

SOME MECHANICAL CHARACTERISTICS OF HIGH-SPEED, HIGH-POWER LOCOMOTIVES.*

BY

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IN discussing this subject it is proposed to avoid all the questions of relative economy of steam and electric operation, whether the latter be by locomotives or by multiple unit cars, for the reason that these questions have been sufficiently discussed by others who have spoken before the Institute.

With the electric locomotives there are certain questions such as the transmission of power from the motor to the driving wheels and the behavior of the complete locomotive considered as a vehicle, particularly with reference to its effects on track structure, which have not received adequate attention. These problems may best be studied with reference to approved types of steam locomotives and my remarks to-night will principally deal with the results of a comparative trial of steam and electric locomotives which was made in 1907 to secure information along this line in connection with the design of electric locomotives for the Pennsylvania Terminal in New York City. It should be understood that at that time but a limited number of types of electric locomotives were available for comparison.

It is my belief that the greatest difficulties, other than financial, of the electric locomotive are mechanical rather than electrical. None of the mechanical arrangements to be described are ideal by any means, and we must not mistake the absence of heavy repairs in the early years of an installation as truly representative of the expenses which will be met later on.

At first blush it would seem that nothing could be more ideal than the connection of a revolving armature and a revolving driving axle, there being no counter-balance disturbances as in the case of driving by reciprocating parts. As a matter of fact, it is not at all simple, for the reason that the driven axle not only revolves but is displaced bodily as well as angularly in the vertical plane.

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Moreover, these displacements of axles and wheels, which are not spring supported, occur suddenly, due to irregularities in the track, hence it is desirable to reduce the unsprung weight to a minimum.

The difficulties from these various disturbances are encountered principally at the higher speeds and are those with which we shall mainly deal.

The different methods of communicating motion from the motor to the driving axle may be considered under the following designations:

A. The simplest method from the mechanical standpoint is that in which the armature is carried directly on the driving axle, the axle boxes sliding in vertical pedestals and the face of the field coils being parallel vertically on each side of the armature. In this construction the whole of the field coils can be rigidly secured to the frame and above the supporting springs. This arrangement permits the easy removal of the driving axles and wheels with the least disturbance of other parts. The disadvantages are the increase in the unsprung weight on the axle and the low centre of gravity of the entire motor. So far this drive has been confined to D. C. operation.

B. Next in simplicity is the geared drive, with the gear on the driving axle engaging a pinion on the motor, one end of the motor frame being carried in bearings on the axle, the other by proper nosing on the truck frame. The disadvantages of this arrangement are the low centre of gravity of the motor as a whole, the considerable unsprung weight and the gear wear, principally that of the pinion. Usually the motors are in pairs between pairs of axles, and in consequence the gyratory disturbance is less than where the motor centre coincides with that of the axle. This general type of drive, which is in common use in street car operation, is, undoubtedly, the one having the widest application and operates with both alternating and direct current.

C. The quill arrangement in which the whole motor is concentric with the axle in its normal position, but is not directly connected, the axial opening of the armature being larger than the diameter of the axle. The physical connection between quill and axle is by springs interposed between pockets in the periphery of the driving wheel centre and the arms of a revolving spider connected to the armature. These springs not only transmit the

driving torque, but also compensate for the axial disturbance of the driving axle. In some installations the motor frame as a whole is spring-supported, so as to assist in assuming a position concentric with the axle. This arrangement has been used both on cars and locomotives, including one of the cars used in the historic Berlin-Zossen high-speed trials of 1901 and 1902. The objections are the low centre of gravity of the motor, the distance between the motors measured from the centre of the truck, the fact that the motor can be removed from the axle only by drawing one of the wheels, and that any lack of concentricity between the quill and the driving axle puts a continued and varying inertia stress on the torque springs. In place of the tangential helical springs other arrangements of springs have been used, as for instance in the Zossen cars, where the springs consisted of radial quarter elliptical springs back to back, engaging pockets in the driving wheels.

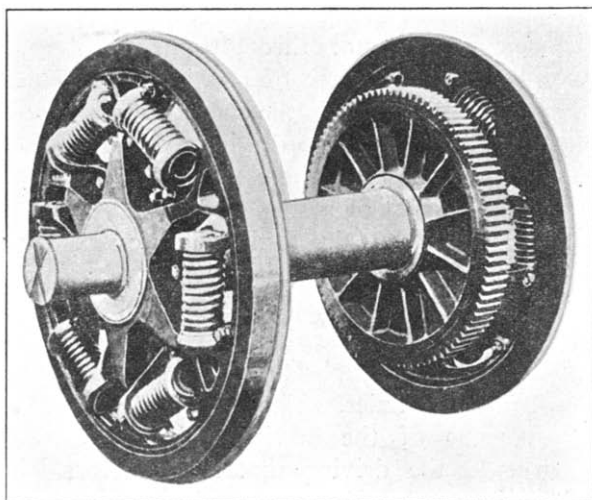
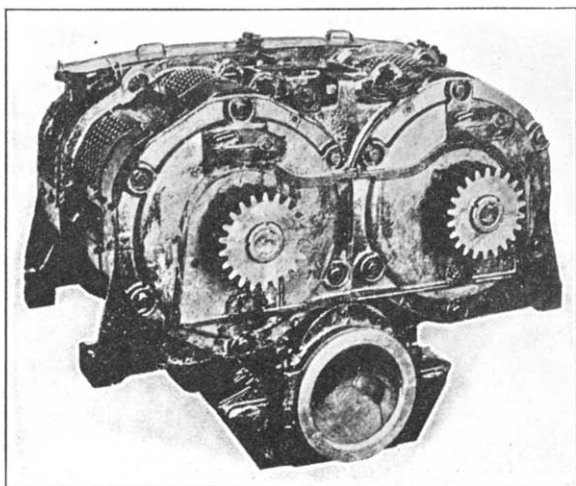
Both arrangements "A" and "C" have the further disadvantage that the ratio of the speed of the motor to that of axle is unity, thus involving higher motor weights than when this ratio is greater.

D. A modification of the quill arrangement is where the quill is driven by one or more motors through spur and pinion arrangement (Fig. 1). The advantage of this is that the motor parts are much more accessible than in the concentric type, and that the speed ratio of motor armature to driving axle may vary through a fairly wide range, and that where two motors drive the same quill the tooth load is that of a single motor. The disadvantage is the increased axle distance due to the width over two motors.

E. This group comprises the various drives by coupling rods in a somewhat similar manner to that of steam locomotives, with the exception that one revolving element is a jack-shaft driven by one or more motors and coupled by crank pins and rods to the crank pins of driving axles. The jack-shaft when placed in the horizontal plane of the driving axles maintains a fixed position relative to the driving motor or motors. The relation between them may be a second set of rods coupling the jack-shaft cranks to a similar pair on the motor; or the jack-shaft may be driven through spur or herring-bone gears cut on the periphery of the disk engaging pinions of one or more motors. These rod connections have been used more largely in Europe

than here. The jack-shaft and rod combination is an exceedingly rigid one and the wheel arrangement forms a more rigid

FIG. 1.



Quill Drive with Geared Motors.

connection than in the case of steam driving through pistons. The advantages are that the removal of driving wheels does not involve electric complications, and that all driving wheels in the

group act together, so that the full adhesion of the group is secured, and it is probable that a higher total adhesion will be available from groups than from single units where the slipping of one unit reduces the total adhesion. The disadvantages are mechanical complication involving exact quartering of all wheels and jack-shafts, the necessity of equal diameter of all driving wheels, and the heating of pins and maintenance of rod bushings. Contrary to expectation the maintenance of jack-shafts involves no great difficulty.

In no type of electric locomotive drives are there counter-balance disturbances due to counterweights, as only rotating masses are in motion.

STARTING POWER OF LOCOMOTIVES.

As governed by adhesion the motor-driven axle in starting has a relatively high adhesion because of the uniform torque of the motor. It is a well-recognized fact that static weighings of locomotives show considerable discrepancies on individual axles. How this discrepancy varies in moving locomotives is not known.

Assuming that the motor torque is greater than adhesion resistance, we have, where axles are individually driven, the adhesion of the axle with the lightest loading governing the adhesion of the group. Where, on the other hand, there is a rod connection between the various axles, we utilize the full adhesion of the group. The presence of the coupling rods does not preclude the application of power to any axle or number of axles, though the usual practice has been to apply all the power to one or more jack-shafts and from them to a group of axles. This utilization of the full adhesion in starting is a matter of importance in any type of locomotive, as usually they will pull heavier trains than they will start.

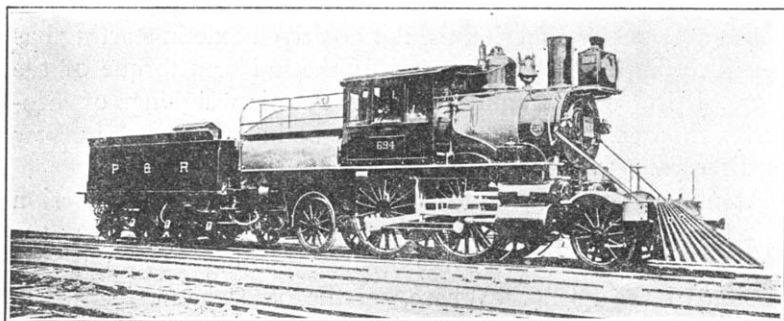
STABILITY OF LOCOMOTIVES.

In the earlier days of steam locomotives the aim was to keep the vertical centre of gravity low with the idea that this was conducive to stability. Not until the Reading Railroad in its introduction of the wide firebox type of locomotive was forced to elevate the boiler so that the firebox would clear the driving wheels, was it recognized that this change had materially improved the steadiness of the locomotive as a vehicle. The reason,

of course, was that the centre of gravity of the parts above the springs acting as an inverted pendulum failed to respond to the many small disturbances which would otherwise have produced side shocks. Since that time designers have not hesitated to raise the centre of gravity of the parts above the springs, and the present limits are chiefly those of overhead clearance.

One other steam locomotive lesson that seems to have been forgotten was that with a short symmetrical wheel arrangement with heavy overhanging weights distributed longitudinally of the whole machine, excessive lateral oscillations were set up which endangered the track and locomotive. Figs. 2 and 3 show loco-

FIG. 2.



Columbian Type (2-4-2) Locomotive.

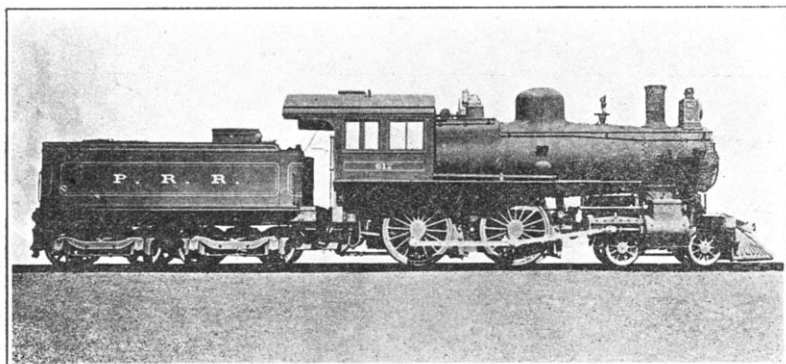
motives of the Columbian or 2-4-2 type and the American or 4-4-0 type. Here are two types of almost the same total wheel-base with nearly the same height of boiler above rail. The weight of the 4-4-0 type was but 7 per cent. greater than that of the 2-4-2 type. The 2-4-2 type was so unstable that it was soon condemned. The 4-4-0 type is notably a steady-running one and its performance will be graphically shown later. The reason for the difference in performance is probably that the wheel arrangement of the 2-4-2 was symmetrical, while that of the other was not.

In the Berlin-Zossen trials the electric cars were carried on two six-wheel trucks the outside axles of each truck being motor-driven by the quill drive. In the original construction the wheel-base of each truck was approximately 12 feet 6 inches, and the trucks were spaced about 48 feet 10 inches, the total length of the vehicle being a little over 72 feet. The road was what would

be considered light as to rail and ballast. When speeds above 90 miles per hour were reached the track began to go to pieces and had to be rebuilt. The construction of the rebuilt track, especially the very elaborate lateral bracing, indicates the severe effect of the lateral shocks in the original trials. The trucks were also rebuilt, the wheel-base being lengthened to 16 feet 5 inches. With the rebuilt roadway and car, speeds up to 125 miles per hour were reached with impunity. This is, so far as known, the highest speed attained by any wheeled vehicle.

The single-unit car does not meet the requirements of passenger transportation as we see it in this country, and the develop-

FIG. 3.



American Type (4-4-0) Locomotive.

ment of electric operation has followed two lines, *viz.*, the substitution of electric for steam locomotives for through service and the use of multiple-unit trains for suburban work. With the latter we will not deal.

When it became necessary to design locomotives to operate the New York terminal of the Pennsylvania Railroad two electric locomotives were designed and built.

Both consisted of two four-wheel trucks with motors for each axle. In both cases the trucks were articulated at the centre and carried the necessary draft gear at the ends, thus the pull was transmitted through the frames of the trucks and not through the superstructure.

In one of these locomotives the motor drive was by gear,

the second method referred to. The other was driven by four concentric motors through quills.

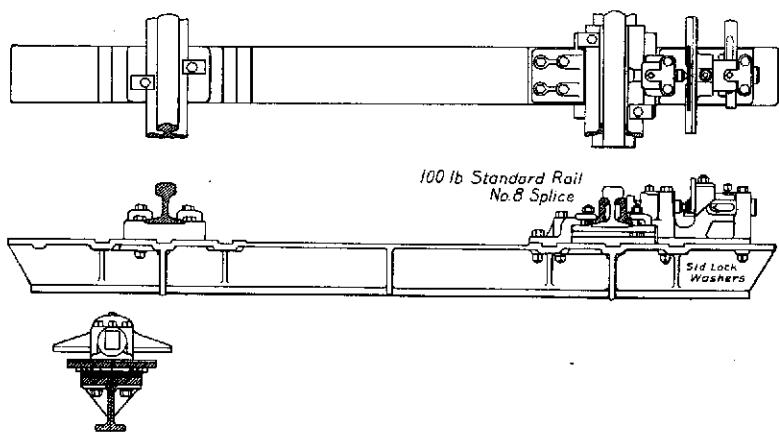
The wheel-base of both were identical, that of the trucks 8 feet 6 inches and the total 26 feet 1 inch.

Both operated by direct-current at 650 volts through third rail.

About the time that they were completed reports of troubles elsewhere made it very desirable that we should ascertain their performance before constructing the large number of locomotives necessary for the operation of the tunnels.

The line of the West Jersey was available for track and current, and it was decided to construct an experimental track with

FIG. 4.



Assembled Recording Tie.

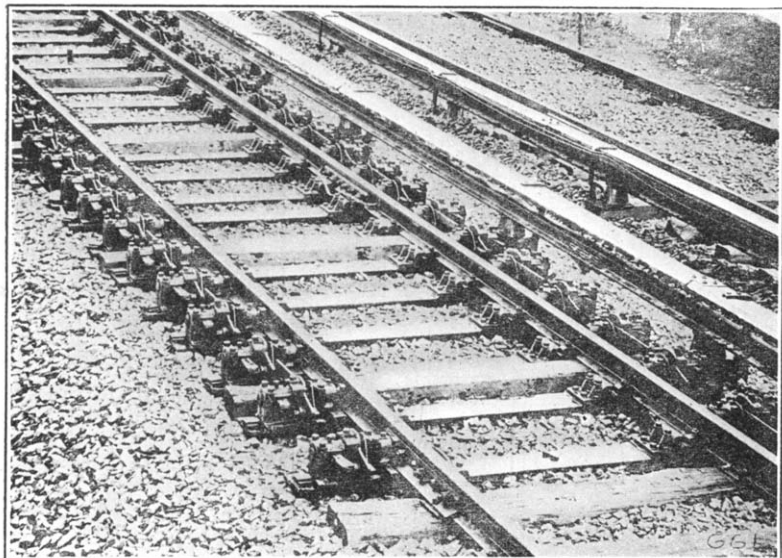
ties which would make some permanent record of the lateral impacts of the locomotives. As it was expected that the bad oscillations would occur on curves, if anywhere, only one end of the tie was arranged to register.

Figs. 4 and 5 show these ties, the end at the outer rail being so constructed that the rail was free laterally, resting on rollers, resisted against outward movement by a bracket carrying a strip of boiler plate, movable longitudinally at will. Against this strip rested a one-inch steel ball which in turn bedded in a plunger bearing against the outside face of rail. (Fig. 6 shows the test track arranged to record at each end, as referred to later; Fig. 7 shows one of the impression plates carrying the record of 30 runs.)

The record obtained with this device was a species of glorified

There was also some question as to the interpretation of the impressions. They were calibrated by static loading in the testing machine and also dynamically by falling weight. The calibration curves showing the results of both of these methods are shown in Figs. 8 and 9.

FIG. 6.



Recording track as subsequently modified to register at each end of each tie.

FIG. 7.

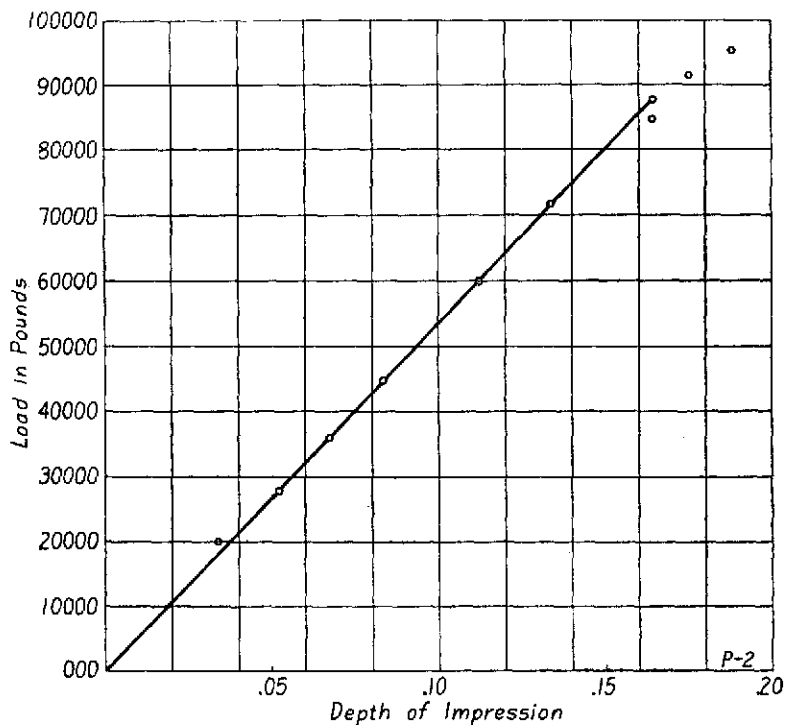


Strip showing impressions.

The recording ties, 80 in number, extending over five rail-lengths, or a total distance of 165 feet, were laid on a one-degree curve in the southbound track, near Franklinville, New Jersey, in 1907. There were 16 of the recording ties to each rail-length and at every splice on both rails the two ties at the splice were so located that the joint between the rails came between the

ties, which at this point were 20 inches apart. The other 14 ties were spaced as uniformly as possible, taking into consideration the necessities for spacing at the rail joints. Tie No. 1 was placed about 28 feet south of the point of curve. The super-elevation of the outer rail of curve was 3 inches, and the elevation

FIG. 8.



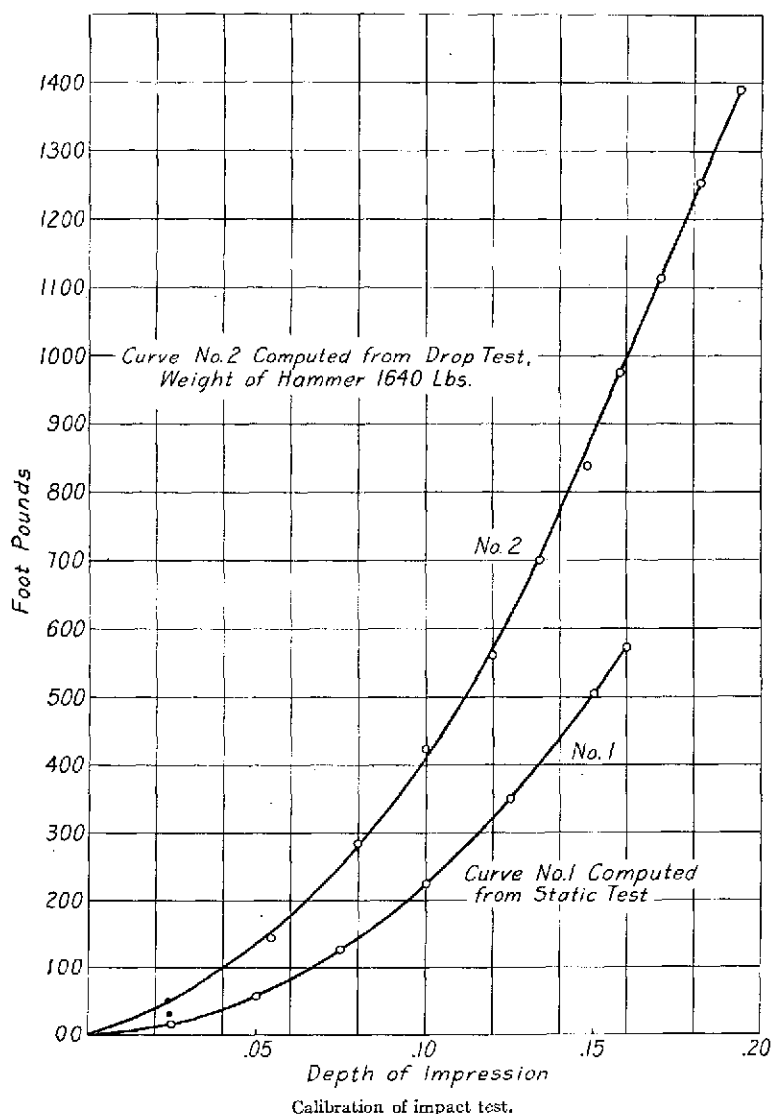
Static calibration of impressions.

of the rail began at a point about 250 feet north of the point of curvature.

Tie plates were used on wooden ties immediately south of the test track for one-quarter of the distance around the curve. The ballast used at the curve was gravel and cinder. The rails were P. R. R. section, 100 pounds to the yard, in good condition. It was specified in arranging the experimental track that it should be lined up in about the best average condition of track used on this piece of road.

The tangent track approaching the curve from the north consisted of 100-pound rails supported by wooden ties, single

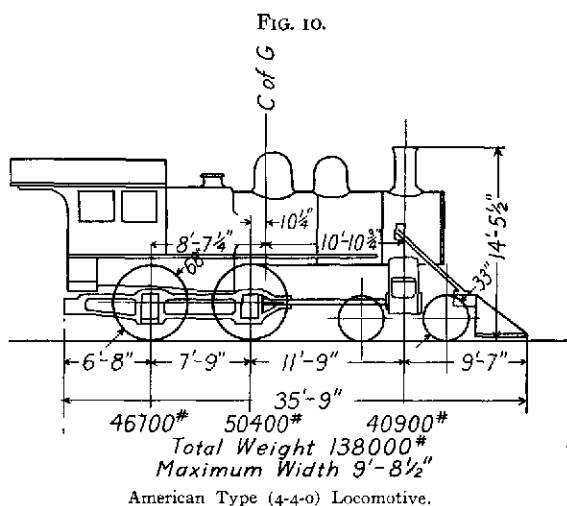
FIG. 9.



spiked. The substructure was of broken stone ballast with the exception of about 1500 feet north of the test track, in the

vicinity of Clayton, where most of the runs were started and where cinder and gravel ballast were used.

After the completion of the runs on the curve, the recording ties were removed to the tangent north of Franklinville station, where the trials were completed. At this location the track consisted of 100-pound rail with broken stone ballast. The speed record was obtained by means of a series of trips, operated by the locomotive passing over them, which broke and made the circuit going to the chronograph. These trips were located such dis-



tance apart that at a speed of 100 miles per hour the time between trips would be one second. Four trips were used for the tests on the curve and seven for those on the tangent, the idea being that failure of one or two trips would not vitiate the record of the run.

Other apparatus used in the tests consisted of speed recorders on the locomotive, which were used only to obtain approximate speeds; and in some of the runs, there was placed on the locomotive a seismograph having three pendulums, giving vibrations in vertical, transverse and longitudinal directions.

For the equipment, there was a choice of a wide variety of steam locomotives, and four electric locomotives were available.

The steam passenger locomotives elected were, one of the

4-4-0 or American type (Fig. 10), the other of the 4-4-2 or Atlantic type (Fig. 11).

The electric locomotives were Nos. 10,001 (Fig. 12) and 10,002 (Fig. 13) already described; No. 10,003, or American type, that is, with two pair of driving wheels and a four-wheel

FIG. 11.

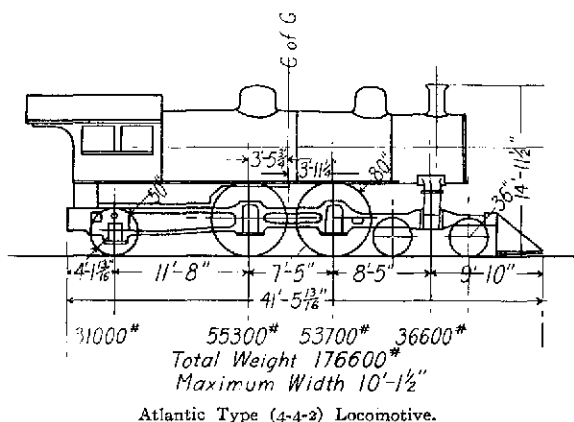
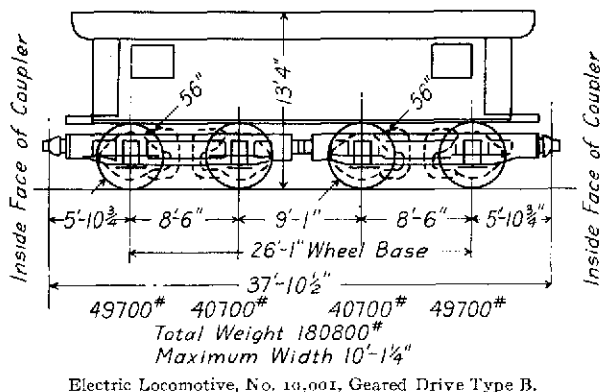


FIG. 12.

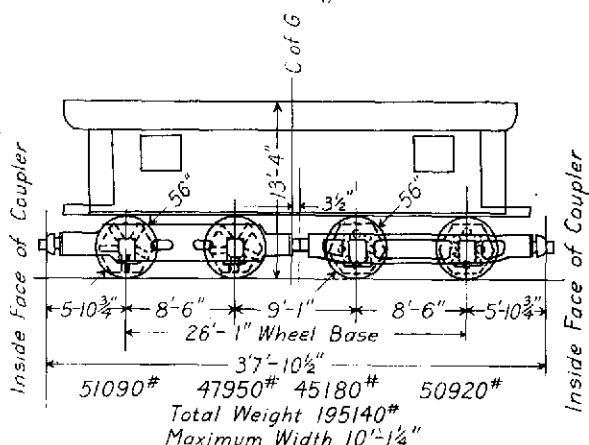


truck (Fig. 14); and No. 028, a brand-new locomotive belonging to the New York, New Haven and Hartford Railroad, which consisted of two four-wheel trucks pivotally connected to the body which carried the draft attachments (Fig. 15).

The drives of Nos. 10,003 and 028 were very similar, consisting of a quill drive (type C).

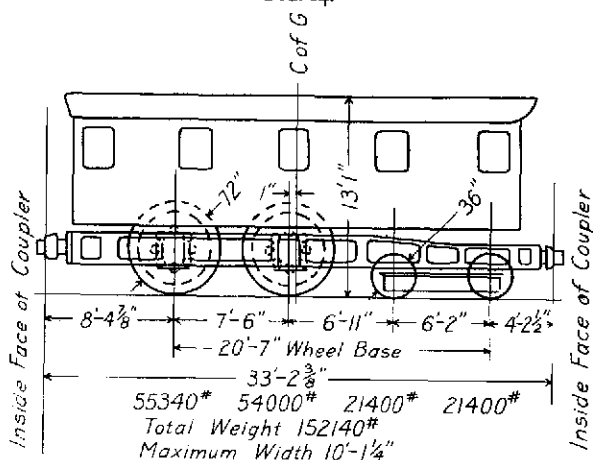
Locomotive No. 10,003 was arranged for A. C. operation, which necessitated provision for D. C. control operation, which

FIG. 13.



Electric Locomotive, No. 10,002, Quill Drive Type C.

FIG. 14.



Electric Locomotive, No. 10,003, Quill Drive Type C.

was placed in a separate car that always accompanied the locomotive.

No. 028 was arranged with double control, A. C.-D. C., so as to facilitate its operation into Grand Central Terminal, New York.

Considered from various standpoints these locomotives ranked as follows:

As regards wheel-base:

	Total Wheel-base	Distance center to center of trucks.
Electric Loco. No. 10,003	20' 7"	17' 6"
Electric Loco. No. 028	22' 6"	14' 6"
Steam, American Type (4-4-0)	22' 9½"	19' 6"
Electric, No. 10,001 and No. 10,002	26' 1"	17' 7"
Steam, Atlantic Type (4-4-2)	30' 9½"	

As regards center of gravity:

	Vertically	Longitudinally
Electric Loco. No. 10,002	42½" above rail	3½" from center
Electric Loco. No. 10,001	45¼"	Centrally
Electric Loco. No. 028	55"	Centrally
Electric Loco. No. 10,003	55"	1" ahead of front drivers
Steam, American Type, (4-4-0)	63"	10¼" ahead of front drivers
Steam, Atlantic Type, (4-4-2)	73"	41¼" ahead of rear drivers

Thus, if length of wheel-base is to govern, the Atlantic-type steam locomotive is the best, and the American-type electric, No. 10,003, should be the worst.

If height of centre of gravity is to be the deciding factor, the Atlantic steam locomotive is still the best, and the articulated quill-drive electric No. 10,002 the worst.

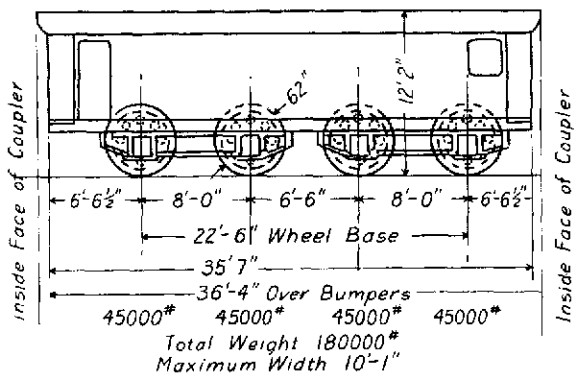
As the object of the trials was to determine stability at express speeds, very few of the runs were made at lower ones, but it is fair to say that with any type of locomotive, steam or electric, not much disturbance should be expected at low speed, consequently progressive speeds were selected up to the maximum speed capacities of the various locomotives.

The runs with the steam locomotives went off very smoothly. Typical records are shown at different speeds for each type (Figs. 16 and 17). The maximum speed for the 4-4-0 type was 83 miles per hour, and for the 4-4-2 type, 95 miles per hour. It is not to be understood that these are practical operating speeds.

When the electric locomotives were run the story was very different, as will be seen from the diagrams (Fig. 18). The record for the geared locomotive, No. 10,001 (type B), shows

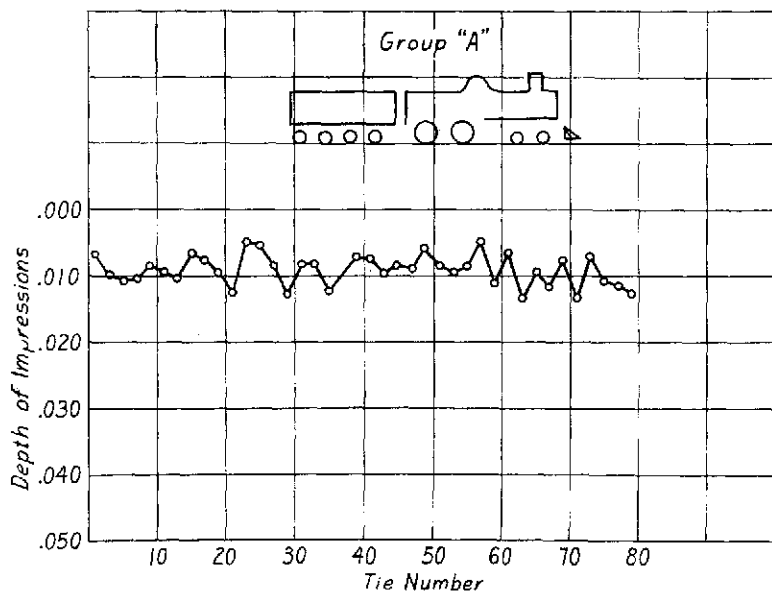
severe oscillation with either end leading, there being three rather pronounced peaks at about the same space interval.

FIG. 15.



Electric Locomotive, No. 028, Quill Drive, Type C. Pivoted Truck.

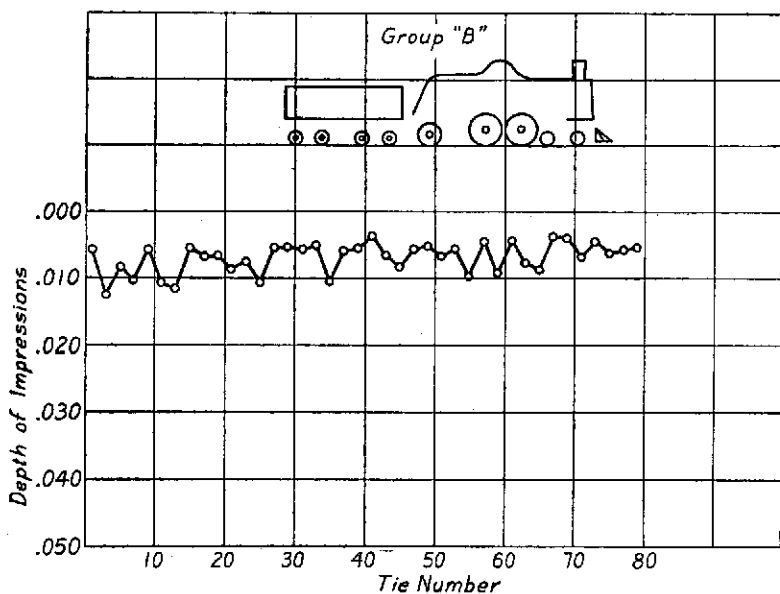
FIG. 16.



Steam Locomotive, American Type (4-4-0), Speed 83.5 M.P.H. on Curve.

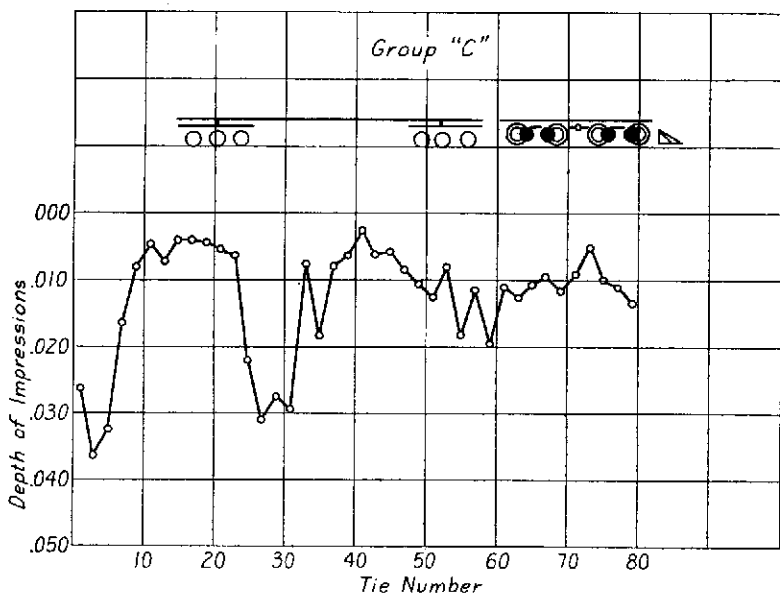
The maximum depth of impressions would indicate a lateral severity about double that with steam locomotives. It is probable that had the ties been arranged to record impressions at each end,

FIG. 17.



Steam Locomotive, Atlantic Type (4-4-2), Speed 95.7 M.P.H., on Curve.

FIG. 18.

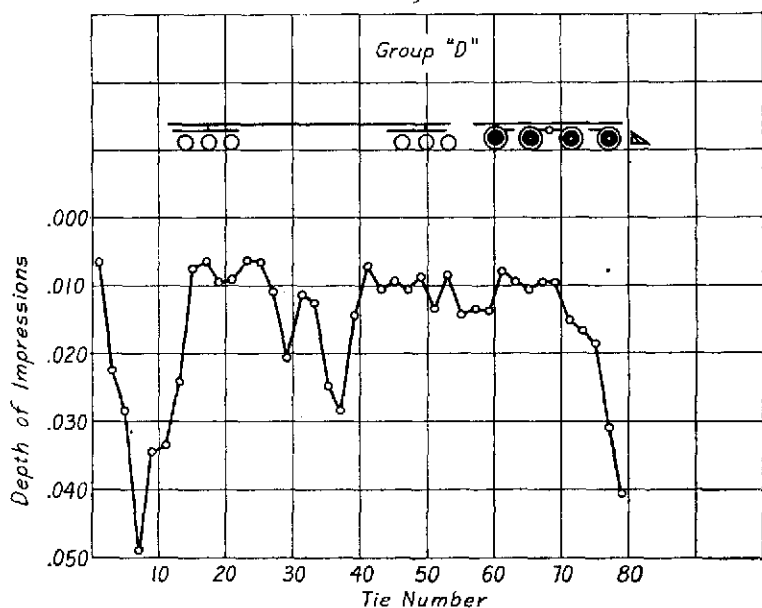


Electric Geared Locomotive, No. 10,001, Speed 71.5 M.P.H., on Curve.

intermediate impacts would have been shown on the opposite rail.

With No. 10,002, articulated quill drive, the records both of depth of impressions and of the seismograph were decidedly the worst of all the locomotives under trial (Fig. 19). While runs were being made with this locomotive the tangent approach track began to spread, with results shown in Fig. 20. The greatest spread was $\frac{7}{8}$ -inch, which caused kinking of the rail and bending of the spikes as shown in Fig. 21. The same thing hap-

FIG. 19.



Electric Locomotive, No. 10,002, Speed 68.3 M.P.H., on Curve.

pened in varying degree where runs were made with different locomotives coupled together, but only when locomotive No. 10,002 happened to be one of the combination.

With the non-articulated locomotive, No. 028, the readings both of the impressions (Fig. 22) and of the seismograph showed a very much better performance, and so far as this set of tests went, the locomotive could not be considered bad. It was, however, tried only on the tangent track after the completion of the tests on the curve. The subsequent history of this type of locomotive in service showed that as wear accumulated the lateral

oscillation became serious, so much so that the locomotives were changed by the addition of a third carrying axle to each truck, thus forming a non-symmetrical arrangement and at the same

FIG. 20.

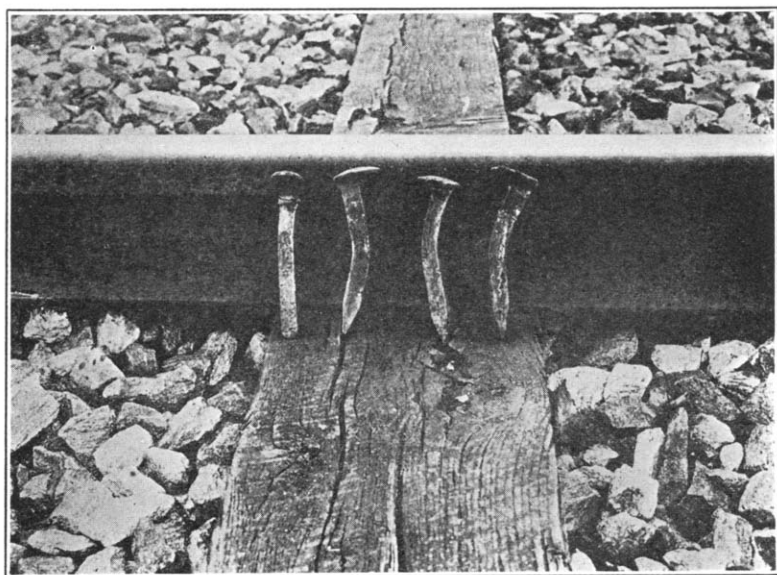


Tangent Track Kinked by Electric Locomotive No. 10,002.

time providing a longer wheel-base. In the light of subsequent tests, it is probable that the smoothness of the diagram for this locomotive was largely due to the absence of end play of the axles in their boxes.

The last of the electric locomotives, No. 10,003, was in fact an eight-wheel American-type locomotive, and the records on both curve and tangent at once put it in the class of the best steam locomotives (Fig. 23). As originally constructed the leading truck had free lateral motion, and an extensive set of runs in both directions showed that while the free swing was an advantage when the truck led, it was a disadvantage when it trailed, and that the best compromise was with truck rigid laterally.

FIG. 21.



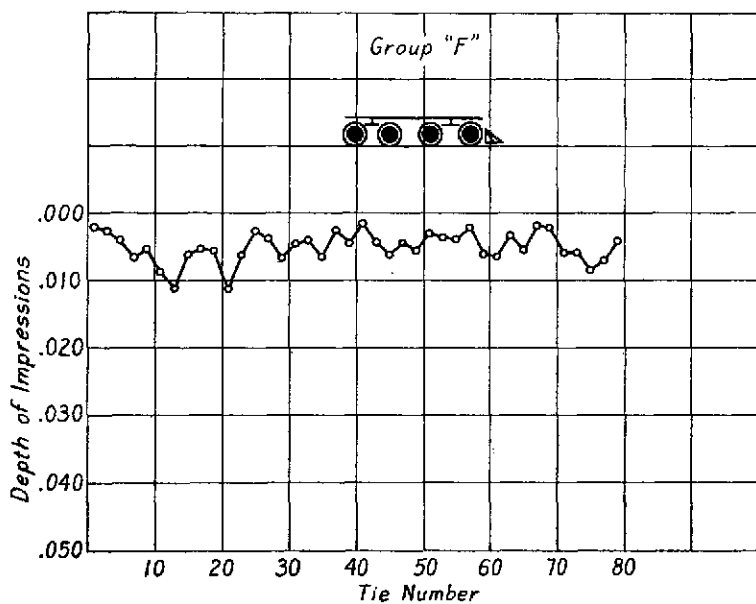
Spikes bent as result of lateral impact on tangent tracks.

These Franklinville tests concluded with runs of different combinations of locomotives coupled together. Apparently when the locomotives were coupled, the number of impressions was increased, but there was no material increase in the depth.

It appeared that in all combinations, including the articulated quill-drive locomotive No. 10,002, the riding of the companion locomotive was worse than when operated by itself (Fig. 24).

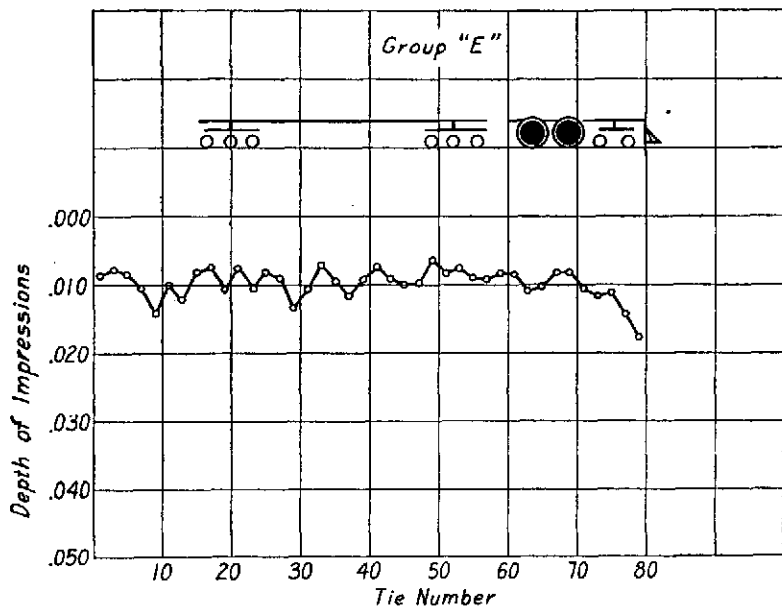
The influence of the approach track had a very marked effect on the results. It was evident that for best results the recording track should have been very much longer to record the resonant

FIG. 22.



Record of Impressions with Electric Locomotive No. 028., on Tangent, Speed 88.3 M.P.H.

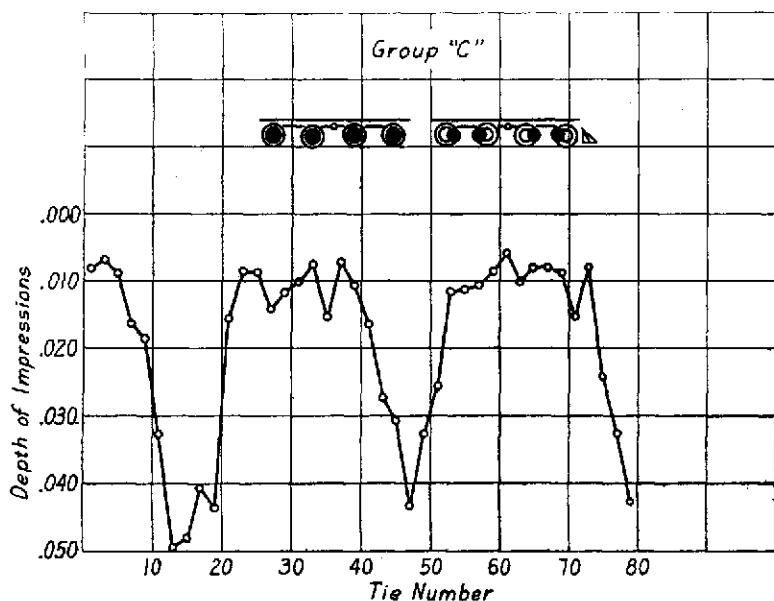
FIG. 23.



Record of Impressions with Electric Locomotive No. 10,003, (4-4-0), Speed 82.6 M.P.H. on Curve.

type of oscillations from their origin through their development to the final dampening. It was also evident that the ties should have been arranged to record on each end.

FIG. 24.



Record of Impressions with Electric Locomotives Nos. 10,001 and 10,002., coupled speed 71.6 M.P.H., on curve.

The severity of the impacts from the impressions measured statically is indicated by the following notes on rail pressures at speeds above 60 miles per hour :

Group A—Steam Locomotive.

No. 6034, Type D-16b (4-4-0).

Maximum readings of 6 runs, speeds between 60.07 and 83.2 M.P.H.

At 60.07 M.P.H.—Impression .0135"—Pressure 7250 lbs.

At 80.0 M.P.H.—Impression .0141"—Pressure 7580 lbs.

Average—74.3 M.P.H.—Impression .0123"—Pressure 6610 lbs.

Group B—Steam Locomotive.

No. 6020, Type E-2, (4-4-2).

Maximum readings of 7 runs, speeds between 59.6 and 95.7 M.P.H.

At 71.2 M.P.H.—Impression .0129"—Pressure 6930 lbs.

At 80.8 M.P.H.—Impression .0159"—Pressure 6550 lbs.

Average—74.4 M.P.H.—Impression .0123"—Pressure 6500 lbs.

Group C—Electric Locomotive No. 10,001.

Forward, No. 2 end ahead.

Maximum readings of 6 runs, speeds between 61.1 and 71.3 M.P.H.

At 71.3 M.P.H.—Impression .0272"—Pressure 14620 lbs.
 At 67.9 M.P.H.—Impression .0193"—Pressure 10370 lbs.
 Average—64.5 M.P.H.—Impression .0165"—Pressure 8870 lbs.
Reversed, No. 1 end ahead.

Maximum readings of 4 runs, speeds between 60.9 and 70.1 M.P.H.
 At 62 and 70.1 M.P.H.—Impression .0289"—Pressure 15530 lbs.
 At 69.7 M.P.H.—Impression .0298"—Pressure 16000 lbs.
 Average—65.7 M.P.H.—Impression .0267"—Pressure 14350 lbs.

Group D—Electric Locomotive No. 10,002.

Maximum readings of 4 runs, speeds between 60.8 and 60.8 and 68.1 M.P.H.
 At 62.8 M.P.H.—Impression .039"—Pressure 20960 lbs.
 At 66.0 M.P.H.—Impression .0311"—Pressure 16720 lbs.
 Average—64.4 M.P.H.—Impression .0291"—Pressure 15640 lbs.

Group E—Electric Locomotive No. 10,003 (4-4-0).

Forward, bolster free.

Maximum readings of 8 runs, speeds between 60.8 and 88.3 M.P.H.
 At 63.3 M.P.H.—Impression .0123"—Pressure 6610 lbs.
 At 72.38 M.P.H.—Impression .0125"—Pressure 6720 lbs.
 Average—74.1 M.P.H.—Impression .0113"—Pressure 6070 lbs.

Forward, bolster blocked.

Maximum readings of 6 runs, speeds between 60.0 and 83.9 M.P.H.
 At 75.1 M.P.H.—Impression .0179"—Pressure 9620 lbs.
 At 83.9 M.P.H.—Impression .0193"—Pressure 10370 lbs.
 Average—73.5 M.P.H.—Impression .0149"—Pressure 8010 lbs.

Reversed, bolster blocked.

Maximum readings of 5 runs, speeds between 65.5 and 84.0 M.P.H.
 At 65.5 and 70 M.P.H.—Impression .0115"—Pressure 6180 lbs.
 At 68.2 M.P.H.—Impression .0117"—Pressure 6290 lbs.
 Average—74.04 M.P.H.—Impression .0106"—Pressure 5700 lbs.

Reversed, bolster free.

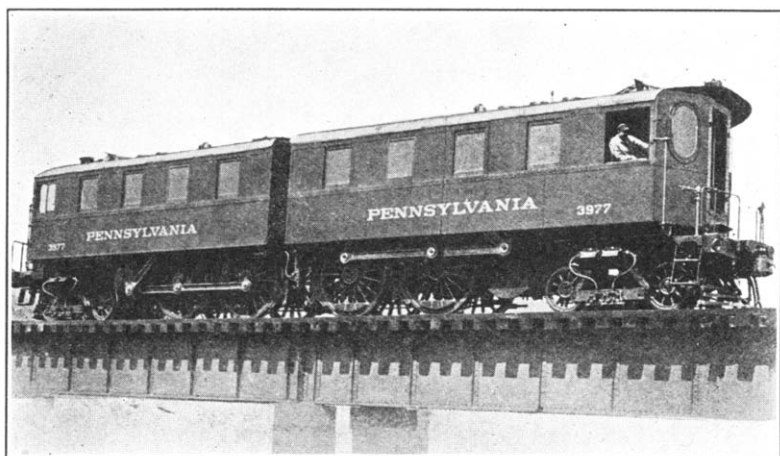
Maximum readings of 5 runs, speeds between 60.4 and 77.5 M.P.H.
 At 68.9 M.P.H.—Impression .0289"—Pressure 15530 lbs.
 At 70.2 M.P.H.—Impression .0281"—Pressure 15100 lbs.
 Average—68.9 M.P.H.—Impression .0236"—Pressure 12700 lbs.

Group F—New Haven Electric Locomotive No. 028.

Maximum readings of 9 runs, speeds between 60 and 88.3 M.P.H.
 At 70.7 and 72.6 M.P.H.—Impression .0197"—Pressure 10370 lbs.
 At 70.8 M.P.H.—Impression .0186"—Pressure 10000 lbs.
 Average—71.7 M.P.H.—Impression .0149"—Pressure 9000 lbs.

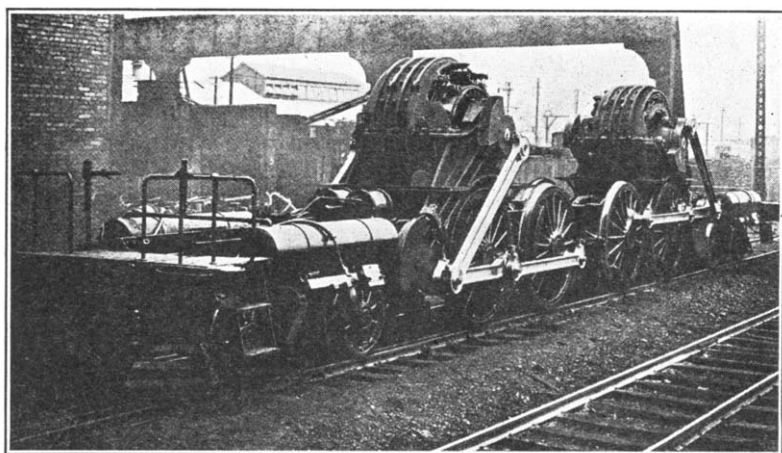
The outstanding fact seemed to be the superior performance of the locomotive with the non-symmetrical wheel arrangement over that with the double four-wheel motor-driven trucks. The articulated truck arrangement was undoubtedly the worst of the combinations, but how much of this was due to the low centre of

FIG. 25.



Type of Electric Locomotive Finally Adopted.

FIG. 26.



Chassis of Electric Locomotive Finally Adopted.

gravity and how much to the articulation setting up a snaking motion was not definitely established.

It is to be noted that one of the double truck motor-driven locomotives and one with two driven axles and leading truck had the same height of centre of gravity, and the latter arrangement was decidedly the better. The comparison is the more interesting because in both of these locomotives the same quill-drive type is used.

The action as the result of the tests was the condemnation of both types of articulated electric locomotives and the preparation of an entirely new design.

The new design consisted of two eight-wheel American-type locomotives coupled back to back, each driven by one motor in the cab and coupled by cranks and rods to a jack-shaft placed in the horizontal axis of the driving wheels, and coupled to them by rods, as in this case of steam locomotives (Figs. 25 and 26). In this design were embodied not only the non-symmetrical wheel spacing of each semi-unit, but also the elevation of the centre of gravity of the spring-borne portion. This design was completed and locomotives built and tested in time to start the operation of the New York Terminal in 1910, and the locomotives have satisfactorily performed that service ever since.

It is not claimed that the question of stability is fully understood. The selection of available wheel arrangements was very limited, but prompt decision was imperative. It is felt that this investigation should be considered as only a starting point for a much more extensive one, which should determine the most desirable arrangements of wheels, of height of centre of gravity, and method of motor drive.

So far as this particular investigation was concerned, the question of electric system was not involved, but, of course, a full discussion of the characteristics of steam and electric locomotives cannot ignore such questions.

Since this set of tests with single-ended ties, other series have been made in which the ties were arranged to record at each end. More ties were used so as to lengthen the test track. As for the equipment, the test included different methods of coupling the semi-units of electric locomotives; also studying the effect of depressions purposely placed in the approach track, the effect of different amounts of end clearance in the axle boxes, variation

in the amount of counterbalancing in steam locomotives, etc. The whole accumulation of data is too voluminous to be included in one paper. Although considerable practical information of value has resulted from the various trials, there is much work yet to be done before the questions of stability are really understood. It is to be regretted that the selection of electric locomotives did not include greater variations in the wheel-base, the method of articulation and height of centre of gravity, but it is believed that the work already done is a very good starting point for future investigations.

Study of Early Fossils. (*U. S. Geological Survey Press Bulletin No. 477*).—The fossil shells of the early invertebrates, or spineless creatures, are of great importance to geologists, for they indicate the geologic period in which the rock beds containing them were formed—in other words, the age of the rock. Each fossiliferous rock bed contains characteristic forms or groups of forms that determine the period in which it was mud or sand. Former Director Powell, of the United States Geological Survey, once tersely explained to a congressional committee the value of paleontology by saying that it is “the geologist's clock,” by which he tells the time in the world's history when any rock bed was formed.

The economic importance of paleontology has been repeatedly shown in this country. In the earlier exploitation of anthracite coal thousands of dollars were fruitlessly expended in New York in search of coal beds, until the New York geologists showed that the beds in that State could contain no coal. The fossils in the New York rocks exploited are of Devonian age, whereas the fossils of the Pennsylvania anthracite coal beds belong to the Carboniferous, a much later period. This discovery at once stopped a useless expenditure of money.

In times of doubt and perplexity the geologist therefore turns to the paleontologist for light on the age and original order of the rock beds he is studying. The study of the animal and plant remains that are embedded in the rocks has thus become an important part of geologic work, and although the specialists who are engaged in this study are few, their work is of high importance.

High Altitudes in Montana. (*U. S. Geological Survey Press Bulletin No. 477*).—Six named peaks in Montana have elevations exceeding 12,000 feet, and several unnamed peaks rise to greater heights, according to the Survey. All these peaks are in the Bear-tooth National Forest, in Carbon County, in the south central part of the State. The highest of these is Granite Peak, 12,850 feet; the next highest is Mount Wood, 12,750 feet.