Reprinted from THE JOURNAL OF THE MARYLAND ACADEMY OF SCIENCES
Vol. III, Nos. 1, 2 and 3, July, 1932

ELECTRIC TRACTION IN SPACE OF THREE DIMENSIONS

FRANK J. SPRAGUE, D.ENG., D.SC., LL.D.

PART II

It is odd that in the old capital of the Confederacy a new enterprise should have been undertaken with an untried system and under conditions of unequalled severity, to say nothing of probable financial perplexities, but it was a chance determination. A franchise for a street railway had been obtained by a New York speculative group, and in the competition for its equipment the Sprague Company had been successful. When the contract was taken there was little to show other than some blue prints, the machines used in Elevated Railway experiments, and the crude ones supplied for storage battery trials.

But with a superabundance of reckless confidence it was signed on terms and guarantees which would ordinarily assign it to the "fool or knave class," in view of our lack of experience. We had, however, an abiding faith that the technical difficulties could be overcome, and were impressed with the need of an unusual effort to break through the wall of inertia of doubt and disbelief, forcibly expressed by example by the pioneer street car builder, John Stephenson, to the effect that no self-propelled car could successfully negotiate the grades and curves encountered on street railways.

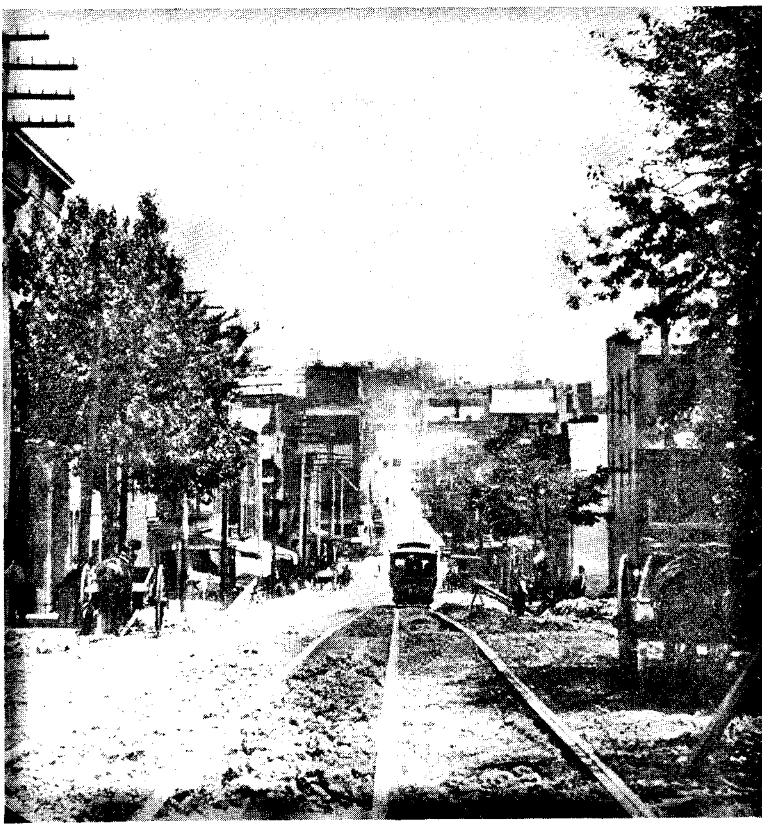
Our obligations called for completion in the short space of ninety days of a 12-mile road, the tracks at the time unlaid and the route only provisionally settled, the equipment of a central station plant of 375-horse power capacity—small now but big then—the construction of an overhead line, and the furnishing of 80 motors and all the appurtenances for the operation for an unbuilt rolling stock of 40 cars. This was nearly as many motors as had been installed on the various experimental and commercial installations throughout the world in nearly ten years. Thirty cars were to be operated at one time, in multiple circuit at 450 volts potential, and on grades of at least 8 per cent. As for payments, they were to be $110,000 "if satisfactory."

It was perhaps fortunate, at least for the immediate future of electric railways, that the difficulties ahead were unforseen, for otherwise my associates might not have approved of the venture. But however disheartening these were at times, however great the expense incurred, and grave as were the risks encountered, they were all justified by the ultimate results, for the Richmond Road, by common consent, is now acknowledged to be the prototype in almost every essential detail of the modern electric trolley system, and its installation may be fairly termed the real beginning of commercial electric traction.

The contract was made in May, 1887, but shortly afterwards I was stricken with typhoid fever, and for many weeks the burden of carrying on rested upon my principal assistants, Lieutenant Oscar T. Crosby, a West Point graduate, and Ensign S. Dana Greene of my own Alma Mater, the United States Naval Academy, both of whom had resigned from the services to enter the electrical field.

Although a multitude of essential details were undetermined, everything possible was done during my enforced absence, and on my way back from a convalescence trip to the West I had the satisfaction of seeing one of my most trusted men, Dave Mason, start a car on the tracks of the railway at St. Joseph—this equipment somewhat antedating that of Richmond. When I resumed general charge of the work I had not seen the Richmond road, but much of the track had been laid, the poles set, the motors were under construction, and experimental work on them and the controlling switches and trolleys was being carried out.

The construction syndicate, none too strong financially, was naturally clamourous for a beginning of operation, while excuses on our part for delay were without number. A trip to Richmond to inspect what had been done disclosed a most discouraging situation, especially after inspecting the improvised car sheds, and seeing the grade of the steepest hill, which varied from 4 to 10 per cent and was about a mile long. The condition of the track and the roadbed was execrable, the former built for profit, not for permanence. Flat 27-pound tram rails of antiquated shape, poorly jointed, unevenly laid and insecurely tied, rested on an

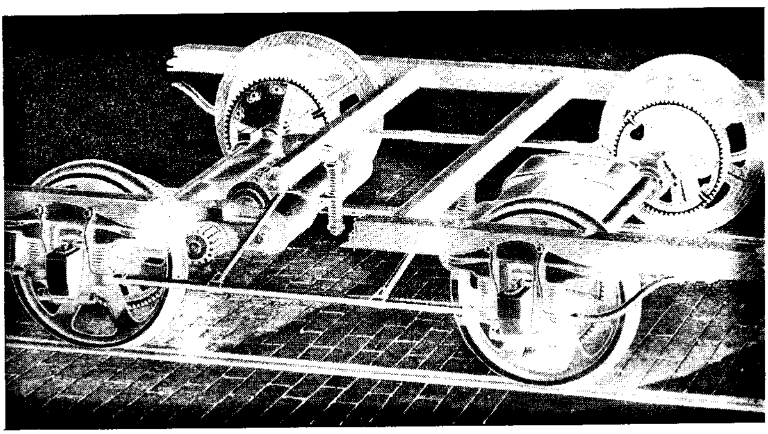


TEN PER CENT GRADE ON RICHMOND ROAD, SHOWING ALSO TRACK CONDITIONS; FROM A PHOTOGRAPH, 1887

unpaved foundation of red clay. Of the many curves some were of only 27 feet radius and with only one guard rail, which permitted them to spread easily. An open lot on which were two roughly covered sheds was the housing terminal. Altogether, there was much to make us appreciate the hazards both technical and financial which had been assumed.

The history of the Richmond road and its tribulations has been too often written to be now dwelt upon at any length. Beginning with experimental runs in the latter part of 1887, it was put into commercial operation in the early part of February, 1888, and there followed a year of alternating successes and failures which taxed the resources of the Sprague Company to the limit, rendered all the more burdensome because of failures in local management and delays in payments.

The general features of this equipment may be briefly summarized as follows: A single small trolley line carried over the



ORIGINAL SPRAGUE SINGLE-GEARED MOTORS, RICHMOND, 1887, 7½ H.P.

center of the track was reinforced by a main conductor, the latter being supplied at central distributing points by feeders from a central station operated on the constant potential system at about 450 volts. The return circuit was by the reinforced rails tied into the street mains. The current was taken from the overhead line, at first by under-contact supported by a vertical pole over the center of the car, similar to the idea proposed for the London Underground Railways, but finally, on the suggestion of one of our draftsmen, Eugene Pommer, we adopted an inclined pole freely pivoted around a trunion supported over the center of the car, with tension springs to hold the trolley wheel against the wire. There is a legend that at Richmond and elsewhere there were devised no less than sixty forms of trolleys.

The motors were mounted, one to each axle, in the wheelbarrow fashion, and geared to them, at first with single reduction and adjustable gears, but later with a double reduction assembly, the free end of the motors being spring-supported from the car

PAT O'SHAUGHNESSY
SETTLES THE SLEET TROUBLE IN RICHMOND WITH A BROOM
Drawn by Jay Hambidge

body. Even without the separate truck, as had been used in the Elevated Railroad experiments and which afterwards became standard practice, this mounting of the motors allowed them to be individually free to follow every variation of the axle movement and yet to at all times maintain a yielding but perfectly meshed engagement with the axle gears. All the weight of the car was thus available for traction, and with controllers at each end it could be operated from either platform by reversing the trolley inclination.

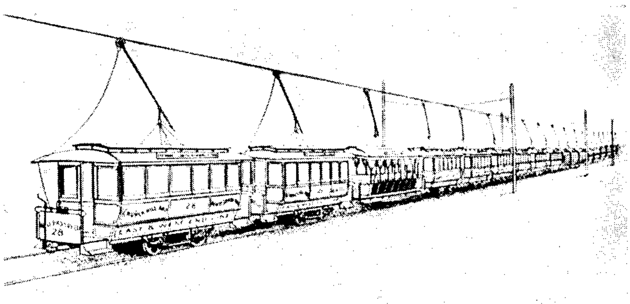
The controlling system at first made the utmost use of the series-parallel arrangement of sectionalized and graded field coils, and armatures as well, the switch for the latter being an independent one. The motors ran in both directions with fixed metallic brushes, of which there were a multitude of designs, but finally the carbon brushes proposed by Van Depoele were adopted.

The well nigh heart-breaking experiences, typified by the message when it was almost impossible to supply armatures as fast as they failed—"Greene, this is hell"—and the record of good and bad performances are largely matters of personal history, some of which were detailed in an address before the National Electric Light Association at the Kansas City meeting in 1890. But despite all, the results accomplished soon commanded the attention of those interested in street transportation, among the more prominent of whom was Henry M. Whitney, president of the West End Railroad in Boston. He has been termed the father of street railroad consolidations, and at that time was contemplating the adoption of the cable system, as was then being operated in a number of other cities.

His attention having been called to the work going on at Allegheny City and Richmond, he visited both installations with some of his associates. One of these was his superintendent, an advocate of cable operation and a disbeliever in electric. One of his objections was the improbability of being able to start a large number of cars promptly enough to clear a congestion. To meet this argument I determined upon a practical trial of somewhat dramatic character. It was customary at night to lay the cars up at one end of the line, a section calculated to carry but a few distributed cars, twenty-two of them being banked up on the night when the test was made.

Near midnight, after he had retired, Mr. Whitney was asked if he would like to see an attempt made to move a large number of cars which had been bunched at the terminal, and on his assent orders were given at the central station to put on extra safety catches, to run the potential up to 500 volts, and to keep the engines going no matter what happened. At the appointed time, on signal the motormen of the 22 cars started as rapidly as they could get clearance headway, but although the potential drop was so great that the car lights could hardly be seen, every car got away and was soon hustling out of sight.

This test was conclusive, and Mr. Whitney on his return to Boston appeared before the Board of Aldermen, and after a glowing eulogy of what he had seen obtained permission to put in a composite line, a part near the old Providence depot of conduit construction, and the balance, to Allston, of overhead construction, Sprague motors being used on all the cars.



THE BUNCHING OF TWENTY-TWO CARS IN RICHMOND, PREPARATORY TO A TEST FOR PRESIDENT WHITNEY OF THE WEST END ROAD, BOSTON
Drawn from a photograph

The Richmond experience, enriched by local receivership and change of management, totaled a loss of fully $75,000, but this was a bagatelle in view of what was accomplished—the launching of the growth of a great industry.

TELEPHONE TROUBLES

The troubles on this road were not individualized to the railway equipment, but soon emphasized the defects already experienced in the telephone system. At that time all telephone installations were made with single wire circuits and ground returns, and hence were subject to all the disturbances incident to leaks and grounds on other circuits, differences of earth potential and sympathetic induction, with resulting "hissing and frying." Long distance service was unknown and impossible. Richmond simply emphasized these troubles, to ameliorate which the local superintendent of the telephone company cut clear from the ground connections and used a common metallic return for all his circuits.

But this was only a partial remedy, and there soon began an intensive legal battle with the telephone interests of the United States, which was fought to a legal and technical finish in twenty-seven states of the Union, as well as in England. In the end the electric railway companies won their right to the common heritage of the earth, represented by their track return, and the telephone companies for their own salvation went up higher and adopted individual balanced metallic circuits, for which improvement in their system they are deeply indebted to the electric railway industry.

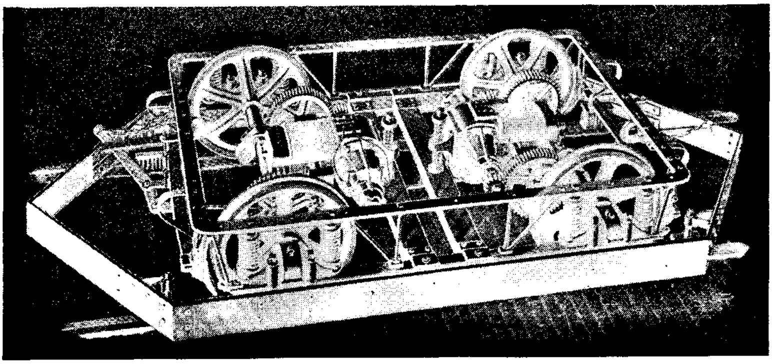
In an historical sketch read before the Electric Club in 1891, the late Franklin Leonard Pope, the second president of the American Institute of Electrical Engineers, referred to the Richmond road, as follows:

> 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.

THE COMMERCIAL BOOM

During this period of incubation there came the near creation of a monopoly in electric traction, the occasion being an opportunity, through Mr. W. J. Clark, to get control of the Van Depoele Company, then in a precarious financial condition. But weighted with their own responsibilities on hand the offer was rejected by the Sprague Company, and the other company soon fell into the hands of the Thomson-Houston Company of Lynn, which had recently entered the railway field and addressed itself to this new industry with commendable energy, two of the earlier installations being made in Washington, D. C., and in Cambridge, Massachusetts.

The initial success of the trial section on the West End system made that road an object of intense commercial rivalry between the Sprague and the Thomson-Houston Companies, the latter having an advantage of local financial association denied the former. Finally, Mr. Whitney decided to abandon the conduit system on account of the many difficulties experienced, and adopted the under-contact over-head trolley for his entire system, the Thomson-Houston Company securing the major contract.



SPRAGUE 15-H.P. MOTORS, 1888; TRUCK MOUNTED

It was a sight of the trolley car operating on the Cambridge-Boston line in the early days which led the venerable Oliver Wendall Holmes to write his rollicking poem, "The Broomstick Train, or The Return of the Witches," which first appeared in the *Atlantic Monthly* and then in "Over the Teacups,"—in which are also found his eulogies of the trolley, one of which, as an example of early reactions, may be quoted:

Look here! There are crowds of people whirled through our streets on these new-fashioned cars, with their witch broom-sticks overhead,—if they don't come from Salem, they ought to,—and not more than one in a dozen of these fish-eyed bipeds thinks or cares a nickel's worth about the miracle which is wrought for their convenience. * * * What do they know or care about this last revelation of the omnipresent spirit of the material universe? We ought to go down on our knees when one of these mighty caravans, car after car, spins by us, under the mystic impulse which seems to know not whether the train is loaded or empty.

The contest between the Sprague and Thomson-Houston Companies was of the keenest character, and the methods of promotion often those of "high pressure salesmanship," but that the trolley had come into its own, and on the basis of the Richmond installation, is indicated by the fact that within two years of its opening more than two hundred roads had been put into operation or were under contract. Communities urged the abandonment of old practices, as evidenced in a call for a mass meeting in New Orleans to demand that mule power on the Carrollton road should change to the new system. The heading of the call, typical of the South, was:

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 spread its influence into the old world, and work was begun in Italy, where the first road, the Florence and Fiésole line, was equipped in 1889. A few days after the opening a speeding car jumped a curve, killing several and wounding many more people. This accident resulted in a temporary shut-down, but operation was resumed after provision was made so that the conductor could take control away from the motorman and electrically brake the car through its own motion, a practice which could well be adopted on all roads operating on steep grades, to avoid the all-too-frequent like disasters. The first road in Germany was installed at Halle by the Allgemeine Elektricitats Gesellschaft, which had taken over the Sprague system, but it was years before there was any general adoption of the electric railway in the more conservative countries.

THE ABSORPTION OF THE SPRAGUE COMPANY

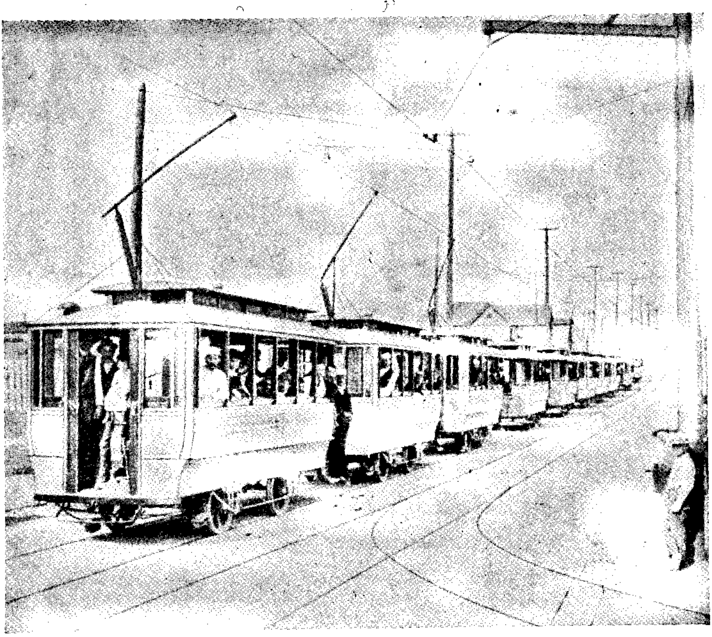
Meanwhile, the Edison General Electric Company, which had become financially interested in the Sprague Company and was manufacturing much of its equipment under contract, came to realize the potential value both in the industrial and electric railway field of that company's business, and was enabled, partly because of a community of interests, to absorb its affiliate. No sooner had this been accomplished than orders were issued that the Sprague system should thereafter be known by another name —113 railways being thus affected—, and also that the trolley was to be abandoned, at least in cities, in favor of a plan proposed by Mr. Edison. This was the use of the two track rails at very low pressure, current to be supplied from a number of motor-generators situated at short intervals apart, a system which necessarily failed. This retrograde attitude, contrary to all sound technique, for a time adversely affected the company's business, and soon, embittered by my personal experience, I resigned my connection with it and later took up another phase of electric traction—that of vertical movement, or the development of the electric elevator.

Meanwhile, the Westinghouse Company, with the aid of agents of the Sprague Company who had lost out in the shuffle, entered the railway field along the same lines, but with excellent engineering, one example of which was the construction of a completely enclosed 4-pole motor.

PROGRESSIVE DEVELOPMENT

The record of the succeeding years is largely one of continuous improvement in detail and practical design, and increase in size of apparatus. The original Richmond motors were only of $7\frac{1}{2}$ horse power capacity and single geared, but the unusual demands made upon them, far beyond contract requirements, made necessary the doubling of capacity, and finally the complete enclosure of the motor, to make good the dictum that motors could run through mud and be washed down with a hose.

Form-wound armature coils, invented by Eickmeyer, replaced unequal windings, metallic brushes gave way to carbon, this important change being initiated by Van Depoele in 1888/9. Cast and wrought iron yielded to steel, two-pole open motors to four-pole closed ones, double reduction gears to single. Series-parallel and resistance control were combined in a single unit by Condict, after Reckenzaun, and the Thomson magnetic blow-out as a protective feature by Potter.



VAN DEPOELE ELECTRIC RAILWAY, DAYTON, 1888; NON-REVERSIBLE TROLLEY POLE ON FRONT END OF CAR

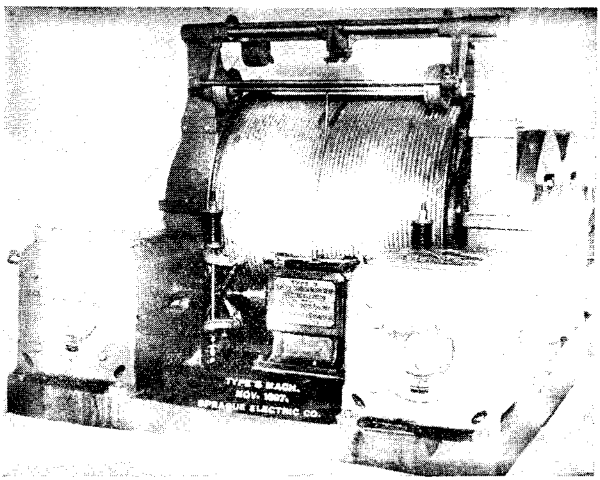
Horse and cable power was rapidly replaced on old lines, and new ones in great numbers were created, practically all using the overhead line with under-contact system, the wheel-barrow suspension of geared motors and series-parallel control. The conduit system used on portions of the Allegheny City and Boston roads had been abandoned, and save for a short section tried in 1893 by Love in Washington it was not until a year later that work was begun on the Lenox Avenue line in New York, and carried to a conclusion sufficiently successful to warrant its widespread adoption in that city under the auspices of W. C. Whitney and H. H. Vreeland, and shortly afterwards in Washington under Connett. But the success of a conduit road had also been demonstrated by Siemens at Budapest at an earlier date. The necessarily heavy cost of course militated against its adoption except under conditions of heavy traffic and where an overhead construction was forbidden.

VERTICAL ELECTRIC TRACTION

Circumstances having for the time divorced me from general railway activities I turned my attention to the solution of the problems involved in elevator operation. The general idea was of course not new, Siemens having exhibited an electric elevator at the Paris Exhibition in 1881. In this the car was partly supported by counterweights, and motion was imparted by a motor carried under the bottom of the car and geared to an upright rack. This ingenious plan was not put to commercial use, but about 1883/4 electric motors began to be used as the primary power for drum elevators operated by shifting belts. One installed in 1884, at the Pemberton Mills, Lawrence, Massachusetts, was the first example of operation at like speeds, up and down, with variable loads and regenerative return of energy to the line when the unbalanced load was in the direction of movement.

Following these applications came mine hoists, with manual control by the operator, but it was not until the early nineties that there was any serious attempt to enter the field generally occupied by the hydraulic elevator. The first assault on high-speed office building service was the installation of a battery of six Sprague-Pratt multiple-sheave electric machines in the Postal Telegraph Building in New York. This installation, following the construction of two single machines, was made in 1893/4 under a contract which guaranteed replacement by any selected type of hydraulic elevator in the event of failure, and was made possible by the foresight and courage of the architect, George Harding, and the owner, John W. Mackay.

With something of the grief attending all new ventures the equipment was carried to success, although threatened at one time, the night of the initial test, with a general collapse. On this occasion, having late in the evening made a successful individual run with the first machine, I in an elated frame of mind directed all the crew save one man to join me. Pilot motor control had been adopted, but on this ascent the car could not be stopped, and as neither the upper limit nor the car safeties had been installed there flashed an unpleasant vision of heading into the overhead sheaves at nearly 400 feet a minute, the snapping of the cables and a 14-story free drop, with a tangled mass of

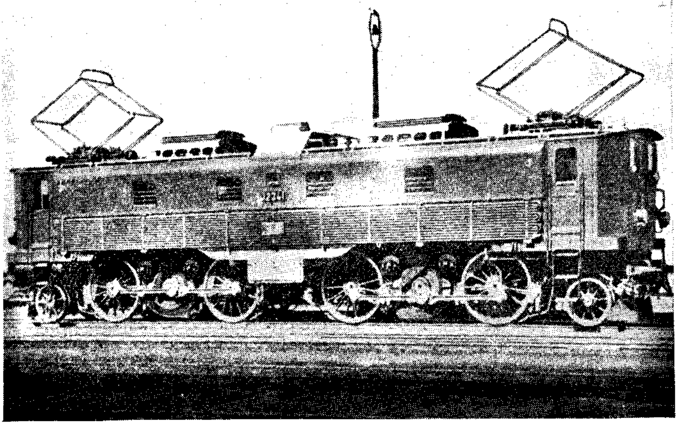


150-H.P. ELEVATOR MACHINE FOR CENTRAL LONDON RAILWAY

humanity and metal the object of a coroner's inspection. This was the picture, and the only one, in mind as without a word to my men and standing rigidly I vainly operated the controller. When two feet above the last floor and with but two more to the limit, the car suddenly stopped, the sole man left in the engine room having had the wit to pull the switch, which cut off the current and operated the electro-mechanical brake. We walked down, but the car followed leisurely under control.

The electric elevator had to face a hard fight, notwithstanding the logic which dictated its development and use, for the equipment of this vital building essential had been along steam and hydraulic lines, the latter well entrenched in the better class of service by long record, backed by a number of well-equipped elevator machine builders, operating more or less in coöperation and all banded against the new departure.

But despite all opposition vertical traction won its way, although it took several years and an expenditure of nearly a million dollars. During this period there were developed not only single, double and triple-deck multiple sheave machines, some installed horizontally and others vertically, but various types of drum



EUROPEAN SINGLE-PHASE LOCOMOTIVE

machines, varying from the small button-controlled "house automatics"—the forerunner of the modern "signal control" elevator—to the great machines built in 1897 for the Central London Railway, 49 of these requiring each a motor capacity of from 100 to 150 horse power. This contract, to break through English conservatism, was taken after offering to run the plant for two years at a fixed cost for power, under a guarantee that the work would be progressed on the whole plant, but subject to rejection without recourse if an expedited equipment in a 30-foot shaft, to be tested by the railroad's engineers, should fail to meet the specifications. This offer was made to Sir Benjamin Baker, the principal consulting engineer, and also designer of the great Firth-of-Forth railroad bridge and the Assuan Dam in Egypt.

Pilot and push button control, the "dead man's" switch, the negative electro-mechanical brake, shunted motor control, and interlocking of car and landing doors with the control circuits were all developed, and a traction-sheave drive proposed, by the Sprague Company before its consolidation with the Otis about 1900.

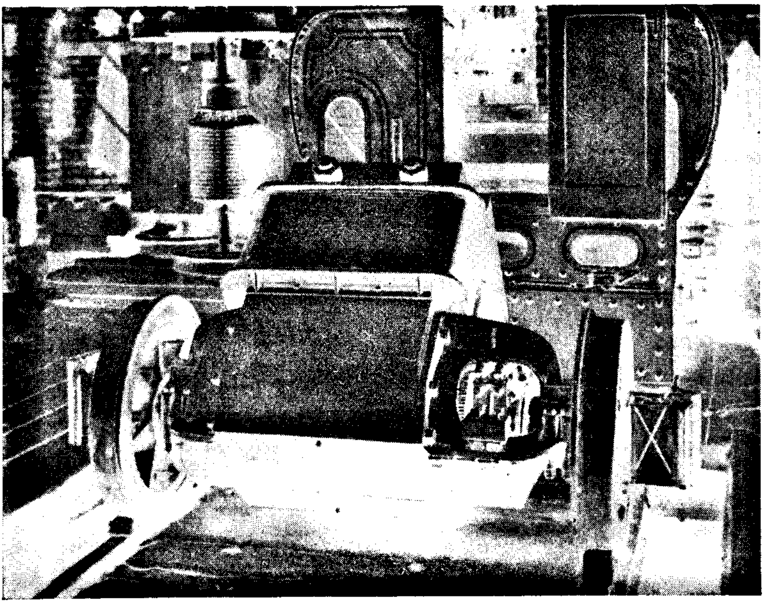
INCREASE OF POTENTIAL

Reverting again to railroad problems, all the early electric railroads were operated without intermediary apparatus on a direct current supply of from 400 to 600 volts, the higher limit being widely considered as the maximum. But while sufficient for the limited distances and motor capacities in vogue, I realized that as distances and unit loads increased the operating potentials must be raised. An illustration of this fact was given at Kansas City in 1890, in an exposition of the characteristics of installations under differing conditions for possible electric operation between New York and Philadelphia. One condition required a pressure of nearly 4000 volts, and I made the prediction that whatever would be required by economic installation would be used without fear of the vagaries of the electric current.

Before the advent of high pressure for individual motors there was a rapid introduction of inter-urban railways, aided by the inventions of Tesla and Ferraris in polyphase transmission, and in transformers and rotaries by Stanley, Bradley and others, as suggested by Arnold, which made possible the combination of the merits of the alternating current and direct current systems through the medium of sub-stations, vital for long distance work where direct current motors of moderate potential were used.

THE ELECTRIC LOCOMOTIVE

The use of electricity for street cars having proved successful, the building of larger motors concentrated in a locomotive naturally followed. In 1890 the City and South London Road under the Thames, originally designed for cable operation, was opened for use with gearless locomotives built by Siemens and Mather and Platt, and two years later the Liverpool Overhead Railway began operations with two-car unit trains, each car having one motor, the two being operated by manual control. In the spring of the same year the Intramural Railway at the Chicago World Fair was equipped, motor cars being used to haul trailers. A direct current supply was used through a third rail, with track return.



Gearless Motor on City and South London Railway, 1890

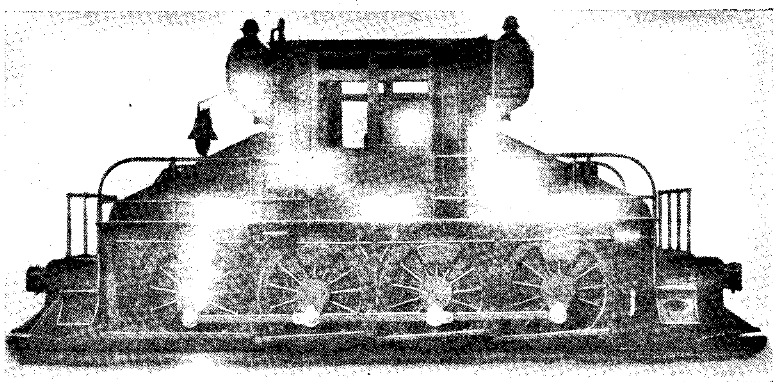
In 1895, the West Side Elevated Road in that city was equipped on the same plan. Then followed the next year the Nantasket Beach Road, a branch of the New Haven, the Lake Street Elevated in Chicago, and the equipment of the Brooklyn Bridge, where motor cars were used, at first for switching trains at the terminal and later across the bridge.

But there were few suggestions of replacing steam locomotives for trunk line operation, despite the construction in 1892/4 by

Sprague, Duncan and Hutchinson of a 1000 horse-power locomotive, with pilot control, for Mr. Henry Villard, proposed but not used for experimental operation near Chicago, and the larger locomotives built by the General Electric Company in 1895 for hauling regular trains through the tunnels in Baltimore.

BIRTH OF MULTIPLE-UNIT CONTROL

Neither the absorption of the Sprague Company in 1890 nor the subsequent taking up the development of the electric elevators had destroyed my interest in electric railways, and particularly the rapid-transit urban problem. For many years I had con-



1000 H.P. D.C. ELECTRIC LOCOMOTIVE, 1892; DESIGNED FOR MR. HENRY VILLARD BY SPRAGUE, DUNCAN AND HUTCHINSON, GEARLESS TYPE; PILOT CONTROL

tinually preached the virtues of an underground four-track express and local system, to be operated electrically, and as early as February, 1891, to silence the objections of a portion of the daily press and to block a proposed extension of the Manhattan Railway up Broadway, I offered in the New York *Evening Post,* under a possible forfeiture of $50,000, to install two electric trains within four months, one to be operated by an electric locomotive and the other by motors under the cars, at speeds up to forty miles an hour—the only condition being that if successful the costs would be reimbursed by whoever secured the rapid transit franchise.