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DETERMINATION OF TRAIN RESISTANCE.

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The rapid development of the use of electricity as a motive power for railway trains has forced the engineer of to-day to the consideration of problems which were relatively unimportant a few years ago.

The tractive resistance of electric cars being the foundation upon which is based the calculations leading to the selection of motive power, equipment has of late claimed considerable attention. Numerous formulae have been developed, and a number of tests have been made to determine the train resistance of electric cars and trains. Amongst these may be mentioned the Buffalo and Lockport Railway tests in 1900 by Mr. W. J. Davis, the Zossen high-speed tests in 1902-3, tests made by the Electric Railway Test Commission on the test car, "Louisiana," in 1904-5, the New York Subway tests in 1905, and tests on the New York Central locomotives in 1905-6. The majority of these tests were made under somewhat unusual conditions of track and equipment, and consequently the results obtained are not generally applicable to traction problems met with in the ordinary inter-urban railway. It was, therefore, with the object in view of obtaining information which would be useful in the selection of motive power equipment for inter-urban railways operating single car trains that a series of experiments was undertaken by the Railway Engineering Department of the University of Illinois.

As the greater part of the expense incurred in making the tests and working up the data obtained was borne by the Engineering Experiment Station of the University, a few words regarding its organization and purpose may not be out of place. The Engineering Experiment Station was established some six years ago, and was modelled along somewhat the same lines as our own Agricultural Experiment Stations. Its object was the promotion of research work, the results of which would furnish information and data which would be beneficial to the industries of the State and aid in the development of its natural resources. In general the work is carried on through the co-operation of the various departments of the Engineering College with the Experiment Station, most of the instructors devoting part of their time to research work along the lines approved by the Experiment Station, and the special apparatus being supplied by the Experiment Station. In this way the experiments are carried on at a minimum expense to the Experiment Station, and the Engineering College obtains considerable equipment for its various laboratories. A great deal of work has already been done on the perfect combustion of Illinois coal, testing of reinforced concrete columns and beams, life-tests on the many forms of incandescent lamps under different operating conditions, and the train resistance of steam trains and electric cars. The results of these experiments are published from time to time in the form of bulletins, which may be obtained upon application to the director.

APPARATUS.

The car used in making the tests to determine train resistance was a standard interurban car and formed part of the laboratory equipment of the Railway Engineering Department. It was built by the Jewett Car Company, and the principal dimensions are as follows:

Length over all	45 feet
Width over all	8 feet 4 inches
Distance between truck centres	22 feet 4 inches
Height from under side of sill to top of roof	9 feet 6 inches

The car is divided into two compartments, the smaller of which contains the recording instruments as well as part of the motor control apparatus. In the larger compartment are a motor generator set for supplying low voltage current for bond testing, a water rheostat for regulating the voltage on the motors, and several other pieces of apparatus for work of a special nature.

The trucks are of the C60 type of the Standard Steel Motor Truck Co. The wheels on one truck are rolled steel and on the other chilled iron. The wheel base is six feet four inches, and the wheels are thirty-three inches in diameter and have the M. C. B. tread and flange. The motive power equipment consists of four No. 101D Westinghouse motors, with a nominal rating of 50 horse-

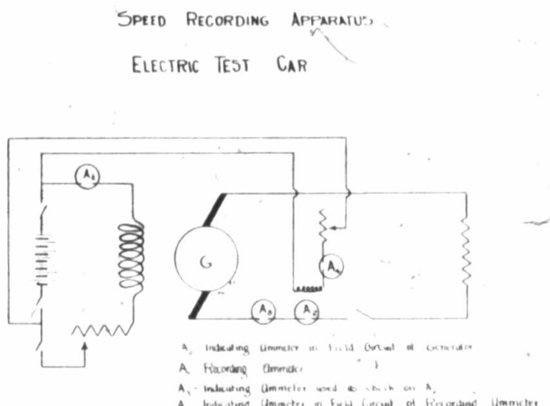


FIG. 3

power. The gear ratio is 22:62, thus giving the car a maximum speed of 45 miles per hour, with a pressure of 500 volts on the trolley-wire. The motor control is the Westinghouse unit switch system of multiple unit control. The switch group, circuit breaker, reverser, limit switch, and line relay are installed in the interior of the car for the purpose of inspection under operating conditions and instruction of students.

The straight air brake system was used, hand brakes being installed for use in emergencies.

INSTRUMENT EQUIPMENT.

The instrument equipment consists of two integrating wattmeters, a recording ammeter, a recording voltmeter, two speed-recorders, an air pressure recorder, and a portable wind vane and anemometer. One integrating wattmeter was used to measure the total power supplied to the motors, and the other one measured the power supplied to the air compressor motor. The recording ammeter and voltmeter were of the General Electric graphic recording type, and gave continuous records of the current supplied to the motors and the voltage across the motor terminals. The speed recorders were of two different types, the first one installed consisting of a recording ammeter of low range connected to a small generator, which was driven from the axle and separately excited from a storage battery carried on the car. The other speed recorder was the well-known Boyer recorder, which was installed for the purpose of checking the speed record obtained by means of the electric speed recorder. The air pressure recorder was connected with the brake cylinder, and was used in making braking tests, as well as serving to show whether or not the brakes were fully released during any tests. The portable anemometer and wind vane were mounted on a tripod and set up in the field adjacent to the track, and were used to determine the direction and velocity of the wind for each individual test. The record sheet or chart was forty inches wide, and was arranged to be operated on either a time base or a distance base. In operating on a time base the paper rolls were driven by a small electric motor, while for operation on a distance base the rolls were driven from the axle by means of a system of gears. A record of distance was obtained by means of a magnetically operated pin, which made an offset in the distance line every 50 feet. The magnet circuit was completed by a contact-maker driven from the axle. The location of the car at any instant was obtained by a pen operated by a magnet, the circuit of which was closed by means of a telegraph key operated manually as the car passed the poles. The time record (Fig. 5.) consisted of two lines operated by magnets, which had their circuits closed every five seconds by a time-marker clock, thus producing offsets in the time lines at five seconds' intervals. In addition to these recording instruments, indicating instruments were also connected in the circuits, and the records were frequently checked with the readings on the indicating instruments. Attempts have been made from time to time to develop an instrument for recording acceleration. The best results have been obtained by using a one-kilowatt transformer having the low tension winding connected in series with the ammeter used for recording speed and the high tension winding connected to a millivoltmeter. The jump spark method of recording was used with partial success, but, owing to the pressure of more important work, this accelerometer was never fully developed.

FIG. 1

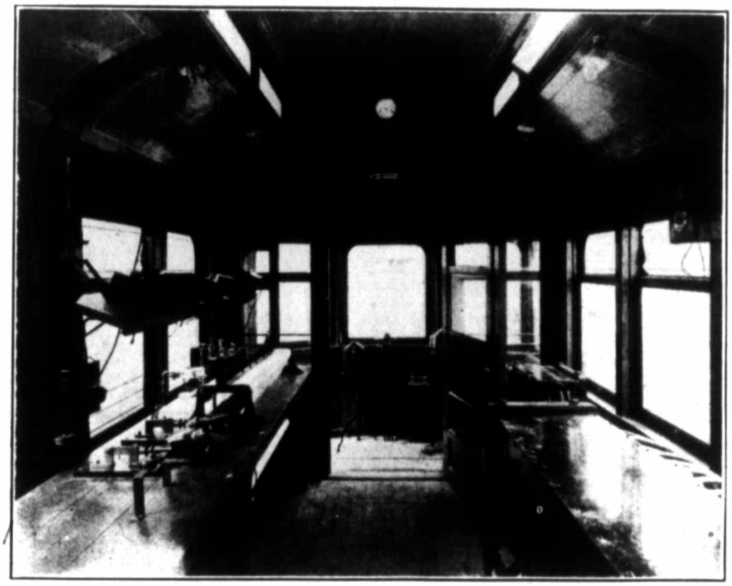


FIG. 2

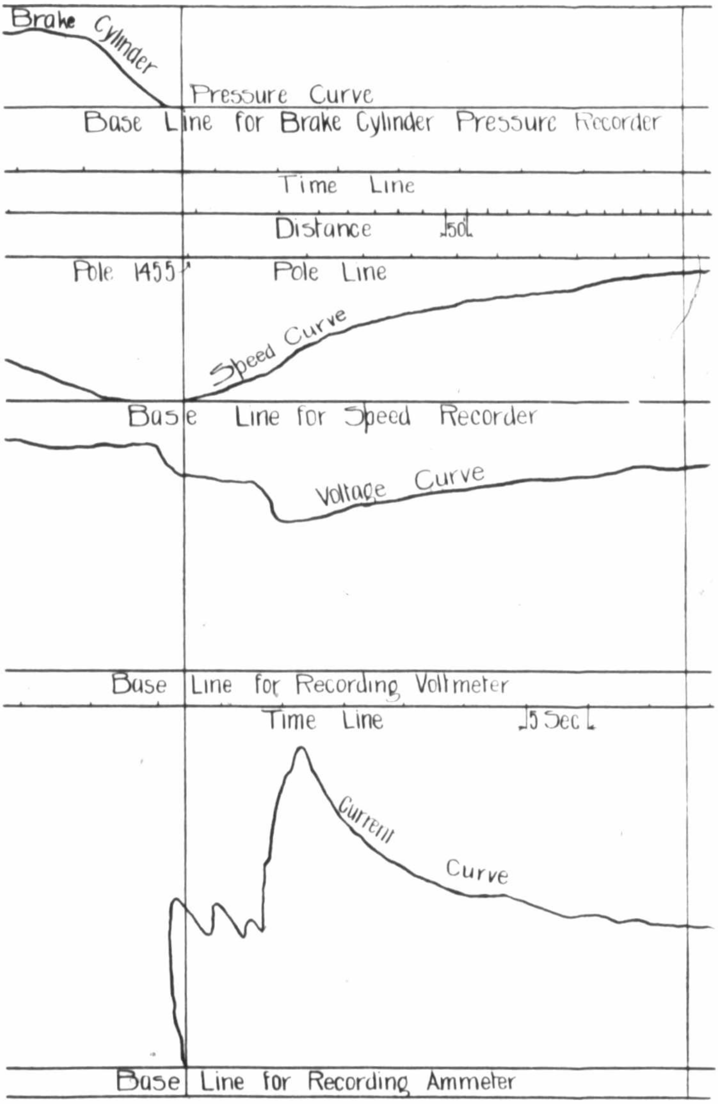

Brake Cylinder
Pressure Curve
Base Line for Brake Cylinder Pressure Recorder
Time Line
Distance
50
Pole 1455
Pole Line
Speed Curve
Base Line for Speed Recorder
Voltage Curve
Base Line for Recording Voltmeter
Time Line
5 Sec
Current
Curve
Base Line for Recording Ammeter

FIG. 4

Description of Track.

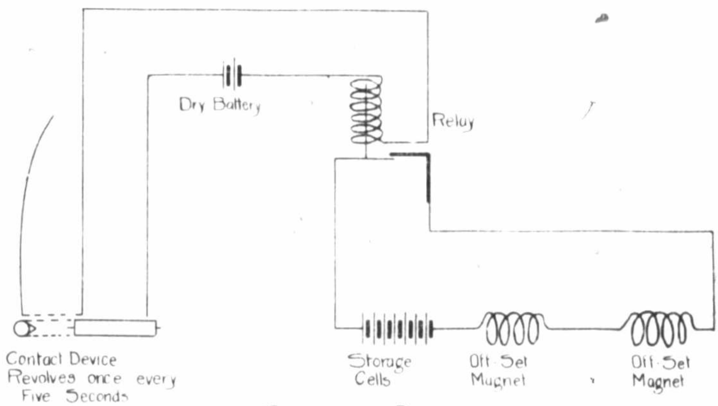
In making the tests the car was operated on the track of the Illinois Traction System between Champaign and Danville. This track was of the ordinary interurban construction, the rails 30 feet in length and 70 pounds to the yard, being supported by sleepers spaced two feet, centre to centre, and the ballast was mostly gravel. A very accurate survey of the track was made and the exact location of each pole determined.

System Followed in Making Tests.

The scheme of operation followed in making the tests was to select a section of track free from grades and curves and of as great a length as possible. Owing to the fact that the kinetic energy of the car at high speeds was relatively large, and reading the speed record to the second decimal place rather difficult, no sections under 1000 feet in length were used, and as this division of the railway system contained a large number of curves, it was impossible to obtain suitable sections much more than 2000 feet long. A certain section of track was selected as the scene of operations for a certain day, and the car was run in both directions over this section as many times as possible. The regular service on this division being frequent, it was unusual to obtain more than forty individual tests in any one day, and the number of tests fell on some days to ten or twelve. The car was run to a point about 1000 feet from the end of the selected section, and brought up to the required speed some time before entering this section. While making the tests to determine the increase of train resistance due to curves, various curves of different radii, ranging from one degree to fifteen degrees, were selected, and accurate surveys made of the curves and sections of tangent track at both ends of the curves. The car was operated at a uniform speed over the section of tangent track before entering the curve, the curve, and the section of tangent track after leaving the curve.

Calculations.

The method followed in working up the data recorded on the charts was as follows. At each end of the sections selected a perpendicular to the base lines was drawn across the chart, and, using a templet to correct for the arc described by the recording pens, the exact locations of each of the pens at the times of entering and leaving the section were obtained. Perpendiculars were then drawn from these points to the various base lines, and the area enclosed by the base line, the record, and the two perpendiculars were obtained by using a planimeter. The mean height was then obtained by dividing the area by the distance between the perpendiculars, and the mean values of current voltage and speed were read on the calibration curves. The time taken to pass



SCHEMATIC DIAGRAM
Time-Recording Apparatus
Electric Test Car
University of Illinois

FIG. 5

over the section was obtained by measuring the time line from the last five second offsets to the perpendiculars at the ends of the section. Knowing the current, voltage, and time, the energy delivered to the motors was calculated. From the speed record the speeds at the entrance and exit of the section were obtained, and the kinetic energy of these speeds calculated. From the profile the elevations were obtained, and the energy input or output due to grade was calculated. Thus energy delivered to the motors plus or minus the change in kinetic energy plus or minus the energy due to grade divided by the length of the section gave the tractive effort over the section. This divided by the weight of the car in tons gave the true train resistance in pounds per ton, the various values of which were then plotted against speed and an average curve drawn which showed the value of train resistance for all of the various speeds. In determining the increase of resistance due to curves the same method was followed, except that the tangential section at each end of the curve section was worked up to avoid any possible error due to change in the relative direction of the wind with respect to the car. The superelevations of all curves were carefully ascertained and made a part of the records.

RESULTS.

A total of about four hundred tests were made in the determination of train resistance for straight, level track, and the values obtained in these tests were plotted. As is to be expected in work of this nature, all of the points did not lie on a curve, so an average curve was drawn such that the sum of the moments of the points lying on one side of the curve was equal to the sum of the moments of the points on the other side of the curve. In this way a curve was obtained which was held to represent the average values of train resistance for ordinary interurban cars on a track of this type. At the same time the fact that a considerable number of points lay further from the curve than any possible error could account for would indicate that the train resistance varies over a considerable range, and shows the necessity of experiments to determine the values of the individual elements of train resistance.

The results of the tests to determine the increase of train resistance due to curvature were plotted in a series of curves showing the increase for curvature of one, two, three, five, eight, ten, and fifteen degrees.

Owing to the fact that these results are to be published shortly by the University of Illinois, it has been found impracticable to reproduce the curves at this time.