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PASSENGER LOCOMOTIVES FOR CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

BY A. F. BATCHELDER

Ry. Locomotive Dept., General Electric Co., Schenectady, N. Y.

AND

S. T. DODD

Ry. & Traction Engineering Dept., General Electric Co., Schenectady, N. Y.

DECEMBER 9th, 1915, may be considered the date of the initial electrical operation over the electrified lines of the Chicago, Milwaukee & St. Paul Railroad. During the following winter the electrification was extended over 440 miles of route from Harlowton, Montana, to Avery, Idaho, a section which crossed the Belt Mts., the Rocky Mts., and the Bitter Roots. The locomotives for this initial electrification were of the geared type, designed and built especially with a view to the most economical operation of the freight service. The locomotives for passenger service differed from the freight locomotives only in the details where it was absolutely necessary to meet the operating requirements, such as changing the gear ratio to increase the speed and providing car heating and lighting equipment.

Three years later, in 1918, the successful operation of the original equipment had convinced the railroad company of the economical advantages of electric operation, and they decided to equip an additional section extending over the Cascade Mts. between Othello, Washington, and Tacoma, Washington, a distance of 212 miles. In choosing the equipment for the new extension, it was decided to give special emphasis to the requirements of passenger service and to purchase locomotives which were primarily designed with this in view, taking advantage of any details which would assist in the proper and economical operation of passenger trains. For the freight service it was decided to retain the geared locomotives that were in use on the

Harlowton-Avery Division, changing the gear ratio where necessary to meet freight conditions and using only locomotives of the new design for passenger service.

To meet the specification for passenger locomotives, the General Electric Company has designed, completed, and tested, a locomotive which appears to embody the necessary qualifications and to successfully fulfill the requirements, both from electrical and mechanical standpoints. In designing the locomotive, particular attention has been given to the features affecting safety, reliability, efficiency, convenience of operation, effect on track, and cost of maintenance. The locomotive has especially good riding qualities; it has no apparent effect on the alignment of the track, and to a marked degree, it is free from transverse movements or oscillation which would tend to create lateral pressures against the rails.

It is the intention of this paper to give a description of this locomotive which differs in many ways from the locomotives which are now in operation on the Harlowton-Avery Division, to indicate the reason for choosing this design, and to call attention to some of the principal features which differ from usual practise. Briefly stated, the service requirements for the locomotive are to operate a [illegible]-ton passenger train over the mountain divisions of the Chicago, Milwaukee & St. Paul Railway at speeds of 25 mi. per hr. up 2 per cent grades with maximum operating speeds of 60 mi. per hr. on the level, and to provide regenerative braking on the down grades at speeds consistent with safe operation. Fig. 1 is a photograph of the locomotive in three-quarter view. Fig. 2 is an outline drawing of the side elevation, giving the general dimensions. Fig. 3 is a section through the apparatus cab, showing the location and arrangement of the principal pieces of apparatus.

It will be seen that the running gear is composed of four individual trucks; two end trucks having three axles each, and two center trucks having four axles each. These trucks are connected together by special articulation joints. The motor armatures are

mounted on the axles and the motor fields are carried on the truck frames.

The superstructure is made in two sections of similar design with a third section between them. The third or central section contains the train heating equipment, which consists of an oil fired steam generator, together with water and oil tanks. This unit is complete in itself, and is carried over supports attached to the two

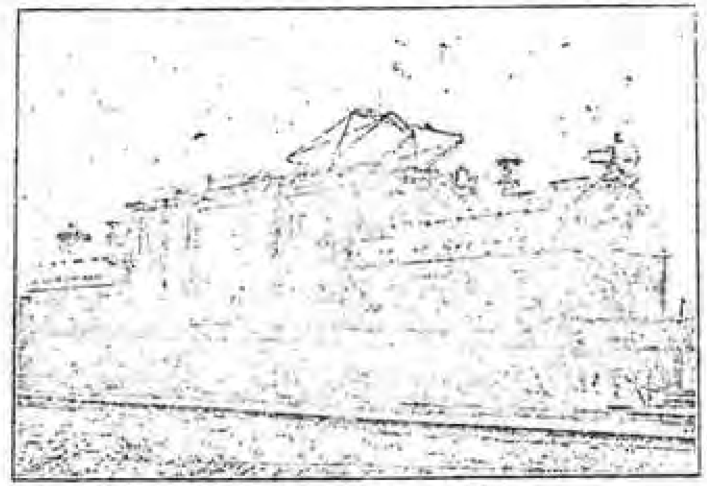

Fig. 1—Three-Quarter View of Locomotive

middle trucks. It can be readily removed for repairs without interfering with any other part of the locomotive. It is placed between the two operating cabs in order to be easy of access to the engineer's helper or fireman, from either location.

The two end sections are similar to each other in appearance. The operator's cab in either section is on the inner end next to the heater cab above described, in order that the operator can be convenient to the heater and in order to allow a maximum space for apparatus in the apparatus cab or outer end section. Another advantage of this arrangement of cabs is that the operator can have access to any section of the locomotive requiring his presence without passing through a section containing high-tension apparatus. The engineer's or operating cab contains a main or master con-

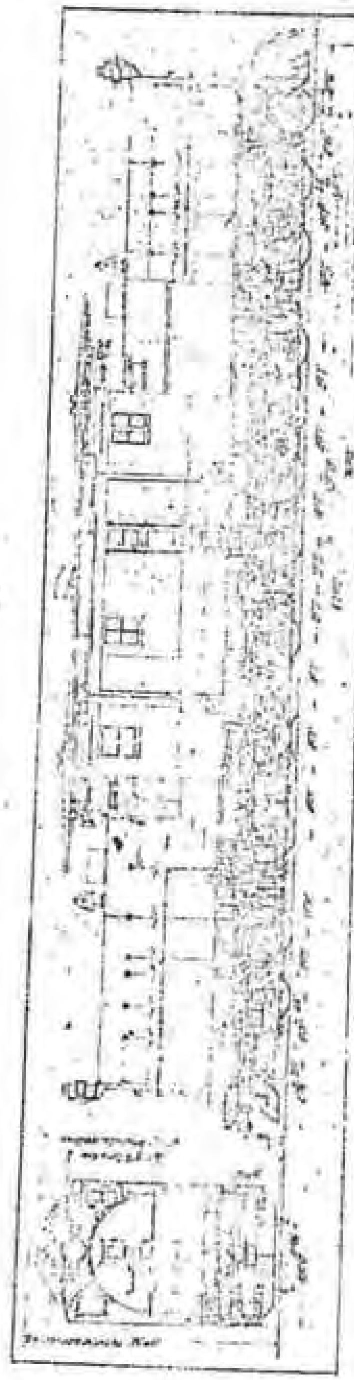

Fig. 2—Outline Drawing and Dimensions of Locomotive

troller, the air brake valves and handles, and an instrument panel, containing air gages, ammeters, and speed indicator. The engineer uses either of the two operating cabs according to the direction in which he is running.

A door gives access from the operating cab to the apparatus section which extends with a cylindrical top to the extreme end of the locomotive. The cylindrical construction naturally adapts itself to the protection of the apparatus included and in addition to this, it has the advantage of allowing a clear vision for the operator from his normal operating position. Contained in this apparatus section are the resistors and contactors to control the power circuits of the locomotive. The starting resistors are placed in two rows on each side of the central passage just above the floor of the superstructure and are covered at the sides by removable covers which when opened will allow the separate resistor boxes to be slid out upon the longitudinal running board outside of the apparatus cab. The air compressor for the air brakes, the motor-generator set for train lighting, and the storage battery for marker lights and emergency control, stand upon the same level as the resistors, and can be removed or replaced in a similar manner. Above the resistors are located the contactors with their arc chutes facing a central aisle two feet wide. This allows ample arcing space and room for inspection of contactors. Above the contactors is the cylindrical roof of the locomotive with trap doors for inspection of the back connections and insulation and for removing the contactors in case replacement is necessary. The whole design and arrangement of this apparatus cab lends itself to a maximum economy of cost and material, as well as to convenience of inspection and repair of apparatus.

Motors

The motors are of the well known bi-polar gearless design which were adopted by the New York Central Railroad 14 years ago, and which have proved by fourteen years' service, operating heavy passenger trains between Grand Central Station and Harmon, to be well suited for the service. This motor has demonstrated its remarkable reliability and low cost of maintenance.

To insure light weight per axle, flexibility in control, good truck arrangement for curving as well as for high-speed running, twelve motors are chosen, each of relatively small capacity. They are especially designed to withstand high temperature, being insulated with mica and asbestos.

Fig. 4 shows the motor armature complete, built directly on the axle with the wheels pressed and keyed in place. The continuous rating of each motor at 1000 volts and with 120 degrees rise by resistance is 266 h.p., corresponding to 3500 lb. tractive effort at the rim of the drivers at a speed of 28.4 mi. per hr. Forced ventilation is employed for cooling. The armature core is provided with holes for the passage of ventilating air. Ventilating blowers are located above each motor armature and deliver air at the commutator end of the motor where it divides, a part passing through the armature and a part back through and around the field coils where it escapes upwards and is afterwards used for ventilating the starting resistors.

This type of motor gives very high power efficiency in average operation, it having no journal bearings or gearing. It lends itself nicely to simple and compact locomotive design as the frame is made use of to furnish the entire path for the magnetic flux. The pole pieces and field coils are fastened to the cross transoms of the trucks and the magnetic flux passes horizontally in series through all twelve motors, finding a return path through the locomotive frame. The articulation joints between the trucks are made in such a manner that large surfaces are in contact to provide an easy path for the flux. The pole pieces are made flat in order to prevent the pole pieces from coming in contact with the armature during the vertical movement of the truck frame on its springs or when removing or assembling the armatures. A minimum clearance of 1/8 in. on each side is allowed between the armature and the pole piece tips. The brushholders are bolted to

the transom allowing the brushes to move up and down with the fields as the frame rides on the truck springs.

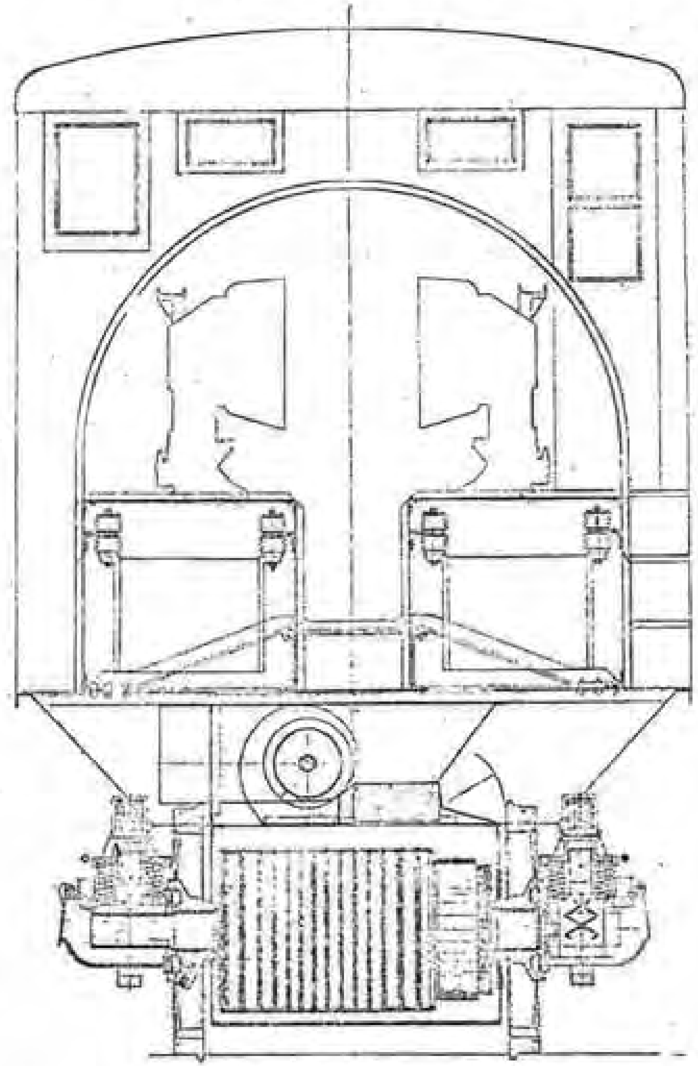

Fig. 3—Cross-Section of Apparatus Cab

CONTROL

In choosing the control apparatus special care has been taken to use individual pieces of apparatus best suited to the particular requirements. Where single independently operating switches are necessary as on the resistance notches, electro-magnetic control is used. Where several switches are required to operate at one time as in changing from series to parallel motor connections, banks of switches with electro-pneumatic cam control are used, thus insuring positive operation, eliminating interlocks, and simplifying the wiring.

The control for motoring is arranged for four motor combinations.

The first combination has nine rheostatic steps, one full field step, and one tapped field step, with twelve motors in series across 3000 volts.

FIG. 4—BI-POLAR GEARLESS ARMATURE AND WHEELS

The second combination has six rheostatic steps, one full field step, and one tapped field step, with six motors in series and two sets in multiple.

The third combination has eight rheostatic steps, one full field step, and one tapped field step, with four motors in series, and three sets in multiple.

The fourth combination has eight rheostatic steps, one full field step, and one tapped field step, with three motors in series, and four sets in multiple.

This results in a total of 39 control steps with a choice of eight operating speeds, exclusive of the resistance steps. The locomotive characteristics on the various steps are clearly shown in Fig. 5.

The regeneration of power for braking is accomplished in a simple manner by using some of the motors

for exciting the fields of the others, which in turn are used as generators to return power to the line.

As a provision against short circuits, or extreme overloads, a quick acting circuit breaker is provided in the apparatus cab which will protect the circuit in less than 1/100 of a second.

MECHANICAL CONSTRUCTION

For flexibility in curving, the running gear is made up of four trucks, each of a relatively short wheel

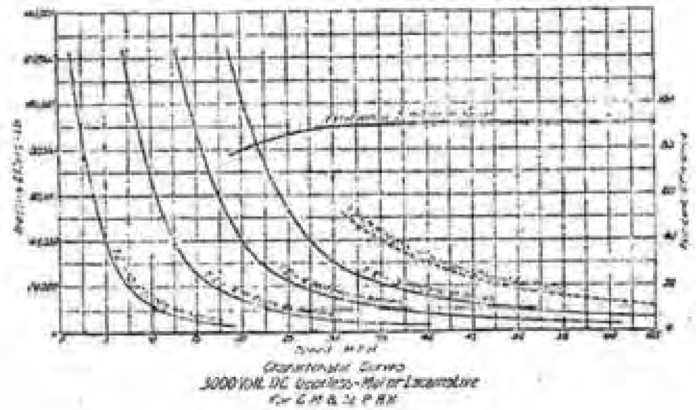

FIG. 5

base. The two middle trucks have four driving axles each; and the two end trucks, two driving axles and one guiding axle each, making a total of 14 axles. The trucks are connected together with articulated joints which allow of no relative lateral movement between them, so that each truck positively leads the following truck. This is for the purpose of reducing flange wear on curves and lateral oscillation on tangent track.

The most important problem that has to be faced in the design of a locomotive for high-speed passenger service is the problem of limiting as far as possible the lateral oscillations of the locomotive structure which tend to distort the track, and to minimize the effect on the track of such oscillations as occur. If a locomotive were built with a rigid wheel base as long as the total wheel base of the present locomotive (67 ft.), the lateral oscillations could not reach any large angular value. However, on account of the long wheel base, such a locomotive would be incapable of taking curves. By articulating the wheel base, as we have done, the locomotive is capable of accommodating itself to track curvature, but at the same time, on account of the articulation between trucks, and the consequent guiding effect of one truck on another, the lateral oscillations on tangent track are minimized in the same manner as would be done by the use of a long rigid wheel base.

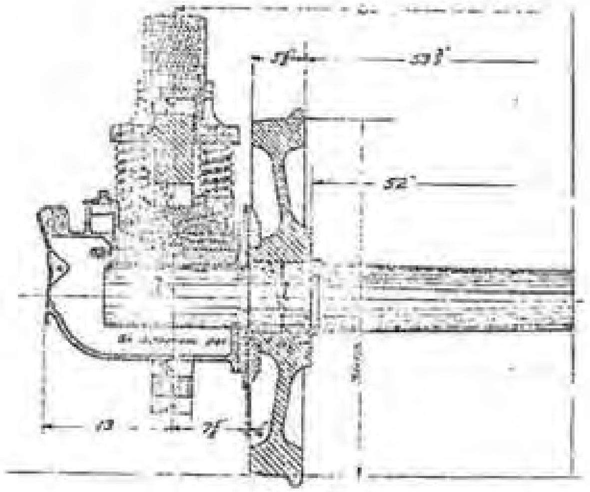

FIG. 6

To soften any lateral blow that may be given against the rail, the leading and trailing axles are allowed a movement of one-half inch relative to the truck frame, either way from their central position. This movement takes place against a resistance introduced by wedges above the journal boxes which tend to hold the box in its central position and to give a dead beat action opposing the motion. This wedge construction is illustrated in Fig. 6. To further protect the track from lateral displacement on the ties, the outer end of the superstructure is carried on rollers, bearing on inclined planes upon the truck frames, while the inner end of the superstructure is

rigidly fastened to one of the middle trucks. This construction tends to hold the leading and trailing trucks in their central position. When a blow is delivered by the leading or trailing truck against the rail head, the superstructure, is displaced laterally across the outer truck. In such a sideways displacement, the weight of the superstructure rolls up on the inclined plane on that side, and thus transfers weight to the rail that is affected and increases the adhesion of the rail to the tie. This action really has two results. It not only increases the holding power between rail and tie at that point, but it introduces a time lag and increases the time and distance during which the pressure is delivered to the rail head.

FIG. 7—SIDE VIEW OF COMPLETE LOCOMOTIVE

As a matter of record, it should be said that the first of these new locomotives was delivered to the railway company at Deer Lodge, Montana, on December 14th, 1919, and was put in operation handling passenger trains between Deer Lodge and Avery.

For convenience of reference a table is attached giving a summary of the principal dimensions and characteristics of this locomotive.

Total weight		521,200 lb.
Total weight on drivers		457,800
Weight per driving axle		38,150
Dead weight per driving axle		9,500
Weight per idle axle		31,700
Dead weight per idle axle		3,500
Length overall	76 ft.	0 in.
Width overall	10 ft.	0 in.
Height over cabs	14 ft.	11⅝ in.

Height over pantograph, locked down	16 ft. 8 in.	
Total wheel base	67 ft. 0 in.	
Max. rigid wheel base	13 ft. 9 in.	
Diameter of driving wheels	44 in.	
Diameter of idle wheels	36 in.	
Size of journals	6 in. by 13 in.	
Dimensions of operator's cab	5 ft. by 10 ft.	
Dimension of heater cab	14 ft. 11 in. by 10 ft.	
Heater capacity	4,000 lb. steam per hr.	
Water capacity	30,000 lb.	
Oil capacity	6,000 lb.	
Compressor capacity	150 cu. ft. per min.	
Number of motors	12	
Type of motor	(bi-polar) GE—100	
Diameter of armature	29 in.	
Clearance between bottom plate and top of rail	5½ in.	
Working range of pantograph	9 ft. 0 in.	
Locomotive Rating	*Tapped field*	*Full field*
Total horsepower, 1 hr. motor rating	3,000	3,500
Total tractive effort 1 hr. motor rating	37,500	48,500
Speed mi. per hr.	35.6	27.1
Total horsepower continuous	3,200	3,200
Total tractive effort continuous	32,000	42,000
Speed, mi. per hr.	37.8	28.4

DISCUSSION ON "PASSENGER LOCOMOTIVES FOR CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY" (BATCHELDER AND DODD) AND "THE BALDWIN-WESTINGHOUSE CHICAGO, MILWAUKEE AND ST. PAUL ELECTRIC LOCOMOTIVES" (STORER), PITTSBURGH, PA., MARCH 12, 1920.

S. Q. Hayes: There is one point I would like to ask Mr. Dodd. One of the illustrations of the G. E. locomotive—the one looking through the apparatus cab—apparently showed all the control leads lying loosely on top of the contactors off on the left hand side. I was wondering whether that were temporary, or whether that was their permanent position in place.

R. L. Wilson: In the early days of the application of electric traction to railroads, I had some experience with it as a practical man. In those days the electric locomotive was so complicated—or it seemed that way to me, at any rate—that there not did seem to be any hope of anybody but an engineering apprentice understanding it. Since that time, I am informed that a man with ordinary intelligence can handle it. From what I have seen tonight it still looks complicated. However, the reliability of all these devices has been proved.

Now, to me, the main point that has been brought out tonight is the absolute divergence of opinion, if you like to so term it, as to how to meet a given problem, particularly mechanically. In looking at the different illustrations, we see that the locomotive described by Mr. Storer has a running gear very similar to the ordinary Pacific type of steam locomotives, which everybody is familiar with, and which apparently has proved satisfactory in a mechanical way, so far as running and the effect on the track is concerned. I imagine that fact is what lead to the adoption of that particular type of running gear, by the engineers who designed the locomotive in question. What led to the other design I do not know, unless it would be to gain electrical efficiency at high speeds. It seems to me that inherently that design would be expected to react on the track more than the other, and that certain devices would have to be introduced in the design and construction to overcome that inherent tendency.

I was much interested in Mr. Dodd's description of what the devices were, the wedges which are on the leading truck and the rollers rolling on an inclined plane elsewhere. That idea of a roller was used—or something corresponding to it—in the first engines which were installed on the New York, New Haven & Hartford system, which had a tendency to oscillate. In that case it was not a roller rolling an inclined plane, but rather a cam effect at each corner, so that when the cab tended to oscillate, it raised the weight on this cam, which tended to bring the cab back into position and stop the oscillation. It seems to me that the fact that these rollers come into play, and act only on one side, and leave the other loose would not be a good thing, although it may work out otherwise.

Now, as Mr. Storer said, the low speed motor is inherently subject to higher losses, copper losses particularly, and I noticed in the paper here that the tractive effort of the locomotive that Mr. Dodd described is 46,000 lb., and that somewhere else it says something about the heating limit being 120 deg., corresponding to 3500 lb. tractive effort. As I understand, the specifications call for 25 miles an hour up a two per cent grade or thereabout, which corresponds to a tractive effort of about 50,000 lb., which would bring an overload on a motor designed for 46,000 lb. tractive effort.

I was wondering, in going up a long grade, which would take an hour to ascend, what temperature the motors would likely attain.

E. H. Martindale: In the paper presented by Mr. Dodd the statement is made: "The continuous rating of each motor at 1000 volts and with 120 deg. rise by resistance is 266 h. p., corresponding to 3500 lb. tractive effort at the rim of the drivers at a speed of 28.4 mi. per hr." I ask Mr. Dodd what the maximum operating temperature is which is allowed on the motor.

R. J. Wensley: I would like to ask Mr. Dodd a question. A couple of years back, or possibly more, there were one or two disastrous wrecks on the New York Central with the low gravity motors, and there were some comments made at the time as to the effect of the low gravity motors on the track, and some claimed that the low gravity motor was to blame for the wreck, claiming that it caused the locomotive to climb off the track. I never heard that satisfactorily explained. Possibly Mr. Dodd can do that.

F. D. Hall: Considerable stress has been laid on the superior efficiency of the gearless motor at high speed. What is the average speed of the locomotive in its day's run?

R. E. Ferris: I would like to ask Mr. Dodd if he anticipates any trouble from snow when the motor is mounted on the axle, and in close to the truck, as the snow conditions are very severe on the Milwaukee Road.

A. M. Candy: Mr. R. L. Wilson brought out a question which I think should prove quite interesting namely, the reference to the complexity of the modern electric locomotive. About ten years ago I had the pleasure of being numbered amongst a group of some 25 or 30 young men who were assigned to work on the Pennsylvania terminal electrification in New York City. When the locomotives for that service were placed in operation a few weeks previous to the official opening of the terminal, there was some question as to whether or not the average railroad man (the locomotive engineer and fireman) could handle these locomotives satisfactorily. As a result, one of us was assigned to each locomotive to be on board at all times when it was in service, so that if anything went wrong of a minor nature the train service would be delayed as little as possible. Each of us prepared himself with a small notebook, in which we had all the schematic diagrams and main wiring diagrams of locomotive, together with the names and numbers of all the wires, control fingers, interlock contacts, etc. We had the sequence of the various switches and the names and numbers of practically all of the control wiring committed to memory, so that at a moment's notice we could tell exactly where to look for trouble in the event of failure of any particular switch or any of the auxiliary equipment. We did an unlimited amount of tutoring with the engineers to teach them this information, and it was quite customary for us to quizz one another as to the method of procedure assuming certain failures should take place. In fact we vied with each other to devise imaginary troubles and the simplest means of correcting or eliminating the failures. The most of us were located on this job and worked faithfully for approximately one year. During all that time, however if my memory serves me correctly, there was not one of us who ever got an opportunity to display the knowledge which he had, because the apparatus, even in the minutest detail, never failed to function properly. Of course, the locomotives were inspected at regular intervals, but the strength and simplicity of the equipment was such that even though the locomotives were operated a great many more miles per inspection than is customary with steam locomotives, they did not cause any train detentions.

It seems to me that in so far as the subject of general electrification of steam railroads is concerned at least, it would be better for us to consider the electric locomotive from the standpoint of being a perfected complex mechanism rather than an experimental complicated mechanism, and that it would be better to point out the advantages of the electric locomotive versus the steam locomotive, rather than to argue extensively among ourselves as to which particular type or design of locomotive is most satisfactory.

There is one other point which I desire to mention, and that is the one brought out by Mr. Dodd in reference to his locomotive, namely, the very free and unobstructed view presented to the engineer through the cab window, looking out along the arch shaped dome over the switching and resistance units. Judging from the illustration thrown upon the screen, it strikes me that the view is certainly not any more obstructed than that obtaining for the average steam locomotive. I do not believe that Mr. Storer mentioned this point in connection with his locomotive, and therefore, I think it would be in order if he would make a few statements relative to this feature.

L. J. Hibbard: Mr. Dodd, in describing his locomotive, mentioned the fact that each main motor had a separate blower motor. I would like to have him tell me what type of motor they use for running each separate blower, and if they expect to have any trouble on these separate blower motors.

Calvert Townley: If I may, I would like to emphasize the remarks brought out by the next to the last speaker. It is well known, that every electrification of steam railroads has been successful. We have now been electrifying roads for a number of years with different types of locomotives. Some of them are more efficient than others, some have lower maintenance cost than others, they vary in degrees of success, but everyone of them has been successful, and as a matter of fact, notwithstanding the large number of types which have been put into use, there are not anything like as many electric locomotive types as there are standard steam locomotive types, and the railroads, accustomed as they are to dealing with steam locomotives, do not think anything of having a large number of different types of steam locomotive on their lines for use for different purposes.

In much of our discussion of this subject, we argue about the value of respective locomotives, and we are in danger of giving our steam railroad friends the idea that the electric locomotive development is doubtful, that we are not sure of ourselves, and that perhaps they had better wait a while and see what happens—

that is the attitude they are likely to take under such circumstances.

Of the two locomotives described tonight, one will perhaps show a better efficiency than the other, one may show a lower cost of maintenance than the other, but I feel sure that each of them will do the work of the Chicago, Milwaukee and St. Paul Railway, to the satisfaction of the railroad company. My reason for speaking in this way is not to discourage discussion, I hope the discussion will bring out every feature of possible advantage—but I think we should emphasize the uniform success which has attended all electrification. Do not let the steam railroad people think we are not sure of ourselves.

If the electrification of steam railroads, ever gets started, it will call for so great a number of locomotives, and so rapidly that if all the existing facilities of the different companies, be devoted to that purpose, they will be nowhere near sufficient. Therefore, it is perhaps well that they do not go too fast. No steam railroad man with an electrified section, would now consider going back to steam, even though from our view point he may have been most reactionary, and looked askance at the electrified part of his lines. After he has become familiar with the electrified system, he recognizes its many advantages, tremendously increased traction, greater speed improved traffic possibilities and other incidental advantages which the electric locomotive affords to an extent not practical with the steam locomotive. The poorest electric locomotive compared with the best steam locomotive easily exhibits a decided margin in its favor.

C. M. Davis: I ask Mr. Storer, to explain the detail of the exciting motor on the leading truck. As I understand it, this motor is geared to the truck axle in much the same way that the ordinary railway motor is geared—this being the case, the gearing, of course, works just the reverse to what it does in the case of the railway motor, when the motor is used to drive the car, that is, a large gear in this case is driven by small pinions.

I should like to have brought out the method of accomplishing this gearing, whether springs are used to soften blows on the teeth when running at high speeds, 60 miles an hour, or what provision is made for taking care of that particular feature.

S. T. Dodd: Mr. Hayes asked about some leads shown in one of the illustrations. The leads were temporary only. The picture was taken before completion of the cab and was used by me to show the location of apparatus before installation of the outside part of the cab.

Another question was asked as to service capacity. I can only say that the motors have ample capacity to perform the service specified by the railroad company and outlined in the paper.

Mr. Ferris asked about the possibility of snow troubles. There will be no trouble on this score as we know from our experience with the New York Central gearless locomotives. If I had been prepared for such a question, I could have shown pictures of electric locomotives running through snow piled up to the windows. Possibly he misunderstands the construction of the gearless motors and thinks they are entirely unprotected. As a matter of fact, there are protecting sheets under the armatures and across the ends so that the armatures are practically as well protected from weather as in the ordinary railway motor. You know that with modern insulation we have very little trouble in that respect from railway motors.

Mr. Candy has referred to the complexity of the electric locomotives. The question of complexity of any mechanism depends largely on the amount of analysis to which you subject it. A steam locomotive is a complex piece of apparatus if you go into a careful analysis of all its features from the chemical composition of the coal to the output at the drivers. I am afraid that electrical engineers too often look at problems from the electrical standpoint and do not pay sufficient attention to the mechanical standpoint. We build locomotives to do service and that is what we should keep in mind rather than the details that go to make up the final combination. Maintenance of equipment tells the whole story, and in that respect the electric locomotive has a record of which to be proud.

The question has been raised as to the center of gravity of these locomotives. The center of gravity of the locomotive as a whole is 57 in. above the rail head. In the first place, I wish to point out that the location of the motor is not the only thing that determines the height of center of gravity. The weight of drawbar and couplers, the end and side frame castings, the cab construction and other mechanical features fix the height within rather narrow limits and the location of the motors is of secondary importance. In the second place the location of the center of gravity has very little to do with the riding qualities of a

double ended locomotive. With such a locomotive equipped with guiding trucks at each end, the locomotive is steered by these guiding trucks and the thrust against the rails is determined by the construction of those trucks rather than by the location of the center of gravity of the main body of the locomotive. This is the reason that in my paper I emphasized the construction of the leading and trailing ends of the locomotive. I wished to show the precautions we had taken to cushion the track thrust when running at high speeds.

Two very different types of locomotives have been presented tonight. It is a source of congratulation both for the users and manufacturers of electric locomotives that such should be the case. In the United States at the present time there are only about 350 electric locomotives in service on steam roads. If we include the trolley roads there may be 700 electric locomotives in service. At the same time there are 63,000 steam locomotives in service. We are just beginning to touch the job of the construction and application of electric equipment to the transportation problem. The sooner we learn how to build locomotives which will meet all the conditions of service, the better it will be for all of us, and I agree with Mr. Storer that it is a splendid thing for all of us to obtain this experience and find out the lines along which we must progress because the big developments are still ahead of us.

N. W. Storer: While appreciating very much the discussions we have had tonight, I regret very much that some of the steam railway engineers who are present did not take part in it. It is all very well for electrical engineers to discuss electric locomotives and to extol their virtues, but we need the side lights that the railway engineers can throw on the subject.

Mr. Townley made an excellent point in bringing to our attention the fact that the electric locomotives that have been built have all done their work better than any steam locomotives that have been put on the road. We should keep that fact in mind.

In the few remarks I made to draw out Mr. Dodd, I had no intention to disparage the gearless type of locomotive. I am more than happy to have that locomotive built, and also one of our own manufacture, which is so absolutely different, and to have them both tried out on the same road. It makes little difference which one does the work the best, it is going to be to the advantage of the electric railway industry to have all types of locomotives thoroughly tested out, in order that the best ones may finally be determined. We are very glad that the two types are to be operating side by side, and if the low friction losses in the gearless type of locomotive, and the absence of gears and other connections between the armatures and the axles, are sufficient to over-balance some of the other features which are not so desirable and which need not be mentioned by me, it may solve some of the difficulties in connection with electric locomotives, one of the greatest of which is the transmission of the torque of the motor to the driving wheels.

I agree very largely with what Mr. Dodd has said about the kick of the locomotive and about the rolling of the cab with the weight up high. There is no question about it, where the cab weight is up high, as it is in our locomotive, it steers a straight course regardless of variations in the road-bed. It is certainly easier on the road-bed to have the weight high than it is to have it down close to the track.

Mr. Davis has asked a question about the performance of the little axle-driven generator. As pointed out in the paper, this is geared directly to the axle like an ordinary interurban motor, and is about the same size. The output of the generator is never more than 25 to 30 kw., so that the duty on the gears is very limited and no special provision has been made to avoid vibration. We do not anticipate any trouble from it.

Presented at the [illegible] meeting of the American Institute of Electrical Engineers, Boston, Mass., April 9, 1920.

THE FIXATION OF ATMOSPHERIC NITROGEN BY THE SILENT ELECTRIC DISCHARGE PROCESS-I

BY C. FRANCIS HARDING
Head, School of Electrical Engineering, Purdue University

AND

K. B. McEACHRON
Research Assistant, Engineering Experiment Station, Purdue University

THE very great increase in the demand for nitrates during the war for the manufacture of explosives and fertilizers, together with the shortage of imported Chile saltpeter, which was the principal source of nitrates before the war, has been emphasized sufficiently in previous papers. This condition of increased demand and curtailed supply led not only to the establishment of many manufacturing plants for the production of nitrates by well-known methods, but also to laboratory research and commercial development in connection with promising new processes.

Such a process, for obtaining nitric acid from the air by means of the silent electric or corona discharge at high voltage, has been investigated throughout a period of several years at Purdue University under the auspices of the Engineering Experiment Station of that institution. Improvements in the yield, resulting from a given input of electrical energy, are being made quite frequently as the investigation progresses and many of the peculiarities of both electrical and chemical reactions of the oxides of nitrogen, combined with ozone, are being disclosed as phenomena incidental to the process under consideration. It has, nevertheless, been considered advisable to present, as a progress report, the results obtained thus far in order that, in the spirit of co-operative research, discussions and suggestions of value will result which in turn will hasten the development of the process. With