A DETERMINATION OF POWER CONSUMPTION ON CURVES FOR A 30-TON ELECTRIC INTERURBAN CAR

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A DETERMINATION OF POWER CONSUMPTION ON CURVES FOR
A 30 TON ELECTRIC INTERURBAN CAR.

A consideration of power consumption must necessarily be closely allied with a consideration of the forces resisting motion or deformation of a body, since it is these forces which absorb the power. For instance, in the case of an electric car or train, the power developed by the motors is consumed by the forces resisting the motion and acceleration of the car.

What is commonly termed true train resistance is made up of resistances which oppose the motion of a train or car running at uniform speed, on level, tangent track, in still air. These resistances are journal friction, rolling resistance, flange friction, oscillatory resistance, and air resistance. In addition to these resistances which are always acting to retard the motion of a car, there are four others, which, from the fact that they are not directly connected in any way with the car, may be termed accidental resistances. They are:-- resistance due to grade, resistance due to acceleration, wind resistance, and resistance due to curves. From the fact that these resistances bear no relation to each other, any one, or combination of them, may act in conjunction with the true train resistance.

Of all these resistances, probably the one concerning which the least is known, is curve resistance. A few tests have been made in the past sixty five years, but the
results are varied and there is no conclusive data at hand. Mr. B. H. Latrobe in 1844 experimented on the Baltimore & Ohio Railroad, and as a result, determined that a curve of one degree exerted a resistance of 0.52 pounds per ton. His were the first important experiments made on this subject in The United States and, though the method was crude and the speed very low, the value determined by him is still used by some companies. His method was to determine the traction by weights suspended in a scale dish weighing 40 pounds, and hanging by a rope over a pulley placed upon the top of a frame resting on a light, four wheeled car, which was pushed by men before the car experimented upon, which followed at a uniform velocity. The speed varied from 1 3/4 to 3 1/2 miles per hour. With this apparatus he determined the traction in pounds per ton first, on tangent track, and then on a curve of 400 foot radius. From a comparison of these values, he found that the traction due to a one degree curve was 0.52 pounds per ton.

The chief difficulties here are; first, the crude method employed to determine the traction, and second, the utter lack of speed range. The value found may be fairly accurate for these very low speeds which are not normal ones at the present day; but it is hardly safe to assume that the traction or resistance due to curves will remain constant through all ranges of speed.

The next detailed results are furnished by an extended experiment upon the largest scale yet carried out
upon the New York & Erie in August and September, 1855, by Zerah Colburn, under the direction of D. C. Callum, then General Superintendent of that road, the object being to determine the relative power required upon the several divisions of the road for the transportation of heavy freight. For this purpose a single engine was run 445 miles over the road with trains varying to suit the ruling grades of the several divisions. Knowing the train tonnage, and time to run over a given section, together with full data concerning that section as to grade, curvature, etc., the resistances overcome were computed. In an article on these tests, the author says, "After a careful examination and comparison of the loads moved over the ruling grades and curves of various sections of the road, it was assumed that the resistance of curves was 0.5 pounds per ton per degree of curvature per 100 feet."

Evidently these tests were quite rough in character and as is stated in the article mentioned, the value 0.5 pounds per ton per degree of curvature of 100 feet is more nearly an assumed value than a calculated one.

The latest tests made to determine the relative resistance of a train on straight track and curves, are those made in September, 1901, by Max H. Wickhorst, Engineer of Tests of the C. B. & Q. Railway at West Alton, Mo., on the St. Louis, Keokuk & Northwestern Railway. These tests were carried out with considerable care on a seven and one half degree curve with about 0.33 per cent grade and having
an approach on straight track with about five per cent grade. In obtaining the data, the dynamometer car belonging to the C. B. & Q. Railway was used, the draw bar pull being recorded by a pen actuated by a hydraulic dynamometer. This car in which records were made of draw bar pull, time, and distance, was coupled between the tender and the remainder of the train. A Boyer speed recorder was placed in the cab, and the engineer was instructed to maintain uniform speed through out each test. After the tests were made, levels were run over this piece of track and the correct profile obtained. In working up the results, the average total draw bar pull was obtained for section of both tangent and curved track, and from this the draw bar pull per ton actual, which was then corrected for acceleration or retardation, and grade. This value was greater on the curved section by an amount due to the curvature. The difference between the values obtained on tangent and curved track, divided by the degree of curvature (7 1/2) gave 1.72 pounds per ton per degree as the resistance due to curvature. This value it will be seen, is decidedly greater than 0.5 and 0.7 pounds per ton per degree of curve which are usually taken. No further tests have been made to reconcile this wide variation, or verify the results. It seems very likely, however, that a higher value than either 0.5 or 0.7 pounds per ton is more nearly correct.

As to the accuracy of this method of determining the resistance due to curves, there is some question. In an
article which appeared in the Railroad Gazette for June 20th. 1902, Mr. J. A. F. Aspinwall comes to the following conclusion in regard to the use of a dynamometer car in determining curve resistance. "It was found that the extra resistance due to the curvature of the line could not be accurately ascertained by means of the recording apparatus. This is due to the fact that the engine on entering the curve is the first to encounter the extra resistance, which causes it to lose speed slightly, relatively to the train: consequently the tension on the draw bar is somewhat decreased. The objection is overcome when the whole train is on the curve and has settled down to a normal speed; by that time, however, the engine was leaving the curve on which the experiments were made. Other than this, the method seems quite logical."

In short, there has been comparatively little investigation of the subject of curve resistance, and even these few are open to criticism.

It shall be the object of this thesis, to further investigate this subject in connection with electric railway operation, and an attempt made to show by certain experimental data, taken for this purpose in a manner hereinafter described, the relation between the resistance and power consumption of a 28 ton electric car on tangent track and on curves.

There are a number of variables such as degree of curvature, superelevation, speed, and wheel base, entering into this consideration, which will undoubtedly have their effect on the value of the resistance. For instance, some experiments have shown that the resistance for curves
of low degree and with long rigid wheel base, is considerably larger than on curves of high degree and for American bogie trucks. In this thesis, however, no attempt will be made to consider any thing but curve resistance in general and its variation with speed.

Curve resistance arises from the slipping of the wheels on the rails, and flange friction. The total slipping on any curve is that due to twisting the truck through an angle equal to the change of direction, or through the central angle of the curve. This causes a longitudinal slipping equal to the difference in length between the inner and outer rails, and at the same time a lateral slipping depending on the length of the wheel base and the central angle of the curve.

First consider the action of a truck on a curve referring to Fig. 1.

![Fig. 1.](image)

Take a four wheeled truck with length b between axles, pulled toward the curve by a force P applied at the center pin. At the moment when the draw bar reaches the curve, the direction of P changes to a tangent to the curve. The truck, however, rolls straight ahead until the forward outer flange
comes against the outer rail. This brings the resistance \( R \) into action, which with an equal force, a component of \( P \), tends to twist the truck across the track and bring the rear inner wheel against the inner rail. It is not known just how far over the inner wheel is drawn, but it seems that it does not wear against the side of the rail. The normal pressure \( S \) resists this twisting movement.

Now in moving from A to B, on the curve, Fig. 2, the truck frame must move through a longitudinal distance \( L \) plus \( b \), of which \( b \) may be neglected because it is so small compared with \( L \); and at the same time must twist through an angle \( \theta \), the central angle of the curve. The truck may at any instant be considered to be revolving about its rear inner wheel, in which case the other three wheels will be moving as indicated by the arrows in Fig. 2, that is, the forward inner wheel will be moving laterally, the forward outer wheel will be moving diagonally, the rear outer wheel, longitudinally, while the rear inner wheel will be twisting on the rail. The force directly responsible for this turning motion is the pressure of the outer rail
against the front outer wheel flange and is induced by the draw bar pull. As is evident from the irregularities of the conditions affecting curve resistance it is practically impossible to follow all the forces involved to the final force at the drawbar. The bearing surface at which this slipping takes place is small and of irregular shape and variable in size with conditions and characteristics of the of the materials of wheel and rail. As an average, the surface does not exceed in area the area of a circle 3/8 inches in diameter.

But this is not the whole of curve resistance. There is a second element entering into the make up of this resistance, namely flange friction. This is a sliding too but is vertical, not longitudinal along the rail, and is a grinding down on the side of the rail. Just how much this sliding is, cannot be told, but it occurs at a point a little in advance of a vertical through the center of the wheel. From the nature of this case also it is well nigh impossible to make any exact determination of its value.

The car with which these tests were made, was built by the Jewett Car Co. It has a length of 45 feet over all, 8 ft. 4 in. in width, and 9 ft. 6 ins. from the underside sill to the top of the roof. The distance between truck centers is 22 ft. 4 ins. The car is divided into two compartments, one 22 ft. 6 ins. long and the other 11 ft. 10 ins. long. The larger compartment is furnished with filing cases and chairs in place of the usual seats. The smaller compartment contains
Plan of Instrument Equipment
Electric Test Car
University of Illinois
an instrument table on which is placed the secondary instruments and apparatus. Some of the electric control apparatus which is usually placed under the car is also hung in this compartment. The weight of the car complete is 55150 pounds.

The trucks are of the C-60 type of the Standard Steel Car Co. The wheel base is 6 ft. 4 ins. and the wheels are 33 ins. in diameter, having the M.C.B. tread and flange. Steel Ball Bearing center plates support the car from the trucks frame. The motive power equipment consists of four No. 101-D Westinghouse motors with a nominal rating of 50 H.P. at 500 volts. The gear ratio is 22:62.

The electric control equipment is the Westinghouse unit switch system of multiple control. The switch group, (#37) circuit breaker, (#36) reverser, (under table) limit switch (#34) and line relay (#35) are hung in the smaller compartment for the purpose of observation under running conditions. The brake system is the straight air system and the compressor, compressor motor governor, brake cylinder, and storage tank were supplied by the National Electric Co. Hand brakes are also installed on the car for emergency purposes.

For this series of tests a water rheostat was placed directly in series with the trolley and motors, in order to keep the current in the motors constant by varying the voltage impressed upon them. In this way it was desired to keep the speed constant.

The recording apparatus consists of instruments to record the current, voltage, speed, time, and distance, and
the auxiliary apparatus for these instruments. These records are made on a sheet of paper 40" wide which is taken from one roll and, after passing over a series of rolls and the recording table where the records are made, it is rolled up on another detachable roller. These rolls and paper drive are operated by a small motor or by gearing from the axle.

The current value is recorded by means of a General Electric Graphic Recording Ammeter (#1 on Blue Print). The instrument is excited from a storage battery and the exciting current is noted and kept constant by means of an indicating ammeter (#17) and a rheostat (#25) check readings of the current are made during each test by means of an ammeter (#167) in the motor circuit. A switch to short circuit the ammeter when it is not in use, is placed near the ammeter (#24).

The Line voltage is recorded by a General Electric Graphic Recording Voltmeter (#27) which is also excited from a storage battery, the exciting current being controlled by a rheostat (#26), and its value noted by the ammeter in the circuit (#197). Check readings are made here by means of an indicating voltmeter connected across the line (#18) whose circuit is opened or closed by a knife switch (#31).

The speed is recorded by a General Electric Graphic Recording Ammeter (#37) for which the diagram of connection is shown Fig 3. A one half K. W. generator is driven from the axle by means of a pair of gears and flexible shaft. The generator is separately excited by a storage battery.
Speed Recording Apparatus

Electric Test Car

A₁—Indicating Ammeter in Field Circuit of Generator
A₂—Recording Ammeter
A₃—Indicating Ammeter Used as Check on A₂
A₄—Indicating Ammeter in Field Circuit of Recording Ammeter

Fig. 8.

JAN. 20, 1908.
The exciting current being controlled and kept constant by a rheostat (1/4) and an ammeter (1/22). The resistance in the generator circuit is kept constant and as the speed increases the voltage increases with it and the current in the circuit increases proportionally with the speed as a result. Check readings of speed are made from an autometer which records momentary values of speed and which operates from the axle drive also.

Brake cylinder pressure is recorded by a gage which is connected by a small pipe to the cylinder. The needle to this gage has been extended and fitted with a pen operating on the recording table.

The power consumed by the motors is obtained from an integrating watt meter (1/23). A separate watt meter indicates the power consumed by the pump motor.

In each of the motor circuits is placed a knife switch which is arranged so that ammeter connections may be made, and the current in each individual circuit may be read.

On a stationary frame over the recording table are mounted the time pens (1/11 and 1/14) which record every five seconds by means of the marker clock (1/9) which closes a storage battery circuit and energizes the magnets of the time pens, thus giving an offset in the time line. A pole marker is also mounted on this bar (1/3). This is operated from a push button by an operator at the center of the car as the center of the car passes each pole. When the push button is closed the magnet of the pole pen is energized and
PROFILE OF ROAD ABOUT DODSON CURVE.
Curves were plotted between car resistance on tangent track, and the speed, car resistance being obtained from runs in each direction, and curve drawn for each direction. In this same way curves were drawn for curve track, the car resistance being determined for runs in each direction. In the case of tangent and curve track, mean curves were plotted which would eliminate to a large extent the effect of wind resistance. The two mean curves transferred to one sheet will allow of comparison between the car resistance of both tangent and level track at the various speeds.

From the profile of the track showing the contour of each rail over this section where the tests were made, the general conditions may easily be seen. The grades, though not desirable, did not have an effect upon the results which would be considered. The rail used over the section was 70 lbs. to the yard and 30 ft. lengths. Rail joints are the Weber type. Cinder and dirt ballast were used over the section. On the curve the superelevation may be determined from the profile showing the height of each rail.

The accompanying drawing (see page 15A) is a tracing of the chart made by the recording instruments on run 15 East made on April 17, 1908. These curves are the true size as recorded but are bunched more closely together than on the original chart which is 40 inches wide. The person punching poles was instructed to make two marks for the poles on entrance to and exit from the curve so that the curve limits
TRACING OF RECORD MADE ON RUN NO 18 EAST MADE APR 17 1908.
would be clearly defined. These can be seen by referring
to the chart page 13A at e and f.

We will first follow through the work necessary to
calculate the car resistance from the chart for the power
method using Run number 15 East, test number 65 and 66 as
an example. Since the method is the same for both curve and
tangent track we will work up that section which was on the
curve. Referring to the chart and the profile (see page 12A)
it is evident that this section is between poles 1575 and
1571. Knowing the distance between all poles (see profile)
we find the length of this section to be 356 feet. Again re-
referring to the profile the elevation at pole 1575 is 724.90
at pole 1571 is 721.66. In going east from pole 1575 to
pole 1571 then there is a fall of 3.24 feet. Now draw normals
through e and f: that is pole marks 1575 and 1571 on the
pole line on the chart. These normals should be drawn so
as to intersect all of the records on the chart. The dis-
tance bc on the time line intercepted by the normal must to
some scale represent the exact time taken by the car to
run over this section. As before mentioned the distance
between two marks on the time line represents five seconds
so that any smaller interval such as bd will be represented
by bd/ad x 5. By this means we find the time in this case
to be 7.92 seconds. We must next make allowance for the
positions of the speed, voltage and current recording
pens for since these pens are at the arc of a circle they
would only be on one of the normals, when in the zero
position. Consequently in the speed curve for instance,
at the instant of passing pole 1575 this pen is recording at point k in place of o as might be expected. This is corrected for by means of a template cut in the form of arc of the circle described by the pens. This brings the real limits of the speed, voltage and the current curves between the short lines parallel to and to the left of the normals. The next to be obtained is the speed at the entrance and exit from the section. Obviously the heights Kh and lm on the speed curve will represent these to the same scale. These heights, in the example taken were 1.77 inches and 1.88 inches respectively and from the calibration curve of the speed recorder (see page 19A) we find these to correspond to 30.8 and 32.6 m.p.h. respectively. Knowing these speeds the kinetic energy of the car at entrance to and exit from the curve can be determined from the equation \[ E = C \times S^2 \] where \( S \) is speed in m.p.h. and \( C \) is a constant depending on the number of operators on the car. The value of \( C \) has been worked out for the car with various numbers of operators and takes account of the energies of translation and rotation. In these calculations the axle and shaft were treated as solid cylinders, the gears, wheels and pinion as hollow cylinders and the armature was considered as made up of two hollow cylinders, the body of the armature and windings constituting one and the commutator the other. From these calculations

\[ C \text{ for the empty car equals 1995.} \]
\[ " \text{ car and one operator equals 2000} \]
\[ " \text{ " two operators }" \text{ 2005} \]

That is add 5 to the value of \( C \) for every additional person on
the car. The number of operators in our example would make C equal 2115. Then E at entrance equals 2115 x 30.8^2 equals 2006374 ft. # and E at exit equals 2115 x 32.6^2 equals 2247737 ft. #'s. Now, by means of a planimeter the areas of the speed, voltage and current curves should be obtained, that is the areas of hklm equals A, pQRS equal C and VWXY equals E respectively also the lengths kH, PS and vY. In our example A equals 2.107 square inches and hm equals 1.16 square inches, C equals 2.787 sq. inches, PS 1.12 sq. inches, E equals 1.689 sq. inches, vY equals 1.14 sq. inches. From these areas and lengths the mean heights of these curves can be found and consequently the mean values of speed, voltage and current from the calibration curves. In the example considered,

Mean height of speed curve 1.816 inches equals 31.6 m.p.h.
" " voltage 2,488 " " 457 volts
" " Current 1.4815 " " 148.15 amps.

Also knowing distance and time the speed can be calculated

\[
S = \frac{356}{7.92} = \frac{1.466}{1.466}
\]

From the average voltage and average current the watts input to the motors is found to be 457 x 148.15 = 67730 from which the energy imparted by the current at the wheel rim in foot pounds is found by the formula

\[
\text{Energy} = \frac{\text{Watts} \times \text{eff} \times \text{time} \times 2655}{3600}
\]

in which 2655 equals foot pounds in a watt hour. The efficiency is obtained from the motor efficiency curve (see page 90).
using 1/4 of the average current for all four motors are in the multiple positions. Then

\[
\text{Energy} = \frac{67730 \times 0.85 \times 7.92 \times 2655}{3600} = 336041 \text{ ft '#s.}
\]

Since the car was accelerating over the section a certain amount of energy was required to produce this effect. In value it equals the difference between the kinetic energies at the entrance and exit, that is 2347737 - 2006374 equals 241363 ft.'s at the same time since the car was going down grade a certain amount of energy equal to the weight of the car times the fall in feet or 58150 \times 3.34 equals 188406 ft.'s. was imparted to the car. Then the energy at the wheel rim minus the energy to accelerate plus the energy imparted by the grade equals the total tractive force over the section; or

\[
336041 - 241363 + 188406 = 283084 \text{ ft.'s.}
\]

This divided by the length of section gives the average traction and when divided by the tonnage of the car gives the net car resistance in pounds per ton.

\[
\frac{283084}{356} = 795.18
\]

\[
\frac{795.18}{29.075} = 27.35 \text{ pounds per ton}
\]

This same procedure was gone through in working up each tangent section also.

Now the only difference between this power method and the coasting method is that in the latter no current is being drawn by the motors and consequently no power is supplied in going over the section. This means that the only energy to be considered is that due to change in kinetic energy and
by grade. The areas of voltage and current curves are zero of course so it necessitates getting only one area, that of the speed curve.

The Table shows the results of 45 runs in both directions on the curve and 45 runs in both directions on tangent track, column 43 showing the values obtained for the car resistance in each case.

Now we wish to eliminate the effect of wind resistance if possible for it was opposing the motion of the car in all runs east and helping it in runs west. To do this the curves on page 22 and 23 were plotted between speed and corresponding values of car resistance. The curves on page 22 are those for tangent track, number B being for runs east, and number C for runs west, and number A is a mean curve which is a close approximation to a curve eliminating the effect of the wind. The curves on page 23 are the same for runs on the curve. On page 24 these 2 mean curves were re-plotted so that they might more easily be compared. It is from these curves that the relation between resistance on curved and tangent track can be determined.

Now it is desired to determine values for the car resistance due to curvature alone and show the effect of speed thereon. Obviously this can be found from our two mean curves on page 24. Since number A gives values of car resistance through a considerable range of speed on tangent track and number B the same for curved track we have only to subtract the values of curve A from those of curve
At corresponding speeds to determine the car resistance due to curvature alone at that speed. In short the value of the ordinates between the two curves represents this resistance due to curvature. To get this in the proper form, that is in pounds per ton per degree of curvature, we must divide by the degrees curvature which in this case was 4' 58'. For example the ordinate intercepted by the two curves at say 20m/pt. is 4.38 pounds per ton which divided by 4 58' (4.96) gives 0.862 as the value of car resistance due to curvature alone in pounds per ton per degree of curvature. In like manner values of this resistance were obtained throughout the speed range and a curve (see page 25) plotted between these values and speed.

The instruments used on these tests for recording speed, voltage and current were previously calibrated by the following method. Several runs were made with indicating instruments in the same circuit with the recording instruments, and a great many check readings taken. These check values, taken from the indicating instruments were recorded on the chart by the point where the pen was recording at the time. From these records the calibration curves on pages 19A and 19B&C were plotted between heights above the base line and speed, voltage and current respectively.

On page 19D is the efficiency curve for the motors in use on the car.
CALIBRATION CURVE

G.E. GRAPHIC RECORDING AMMETER
GIVING A RECORD OF SPEED
EXCITING CURRENT 1.22 AMPERES
GENERATION EXCITING CURRENT 2.0 AMPERES
MADE 4-08.
CALIBRATION CURVE
G.E. GRAPHIC RECORDING AMMETER.
EXCITING CURRENT 12 AMPERES.
LARGE COILS IN SERIES.
MADE 4-08.
As was to be expected, the curve of resistance due to curvature on page 25 which, by the way, is the final result aimed at in this thesis, shows that the resistance offered rises with the speed according to some law determined by the form of the curve on page 25. No attempt will be made at this time to determine just what this relation is however. The values arrived at are considerably lower than those determined by the C. B. & Q.'s West Alton tests and above those obtained by the early experimentors on the subject. Where the C. B. & Q. found the value 1.72 pounds per ton per degree at from 18 to 20 m.p.h., the value arrived at by the experiment herein described is 0.89 at 20 m.p.h. This does not necessarily mean that either of these values is wrong; for the general conditions, class of service, etc. are so widely different as to easily account for a difference in values.

There are a number of errors entering into such a determination as this. They are such as:

1. Irregularities of road bed etc.
2. Effect of wind resistance.
3. Errors in obtaining areas and lengths on chart.
4. Errors caused by not accounting for superelevation.

Of these the error due to number 1. is probably not large and cannot be accounted for or eliminated. Number 2 was eliminated by the method, before described, of making the runs in both directions and using a mean curve as the final value, and
number 3 is probably the largest and the same time one of the hardest to eliminate. It is caused chiefly by the small areas and lengths considered so that a slight error in either area or length causes a relatively larger error in the final value. This error could be greatly reduced by speeding up the paper drive and so getting larger areas and lengths to consider thus making the possible error much smaller in proportion. It is not known positively that number 4 would introduce any error but since this is true it is well to consider it as possible error. It would have been well to have investigated this matter but since it did not come within the scope of this thesis nothing was done in this regard.

As to accuracy of the final results little further than this can be said except that they seem to be quite reasonable in comparison with the results of other tests.
Relation between speed—miles per hour and car resistance—lbs. per ton on tangent track.

A - Mean curve
B - Runs East
C - Runs West

Speed — miles per hour

Car resistance—pounds per ton
RELATION BETWEEN
SPEED—MILES PER HOUR
AND
CAR RESISTANCE—LBS. PER TON
ON
CURVE TRACK
A—MEAN CURVE
B—RUNS EAST
C—RUNS WEST

CAR RESISTANCE—POUNDS PER TON

SPEED—MILES PER HOUR

0 5 10 15 20 25 30 35 40 45 50
## Electric Test Car Resistance on Curve and Tangent Track

### Observations Made by Union and Harris Personnel in the Engine Shop of the Union Pacific Railroad During the Rural Division of Illinois Traction System

**April 7 and May 8, 1913**

<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Speed (km/h)</th>
<th>Current (amps)</th>
<th>Voltage (volts)</th>
<th>Resistance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Notes
- **Current** and **Voltage** measurements taken at various intervals.
- **Resistance** calculated from the formula: 
  \[ R = \frac{V}{I} \]
  where \( R \) is resistance, \( V \) is voltage, and \( I \) is current.
- **Date** range from April 7 to May 8, 1913.
- **Speed** varies between different entries.
- **Current** and **Voltage** values range from minimum to maximum limits.

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This table provides a comprehensive view of the resistance测试 on the electric test car, offering insights into the operational efficiency of the Union Pacific Railroad's Illinois Traction System during the specified period.