Summary of French Mission's Report on Railway Electrification*

By A. Mauduit

Secretary of the Mission and Professor of the Faculty of Science of the University of Nancy (France)

Destruction of French coal mines by the invading Germans and intensified production during the war so depleted the coal resources of France as to force the Government to take active steps toward providing for future requirements. Because electrification of the steam railroads would relieve the situation immensely, a commission of experts was sent to America for the purpose of studying our systems of railroad electrification, comparing them with those employed in Europe, and making recommendation as to the best system to install on French railroads. The commission has completed its work; and M. Mauduit, Secretary of the Mission, has prepared the following summary of its activities. It is of particular interest to note that he states that he "does not hesitate to formally conclude in favor of the adoption of this [high-voltage direct-current] system, and he believes it to be actually the only system suitable for the electrification of heavy traffic lines."—Editor.

The Minister of Public Works (France) formed, by the resolution of November 14, 1918, in accordance with the upper chamber of Public Works, a commission of students charged to examine the propositions submitted by the railway systems of the Paris-Lyons-Mediterranean, the Orleans, and the Midi for the electrification of approximately 10,000 kilometers of the lines of their systems.

This committee, composed of the most qualified technical men of the administration and of the railway systems, believed that it was necessary to propose to the Minister to send to the United States a commission of engineer specialists, instructed to obtain all information relative to the recent progress of electric traction.

Organization and Composition of the Mission

The mission was comprised of thirteen members as follows:

- Major D'Anglards, and Professor A. Mauduit of the faculty of Sciences of the University of Nancy, attached to the Administration of Railways, delegates of the Ministry of Public Works and Transports.
- M. Pomey, Chief Engineer of the Post and Telegraph, and M. Lecorbeiller, Engineer, delegated by the Administration of the Post and Telegraph.
- M. Debray, Chief Inspector, and M. Barillot, Inspector, delegates of the State Railways.
- M. Sabouret, Chief Engineer, attached to the Administration, M. Balling, Principal Maintenance Engineer of the line, and M. Parodi, Chief Engineer, all three delegated by the Orleans Railway.
- M. Japiot, Chief Engineer of material, and M. Ferrand, Chief Engineer of the central maintenance service, both delegated by the Paris-Lyons-Mediterranean Company.
- M. Bachellery, Chief Engineer attached to the Administration, and M. Leboucher, Principal Engineer of Motor Power, delegates from the Midi Railway Company.

The greater part of the members of the Commission left Paris the 15th of April for America and returned to Paris the 22nd of July, 1919.

Itinerary and Work of the Mission

Arriving at New York on April 25th, we got in touch with the representatives of different construction companies, manufacturing companies, and railway companies, and visited the following electric railways:

New York Central; direct current 600 volts with third rail.

New York, New Haven & Hartford; single-phase, at 11,000 volts, 25 cycles.

Pennsylvania Railroad and Long Island; direct current, 600 volts, with third rail.

Suburban Lines; that carry a considerable freight traffic.

We also visited a certain number of steam central stations for electric power; the Interborough Rapid Transit Company and the New York Edison Company, together with the Hydro-electric Central Station of Niagara and Steam Central Station at Buffalo.

From May 8th to 10th we made a visit to the works of the General Electric Company at Schenectady, New York, and discussed with the principal engineers of that Company questions concerning railway electrification in general and particularly the electrification with high-tension direct current (3000 volts) of the Chicago, Milwaukee & St. Paul (710 kilometers in operation) installed by the General Electric Company.

From the 11th to the 25th of May, we visited the following installations:

Electrification of the Norfolk and Western Railway; single-phase, 11,000 volts, 25 cycles, from Bluefield to Vivian, Virginia.

Electrification of the Pennsylvania Railroad; single-phase, 11,000 volts, 25 cycles, from Philadelphia to Paoli.

* Translated from the *Journal Officiel De La Republic Francais*, August 13, 1919.

Washington, Baltimore and Annapolis Electric Ry.; direct current, 1200 volts (Interurban).

The Baldwin Locomotive Works at Philadelphia.

The repair shops and factory of the Pennsylvania R. R. at Altoona.

From May 25th to 28th we visited the factory of the Westinghouse Mfg. Co., at Pittsburgh, and discussed with their engineers the subject of electrification in general, and particularly the single-phase and single-to-three-phase systems installed by that Company and also the new direct-current 3000-volt locomotives for the extension of the electrified portion of the Chicago, Milwaukee & St. Paul Rwy.

From May 29th to June 4th different visits were made to the electric locomotive factory of the General Electric Company at Erie, Pa., to automatic railway substations for 600-volt direct current, both of Westinghouse and General Electric designs, and to the Chicago, Lake Shore, and South Bend Electric Railway single-phase 6600 volts 25 cycles.

From June 5th to June 14th a complete study of the Chicago, Milwaukee & St. Paul Railway was made, including the sections in operation from Harlowton to Avery (710-kilometers, Rocky Mountain and Missoula Divisions), the section in the course of construction from Othello to Tacoma and Seattle (360-kilometer Cascade and Coast Divisions) all direct current at 3000 volts, and the repair shops and supply depot at Deer Lodge, Montana.

A visit was made to the three hydro-electric stations of the Montana Power Company, which furnish the three-phase 100,000-volt 60-cycle current to the electric railroad. The stations were the Rainbow (35,000 kw.), the Great Falls (48,000 kw.), the Holter (48,000 kw.) all three on the Missouri River.

The following installations were also studied:

Central California Traction Company; the line from Stockton to Sacramento (72 kilometers) in California, equipped with the inverted third-rail for 1200 volts direct-current, a unique American example of the application of the third rail to rather high voltage.

The Pacific Electric Railway system; suburban and interurban lines around Los Angeles, from 600 to 1200 volts direct-current.

The hydro electric station of the Puget Sound Light & Power Company on the White River, near Seattle, Washington; 48,000 kw., 55,000 volts with a head of 130 meters.

The principal incoming substation of the Utah Power & Light Company at Salt Lake City, Utah; outdoor substation at 120,000 volts 25,000 kw. with a regulation by synchronous condensers (located inside a small special building).

The Great Western Power Company of San Francisco, California; their hydro-electric plant at Los-Plumas, California, on the Feather River with a head of 138 meters, 65,000 kw., 115,000 volts and a double line on unique poles for 246 kilometers to the incoming substation at Oakland.

The oil burning steam central station of the Pacific Gas and Electric Company at San Francisco; 57,000 kw.

The Southern California Edison Company of Los Angeles; the two hydro-electric plants nearby at Big Creek in the Sierra-Nevadas, each of 25,000 kw., 600 meter head, 150,000 to 160,000 volts and the two 400-kilometer lines made of aluminum and steel on separate towers; the incoming substation at Eagle Rock, near Los Angeles, 150,000 volts, with regulation by synchronous condensers.

Apart from the general duty of the Mission, consisting of collecting all useful documents on the electrification of railways and the distribution of electric energy at high tension, the principal duty was to find out, on summing up all the information gained by the study of the Swiss and Italian Electric Railways on one side and the American on the other, if a system of electric traction existed for large systems distinctly, superior to all others and able to be adopted to the exclusion of all others by all the different companies interested for the projected electrification in the center and the south of France.

From the four systems of electric traction actually in operation on great lines of the world, that is, the single-phase, three-phase, single-to-three-phase, and high-tension direct-current, the three-phase has already been studied in detail in Italy, where it is largely used, while it is not used to any appreciable extent in any other country, and the single-phase has been equally studied in operation in France on the Midi Railway and in Switzerland on the Loetchberg Lines and in construction on the Swiss Federal Railways which have adopted this system for the gradual electrification of all their systems, the electrification actually intended and even in the course of construction for the Gothard Railway.

The single-to-three-phase, and the high-tension direct-current systems are used only in America, and so became the principal object of the work of the mission. At the same time, the examination of American single-phase installations (25-cycle, while the analogous French installations are 16-cycle,) allowed the completion of the study of monophase installation.

The total information of all kinds gathered in America forms the subject of a detailed report by M. Mauduit. This report was submitted at the October, 1919, meeting of the Technical Sub-Commission in order to serve as a basis for the discussion of a proposition tending to make a choice of a traction system, different for the individual companies but following a general formula established by this Sub-Commission with the approval of the whole committee.

The purpose of this summary of the report is to give only the most important results and the principal impressions obtained from the American experience, together with the personal conclusions of the writer. The documents have been gathered by all members of the commission, perhaps together and perhaps separately, but the opinions expressed in this article, while they are in general the concensus of the general impressions of the Mission, are personal opinions and only bind the writer, since they have not been approved by the technical sub-commission in the presence of all the members of this commission, called before this commission to complete and discuss them.

Monophase Electrification

The principal lines equipped with monophase current are the New York, New Haven & Hartford Railroad and the Pennsylvania Railroad, from Philadelphia to Paoli. Although these lines are suburban lines, they are interesting to study since the system of traction employed is applicable to larger lines, and the same as that of the French Midi road save that the frequency is 25 cycles instead of 16.

New York, New Haven & Hartford Railroad

The electrification of this system was decided upon in accordance with the order of New York State; it has a total of 102 kilometers electrified and takes in a part of the direct-current inverted third-rail system in the common terminal with the New York Central Railroad, when leaving New York.

The outlying part is 11,000 volts single phase, with an overhead trolley wire. The necessity of operating partly on 600 volts direct-current and partly on 11,000 volts single-phase greatly complicates the equipment of the locomotives which must run into the city of New York.

The traffic is important and the technical operation adequate after many difficulties of the first years were surmounted. These difficulties mainly consisted in struggling against accidents due to the frequent short circuits on the trolley wire, or on the power feeders, and against the interference set up in the telegraph and telephone lines adjoining and belonging to different companies.

The solution of these problems has been found, but at the price of complicated organization, delicate and costly to install and maintain. The telephone lines have been put underground in lead covered cables; the distribution of power has been made at 22,000 volts by means of 30 compensating auto-transformers, spread over the 102 kilometers of the road to lessen the height of the voltage surges in the line, and to reduce the interference on the telegraph and telephone lines. This installation is in place of the transformers for this work on the Midi road with the additional advantage of the reduction of the voltage.

The equipment includes 103 locomotives and 26 motor cars; the cost of maintenance is comparatively high and the personnel of the repair shops quite numerous. The single-phase motors are very delicate and require very careful watching of the commutator.

Pennsylvania Railroad

The lines from Philadelphia to Paoli are 32 kilometers with four tracks and from north Philadelphia to Chestnut Hill are 20 kilometers with two tracks.

The equipment includes only motor cars, not locomotives, and the service varies from suburban type to heavy traffic. The technical operation is good, the motors are not required to operate on both direct current and monophase current, are of a more modern type, and possess better commutation.

Special precautions have been taken to prevent short circuits, and the struggle against interference on the telegraph and telephone lines has been solved after a fashion: (1) by placing these lines in lead covered cables underground; (2) by the use of frequent feeder transformers (5 for the 52 kilometers of road); and (3) by the use of track transformers placed along the track at very short distances, approximately one kilometer.

Under normal conditions, the operation of the signal lines is adequate, but short circuits although rare produce important disturbances. A very interesting preparatory register connected on an extra wire, placed in a cable, permits the control at any moment of the interference voltage induced in the telegraph and telephone lines.

The American monophase traction installations, especially on account of the high frequency adopted (25 cycles instead of the 16 cycles in Europe) a frequency which was imposed by the local conditions in order that the numerous distribution systems at this frequency might be directly utilized, and the employment of motors often not quite so good as those which have been found on the Midi and in Switzerland, showed an installation less perfected than the similar installations in Europe.

At the same time the struggle against interference with telephone and telegraph lines has been carried to a considerable perfection and there will certainly be a considerable discussion in the large report of this system of traction in France, if it is adopted. On the other hand, the trolley lines with catenary suspension are remarkably well made.

If we assemble now the experience of France, Switzerland and America, we are forced to conclude that the monophase system is still far from the point of presenting the solution to a number of problems insufficiently solved in actual practice, notably the production of a motor capable of exerting a heavy torque for a considerable time without rotating, in order to be able to start heavy trains on the important grades, and of regenerative braking.

Furthermore, this system leads to complicated equipment for the protection of the neighboring telephone circuits, which considerably augments the cost of installation. Without this consideration the cost would be distinctly less than similar costs with the three-phase and high-tension direct-current systems.

The expenses of maintenance of the rolling stock are always higher than in the latter two systems and the motors are less rugged and capable of less overload.

Single-to-three-phase Electrification

In the single-to-three-phase system which the American calls split-phase, the power is furnished to a single contact wire as in the monophase with the return by the rails as in the single-phase form, but it is transformed in the locomotives by means of a special converter to three-phase power and the motors used with this last locomotive are three-phase induction motors. The aim of this installation is to profit from the single-contact wire of the monophase system (while the Italian three-phase requires two trolley wires in addition to the rail serving as a return) and from the three-phase induction motor, rugged and economical and capable of exerting heavy torque for several minutes without rotation and of pulling the heaviest trains which, up to now, has not been obtained with the ordinary commutator monophase motor.

There only exists at this time one line operating with this system. It is the line from Bluefield to Vivian of the Norfolk & Western Railway, in the Appalachian Mountains in Virginia and West Virginia, for a length of 48 kilometers with two or three tracks, and numerous curves and grades reaching 20 millimeters per meter.

These locomotives are flexible and robust, but their operation brings out different mechanical and electrical faults which have not been corrected up to this time in an adequate fashion and, on account of which, this installation may be considered to be as yet only in the test period, and the maintenance expense of the rolling stock is greater than that of the other systems.

From the mechanical point of view the transmission of motion from the motors to the axles, which is made by "jack shafts" and horizontal cranks, occasions rapid wear of the bearings, and even a dislocation of the frame or the breaking of the cranks, on account of enormous forces developed at the time of the vertical displacement of the frame.

From an electrical point of view the principal inconveniences are the following: The three-phase power produced by the converter actually is not perfectly symmetrical, and the phases do not have equal currents. Furthermore, the rotors of the motors are connected to different liquid rheostats, and the loads are not always equally divided between the different motors, very often with considerable differences. A regulation of loads by the engineer has been provided but the latter, very busy, can only make sure of a very imperfect adjustment, and the motors consequently often deteriorate rapidly. The power-factor is very low, on account of the presence of the induction converter which adds its magnetizing losses to those of the motors.

To remedy these defects, with the exception of the distribution of the load between the motors, the manufacturer is taking up at this moment the use of a synchronous converter to give a good power-factor and to make the three-phase current more symetrical; but no practical application of this new apparatus has been made yet, and it must be feared that there will be very great instability on the occasion of breaks in the trolley wire.

On account of the numerous repairs in progress and of the lack of electric locomotives due to the war, the operation of this portion from Bluefield to Vivian still requires many steam locomotives. The Pennsylvania Railroad is taking up on its own account a single-to-three-phase application on the four track line from Altoona to Johnstown on the road from Philadelphia to Chicago. A test locomotive is in the course of being tried out, but no permanent installation has been started on the road.

In conclusion, the single-to-three-phase system, in which the principle at first glance seems very interesting, and which supplies an effectual assistance to the monophase system by the employment of locomotives or motor cars with monophase only for the express trains or light trains, and of locomotives single-to-three-phase for the heavy and slow trains, all these locomotives being supplied by the same trolley wire with monophase current, is found to present in practice numerous faults which have not yet been corrected, and on account of which this system has not come up to the hopes with which it was regarded when started.

High-tension Direct-current Electrification

Already the 600-volt direct-current system has been utilized for a long time, in a standard method for city and suburban electric railways, either with a trolley wire for the tramways, or with a third rail for the suburban railways (the line of the Invalides to Versaille and from Paris to Juvisy, of the Metropolitan).

In the United States, the greater part of the interurban lines operate at 1200 volts direct current with an overhead trolley wire. A considerable number of these lines are really railroads with both passenger and freight traffic, and attain speeds of 60 to 80 kilometers per hour. Many of them were originally equipped with single-phase current, at voltage varying from 3000 to 6600 volts, but have been made over for direct current at 1200 and 1500 volts. The equipment for this latter voltage is now as standard as that for tramways at 600 volts.

Encouraged by the excellent operation of these installations the Americans have tried, with like success, to raise the direct-current voltage to 2400 volts, and have equipped in this manner the mining line from Butte to Anaconda of the Butte, Anaconda & Pacific Railway (Montana), 53 kilometers of main track. Following this they have executed, at 3000 volts, the electrification of the world, from Harlowton to Avery, 710 kilometers, main track across the Rocky Mountains and the Missoula region on the Chicago, Milwaukee & St. Paul Railway.

The electrification of the second section of 360 kilometers, between Othello and Tacoma, Seattle, as far as the Pacific, is in the course of construction*, and that of the portion comprised between Avery and Othello, about the same distance, has already been decided upon.

We studied with particular care this installation of the Chicago, Milwaukee and St. Paul, and all the members were unanimous in considering that this electrification, by far the most important in the world, was at the same time greatly superior to all the others on account of the excellence of its technical operation from all points of view.

The electric power is furnished by the Montana Power Company and is three-phase 100,000 volts. It is transformed to direct current in rotary substations consisting of motor generator sets, which are composed of a synchronous motor and two generators for direct current, mounted on the same shaft and coupled electrically in series in such a manner that each produces only 1500 volts on the commutator.

These substations are the most delicate and most expensive part of this traction system, but they are only to the number of 14 for the 710 kilometers (about 1 every 50 kilometers) and operate very excellently. They require only a personnel of three men each, a chief and two aides for continuous operation with a power from 4000 to 6000 kw. By the use of flash barriers on the commutators, and of extra fast circuit breakers† in the main line, accidents resulting from the most redoubtable phenomenon of direct-current circuits, namely, the flash of fire on the commutators (flash over) in the case of short circuit, have been eliminated.

The excellence of the installation of these substations counts for a great deal in the success obtained by the high-tension direct-current project.

At the relatively low tension, 3000 volts on the trolley wire (in place of 11,000 to 15,000 volts for single phase) gives a correspondingly great volume of current to obtain the pull on heavy trains. Experience has shown that with a double trolley wire

* This second section of the C., M. & St. P. Ry. will have been placed in electric operation before this article is printed.—Ed.

† These breakers are described in the article "High-speed Circuit Breakers for the C., M. & St. P. Electrification," by C. H. Hill, General Electric Review, September, 1918, and also in the article, "A New Type of High-speed Circuit Breaker," by J. F. Tritle, in this issue.—Ed.

and a pantograph trolley with a double shoe and quadruple contact a current of 1500 to 2000 amperes is easily obtained at a speed of 80 to 96 kilometers per hour, and 4000 amperes at a speed of 25 kilometers per hour, which is more than sufficient for the heaviest trains and the greatest powers.

The locomotives are very easy to run and operate perfectly, the series direct-current motor being of all others the ideal motor for traction work as has long been shown by the experience of tramways and suburban railways. They are capable of regenerative braking, marvellously regulated, which assures the most flexible progress on down grades and occasions an important economy of the power, the tires of the wheels, and the brake shoes. A single armature winder with an assistant assures the operation of the 336 motors of the 42 locomotives in the service, while the former storage of steam locomotives at Deer Lodge, corresponding to 360 kilometers of line, is sufficient for the installation of the storage of the electric locomotives and the repair shops for the total distance electrified, which is 710 kilometers.

A single locomotive is sufficient to pull passenger trains of 900 to 1000 tons American, even on grades of 20 millimeters per meter. Freight trains of 2800 American tons are pulled by a single locomotive on grades of 10 millimeters (the tractive effort is then 32.8 metric tons) and by two locomotives on greater slopes. The average weight carried by freight trains is about 1900 American tons. In trains pulled by two locomotives, the second machine is placed in the middle of the train and not at the end. It must be said furthermore that the break-up of a train is not feared in America as all the freight trains, like the passenger trains, are provided with an automatic air brake on every car.

A considerable advantage of the direct-current system is that it does not seem to have any but the slightest interference with the telegraph and telephone lines, in fact insignificant. We are well able to report that one may telephone very easily on the service lines of the railroad placed all along the tracks on an aerial wire without any protection.

A multiplex printing apparatus for the telegraph service, worked between Spokane and Helena with an earth return, was diverted especially for us in such a fashion as to use a wire placed on the poles of the electric railroad for a distance of 270 kilometers. This operated perfectly during eight days without even being troubled by three short circuits made very complete intentionally between the trolley wire and the rail in the course of the telegraph wire.

In spite of the loss of energy due to transformation of three-phase current to direct current in rotary substations, operating continuously, and although the load is comparatively light, that is, two passenger trains and three to four freight trains in each direction per day, the efficiency of the system is good; 27 watthours per metric ton kilometer which corresponds to an over-all efficiency of 50 per cent from the point of purchase from the producer up to the point of consumption.

Conclusions Relative to the Choice of an Electric Traction System

On account of the remarkable results obtained by the Chicago, Milwaukee & St. Paul Rwy. with 3000-volts direct current, the writer does not hesitate to formally conclude in favor of the adoption of this system, and he believes it to be actually the only system suitable for the electrification of heavy traction lines.

It is possible that with the single-phase system, which at the first glance shows the advantage of lending itself to a great variety of combinations, satisfactory operation may some day be obtained, but it is, without doubt, the fact that the actual practice is far from being desirable at this time.

Direct current presents the inconvenience of being a little more expensive in first cost, on account of the rotary substations required to transform the 50-cycle three-phase current generally produced in the (French) central stations. Nevertheless, it must be said that to obtain economy in this regard with the monophase installation, it is necessary to generate directly the single-phase current at a low frequency (16 cycles) by means of special electric generating groups, so that if it is wished to utilize the current produced normally by the central station (three-phase at 50 cycles) it is necessary to go back to the rotary transformation, the same with the single phase as with the direct current. From this point of view, the direct current offers the advantage of being able to use the current of any station under the same conditions.

So far as the expense of operation is concerned, the complete and exact calculations compiled by the engineering services of the different companies could only show the comparison between the different systems; the writer, nevertheless, estimates that the difference would not be great, and would not come into consideration in the choice of the system.

The almost complete absence of interference on the telephone and telegraph lines constitutes for direct current a very considerable superiority over the other systems.

We have not spoken of the three-phase system, which, in America, has only an insignificant local application. Dispite certain advantages obtained by the Italians, we are of the opinion that it should be rejected especially in consequence of the complexity and of the high price of installation and maintenance of the two trolley wires.

Economic Considerations of Electric Traction

From the economic point of view, the papers which we brought back from America are much less complete and less accurate than the technical information.

On the other hand it is necessary, in judging from the American experience the future economy of European electric traction, to make considerable modifications in the figures in the case of two principle items, which differ in the American installation from the European installation.

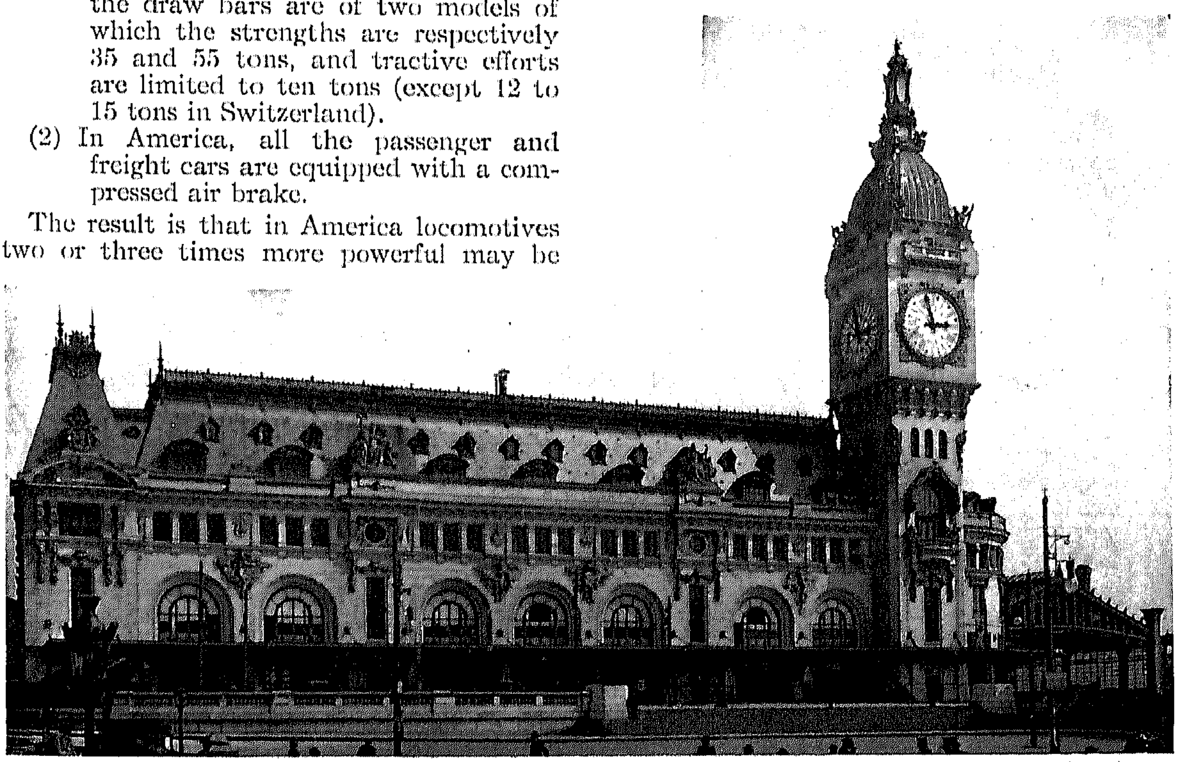
(1) In America, the coupling employed has a strength against breaking of about 135 tons, and the tractive efforts are allowable up to 40 tons. In Europe, the draw bars are of two models of which the strengths are respectively 35 and 55 tons, and tractive efforts are limited to ten tons (except 12 to 15 tons in Switzerland).

(2) In America, all the passenger and freight cars are equipped with a compressed air brake.

The result is that in America locomotives two or three times more powerful may be employed, with freight trains two or three times longer and heavier than in Europe, and that the personnel on these trains is relatively much smaller which completely changes the expense of operation.

The accurate calculations made by the Companies, and above all the results of the first electrifications installed and the consideration of the exact prices of coal, can alone show under what conditions electric traction will be more economical than steam traction. It is known, however, from another source, that the economy will be mostly felt on the lines having steep grades and heavy traffic; and it is probable that for many lines differing too greatly from these conditions, electric traction will be more expensive than steam traction.

Nevertheless the necessity, more and more important, of economizing coal, and the great advantages, which, it is well known, are linked with electrification, render it necessary that the most rapid construction of the first works be carried out in view of the gradual electrification of the most interesting lines of the systems of the Paris-Orleans Railway, the Paris-Lyons-Mediterranean Railway, and the Midi Railway.



Courtesy of Railway Age

La Gare de Lyon, Paris