(*Paper No. 2266.*)

"Electrical Tramways: the Bessbrook and Newry Tramway."

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ALTHOUGH the subject of the application of electricity to locomotion has been much discussed during the last few years, comparatively few attempts have been made at its practical realization. The first electrical tramway in the United Kingdom, constructed between Portrush and Bushmills, in the north of Ireland, was opened for traffic in October, 1883, and has since been extended. In his lecture before the Institution[1] in March, 1883, the late Sir William Siemens gave a general description of this line, and the electrical details were further discussed in a Paper read before the Society of Arts in April, 1883, by the Author.[2] In 1883 Mr. Magnus Volk constructed a line along the foreshore at Brighton, upon which a single car has since been running regularly, and Messrs. Siemens Brothers have a short length of line in operation on the pier at Ryde. On a larger scale is the tramway along the promenade at Blackpool, 2 miles in length, constructed by Mr. Holroyd Smith. The construction and method of working have been fully described by Mr. Smith, in a Paper read before the British Association at the Birmingham meeting, 1886.[3] The conductor, as in the before-mentioned lines, is continuous, and several cars are in motion on the track at the same time. The cars are of various sizes, and accommodate from thirty to fifty-six persons. The track is nearly level, and a speed of 6 miles per hour is generally attained. Mr. Reckenzaun and Mr. Elieson have also done much in the application of storage batteries to tramway work.

In none of these instances has any attempt been made at the regular haulage of minerals and goods, nor at the operation of cars larger than the ordinary tramway type. Probably in no case has the effective power of any single motor exceeded about 4 HP. In July, 1884, Mr. Barcroft, of the Bessbrook Spinning Company, whose extensive flax-mills and stone-quarries are situated at Bessbrook, about 3 miles from Newry on Carlingford

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[1] The Inst. C.E. Lectures on "The Practical Applications of Electricity." Session 1882–83. "The Electrical Transmission and Storage of Power." By Dr. C. William Siemens.

[2] Journal of the Society of Arts, vol. xxxi. p. 531.

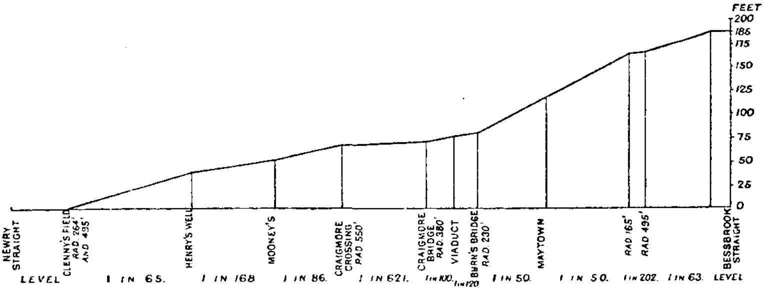
[3] See *The Electrician*, September 10, 1886.

Lough, suggested to the Author that the line, which the company had decided to make between Newry and Bessbrook for the carriage of coal and flax from the wharves to the mills and the down traffic of manufactured goods, might be worked electrically, for which the abundant water-power available offered exceptional advantages. The following conditions were to be met. Ten trains to be run in each direction per day, providing for a daily traffic each way of 100 tons of minerals and goods, and capable of dealing with 200 tons in any single day, in addition to the passenger traffic: the electrical locomotive to be capable of drawing a gross load of 18 tons on the up-journey, in addition to the tare of the car itself and its full complement of passengers, at an average speed of 6 miles per hour, and a load of 12 tons at an average speed of 9 miles per hour. The company agreed to place the line entirely at the disposal of the Author for a period of time, and to purchase the electrical plant at a fixed sum, when the above conditions had been complied with, and it had been shown that the cost of working, as evidenced by six months' trial, did not exceed the cost of steam traction on a similar line. The work was commenced in November, 1884, and the line opened for traffic in October, 1885, and was formally taken over by the company as having fulfilled the conditions of the contract in the following April. Since that time it has been in regular daily operation.

General Description of the Line.

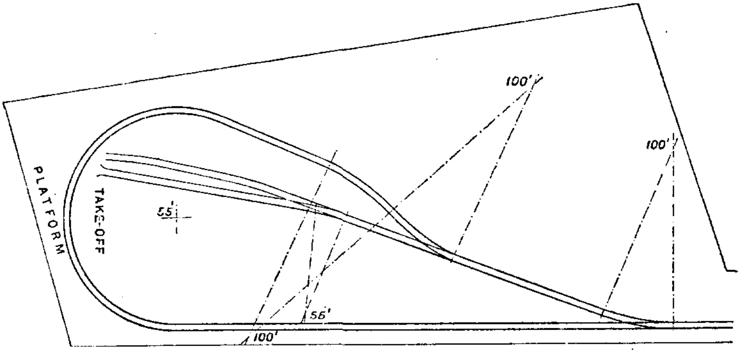
The line commences at the Edward Street Terminus of the Newry branch of the Great Northern Railway, and runs parallel to it for about $\frac{3}{4}$ mile, and then passing through a cutting follows the course of the Camlough stream, running under the central arch of the viaduct on the main Great Northern line, which crosses the valley at a height in the centre of 126 feet. Near the viaduct is the first station, close to the small village of Craigmore and an outlying mill of the Bessbrook Company. Proceeding up the valley with a gradient of 1 in 50, the county road is crossed diagonally by a level-crossing 50 yards in length, near which is the second station, Millvale, at which point the line crosses the stream and the turbine and generating dynamos are erected; the line again crosses the stream $\frac{3}{4}$ mile from Millvale, and thence runs into the terminus at Bessbrook, where a station and carriage shed are erected. The total length of the line is 3 miles 2·4 chains, and the average gradient 1 in 86, the maximum gradient being 1 in 50 (Fig. 1). The gauge is 3 feet, and the rails are at

Fig. 1.



Vertical scale 1 inch = 200 feet.
Horizontal „ 1 „ = 4,000 „

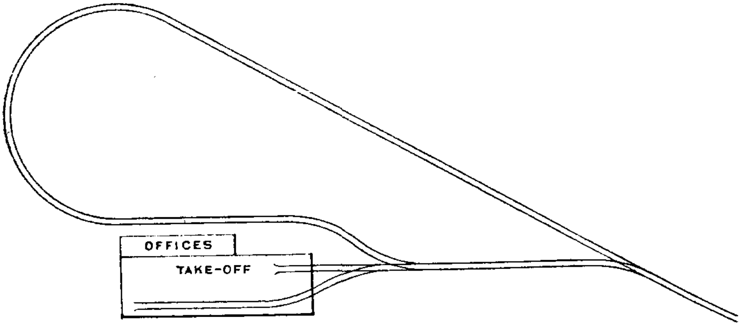
Fig. 2.



Plan of Arrangement of Lines at Newry.

Scale 1 inch = 100 feet.

Fig. 3.



Plan of Arrangement of Lines at Bessbrook.

Scale 1 inch = 100 feet.

present single, but land has been acquired for a double line. At each terminus is a loop of 55-feet radius (Figs. 2 and 3), so that the cars do not need reversing, except in coupling up the wagons or shunting in the sidings. The permanent way has been laid out and constructed under the supervision of Mr. J. L. D. Meares.

Locomotive Equipment.

The locomotive equipment of the line consists of two passenger cars, 33 feet and 21 feet 8 inches long respectively, each provided with a motor. The body of the car is carried on two four-wheeled bogies with a wheel-base 4 feet 6 inches, the motor being carried on the front bogie independent of the body of the car (Fig. 4). This arrangement enables the cars to traverse the 55-feet curves at the termini with great facility, and also relieves the body of the car from the vibration due to the driving. The body of the longer car is divided into three compartments, the front one covers the motor, the second forms a second-class compartment seating twenty-four passengers, and the third a first-class compartment seating ten passengers, separated from the second by a cross-passage. The front bogie carrying the motor has an extended platform, projecting 3 feet 7 inches beyond the body of the car, and communicating by a slide-door with the dynamo-compartment, thus giving the driver direct access to all parts of the driving machinery, which are at the same time entirely boxed off from the passenger compartments. All four wheels are braked by a powerful screw-brake worked from the front of the driving-platform, on which is also fixed the switch-board controlling the motor. The wheels of the back bogie are braked by a chain-brake worked from the cross-passage and are under the control of the conductor. This brake is also prepared for coupling to the wagons. The total weight of the car is 8¼ tons, distributed as follows:—

	Tons.	cwt.	qrs.
Car-body	3	6	1
Leading bogie	1	17	2
Trailing „	1	0	0
Dynamo, bed-plate, armature, and accessories .	2	1	1
	8	5	0

The shorter locomotive-car is similar, but without the first-class compartment. Both cars were built by the Ashbury Carriage Company, of Manchester. There is also a third passenger-car of the same length as the first, and accommodating forty-four pas-

FIG. 4.

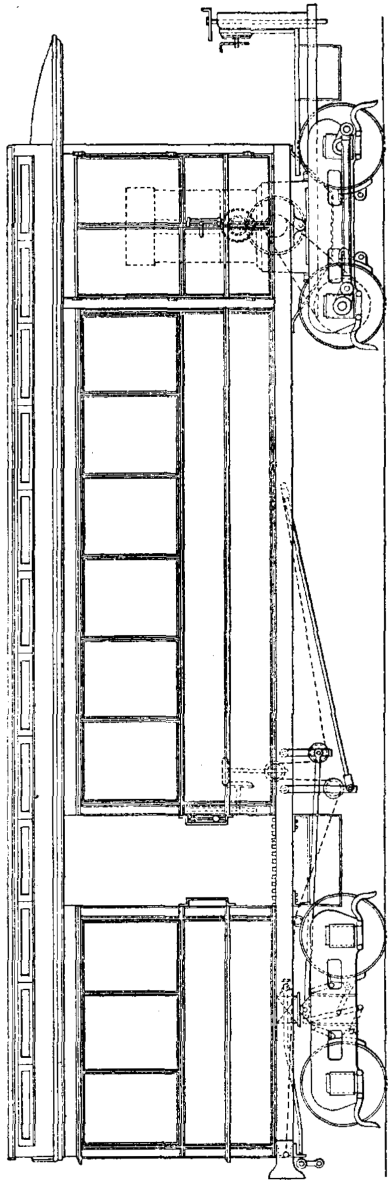
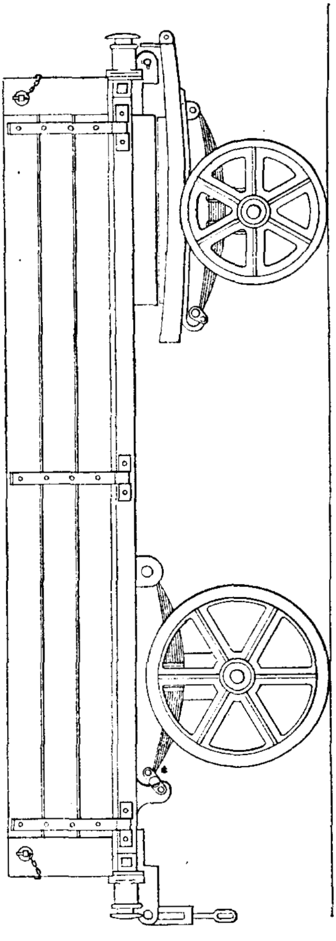


FIG. 5.

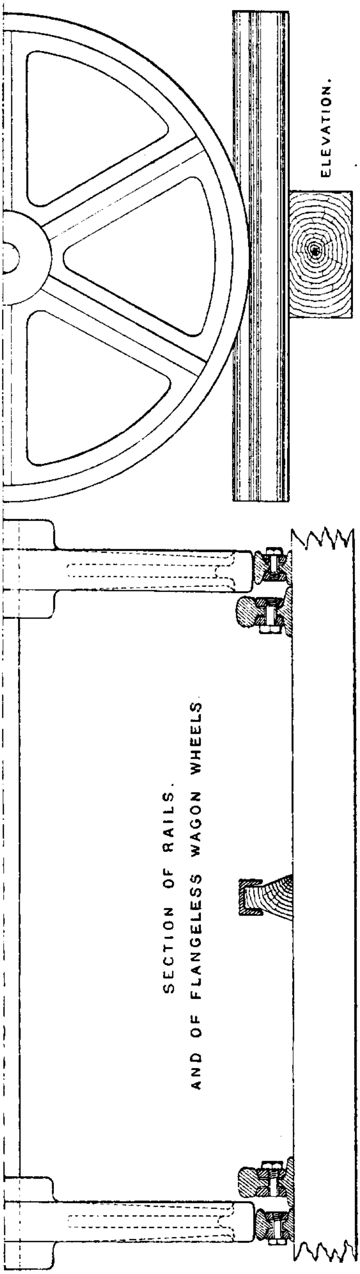


sengers, and similarly carried on two four-wheeled bogies. This car weighs 5½ tons, and was constructed by the Starbuck Company, of Birkenhead.

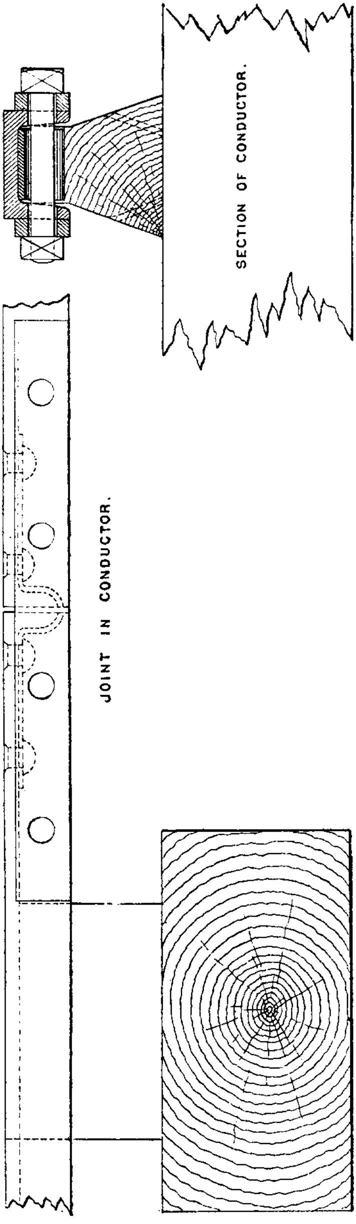
THE USE OF WAGONS WITH FLANGELESS WHEELS.

Apart from the electrical working of the line, an important and novel feature is the plan by which the wagons used on the line can also be used on the ordinary public roads, so avoiding the necessity of transhipment, and enabling goods to be loaded at the wharves, and drawn to the line by horse-power, and again delivered at any part of the mill premises. The plan was originally suggested in 1880, by Mr. Alfred Holt, M. Inst. C.E., of Liverpool, and was embodied in the Lancashire Plateways Scheme, for which a Bill was lodged in the autumn of 1882, and subsequently withdrawn. The idea has been worked out in a practical form with great success by Mr. Henry Barcroft, of Newry, one of the directors of the company. The wheels of the wagons are constructed without flanges, with tires 2¾ inches wide, which is sufficient for use on ordinary roads (Fig. 5). Outside the tramway rails, which are of steel, and 41·25 lbs. per yard section, second rails are laid, having a section of 23·75 lbs. per yard, with the head ⅞ inch below the head of the larger rails. The flangeless wheels run upon these lower rails, the ordinary rails forming the inside guard (Figs. 6). The wheels are loose on the axles; but the latter are not fixed, but are carried in journals, so that there is freedom in both wheel and axle, which considerably reduces the friction, especially in travelling round curves. The front part of the wagon is supported on a fore-carriage, which can either be pinned or allowed freedom of motion, as in an ordinary road vehicle (Fig. 4). The buffers are fixed on the truck-frame, and no buffing is done against the fore-carriage. There is a single central coupling arranged to engage in a jaw in the fore-carriage, so as to guide it when not pinned. Shafts are attached to the fore-carriage when the wagon is to be used on the ordinary roads. The weight of each wagon without the shafts is 23¼ cwt., and the wagons are of sufficient strength to carry a load of 2 tons. This load is not too much for a single horse on roadways where there are no steep gradients; on steep gradients two horses are required. The double line of rails is not continued round the curves at the termini, but a take-off is arranged (Figs. 2 and 3) into which the wagons are run by the car. The shafts are then affixed, and the wagons drawn off by horses. Twenty-two of these wagons have been supplied

Figs. 6.


ELEVATION.
SECTION OF RAILS.
AND OF FLANGELESS WAGON WHEELS.

Figs. 7.


SECTION OF CONDUCTOR.
JOINT IN CONDUCTOR.

to the Tramway Company by the Ashbury Carriage Company, and have been in constant use for eighteen months. Experience has shown that the wear and tear, both on the wheels and rails, is not excessive, and that the traction does not much exceed, if at all, that of ordinary trucks with flanged wheels. No difficulty has been found with the horse traction on ordinary roads, and the taking on and off is conducted with great rapidity. The utility and wide applicability of this plan are obvious, and it may do much to develop the introduction of short tramways where the cost of transhipment would be fatal to the ordinary methods of working.

Hydraulic Automatic Gate-Opener.

Another novel device introduced by Mr. Barcroft is an automatic hydraulic apparatus for opening the gates protecting the level crossing of the county road. The regulations of the Board of Trade require that gates should be provided at such crossings, and that they should be closed immediately after the passage of the train. To avoid the cost of a gateman, the following plan has been adopted. As the locomotive car approaches the crossing at a distance of about 50 yards, a suitable arm attached to the foot-board strikes a lever pivoted on one side of the permanent way, and turns it over. The lever is connected with a three-way cock, which, when opened, withdraws the water from a cylinder provided with a float. To this float a wire rope is attached, which opens the gates on both sides of the crossing as the float sinks in the cylinder. After passing the crossing, the car strikes a second lever similarly situated and connected by a second wire rope to the three-way cock. When the lever is thrown over, the cock is turned so as to admit water from a cistern placed at a higher level into the cylinder, raising the float and closing the gates, the float being assisted by a balance-weight attached to each gate.

Generator Station.

The generating machinery is fixed at Millvale, a distance of 68 chains from the Bessbrook terminus. At this point, in close proximity to the line, there is an available fall of 28 feet in the Camlough stream, down which there is a guaranteed minimum flow of 3,000,000 gallons per day. The turbine is an inward-flow vortex wheel with double buckets, working on a horizontal shaft extended into the dynamo shed, from which the dynamos are driven direct with belts. The capacity of the wheel is 1,504 cubic feet per minute, and when running at 290 revolutions per minute should develop a maximum power of 62 HP. It is worked with a tail draught of 13 feet. The admission of water is controlled by a shutter-valve regulating the flow uniformly through each bucket of the wheel, and actuated either by hand or by a centrifugal governor. The latter is not direct acting, but as its balls rise or fall beyond certain limits, couples one of a pair of right- and left-hand bevel-wheels driven by a wheel on the governor-spindle to a small countershaft, geared with the valve-spindle.

There are two generating dynamos of the Edison-Hopkinson type, manufactured by Messrs. Mather and Platt, of Manchester. Each is shunt-wound, and intended for a normal output of 250 volts, 72 amperes, at a speed of 1,000 revolutions per minute; but they are never used coupled, as one dynamo is found to be sufficient for the working of the line. Although the average current for a day's work does not exceed 72 amperes, the current required for starting a heavy train on a steep gradient may be three times this amount. It is essential, therefore, that a dynamo intended for such purposes should not only be mechanically strong enough to develop an output far exceeding its normal output, but also that its design should be such that the variation in the lead of the brushes with the current should be as small as possible, and that the fall in electromotive force as the current increases should not be excessive. The latter condition can be met by compound winding, but on the other hand the ease with which shunt machines can be coupled parallel is in favour of their use. It is also of considerable importance to keep the self-induction of the main circuit as a whole as low as possible, otherwise the sudden variations in current at stopping or starting of the train is a severe strain on the insulation both of the generator and motor dynamos and on the conductor cables. If the generator dynamo were series-wound, or partially so, the self-induction of the circuit would be considerably greater than with a simple shunt-wound generator. Both by reason of the small variation in lead and electromotive force, and also the mechanical strength of the drum form of armature, the dynamos employed are particularly well suited for the purpose, and have given most satisfactory results. The resistance of the field-magnets is 74 ohms, and of the armature 0·12 ohm; consequently the electrical efficiency, when working with the normal current, is 92·2 per cent., and the commercial efficiency 90·4 per cent.

CONDUCTOR.

The conductor (Figs. 7, p. 199) is of channel-steel, laid midway between the rails, and carried on wooden insulators nailed to alternate sleepers. The channel form presents several obvious advantages. It can be obtained readily in a variety of stock sections without being specially rolled for the purpose. It does not require to be secured, but can be simply laid on the insulators which fit into the channel, and while allowing longitudinal motion to compensate for changes of temperature, hold it laterally. It is also a most convenient section for making the joints between consecutive lengths. The joint must be sufficiently strong mechanically and at the same time offer no electrical resistance. Double fish-plates placed externally on either side the webs are sufficient for the first object, but the rust between the surfaces in contact often causes almost complete insulation. The electrical connection is therefore made independently by a strip of soft copper of such section that its conductivity is about the same as the steel. It is bent in a U form to allow for the expansion and contraction of the channel. These strips are riveted in the channel with double copper rivets, care having been taken that the hole in the channel was perfectly free from rust before the riveting. At the several crossings of occupation roads, twelve in number, the electrical continuity of the conductor is broken by insulating a section of the channel, and the current is conveyed by a cable laid beneath the sleepers. The top of the channel being level with the rails, the intervening space can be paved or planked, thus making a good roadway without interfering with the mechanical continuity of the conductor. As none of these crossings exceed in width the length of the locomotive cars, the leading collector makes contact on one side the crossing before the back collector breaks on the other. The cables are of stranded copper wire, consisting of thirty-seven No. 14 B. W. G.—1st, cotton lapped and varnished; 2nd, heavily covered with pure rubber; 3rd and 4th, double served with best rubber separator; 5th, covered with pure rubber; 6th and 7th, taped with double-served proof tape, the cable then vulcanized and made water-tight; 8th, lapped with thick serving of tarred hemp; 9th, braided overall and heavily compounded.

In constructing a conductor of iron or steel, it is of the utmost importance to specify the composition. Steel may be obtained with a specific resistance, varying from 0·00001 ohm to 0·00007 ohm, according to the amount of carbon, silicon, and particularly manganese.[1] The steel used was manufactured by the Darlington Steel and Iron Company, and specified not to exceed in carbon 0·15 per cent.; silicon, 0·05 per cent.; manganese, 1·00 per cent. The actual composition according to the makers' analysis is: carbon, 0·09 per cent.; silicon, 0·02 per cent.; manganese, 0·63 per cent.; and the specific resistance 0·0000121 ohm. The weight per foot of the conductor is 4·33 lbs. (6·46 kilograms per metre), and the section 1·367 square inch (8·817 square centimetres). The cost, delivered at the wharf at Newry, was £7 10*s.* per ton. High conductivity copper could not at that time be bought under £84 per ton, with a specific resistance of 0·0000016 ohm, showing a gain in favour of steel over copper, having regard to weight and conductivity, in the ratio of 3 to 2.

At one point the line crosses a country road obliquely, the crossing being 150 feet in length. The method before described of bridging the gap was here not feasible, and it was necessary to resort to some other device. A copper wire was slung centrally between the rails from cross-bars carried on posts, placed on each side the rails at either end of the crossing, the lowest part of the catenary being 15 feet above the road-level, to meet the requirements of the Board of Trade. An overhead collector, formed of bar-iron, fixed above the roof of the car, passes under the cross-bar, and immediately makes contact with the wire before the back collector leaves the ground conductor, and continues to make a rubbing contact until the leading collector has again made contact with the ground conductor on the other side the crossing. This method of carrying the conductor and making contact with it was devised in 1885 by the Author's brother, Dr. John Hopkinson, and has proved in every way a most complete success. The collector on the roof of the car, though merely a bar of flat-iron 1 inch wide greased with tallow once a week, makes a perfect contact with the copper wire sufficiently good for transmitting 120 amperes. After an experience of two years there is no perceptible wear on the wire except at the point where it is picked up by the collector, and even here it is very small. An overhead conductor has many advantages over one placed on the ground level or beneath. There is no interference with crossings; it is less subject to malicious or accidental injury; and particularly, perfect insulation and isolation can be secured, enabling currents

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[1] "Magnetization of Iron." By John Hopkinson, Phil. Trans. 1885, vol. 176, p. 463.

of much higher potential to be used with safety. There is no doubt that some animals cannot stand a shock of 300 volts, and it is probable that the Board of Trade would not sanction the use of any higher potential, if there was a possibility of the conductor being accidentally touched. With an overhead conductor there is no such risk, and much higher potentials would be permissible, giving greater economy in the transmission of the power. On the other hand, the difficulty of making contact with an overhead conductor has hitherto opposed almost insuperable difficulties, now obviated by this simple device. In the crossing above referred to, two catenaries are used with the points of support at different levels, in order to reduce the tension of the wire and the pull on the posts, which in this instance is not balanced by a like pull on the opposite side, as would be the case were the conductor constructed throughout on this principle. The wires are of hard drawn copper, No. 4 B. W. G., and the actual tension is 120 lbs. The inclination of the catenaries to the horizontal is $\tan^{-1}\frac{3}{35}$, and the collector clears the underside of the cross-bar by 5½ inches, and therefore picks up the conductor at a distance of 64 inches from the posts.

The insulators upon which the channel-steel is supported are blocks of poplar wood, 5 inches long. These are carefully dried, and then impregnated with boiling paraffin. A block of dried poplar will absorb as much as 75 per cent. of its own weight of paraffin, which permeates through the whole mass. These blocks have proved efficient insulators, and are apparently standing well. The actual measured insulation of the conductor, under unfavourable circumstances as regards weather and when charged to a potential of 250 volts, is about 900 to 1,000 ohms per mile, approximately the same as the Author obtained at Portrush.[1] Such an insulation is sufficient for practical purposes. It represents a loss through leakage of ¼ ampere or one-tenth of a horse-power per mile. The actual measured leakage current of the whole line in wet weather amounts to nearly four times the above amount, the excess being probably due to some slight fault in the cables and arrangements at the points and crossings.

The circuit is completed by the rails of the permanent-way, which are uninsulated. As is the case with the conductor, the fishplate connections are not sufficient, and are supplemented

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[1] Mr. Holroyd Smith, with an underground conductor, found the leakage current to vary from 30 to 100 amperes, with an electromotive force of 220 volts, showing an insulation resistance of 4·4 to 13·2 ohms per mile.

by flexible copper strips riveted to the under surface of the rails. The specific resistance of the steel rails (Barrow Hematite) is 0·0000166 ohm, and hence the total resistance of the four rails, having an aggregate area of 12·4 square inches, is 0·033 ohm per mile. The resistance of the conductor is 0·221, making the resistance of the circuit 0·254 ohm per mile. Allowing for the earth and for some contact resistance, probably 0·25 ohm per mile fairly represents the average resistance (0·156 ohm per kilometre). The electrical connection of the rails of the permanent-way is essential, since the earth connection is of little value, as the rails are practically insulated by the sleepers and dry ballast. A curious confirmation of this occurred during a severe thunderstorm. At the first flash a man employed at the Newry end of the line, who was touching the rails but not the conductor and standing on wet ground, received a smart shock, and simultaneously with the lightning flash the attendant observed a blaze of light from the earth-brush of the generating dynamo. At the second flash a similar discharge was observed at the brushes, and at the third flash, more intense than the others, the same occurred again, and the fusible plug connecting the conductor with the dynamos gave way, and two men engaged at the Bessbrook end of the line and touching the rails but not the conductor received severe shocks. Clearly in each case the system as a whole had been struck, and the charge was making the best of its way to the earth. After this occurrence the precaution was taken of connecting the rails of the permanent-way to the earth at several points.

MOTORS.

Each locomotive-car is fitted with an Edison-Hopkinson dynamo-motor. As previously mentioned, the motor is fixed on the leading bogie, and is entirely independent of the body of the car. The armature shaft carries a double helical toothed steel pinion, 6·05 inches in diameter, gearing into a steel wheel 21·08 inches diameter, carried on a small counter-shaft running in bearings fixed on the bed of the motor. This shaft also carries a chain pinion-wheel of steel, 8·8 inches diameter, on the extended boss of which the helical toothed wheel is keyed. The chain-pinion drives with chain-gear on to a wheel 21 inches in diameter, keyed on to the back axle of the bogie, the wheels of which are 28 inches in diameter. This gives a ratio of gear of 8·3 to 1; hence a speed of 1 mile per hour corresponds to 100 revolutions per minute of the dynamo axle. To give the necessary adhesion, the axles are coupled with outside connecting-rods.

The motors are series-wound with such a number of convolutions that the magnets are nearly saturated with 72 amperes, which is also the normal current for the armature. The resistance of the magnets is 0·113 ohm, and of the armature, 0·112 ohm; hence, if the potential between the terminals be 220 volts, the electrical efficiency with the normal current is 92·6 per cent., and the commercial efficiency 90·7 per cent., the power developed being nearly 20 HP. In actual work the power of the motor frequently exceeds this amount. To transmit this power with the car running at, say 7 miles per hour, the tension of the chain would be 1,430 lbs., and the speed 460 feet per minute. At starting on a gradient with the full load, the tension may reach 3,400 lbs., and with the car running at the maximum rate, the speed may reach 1,300 feet per minute. Considerable difficulty was experienced in obtaining a chain strong enough to stand the high working tension, and at the same time not unduly heavy for running at the high speed. Several chains of the well-known tricycle form were tried. In these the inside link is fitted with two tubes, through which the pins of the outside link pass, so as to give a wearing surface across the full width of the chain. The tube is protected by a loose roller, intended also to reduce the friction. It was found, however, that the impact of the chain against the teeth of the wheel flattened out the rollers, and ultimately split them; also, sooner or later the tube became loose in the inside links, and began to wear. A steel chain, specially constructed by Mr. Hans Renold, was finally tried, in which the tubes were keyed as well as riveted in the inner links, and the pins in the outer, and the rollers abandoned (Figs. 8). The average breaking-stress of the steel is 43½ tons per square inch.

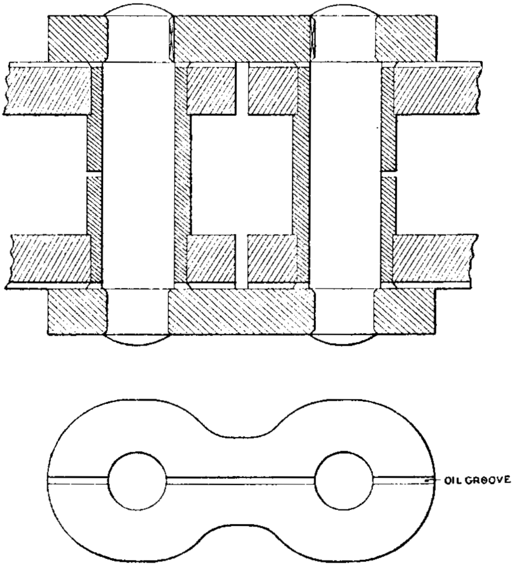
Pitch of chain . . . . . . = 2·125 inches.
Weight . . . . = 8·5 lbs. per linear foot.
Strength of pins against shear = 13·8 tons.
„ outside links . . = 10·2 „
„ inside „ . . . = 14·8 „

The wearing surface per foot of chain is 16 square inches, whereas in the ordinary bowl or stud chain of the same strength the wearing surface would not exceed 2·5 square inches. One of these chains has been at work over eighteen months without showing signs of wear or stretching.

The current is conveyed from the conductor by two collectors fixed on the bogies. These form a good rubbing contact on the upper surface of the conductor. From them the current passes to the reversing and regulating switch fixed on the splash-board of the leading bogie. To avoid throwing the full load suddenly on the generator and motor dynamos, a series of resistances are first thrown into circuit and cut out one by one. After passing through the armature and magnets the current returns through the axle-boxes and wheels to the rails.

The potential allowed by the Board of Trade is 300 volts, but the actual potential employed is 250 volts only.

Figs. 8.



Steel Chain for Locomotive Tramcar.
½ full size.

The trains are commonly composed of one locomotive-car and three or four trucks, but frequently a second passenger-car is coupled, or the number of trucks increased to six. Thus a gross load of 30 tons is constantly drawn at a speed of 6 or 7 miles per hour, on a gradient of 1 in 50.

Efficiency Experiments.

In order to test the efficiency of all the component parts under various conditions of load, several series of observations were made as the car travelled from Newry to Bessbrook with six, four, and no trucks respectively. The flow of water, the potential of the conductor, and the speed of the car were ascertained at frequent intervals, and the results plotted in the form of curves, with the time as abscissa. From these observations and the known resistances of the generator, motor, and conductor, the loss in the several portions of the system, and the actual power developed by the motor, can be readily calculated, and the results similarly shown in a graphic form. The points representing actual observations are joined by straight lines, though no doubt a line of continuous curvature would more accurately represent the fact; but the method employed has the advantage of distinguishing at a glance observation from interpolation.

The curves, Plate 1, Fig. 1, give the results for a journey with a gross load of 28 tons 12 cwt. 3 qrs., including the locomotive car.

The curves, Fig. 2, for a gross load of 21 tons 18 cwt.

The curves, Fig. 3, for a gross load of 8 tons 16 cwt.

Hitherto, writers on electrical locomotion have considered the question of mechanical efficiency from individual observations made at a given instant, when the conditions might or might not be favourable. By a suitable choice of conditions it is very easy to deduce extraordinary high figures of efficiency for electrical working; but such figures are misleading, and not a fair basis of comparison with other modes of locomotion. Since the conditions are constantly varying between very wide limits, any calculation of efficiency ought to take account of the average conditions, or, in other words, the results of a series of individual observations taken at intervals ought to be integrated in respect of time. The curves enable this to be readily done by determining the areas bounded by them and the axis of abscissas. The results are given for the three series of curves in Tables I, II, and III in the Appendix.

Table IV in the Appendix also gives the results of the integration for the three journeys, showing the work done by the water, the electrical energy developed by the generator, the loss in leakage, resistance of line, magnets and armature of generator and motor respectively, and the mechanical work done by the motor, all expressed in foot-lbs. Table V gives the results in Table IV tabulated as percentages of the total energy of the water, and also of the electrical work done by the generator. It will be observed that the efficiency of the whole combination varies from 26·1 per cent. for the light load to 41·3 per cent. for the heavy load; whereas the efficiency of the electrical portion varies from 69·4 per cent. for the heavy load to 76·8 per cent. for the light load. This is explained entirely by the very low efficiency of the turbine when running with a light load. When loaded to nearly its maximum capacity its efficiency is 60 per cent., which is not unfavourable, considering that the load is constantly varying, and that the friction of the shaft, belts, and dynamos, as also the power required to drive the governor, are included. Considering the problem as an electrical one only, it appears that the efficiency does not vary greatly with the load, falling only from 76·8 per cent. to 69·4 per cent., as the load is more than trebled. Taking the average of the three journeys:—

Electrical efficiency . . . . . = 72·7 per cent.
„ loss in generator . . = 8·6 „
„ „ leakage . . = 5·7 „
„ „ line resistance = 6·6 „
„ „ motor . . . = 7·7 „ [1]

The loss as given above in the generator and motor does not include the friction of the bearings nor the power required to turn the armature in the excited fields, when no current is passing through it, both of which, however, are very small.

Comparing the proportion of the total energy of the water, which can be applied to traction in the electrical locomotive, with the proportion of the total energy of coal, which can be usefully applied in a steam-locomotive, the former has been seen to be over 40 per cent. Mr. G. C. Cuningham, M. Inst. C.E., estimates the latter from experiments tried on the Canada Southern Railway at 3·5 per cent.[2]

Referring again to Table IV, if the work done against gravity be subtracted from the total work done by the motor, the remainder represents the work done against all the frictional resistances. From this and from the distance traversed the mean tractive force can be at once deduced. The results for the three journeys are respectively 28·9, 27·4, and 37·1 lbs. per ton of gross load hauled. The two former agree well. The increase in the third is due to two causes, first, the mean speed is nearly double that in the first journey, the effect of which on the mean tractive force would be increased by the frequent and sharp curves of the line; secondly, the locomotive car having no trucks attached to it on the third

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[1] It will be observed in the tables that the totals given do not always correspond exactly with the sums of the components. This arises from the curves being separately integrated. The error of about 1 per cent. is a measure of the accuracy of the method.

[2] Minutes of Proceedings Inst. C.E. vol. lxxxiii. p. 325.

journey, the friction of the driving-gear, connecting-rods, &c., would bear a much larger proportion to the whole. The values given above for the tractive force include the friction of the chain and driving-gear, as also that of the motor dynamo in its bearings, and the couple required to turn the armature with the fields excited but no current passing through it. It corresponds in a steam-locomotive to the product of the mean pressure on the piston and the ratio of the throw of the crank to the radius of the driving-wheel.

The foregoing results also afford some examples illustrative of the general theory of a series-wound motor. In such a motor let L be the couple on the armature shaft; R the resistance of the series coils and armature; r the additional resistance inserted; C the current; P the potential of the conductor; E the electromotive force of the motor; and ω the angular velocity of the armature. Then

$$L \omega = E C$$

$$\text{And } \; E = P - \overline{R + r}\, C.$$

$L\omega$ here includes the power lost in the armature of the dynamo through the reversal of its magnetization, the power lost through the short-circuiting of successive coils at the commutator and local currents in the core, also friction of the bearings, in addition to the useful work done by the motor, as measured by a brake. The first of these losses, which is or ought to be the most important, is proportional to the velocity ω, and the latter with sufficient accuracy for the present purpose may be assumed to be so. $(L + l)$ may therefore be written for L, where L represents the couple doing useful work external to the dynamo. Let $E = \frac{\omega}{\Omega} f(C)$ be the characteristic curve of the dynamo, then

$$L + l = \frac{C f(C)}{\Omega}.$$

C is therefore independent of the velocity, and depends upon the couples only. It must be remembered that C being measured in amperes, L and l are measured in the corresponding C. G. S. unit of work denominated by the late Sir William Siemens a "Joule." (One Joule $= 10^7$ ergs $= 0 \cdot 74$ foot-lb.) Since within very wide limits $f(C)$ increases as C increases, $L + l$ increases as C increases. In this lies the chief advantage of a series-wound dynamo for locomotive purposes. The maximum couple which a steam-locomotive can exert is limited by the steam-pressure and the area and stroke of the piston. In a water-wheel the couple cannot exceed the product of the radius of the wheel and the maximum weight of water its buckets can contain. So in a turbine. In a series-wound dynamo there is no limit to the couple it can momentarily exert, except the mechanical strength of the armature, provided the potential of the conductor does not fall below $\overline{R + r}\ C$. It may be said that the current is limited by the couple turning the generating dynamo. This no doubt is true, but in many cases the generating dynamo is sufficient for working several motors, and the motor which at the instant requires to exert the greatest pull can draw the full current of the generator; and in every case there is the momentum of the generating dynamo and of the engine or other prime motor driving it, which must be exhausted before the amount of current is limited. In the present instance the motors on the cars are designed for working continuously with a current of 72 amperes, with which current the couple the dynamo exerts is 183 Joules, or 135 foot-lbs., which is increased to 1,120 foot-lbs. on the axle, equivalent to a tractive force of 960 lbs. The observed current required to start a train of 29 tons on an incline of 1 in 50 was 170 amperes (Plate 1, Fig. 1), corresponding to a tractive force of 2,544 lbs., equal to 88 lbs. per ton, or about three times the normal tractive force exerted by the motor. For a line such as the one under discussion a simple shunt-wound motor would be useless, since at the moment of starting on a steep incline the potential of the conductor at the motor may be reduced to one half its normal amount through the resistance in circuit, and consequently the magnetizing force reduced in like proportion, when the fields would almost entirely lose their magnetism. A compound-wound machine might be used, and would have the advantage that the speed would not exceed a certain limit, however small the load might be, but in the present instance such a provision was unnecessary. A further advantage in the use of a series-wound machine is the facility with which a motor of the Edison-Hopkinson type when wound in this manner can be reversed. In general, to reverse the direction of rotation of a motor the lead of the brushes must be reversed at the same time as the current through the armature, or there will be destructive sparking at the commutator. But if the lead can be reduced to such an extent that the brushes may be fixed at the neutral point without causing injurious sparking, it is only necessary to reverse the current. It is known that the angle of lead depends upon the disturbance of the magnetic field in the gap between the pole-pieces, due to the current round the armature, but no successful attempt has yet been made to express the variation of the angle of lead in terms of the geometrical constants of the machine and the magnetizing forces. The disturbance of the field can, however, be minimised by maintaining the magnetizing forces in the field magnets very large compared with those in the armature, as is the case in a series-wound machine. In the present instance it has been found unnecessary to make any provision for the change of lead and the reversal of rotation is effected by reversing the current only.

Referring to curves, Plate 1, Fig. 1, it is seen that on an incline of 1 in 621 the locomotive car, when drawing a gross load of 28·6 tons, absorbed a current of 60 amperes, and that the electromotive force of the motor was 222 volts. From these measured results the couple exerted by the motor and the speed can be readily determined by aid of the characteristic curve. With a current of 60 amperes through the magnet coils, the electromotive force of the motor is 260 volts at a speed of 1,000 revolutions per minute, and therefore with 222 volts the speed will be 854 revolutions per minute, corresponding to a speed of travel of 8·57 miles per hour as against 8·4 miles measured. Again the couple exerted by the motor will be

$$\frac{222 \times 60 \times 60}{854 \times 2\,\pi} \text{ Joules} = 149 \text{ Joules} = 110 \text{ foot-lbs.}$$

This is equivalent to 913 foot-lbs. on the axle of the car, or a tractive force of 785 lbs., *i.e.* 27·4 lbs. per ton. From this must be deducted 3·4 lbs. per ton for gravity, leaving 24 lbs. per ton, as against 28·9 lbs., the tractive force calculated from the mean of the work done over the complete journey. In the latter the force required to overcome the resistance of the curves, which are both numerous and sharp, is included, whereas the former figure applies to a straight portion of the line. This is probably sufficient to account for the difference between the figures. The example shows how precisely the results obtainable from an electromotor when used for locomotion can be calculated.

USE OF STORAGE BATTERIES.

It is interesting to consider how far the system of storage batteries would be applicable to a line where heavy traffic has to be accommodated. In the first journey, with a load of 28·6 tons, the total work done by the motor was 12·6 HP. hours, and the loss in the motor was 2·07 HP. hours, hence the total electrical energy absorbed by the motor was 14·67 HP. hours in thirty-six minutes or at the rate of 24·4 HP. According to results published by Mr. Reckenzaun in a communication to the American National Electric Light Association, a cell suitable for tramcar work, weighing 41 lbs., has a useful capacity of 137 to 156 ampere-hours, according as the rate of discharge is varied from 46 to 22 amperes; the electromotive force falling during discharge from 2·1 volts to 1·87 volt. Hence 1 ton of storage cells can do work usefully at the average rate of 3,700 watts, or 4·9 HP. From these data the weight of battery required to do the work actually accomplished at Bessbrook can be readily deduced. Remembering that the battery itself has to be carried, and making no allowance for increased weight in the framework of the car, the weight of battery required is 6 tons. But this additional weight would necessitate a considerably larger locomotive-car with a stronger frame and more powerful motor, which would again increase the weight of the train and the weight of the cells required. If the former be taken at 4·4 tons, the latter would be about 1 ton; hence the gross weight of the train would be increased to 40 tons, including the battery, weighing 7 tons. Assuming the efficiency of the battery to be 70 per cent., which is probably a favourable assumption, when the rate of discharge is variable, the electrical energy required to charge the battery for one journey would be 29·3 HP.-hours as against 16·4 HP.-hours required for the same work on the continuous conductor principle. Thus from the point of view of economy of power the comparison is greatly in favour of the continuous-conductor. There are the further considerations of first cost and depreciation of plant. To provide for the continuous working of the line two sets of accumulators would be required, which, taken at the present price of £60 per ton, would cost £840, to which must be added the cost of the larger locomotive-cars and more powerful motors. This would increase the cost to at least £1,200. Now the cost of the conductor, which is the only part replaced by the battery, was £600 (see Appendix). Again, the depreciation of the cells cannot be estimated at less than 40 per cent. per annum, whereas the conductor practically suffers no depreciation.

COMPARISON WITH WIRE-ROPE TRACTION.

Traction by a continuously moving wire-rope has many points in common with an electrical system on the continuous-conductor principle, and the efficiency of the two methods can be readily compared. In a comprehensive review of the working of the cable tramways in San Francisco, Mr. Hanscom[1] gives the following results obtained from careful measurements on seven different lines:—

Total indicated power of engines	798·7 HP.
Total power absorbed in moving the cables .	548·2 „
„ „ „ cars and passengers.	250·5 „

Hence on the average 32 per cent. of the total indicated power is available for moving the cars and passengers. Now in comparing this with the results obtained on the Bessbrook line, it must be remembered that a portion only of the net power developed by the motor is available for moving the cars, part being required for moving the motor and its carriage. About 3·5 tons of the total of 28·6 tons represents the dead-weight, and hence about 88 per cent. only of the net power is available for moving the effective load. Again, if for water-power steam-power were substituted, about 15 per cent. of the indicated power would be available for driving the generator dynamo. Hence the ratio of the power available for moving effective load to the total indicated power would be 54 per cent. as against 32 per cent. on the cable system.

In instituting the above comparison, both systems may be considered to be working under conditions calculated to favourably develop the characteristic features of each. The grades on the San Francisco lines are in cases as steep as 1 in 6, and 1 in 10 is not uncommon. On such lines any system of electrical propulsion, except perhaps by a geared locomotive, would be entirely inapplicable. On the other hand, the wire-rope system would present less favourable comparative results, if applied to a line similar to the Bessbrook line, where the gradients are less severe.

The Paper is accompanied by a series of drawings, from which Plate 1 and the Figs. in the text have been prepared.

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[1] "Cable Railway Propulsion," by W. W. Hanscom. Transactions of the Technical Society of the Pacific Coast, 1884. Vol. i. p. 63.

[APPENDIX.

APPENDIX.

Cost of Construction.

The cost of the electrical equipment of the line may be briefly summarized as follows:—

	£.	s.	d.
Turbine, pentrough, and driving-gear	330	0	0
Two generator dynamos, measuring instruments, and driving-belts	450	0	0
Conductor, at £200 per mile	600	0	0
Two locomotive cars, including their entire electrical equipment	1,120	0	0
	2,500	0	0

Each of the above items including delivery and erection.

Cost of Working.

The cost of haulage was carefully ascertained over a period of five months from November 21st, 1885, to April 22nd, 1886.

	£.	s.	d.
Wages of driver and attendant at generator station	32	7	6
Sundry repairs	6	1	0
Oil, grease, and waste	5	4	10
Rental of water-power	59	16	0
Dynamo brushes, renewals of driving-chain, and commutators	14	11	6
	118	0	10

Train-mileage = 8,652.
Hence cost per train-mile = 3·3*d.*

For the six months ending June 30th, 1887, during which period there had been a goods traffic of 8,000 tons over the line, a much larger amount than in the period referred to above, the cost per train-mile was somewhat greater, as follows:—

	£.	s.	d.
Wages	50	18	0
Sundry repairs and alterations, including the cost of changing the winding of four armatures of the dynamos	34	14	3
Oil, grease, and waste	10	0	0
Rental of water-power	71	15	0
Dynamo brushes and sundry renewals	12	5	10
	179	13	1

Train-mileage, 10,176.
Hence cost per train-mile, 4·2*d.*

The above figures do not include anything for depreciation or for general supervision.

TABLE I.—RESULTS OF INTEGRATION OF CURVES, Plate 1, Fig. 1.

Total water-power	30·4	HP. hours.
„ electrical-power developed by generator	18·1	„
Net power of motor	12·6	„
Loss in generator	1·68	„
„ line resistance	1·82	„
„ leakage	0·71	„
„ motor	2·07	„
Sum of electrical losses	6·31	„

TABLE II.—RESULTS OF INTEGRATION OF CURVES, Plate 1, Fig. 2.

Total water-power	20·63	HP. hours.
„ electrical-power developed by generator	10·86	„
Net power of motor	7·82	„
Loss in generator	0·88	„
„ line resistance	0·65	„
„ leakage	0·52	„
„ motor	0·90	„
Sum of electrical losses	2·95	„

TABLE III.—RESULTS OF INTEGRATION OF CURVES, Plate 1, Fig. 3.

Total water-power	13·9	HP. hours.
„ electrical-power developed by generator	4·71	„
Net power of motor	3·62	„
Loss in generator	0·40	„
„ line resistance	0·14	„
„ leakage	0·39	„
„ motor	0·165	„
Sum of electrical losses	1·1	„

TABLE IV.

——	First Journey.	Second Journey.	Third Journey.
	Tons. cwt. qrs.	Tons. cwt. qrs.	Tons. cwt. qrs.
Gross load	28 12 3	21 18 0	8 16 0
Mean speed in miles per hour	5·7	7·2	11·3
Total energy of water in foot-lbs.	60,291,000	40,860,600	27,522,000
Total electrical energy developed by generator in foot-lbs.	35,871,000	21,516,000	9,332,400
Net mechanical energy developed by motor in foot-lbs.	24,928,200	15,493,500	7,170,900
Sum of electrical losses in foot-lbs.	12,493,800	5,841,000	2,174,700
Loss in generator in foot-lbs.	3,343,000	1,735,800	801,900
„ leakage „	1,420,300	1,029,600	775,500
„ resistance of line in foot-lbs.	3,613,500	1,296,900	287,100
„ motor in foot-lbs.	4,098,600	1,791,900	326,700
Total work done against gravity	11,867,400	7,356,800	2,858,300
„ „ friction	13,060,800	8,136,700	4,312,600
Mean tractive force, exclusive of gravity in lbs. per ton	28·9	27·4	37·1

TABLE V.—PERCENTAGES.

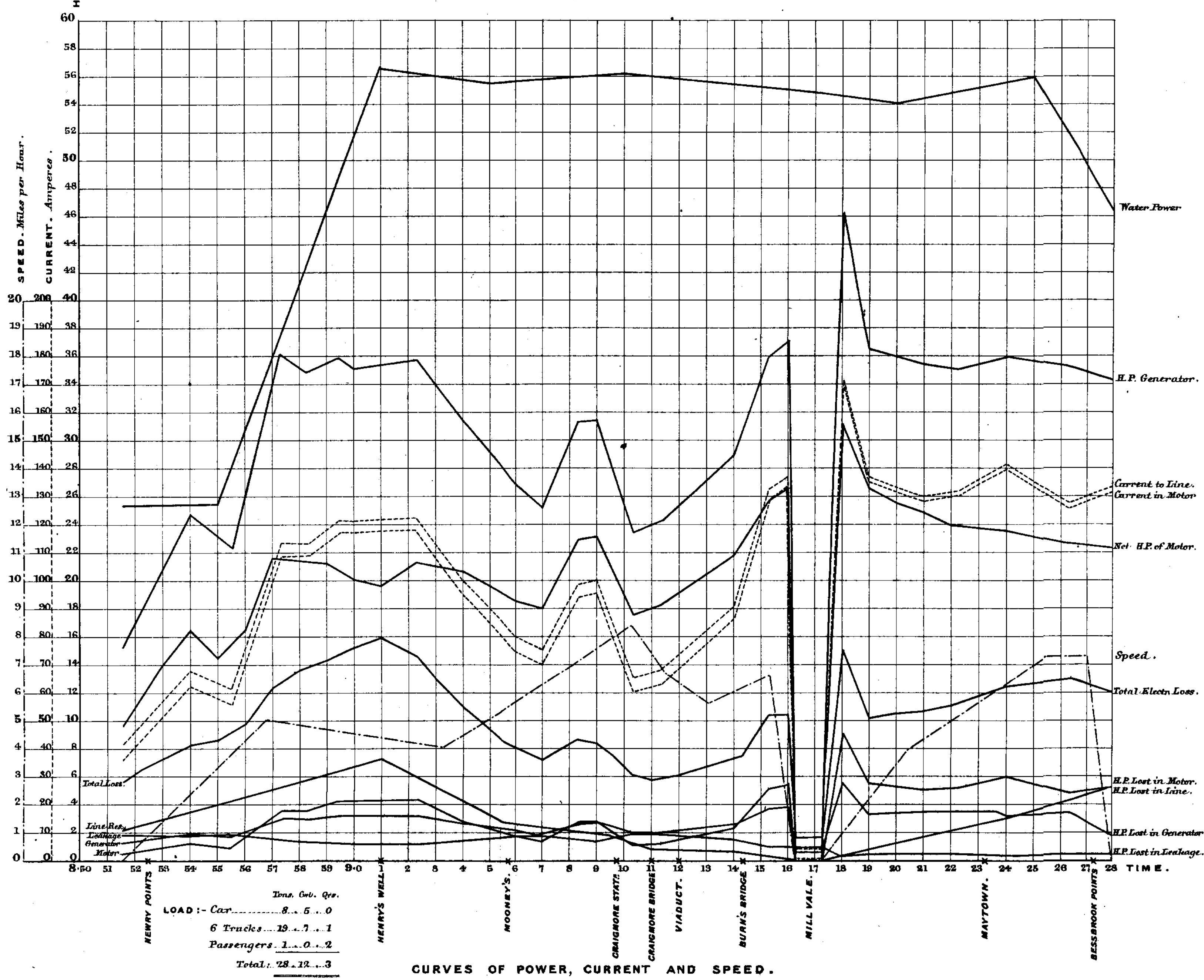
—	First Journey.		Second Journey.		Third Journey.	
	Of the Water Power.	Of Total Power of Generator.	Of the Water Power.	Of Total Power of Generator.	Of the Water Power.	Of Total Power of Generator.
Water-power . . .	100·0	..	100·0	..	100·0	..
Generator-power . .	59·5	100·0	52·6	100·0	33·9	100·0
Net motor-power . .	41·3	69·4	37·9	72·0	26·1	76·8
Loss in generator .	5·5	9·3	4·2	8·0	2·9	8·6
„ leakage . .	2·3	3·9	2·5	4·8	2·8	8·3
„ line resistance	6·0	10·6	3·2	6·0	1·0	3·1
„ motor . . .	6·8	11·4	4·4	8·3	1·2	3·5

[DISCUSSION.

ELECTRICAL TRAMWAYS.

THE BESSBROOK AND NEWRY TRAMWAY.

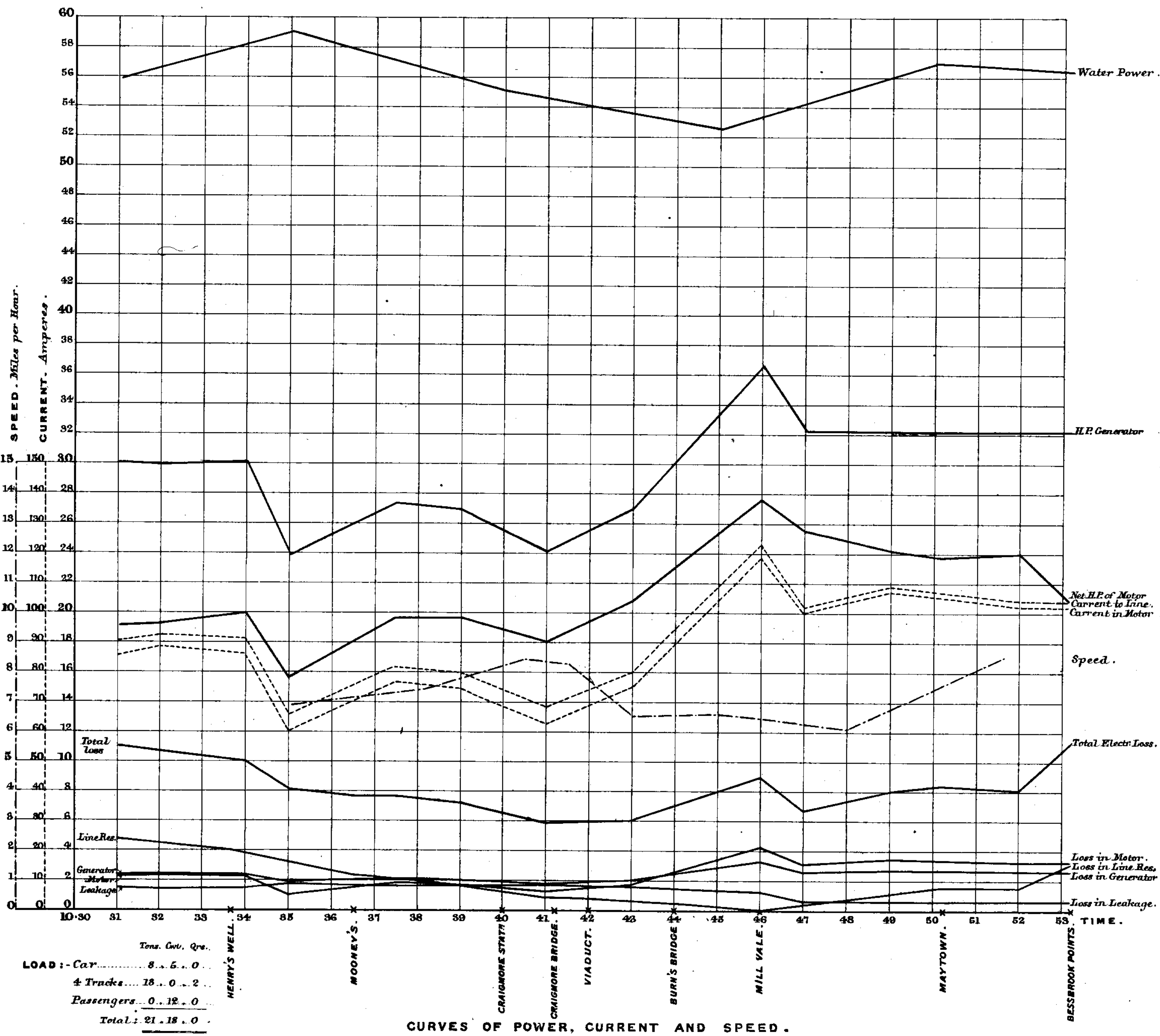
Fig: 1.



	Tons.	Cwt.	Qrs.
LOAD:- Car	8	5	0
6 Trucks	19	7	1
Passengers	1	0	2
Total:	28	12	3

CURVES OF POWER, CURRENT AND SPEED.

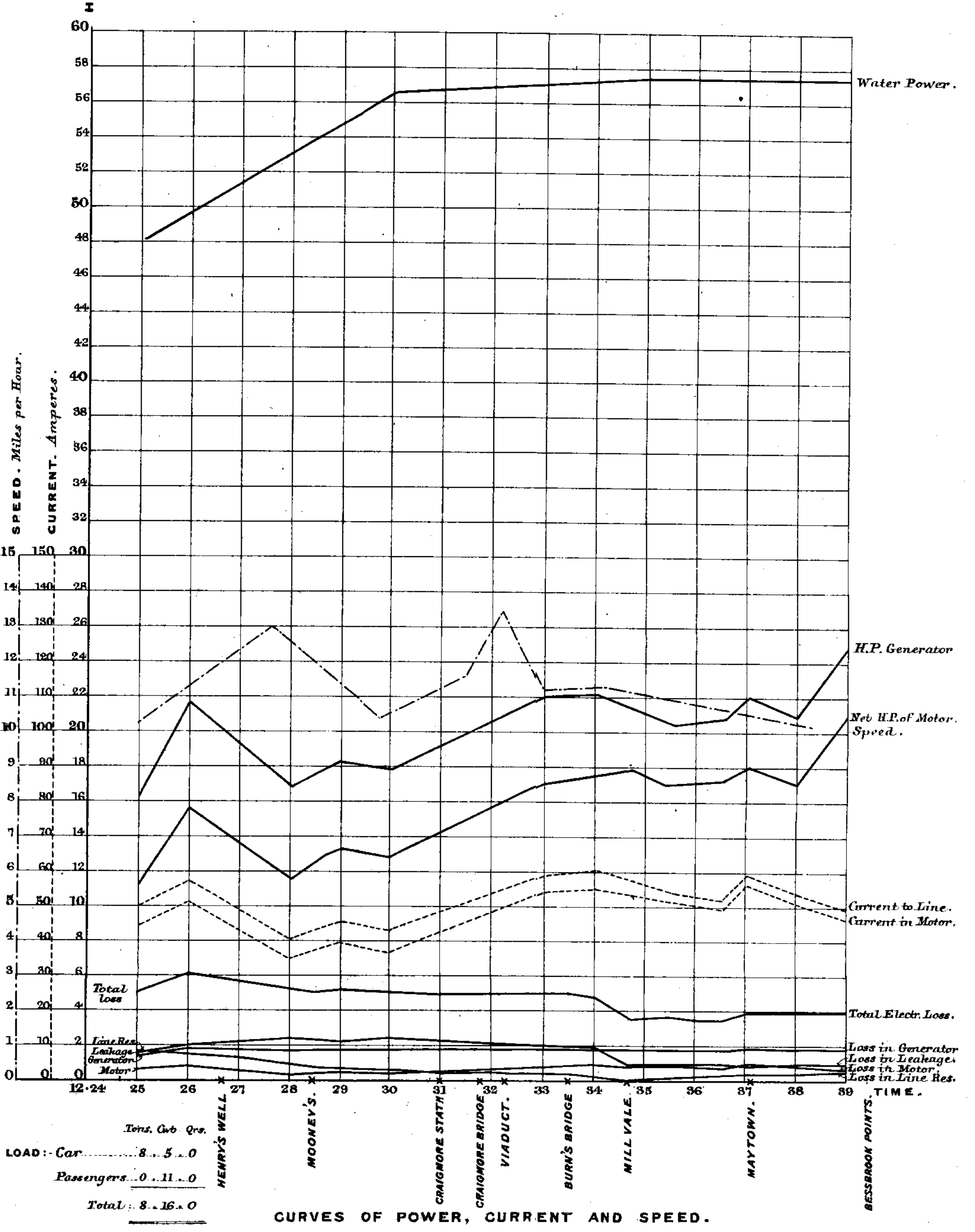
Fig: 2.



	Tons.	Cwt.	Qrs.
LOAD:- Car	8	5	0
4 Trucks	18	0	2
Passengers	0	12	0
Total:	21	18	0

CURVES OF POWER, CURRENT AND SPEED.

Fig: 3.



	Tons.	Cwt.	Qrs.
LOAD:- Car	8	5	0
Passengers	0	11	0
Total:	8	16	0

CURVES OF POWER, CURRENT AND SPEED.

E. HOPKINSON, DELT

THOS. KELL & SON, LITH. 40, KING ST. COVENT GARDEN.