being always in the form of sympathetic interest and not a solution of his problems for him. This training should also be supplemented by a broadening of the minor official's knowledge and training, through the medium of the street railway publications and of the state and national conventions. The members of this class of employees should be encouraged with every chance to prepare a paper or to participate in the discussion of subjects at these conventions. His contribution should be made the subject of comment and discussion by the entire official family of the company. It could well be distributed among all the employees of the company, for the work or attainments of one member of the company might well be considered the property and pride of the whole company.

In conclusion, no organization should lose sight of the fact that its success and prosperity is due to the work of its combined forces, and no man in its employ who has risen in any degree whatsoever above the ranks should be too unimportant to have his growth and development followed with careful and individual concern. The employee may not know that his natural talent is being studied; that his character is being developed; that his training is being systematically carried on by advice, counsel, or by direction. He only knows that as he becomes qualified the position of greater responsibility awaits him; that as more responsibilities fall upon him, greater avenues will open for him to become acquainted with the manner in which to meet such responsibilities; that as the time arrives when he has exhausted the possibilities of the line of work in which he is engaged, he may many times, without previous request, be transferred to other work, opening up possibilities for a new development. He further knows that so long as he is ambitious to advance, he need not worry about his position, and thus he has that peace of mind which is the best environment for the growth of ideas.

The Engineering Development of the Electric Railway*

Beginning with the researches of Prof. Joseph Henry, the author traces the history of electric traction in this country and abroad, and tells in detail of the Richmond electrification in which his company lost $75,000 *on a* $110,000 *contract*

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SPEAKING generally, the whole electrical industry, so far as it is dependent upon dynamo electric machinery, may be said primarily and largely to rest upon the researches of the famous American scientist, Joseph Henry. The first real suggestion of the electric railway in the United States seems to have come from a Vermont blacksmith, Thomas Davenport, who is reported to have operated a toy motor on a small railway in 1834. In 1838 Robert Davidson, a Scotchman from Aberdeen, began the construction of a locomotive equipped with a motor. His engine attained the respectable speed of 4 m.p.h. in a trial conducted on the Edinburgh-Glasgow Railroad. Among other pioneers were Prof. Moses G. Farmer and Professor Page, the latter with the government aid constructing a small primary battery car which reached 19 m.p.h. on a road between Washington and Bladenburg.

The above and other experiments were doomed to commercial failure not alone because the source of power was the primary battery, but because the motors were of crude design and construction, based upon the attraction of keepers or solenoids. Between 1845 and 1870 the self-exciting dynamo was developed and between 1867 and 1872 its reversibility was discovered. However, in the quarter century ending in 1875 there appeared to be a complete cessation of electric railway experiments.

EARLY COMMERCIAL WORK

Among the European concerns engaged in building dynamos for lighting and other purposes that of Siemens was the most prominent. In 1879 this firm showed at the Berlin Exposition a small car operated from a third-rail with track return. Soon after among other inventors Stephen D. Field and Thomas A. Edison began electric railway experiments. Priority of invention was awarded to Field, who early contemplated the operation of street cars in San Francisco. In 1880 Edison built a small road at his Menlo Park laboratory, and in the following year Siemens and Halske established a 1½-mile, one-car line at Lichterfelde, near Berlin. The latter may be considered the first commercial electric railroad. This equipment was followed by one at the Paris Exposition where overhead distribution was used for the first time.

In 1881 I constructed at the torpedo station, Newport, a dynamo which had two armature circuits and a plug switch by means of which series-parallel combinations could be made. Tests of the machine under these conditions were made, first as a dynamo and later as a motor. Some years later there was combined with the simple series-parallel control the variation of current strength by varying a resistance in the circuits of the motors. The validity of the patent on this invention was not established for some time, and in the end an adjudication of the claims of rival inventors was avoided probably by the combination of the contending interests.

In the early eighties other inventors were becoming active, among them Dr. Finney of Pittsburgh, Professors Ayrton and Perry of England, Dr. Fleeming Jenkin of Scotland. Siemens and Halske constructed an experimental road near Meron, in the Tyrol, to demonstrate the possibilities of electric traction for the St. Gothard tunnel, and also small lines at Frankfort and Molding.

In 1882, while connected with the United States Navy, I procured an assignment to the *Lancaster*, sailing for the Mediterranean, then received leave from my ship, and subsequently obtained orders to the British Elec-

*Abstract of a paper delivered before the Atlantic City convention of the American Electric Railway Association on Oct. 12, 1916.

trical Exposition at Syderham. While riding on the underground road I conceived an ideal of electric propulsion based upon the use of the tracks as one conductor and for the other a system of rigid overhead conductors all in one plane. Soon after, resigning from the Navy, I returned to the United States and, after spending nearly a year with Mr. Edison, formed the Sprague Electric Railway & Motor Company. At the same time the Edison and Field interests combined to form the Electric Railway Company of the United States, and operated a small locomotive, the "Judge," which ran around the gallery of a building at the Chicago Railway Exhibition. In the winter of 1882-1883 a Belgian woodworker, Charles J. Van Depoele, conducted experiments in or near his works in Chicago with a small car, the current being taken from a wire laid in a trough. This was exhibited at the Chicago Industrial Exhibition. He is also reported to have tried an experiment in which he used an overhead wire with an underrunning contact wheel, and this formed the basis of a hard-fought interference between him and myself.

Among the active workers of this period was Leo Daft, who made his first experiments at his company's works in Greenville, N. J., in 1883. In November of that year, he ran a locomotive, the "Ampere," on the Saratoga & Mount McGregor Railway, where it pulled a full-sized car. There was considerable activity during the following two years in Great Britain and in this country. For example, in August, 1885, 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. This was operated at intervals during the winter and then abandoned. John C. Henry also installed and operated in Kansas City a railway supplied with two overhead conductors on each of which traveled a small trolley. He later, elsewhere, used the rail return.

In the early part of 1885 Prof. Sydney Short of Denver began a series of experiments on a series system, a constant current being sent through all the motors of the line, but later adopted the multiple distribution. He also attempted the use of gearless motors, but soon reverted to the geared type. In August of this year Daft began his work on the Hampden branch of the Baltimore Union Passenger Railway, which, I believe, was the first regularly operated electric road in this country. Encouraged by his success, he undertook the equipment of a 2-mile section on the Ninth Avenue Elevated Railroad in New York. Here, during the latter part of 1885 he operated a locomotive called the "Benjamin Franklin," which, pulling a train of cars, made several trips. A speed of 25 m.p.h. was sometimes obtained, and on one test an 8-car train was pulled up a grade of nearly 2 per cent at a 7-mile gait. During this and the following year Van Depoele installed a number of small roads.

THE RICHMOND ROAD AND PRECEDING EXPERIMENTS

After separating from Mr. Edison in 1884 I formed the company already mentioned, which had a nominal capital of $100,000, and from which I received a salary of $2,500. At first the stationary motor business was developed, but my mind soon reverted to railway problems.

In a paper read before the Society of Arts in Boston in 1885 a novel scheme of operation for the Manhattan system was outlined involving the now universally used "wheelbarrow" system of motor suspension. The opportunity later arose to try the experiment in which at first Jay Gould, one of the principal owners of the Manhattan Elevated, was interested. The experiments, which were first made on a short track between the walls of a sugar refinery, were later transferred to the Thirty-fourth Street branch of the railway. They were witnessed in May, 1886, by a large number of officials of the Elevated and other enterprises, among these officials being Cyrus W. Field and the Duke of Sutherland.

After this test I disposed of a sixth of my interest in the company for $50,000, a very acceptable help in a time of need. The experiments were continued, but the stockholders and directors of the road took no further interest in them, and I turned my attention to trolley problems.

A New York politician, who had secured a franchise for an electric railway in Richmond, Va., had associated with him in the enterprise a banker and a merchant in railway materials. A short time before my company had taken a small contract for the Union Passenger Railway at St. Joseph, Mo., and secured the one for the Richmond Union Passenger Railway in May, 1887. The latter 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 375 hp. power plant, and the furnishing of forty cars with eighty motors and all appurtenances necessary for their operation. Thirty cars were to be operated at one time, and grades up to 8 per cent were to be mounted. Finally the payment was to be $110,000 if satisfactory.

My immediate assistants on the Richmond work were Lieut. Oscar T. Crosby, a West Point graduate, and Ensign S. Dana Greene, from the Naval Academy. On account of an attack of typhoid fever I was, at a critical period, absent from work nine weeks, being almost the entire burden on my associates. When the contract was undertaken we had only a blueprint of a machine and some rough experimental apparatus.

After overcoming difficulties one by one, we began experimental runs in November, 1887, but various troubles had brought us to the end of the following January when it had become vital to begin regular operation. At this time we prepared to open the line with about ten cars. As a preliminary to regular operation we spent a day carrying loads of children, and about February 2, 1888, in a drizzling rain, we opened the line for regular service. The day was one of disappointments, as difficulties in operating the equipment developed. Troubles with gears, commutators, brushes, etc., had to be overcome. We managed, however, to keep the cars moving and gradually our greater difficulties began to lessen, even if new ones cropped up. By May 4 there were thirty cars in operation, and finally forty cars.

A most important experiment of banking the cars occurred one night on the occasion of the visit of President Henry M. Whitney and a number of directors of the West End Railway of Boston, Mass. General Manager Longstreet of the railway was a strong advocate of cable operation and had doubted the possibility of handling the cars electrically when badly bunched. On this occasion twenty-two motormen started their cars at the extreme end of a section of the line designed for four. This test was conclusive and the fate of the cable in Boston was settled. Richmond's troubles were buried under an immediate financial loss to my company of $75,000, fully compensated for in the subsequent unparalleled growth of a great industry. Among the characteristic features established by this installation were: the main and working conductors and feeders, with bonded rails and earth return; the universal movement, reversible trolley in the center of a car; double-ended control; axle-suspended motors; series parallel group-

ing; variation of field resistance; fixed end-contact brushes, and lightning arresters.

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 consolidations of street railways, were followed by a period of extraordinary activity in commercial and technical development in which for a time the Sprague and Thomson-Houston companies were principal competitors.

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. The first road in Germany was installed at Halle, by our agents, the Allgemeine Elektricitäts 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 Electric Railway & Motor Company was absorbed in 1890 by the Edison General Electric Company, and soon after I severed my connection with it and took up the development of high-speed passenger, freight and automatic house electric elevators in opposition to the hydraulic trust. The Edison Company was later combined with the Thomson-Houston Company and others in the General Electric Company. 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 and abroad. The record of the succeeding years is largely that of an extraordinary industrial development, with continuous improvement in the service rendered and increase in the size of apparatus.

Heavier Traction

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. Meanwhile, I was keenly interested in the rapid-transit problem, and urgently advocated a four-track underground electric railway for New York. I also offered, under heavy forfeiture, to install on the elevated road a train to be operated by a locomotive car, also one to be operated by motors under the cars under a pilot control, and to make an express speed of 40 m.p.h.

Two years later the Liverpool overhead railway 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, the equipment being supplied by the General Electric Company. 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 Railroad in that city was equipped on the same general plan. In the following year the Nantasket Beach Road, a branch of the New York & New Haven Railroad, was put in operation, and in September the Lake Street Elevated of Chicago followed. Soon afterward 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 on regular roads, and only occasionally were electric locomotives used and then only for some special reason.

These various equipments, all following steam precedents, seemed a pitiful falling short of the possibilities of electric train operation. Upon taking up the development of electric elevators I adopted distant control of the main motor-controller from a master switch. Pondering over the elevated railway train problem one day, the thought suddenly flashed upon me: Why not apply the same principle to train operation? That is, make a train unit by the combination of a number of individual cars, each complete in all respects, and provide for operating all the controllers simultaneously through a train line from the master switch on any car. 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.

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 at Chicago.

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 an earnest of my confidence I supplemented the report by an offer to personally undertake the equipment of the general plan outlined, which set with the indorsement of the engineers. This was followed by a visit to Chicago, but the contract was not concluded until after I left for Europe, and then only after a very bitter fight with various companies and under most onerous conditions, supplemented by a $100,000 bond for performance.

On July 16, 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. Three months later locomotives had been entirely abandoned, and the whole 120 cars were in operation, the local work being largely supervised by my assistant, Frank H. Shepard.

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 connection of the speed circuits, but when the cars were reversed the direction controlling circuits were automatically reversed. So, also, whatever the grouping of cars, like movement of the master switch with reference to the facing of the track produced like relative direction of movement. These principles are fundamental, whatever the changes of physical details.

As an alternative 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, 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.

STEAM RAILROAD ELECTRIFICATION

Following a serious accident in the yard tunnel of New York Central road some years ago, the first great step in main line electrification was taken when electricity was adopted for operation at and for some distance from the main New York terminal. 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 a plan for a new type of locomotive was adopted by the General Electric Company, originally proposed by Mr. Batchelder. This called for the use of bi-polar motors, in which the fields of the motors were carried in a horizontal plane, were supported by, and made an integral part of, the locomotive frame and were 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, and were free to move up and down relative to the armatures. These locomotives were the first to be equipped with the multiple-unit control so that two or more could be operated together. On this equipment was first developed the Wilgus and Sprague standard under-contact third rail.

Even in the early days of electric railroading it soon became apparent that at the prevailing 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 as soon as the distance became considerable. I was, therefore, always an advocate of improvements looking to the use of higher potentials, and especially urged the raising of direct current potential to its practical limit. For a long time this seemed to be impracticable.

Meanwhile the system of polyphase alternating current transmission and conversion to direct current at substations through the intermediary of step-down transformers and rotary converters or motor generators had been developed, and many engineers became the ardent advocates of 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 single-phase alternating current operated at high potential on the trolley wire, speed control to be attained by the use of a step-down transformer.

The great difference of opinion among engineers and manufacturers early gave rise to bitter controversies. During a long period of doubt among many as to the results of single-phase operation, my attention was called to the developments which were taking place in variable-speed motors for ordinary industrial purposes by making use of my old inter-pole winding, localized to small extra poles carried between the main field of the motors, and in consequence I urged a test of this practice on railway motors. The first results were so remarkable that I instantly saw the possibilities of a great increase in the potential which could be used in direct-current operation. 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 would maintain a supremacy not alone on urban and interurban roads, but also in trunk line operation.

The experience of the past few years seems to have demonstrated the soundness of these conclusions, for while the New Haven system has been, necessarily, maintained and extended, most of the other single-phase installations in the country have been abandoned, while, on the other hand, some of the most difficult and extended freight lines, deemed by many engineers barred to direct-current operation, have now adopted direct current at from 2500 to 3000 volts working potential, as illustrated by the Butte, Anaconda & Pacific Railway and the 440-mile section of the Chicago, Milwaukee & St. Paul Railway.

There are, of course, alternative methods which are still in use, as, for example, the polyphase system used on the Great Northern Railway, important installations of which have been made in Switzerland. One of the most ambitious attempts of this character was that by two German companies, thirteen years ago, on the Zossen military line, where was made the highest record for speed of a car carrying passengers, about 126 m.p.h., the current being collected at 10,000 volts from three overhead wires by sliding contacts. The multiplicity of conductors, however, distinctly militates against this general 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.

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 a locomotive of apparatus for changing the energy of the single-phase current into two-phase current to be used in a polyphase motor, as on the Norfolk & Westtern Railway. Conversion into a pulsating direct current by the use of a mercury rectifier carried on the locomotive has been tried out quite extensively in experimental equipments, and also the use of mercury rectifiers operated from polyphase currents at substations, in both cases in connection with direct-current motors.

Following the general plans suggested by me in a study of electrification for the Sacramento Division of the Southern Pacific Company a number of years ago, the Chicago, Milwaukee & St. Paul locomotives use, instead of the ordinary series motors, independent excitation of the field magnets from motor generators, which makes it possible not only to use the motors for brakes in a circuit closed around the armatures when disconnected from the line, but also to regenerate current on down grades while connected to the line.

THE FUTURE

Despite the enormous advances made and the results accomplished in electric railway development it would be folly for the electrical engineer to assume that we have arrived at the limit of invention or improvements. The urban and interurban fields, with the constant linking up of smaller systems into more extended systems, goes on apace, but the trunk-line systems are still largely steam operated. It is possible, and quite probable, that irrespective of any improvements which may develop or any new inventions which may appear the financial question will continue, as heretofore, to largely govern the question of change of motive power in the more extended fields.

It is certain that there must be co-operation in the important matter of power supply, and it is probable that the whole trunk line problem will appear less formidable with the elimination of the requirements of the installation of individual power houses with their necessary reserves, and the use of current from great power houses properly linked together which in addition to their reliability can make full use of the diversity factor in a multiplicity of demand.