwise exactly as the vehicle tested. Then again, the charging rate which was adopted for the intermediate charge might have been trebled without damage to the battery, and instead of adding a mere 21 miles to the effective radius of action, the hour and a half available for lunch would have added a further 40 miles

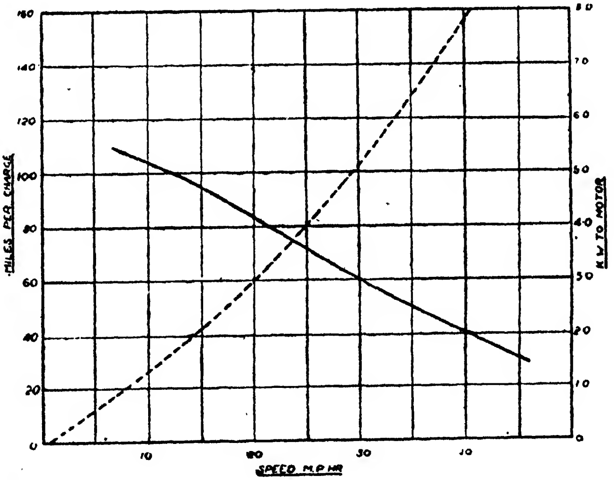

Fig. 101.—CURVES SHOWING RELATIONSHIP OF MILES PER CHARGE (BLACK) AND KW. TO MOTOR (DOTTED) TO SPEED IN MILES PER HOUR. (*L. Murphy.*)

in less time. Therefore, with only one stop for recharging during the day, a distance of 100 miles per day is readily obtainable, and, should the tourist require more, a further stop of, say, 1 hour at tea-time would add an additional 20 miles. In other words, it is quite within the scope of such a vehicle to make a journey from London to Bournemouth, or from London to Clacton, in a day, and give the user a very comfortable journey with time available *en route* for sightseeing and meals.

A Prospective Design

This induced the designer of the car, the late Mr. Leonard Murphy, to consider the matter further, and he visualised a car[1] as outlined in Fig. 99—a light four-seater saloon, the relative details for power calculation being :

	Ft.	in.
Wheelbase	7	6
Track	4	0
Wheel Diameter	2	3
Tyre Section	0	$4\frac{1}{2}$
Gear Efficiency	over 99 per cent.	

Weights :	Cwt.
Chassis	9
Body	$3\frac{1}{2}$
Spares and Tools	$\frac{1}{2}$
Battery	14
Passenger Load	6
	33 = 1·65 tons

The resulting Rolling Resistance per ton = $57\frac{1}{2}$ lb.

Overall Width	4 ft. 8 in.
Overall Height	4 ft. 10 in.
Frontal Area	18 sq. ft.

The resulting Head Resistance = $0{\cdot}001 \times 18 \times V^2 = 0{\cdot}018V^2$.

The combination of head and rolling resistance for this example has been plotted against speed in Fig. 102, from which it will be seen that a continuous effort of 80 lb. is required to drive the car at 35 m.p.h.

Clearly, therefore, on level roads and at a steady speed of 35 m.p.h., this car will absorb energy as follows :

$$80 \times 5280 \text{ ft.-lb. per mile ; or}$$

$$\frac{80 \times 5280 \times 35}{60} \text{ ft.-lb. per minute ; which equals}$$

$$\frac{80 \times 5280 \times 35}{60 \times 33{,}000} \text{ or } 7{\cdot}49 \text{ h.p.}$$

The best electric-motor efficiencies so far available are approximately 88 per cent. at normal load, rising to 90 per cent. at one and a half times

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[1] *Electric Vehicles*, vol. XXVI, pp. 172–8 and 202–5.

normal, and then dropping again to 82 per cent. at three times normal. Taking the combined motor and gearing efficiency, we must therefore assume that only 87 per cent. of the energy delivered to the motor can be converted into car motion on level roads at 35 m.p.h. This means, therefore, that the motor will absorb :

$$\frac{7{\cdot}49 \times 746 \times 100}{87} = 6{,}450 \text{ watts.}$$

Reference to Fig. 100 will show the relation between battery loading and the duration of discharge which a lead-acid battery will give. The basis of this curve is the discharge rate in watts per pound weight of complete battery, and the curve shows how the result becomes unfavourable when the discharge rate is increased, as must occur with increased vehicle speed. With a battery weight of 14 cwt. (1,570 lb.), the loading at 6,450 watts is obviously 4·1 watts per pound, from which we see that the battery will maintain its discharge for 1·375 hours and, therefore, under the ideal conditions postulated, the vehicle would run for 35 × 1·375, or 48 miles.

This process of analysis has been worked out for a range of speeds up to 40 m.p.h. and the results plotted in Fig. 101. It will be seen that, owing to the exceptionally high proportion of battery weight in this vehicle, a distance of no less than 100 miles per charge can be obtained at 12 m.p.h., but only 40 miles per charge at 40 m.p.h. These figures are definitely encouraging.

However, smooth level roads and constant speed do not apply in practice, and it becomes necessary to check the maximum theoretical mileage against some practical results. No figures were available to Mr. Murphy for a speed of 35 m.p.h., but the practical examples of his in Table XI of driving on country roads with normal gradients and traffic conditions are instructive.

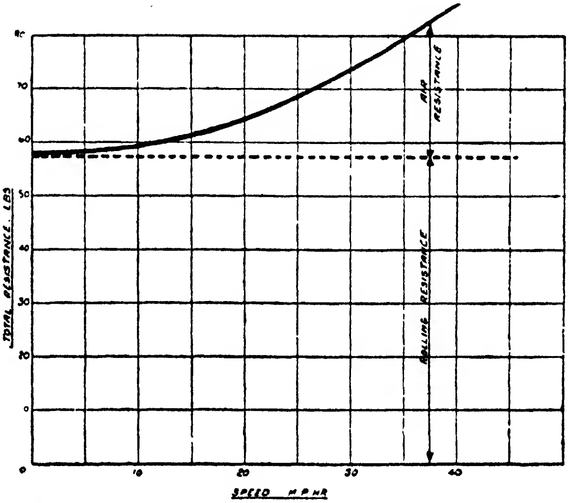

Fig. 102.—CURVE SHOWING THE RELATION BETWEEN ROLLING RESISTANCE AND SPEED. (*L. Murphy.*)

In both examples in this table the head-resistance constant was probably about 0·0015 instead of the minimum practicable figure of 0·001, and in car B the gear efficiency was not more than 95 per cent. instead of 99 per cent. taken (Fig. 103). The most important discrepancy, however, occurs in the ratio of battery to total weight, which is 42·3 per cent. in the ideal car illustrated in Fig. 99, but only 38 per cent. for car A and 32·7 per cent. for car B. If these factors are taken into account, it will be found that car A has actually slightly exceeded its theoretical best mileage under practical running conditions, while car B is substantially in agreement with the ideal result.

TABLE XI

	Car A	*Car B*
Average Speed	24 m.p.h.	28 m.p.h.
Gross Weight	1·45 tons	1·3 tons
Battery Weight	11 cwt.	8½ cwt.
Actual Miles per Charge	65	43
Mileage Calculated for Car in Example at this Speed	73	62

This is a surprising but also a very helpful discovery, and shows that the theoretical treatment may be applied with confidence for speeds up to 30 m.p.h. The reason is to be found in the actual behaviour of a lead battery under road conditions, and this is in fact much better than indicated by discharge tests at constant-power output.

It is common knowledge among electric-vehicle operators that when an ampere-hour meter is fitted, the discharge obtained on the road is substantially above that quoted by the battery manufacturers as the five-hour rating of the battery. It is not often realised that in fact the discharge takes place on the road in a total running time of only 2 to 2½ hours, hence the operator should expect only about 80 per cent. of the manufacturers' rating, and the calculated mileage has been based on this reduction of capacity. Without going into matters very

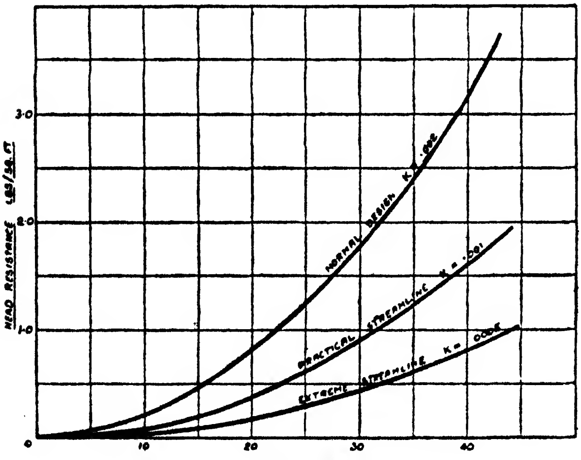

Fig. 103.—CURVES SHOWING THE RELATION BETWEEN HEAD RESISTANCE AND SPEED. (*L. Murphy.*)

deeply, it appears that the performance is improved, mainly due to motion of the electrolyte caused by swaying, acceleration, and braking, together with the fact that practical driving involves a continually varying rate of discharge with intermittent rest periods. It comes to this, therefore, that the battery does actually give some 20 to 25 per cent. more than would be expected from its discharge performance at the 2–2½-hour rate when stationary, and this advantage about balances out the losses due to occasional braking and hill climbing.

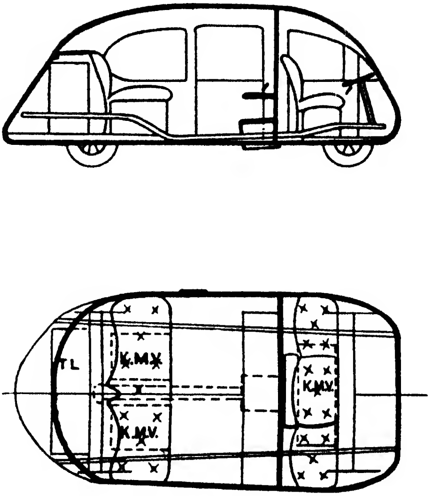

Fig. 104.—OUTLINE DESIGN FOR A BATTERY-ELECTRIC TAXI BY MR. G. O. MCLEAN

High-speed Difficulties

In dealing with speeds above 30 m.p.h., however, a word of warning is necessary.

For example, a distance of 48 miles per charge at 35 m.p.h., as found in the hypothetical car, implies a time of discharge of only 1·375 hours, in which case it is practically certain that the five-hour rating of the battery will not be obtained. Moreover, a vehicle in motion represents stored energy which must be drawn from the battery while attaining speed and wastefully dissipated when the brakes are used for stopping or slowing down. This energy is proportional to the square of the speed, hence, to get up to 40 m.p.h. means taking out of the battery not less than sixteen times the amount of energy necessary to attain 10 m.p.h. If the speed is raised to 60 m.p.h. the demand on the battery for acceleration is so heavy that the car will only attain full speed from standstill three times before the battery is completely exhausted.

As a practical compromise, therefore, it appears that speed should be limited to 30 m.p.h., when the results will be as shown in Fig. 101, giving 60 miles per charge with a lead battery, a performance which even under the conditions prevailing just prior to the war would be sufficiently good when combined with the inherent virtues of the electric type to make many users prefer this type to petrol.

Mr. Murphy's figures for comparative cost of operation for 10,000 miles per annum were as set out in Table XII.

Obviously many of these items are debatable, but making all allowances for variations due to local conditions, care in operation, etc., the fact remains that the electric is always cheaper to operate. The taxation figures may be regarded as artificial, but the fact that the electric is free

TABLE XII

	Electric		Petrol	
	£	s.	£	s.
Electricity at ½*d.* per Unit	17	0	—	
Petrol at 1*s.* 6*d.* per Gallon	—		30	0
Lubricants	0	10	3	0
Battery Maintenance	20	0	2	0
Chassis Maintenance	1	0	10	0
Insurance (third party)	7	0	12	10
Tax	7	4	18	0
Total of those items	£52	14	£75	10

from nuisance features amply justifies the authorities in favouring the type, and this state of affairs will almost certainly continue.

Electric Taxis

Curiously, electric taxis have been used on the Continent and in America, but not in London or in other towns in Great Britain, so far as the author is aware, since about 1910, when the rapid development and enormous cheapening of the petrol vehicle caused them to disappear from the streets, a contributing factor being limited range. That is, the electric had to decline a fare who desired a long run, so that, in other words, they were mainly used for short runs in the West End.

They resembled the horse brougham, as did the electric car of those days. To-day the Licensing Regulations enter into the question considerably. It is quite possible to design an electric which would entirely conform to the regulations, but it would probably be ugly as a consequence of following them rigidly. Actually also in the case of electrics many of them could safely be dispensed with. The conditions regarding steering and general safety can be readily complied with. Briefly they are :

Steering wheel on right ; no possibility of overlock ; bolts to have castellated nuts and split pins ; turning circle under 25 ft. ; brakes to act on all four wheels, and to be actuated by direct mechanical means (excluding cable connections) ; all glass of safety type. It is when one comes to clauses regarding dimensions of chassis and seating that the electric designer has ideas different from those of the police. The regulations have, of course, been drawn up to ensure the maximum comfort of the passengers, and have been based on our internal-combustion vehicle practice.

The problem of the electric designer is to dispose of the battery crates ; and whereas the pannier method of carrying batteries offers many advantages for commercial vans, it is impossible in a vehicle requiring large doors (21 in. width) and low steps. The " fore-and-aft " method of

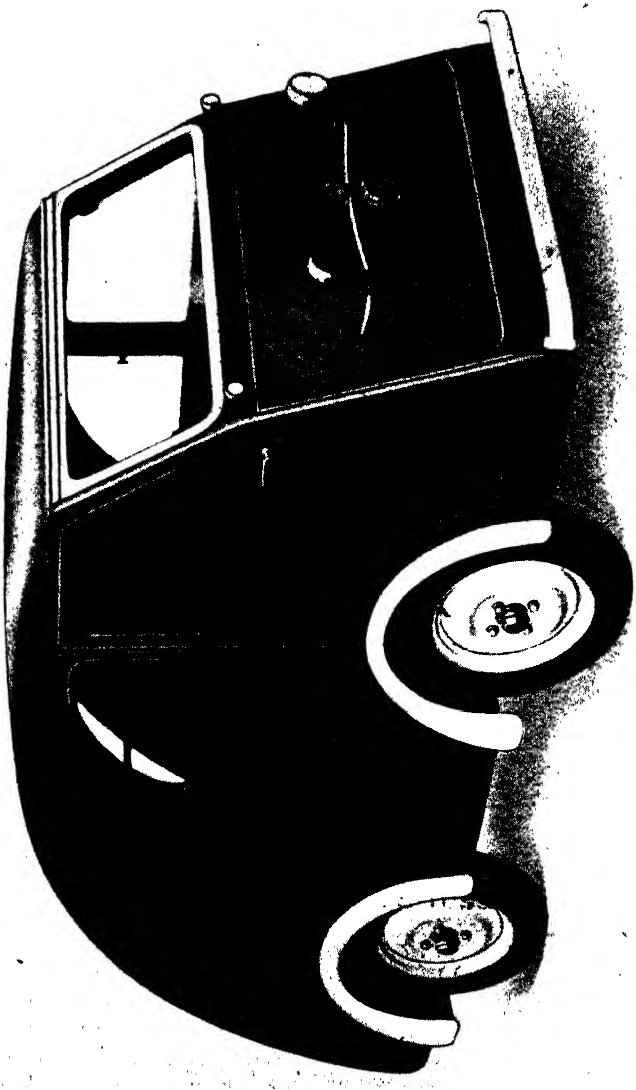

Fig. 105.—Wilson Electric Utility Car

disposal makes an unstable vehicle for steering ; and the final alternative is to place the battery crates "athwart ship." This virtually means placing them under the seats or in special compartments which would waste space.

In 1941, Mr. G. O. McLean, M.Eng., put forward a suggestion for a battery-electric taxi[1] which has several points of interest. This differed in certain points from the clauses of the Metropolitan Police Regulations. The chassis dimensions are only 3 ft. 6 in. track, and 6 ft. 2 in. wheelbase, against a minimum track of 4 ft. 6 in.—but the low slinging of the battery ensures a low centre of gravity and hence absolute freedom from the risk of capsizing, and it is possible that such dimensions would be passed, providing that the track exceeds half the wheelbase.

The overall width (between body panels) exceeds the track width by about 15 per cent., and the regulation figure is 5 per cent. Here again the inherent stability of the electric may be a deciding factor in favour of laxity. The distance between seat and roof is 33 in., from floor to roof is 48 in., whereas regulations give minimums of 40 in. and 54 in.

Probably the growing tendency to produce taxis on modern saloon-car lines will tend to alter the regulations somewhat in this connection. The scheme devised by Mr. McLean is shown in outline in Fig. 104.

Advantage of Rapid Acceleration

We have grown more and more used to travelling at speed, or perhaps it is better expressed as attempting to travel at speed, because that is what it amounts to under modern traffic conditions. The short distances between stops do not really provide the opportunity to gain real advantage from the speed availability of the petrol car. Gear changing takes an interval of time which markedly affects the ability to get away quickly. The primary cause is the unfortunate speed-torque characteristic of the petrol engine, which means that it is necessary to work this type of engine in normal level running work at about one-quarter of the load which it is capable of carrying. To be able to ascend hills without gear changing, the petrol car has to be fitted with an engine of a size far beyond the size necessary to propel on the level, whereas the electric motor will give rapid acceleration and will sustain a heavy overload which the petrol engine will not. This point regarding acceleration is brought out in the curves in Fig. 7, which relate to a light electric runabout, a 20-h.p. petrol car, and a petrol taxicab. The electric saves about two-thirds of the time required to attain a speed of 30 miles an hour by the petrol car. The electric, therefore, is very suitable for use as a town runabout.

Charging on Tour

There are greater possibilities for using an electric for touring purposes than is generally realised, now that the development of the grid has made

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[1] *Electric Vehicles*, vol. XXV, p. 254.

available over large areas a supply of electricity at 230 volts A.C. Runs of very long distances are not a really practical proposition in competition with a petrol car, i.e. runs of 200 or 300 miles in a day, or in a short period of hours ; but a light electric with a range of 30 to 40 miles for town work would probably cover 50 miles on roads where frequent stopping did not occur.

There is also the point that a lightweight chassis designed for a 15-cwt. payload delivery vehicle would carry a light four-seater passenger body, and after allowing for three passengers (there is a driver in each case), each weighing 12 stones, i.e. a total of 504 lb., plus perhaps luggage bringing the total to 580 lb., this would mean that the load is about 40 per cent. of the permissible one. A metal rectifier carried on the vehicle would add about 300 lb. to the weight, still leaving a margin for increased battery size and increased weight on that account. Such a vehicle could obtain a boost charge in almost any town, and similarly could be charged at night.

This plan also opens up possibilities for the traveller representing a firm making ladies' coats or dresses, to use an electric in towns, and for short runs from town to town in an area, because the load is light, and there is therefore sufficient to spare on a 10- or 15-cwt.-payload vehicle for carrying the charger. There is nothing to prevent the charger being designed to fit into the vehicle, so that the space occupied is made as little disadvantageous to load carrying as possible.

Commercial Models

The *Wilson-Electric* utility car has a mileage per charge of 40 to 50 miles, and is intended for use for the daily run to the office, the station, the cinema, etc., and is a smart-looking streamlined vehicle. It possesses lively acceleration and a speed of 23–28 miles per hour, quite sufficient for town use. For use in exceptionally hilly districts the makers fit a rear axle of higher ratio than normal which, though reducing the speed on the level, improves hill-climbing performance and acceleration. The standard body is coach built and has full-length doors fitted with opening windows. At the rear of the body is arranged a hinged glass panel light, giving really good visibility from the rear of the car and also providing access to the parcel compartment. The overall dimensions are : length 11 ft. 2 in., width 4 ft. 4 in., wheelbase 5 ft. 1 in. The battery is an Exide-Ironclad 30 cells M.V.U.13 210 ampere-hours. The motor is a G.E.C. series-traction type, and the controller is of the Wilson fluid automatic type already described in Chapter III B. Bendix brakes are fitted to all four wheels, and steering is of the Marles Weller type.

The *Cleco* electric saloon is designed for a range of 50–60 miles per charge at an even speed of 20 miles per hour, or 35 miles non-stop at 30 miles per hour. The controller provides for speeds of 3, 14, 24, and 30 m.p.h., the first speed being intended for manœuvring when entering the garage or parking. It has a short chassis, having a wheelbase of 6 ft. 4 in. and a track of 4 ft. 2 in., full-length doors and two side windows. The batteries are carried in two sections, one at the rear and one in front under the bonnet. In ordinary respects the chassis is similar to the description of the Cleco vehicle in Chapter III B.

Chapter X

BATTERIES

IT is impossible, of course, to treat completely the subject of secondary batteries or accumulators in a single chapter of a book, but it is not so generally appreciated as it might be that batteries intended for use as traction batteries differ in several respects, but not in theory of operation, from secondary batteries for other purposes. It should, therefore, be of service to those interested in electric vehicles to have set out a broad outline of battery requirements, and some information concerning available makes and their distinguishing features.

The ordinary stationary battery is designed to stand on a stillage in a well-ventilated room, with each cell well separated from its neighbour, convenient for inspection, and the question of weight affects the problem only so far as the cost of lead is concerned.

The traction or vehicle battery, on the other hand, has to be confined in as small a space as practicable, is contained in a box or similar container, weight is a most important matter because it represents dead weight to be carried, and on occasion provision must be made for a rate of discharge which would normally discharge the cells if continued for 15 minutes. Sometimes, also, quick rates of charge, commonly known as a boosting charge, have to be used. Most of these requirements are the antithesis of each other, and consequently, in common with many other engineering problems, a compromise has to be struck.

For example, heavy plates will give a longer useful life, but increase the dead weight ; light plates help the payload but shorten the battery life. Compactness calls for very effective separation between plates. Transport calls for sealing of the stationary battery to prevent sloppage of the electrolyte, while the stationary battery can have an open top, therefore inspection of plates is difficult with one and easy with the other.

Then again, lack of ventilation tends to create a temperature rise on charging which is undesirable, yet battery housing, if reasonably dust proof and dirt proof, can only provide a nominal degree of ventilation.

Assuming the vehicle operates for six days a week for 50 weeks in the year, and is charged nightly, then the battery has to stand up to 300 cycles of charge and discharge per annum, each discharge probably being equal to 75 per cent. of the five-hour rated capacity of the battery. This is by no means a light duty, and a heavier one than the stationary battery usually has to sustain, but the life of the battery will be lengthened if the temperature of the electrolyte, by means of correct charging, and as

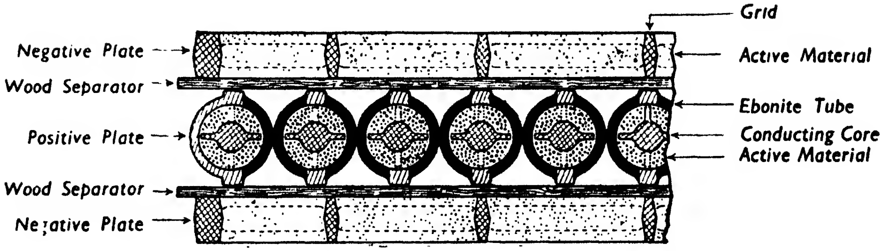


Fig. 106.—HORIZONTAL SECTION OF A PORTION OF A POSITIVE PLATE OF AN EXIDE CELL WITH A SEPARATOR AND NEGATIVE PLATE ON EACH SIDE

much ventilation as possible, can be prevented from exceeding a temperature of 25° F. above that of the surrounding atmosphere. It is during charging that this becomes specially important, and boost charges should be cut off on the appearance of heavy gassing.

There is a limit beyond which it is impracticable to reduce the spacing between electrodes in order to accommodate more plates per cell to increase capacity in a given space, because in doing so the electrolyte would have to be displaced to an undesirable extent. On the other hand, if thinner plates are used, with the same idea in view, mechanical strength has to be sacrificed—an important point with a traction battery.

It can thus be seen that the battery designer has to modify the compromise between weight, volume, and capacity according to the demand, that is, the working conditions the battery has to fulfil, and various makers have produced batteries for electric vehicles which adequately meet these conditions, and many instances have occurred where the useful life of the battery has well exceeded the period guaranteed by the makers. It will be noted also that while there has been no change in the general chemical action—i.e. lead-acid and the alkali (nickel-iron or nickel-cadmium with alkali electrolyte) are still the two prevailing types—there has been improvement and much ingenuity displayed in designing plates to hold the paste, separators, etc., with the result that batteries are more suited to the purpose to which they are applied, and their useful and guaranteed life has been extended during the past twenty years.

Various makers have followed different underlying policies in designing electric-vehicle batteries, some adhering to a policy of aiming at robustness and durability, while others have developed a battery of comparatively lighter weight. The user can, generally speaking, make a free choice of battery, as the battery container on the vehicle is designed to take, or accommodate, more than one make of battery, and more than one type of one make of battery (i.e. using the word type mainly in regard to

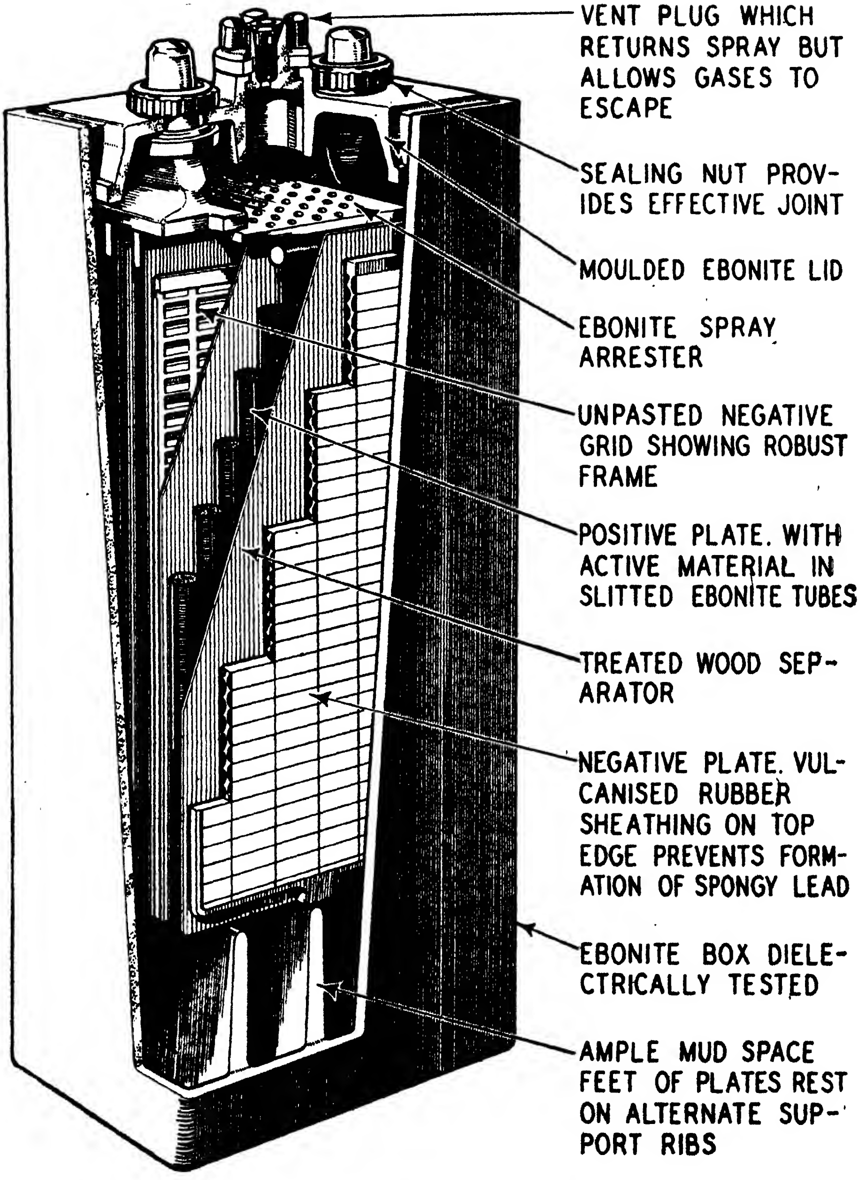


Fig. 107.—The Exide-Ironclad battery, showing method of construction and component parts

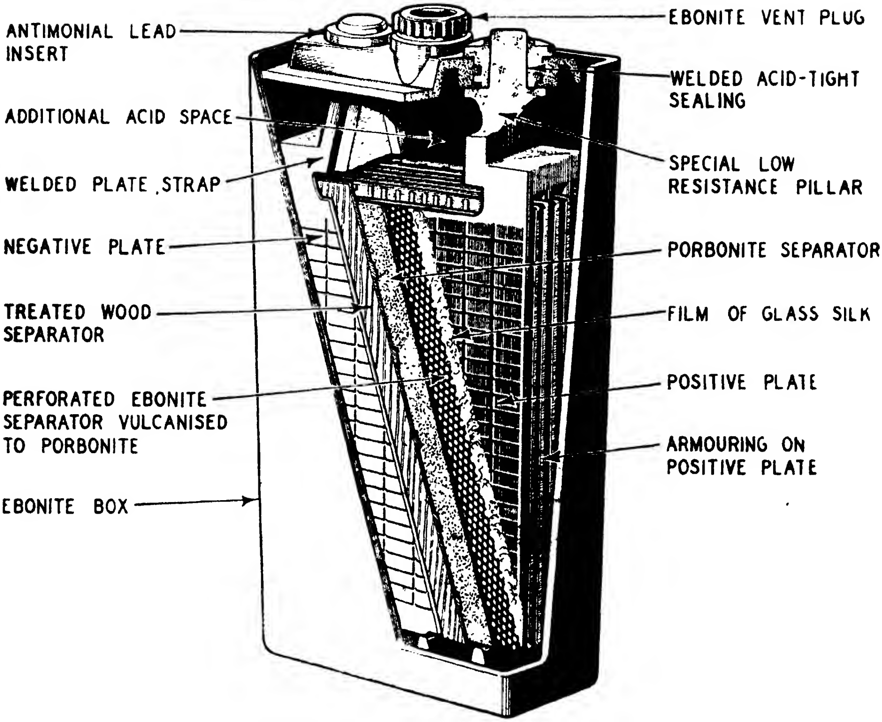


Fig. 108.—Sectional view of a "Young" traction-type cell

capacity). As explained in previous chapters, the capacity of the battery required varies with the duty the vehicle has to perform, and the nature of the roads over which it is operated. The capacity required for a vehicle doing a defined route mileage with a defined number of stops, in a level town like Worthing, would be less than that required for an identical vehicle doing the same duty in Guildford or Hampstead, which are hilly in character.

The choice between lead-acid or alkali is to a degree a matter of individual preference and economics. The lead-acid is the cheaper in first cost, but has a shorter life. The alkali costs more, but will better withstand rough usage so far as charging is concerned. The energy efficiency of the alkali cell is about 60–65 per cent. and of the lead-acid 75–80 per cent. The voltage per cell on discharge is 1·2 volts, as against 1·9 volts for the lead-acid type.

In this country, so far as vehicles are concerned, most vehicle manufacturers provide for lead-acid batteries as the standard, though alkali are fitted on request.

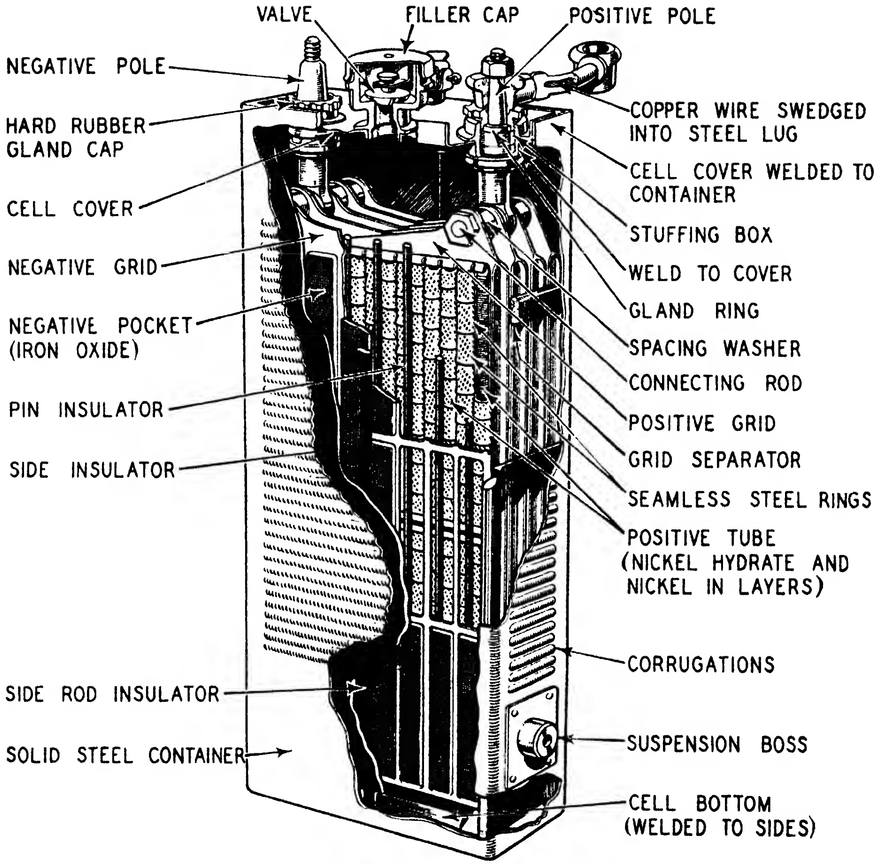


Fig. 109.—Edison nickel-iron cell, showing the component parts and method of construction

The performance of a lead-acid vehicle battery lies between 11 and 12 watt-hours per pound weight, while the theoretical limit is in the neighbourhood of 73 watt-hours per pound.

The Lead-acid Battery

The lead-acid battery consists of a number of pairs of positive and negative plates, of lead peroxide and spongy electrolytically reduced lead respectively, made on grids of lead-antimony alloy, and immersed in sulphuric-acid solution of a specific gravity of 1·285. Actually pasted on the positive grids will be a mixture of lead peroxide with a proportion of lower oxides and a small quantity of lead sulphate. The material for

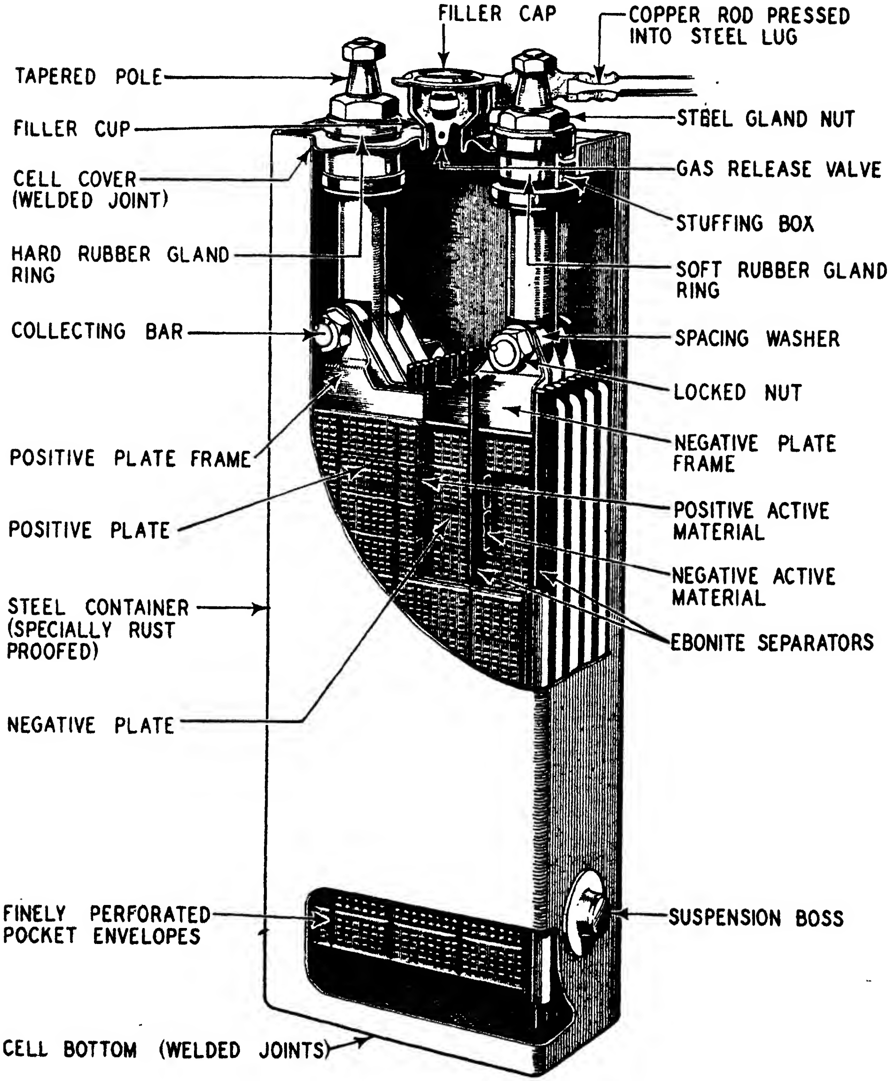


Fig. 110.—Sectional view of NIFE nickel-cadmium alkaline accumulator the negative grid is mainly electrolytically reduced lead in a spongy form, together with a small quantity of lead sulphate.

Under ideal or theoretical conditions, the lead-acid battery when fully charged can be represented by the following :

Positive Plates	*Electrolyte*	*Negative Plates*
PbO_2	$2H_2SO_4$	Pb
(Lead peroxide)	(Sulphuric acid solution)	(Spongy electrolytically reduced lead)

The actions which occur during discharge, if gone into in full detail, have called forth a great deal of scientific argument and discussion, but to make the matter clear in an elementary form, the following equation may be said to represent the picture of the cycle of charge and discharge :

On charge $2PbSO_4 + 2H_2O$ becomes $PbO_2 + 2H_2SO_4 + Pb$
On discharge Both plates Positive Negative

Reading the above from left to right, the changes occurring on charge are given, while reading from right to left the phenomena of discharge is represented, i.e. both plates on discharge assume a condition of electrolytically produced lead sulphate with a thoroughly discharged cell. Of course, in practice the cell is not completely discharged.

It is also not possible in practice to attain a degree of porosity in the plates which will ensure that every portion of the active material can be in molecular contact with the electrolyte, and at the same time ensure that there is an intimate electrical contact throughout the mass to provide that the conductance of the plate is sufficient to distribute the current uniformly within every portion of the interior. As the equation shows, the action of the cell is to produce lead sulphate, and this is formed in layers which merge one into the other from the outer face of the plate to the interior. The effect of this sulphation is to clog up the pores of the active material and to hinder free access of the electrolyte. Hence, it is in designing the grids, the method of forming the plates, and in the type of separator between plates that the various makes of lead-acid cell differ, each maker having attempted to arrive at a design which gives greater efficiency, i.e. co-efficient of use combined with durability.

In the description of various makes which follows, it is these points that have been brought out. The actual basic theory of working of the lead-acid cell of course applies to all of them.

The *Exide-Ironclad* battery is significant for the construction of the positive plate, whch is built up from a number of specially shaped antimonial-lead rods being held in a vertical plane by top and bottom lead castings. These rods are surrounded by sheaths or tubes of ebonite in which they stand centrally, the space between the rod and the tube being filled with the active material (oxide of lead), which is so applied that it entirely fills the space round the rod inside the ebonite tube, and when fully "formed" becomes a solid, yet porous, cylindrical mass. Not only does this method of construction ensure good contact with the supporting rod, but it provides a very high degree of porosity, thus allowing the electrolyte to thoroughly penetrate the active material.

The negative plate is of Exide standard type but thicker. The frame is of antimonial lead, and horizontal bars or ridges on each face support a continuous strip of active material, which is applied in the form of a paste. A vulcanised-rubber sheathing is placed at the top of the plate to prevent shorts with the top bar of the positive plate.

The separators are made of specially prepared and treated wood, and are placed on each side of the positive plate. The ebonite tubes of the positive plates have a vertical ridge on each side, and these ridges bear against the separators holding them against the negative plates. The whole assembly forms a strongly built-up mass, which would be solid but for the space left for the electrolyte by using circular-section tubes in the positive plate. The container is moulded ebonite and has a specially designed vent plug which prevents splashing but allows gas to escape.

The D.P. *Kathanode* battery is a form of battery employing what are known as pasted plates,.and in this the problem of retaining the active material in the plates, and maintaining porosity at the same time, has been solved by closely wrapping each positive plate in a form of felt made from spun-glass fibres, which provides a filter-like action, and at the same time prevents particles of solid material from leaving the plate, and gives free passage to liquids and gases. This also provides the advantage that more simple designs of grid can be used for the plate, which in turn gives greater mechanical strength and reduced weight.

The *Britannia* battery follows the multitubular plan for the positive plate, each tube being of ebonite, double ribbed to give mechanical strength, and slotted horizontally to provide access for the electrolyte to the active material. The active material is compressed against a hard lead core, specially shaped to ensure rigidity, and to provide good contact The negative plates are of the pasted type and have a specially designed grid formation, and a channel strip of rubber is vulcanised along the top edge of the plate to prevent sediment forming spongy lead. Specially treated wood is used as the separator.

Oldham batteries have pasted type plates, and the grids are specially constructed to provide for retention of the active material. It is thus a flat-plate type of battery, and Port Oxford cedar is used for the separator, reinforced with vitreous felt, which it is claimed provides exceptional resiliency, and while giving support to the active material does not increase the internal resistance of the cell.

The *Tudor* battery also follows pasted flat-plate type practice, but the positive plates are completely enclosed in felted glass wool, and between this and the negative plate a finely perforated thin ebonite sheet and a

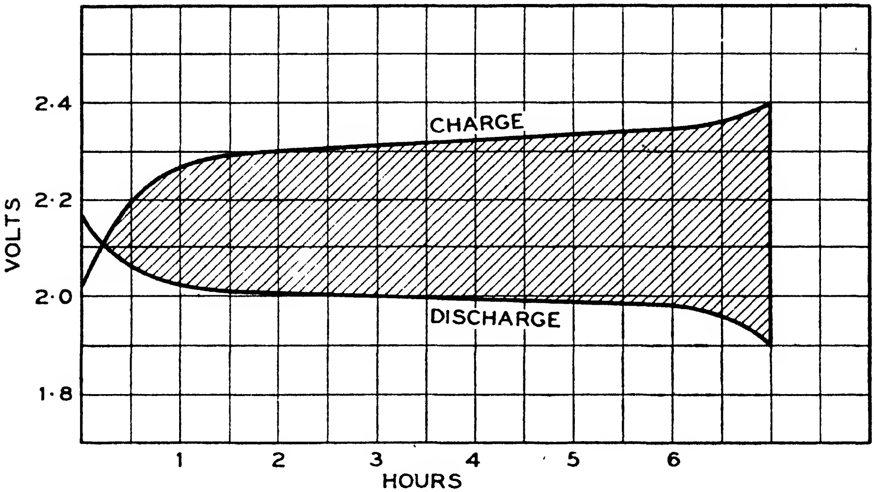


Fig. 111.—RELATIONSHIP BETWEEN VOLTAGE OF CHARGE AND DISCHARGE FOR A LEAD-ACID BATTERY

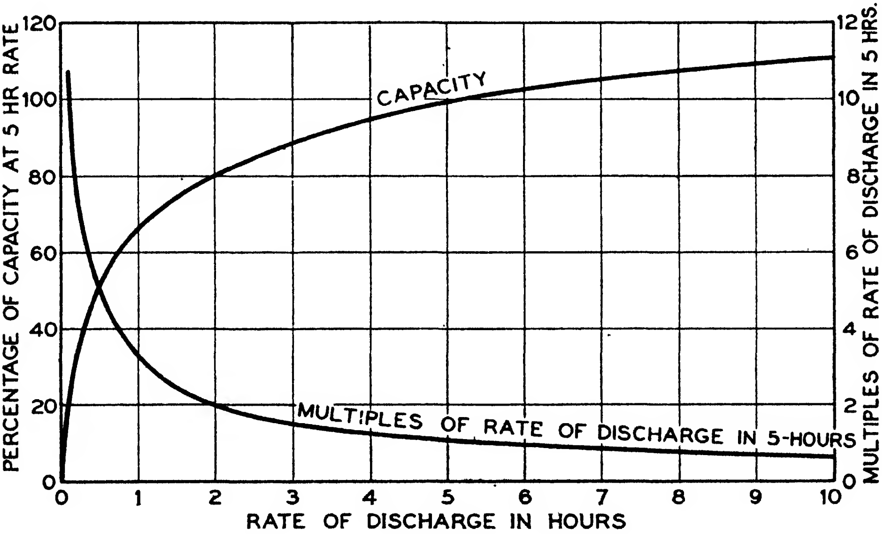


Fig. 112.—CURVES SHOWING RELATIONSHIP BETWEEN RATE OF DISCHARGE AND CAPACITY OBTAINABLE AT THE FIVE-HOUR RATE FROM A D.P. KATHANODE CELL

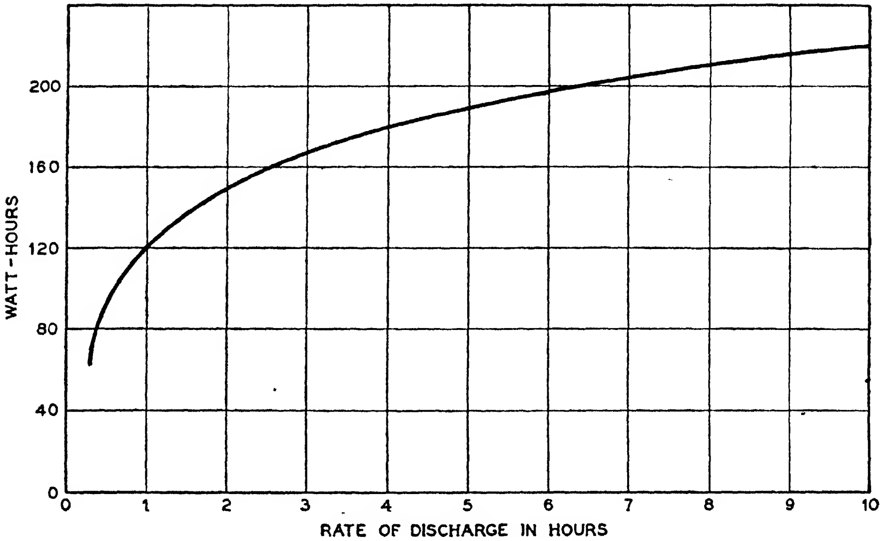


Fig. 113.—CURVE SHOWING WATT-HOUR OUTPUT OF A D.P. KATHANODE CELL

Having a capacity of 100 ampere hours at the 5-hour rate of discharge, when discharged at any rate between the ¼- to 10-hour rate.

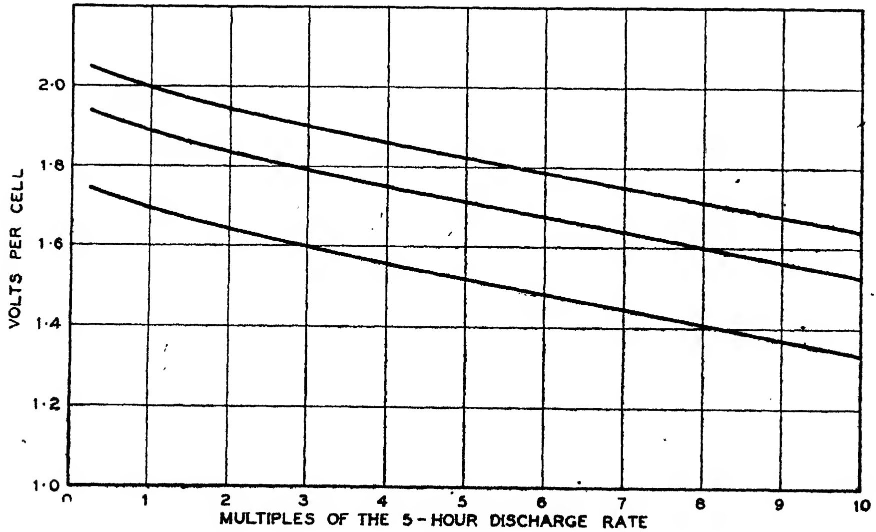


Fig. 114.—CURVES SHOWING RELATION BETWEEN CELL VOLTAGE AND RATES OF DISCHARGE EXPRESSED AS MULTIPLES OF THE 5-HOUR RATE FOR A D.P. KATHANODE CELL double-sided ribbed wood diaphragm is inserted, so that whilst the complete element forms a compact block, it has considerable elasticity to withstand mechanical stresses.

The *Young* battery plate has a specially designed grid and is of the pasted type. The positive plates are protected with special envelopes consisting of a film of glass silk in conjunction with a flat sheet of perforated ebonite, inseparably united by vulcanisation to a porous ("Porbonite") separator. These three different separations are placed each side of the positive plate and the whole is sealed along both sides and bottom, completely armouring the electrode. The sealing is effected by means of a strip of soft rubber vulcanised to the separators. A treated wood separator is also used with the flat surface to the negative plate, and a ribbed side placed against the "Porbonite" separator.

Alkaline Batteries

The typical alkaline cell, which, as its name implies, employs an alkali electrolyte instead of an acid one, consists of an assembly of perforated unit pockets or tubes made from a thin-steel nickel-plated strip. This provides for strength in construction, light weight, and immunity from attack by the electrolyte. The positive plate contains nickel oxide and the negative plate contains iron oxide in the case of the Edison cell and the Britannia battery, or iron-cadmium oxide in the "Nife" type of cell. In each case the electrolyte is a solution of potassium hydrates—KOH—commonly known as caustic potash. Once again there is difficulty in giving a chemical equation which exactly expresses the phenomena of charge and discharge in a nickel-iron cell. The staff of the Edison Laboratory (U.S.A.), however, did put forward the following as a means of giving a simple explanation of what is really a complicated set of reactions :

$$\begin{array}{ccccccccccc} \textit{Positive} & & \textit{Electrolyte} & & \textit{Negative} & & \textit{Positive} & & \textit{Electrolyte} & & \textit{Negative} \\ 6NiO_2 & + & 8KOH & + & 3Fe & \text{becomes} & 2Ni_3O_4 & + & 8KOH & + & Fe_3O_4 \end{array}$$

$$\text{Discharge}\longrightarrow\qquad\longleftarrow\text{Charge}$$

As stated, there is a series of complicated reactions which the above equation ignores, and for this reason it is difficult to compute the coefficient of utilisation of the active materials, but it has been stated that the figures for the Edison are 21·5 per cent. for the positive and 17·3 per cent. for the negative, and for the "Nife" 23 per cent. and 42 per cent. respectively.

In alkali cells the electrolyte has no chemical effect on the plates and the cell is practically unaffected if it stands idle for a long time, which of course is not the case with a lead-acid battery. On the other hand, a vehicle battery is not generally left uncharged for a lengthy period, because the vehicle is desired to be in use, and cannot be in use unless the battery is charged. The alkali cell has a voltage of only 1·2 volts on discharge, and therefore more cells are needed to give a certain voltage than is the case with lead-acid batteries.

It may be said, however, that all makes mentioned of both types, acid and alkali, have proved suitable for use with vehicles, locomotives, and trucks, and as has been said, choice is largely a matter of personal opinion or experience, and economics so far as life and price are concerned.

There is also the Drumm battery of the alkali type, which works on the principle of zinc hydrogen deposition on nickel or a special nickel alloy. However, so far as the author is aware it has only been applied to a train service between Dublin and Bray, in Ireland, and he has not heard of its use for vehicles or trucks.

Efficiency

The efficiency of a battery, i.e. the relation of output to input, can be measured in either ampere-hours or in watt-hours, but naturally the results differ, the former always being higher than the latter. This difference is due to the fact that the charging voltage is always higher than the discharge voltage, and the difference may be as much as 10 per cent., i.e. 85 per cent. compared with 75 per cent. for a lead-acid, and for an alkali battery 80 per cent. ampere-hour efficiency and 65 per cent. watt-hour efficiency.

Characteristics

For convenience the characteristics of the types of cell are tabulated in Table XIII.

Performance

The performance of batteries is indicated by means of graphs, and makers supply graphs relating to their own particular cells or batteries of cells. Those shown in Figs 112, 113, 114, 115, and 116 relate to D.P. Kathanode cells. Those in Fig. 112 show the relationship between the rate of discharge and the capacity obtainable at the five-hour rate. The top curve is a time-capacity curve, and is obtained by plotting the percentage capacity which can be obtained from a cell at a constant rate of discharge, against the number of hours during which the cell will carry the rate in question before dropping below the permissible final voltage. The capacity at the five-hour rate has been taken as the maximum and the capacities at all other rates as a percentage of these figures. For example, at the three-hour rate, i.e. the rate at which the cell will sustain for three hours, the capacity of the cell is given by the height of the ordinate drawn from the point marked three hours on the time scale to its intersection with the curve. This is 89·3 per cent. of the capacity at the five-hour rate. Similarly, the capacity at the one-hour rate is 66·4 per cent. of the capacity at the five-hour rate. The lower curve shows the

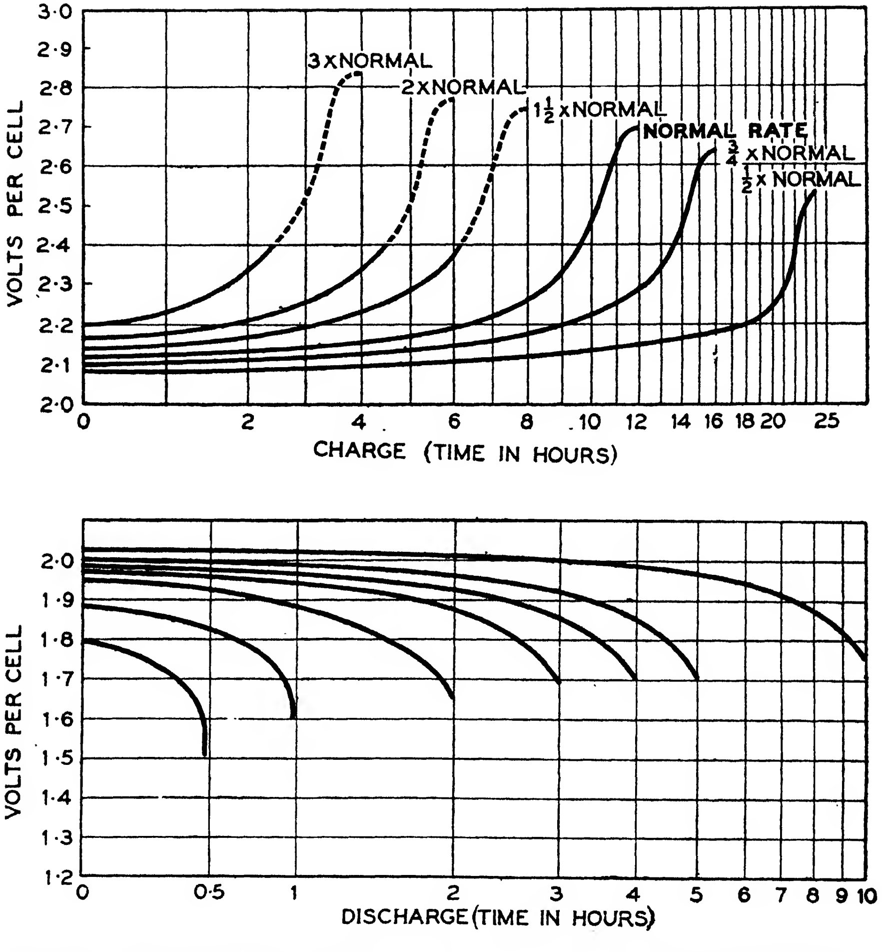


Fig. 115.—REPRESENTATIVE CURVES OF CHARGE AND DISCHARGE FOR D.P. KATHANODE BATTERIES

Note.—Cells should not be charged at a rate exceeding the normal when voltage reaches 2·4 volts. The top three curves are, therefore, shown as dotted lines above normal voltage.

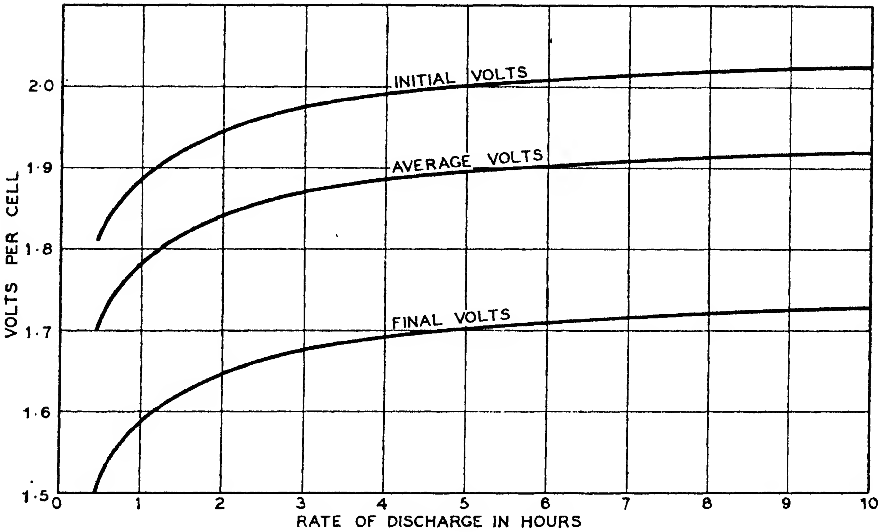


Fig. 116.—Curves showing relationship between rate of discharge and cell voltage for D.P. Kathanode cell

TABLE XIII.—CHARACTERISTICS OF LEAD-ACID AND ALKALI CELLS

	Lead-acid	*Alkali*
First Cost	Low	Higher
Life	3 years +	8–10 years
Voltage per Cell on Discharge	1·9	1·2
Number of Cells for Given Voltage	x	$x + \frac{63}{100} x$
Capacity in Watts per lb.	11·5	14–15
Internal Resistance	Low	High
Fall in Capacity on High Discharge Rates	High	Low
Boost-charging	Limited by gassing and temperature	Limited by temperature
Watt-hour Efficiency	75	60
Ampere-hour Efficiency	85	77

relation between the rate of discharge and duration of discharge. Hence it can be seen at a glance how long a cell of any given capacity will sustain any given rate of discharge before dropping below the permissible final voltage. Conversely it can be seen what rate of discharge will run a cell down in any given time, the rates of discharge being plotted as multiples of the five-hour rate, which is taken on the curve as being unity. Thus, at a rate of discharge equal to three times the five-hour rate of discharge, a

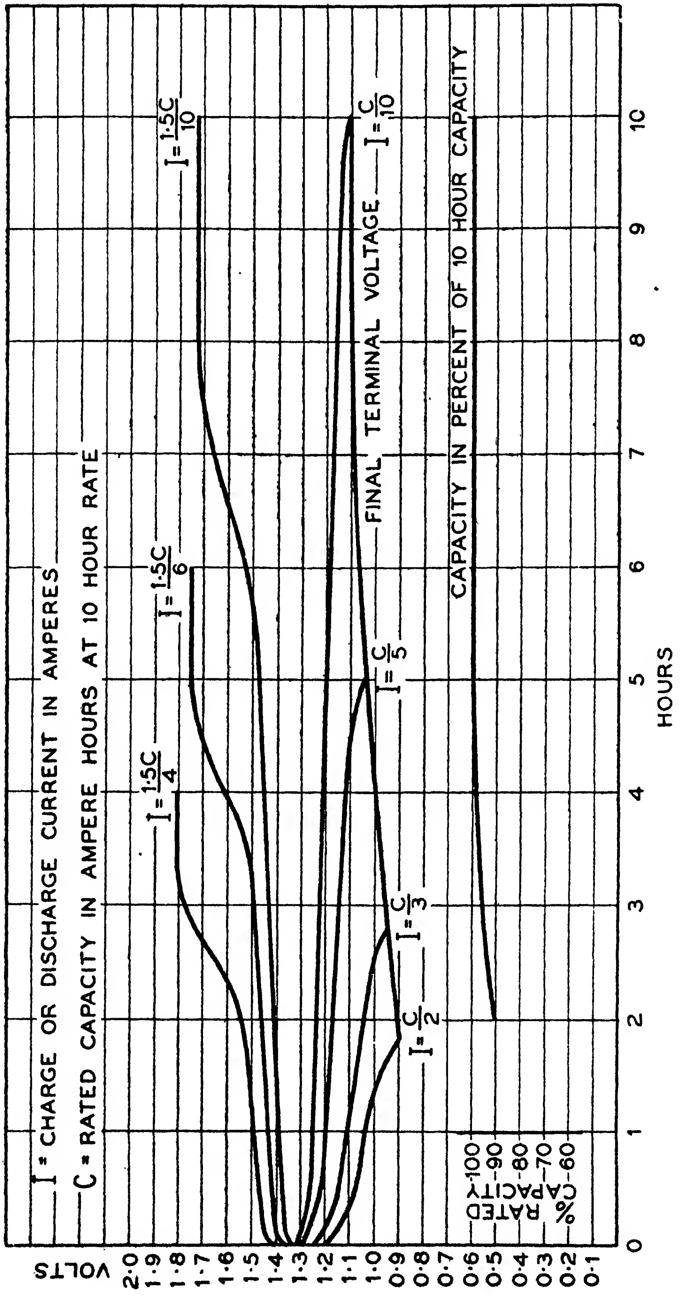


Fig. 117.—Characteristic curves of Nife alkali cells cell will last 1 hour 10 minutes, or conversely, to run a cell down in two and half hours a rate equal to 1·7 times the five-hour rate is necessary.

Fig. 113 shows the watt-hour output of a cell having a capacity of 100 ampere-hours at the five-hour rate of discharge, when discharged at any rate between the quarter-hour to ten-hour rate. Fig. 114 shows the relationship between cell voltage and rates of discharge expressed as multiples of the five-hour rate.

Fig. 111 shows typical, i.e. average charge and discharge curves for a lead-acid cell, and the shaded portion indicates lost volts, and explains the difference that exists between ampere-hour and watt-hour efficiency (see p. 164).

The characteristic curves for "Nife" alkaline cells are shown in Fig. 117.

Chapter XI

BATTERY CHARGING AND CHARGING EQUIPMENT

DESPITE progress made with the grid scheme, there are still places in this country, and of course some abroad, where direct-current supply is provided, and as the alternative methods of battery charging differ as between A.C. and D.C., it is necessary to include a brief reference to battery charging from a D.C. supply.

Charging from Direct-current Mains

For charging one or more batteries from a D.C. supply, the voltage of which is above that of the batteries to be charged, three alternative methods are available :

(*a*) To charge each battery separately by placing it across the mains with sufficient resistance in series with the battery to cause the required drop in voltage.

(*b*) To connect the batteries in series with one another, so that their combined voltage approaches that of the supply, the excess voltage being absorbed by a resistance placed in series with the batteries.

(*c*) To use a motor generator to reduce the supply voltage to that required for battery charging.

When the supply voltage is greatly in excess of the voltage required for charging, for example, when the supply voltage is 230 and the charging voltage 100, method (*a*) is wasteful, due to the comparatively large resistance required and the consequent losses therein.

It might at first thought appear that method (*c*) would always be the most efficient, but such is not always the case.

For example, consider the case of two batteries of 196 ampere-hours capacity, 36 cells each, and discharged equally so that 150 ampere-hours have to be put back into the battery, the mains voltage being 200. (The voltage per cell on charging is 2·4 volts.) In this case, charging by method (*b*), the energy taken from the supply mains will be 200 × 150 watt-hours = 30 units (1 unit $\doteq$ 1,000 watt-hours). On the other hand, if method (*c*) is used, i.e. a motor generator, efficiency say 58 per cent., the position will be as follows :

Average voltage required . . .	$2{\cdot}4 \times 36$	$= 86{\cdot}4$
Ampere-hours required by one battery .	150	
Units required by one battery . .	$\frac{86{\cdot}4 \times 150}{1000}$	$= 12{\cdot}9$
Total units for both batteries. . .	$12{\cdot}9 \times 2$	$= 25{\cdot}8$
Input of generator	$\frac{25{\cdot}8 \times 100}{58}$	$= 44{\cdot}5$ units

In this case, therefore, the motor-generator method (*c*) requires 48 per cent. more energy than method (*b*), which does not involve the use of running machinery.

One difficulty associated with charging more than one battery at a time on one circuit was that if an automatic method of cutting off the charge were adopted, the cutting out of circuit of one battery affected the charging of the others, and only the battery which was charged first obtained a full charge ; or alternatively, if the automatic control were based on stoppage of charging when the most-discharged battery was fully charged, the other or others which required a smaller charge were subjected to overcharging.

To overcome that difficulty, it became customary to put the most-discharged battery on charge first until the ampere-hour meter showed an equal discharge state to the other, when the two batteries were put in series across the mains, and of course both were fully charged when either one cut out of circuit automatically. This remedy, however, requires the presence of an attendant, which, naturally, it is desirable to avoid if possible.

As a means of overcoming the necessity for an attendant, Electricars Ltd. designed a charging panel for two or more circuits (i.e. batteries), the resistance being so controlled by contactors that the batteries could be placed on charge in series with one another irrespective of their state of charge or capacity, provided that the charging rate adopted was not too great for the

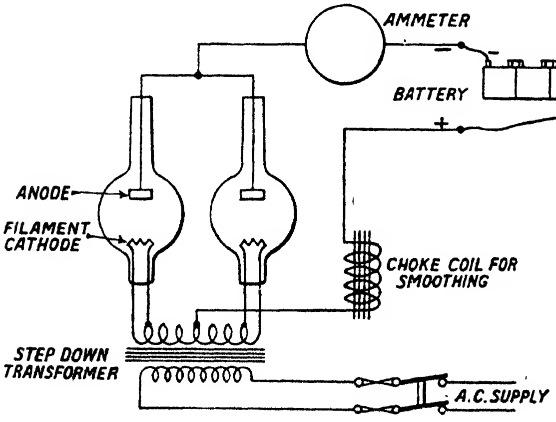


Fig. 118.—Schematic diagram of connections for full-wave charging with a hot cathode rectifier from A.C. mains

Fig. 119.—DAVENSET DRIMET METAL RECTIFIER CHARGER. (*Partridge, Wilson & Co., Ltd.*)

smallest battery. Actually the principle was that each battery when fully charged was taken out of circuit automatically, and a resistance switched in to keep the charging rate constant. The whole operation was automatic, each battery being connected to an ampere-hour meter containing an auxiliary contact switch which controlled the exciter coils of the contactors in each circuit. The switch was normally closed, but opened when the dial hand of the meter had rotated to the "fully charged" position. When the last battery on charge " cut out," all consumption stopped. This method therefore tended towards good efficiency without the necessity of having an attendant present during charging, which, in ordinary circumstances, means a period of from eight to ten hours, and generally at night, because by charging batteries at night, i.e. during the off-peak period of load for the supply station, electrical energy can be obtained at a very low price.

Charging from Alternating-current Mains

As is the case with direct current, there is more than one way of charging from alternating-current mains, the supply from which in this country is standardised at 230 volts, though there are still some exceptions. The methods available are :

(*a*) By using a motor generator, a machine designed with an A.C. motor coupled to a D.C. generator on one shaft.

(*b*) By using a rectifier, of which there are three types, viz. metal rectifiers, valve rectifiers, and mercury-arc rectifiers.

As those in class (*b*) do not involve the use of running machinery, they are naturally the most generally used, and they are designed for automatic operation, i.e. after connecting up and switching on, switching off is automatically effected when the battery is charged. They are both very similar in operation, the principal difference being that metal rectifiers do not employ a valve, which in time has to be replaced.

Cutting-off is arranged for by means of an ampere-hour meter, which

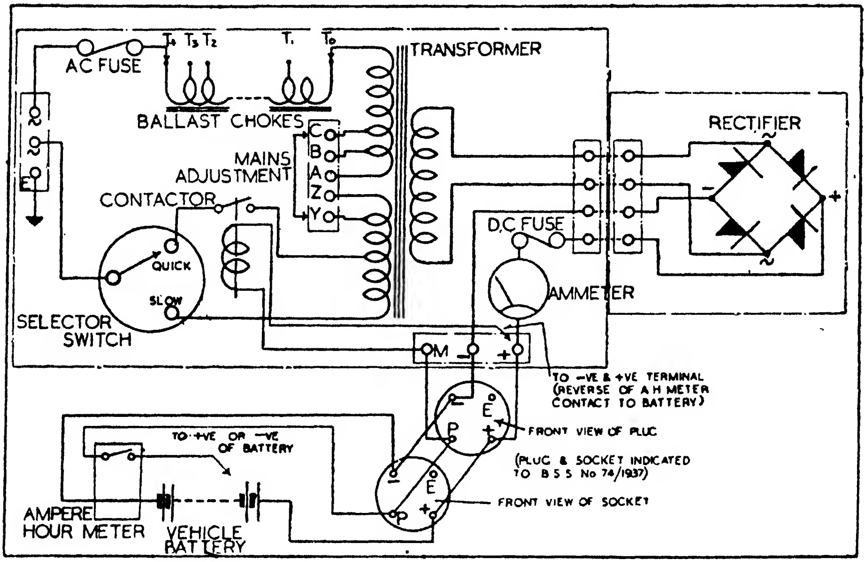


Fig. 120.—Circuit diagram of a Westinghouse charger

is generally mounted on the vehicle. This, on connection by plugging in to the charger, operates in conjunction with either a contactor or circuit breaker on the charger. Two contacts in series with the battery and contactor coil are fitted to the ampere-hour meter, and where these contacts are closed during the charging period, a contactor is fitted to the charger. On the other hand, when the contacts are open with the batteries on charge, a circuit breaker is fitted to the charger. Broadly speaking, the former is the method more generally adopted by vehicle manufacturers, but either method is equally reliable in preventing the batteries from being overcharged.

Tapering of the charging current, for giving a taper charge, or a charge at a gradually reduced rate, is effected by means of a choke or resistance fitted on the A.C. side of the charger. This choke also acts as a ballast to guard against fluctuations in the mains supply voltage, which under statutory regulations is permitted to vary by as much as plus or minus 6 per cent. of the declared voltage, a serious margin so far as battery charging is concerned, but not so serious for other purposes.

For the purpose of "equalising" charges, which is done at a lower rate, the rate of charge is varied by using a different tapping on the winding of the transformer employed to reduce the main supply voltage, and this additional tapping is brought out to one position of a two-way selector switch mounted on the charger.

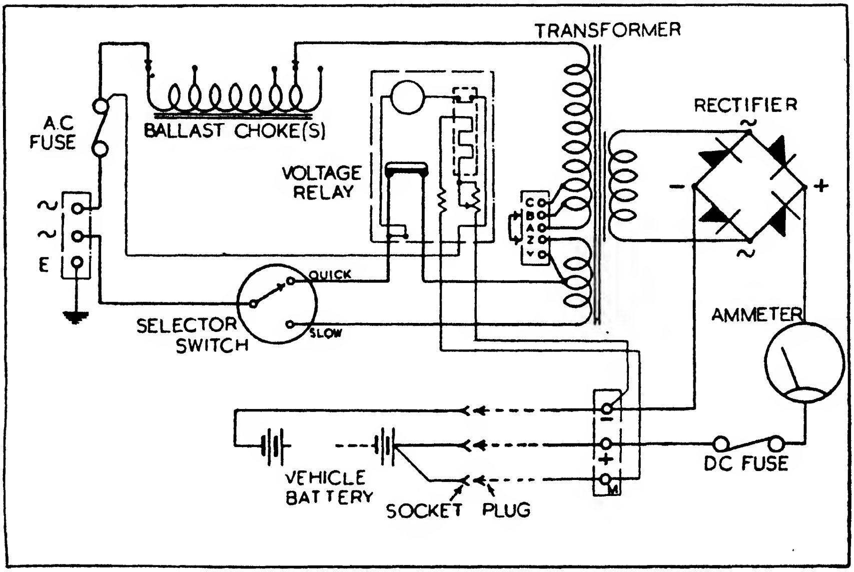


Fig. 121.—CIRCUIT DIAGRAM OF A WESTINGHOUSE CHARGER
Controlled by a Metropolitan-Vickers type MJV relay.

Stabilising by Choke or Resistance

It is stated in the preceding paragraph that, as a current-limiting device, either a choke or a resistance may be used. Actually there is an important difference. The resistance is wasteful, and while a choke is somewhat more costly in the first instance, that extra cost is more than recouped in the end by means of reduced operating costs. Take the case of a thirty-cell battery to be charged at 20 amperes. This means using a resistance which consumes 600 watts, while a choke for the same purpose will consume about 30 watts, i.e. one-twentieth of the loss involved by the resistance method.

Group Charging

It is possible to have one charger for a fleet of vehicles, but in general this is not the best method to adopt. For instance, if there should be any defect, the batteries of all the vehicles connected to the charger would be affected, and this would only be discovered in the morning when the drivers were preparing to take the vehicles out for the morning round. Thus a large distribution of bread or milk might be disorganised. Secondly, the electrical efficiency of a group charger is lower than that of a smaller charger for each vehicle, because ballast resistances

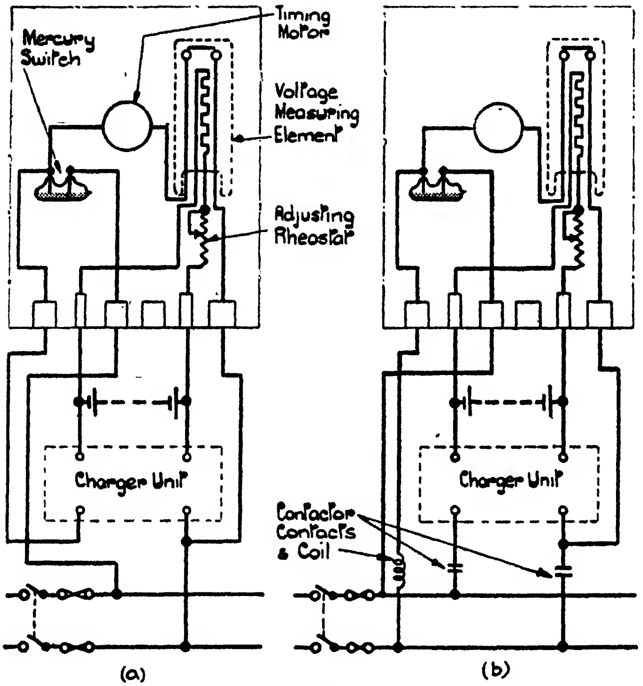


Fig. 122.—Schematic diagram of connections of the Metropolitan-Vickers MJV relay

(*a*) Without, and (*b*) with a contactor in the main circuit.

have to be employed on the D.C. side to provide for the correct distribution of current, and the introduction of further resistances means losses. In the Davenset charger, described on another page, special methods are employed to overcome these difficulties. Thirdly, a group charger lacks flexibility, that is, if it should prove desirable to move a vehicle to another depot, a charger will be required for it at that depot, whereas if a charger per vehicle is provided at the main depot, then on a vehicle being moved the charger can be transferred with it.

Portable Chargers

The only points that prevent the charger forming part of the vehicle are weight and space occupied. Naturally, at least so far as a delivery vehicle is concerned, it is desirable to have as much payload capacity and space for carrying the load as possible. The charger for a lightweight vehicle of the 10-cwt. payload class would weigh about 2½ cwt., thus reducing the payload capacity of the vehicle by 25 per cent. Nevertheless, there are cases where it is more economical to carry a charger on the vehicle than for the vehicle to travel back to a depot some miles away for recharging the battery.

A case in point would be where an electricity supply authority used a vehicle as a portable showroom in a large area. In that case it is better for the vehicle to be able to move around carrying the charger with it, than to place chargers at a very large number of points in a large area.

Fig. 123.—THE METROPOLITAN-VICKERS TYPE MJV BATTERY-CHARGING RELAY

Sizes of Charger

From the foregoing it will be seen that with A.C. supply and a modern charger, the charging of the batteries becomes an automatic process, and can be controlled by the ampere-hour meter fitted to the vehicle, which performs the dual function of indicating, when the vehicle is on the road, how much electrical energy has been taken out of the battery, and of switching the charger off automatically when the battery reaches a charged state. Actually the ampere-hour meter is designed to allow the charger to put into the battery 20 per cent. more ampere-hours than were taken out, to make up for losses, and in calculating the size of charger required this has to be allowed for.

The size of charger required can be arrived at by increasing the rated capacity of the battery by a fifth, i.e. 20 per cent., and dividing this figure by the number of hours available for charging (usually 8 or 10 hours). The resultant figure will be the mean charging rate over the whole period of charge.

Boosting Charge

In many cases, particularly with delivery vehicles, the vehicle returns to the garage or depot at midday, and then goes out on an afternoon round, there being a rest period for the driver's meal-time. This can be taken advantage of by giving the battery a charge, generally termed a " boosting charge." The battery when undergoing a boosting charge is generally charged at a relatively high rate.

Equalising Charge

Battery manufacturers recommend that a lead-acid cell should be given an overcharge at periodical intervals of a week or a fortnight, at a low charging rate, usually about half the rate at which charging finishes. This is known as an equalising charge.

Makes of A.C. Chargers

All *Westinghouse* chargers incorporate metal rectifiers, and the correct charge taper is determined by a ballast choke. They are entirely automatic and switch off when the battery is fully charged. The transformer is of the double-wound air-cooled shell type and covers a range of 200–250 volts 50 cycles single-phase A.C., but transformers for other A.C. supplies can be fitted when needed. A tapping on the primary winding provides for a lower-rate equalising charge. The metal rectifier is of the full-wave type. An iron-cored choke in the A.C. side of the charger prevents fluctuations of current due to variations in the supply voltage and also produces the taper charge. The maximum charge rate is given at 2 volts per cell for commencement of the charge, and tapers automatically to 40/50 per cent. of the maximum at the finish. The equalising position on

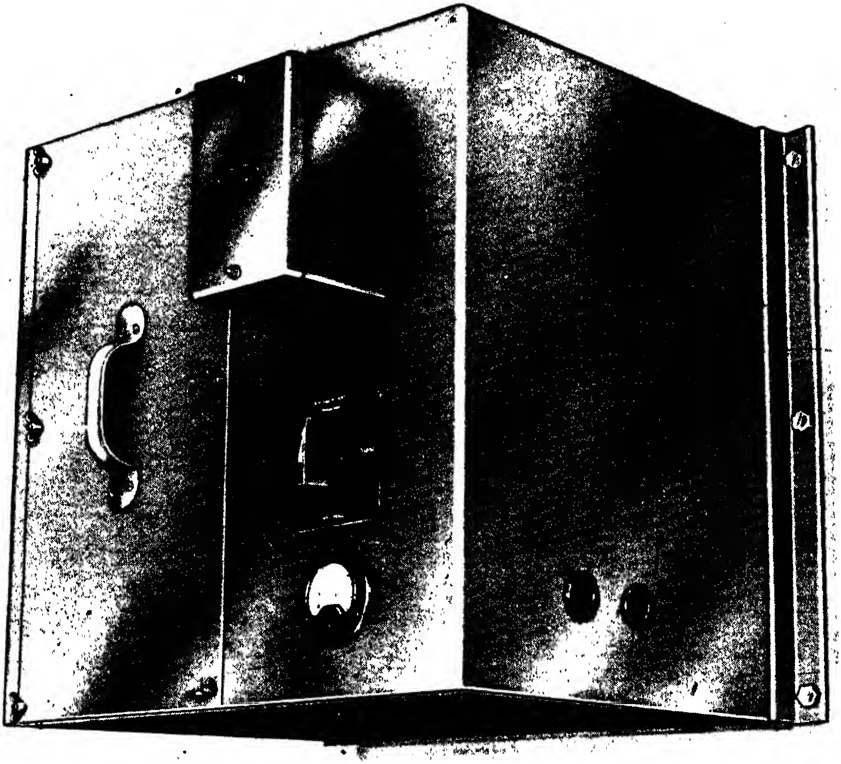


Fig. 124.—HEWITTIC MERCURY-ARC TYPE WALL-MOUNTING ELECTRIC-VEHICLE BATTERY CHARGER

the selector switch provides a lower rate of charge for periodical overcharging, i.e. giving an equalising charge. When control by means of a Metropolitan-Vickers MJV Relay is employed, the connections between the charger and the vehicle are the same, but the contactor on the charger is omitted and its place taken by a mercury switch incorporated in the relay, or when the current to be broken is beyond the capacity of the mercury switch, a separate contactor is mounted on the charger. A schematic diagram of the system is shown in Figs. 121 and 122.

The *Davenset* chargers are made in two types, metal rectifier and valve respectively. Both have double-wound, air-cooled transformers, the primaries being wound for 200–250 volts 40–100 cycles. Both also have a rotary four-position switch giving " off," " normal," and " equalising " positions. The metal rectifier is bridge-connected, giving full-wave rectification. The valve rectifier is a full-wave oxide-cathode gas-filled valve, which bears a maker's guarantee for two years. A time-delay switch is provided, which switches the battery into circuit, when sufficient time has elapsed after switching on the mains for the cathode of the valve to attain its full working temperature.

There is also a Davenset group charger, it being claimed that where several vehicles have to be charged from a three-phase A.C. supply, considerable saving can be effected by group charging, each group consisting of batteries for from four to eight vehicles. The Davenset group rectifier incorporates a separate rectifying valve in each phase, and if one valve fails, the others continue to operate with only a slight reduction in the charging rate. The rectifier is so designed that each vehicle receives a charging rate, which depends upon the state of charge of its battery, and as each battery is cut out at the end of its charge, those remaining are not materially affected.

The *Hewittic* charger is of the mercury-arc type, and essentially consists of a transformer and a Hewittic rectifier bulb. It is automatic in action, regulation of the charging current to suit the condition of the battery being obtained by incorporating a choke in the A.C. side of the rectifier, and a contactor controlled by the ampere-hour meter on the vehicle cuts off the supply to the rectifier when the battery is fully charged. In the case of large fleets of vehicles of different sizes, a number of small individual rectifiers can be used, each fitted with adjustable tappings to cover the range of batteries fitted to the various vehicles, or a multi-circuit Hewittic mercury-arc rectifier can be used, to control up to three batteries per rectifier. In each case the charge is automatically controlled by means of A.C. chokes, as in the case of the single-unit equipment. If a wide voltage range is required for special battery-charging conditions, the rectifier can be fitted with grid control, which gives a smooth and even control of the voltage over the whole range of the voltage output of the rectifier. This control is very simple to operate, it merely being necessary for the operator to turn the small handwheel to vary the voltage to the required value.

An Essential for Development

In order that the market and the possibilities for electric vehicles shall be developed adequately, it is essential that the facilities available for battery charging shall be widely extended.

No great development can be expected so long as it is necessary for the battery-driven vehicle to be charged always in its own garage.

The establishment of public charging stations at which vehicles could receive a high-rate boosting charge, or, alternatively, have their exhausted batteries replaced by fully-charged batteries, would open the way for a ten-fold development in battery-driven vehicles.

Chapter XII

CARE AND MAINTENANCE OF VEHICLES

THE chassis of an electric vehicle, in comparison with that of the petrol vehicle, requires comparatively little attention, and this is perhaps a disadvantage, because it tends to become neglected. The petrol vehicle travels fast over all kinds of road surfaces, and therefore the springs, shackles, etc., have a considerable amount of work to do, and greasing and cleaning have to be done regularly at short intervals if the vehicle is to be kept in really good mechanical condition.

On the other hand, the electric vehicle has a maximum speed of between 30 and 35 m.p.h., and generally it is limited to short-radius work in towns or urban areas, where the road surfaces are comparatively good and the wear and tear on the mechanical parts of the chassis are light.

Mechanical Parts

The spring shackles require greasing at intervals, a grease gun being the usual method adopted. Also at longer but regular intervals the springs should be greased ; as otherwise rust, which inevitably forms, causes the springs to become harsh in action, and the vehicle does not ride as smoothly as it did when new. Bad riding action may cause damage to the goods carried, eggs, for example. The greasing of springs need no longer be a difficult matter, as the Terry leaf-spring greaser (see Fig. 125) makes it a simple and straightforward matter. The greaser is placed across the springs, and the knife edges are set on opposite sides of the spring, when by screwing up with a spanner the knife edges are forced towards each other so that the leaves of the spring are opened. The grease gun is then used to force a small amount of lubricant between the leaves.

The wheel bearings must, of course, be greased frequently. In fact, undue wear on the king pins and bearings is nearly always attributable to lack of care in lubrication. The steering gear should also be given careful attention in regard to the same point.

Electrical Parts

The motor bearings only require greasing about every ten to thirteen weeks. It is harmful to let the motor bearings run without grease, and equally harmful to overlubricate them.

Every fortnight the commutator cover should be removed for inspection of the commutator and brushes. Scoring or burning on the commutator indicates bad adjustment of the brushes, which leads to wearing, which ultimately causes heavy sparking, and probably necessity for removal of the armature and turning up of the commutator. Any carbon

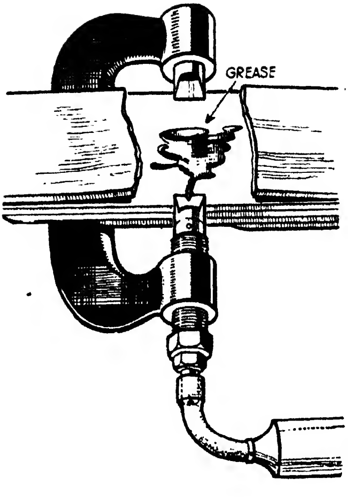


Fig. 125.—THE "TERRY" LEAF-SPRING GREASER IN USE

The top leaf of the spring has been cut away to show the method of working.

dust seen to have accumulated when inspection is carried out should be blown or brushed out. Brushes that are seen to be worn should be replaced, and if they are working stiffly in their guides they should be eased by scraping with glass-paper—assuming that the guides themselves are known to be clean.

The controller should be inspected at weekly intervals and oil applied at the lubricating points if necessary. The condition of the contact fingers and drum segments should be examined for signs of burning in the entering and trailing edges of the segments, and on the contact tips of the pressure fingers. Removal of any roughness can be effected with glass-paper, but if there are indications of excessive burning, which may be caused by a loose or incorrectly adjusted pressure finger, or by the control drum not being correctly located in the running positions due to some fault of the notch-registering mechanism, the trouble must be traced and the cause eradicated. After inspection, and adjustment if necessary, the drum fingers and finger-support bar should be wiped clean with a dry cloth, and the drum segments smeared slightly with vaseline. In some makes of vehicle (see Chapter III B) contact is made by a contactor, and some vehicles fitted with foot control have three contactors and no drum, while those fitted with hand control have one contactor and a drum controller. If the contactor of one of the latter type should stick in, the sparking, which is inevitable when the circuit is broken, will take place on the drum itself, and cause damage to the contacts. If the contactor is operating properly the drum should not show the slightest sign of arcing or burning. In operation the contactor should be heard to go in with a loud " click " at each speed change when the pedal is depressed, and drivers should be instructed to report the matter if they do not hear this click from the contactor. The contactor contacts should be examined every two months, and if they show signs of wear, or if they have hollowed out, they should be replaced.

Battery

So far as the battery is concerned, full instructions are provided by the battery manufacturer, but the following condensed instructions for Exide (lead-acid) batteries may be given here :

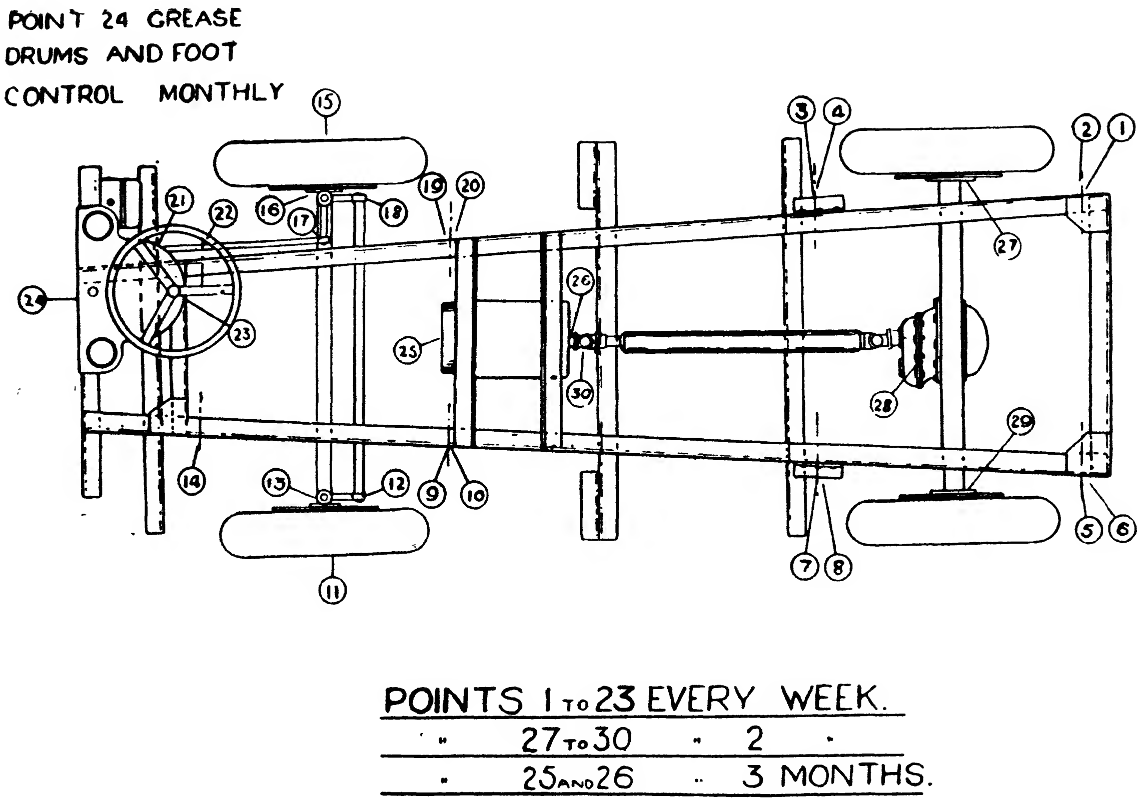


Fig. 126.—A greasing-point chart in the garage aids toward efficient maintenance
(The above chart refers to a Morrison chassis.)

(1) Maintain acid level by adding nothing but distilled water ; do this as occasion demands to keep the spray arresters just covered.

(2) Only charge the battery as frequently as service demands.

(3) Give an equalising charge after every five or six cycles of charge and discharge, with a minimum of one per month.

(4) Keep all connections tight, and the battery clean and free from acid or dirt exteriorly.

(5) See that battery leads are replaced and fixed in position by the spring clips.

Instructions to Drivers

It is well to have displayed in the garage an inspection sheet for drivers to serve as a reminder of what has to be done regularly in the maintenance of the vehicle. The following will serve as an example :

WEEKLY

Examine acid level in batteries and top up with *distilled* water.
Take hydrometer readings of battery.
Check tyre pressures.
Lubricate brake mechanism, axles, and steering gear.

MONTHLY

Apply grease to all chassis and steering nipples.
Give battery an equalising charge.
Take hydrometer readings.
Inspect motor brush gear.
Inspect contactor and controller.
Inspect oil level in rear axle.
Adjust brakes.

QUARTERLY

Grease front and rear hubs.
Take up play in front hubs, if necessary.

HALF-YEARLY

Clean chassis.
Thoroughly inspect chassis, and check all nuts and bolts for tightness.
Lubricate door hinges.

As the battery is the most expensive single item as well as the item most liable to deterioration through neglect or misuse, the greatest care should be taken to ensure that it receives adequate maintenance.

A very important point to remember in this connection is that, if for any reason a vehicle remains unused for a week or longer period, it is

ELECTRIC VEHICLE RECORD

R.D.G.249

H.C.D. NO...............

MAKE ....GALLS. ....GOODS £ ....

DEPOT ....DATE ....

VEHICLE REG. NO...SPEEDO. READING ....

EVERY WEEK

1. Chassis Lubrication. Check grease points (see Fig. 125). Check reservoir ....
* 2. Check tyre pressures ....
3. Top up batteries ....
4. Clean windscreen ....

EVERY MONTH

1. Examine and clean contact points in foot or hand control ....
2. Examine and clean contact points that foot or hand control operates ....
3. Check fluid level in foot or hand control bucket ....
4. Check brake adjustment and add Lockheed fluid as necessary ....
* 5. Set ampere hour meter back amps., and put on charge ....
6. Examine and grease battery terminals ....
7. Check steering box for adequate supply of Lubricant ....
8. Spray road springs ....
9. Check wheel nuts for tightness ....

EVERY QUARTER

1. Check commutator brushes on motor and clean commutator ....
2. Grease motor bearings ....
3. Take pilot cell readings ....
4. Grease front and rear wheel hubs ....
5. Change oil in driving axle after first 1,000 miles and then quarterly ....
6. Check road spring U-bolts for tightness ....
7. Check front wheel alignment ....
8. Inspection report sent to H/O ....

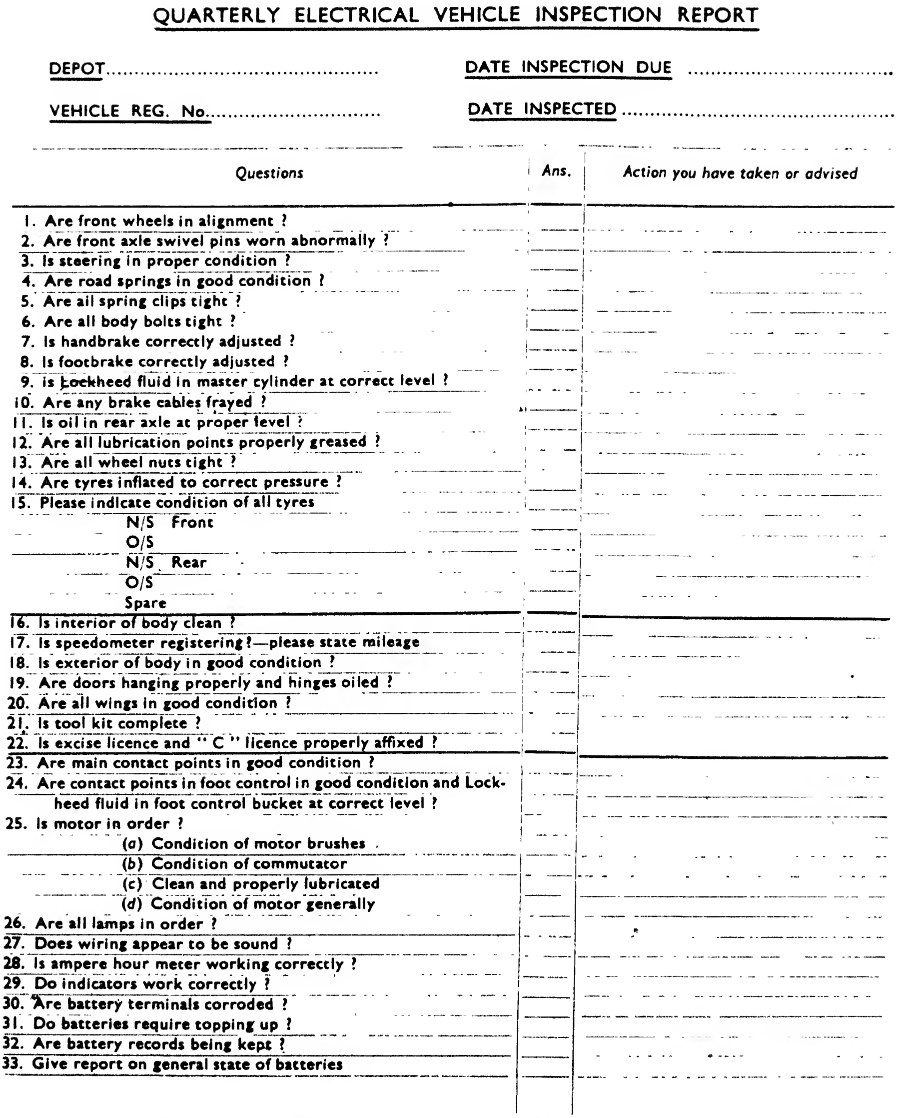
NOTE

USE THE FOLLOWING OILS:

Rear axle and steering	Silvertown S.C.2.K.
Motor bearings	„ G.G.10.
Wheel hubs and grease gun	„ G.G.1.

* As specified by Makers.

Fig. 127.—Weekly maintenance record sheet



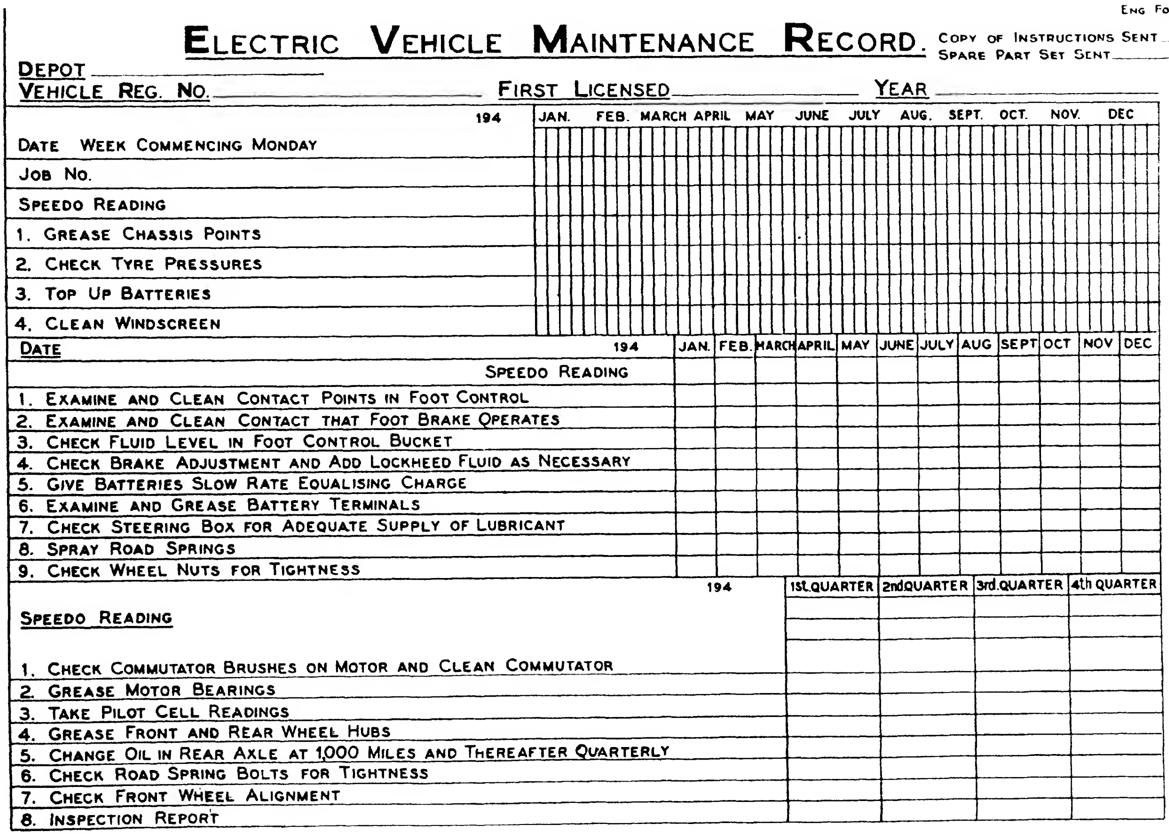
QUARTERLY ELECTRICAL VEHICLE INSPECTION REPORT

DEPOT... DATE INSPECTION DUE ....

VEHICLE REG. No............................. DATE INSPECTED ....

Questions	Ans.	Action you have taken or advised
1. Are front wheels in alignment ?		
2. Are front axle swivel pins worn abnormally ?		
3. Is steering in proper condition ?		
4. Are road springs in good condition ?		
5. Are all spring clips tight ?		
6. Are all body bolts tight ?		
7. Is handbrake correctly adjusted ?		
8. Is footbrake correctly adjusted ?		
9. Is Lockheed fluid in master cylinder at correct level ?		
10. Are any brake cables frayed ?		
11. Is oil in rear axle at proper level ?		
12. Are all lubrication points properly greased ?		
13. Are all wheel nuts tight ?		
14. Are tyres inflated to correct pressure ?		
15. Please indicate condition of all tyres		
N/S Front		
O/S		
N/S Rear		
O/S		
Spare		
16. Is interior of body clean ?		
17. Is speedometer registering?—please state mileage		
18. Is exterior of body in good condition ?		
19. Are doors hanging properly and hinges oiled ?		
20. Are all wings in good condition ?		
21. Is tool kit complete ?		
22. Is excise licence and " C " licence properly affixed ?		
23. Are main contact points in good condition ?		
24. Are contact points in foot control in good condition and Lockheed fluid in foot control bucket at correct level ?		
25. Is motor in order ?		
(a) Condition of motor brushes		
(b) Condition of commutator		
(c) Clean and properly lubricated		
(d) Condition of motor generally		
26. Are all lamps in order ?		
27. Does wiring appear to be sound ?		
28. Is ampere hour meter working correctly ?		
29. Do indicators work correctly ?		
30. Are battery terminals corroded ?		
31. Do batteries require topping up ?		
32. Are battery records being kept ?		
33. Give report on general state of batteries		

Fig. 128.—QUARTERLY VEHICLE INSPECTION REPORT FORM



Eng Form No 74.

Electric Vehicle Maintenance Record.

Copy of Instructions Sent ____________
Spare Part Set Sent ____________

Depot ____________
Vehicle Reg. No. ____________ First Licensed ____________ Year ____________

194	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC
Date Week Commencing Monday												
Job No.												
Speedo Reading												
1. Grease Chassis Points												
2. Check Tyre Pressures												
3. Top Up Batteries												
4. Clean Windscreen												

Date 194	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Speedo Reading												
1. Examine and Clean Contact Points in Foot Control												
2. Examine and Clean Contact that Foot Brake Operates												
3. Check Fluid Level in Foot Control Bucket												
4. Check Brake Adjustment and Add Lockheed Fluid as Necessary												
5. Give Batteries Slow Rate Equalising Charge												
6. Examine and Grease Battery Terminals												
7. Check Steering Box for Adequate Supply of Lubricant												
8. Spray Road Springs												
9. Check Wheel Nuts for Tightness												

194	1st. QUARTER	2nd QUARTER	3rd. QUARTER	4th QUARTER
Speedo Reading				
1. Check Commutator Brushes on Motor and Clean Commutator				
2. Grease Motor Bearings				
3. Take Pilot Cell Readings				
4. Grease Front and Rear Wheel Hubs				
5. Change Oil in Rear Axle at 1,000 Miles and Thereafter Quarterly				
6. Check Road Spring Bolts for Tightness				
7. Check Front Wheel Alignment				
8. Inspection Report				

Fig. 129.—Permanent maintenance record advisable to give a short charge to maintain the plates and electrolyte in a healthy state, and to neutralise any incipient sulphating.

Another point which may be mentioned in this connection is that, if a battery-driven vehicle is first put into commission, say, at the end of the summer, the topping-up required during the first six months of service may be comparatively small. This may give an inexperienced owner an entirely wrong impression as to the necessity for and importance of topping-up. With the coming of warmer weather, the evaporation takes place at a much higher rate and considerably more distilled water will be necessary at each weekly inspection.

A Maintenance System

Electric vehicles are now operated for delivery purposes by many large concerns whose activities are spread over a considerable area, and the vehicles are therefore not housed in one garage. In such cases, in order that the transport manager may have adequate control over the maintenance of a large fleet of vehicles, it becomes imperative to operate a system which provides him with a clear picture of the work done and the condition of each vehicle.

A good example of such a system is the one operated by the transport manager of Home Counties Dairies, Ltd., and described in *Electric Vehicles* (vol. XXV, p. 230). This concern has its headquarters at Guildford in Surrey, and owns a number of dairies in southern England lying between Guildford and Bath and Eastbourne and Portsmouth, the fleet in 1941 numbering 150 vehicles.

Maintenance control is operated by means of a weekly report form shown in Fig. 127, upon which are also printed the items requiring attention monthly and quarterly. This form has to be filled in by the person responsible for maintenance work, and forwarded to the head office. Also each vehicle has to undergo a very thorough quarterly inspection, which has been designed to omit no single matter that might suffer through lack of periodical attention.

The form of this quarterly inspection is shown in Fig. 128, and it will be seen that it is divided into three parts—general chassis, body work, and electrical. On the reverse of the report, space is provided for the inspector's comments. A maintenance record, Fig. 129, for each vehicle is kept at the head office. On this the details from the weekly report sheet are entered up in the appropriate section on the form. The form, Fig. 129, is divided into sections covering the weekly, monthly, and quarterly items, and it thus provides a complete annual record of the vehicle to which it refers.

Chapter XIII

FUTURE DEVELOPMENT

IT is hoped that the foregoing chapters and the accompanying illustrations have shown, not in the propaganda but in the analytical sense, that electric vehicles are a practical proposition. They definitely fulfil a need in the transport system of to-day, i.e. short-run, frequent-stop service, be it in connection with the delivery of food, the collection of refuse, or the conveyance of persons to or from the shops or station.

That field at present lies within the crowded traffic areas, which, so far as the metropolis is concerned, may be said to be within a ten-mile radius of Charing Cross. That is, an area bounded by Enfield, Woodford, Ilford, Woolwich, Eltham, Bromley, Croydon, Kingston, Richmond, Ealing, Wembley, and Edgware. In other large cities and towns a similar position exists, though the length of the radius is smaller.

Why, then, despite the progress that has been made and despite the considerable number of satisfied users, does one not see more electrics on the road ? The answer is not of the kind that can be contained in a single sentence.

Quantity Production

In the first place, electrics have started, as petrol vehicles once started, as a purely engineering job, a few being built in batches, each very well built, and each, so far as the chassis is concerned, being capable of giving many years of reliable service. The very fact, however, that they were built in small quantities at a time made the price higher in comparison with that of petrol vehicles, which in 1939 were being turned out not in tens but in hundreds every working day.

Electrics so far have not attracted mass capital for mass-scale production, but prior to the outbreak of war there were signs of changes in that direction, signs which indicated that someone would get busy along the lines of producing a chassis, motor, controller, and rear axle specially designed for the job in a limited range of sizes, and with a defined range of bodies which would fit a given chassis, and provide for the broad classification of purchasers' requirements.

After the second year of war the members of a Committee of the Electric Vehicle Association of Great Britain got to work seriously on the question of standardisation, largely then in view of the restriction of steel supplies, but no doubt ultimately the work done will prove to be of value in after-war development.

Greater standardisation and bulk production is therefore one of the means by which cost might be reduced.

It has to be borne in mind that petrol vehicles only gradually reached the mass-production, low-price advantage they now enjoy ; they too were built up more or less piece by piece, and were once very much more expensive than now.

Then again, it requires a certain output before it pays to make dies for a pressed-steel body. Such a body for electrics might incorporate the battery crate, and the body might be welded to the chassis, as is done in the case of the Ford light car.

Bodies

There have always been firms, and probably always will be, who will call for bodies to their own particular requirements, just as there will always be a sale for cars with special coachbuilt bodies, but in effect the output of electric-vehicle bodies by each maker is to a large extent the same. In other words, the mass-produced body has not yet come into being so far as the electric-vehicle industry is concerned. But it may happen by an amalgamation of interests that a body builder, battery maker, and motor manufacturer will combine to produce electric delivery vehicles *en masse*, offering standard types for, say, milk, meat, laundry, etc. Done on really mass-production lines, that would help to reduce costs very considerably.

The bodywork of Morrison-Electricar vehicles of 10/20-cwt. size has been designed for war-time purposes in co-operation with the Ministry of Transport with the object in mind of conserving material. As will be seen from Figs. 132, 133, and 134, the body design is adaptable for either one opening at the rear by means of a roller shutter, or all panels removed, or one panel removed, or any combination of the foregoing

It may be pointed out that after the war there may be a marked development in the use of lightweight materials for van chassis and bodies which could materially add to the performance of electrics. The price of these lightweight materials will no doubt be very much lower than pre-war, because of the exceedingly large manufacturing capacity which has been built up during the war years. There have been developments in the U.S.A. with the use of plastic bodies for cars. It is thought that while this material may cost more, it will considerably reduce fabricating cost, because fewer forming and finishing operations will be required. A rear door in steel, for example, takes seven stamping operations, as against two operations to form a door in plastic.

Plastic body panels a quarter of an inch thick have ten times more impact resistance than the steel body panels generally used. These and other tendencies in design towards reduction in weight will call for careful watching on the part of those who design electric vans in the future.

Motors

While certain makers of electric vehicles manufacture their own motors, others purchase them in the open market, and standard mass-produced motors have long been a service offered in the industry. It has to be borne in mind, however, that efficiencies vary considerably, and, naturally, price is often a determining factor. In many applications to general industrial utility, really high efficiency of a motor may not prove to justify the increase in first costs, but on an electric vehicle it is a matter of primary importance. On electric vehicles it is essential that the best possible use be made of the energy taken from the battery, which is a dead-weight store of energy that has to be carried around. There are signs that the significance of this question of motor efficiency is not realised as fully as it should be. It might therefore help in promoting the use of electrics if a B.S. Specification was produced for an electric-vehicle motor.

Batteries

A study of manufacturers' catalogues reveals that there are a number of variations in the dimensions of batteries, i.e. height, width, and depth, consequently if the purchaser is to have freedom of choice in selecting a battery from any one of the several firms who to-day make them, the battery box or container on the vehicle has to be of a size to accommodate the largest or the largest of perhaps three or four makes, and the battery crate has therefore to be wedged in order that it may not slip about. Then again, there is considerable variation in voltage, and while it is not practical, possibly, to determine a standard voltage for all vehicles, the range might certainly be shortened, and similarly the ampere-hour capacity might be standard to a few capacities at the five-hour rate. Thus voltages might be 60 volts (30 cells), 72 volts (36 cells) or 144 volts (72 cells), and the capacities at the five-hour rate 180, 240, 300. Voltage affects the number of cells, and ampere-hour capacity the area of the plate. Thus both affect the dimensions of the battery container.

Batteries are now of two general types—alkali and lead-acid : at one early period there was only the lead-acid. Then in 1900 Edison remarked to Mr. R. H. Beach, of the General Electric Company of America : " Beach, I don't think Nature would be so unkind as to withhold the secret of a good storage battery if a real earnest hunt is made. I'm going to hunt." That hunt was continued with unceasing endeavour until 1909, when Edison presented his alkaline battery to the world. Some 10,000 experiments went into the discovery of that battery.

The discovery of a less costly and more efficient (i.e. giving more watts per lb.) battery would be of benefit to the electrical industry as a whole as well as to the vehicle section of it, and it may be said that this is a problem which has for years engaged the closest attention of the larger firms who specialise in battery manufacture. It is their constant endeavour to provide accumulators giving more watts per lb.

Charging

There are two methods of providing greater charging facilities, which at least until the grid came into being was one of the retarding influences on electric-vehicle development. To-day, by using the modern rectifier type of charger, charging can be an automatic process not calling for the continued presence of a skilled attendant. Garages, by installing a charger, could provide the same facilities for battery charging as they do for petrol supply, and by means of a time-switch-controlled meter it could be arranged that night charging during off-peak hours could be measured separately, thus gaining the advantage of the cheaper rate.

The other is by means of a chain of alternative-battery stations where, on the lines of a chain library, a subscriber could exchange a run-down battery for a fully charged one and drive away again within a few minutes. This would require a considerable amount of capital, but has been visualised by a number of persons in the past twenty years.

Actually before the war, electric-vehicle manufacturers in Germany were formulating such a scheme, and battery sizes were to be standardised. Each battery container was to hold twenty cells, and 3-ton vehicles were to have two containers and a forty-cell battery. A 5-ton vehicle was to have four containers of twenty cells each, i.e. an eighty-cell battery. Each container was to be suspended from the chassis on the outer sides, and means provided for easy access for topping up the electrolyte or for withdrawing the battery. There was also a proposal to provide public charging stations in connection with electricity supply, where charged standard-size batteries in twenty-cell containers would be available.

Noise

During the war period we have become used to living under control, to being told what we may and may not do, what we can and can not have, etc. Shall we ever return to the pre-war condition of *laissez-faire* ? It is doubtful. Progress itself is reaching a stage where it demands control. Noise in daily life has increased a thousandfold with the machine era. Shall we go on letting the smallest unit of mechanical road transport, the motor-cycle, make the most noise. Possibly not. More stringent steps may be taken by those in authority to control traffic noise.

Of recent years silence of operation has been a powerful factor in the selection of new vehicles by the companies whose deliveries have to be made in the early mornings, before half or more of the people of the world have found it necessary to get out of their beds. Replacements of both horse and petrol vehicles have been made by silent electrically driven ones for this reason, and this movement would have been much greater if the electric vehicles had not cost just twice as much as the petrol vans.

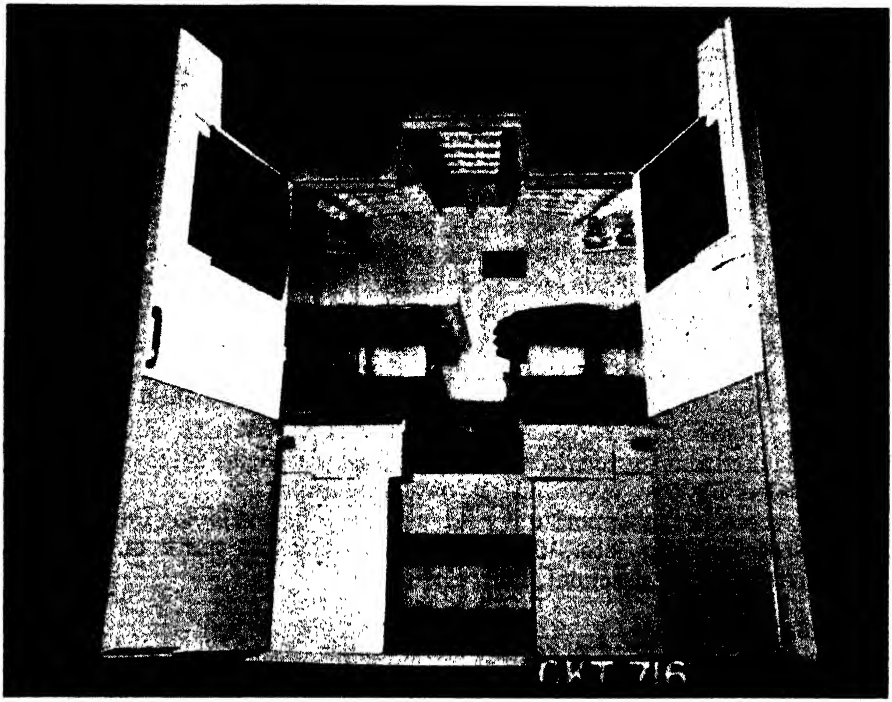


Fig. 130.—Interior view of A.R.P. ambulance. (*Tilling-Stevens Ltd.*)

This growing demand on the part of the public for a greater consideration of the amenities of life will be unanswerable in any other way than by the replacement of all other forms of transport by the electric as soon as that form of transport is no more costly than its competitors. The milk and bread buyers contend that they have as much right to be heard in such matters as the shareholders of the companies who carry out the service for which they receive payment.

Health Services

Developments in connection with public-health services have increased rapidly since the 1920 era, and are likely to increase still more rapidly in the post-war period. Many of these will call for the conveyance of patients within limited areas, for which purposes the electric vehicle is ideally suited, being quiet and smooth-running; ready for operation instantly without previous warming up; has no fire risk and emits no noxious vapours. As far back as 1907 the City of London Police put into operation two Electromobile ambulances, and in 1916 added a third, a Cedes. These vehicles proved very satisfactory and were in operation until 1928, when they were replaced by petrol vehicles because maintenance charges were becoming high. After nearly twenty years' service one might expect that to be the case.

In 1942 Tilling-Stevens Ltd. adapted one of their delivery vehicles for use as an ambulance in connection with their works A.R.P. service. It was found possible to provide accommodation for four stretcher cases or two stretcher and eight sitting cases or, alternatively, sixteen sitting cases.

The stretcher beds were of standard size, and each fitted with blankets, draw-sheets, rubber sheet, and pillows. The stretcher runways were raised from the floor, and fitted with an outside runner to eliminate any risk of the stretcher leaving the platform. In addition, the stretchers were secured by a catch at the head. The rear folding doors were braked pneumatically to prevent their slamming suddenly, and a sliding door in the partition permitted an attendant sitting alongside the driver to keep an eye on his cases. A clerestory-type roof furnished additional headroom, lighting, and ventilation ; it was fitted with sliding glass panels blacked out by curtains on runners. Artificial interior lighting was afforded by two press-button battery lamps.

Then there is the opportunity for using electric vehicles for the conveyance of bedding, etc., for disinfection, the transport of crippled children to and from school, etc.

Postal Services

Reference has been made in a previous chapter to the use of lightweight electric vans by the Post Office, and it would seem that there is

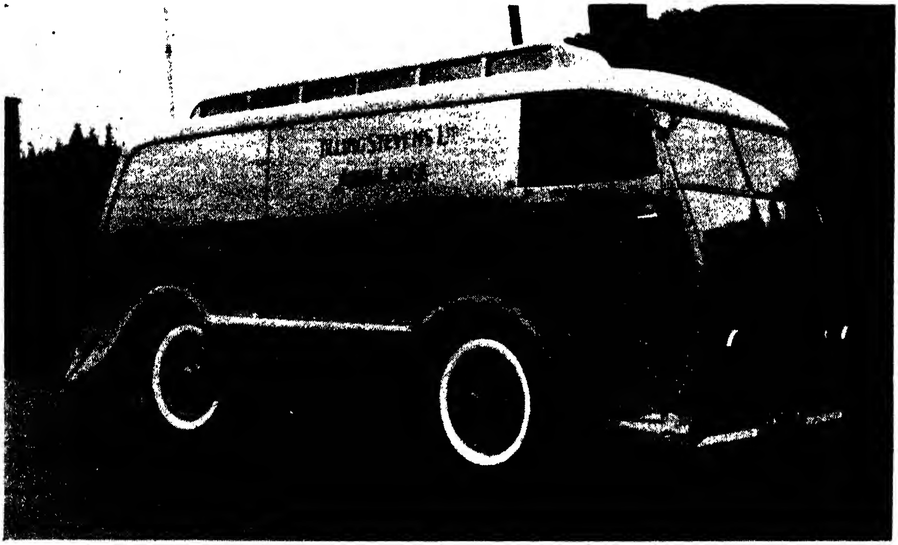


Fig. 131.—BATTERY-ELECTRIC A.R.P. AMBULANCE
Built by Tilling-Stevens Ltd.

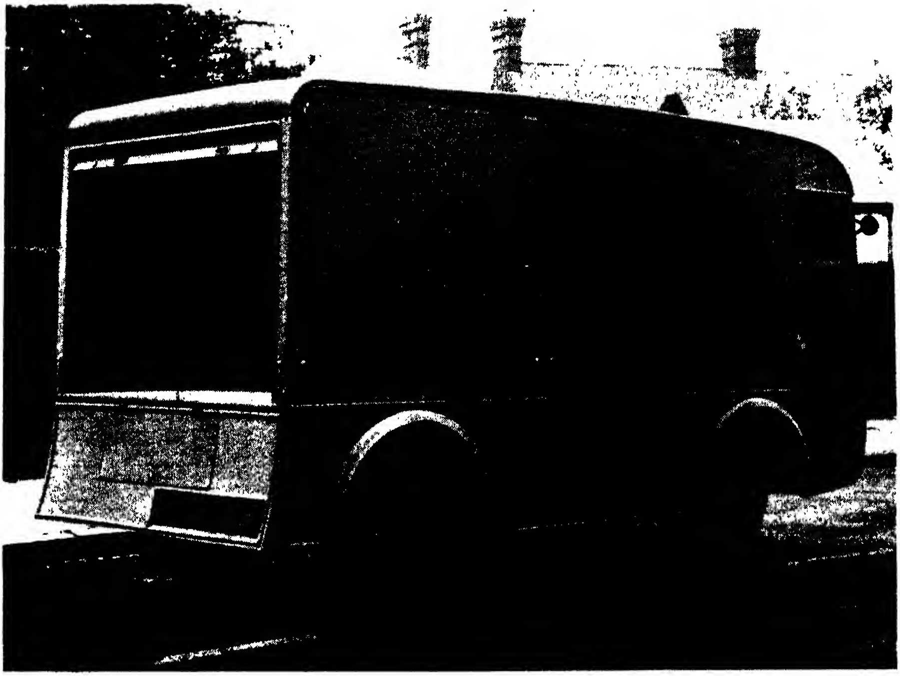


Fig. 132.—Standard war-time Morrison body with opening at rear

opportunity for the much wider use of electric vehicles in connection with the postal services in the larger towns in this country.

In Germany development has been marked, in fact, that country was most progressive in using mechanical transport and discarding horse-drawn vehicles. This was possibly a part of the national policy of that country in connection with developing the use of home-produced products. An official statement made by the Reichspost Minister, Herr Hubrig, when addressing the Elektrotechnisch Verein in Berlin in 1937, drew attention to the fact that the German postal authorities at that time had 2,400 electric vehicles in use and experience over a number of years had shown that:

(1) Although the first cost of the electric is higher than that of the petrol, owing to the much longer life of the electric it is the most economical in the long run.

(2) Maintenance and repair costs are much lower with electric vehicles than with petrol.

(3) Tyre renewals for electrics are 30 per cent. less than with petrol vehicles.

(4) Experience with 800 to 1,000 electric vehicles used for parcel-

post deliveries in Berlin showed that petrol vehicles used for the same service cost 40 per cent. more to operate.

Herr Hubrig, in dealing with the question of imported products, calculated that a 2-ton electric postal van employed on parcel deliveries used 2·83 kg. per 100 km. of lead, i.e. renewal of lead for the battery plates amounted to 6·26 lb. per 62 miles. As 80 per cent. of the lead in new battery plates was recovered from old ones, 0·57 kg. of new lead was required for every 100 km. Germany at that time imported about half her requirements of lead, which meant that a 2-ton electric called for the importation of 0·28 kg. for every 100 km. run.

On the other hand, he showed that a 2-ton diesel engine motor-lorry used for parcel deliveries took 18 kg. of oil per 100 km. About 85 per cent. of Germany's oil requirements were then imported, and the relative cost in oil and lead for the diesel lorry and the electric van was one shilling and threepence per 100 km. for diesel against one penny for electric.

The German Post Office first used a battery-electric vehicle in 1909, and by 1914 they had 220 in use. From 1924 onwards the number in use increased rapidly, and in 1935 official figures showed that in Berlin the Post Office operated 1,300 electrics and 395 petrol vans.

In that year, i.e. in 1935, electrics were used in all large centres such

Fig. 133.—Morrison war-time body with no panels

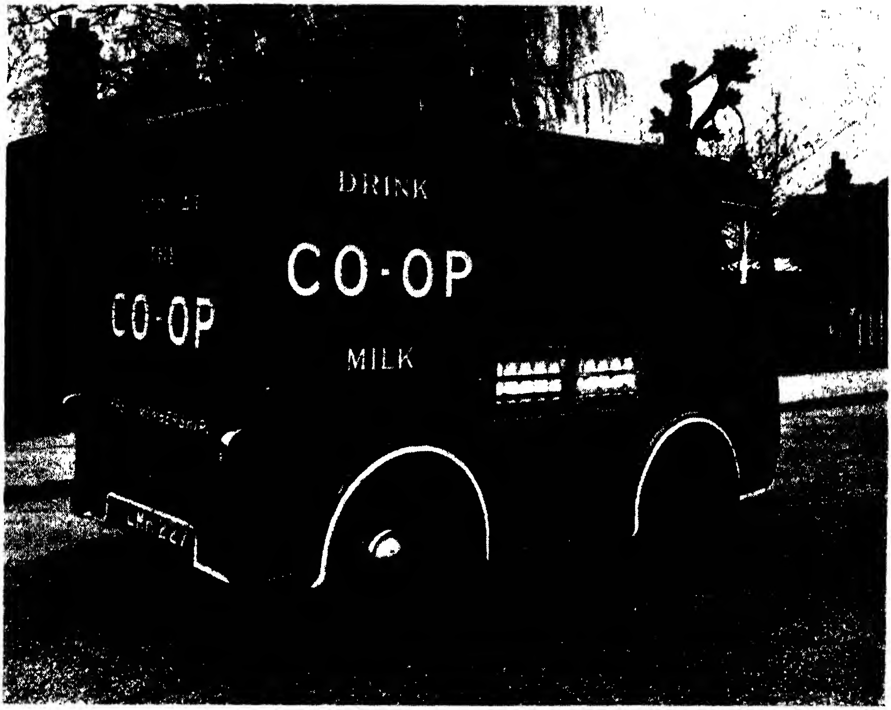


Fig. 134.—MORRISON WAR-TIME BODY WITH CENTRE OPENING AND SHUTTERS AT REAR END

as Berlin, Breslau, Dresden, Dusseldorf, Frankfort, Hamburg, etc., the total fleet amounting to 2,400.

Switzerland provides a further example of the use of electric vehicles for postal services. Zurich, despite the very hilly nature of the area, has a fine electric-vehicle charging depot and garage, where fifty vehicles can be charged at one time. The fleet of vehicles used by the Zurich postal authorities consists partly of four-wheeled two-tonners, and partly of light three-wheelers.

The three-wheel vehicles have given good service over a period of some eighteen years, and travel between 35 and 40 miles on one charge at an average speed of 15 m.p.h. when carrying loads up to 15 cwt. The drive is on the rear axle through a double-reduction gear, the battery having a capacity of 190 ampere-hours and consisting of 15 cells.

Load

The development of the use of electric vehicles affects the future progress of electricity supply to a greater extent than many connected with that industry seem to realise. Before the war there were some

25,000 taxi-cabs in this country. If 10,000 of these were assumed to be limited to short-run service and were changed to electric cabs, it would mean a load of some 60,000,000 units a year, and an off-peak load too. Then consider milk and bread distribution. This is generally acknowledged to be a most suitable field for electric vehicles. A milk roundsman covers from 100 to 400 customers, according to the district. Supposing the average is 250, which means that for England alone 40,000 roundsmen and vehicles are required. If half of the vehicles were electric, the load would be over 100,000,000 units a year. Then add bread delivery and other short-run deliveries for stores and distributive trades, and it can be seen that a figure of between 400,000,000 and 500,000,000 units a year is not an over-optimistic estimate.

According to statistics given in *Garcke's Manual of Electrical Undertakings*, this would be greater than the street-lighting load for all Authorised Undertakings and 37 per cent. of the total traction load. The latter is going down so far as tramways are concerned, but electric vehicles seem to offer a very desirable means of replacing the falling tramway load, and the electric-vehicle charging load need not coincide with the lighting, domestic, or traction peaks ; in fact, it would fill in the at present unavoidable valleys in the load curve (Fig. 55).

GLOSSARY OF TECHNICAL TERMS

Term	*Abbreviation or Symbol*	*Definition*
Ampere	A or I	Unit of flow of electricity. (Compare flow of water through pipe.)
Volt	V or E	Unit of electrical pressure. (Compare head of water in tank.)
Ohm	R	Unit of electrical resistance. (Compare mechanical friction.)
Ohm's Law	—	Ampere, Volt, and Ohm are related as: $V = I \times R$, i.e. 1 volt is the pressure required to give a flow of 1 ampere through a resistance of 1 ohm.
Watt	W	Rate of doing electrical work, and related to volt, ampere, and resistance thus: $W = V \times I = I^2 \times R$.
Kilowatt	Kw	1,000 watts.
Kilowatt-hour	kWh	Unit of electrical energy and basis of charge for use of electricity. One kWh is used when 1 kW has been taken for 1 hour. Equivalent to 1·34 horse-power hours.
Ampere-hour	Ah	One ampere-hour represents a flow of 1 ampere of electricity for 1 hour.
Watt-hour	Wh	One watt-hour represents the flow of 1 ampere of electricity at a pressure of 1 volt for 1 hour; or the work of 1 watt for 1 hour.
Direct Current	D.C.	Current passing continuously in one direction through a circuit (as through a circuit supplied by a battery).
Alternating Current	A.C.	Current that periodically reverses its direction through a circuit (as is usually the case with public supplies).
Transformer	—	Device for reducing or increasing the voltage of an alternating-current supply.
Rectifier	—	Device for giving a D.C. supply from an A.C. source. Rectifiers and transformers combined are frequently used to give direct current at low voltage for battery charging from alternating current at high voltage.
Speed	Ft. per sec.	Distance travelled per unit of time. Alternatively: ft. per min. or miles per hour (60 m.p.h. = 88 ft. per sec.).
Acceleration	Ft. per sec. per sec.	Rate at which speed is increased or decreased (e.g. "the speed was increased by 60 ft. per second per second"). Decreasing speed is sometimes called deceleration.

GLOSSARY OF TECHNICAL TERMS—*continued*

Term	*Abbreviation or Symbol*	*Definition*
Foot-pound . .	Ft.-lb.	Unit of mechanical work. One ft.-lb. is work required to lift a weight of 1 lb. through a height of 1 ft.
Horse-power . .	h.p.	Unit of mechanical power. Equivalent to 550 ft.-lb. per sec., or 33,000 ft.-lb. per minute, or 746 watts or 0·746 kilowatts.
Tractive Effort .	—	Work required, usually in ft.-lb., to pull a certain load. Depends upon weight of load, surface over which load has to be pulled, and other resistances, such as windage and friction of moving parts.
Specific Gravity .	Sp. gr.	The weight of a material compared with the weight of an equal volume of water. The sp. gr. of sulphuric acid (concentrated) is 1·843 ; i.e. sulphuric acid is 1·8 times as heavy as water. The sp. gr. of acid in a battery falls as the battery is discharged and can be used to indicate the state of the battery.
Hydrometer .	—	A weighted float, either dropped into a battery, or contained in a sampling syringe, which indicates by its depth of immersion the specific gravity of the acid.

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Developments of Electric Road Transport	E. W. Ashcroft	1936, p. 2215
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Appendix

STANDARD SPECIFICATION FOR BATTERY-ELECTRIC VEHICLE

ON the outbreak of the present war, it was naturally hoped that there would be very marked development in the use of battery-electric vehicles, as electrical energy was a home-produced source of power. However, it eventually proved that necessary restriction on the use of raw materials, e.g. steel, hampered the expected progress, and at the suggestion of the Ministry of Supply, the Electric Vehicle Association formed a Standardisation Sub-committee for the purpose of preparing a specification for a standard electric vehicle of 1-ton payload capacity, which would have interchangeable parts and could be produced in quantity. Unfortunately, before the deliberations of the sub-committee were completed, the war situation had altered, rubber became even more important than petrol, consequently retail deliveries were restricted by Government action, and the production of a thousand standard vehicles, which was proposed, was retarded.

The design and specification, which is briefly outlined here, is none the less of interest, because it marks a distinct step forward toward the mass production of electric vehicles.

The chassis frame is of simple but strong design with cross-members upon which the body is directly mounted, the front being dropped to afford easy access to the driver's seat.

Transmission is direct from the motor to the back axle through a short, one piece tubular shaft equipped with Layrub patented joints giving a cushioned drive and requiring no lubrication.

The back axle is of the double-reduction type with three-quarter floating shafts of high-tensile steel carried on roller bearings, and a casing formed in one piece of the banjo type. The first reduction is obtained by helical gearing, and the final drive is effected by spiral bevels.

An H-sectioned front axle of high-tensile steel is employed. In this, the pivots are inclined ; they afford a large bearing area and are provided with radial-roller thrust bearings. Taper-roller bearings are used for the wheels, and self-aligning interchangeable ball joints are provided on the track rod and drag link.

Steering is effected by an 18-in. steering wheel with Marles double-roller gear, the design allowing a small turning circle and self-centring steering.

Lockheed-operated Girling brakes are mounted at front and rear, the foot brake working on low pedal- and pipe-line pressure. The hand-brake lever is of the Bendix telescopic pistol-grip type, with a rack and pawl device, and so positioned as not to impede ingress or exit at either side of the cab. This parking brake works through a mechanical rod-operated compensator and acts only on the rear wheels.

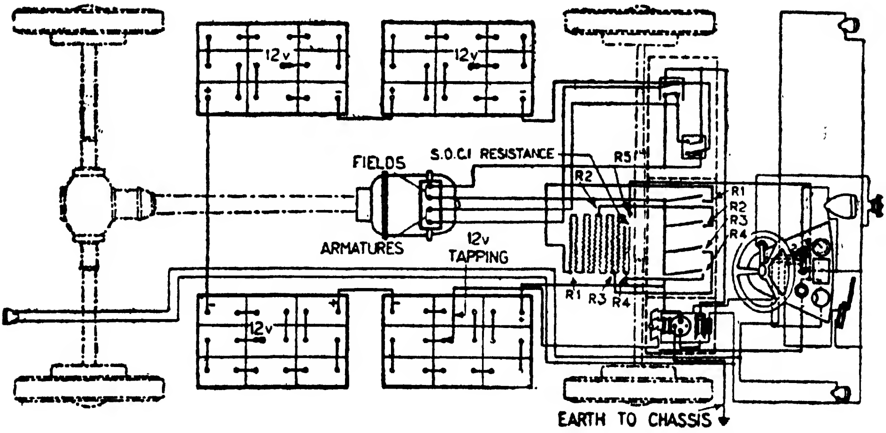


Fig. 1.—OUTLINE DESIGN OF CHASSIS OF STANDARD ONE-TON BATTERY-ELECTRIC DELIVERY VEHICLE SHOWING THE WIRING CONNECTIONS

Detachable steel-disc wheels are employed which carry single 23-in. by 5-in. high-pressure tyres, and a spare wheel is included in the equipment.

On the electrical side, the motor, of G.E.C. manufacture, is rated at 8 h.p. and the specification for it is that laid down by the Ministry of Supply Machine Tool Control (D.I.E.E.). It embodies British Standards Specification 173/1941, as regards both rating and construction.

A Wilson delay-action four-speed controller with foot-operated hydraulic mechanism provides progressive acceleration, and prevents excessive wear or stressing which might otherwise occur through too rapid operation. A B.S.S. 50-amp. charging plug is mounted in the controller assembly, and is arranged with an interlocking, double-pole isolating switch for the 12-volt lighting system and accessories.

The battery consists of thirty-six lead-acid cells grouped in sets of nine and fitted into steel trays, two being mounted in pannier fashion at each side of the main frame members. The trays are of standard dimensions so that they are interchangeable so far as a particular vehicle or other vehicle of similar type is concerned, and will accommodate batteries made by any of the well-known makers.

A suppressed zero moving-coil volt-meter, calibrated on similar lines to those of the conventional motor-vehicle fuel gauge, is mounted on the dash panel. Measurement of the state of voltage of the battery can be obtained, as required, by operating a press switch.

A standard body has also been designed which may be quickly changed to suit the particular class of transport work which has to be undertaken. Interchangeable canvas side screens are provided instead of doors.

An outline diagram (Fig. 1) shows the general arrangement of the chassis, and the wiring connections.

INDEX

CHARGING UNDER CONTROL

At the time of Waterloo, charges were made by courageous cavalrymen on mettlesome horses—modern warfare demands the more prosaic but efficient tank crews.

So, too, obsolete methods of charging batteries have yielded to the control of the tried and trusted METROVICK

TYPE MJV BATTERY CHARGE TIMING RELAY

thousands of which have been supplied over a number of years.

- **ENSURES CORRECT CHARGING**
- **PROMOTES LONGER BATTERY LIFE**
- **ENTIRELY AUTOMATIC IN ACTION**
- **SIMPLIFIES BATTERY MAINTENANCE**
- **PROVED RELIABILITY**

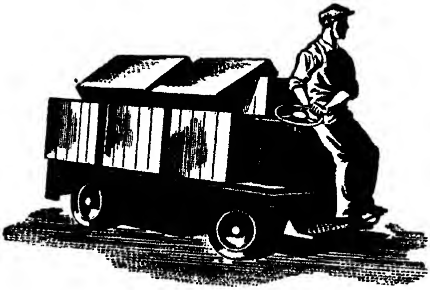
METROPOLITAN Vickers
ELECTRICAL CO., LTD.
TRAFFORD PARK · MANCHESTER 17

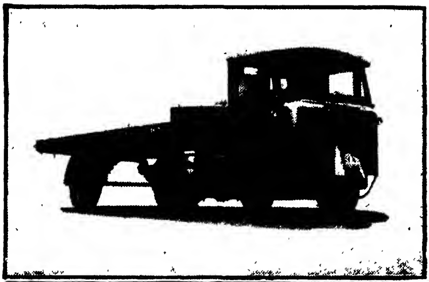
AEI

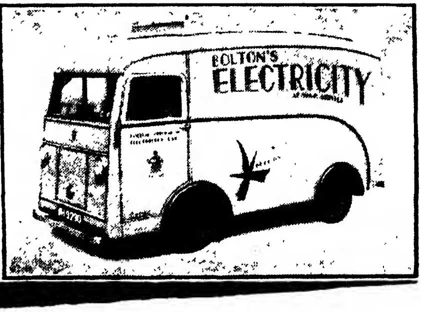
G/H301

COSMOS LAMPS *Metrovick's 'light' product*

For Powering ELECTRIC VEHICLES AND TRUCKS of all types






BOLTON'S
ELECTRICITY

Typical large Hewittic rectifier for mass charging of batteries.

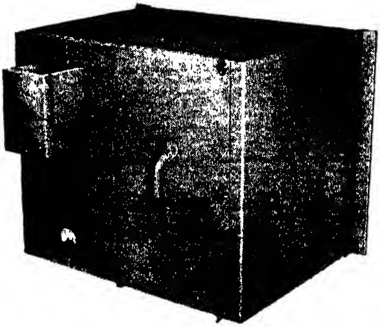
Large or small scale battery charging

Hewittic Rectifiers are made in a range of equipment for large- or small-scale vehicle battery charging, in types designed for the simple, trouble-free charging of batteries for single vehicles or for the mass charging of batteries for a fleet of vehicles, battery locomotives, etc.

Developed through some 35 years of rectifier experience, the Hewittic rectifier is the finest of all charging plant, with these specific advantages :—

- No attention required, negligible maintenance charges, first cost is last cost.
- Efficiency 10–15% higher than that of metal rectifiers, with an equivalent economy in power costs.
- No deterioration in service —efficiency the same in 10 years as when installed.
- Unaffected by heavy overloads or polarity reversal.
- Less affected by dust and damp.
- Selected by leading vehicle battery makers for the correct forming of their battery plates.

SIMPLICITY. The system of charging is reduced to absolute simplicity in the Hewittic mercury arc rectifier. Merely plug in the battery and close the main switch. The battery then charges automatically and is automatically cut off when fully charged. A slow equalising charge can be given periodically by altering a switch position.

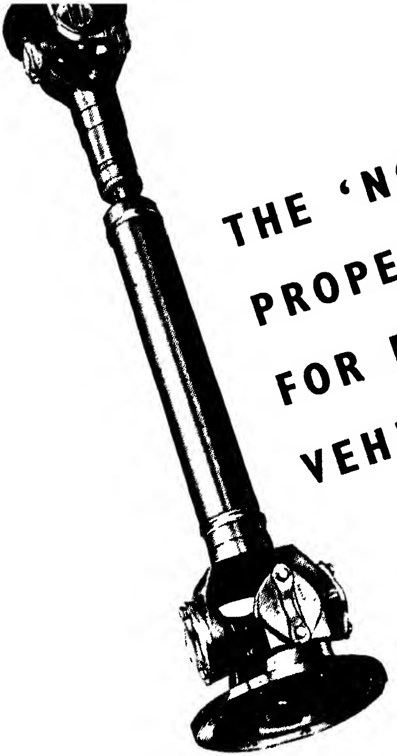


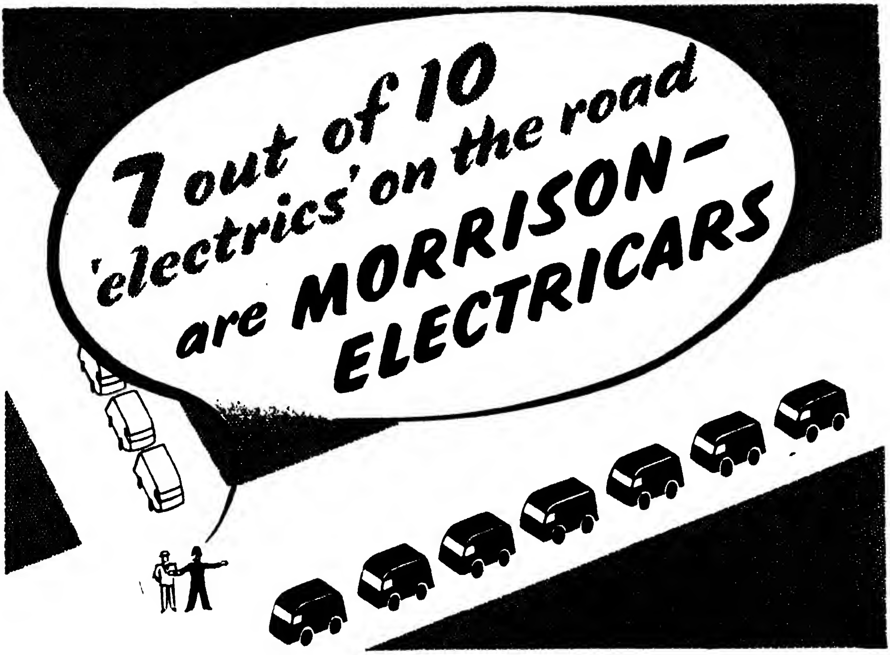
The Hewittic wall-mounting battery charger.

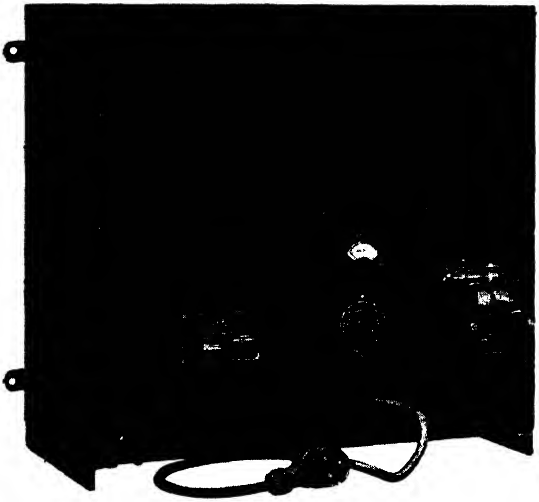
Hewittic Rectifiers

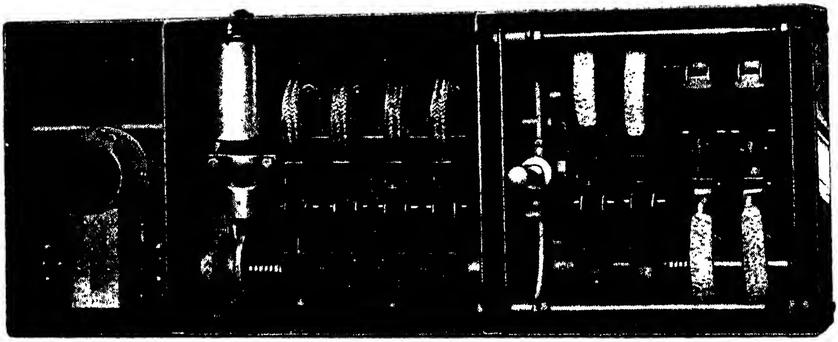
HEWITTIC ELECTRIC CO., LTD., Walton-on-Thames, Surrey

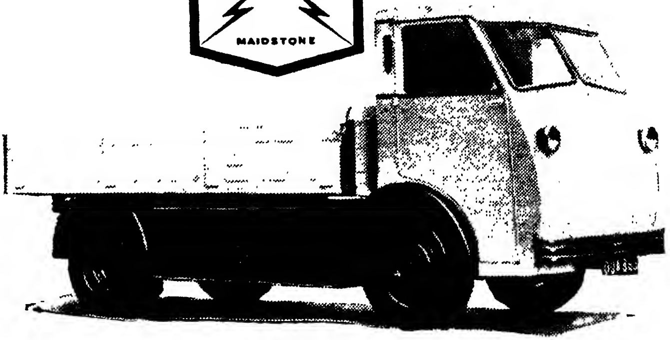
Telephone : Walton-on-Thames 760 (8 lines). **Telegrams : Hewittic, Walton-on-Thames**



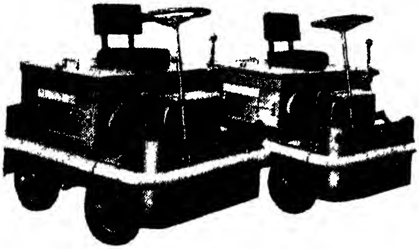

7 out of 10
'electrics' on the road
are MORRISON-
ELECTRICARS







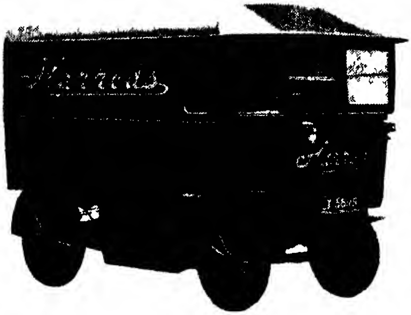
EDISON
BATTERIES
FOR ELECTRIC VEHICLES & TRUCKS



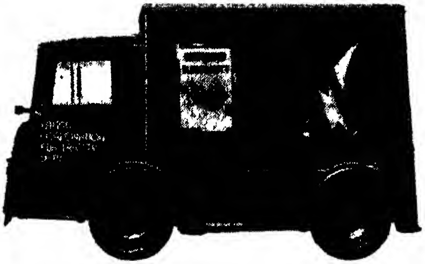
G.W.R. Tractors powered by Edison Batteries Supplied by Greenwood & Batley, Ltd , Leeds

All Steel • No Lead • Long Life • No Acid • Lightweight •

The Edison Battery is ruggedly built to withstand the heavy demands of traction usage. Its tubular positive plate construction gives it the strongest positive plate ever used in a storage battery. Yet for all its strength, the Edison all-steel battery is light in weight. In addition, it does *not* deteriorate, neither does it give off corrosive acid fumes, nor come to harm if stored for long periods.



HARRODS' FLEET OF ELECTRIC VEHICLES equipped with Edison Storage Batteries has now covered 10,000,000 miles



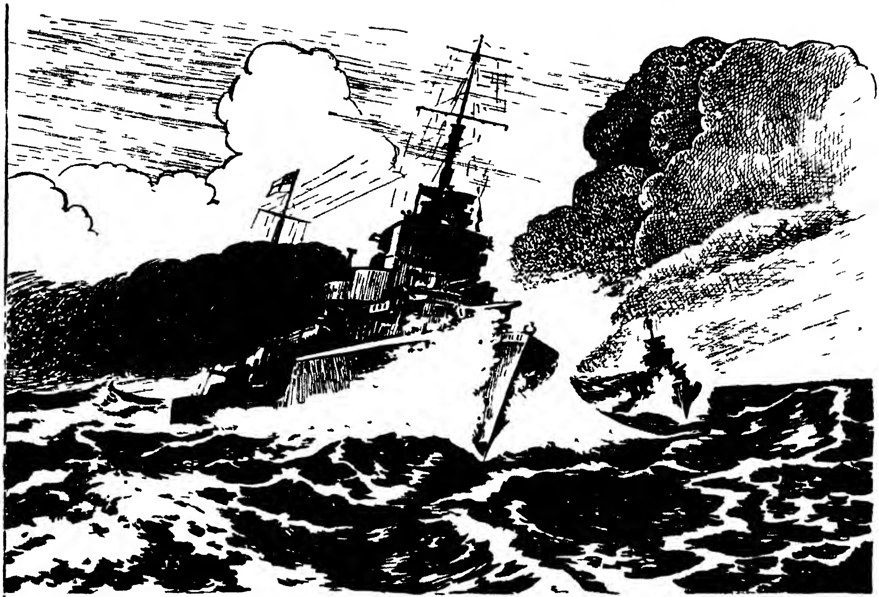
This 15/20-cwt. vehicle fitted with an Edison Battery of 60 type A-5 cells was supplied to the Ealing Corporation Electricity Department by Messrs. Metropolitan-Vickers Electrical Co. Ltd.

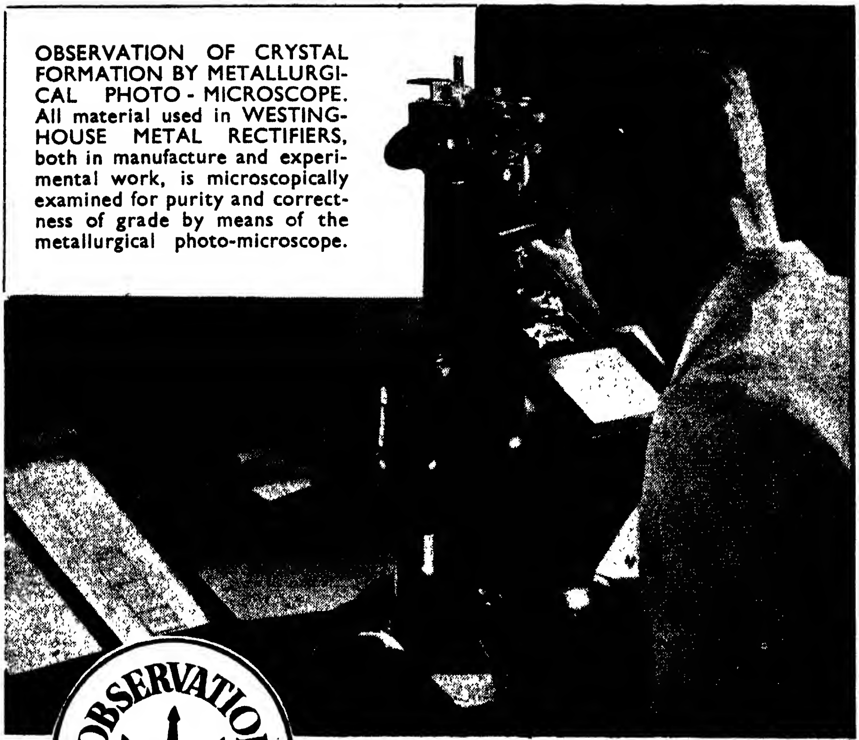
EDISON STORAGE BATTERIES ARE GUARANTEED FOR TEN YEARS

LOOK FOR THE NAME EDISON ON THE FILLER CAP OF EVERY CELL

THOMAS A. EDISON LTD. (Edison Storage Battery Division)

Victoria House, Southampton Row, London, W.C.1 *'Phone : Holborn 6673/4 'Grams : Acredison, Westcent, London*





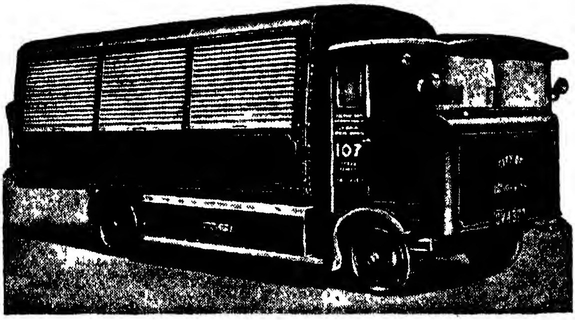
OBSERVATION OF CRYSTAL FORMATION BY METALLURGICAL PHOTO-MICROSCOPE. All material used in WESTINGHOUSE METAL RECTIFIERS, both in manufacture and experimental work, is microscopically examined for purity and correctness of grade by means of the metallurgical photo-microscope.

OBSERVATION

In spite of greatly increased production we are unable to supply Westinghouse Rectifiers as freely as we would wish. We hope customers will understand and accept our assurance that the constant research now going on in our laboratories and designing departments is resulting in Rectifiers of remarkably advanced design which will be available after the war.

Westinghouse Rectifiers

WESTINGHOUSE BRAKE & SIGNAL CO. LTD., Pew Hill House, Chippenham, Wilts.



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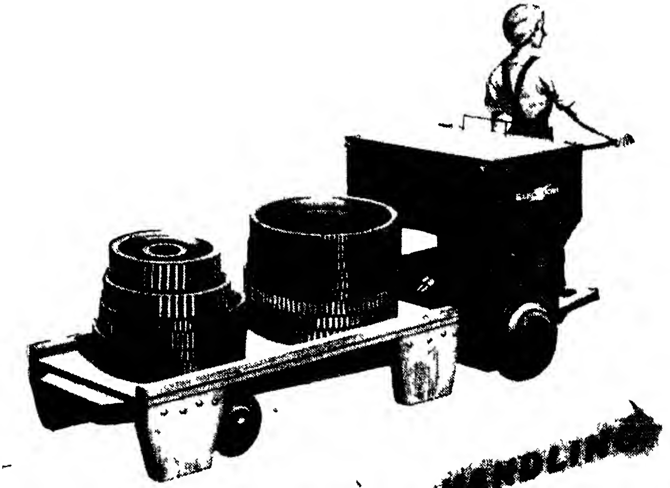


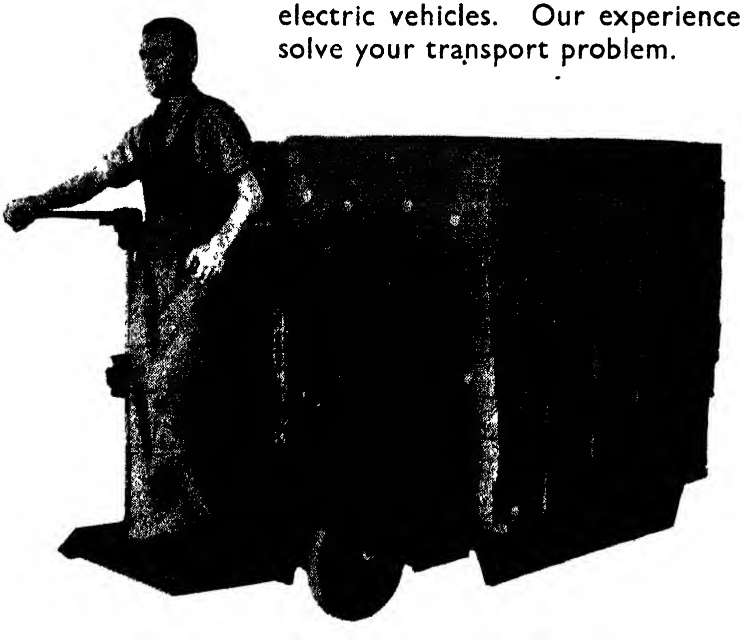

Why Sir–
you'll cut costs
considerably
if you fit...

READY for any JOB!

Greenbat experience in the manufacture of these trucks has brought them to a very high standard of efficiency; they are used by many well-known firms in every branch of industry.

Greenbat electric trucks are swift, smooth running, silent, free from fumes and fire risk—there is no fuel problem either.

For the past twenty-five years 'Greenbats' have been the aristocrats of electric vehicles. Our experience can solve your transport problem.



GREENBAT ELECTRIC TRUCKS

GREENWOOD & BATLEY LTD.
ALBION WORKS LEEDS

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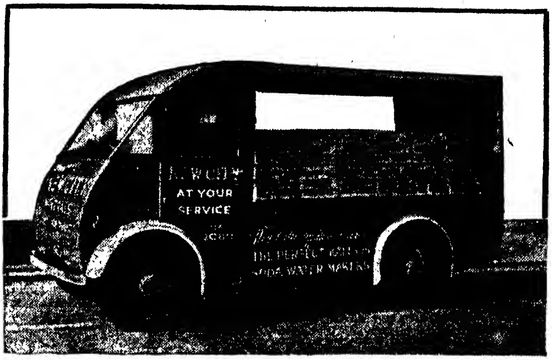
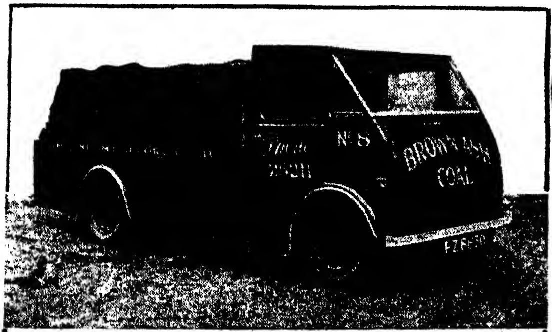
A Tudor-powered delivery van of the New City Syphon Service, built by Midland Vehicles, Ltd.



The growing use of 'ELECTRICS'

Recent years have seen more and more trades using 'Electrics,' and each trade using more and more vehicles of this type. For town work they have many advantages, and when powered by Tudor Accumulators, maximum economy and the greatest reliability are assured.

Tudor Accumulators are used extensively for electric transport by Corporations and other large progressive bodies because, after making strict tests and cost comparisons, they too have found Tudor Accumulators are the most economical.



Electric lorry built by Midland Vehicles, Ltd., powered by Tudor Accumulators, and operated by the Antrim Iron Ore Co., Ltd.

WT 32/43

TUDOR

ACCUMULATORS

★

THE TUDOR ACCUMULATOR
COMPANY LTD.
50 GROSVENOR GARDENS,
LONDON, S.W.1
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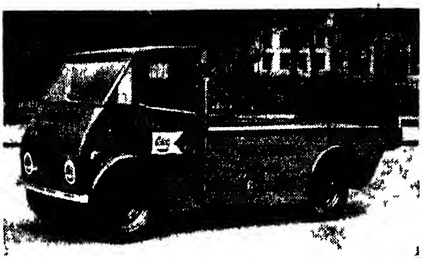
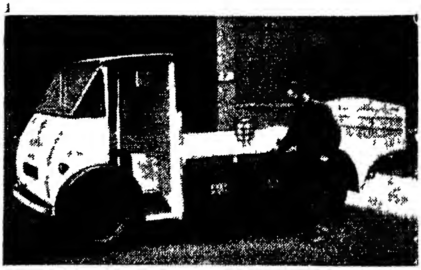


The 'Midland Electric' illustrated on the left is used by the
LANCASHIRE ASSOCIATED COLLIERIES
for delivering coal in cwt. bags. Operated by one man. The illustration below is one of a large fleet supplied to
MIDLAND COUNTIES DAIRY, LTD.

Patented roller carriers enable the batteries to be withdrawn for weekly inspection, cleaning and topping up. Charging is carried out every night—without withdrawing batteries—simply by plugging in and switching on at the charger.



'ELECTRICS'
WITH
HIGHER STANDARD PERFORMANCE

The modern design of 'Midland Electrics' has not been concerned with good appearance only. It has raised the standard of the all-round efficiency of the electric transport vehicle. Less body weight gives a greater power-to-weight ratio, and the absence of front 'overhang' has made really powerful braking possible. Cushioned drive is a refinement which saves the transmission from shocks and stresses, and enhances the smoothness of running.

A further important feature of 'Midlands' is the accessibility of all vital parts, and the ease with which batteries can be withdrawn for inspection. Because of these and other advantages—all contributing to speed, simplified maintenance and economical operation, users of large fleets of 'electrics' favour 'Midlands.

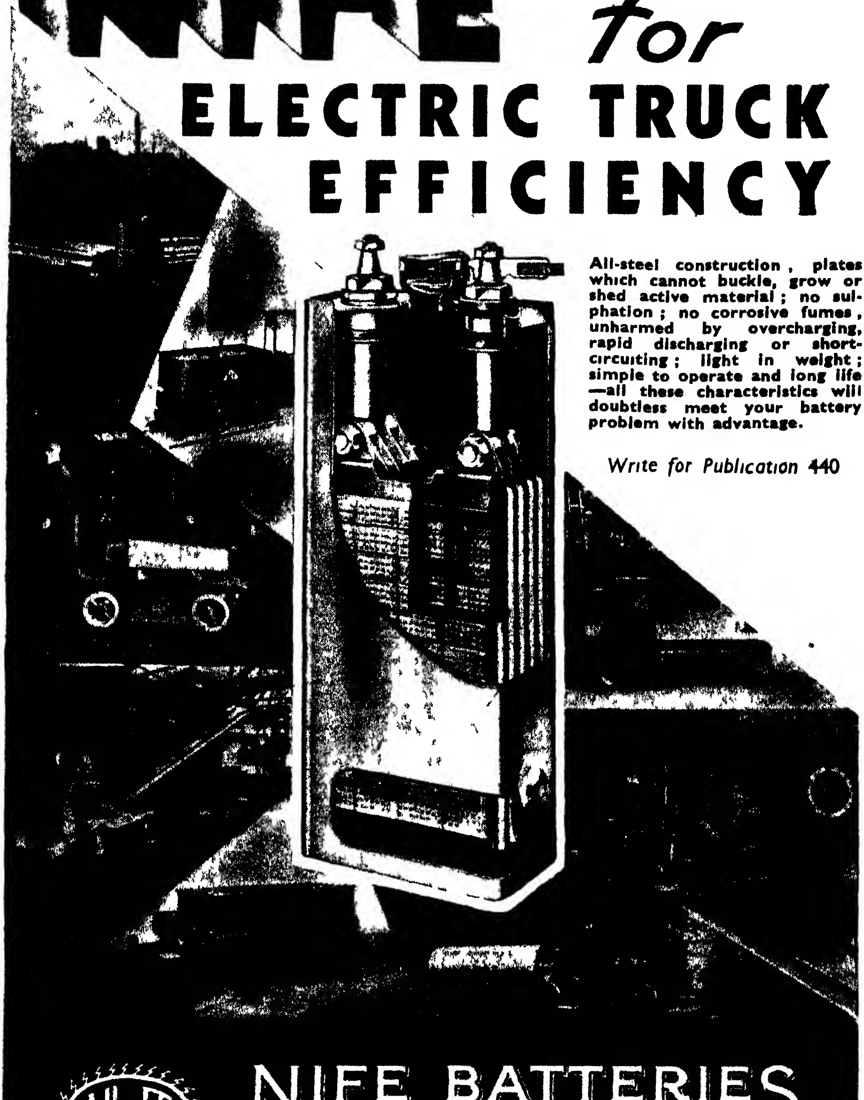
Full details of 'Midland Electrics', for 10 to 35 cwt. pay loads, will be sent on request.

MIDLAND
Electric
VEHICLES

Midland Vehicles Ltd., Upper Grove Street, Leamington Spa
Telephone: 2587 Telegrams: 'Motive' Leamington Spa

M.E.27/43

NIFE *for* ELECTRIC TRUCK EFFICIENCY



All-steel construction, plates which cannot buckle, grow or shed active material; no sulphation; no corrosive fumes, unharmed by overcharging, rapid discharging or short-circuiting; light in weight; simple to operate and long life—all these characteristics will doubtless meet your battery problem with advantage.

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