ELECTRIC TRACTION—A REVIEW.*

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A RECENT announcement states that in the United States alone electric railways cover a trackage of 44,000 miles and represent a capital investment of approximately \$5,000,000,000, while 300,000 men are employed and over 14,000,000,000 passengers are carried annually—ten times as many as are carried by the steam railroads of the country.

In addition, there is the like class of roads in foreign countries, and thousands of miles of trunk lines here and abroad which are electrically operated or for which electrical equipment is planned. This is a brief epitomé of one of the most astounding of industrial growths, the product of but a third of a century of effort.

In accepting the invitation to present a paper reviewing this great development I cannot but feel something of that embarrassment which must unavoidably attend the presentation of facts which, if stated correctly from a historical standpoint, must include something of one's personal contributions, especially as one must lack that true perspective for which time, distance and the impersonality of an historian are essential. But, to quote a distinguished predecessor, reminiscence is one of the privileges of advancing years and an accumulation of experience, and is sometimes permitted by a kindly audience.

The history of the electric railway may be considered as covering various periods—such as, the inception of basic principles, the early crude experiments, the invention and evolution of the dynamo-electric machine, the discovery of the principle of self-excitation and the reversibility of function, the scattered attempts at commercial operation, the advent of the modern trolley, the succeeding technical and commercial developments, trunk-line operation and future possibilities. As to these I shall draw quite freely upon my previous papers on the same general subject.

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DISCOVERIES OF FARADAY AND HENRY.

Whatever moderns may have done, two names stand out in the early dawn of the electric art, undimmed by the glory of any subsequent achievements. On Christmas morn, just a hundred years ago, Michael Faraday, "late bookkeeper's apprentice, and now turned philosopher," announced the all-important discovery that it was possible to produce mechanical motion through the agency of the electric current and magnetic attraction, and ten years later Joseph Henry, then a Professor of Natural Philosophy in the Albany Academy, who had antedated Faraday in the discovery of electro-magnetic induction between unmoved conductors, announced in a letter to Professor Silliman, of New Haven, another advance, as follows: "I have lately succeeded in producing motion by a little machine which I believe has never before been applied in mechanics, by magnetic attraction and repulsion."

But Henry, coolly analyzing the limitations of the electro-magnetic motor, which, however it might be improved, was still dependent upon the burning of zinc in a primary battery, and clearly recognizing the economic fallacy of any attempt to substitute it for coal as a source of energy, avoided committing himself to impracticable attempts for its introduction into the mechanical world.

THOMAS DAVENPORT, THE PIONEER.

It, therefore, fell to one Thomas Davenport, a blacksmith of Brandon, Vermont, of whom it has been said that his was a mind which could not be confined to any shop less than the canopy of Heaven, to throw himself heart and soul into the attempt to create an industrial revolution by electricity—a project that, at the time, was certain to prove illusory; and to this same man, in all justice, must be given the credit, in this country at least, for the first crude suggestion of an electric railway—the operation of a moving vehicle by electric power supplied from a stationary source.

From about 1833, when Davenport began his electrical career, until his early death in 1851, his life was the typical one of many inventors who have blazed the path for others, the active strivings of a fertile mind urged to constant endeavors and dreaming great dreams, finally beaten to the wall, partly because of the lack of financial assistance but more because he lacked the essential of commercial success, a suitable economic source of electric power.

By 1834 he had built his first crude motor; in the next year he devised the commutator; and in 1836-37 he illustrated on a miniature circular track, two feet in diameter, the principle of an electric railway using current from a central source, with return through the rails.

On February 25, 1837, Davenport was granted the first and broadest patent in America on this general subject, the character of which is indicated by the following claim:

The discovery here claimed and desired to be secured by Letters Patent consists in applying magnetic and electro-magnetic power as a principle for machinery in the manner above described, or in any other substantially the same in principle.

This wording may fairly be declared to cover the whole field of the utilization of electric power.

I have only touched upon Davenport's activities, the number of which are amazing, but refer to his work to emphasize not only its creative originality and importance, but the undoubted fact that had he had the advantages of the developments which followed in the succeeding years in the evolution of the dynamo, the machine for converting mechanical energy into electricity, and the converse, many of the advances now credited to other inventors would undoubtedly have been his.

OTHER EARLY WORKERS.

A close rival of Davenport was the Russian engineer, Jacobi, who also in 1834 had produced an electric motor, and three years later actually propelled a boat on the river Neva with energy from primary batteries. This decade seems to have been prolific not alone in attempts to apply electric motors to industrial purposes but in a belief in its ultimate universality of adoption. One of the most notable attempts made was that of a Scotch engineer, Robert Davidson, who in 1838 began the construction of an electric locomotive which had a test on the Edinboro-Glasgow Railway; and the thought of many workers was well voiced in the remarkable prediction by Lieutenant LeCount of the British Navy, who in a "Treatise on Railways" published by Black, of Edinburgh, in 1839, said:

We have no hesitation in saying that electro-magnetism will at no distant day compete with steam as a motive power, and successfully.

The use of rails for carrying the electric current is said to have

been indicated in an English patent issued to Henry Pincus in 1840, and a like use in an American patent issued to Lilley and Colton in 1847. Whatever the fact, it is well established that in the latter year, Prof. Moses G. Farmer, who was one of the ablest of early American scientists, operated an experimental car, carrying two passengers, at Dover, New Hampshire, which was supplied by battery current: Three years later Professor Page, of the Smithsonian Institution, with Congressional aid, constructed a number of motors. With one of these, on April 29, 1851, and with current supplied from a battery of one hundred Grove cells carried on a small car, he operated the latter on a road between Washington and Bladenburg, where it got up to a speed of nineteen miles an hour, with resultant destruction of the batteries and an end of the experiment.

In this same year an instrument maker of Boston, Thomas Hall, made a small motor which was operated by current conveyed to the rails from a primary battery. Nine years later he exhibited a model called the "Volta" at the Mechanics Fair in Boston. Some years before this patents issued to inventors abroad had indicated the possibility of taking current from a suspended conductor.

EVOLUTION OF THE DYNAMO.

These various experiments were, of course, doomed to commercial failure, not alone because the motors were of a crude construction, based upon the attraction of keepers or solenoids, but because the source of power was in all cases a primary battery. They were, however, indicative of what would come later when the evolution of the modern dynamo should take place.

Beginning with improvements by Wheatstone and Cook in 1845, and by Hjorth in 1854, there appeared in 1853 an inventor whose name is, unhappily, now not even known, who is reported to have clearly set forth the vital idea of self-excitation of the field magnets.

The modern dynamo-electric machine dates from the epoch-making invention of the continuous current dynamo by Pacinotti in 1861, which was followed by the announcement of the principle of self-excitation, independently and practically simultaneously, by the Englishmen, Wheatstone, Varley and Ladd, the German, Siemens, and the American, Farmer, in 1866-67.

Three years later a Frenchman, Gramme, combined the two vital features in a single machine, and to him is fairly due the credit of producing the first practical commercial machine for continuous current operation, whether used as a dynamo or motor.

The ring form of armature, invented by Pacinotti and improved by Gramme, ultimately gave way to the drum form of winding proposed by Von Hefner Alteneck of the Siemens firm of Berlin, and also independently by the late Prof. Henry Rowland of the Johns Hopkins University.

REVERSIBILITY OF FUNCTION.

Some time, apparently, relapsed after the development of the self-exciting machine before the remarkable characteristic of the reversibility of function was discovered, with the necessary corollary, the electric transmission of energy by the use of two similar machines connected in the same circuit, one driven by power and generating electricity, and the other receiving electricity and developing mechanical power.

It is claimed that this vitally important fact was discovered by Pacinotti in 1867, but it is certain that for the time being no use of it was made. In 1873, however, Messrs. Gramme and Fontaine demonstrated it at the Vienna Exhibition, where a number of Gramme machines were in use. This discovery is said to have been due to the mistake of a workman who coupled a machine to a live circuit and was astonished to see it begin to rotate. This is quite likely, as the same thing has happened in recent years. Gramme instantly saw the significance of this unexpected occurrence, concerning which the great Maxwell expressed the opinion that it was the most important discovery of modern times.

In the nearly quarter of a century ending in 1875, during which period the modern dynamo and motor had been created, there appeared to be a complete cessation of electric railway experiments. It was not until the latter year that George Greene, a mechanic of Kalamazoo, Michigan, is reported to have built a small motor which was supplied from a battery through an overhead line, with track return, and three years later constructed another larger model. Lacking appreciation of the necessity of using a dynamo for a generator of electricity instead of a battery, or possibly being

without means to get one, his work came to naught. Greene applied for a patent in 1879, and was finally allowed some very broad claims.

FIRST SIEMENS' WORK.

Among the European concerns engaged in buiding dynamos for electric lighting and other purposes, that of Siemens was the most prominent, and naturally the transmission of power soon commanded its attention, with the result that in 1879 this firm showed at the Berlin Exhibition a small car, operating on a track about a third of a mile long, which used a dynamo-electric motor and took current from a third rail, with track return, supplied by a stationary dynamo. On this locomotive the motor was carried longitudinally, the revolutions of the armature being transmitted through spur and beveled gears to a central shaft, from which connection was made to the wheels. Three small cars carrying about twenty people were pulled by it at a speed of eight miles an hour.

In the next year Egger exhibited a model in which the current was supplied through the running rails, and Messrs. Bontemps and Desprez, of Paris, proposed a scheme for the use of miniature electric locomotives in place of the pneumatic transmission of dispatches. This is the same Desprez who actively conducted some of the earliest important experiments in the transmission of power over long distances with direct current at high potentials.

ADVENT OF FIELD AND EDISON.

While these developments were going on abroad two American inventors, the late Stephen D. Field and Thomas A. Edison, began electric railway experiments, but, subject to the claims made for Greene, the credit of the first serious attempt in the United States at this period must be awarded to Field, who, while living in San Francisco in 1877, is reported to have conceived the idea that electric power might be substituted for the cable then used to propel street cars in that city. To carry out some proposed experiments, the first of which was to operate an elevator, he ordered a dynamo machine from Europe. This being lost he ordered a second one. In 1879, his resources being exhausted, he returned to New York and laid his plans for the electric operation of cars with current supplied through a conductor carried in

a slotted conduit before the late Franklin Leonard Pope. In this year he filed a caveat, and followed it by a regular patent application in the next year. This disclosed plans for an electric railway designed to use current from a stationary dynamo, transmitted through a third rail or an insulated conductor enclosed in and protected by a conduit, the traffic rails, divided into sections, forming the return circuit.

Mr. Edison, at this time, was within reach of great electric possibilities, although actually missing them, for in the face of much adverse criticism he had developed, in connection with his electric-lighting system, a low, internal, resistance dynamo with high-resistance shunt field and many of the features of the multiple-arc system of distribution, analogous to that used in gas and water supply.

In 1880 he built a small road at his laboratory at Menlo Park, on which he ran a single locomotive equipped with a lighting dynamo used as a motor. The power was transmitted to the car axle by a belt and the two rails were used as conductors, one set of wheels being insulated. In this year Siemens, Field and Edison became involved in a patent interference. Siemens being ruled out by office limitations as to evidence relating to work abroad, the immediate issue narrowed down to Field and Edison and was decided in favor of the former, to whom was issued a patent covering "the combination of an electric motor operated by means of current from a stationary source of electricity conducted through the rails," a claim manifestly absurd in view of the previous art and void on the ground that the mere substitution of a dynamo in the place of a battery did not constitute invention.

In general, however, because of the facts of equivalency, and also on account of the records of early experimental work, the claims obtained in the patents of this period were distinguished by their paucity and limitations.

FIRST COMMERCIAL ELECTRIC RAILWAY.

The demonstration by Messrs. Siemens and Halske in Berlin in 1879 was followed by other exhibitions by them at Brussels, Düsseldorf and Frankfurt, and then they established a short one-car line a mile and a half long at Lichterfelde, near Berlin. This small road was opened for traffic in May, 1881, and may be considered the first commercial electric road on which fares were

collected. The motor was carried on a frame beneath the car body between the axles, the power being transmitted by steel cables from the armature to drums on the axles. The car had a capacity of twenty-six passengers and could make a maximum speed of about thirty miles per hour. The electrical pressure was low, only about 100 volts, and the two rails were used as conductors. This line continued in actual service for a number of years, the method of current supply, however, being later replaced by two conductors carried on tops of poles, upon which ran a small carriage connected with the car by the flexible cable.

This equipment was followed by one at the Paris Exhibition, where overhead distribution was used for the first time; the conductors in this case consisting of two tubes slotted on the under side and supported by wooden insulators, which tubes contained skids held in contact by an under-running wheel pressed up by springs carried on a frame-work supported by the conductors. Connection with the car was made by flexible conductors, and the power from the motor, which was carried between the axles, was transmitted by a flexible chain.

About this time Field constructed and put into operation an electric locomotive on a track in Massachusetts, but this experiment was soon abandoned.

SERIES-PARALLEL CONTROL.

Up to 1881 all proposals to use motors were based upon their individual and separate control, but Dr. John Hopkinson, an English scientist of exceptional mathematical and scientific knowledge, in a patent for the application of motors to hoists, proposed both for them and for tramways the grouping of two motors in series-parallel arrangement, by which method either two motors, or one motor with two armature circuits, could be run at half or full speed by providing a switch so that the current from a source of constant potential could be sent through the two circuits in series or parallel.

In the same year, and quite independently, I constructed a small dynamo at the Torpedo Station, Newport, which had two armature circuits and a switch by means of which like series-parallel combinations could be made, and tests of the machine under these conditions were conducted, first as a dynamo and later as a motor. The direct change-over from one combination

to the other, however, with high electrical pressures or large currents, would be too abrupt and destructive of the controlling switch, and so this practice did not come into commercial use until some time later, when there was combined with the simple series-parallel control a variation of current strength by a resistance in the circuit of the motor, either by varying the arrangement of section of field coils or the amount of external resistance, thus making the change-over easier and giving additional speed increments.

The two functions being progressively effected by Condit by the movement of a single handle, his controller as modified by the addition of the magnetic blowout by Thompson and Potter became a practical feature in everyday operation, and for a long time the validity of patent covering this combustion was upheld. A final adjudication, on the discovery of an Austrian patent issued to Reckenzaun, who had conducted a number of experiments with storage-battery cars, was probably avoided by a combination of the contending interests.

FURTHER ACTIVITIES.

The year 1882 was marked by an increase in electric railway activities. In Europe, the Siemens firm constructed an experimental road near Meran in the Tyrol to demonstrate the possibilities of electric traction for the St. Gotthard Tunnel, and small lines at Frankfort and Molding, followed by a proposal for a combined elevated and underground railroad for Vienna.

In the fall of that year Doctor Finney, of Pittsburgh, devised a system for operating electrically propelled omnibuses with current taken from overhead wires carrying a small trolley connected to the vehicle with a flexible cable. About the same time in England, Professors Ayrton and Perry read a paper on Automatic Railways before the Royal Institution, and Dr. Fleeming Jenkin, the distinguished Scotch scientist, proposed a telepherage system, or automatic overhead railway for carrying merchandise, plans for which were developed by them in concert.

In the same year, Mr. Edison, at the instance of the late Mr. Henry Villard, undertook further experiments at Menlo Park, but save in extent there was little of novelty shown. Both Field and Edison took out some additional patents, one of the latter's being for the control of motors on different cars by a single main controller on a pilot locomotive, a plan never put in

use. Although Field later undertook some isolated experiments, and Edison, at a much later date, essayed an unfortunate attempt to use rail supply at very low potential differences as a substitute for the trolley, both inventors soon ceased to become active factors in the development of the art.

THE MODERN TROLLEY.

Opportunity is often responsible for inventions, and it was largely so for my entry into the electric railway field. As a cadet at the United States Naval Academy in 1874-78 I had become intensely interested in various electrical inventions, and in 1879 and 1881 I had actively begun electrical experiments, the intervening year being spent on a cruise around the world. While on duty on the training ship *Minnesota* in the latter year I made an attempt to introduce the incandescent electric light into the Naval service, current to be supplied from an Edison dynamo driven by a single-cylinder, fly-wheel pump which I intended to divert from its normal duty. But not effecting the loan of a machine this ambition was for the time not realized.

The principal activities of this period concerned the electric lighting field, and were marked by sharp recriminations between the advocates of series arc lights operated with a constant current at a high pressure and the multiple-arc distribution of high-resistance incandescent lamps at a constant pressure. The application of electricity to motive power seemed to have been largely lost sight of, and the various companies which were formed manifested their limitations by their names, being generally known as "illuminating" or "lighting" companies.

My ambitions being aroused by the opening of the Paris Electrical Exhibition in 1880-81, I terminated my experiments at the Torpedo Station and applied for orders to Paris, failing which I procured an assignment to the *Lancaster*, sailing for the Mediterranean, with leave on arrival, and subsequent orders to the Electrical Exhibition held in 1882 at Sydenham, England. As secretary of a jury I had charge of the testing of dynamos and gas engines. To the best of my recollection there were no stationary electric motors exhibited, but there were many lighting exhibits, the principal one being Edison's, and of course there were no electric railways. While riding upon the underground road I conceived an idea of electric propulsion based upon the use of the

tracks as one conductor, and for the other a system of rigid overhead rails, all in one plane, following the centre line of all tracks and switches, contact with the same to be made by an upward-pressing wheel or cylinder carried by the car over the centre of the truck and supported by springs with lateral movement so as to accommodate the motion of the car upon its springs. This plan followed an earlier suggestion to use a conductor carried between the rails, discarded because of the great complexity of switches which I noted at one of the principal stations.

Resigning from the Naval service, with a year's leave, I returned to the United States in the spring of 1883 to become an assistant of Mr. Edison in connection with his electric light station, and while engaged in this duty I developed a mathematical means for determining and improving the system of central station distribution. I found time, also, to conduct experiments with electric motors, and as a result of my awakened ambition in this field I had a clash with my employer within a year, and formed the Sprague Electric Railway and Motor Company, which was destined to play a leading part in the advancement of the art.

Meanwhile the Edison and Field interests had combined in the Electric Railway Company of the United States, its first move being the exhibition of a small locomotive called the "Judge," which run around the gallery of a building at the Chicago Railway Exhibition. A Weston dynamo was used for the motor, geared to a jackshaft from which power was transmitted to the wheels by belts. The current was supplied from a centre rail, with track return, a lever operated clutches on the driving shaft, and the speed was varied by resistances in the circuit. For reversing the motor two sets of brushes were used, only one pair of which could be thrown in circuit at a time by a lever and disc geared to the brush-holding arms.

VAN DEPOELE'S ACTIVITIES.

Early in this year a Belgian woodworker, Charles J. Van Depoele, who was interested in electrical work, attacked the railway problem in energetic fashion, and being a tireless worker and prolific inventor, left a permanent impress upon it. His first experiments were conducted in or near his works in Chicago, in the winter of 1882-83, where a car was operated by an arc-light dynamo used as a motor, the current being taken from a wire laid

in a trough; and in the autumn the car was shown at the Chicago Industrial Exhibition. This venture was followed by considerable work to which reference will be made later.

About this time Van Depoele is reported to have tried an experiment in which he used an overhead wire with an under-running contact wheel, and this formed the basis of an interference between us, involving the issue of the under-running trolley. Neither of us had applied for patents until about 1886, and while each had made the invention quite independently, it is a moot question if my conception while abroad was not the earlier and more complete. In the interference proceedings, however, despite the fact that I was a Naval officer and had been abroad on duty, the Patent Office ruled that my testimony as to the conception of invention could only be accepted as of the date of my return to the United States in May, 1883. On the basis of this ruling concession of issue of the patent was yielded to Van Depoele, but on account of the closeness of the dates of conception, and possibly because of doubt as to the legality of the Patent Office action, this was on condition that the Sprague company should have free license to use the under-running trolley, while certain special features covering the working conductors and feeders were not reciprocally permitted.

LEO DAFT'S EXPERIMENTS.

Among the active American workers of this period was Leo Daft, who after engaging in the development of motors for stationary work had applied himself to the electric railway problem, making his first experiments at his company's works in Greenville, New Jersey, in 1883. These were resumed in November of that year on the Saratoga and Mt. McGregor Railway, where a locomotive called the "Ampère" pulled a full-sized car. The motor was mounted on a truck and connected by belts to a jack-shaft, from which other belts led to pulleys on the driving axles. The current was supplied from a central rail, with the running rails for return, and at comparatively low potential, while variation of speed was obtained by modifications of field windings.

Meanwhile, commercial work had begun in Great Britain, the first installation being the Portrush Electric Railway to the Giant's Causeway in Ireland, installed in 1883 by Siemens Brothers of London under the direction of Dr. John Hopkinson. The power

was generated by a water turbine, and the current transmitted by a third rail carried on posts alongside the track, with track return, the pressure used being about 250 volts. In the same year there was installed a short road at Brighton, using the running rails, and also experiments conducted with storage batteries at Kew Bridge, London.

The year 1885 showed at least equal activities. Van Depoele operated a train pulled by a dummy at the Toronto Exhibition, taking the current from a conduit below the car; and Daft installed small exhibition roads at the Mechanics' Fair, Boston, the Point of Pines and Coney Island. In August Messrs. Bentley and Knight, who had conducted some experiments in the yards of the Brush Electric Company at Cleveland in the previous autumn, installed a conduit system on the tracks of the East Cleveland Railway Company. This equipment covered a section of the road two miles long, and the conduits were of wood laid between the tracks. Two cars were employed, each of which was equipped with a motor carried under the car and transmitting power to the axle by wire cables. The current was supplied from a Brush constant-current, arc-light dynamo. The equipment operated at intervals during the winter and was then abandoned.

In this year, also, Dr. Wellington Adams, of St. Louis, proposed a radical departure in motor mounting. According to this the armature was carried directly on the axles and the field magnets by a frame rigidly secured to the axle-boxes, this frame also carrying an intermediate gear which formed the connection between the armature pinion and the axle gear. In operation the armature and axle revolved in opposite direction. The scheme was found impracticable and was not introduced commercially.

THE KANSAS CITY ROAD.

In 1884-85 another inventor, John C. Henry, installed and operated in Kansas City a railway supplied by two overhead conductors, on each of which travelled a small trolley connected to the car by a flexible cable. The motor was mounted on a frame carried on the car axle, to which the power was transmitted through a clutch, and a nest of change-gears giving five speeds, very much after the fashion of present-day automobile practice. Subsequently equipping a portion of another road, he conducted a number of experiments in some of which the rails were used as a

return. Various collectors were devised, and one is said to have been carried on the car, but the final selection was a trolley with four wheels disposed in a horizontal plane, carried by and gripping the sides of the trolley wire, and pulled along by a flexible cable connecting it to the car. This feature, using one overhead wire and the rail return, was used on a small road installed by Henry at San Diego, California, two years later.

In the early part of 1885 Prof. Sidney Short, of Denver, began a series of experiments on a short piece of track, followed by the construction, in connection with J. W. Nesmith, of a section of road for conduit operation. The series system was used, a constant current being sent through all the motors on the line in series, by automatically sectionalizing the conductors, the total potential varying according to the number and duty of the motors. Speed and direction of movement were varied by shifting the commutator brushes or diverting a part of the current around the motor. The experiments were continued into the following year and were repeated at Columbus, but failed because of the principle involved. Later, adopting multiple distribution and operation, where each motor is independently supplied from a source of constant pressure, Short attempted the use of gearless motors, but soon reverted to the geared type.

FIRST U. S. COMMERCIAL ROAD.

Daft began work on the Hampden Branch of the Baltimore Union Passenger Railway in August of this year, at first with two motors which pulled regular street cars, and doubled his equipment the following year. Current was taken from a centre rail, with track return, except at crossings, where an overhead conductor was installed, the connection to which was made by a transversely hinged arm carried on the car and pressed upward by a spring. Power was transmitted by a pinion connected with an internal gear on one of the axles.

I believe that this was the first regularly operated electric road in the country, and the conditions of the contract required a year's satisfactory operation before payment. It is said that a certain scientist remarked that any one who would undertake such contract was either a fool or a knave, but this was not the only instance in which those who were strong in the faith were willing to take great risks. That this opportunity came to Daft was due

to the progressive instincts and determination of Thomas C. Robins, an earnest believer in the possibilities of electric traction, whose efforts met with much of indifference and opposition on the part of the owners of the road.

Encouraged by his success in Batimore, Daft soon undertook a more ambitious experiment, the equipment of a two-mile section on the Ninth Avenue Elevated Railroad, New York, where in the summer of 1885 he operated a locomotive called the "Benjamin Franklin," which, pulling a train of cars, made several trips. The motor was mounted on a platform and pivoted at one end, power being communicated to the driving axle through grooved friction gears held in close contact by the weight of the machine reinforced by an adjusting screw. The experiments were soon suspended, and not resumed until three years later, when for several weeks a rebuilt and improved "Benjamin Franklin" was frequently run between the steam trains on the section between Fourteenth and Fiftieth Streets. A speed as high as twenty-five miles per hour was sometimes obtained, and on one test an eight-car train was pulled up the maximum grade of nearly two per cent. at a seven-mile gait. The adoption of a low potential, to which Daft seemed to have then committed himself, militated against higher speeds.

In the summer of 1885 Van Depoele resumed the operation of the train at the Toronto Exhibition, but on this occasion he used an overhead wire carried on brackets, with a weighted arm pressing a contact wheel up against it. His first commercial installation was made in the autumn at South Bend, Indiana, where five small cars were operated, followed by one at Minneapolis, where an electric car took the place of a steam locomotive. In the following year he installed small roads at Windsor, Canada; Appleton, Wisconsin; Ft. Huron, Michigan; Scranton, Pennsylvania; and Montgomery, Alabama, using on the last a non-reversible under-running trolley carried on the forward end of the car, which was run around a loop for return movement, but on some other roads a travelling trolley carried on the overhead wire and connected to the car by a flexible cable.

Abroad little was being done. Mr. Anthony Reckenzaun, an advocate of storage battery operation, had conducted some tests in 1883 with an electric launch, and then operated cars in 1884-85 at Millwall and Battersea, England, following with a similar demonstration in Berlin at the end of the latter year. His car

body was mounted on bogie trucks, each of which carried a motor connected by worm gearing to one of its axles. Two sets of brushes were used for reversal, and the speed was varied by grouping the motor armature and field circuits, sometimes also by the use of a starting resistance.

A short road was installed at Bessbrook-Newry under the direction of the Messrs. Hopkinson in 1885, and also one at Ryde in 1886, in which year also Holroyd Smith installed the Blackpool road. In this a conduit system was used with a complete metallic circuit. The motor was carried under the car between the axles and connected by chain gearing. Fixed brushes with end contact were used for both directions in running.

SPRAGUE EXPERIMENTS.

When I separated from Mr. Edison in 1884 and formed my own company it was at considerable personal risk. The company was only a paper one, with a nominal \$100,000 capital, all issued to me for inventions and patents, and for which I was to bear the cost of all experimental expenses and perform sundry services for a modest salary which I was to pay to myself. A few shares having been sold and the proceeds soon used for personal expenses, I made a verbal contract with Mr. E. H. Johnson, then president of one of the Edison Companies, by means of which he was to advance certain moneys for a specified interest in the company. One small room sufficed for our business requirements, and the stationary motor development was carried on in the shops of Bergman and Company, New York. But in the fall of the year we had made progress enough to be able to send to the Philadelphia Electrical Exposition a number of motors, among others a new constant-speed non-sparking type, which was the forerunner of a rapidly growing business, accentuated by the endorsement in 1885 by the parent Edison Company for its use by their licensees.

ELEVATED RAILROAD EXPERIMENTS.

My mind, however, soon reverted to the railway problem, and having conceived in 1885 a novel scheme of operation for the Manhattan system, this embracing the now universally used "wheelbarrow" method of motor suspension, I elaborated it to some extent in a paper read before the Society of Arts in Boston in December, 1885. In addition to the axle mounting of the

motors, which were shunt wound, resistances were provided in both the armature and field circuits for variation of speed, return of current to the line and for electric braking.

About this time the Edison-Field interests had installed a battery of small dynamos in the old Durant Sugar Refinery on East Twenty-fourth Street, New York, and Field had made a short trial of a locomotive controlled by a water-rheostat on the Thirty-fourth Street Branch of the Elevated, where a third rail had been laid between the tracks. I had already begun the construction of motors to demonstrate the plans described at the Society of Arts, and the Edison-Field activities having come to a halt arrangements were made by Mr. Johnson for the prosecution of my experiments in connection with the same generating equipment.

The first tests were carried on with two motors mounted on an elevated railway truck under a flat-bottom car, on a track about 200 feet long between the walls of the refinery. Among those who came to see these experiments was the late Jay Gould, then one of the principal owners of the Manhattan Elevated, and it is likely that overconfidence on my part was one of the causes of his subsequent lack of interest in electric developments. Mr. Gould was a man of small stature, and during the operation of the car was standing near the controller and an open safety fuse. On account of the short space for operation the controller which governed the motors for both running and braking was handled quite abruptly, with the result that the fuse blew, with a startling flash, followed by Mr. Gould's attempt to jump off the car.

The experiments were later transferred to the Thirty-fourth Street Branch, and in May of 1886 were witnessed there by a large number of officials connected with the elevated and other enterprises, but although the work continued until December I believe no stockholder or director of the Manhattan road apparently took any further interest in the outcome. But the machines used were the parent models of the modern railway motor. They were centered through their brackets, wheelbarrow fashion, on the driving axles and suspended at the free ends by springs from the transoms. They were single geared, had one set of brushes, were without weather protection, and were used not only for propelling the car but for regenerative braking. During the latter part of the experiments a second pair of motors was added, with

an interpole winding to maintain fixed non-sparking positions for the brushes. Soon afterwards one of these motors was put into service at the East Boston Sugar Refinery, taking current from a trolley carried on an overhead wire, and was later rescued and the winding restored to illustrate the interpole winding which later has become so important. Two others later operated the first electric snow-sweeper and ice-cutter on the Allston division of the West End Railway in Boston in 1888.

Like many other inventors I was apparently ahead of the times, and, changing my plans for the time, on the suggestion of Mr. J. H. Vail I soon began the equipment of a locomotive car, to be equipped with four seventy-five horsepower motors, each with two armatures geared to the axles and with the magnetic fields in tandem as on the present New York Central locomotives. This is still used for experimental purposes in Schenectady.

URNS TO TROLLEY PROBLEMS.

The Elevated field offering little of immediate promise, I soon turned my attention to the trolley problem.

Reviewing the conditions at this time, eight years after the Berlin Exhibition by Siemens, it appears that, including every kind of equipment, there had been made only about nine installations in Europe and ten in the United States, with an aggregate of about sixty miles of track and less than a hundred motors and motor cars, characterized by the utmost diversity of practice. There were high and low pressures, series and multiple circuits, traffic-rail conductors and conduits, third-rail return, slotted-overhead tubes, single- and double-overhead wires with single- and double-travellers on them, and upward-pressing arms carried on the cars. The motors were of varied construction and control, generally using two sets of brushes for reversal of movement. One motor to a car usually constituted an equipment, being carried on a dummy or on the front platform, and were connected to one axle by a belt or chain drive. The cars were mostly single ended and controlled from one point. The art was in a chaotic state, and commercial success on a large scale, involving radical departures in practice, was needed to focus the advantages of electric traction, even then thrusting themselves into prominence.

Supplementing small additional roads by Van Depoele at St. Catharine's, Ontario; Lima, Ohio; Binghamton, New York; and

Jamaica, Long Island; and by Daft at Asbury Park, New Jersey; and Los Angeles, California, such an opportunity came in the spring of 1887—and, by good fortune, to my company—in the contracts for the Union Passenger Railways of St. Joseph, Missouri; and Richmond, Virginia; and about the same time one of somewhat different character to the Bentley-Knight Company, on the Observatory Hill Passenger Railway of Allegheny City, Pennsylvania. That year may be said to mark the beginning of the modern commercial development.

The latter road was about four miles long, one-quarter being of conduit construction and the remainder having a double trolley line on side poles, with a travelling trolley connected to the car with flexible cables. It presented unusual difficulties. There were thirty-four regular curves and numerous heavy grades, the maximum being over twelve per cent. and one averaging six per cent. for nearly a mile. The cars were equipped with two fifteen horsepower motors geared to the axles and overhung. The control was by resistance variation. This line was opened early in 1888 and continued in successful service for some time; but the conduit was finally abandoned, and a new equipment was installed with under-running trolley.

THE RICHMOND ROAD.

In the capital of the old Confederacy a new one was assaulted, but this time it was one of physical difficulties, adverse financial and operating conditions, and all the ills of a new and untried system. When my company took the contracts for roads at St. Joseph and Richmond we had little to show other than some blueprints, the machines used on the elevated railroad experiments, and some crude machines used in connection with storage battery operation, but confidence was strong and the contracts were taken under terms, price and guarantee easily placing them ordinarily in the “knave or fool” class, especially in view of the unprepared state of the company to undertake a work of such magnitude. I have, however, always had an abiding faith in the necessity of backing one’s faith in a new development to the limit of one’s capacity, and the need of this undertaking to break through the inertia of doubt and disbelief.

The Richmond contract called for the completion in ninety days of the equipment of a road having about twelve miles of

track, at that time unlaid and with the route only provisionally determined; the construction of a complete steam and electric central-station plant of three-hundred-and-seventy-five horsepower capacity; the construction of an overhead line; and the furnishing of forty cars with eighty motors and all the appurtenances necessary for their operation. This was nearly as many motors as had been installed on all the cars throughout the rest of the world. Thirty cars were to be operated at one time, and grades as steep as eight per cent. were to be mounted. Finally, the payment was to be \$110,000—"if satisfactory."

Fortunately for the future of electric railways the difficulties ahead could not be foreseen, otherwise the contract might never have been closed. But disheartening as these were, great as was the expense incurred and grave as were the risks encountered, they were justified by the results, for the Richmond road, by common consent, stands as the prototype in almost every essential detail of the modern electric-trolley system, and its installation marked the real beginning of the great industry of electric traction.

The contract was made in May, 1887, and shortly afterwards I was stricken with typhoid fever, leaving for the time being the burden on my two principal assistants, Lieut. Oscar T. Crosby, a West Point graduate, and Ensign S. Dana Green, of my own Alma Mater, the Naval Academy, both of whom had resigned to enter the electrical field.

Although a hundred and one essential details were under-terminated, during my absence everything possible was done, and on my way back from a convalescent trip to the West I had the pleasure of seeing one of my trusted men, David Mason, start a car on the track at St. Joseph, and immediately afterwards I resumed general charge of the work. I had not yet seen the Richmond road, but much of the track-work was finished, poles were set, many of the motors constructed, and experimental work on them and the controlling switches and trolleys was under way.

The construction syndicate was clamorous for operation to begin, excuses on our part were without number. I shall never forget my feelings when, after inspecting the improvised car sheds at one end of the line, I reached the foot of the steepest hill on my return, and faced a grade varying from four to ten per cent. and about a mile long. The condition of the track was simply execrable, built for profit, not for permanence. The flat twenty-seven-

pound tram rails, of antiquated shape, were poorly jointed, unevenly laid and insecurely tied, on a foundation of red clay. The many curves were sharp, some with a twenty-seven-foot radius; they had only one guard rail and spread easily. The car-house was an open lot on which were two roughly covered sheds. Altogether, I began to realize the extreme hazards, both electrical and financial, which had been imposed upon my company.

The history of the Richmond road has been too often written to dwell upon it at any length here. Suffice it to say that after experimental runs in the latter part of 1887 it was put into commercial operation in the beginning of February, 1888, and for a year there followed an experimental period of development which taxed the resources of the company to the limit.

The general features characterizing it may be briefly summarized as follows: A system of distribution by an overhead line carried over the centre of the track, reinforced by a continuous main conductor, in turn supplied at central distributing points by feeders from a constant-potential plant operated at about 450 volts, with reinforced track return. The current was taken from the overhead line, at first by fixed upper-pressure contacts and subsequently by a wheel carried on a pole supported over the centre of the car and having free up-and-down reversible movement. Motors, one to each, were centered on the axles, and geared to them; at first by single and then by double reduction gears, the outer ends being spring supported from the car body, so that the motors were individually free to follow every variation of axle movement and yet maintain at all times a yielding touch upon the gears and absolute parallelism. All the weight of the car was available for traction and the cars could be operated in either direction from either platform. The controlling system was at first by graded resistances, effected by variation of the field coils from series to multiple relations, and series-parallel control of armatures by a separate switch. Motors were run in both directions with fixed brushes, at first laminated ones placed at an angle, later solid metallic ones with radial bearing, and finally carbon, as proposed by Van Depoele.

The well-nigh heartbreaking experiences and the record of good and bad performances are largely matters of personal history, but the results accomplished soon commanded the attention of those interested in street transportation, most prominent among

whom at that time was Henry M. Whitney, President of the West End Railway of Boston, who was considering the adoption of the cable. He consented to come to Richmond, and accompanied by his associates stopped also at Allegheny City to see the underground conduit of the Bentley-Knight Company. The demonstrations made for his benefit were conclusive, the cable proposal was abandoned, and orders given for trial installations of both the overhead and underground systems to run from the Providence depot in Boston to the suburb of Allston.

Richmond's early troubles were buried under an immediate financial loss to my company of about \$75,000, fully compensated for, however, in the subsequent growth of a great industry.

TELEPHONE TROUBLES AND THE BOOM.

To enliven the general situation, however, no sooner was the single overhead trolley with track return adopted than there began a battle with the telephone companies, who claimed the earth and all therein, which was fought to a legal and technical finish in twenty-seven States of the Union, as well as in England. The troubles which they were already experiencing because of the use of grounded circuits were intensified wherever there was an electric railway, partly because of sympathetic induction and partly because of derived circuits, which made the hissing and frying noises intolerable, to say nothing of frequent burn-outs of telephone circuits. Hence the trouble, but in the end we remained below, and they for their own salvation went up higher and adopted complete metallic circuits, for which improvement the electric-railroad men are entitled to the gratitude of the community.

Franklin Leonard Pope, in a historical sketch read before the Electric Club in 1891, referred to this pioneer enterprise in the following words:

Laboring under enormous difficulties and drawbacks Sprague succeeded, by the completion and operation of this (Richmond) plant in establishing beyond peradventure the future supremacy of the electric street railway, and many of the characteristic features at that time designed and introduced by him have practically become standards in the modern system, and are found in nearly every one of the thousands of cars now in service.

OFFERED THE VAN DEPOELE COMPANY.

During the progress of the installation at Richmond the Van Depoele Company was offered to me by William J. Clark; but partly because of confidence in my own work and lack of appreciation of Van Depoele's, to say nothing of the fact that our resources were already taxed to the limit, the offer was not long considered, and shortly afterward it fell into the hands of the Thomson-Houston Company, which had only a short time previously entered the railway field.

The final success of the Richmond road, the rapid equipment of a number of others, and especially the adoption of electricity on the West End Road of Boston by Mr. Whitney, whose first installation was part conduit and part trolley, and to whom must be awarded the credit for initiating the modern consolidation of street railways, were followed by a period of extraordinary activity in commercial and technical developments, in which for a time the Sprague and Thomson-Houston companies were the principal competitors, more than two hundred roads being put in operation or under contract within two years. The contest between the companies was of the keenest sort and the methods of exploitation most varied; but in the general progress they were aided by the rapidly growing interest and belief in electric railways and the pressure exerted in many communities to abandon old practices. An amusing illustration is offered by the call for a mass-meeting held in New Orleans to demand that a line operated by mule power should change to the new system. The heading of the call, here reproduced, is typical of the South.

LINCOLN SET THE NEGROES FREE!
SPRAGUE HAS SET THE MULE FREE!

THE LONG-EARED MULE NO MORE SHALL ADORN OUR STREETS.

The progress made in the United States soon commanded the attention of the Old World, and work was begun along the same lines in Italy, where I installed the first road, the Florence-Fiesole, in 1889. A few days after the opening a car jumped a curve, killed and wounded about twenty people, and we were finally permitted to resume operation after installing a short-circuiting switch which could be operated by the conductor, thus permitting electric braking by reversal of the controller. The

first road in Germany was installed at Halle, by our agents, the Allgemeine Elektrizitäts Gesellschaft, but it was not until a number of years later that there was any general adoption of the electric railway in the more conservative countries.

Meanwhile, the Sprague Company was absorbed in 1890 by the Edison-General Electric; and soon afterwards, embittered by personal experiences in an attempted suppression of my name and a suggested abandonment of the trolley in favor of the use of low-potential rails, and the proposed creation of a new motor, all failures, I severed my connection with it. The Edison Company was later combined with the Thomson-Houston Company in the General Electric. The Westinghouse Company had meanwhile actively entered the field, and for a number of years these great companies have done the larger part of the electric railway work in this country.

RECORD OF DEVELOPMENT.

The record of the succeeding years is largely that of an extraordinary industrial development, with continuous improvement in, and increase in size of, the apparatus. Form-wound armatures, proposed by Eickenmeyer, replaced irregular windings, and metallic brushes had given way to carbon, this single change, initiated by Van Depoele in 1888-89, going a long way toward making the art a success. Cast and wrought iron yielded to steel, two-pole motors to four, double-reduction gears to single, and open motors to closed ones protected by their own castings.

The horse and cable virtually disappeared on old lines, and new ones in great number were created, the overhead-trolley system being almost universally adopted. The conduit system used on a portion of the Allegheny and Boston lines had been abandoned; and although in 1893 a short line was tried in Washington on the Love plan it was not until the following year that work was begun in New York on the Lenox Avenue line, and finally carried to that successful conclusion which warranted its widespread adoption in that city under the auspices of William C. Whitney and Herbert H. Vreeland, and shortly afterwards in Washington under Connett. Abroad, a Siemens road had been in operation at Budapest since 1889. On account of the necessarily heavy cost of construction street-railway managers would not undertake any such

investment except under most favorable traffic conditions, and only when impelled by prohibition of the use of overhead wires.

INCREASE OF POTENTIAL.

Richmond and the many roads that were contracted for during the next few years were all operated on the system of direct supply, that is, by direct current without the intermediary of substations, and at voltages not exceeding 600 volts. While this was sufficient to meet the requirements of the times, in the very early days I realized the economic necessity of raising the working potential, especially if the matter of general railway electrification was to be attempted. This conclusion was illustrated in the potentials specified as required in a project to electrify the New York and Philadelphia Division of the Pennsylvania Railroad, as outlined in a paper read by me before the National Electric Light Association at Kansas in 1890.

Prior, however, to any serious consideration of this class of operation there began a rapid introduction of interurban railways, which was soon aided by applying the developments which had been made in polyphase transmission by Ferraris and Tesla, and in transformers and rotaries by Stanley, Bradley and others, which made possible the economies of alternating current transmission at high potentials and the advantages of direct-current motor operation, through the intermediary of step-down transformers and rotaries or motor-generators, all vital to long-distance and high-powered work where direct-current motors are used.

LOCOMOTIVES APPEAR.

Soon after the use of electricity for single cars had proved successful, heavier operations were naturally attempted, and as early as November, 1890, a line on the South London Road which was originally designed for cable was opened, the trains being pulled by electric locomotives equipped with a pair of gearless motors having armatures mounted on the axles of the drivers. Two years later the Liverpool overhead trolley was put in operation. Here the trains were composed of two-car units, each car having one motor, the two being operated by hand control. In the spring of the same year, 1893, the Intramural Railway was constructed at the World's Fair, Chicago, where motor cars with

hand control were used to pull trail-cars, and a third-rail supply with track return was adopted.

In 1895 the Metropolitan West Side Elevated Road in that city was equipped on the same general plan. In the following year the Nantasket Beach Road, a branch of the New York and New Haven Railway, was put in operation, and in September the Lake Street Elevated of Chicago. Soon afterwards electric service was instituted on the Brooklyn Bridge, motor-cars being used to handle the trains, at first at the terminals and later across the bridge.

There were few attempts, however, to replace steam operation, and only occasionally were electric locomotives used for some special reason. Among the earlier ones in the United States was one of a thousand horsepower, designed by the firm of Sprague, Duncan and Hutchinson. This was provided with a pilot-lever pneumatic control, and was built in 1892-94 for Mr. Henry Villard, for experimental operation on a line out of Chicago which was never undertaken. A still larger locomotive was built by the General Electric Company and used for operating the trains in the Baltimore and Ohio tunnel in 1895.

THE MULTIPLE-UNIT SYSTEM.

Meanwhile, although for the time being out of active railway work, having taken up the problem of vertical transportation, that of electric elevators, I was keenly interested in the rapid-transit problem, and urgently advocated a four-track, underground, electric railway for New York. To silence the objections of a portion of the daily press, in February, 1891, I offered under heavy forfeiture to install, in four months, on the elevated road a train to be operated by a locomotive car, also one to be operated by motors under the cars with a pilot control, and to make an express speed of forty miles an hour.

All proposals which followed steam precedents seemed a pitiful falling short of the possibilities of electric-train operation. In the development of electric elevators I had adopted distant control of the main motor-controller from a master switch. On the first large contract, that for the Postal Telegraph Building in New York, I had provided for the supplemental control and operation of any elevator in the plant from a single master switch in the basement, with the resultant possibility of simultaneous movement of all of them from one switch.

While pondering over the elevated electric-railway train problem one day the thought suddenly flashed upon me: Why not apply the same principle to train operation? That is, make up trains at any length by the combination of car units, a part or all of them equipped with motors, but all equipped with train lines, without regard to number, end relation or sequence, and to control such trains from either end of any car by a master switch connected to the common train line.

The idea, sketched on a scrap of paper, marked the complete birth of this new method, then named and now everywhere known as the "multiple-unit system." Its great possibilities instantly absorbed my interest, for I saw the opening of a new epoch in electric-railway operation. Here was a way to give a train of any length all the characteristics of a single car, with every facility of operation demanded by the most exacting conditions of service and capacity.

FIRST EQUIPMENT IN CHICAGO.

After two abortive attempts to get the privilege to demonstrate the advantages of the system at my own expense on the Manhattan road in New York an unexpected opportunity suddenly arose in the spring of 1897, when I was requested to act as the consulting engineer of the South Side Elevated Railway of Chicago. A brief inspection of the layout showed a field ripe for multiple-unit application, which I briefly explained to Sargent and Lundy, the engineers, and to Mr. Clark of the General Electric Company, fortunately all old friends. I hastily drew up a report, the main feature of which was an argument in favor of the abandonment of locomotive cars and the adoption of individual equipment under common control—in short, the multiple-unit system. As evidence of my confidence I supplemented the report by an offer to personally undertake the equipment on the general plan outlined, which met with the indorsement of the engineers. The contract was not concluded until after I left for Europe, and then only after a bitter contest with various companies and under most onerous conditions, supplemented by a \$100,000 bond for performance.

HARD CONDITIONS IMPOSED.

Among other things I was immediately to begin work on the entire equipment and to have six cars ready for operation, in two

months, on a standard track supplied by me, the manner of making the test to be prescribed by the officers and engineers of the road and to be to their satisfaction. Should the test not be concluded by the date set, or prove unsatisfactory, the contract could be cancelled. Further tests could be called for elsewhere and the remaining equipments were to be completed by specified dates. As soon as the power-house and road were ready there was to be another test of not less than twenty equipments under service conditions for a period of not less than ten days. Should these equipments prove unsatisfactory the right still remained for the railroad company to cancel the contract and to require waiver of all claims.

I did not return to New York until about the middle of June, so that most of my instructions for the trial equipments were by cable, and the actual preparation was made within about thirty days, despite a wholesale strike of the mechanics employed in the shops of the new Sprague Electric Company, which soon took over the contract.

On July 11, 1897, two cars were put into operation on the tracks of the General Electric Company at Schenectady, and on the 26th, the half-century anniversary of Professor Farmer's test of a model electric railway at Dover, my ten-year-old son operated a six-car train in the presence of the officers and engineers of the South Side Elevated Road at Schenectady.

In November a test train of five cars was put in operation in Chicago, and on the 20th of the following April twenty cars, seventeen of which (one in flames) were taken off during the day because of defective rheostats; but with the last three-car train I had the satisfaction of pushing a steam train around a curve. Three months later, a year after the Schenectady test, locomotives had been entirely abandoned and the whole one hundred and twenty cars were in operation.

The controllers for the original Chicago equipment were of the ordinary street-car type, operated by pilot motors automatically retarded by any excess of current in the motors during acceleration. The train line contained three speed- and two direction-controlling wires terminating in couplers at each end of the car. The disposition of the control wires and their connection to the master switches was such that whatever the number, sequence or end relation of the cars there was never any change in the connec-

tion of the speed circuits, while when any car was reversed in make-up position the direction-controlling circuits were automatically reversed. So, also, whatever the grouping of cars, like movement of the master switch with reference to facing the track produced like relative direction of movement. These principles are fundamental whatever the changes of physical details.

As an alternative physical construction the Westinghouse Company first used a step-by-step pneumatic motor to operate the controller, and later, on account of the increase of duty, both the General Electric Company, which finally absorbed the Sprague Company, and the Westinghouse Company replaced the single cylinder form of controller by a combination of individual contactors each under a magnetic blowout, although later there was a return to cylinder operation.

The multiple-unit system is now a fundamental essential, the world over, for all electric-train operation where two or more equipped cars or locomotives are controlled from a common source, and its value in dense rapid-transit service like the Elevated and Subway in New York is indicated by the enormous increase of capacity compared with any other method of operation, a practical result which could not be equalled in any other way on the present subways alone for less than \$100,000,000 capital cost of construction.

MAIN LINE ELECTRIFICATION.

Following a serious accident in the yard tunnel of the New York Central road, the first important step in America in main-line electrification was taken when a new station was determined upon, and electricity adopted for operation at and for some distance from the main New York terminal, in 1902-03; and here again there was a radical departure in engineering practice. Up to that time all motors used for railway purposes maintained a fixed relation between the armature and the field, but when this project was finally taken up under the guidance of an Electrical Commission, presided over by the then vice-president, Mr. W. J. Wilgus, and of which commission I was a member, a plan for a new type of locomotive, proposed by Mr. Batchelder, was submitted by the General Electric Company. This called for the use of bi-polar motors, the fields of which, carried in a horizontal plane, were supported by and made an integral part of the locomotive frame,

and hence carried above the suspension springs. The armatures were rigidly secured to the axles, and the fields, with flattened pole pieces and a comparatively large air gap, were free to move vertically relative to the armatures. All brackets and gears were thus dispensed with and the motor reduced to the simplest form. Although ridiculed by many engineers at the time the new design was accepted and has proven entirely satisfactory. These locomotives were the first to be equipped with the multiple-unit control so that two or more could be operated together, the same as the suburban cars. On this equipment was first developed the W. and S. under-contact rail.

In Europe the first important main-line electrification projects were carried out on the polyphase system, with a high degree of technical skill, by the Ganz Company on the Valtellina and the Simplon Tunnel lines. On these the axle mounting was abandoned, and the motors were carried on the locomotive frame, being connected to the drivers by side rods.

ALTERNATING VS. DIRECT-CURRENT MOTORS.

As already stated, in the early days of electric railroading it was apparent that at the electric pressures commonly used, from 450 to 600 volts, the field of operation would be restricted by the large investment required for copper, not of course within ordinary city limits but when the distances became considerable. I had, therefore, advocated improvements looking to the raising of direct-current potentials. For a long time this seemed impracticable to many engineers.

Meanwhile, the system of polyphase alternating-current transmission, with conversion to direct current at substations through the intermediary of step-down transformers and rotary converters or motor generators, had been developed to such an extent that the field of operation from a single central station was materially broadened. Of course, there was the investment at the substations, by no means a small one, and many engineers ardently recommended the abandonment of all consideration of the use of direct current for interurban and trunk-line operation, and urged the adoption for this purpose of either polyphase or single-phase alternating-current motors, with direct supply at high potential on the trolley wire, speed control to be attained by the use of a step-down transformer or otherwise.

Among the engineers who became prominently interested in this technical development may be mentioned Lamme, Finze, Winter, Eichberg and Steinmetz. It was conducted along two or three different lines. One type, originally proposed by Thomson and known as the "repulsion" motor, had the field supplied direct at the full-trolley potential. This has been largely abandoned, although an alternative of this form was developed by European engineers, in which latter type a variable potential was supplied to the armature from a transformer.

Another, and more successful type, is the series-commutator motor, much like the ordinary direct-current motor, except that the iron in the magnets is laminated to prevent loss and the pole pieces have an additional compensating winding across their faces. The high-tension current from the trolley is transformed to low tension on the locomotive and speed regulation is obtained by the use of the rheostats or voltage variations on transformers. Naturally, there are many variations in detail introduced on the equipments actually installed for railway service.

The great difference of opinion among American engineers and manufacturers gave rise to bitter controversies, which rose to a climax at the time of the adoption of the single-phase series-commutator type of motor on the New Haven road, whose trains had likewise to operate over a considerable section of the New York Central tracks at their common terminal.

THE INTERPOLE MOTOR.

Having been in the forefront of this controversy, the outcome has been of special interest. During a long period of doubt among many as to the results of single-phase operation my attention was called to developments which had taken place in variable-speed, direct-current motors for ordinary industrial purposes by making use of my old interpole winding, localized on small extra poles carried between the main poles of the motors, and in consequence I urged a test of this practice on railway motors. The first results attained were so remarkable that I instantly saw the possibilities of a great increase in the potential which could be used in direct-current operation, and that if this improvement was carried to a logical conclusion the probabilities were that the economical requirements of the larger problems could be met by this system. On account of certain inherent defects in the single-

phase motor it also seemed likely that it would gradually be abandoned, and since its sole claim for use had been based upon the economy of installation and transmission direct current might maintain its supremacy not alone upon urban and interurban roads but also in trunk-line operation.

There was, indeed, the specific lack of capacity inherent to a single-phase motor, to combat which increased armature speeds were supplemented by air-blast cooling. But of course these were equally applicable to the more sturdy direct-current motor, and were soon adapted for it, so that the relative capacities for equal weight efficiencies and heating remains as originally indicated, at least where twenty-five cycles are used.

Despite this general fact the single-phase system, which attained an early vogue in Switzerland, has continued to receive the support of the engineers of that country in its use on the State Railways, generally with 15,000-volt trolley supply, but at the low frequency of fifteen cycles.

Lack of relative motor capacity does not characterize the polyphase motor, and it has received the support of Italian engineers in several of their major installations, comparatively low trolley potentials and low frequencies being used.

In the United States a notable example of use is that on the Great Northern Railways. One of the most ambitious attempts on this plan was that undertaken by two German companies, many years ago, on the Zossen Military Line, where was made the highest record for speed of a car carrying passengers—about 126 miles per hour—the current being collected at 10,000 volts from three overhead wires by sliding contact.

The multiplicity of conductors, however, distinctly militates against the polyphase trolley system as a solution of the larger railway problem, despite the high ratio of motive power to weight and the easy use of the motor for braking by regeneration, quite independently of other limitations affecting trunk-line transportation in general and the supply of power for such from central power plants as are also used for the industrial supply of light and power.

Additional methods of using single-phase alternating currents on the working conductor have been proposed and put into practice, but these eliminate the single-phase motors entirely. Among them is the introduction on the locomotive of apparatus for changing the energy of the single-phase trolley current into polyphase cur-

rent to be used in polyphase motors, as on the Norfolk and Western Railroad.

Conversion into a pulsating direct current by the use of a mercury rectifier carried on the locomotive has been tried out quite extensively on experimental equipment, and also the use of mercury rectifiers operated from polyphase currents at substations, in both cases in connection with direct-current motors.

On the whole, the experience of the past twenty years seems to have demonstrated the soundness of the conclusions advanced with regard to direct-current development, for while the New Haven system has been necessarily maintained and extended, many of the other single-phase motor installations in the country have been abandoned, and on the other hand some of the most difficult and extended freight lines, at one time deemed by many engineers barred to direct-current operation, have adopted direct current at from 2400 to 3000 volts working potential, as illustrated by the Butte and Montana Railroad and the six hundred miles on the Chicago, Milwaukee and St. Paul Railway, this latter being the most ambitious project thus far undertaken. Following in general a plan suggested in a study of electrification for the Sacramento Division of the Southern Pacific Railroad some years ago, the St. Paul uses the motors for regeneration and braking on down grades.

Nor is the vogue of the direct-current operation confined to the United States, for French and English commissions have reported in favor of its general adoption, and on the Midi Railway of France single-phase operation has been abandoned in favor of direct-current motor operation, the conversion of A. C. to D. C. current at the substations to be effected by large capacity mercury rectifiers.

Incidentally, the development of the automatic substation, with material elimination of attendance, and a general raising of line potential and consequent efficiency by a more frequent distribution of smaller conversion units, will add to the extent and flexibility of the direct-current system.

Finally, a recognition that railroads are but one of many diversified users of electric power, and that for financial and economic reasons common sources of supply should be utilized, will prove influential in determining that system which best lends itself

to the requirements in the matter of frequencies of the most economical high tension transmission.

THE FUTURE.

It has been said that the throb of the locomotive was the heartbeat of civilization, and so the hum of the motor may well be considered a song of emancipation. Every country with expanding resources owes its growth and prosperity largely to the development of its arteries for transportation, and its future will in a large measure depend upon the efficiency with which such continues to respond to the demands made upon them.

It has been predicted that, with normal growth, traffic requirements in the United States will be doubled well within a score of years, but already many of the trunk lines are within sight of the limit of capacity at terminals and portions of the rights of way, under existing conditions of operation. The transportation problem, therefore, promises to be one of the most serious which confronts railway and governmental execution.

Increase of capacity is the coming vital need, to be achieved where possible along existing lines and by existing methods, but where these fail then in the adoption of a motive power which permits material or even radical changes in train make-ups and operation, and increase of capacity.

The steam locomotive and its rival cannot be compared simply as machines, for there are inherent differences between them. However improved, the former remains a moving power plant, limited both as to its maximum and continuous rate of power development by the capacity of its boiler and a portable fuel supply. It is an independent entity, which fact has certain advantages but also certain disadvantages.

The electric locomotive, on the other hand, is a transformer of electric energy created at distant power stations and transmitted to it by stationary conductors. Thanks to the multiple-unit system any desired concentration of power units under a common control is possible, and any number of power plants, taking their energy from centuries-old and diminishing supplies, of increasing cost, or the annually renewed white coal of the mountains, can be joined together in common supply.

Already it has been conclusively demonstrated that with the electric locomotive any given mountain traffic can be handled with

a fewer number of units and at higher speeds; that it is capable, of longer hours of continuous service under adverse weather conditions and with less terminal inspection and repairs; that train schedules can be increased not only because of the superior speed on heavy grades but because of the elimination of waits for coal and water supplies, with fewer lay-overs at a reduced number of passing points on single-track railroads; that there may be a material reduction of useless dead-tonnage haul; and that if there were universal electrification there could be saved at least one-half of the coal now used on railroads, which already amounts to a quarter of the total mined.

Among other outstanding facts it has also been established that any required amount of power can be transmitted over long distances with entire reliability and with limited losses; that it can be stepped down from very high to any required potentials at local centres of supply; that it can be distributed thence in the form of single or polyphase alternating, or direct current, the former by overhead conductors and the latter by both overhead and third-rail iron conductors; and that it can then be used in any form desired in the motive-power equipment—in short, that electricity itself, now a source of power and its character still unknown, is at once the most docile, tractable and universal servant of man.

But despite the enormous advances made and the results already accomplished it would be folly for the electrical engineer or the railroad man to assume that the limits of invention or development had been reached, as evidenced by the steady march of improvement to meet new problems and recent remarkable prophecies of things to come.

The urban and interurban fields, with the constant linking up of smaller systems into more extended systems, has gone on apace, but the trunk-line systems are still largely steam operated, and there are wide differences of opinion among engineers as to whether a single system will be dominant, and if so, what one, or whether the varying conditions and demands will be best met by specific solutions.

The financial question involved in the large cost of equipment cannot but remain a factor which will often prove controlling, for electrical operation will not be generally adopted except there be a commensurate gain of some kind. Where coal at low unit

cost is the source of power the gain in economy alone will not warrant the adoption of electricity on independently operated roads, but where coal is high in price or water power can be gotten at a reasonable cost then there is a valid reason for the change.

Excluding special cases, what will ultimately be constructively influential will be that need of increase in existing or available track capacity which I have already indicated, which is undoubtedly possible to a system which permits of individual and simultaneous control of a concentrated or distributed power plant greater than can be gotten by any other means, and can eliminate from its tracks the transportation of its fuel. It seems certain, however, that there must be coöperation in the important matter of power supply, and the general trunk-line problem will appear less formidable with the elimination of the requirements of installation of individual power houses, with their necessary reserves, and the use of current from great power plants properly linked together, which in addition to their reliability can make full use of the diversity factor in a multitude of demands.

Finer Dust Particles in Air.—A. L. MEYER, of Johns Hopkins University (*Jour. Ind. Hygiene*, 1921, iii, 51-56), has devised a simple method for the determination of the number of finer dust particles in air. The sample is collected in a Luer syringe which is graduated to 100 c.c. and has a total capacity of 160 c.c. The count of the particles is made in a Levy blood-counting apparatus. The syringe is thoroughly cleansed, then filled with distilled water free from air bubbles. This water is forced completely out, and 20 c.c. of distilled water are drawn into the syringe from a flask which is provided with a filter of cotton wool. A sample of air, with a volume of approximately 100 c.c., is now drawn into the syringe, and its exact volume is read from the graduations. The nozzle of the syringe is covered with a rubber membrane which is held tightly in place. After shaking vigorously for one minute with an up-and-down motion, the syringe is held in a vertical position; and the water is forced to the very tip of the nozzle, then withdrawn so that a small bubble of air is admitted. Any particles of dust which have adhered to the narrow region of the nozzle are also brought into suspension by the latter manipulation. The metal connecting piece is attached to the syringe; and one drop of the liquid is permitted to flow into the chamber of the counting apparatus. After the particles have settled, count is made of the number present in two fields, each one square millimetre in area.

J. S. H.