EFFICIENCY OF OPERATION OF INTERURBAN TEST-CAR

BY

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THESIS

For the Degree of Bachelor of Science
in Electrical Engineering

COLLEGE OF ENGINEERING
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

GEORGE WEBSTER SATTHOFF, HERBERT JOSEPH WEAVER and

LAWRENCE FISHER WOOSTER

ENTITLED EFFICIENCY OF OPERATION OF INTERURBAN TEST CAR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Electrical Engineering

Morgan Brooks,

HEAD OF DEPARTMENT OF Electrical Engineering

ACKNOWLEDGEMENT.

The writers here wish to express their thanks to the Illinois Traction System through whose kindness the tests were made possible, and to those of its employees who were of assistance in making the runs.

Much credit is also due Mr. E. I. Wenger of the Electrical Engineering Department, whose personal aid in conducting the tests has been most valuable.

EFFICIENCY OF OPERATION OF INTERURBAN TEST CAR.

-Description of Car-

The following series of tests was conducted on the Electric Test Car recently purchased by the University of Illinois. This car is of the regular interurban type, built by the Jewett Car Co., the baggage and smoking compartment being given over to instruments. Its length over all is forty-five feet. The trucks are the Standard Steel Company's C-60 type, the wheels on one truck being of rolled steel and those on the other of Cast iron. The equipment is the latest Westinghouse system of pneumatic multiple unit control, with four forty-horse power Westinghouse No. 101-D motors. This system is operated by current from a storage battery through the master controller. The battery current actuates air valves which in turn operate the individual switches in the switch group. This switch group together with the reverser and circuit-breaker is placed in the instrument room for instructional purposes. An interlocking device on the switch group controls the order of operation of the individual switches. There is also a limit switch in connection which prevents the switches from closing and cutting out resistance until the current in the motor circuit falls below a certain predetermined value, and a line relay which cuts out the switches in case of no voltage.

The instrumental equipment consists of a recording ammeter and a recording voltmeter both of General Electric make, a Thompson integrating wattmeter, and an autometer made by the


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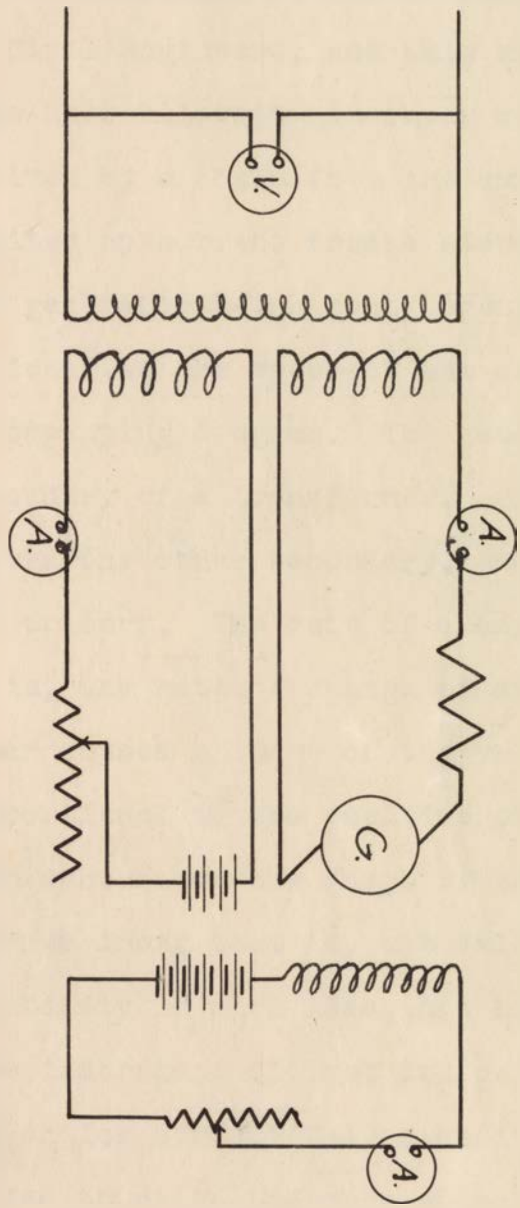
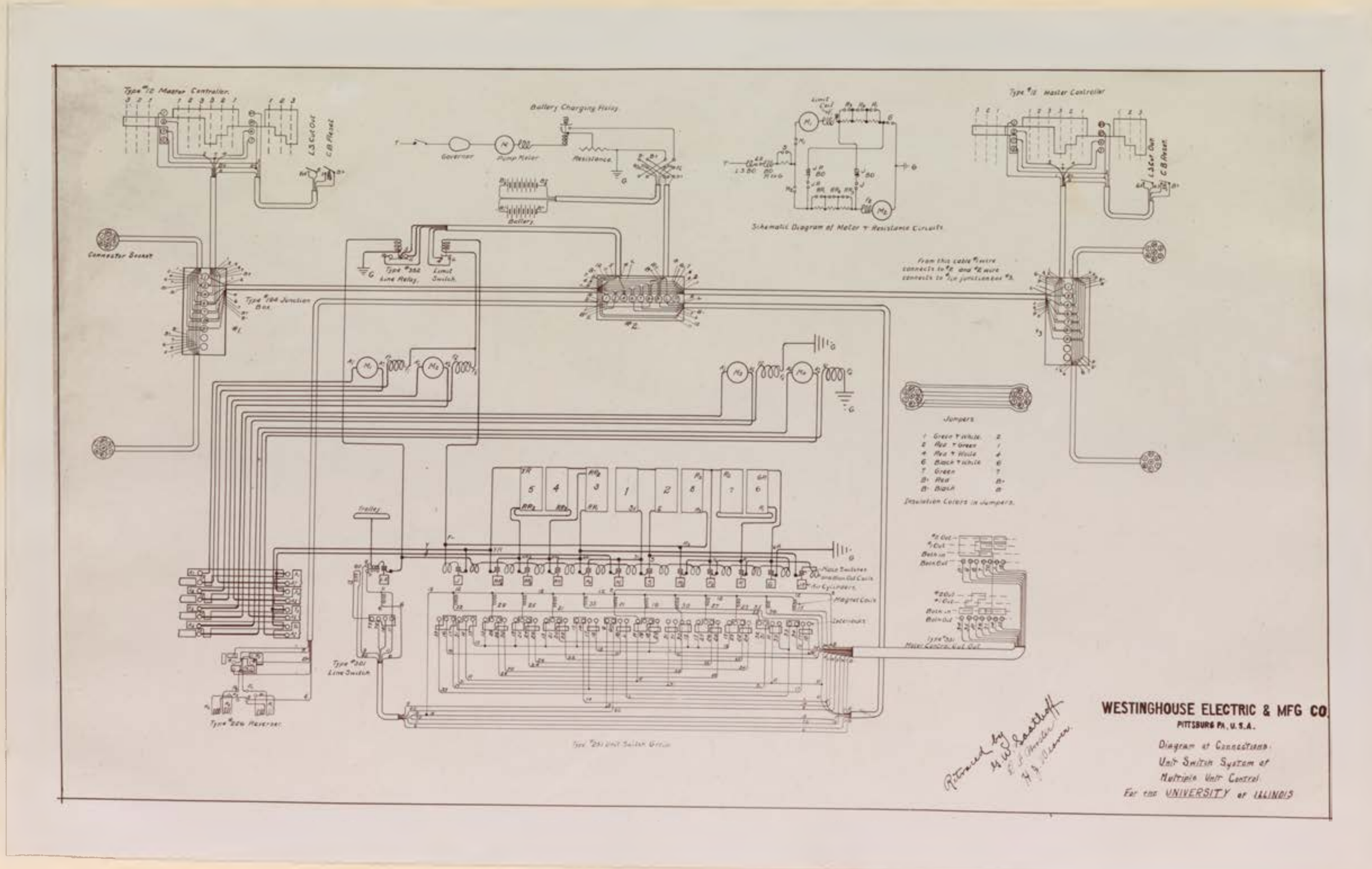
TEST CAR
ELECTRICAL ENGINEERING

DIAGRAM OF CONNECTIONS FOR GENERATOR AND TRANSFORMER.



Warner Instrument Company, which gives the speed in miles per hour at any instant and also shows the mileage for the trip and the total distance travelled by the car. Some trouble was experienced in determining the rate of acceleration but a method was suggested in an article published in the Proceedings of the Canadian Society of Civil Engineers, and this method was finally adopted. A small one-half kilowatt generator was mounted on one of the trucks and driven by a chain from the axle. The generator was heavily over-excited by current from a storage battery, and the current from the generator being sent through a constant resistance was proportional to the speed of the car. Connections are shown on the accompanying diagram. The generator current was sent through one secondary of a transformer, current from a storage battery through the other secondary, and a voltmeter was connected across the primary. The rate of change of current from the generator, that is, the rate of change of speed (or the acceleration) of the car causes a throw of the voltmeter needle, this throw being proportional to the positive or negative acceleration of the car. On account of the shape of the magnetization curve of the transformer iron, that is, the existence of a lower loop where the permeability is much less than higher on the curve, it was found that the instrument did not indicate acceleration as large proportionally on low current values as it did on higher values. It was decided to raise the zero of magnetization, and this is the purpose of the battery current through the second coil. By properly adjusting the current in this coil the zero of flux is

brought up above the lower bend of the magnetization curve and all the variations in current are on the part of the curve where the permeability is at a maximum and practically constant, and since the acceleration by the transformer method depends upon the permeability the readings were more nearly proportional. The curvature of the track may be obtained at any instant by the apparatus described below. On one side of each truck was placed a sector of a circle concentric with the center bearing plate. This sector has a grooved face on which wires are wound, and these wires give motion to drums whose shafts extend up through the floor of the car. By means of wires the motion of these two shafts is averaged and transmitted to the recording pen. On the record thus obtained is read the degree of curvature of the track. Continuous records of speed, acceleration, and curvature were made on a single roll of paper. A piece of apparatus was designed especially for this purpose, the paper was fed over a glass plate and stylographic pens were used to mark the record on the paper. These pens were mounted in carriages running on guide rods, their motion being controlled by cords passing around pulleys which are placed above the indicating instruments.


Type #12 Master Controller.
L.S.Cut Out
C.B.Reset
Battery Charging Relay
Governor
Pump Motor
Resistance
Battery
Connector Socket
Type #382 Line Relay.
Limit Switch.
Type #184 Junction Box.
Schematic Diagram of Motor & Resistance Circuits
Type #12 Master Controller
From this cable #1 wire connects to #2 and #2 wire connects to #1 in junction box #3.
Jumpers
1 Green & White. 2
2 Red & Green 1
4 Red & White 4
6 Black & White 6
7 Green 7
B+ Red B+
B- Black B-
Insulation Colors in Jumpers.
Trolley
Main Switches
Magnet Coils
Air Cylinders
Interlocks
Type #201 Line Switch.
Type #256 Reverser.
Type #251 Unit Switch Group
Motor Control Cut Out
WESTINGHOUSE ELECTRIC & MFG CO.
PITTSBURG PA., U.S.A.
Diagram of Connections.
Unit Switch System of
Multiple Unit Control
For the UNIVERSITY of ILLINOIS

TESTS.

The tests were made on the tracks of the Danville, Urbana, and Champaign Electric Railway. The track is thirty-one and nine-tenths miles long from the Urbana Courthouse to the Danville Plaza, and has a large number of curves, grades and stretches of straight level track, affording an excellent opportunity for experiment.

In conducting the tests special attention was paid to the following:

(1) Power required to maintain a speed of thirty miles per hour on level track.

(2) Power required to start the car on level track.

(3) Power required to get up to speed on straight track at different rates of acceleration.

(4) Power required to get up speed on curves at different rates of acceleration.

(5) Power lost on Middle Fork grades.

(6) Power lost per stop of car.

(7) Power consumption per ton-mile.

(8) Power consumed by air-compressor per car mile.

(1) POWER REQUIRED TO MAINTAIN SPEED OF THIRTY MILES PER HOUR ON LEVEL TRACK.

The data for this test was taken from the ammeter and voltmeter curves for a complete run and was compiled in table No.1. Time and distance were obtained from the auxiliary marks on the continuous records. The Voltage and current curves were integrated between reference points and the mean ordinates calculated. The Reference points were so chosen that between them the car maintained a speed of approximately 30 miles per hour. From these values were obtained the kilowatt-hours per ton-mile. The average power was found to be 47.1 watt-hours per ton-mile which value was used in subsequent calculations.

POWER REQUIRED TO MAINTAIN SPEED OF 30 MILES PER HOUR ON LEVEL TRACK.

Distance in Feet	Time in Seconds	Average Voltage	Average Current	Kilo-watts	Kilo-watt-hours	Watt-hours per Ton-mile
1000	23.0	484	125	60.5	.386	65.2
2000	32.2	481	110	52.9	.474	40.0
2000	32.0	531	125	66.5	.591	49.9
2000	34.2	423	100	42.3	.401	33.9
1500	30.0	362	129	46.7	.389	43.8
1500	33.5	365	119	43.4	.404	45.4
1000	18.5	490	136	66.6	.342	57.8
1000	23.3	341	125	42.7	.277	46.8
2000	30.0	392	148	58.0	.483	40.8
Average Watt-hours per Ton-mile = 47.1						

TABLE NO. 1.

(2) POWER REQUIRED TO START THE CAR ON LEVEL TRACK.

In column 5 of table No. 2 is found a series of readings of the power required to start the car on level track. These power readings were obtained by counting the revolutions of the watt-meter disc. By observation 500 feet was found to be about the average distance passed over in starting the car, so a stretch of straight track 500 feet long was chosen with poles at each end. The car was run back and forth over this stretch and readings taken for both directions to eliminate errors due to wind resistance and any slight variations in elevation of the track. The average value of 470 watt-hours was taken from curve No. L.

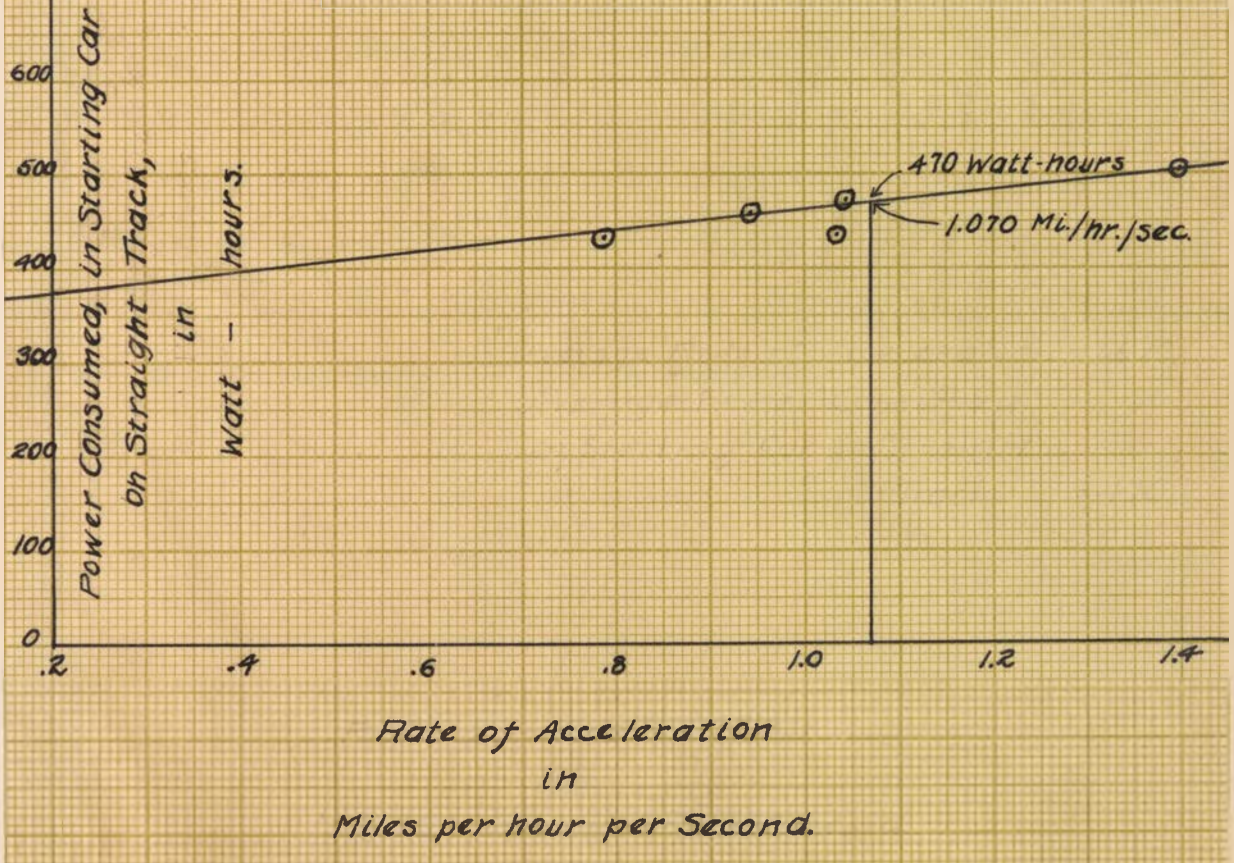
POWER CONSUMED IN STARTING CAR ON STRAIGHT TRACK.

Time in Seconds.	Maximum Speed Attained.	Weight on Relay Plunger.	Average Rate of Acceleration	Power Required Watt-hours	Average of Acceleration	Average Watt-hours
23.3	25.8	5.00	1.109	443	1.035	435
25.7	24.7	5.00	0.961	427		
23.0	28.1	4.50	1.220	525	1.397	503
20.0	31.4	4.50	1.570	480		
25.5	24.3	4.50	0.953	488	1.044	473
22.0	25.0	4.50	1.135	458		
26.0	22.2	3.50	0.854	465	0.942	458
24.0	24.7	3.50	1.030	450		
29.0	21.7	2.75	0.748	435	0.789	432
27.5	22.8	2.75	0.830	428		
For Average Power to Start See Curve No. 1.						

TABLE NO. 2.

Curve No. 1.
Showing Relation
between
Power Consumed in Starting Car
on Straight Track,
and
Rate of Acceleration.

Average Rate of Acceleration = 1.070
Average Power Consumed in Starting
Car on Straight Track = 470



(3) POWER REQUIRED TO GET UP SPEED ON STRAIGHT TRACK AT DIFFERENT RATES OF ACCELERATION.

These tests were made on a straight piece of track 500 feet long as in test No. 2. From standstill the car was brought up to the maximum speed attainable in 500 feet at the rate of acceleration allowed by the limit switch. In order to obtain different rates of acceleration the weight of the limit switch plunger was decreased from time to time. The time, maximum speed, weight on the limit switch, and power consumed, were observed and compiled into table No. 2. From these values were calculated the average acceleration for the different trials. The power consumption was determined by counting therevolutions of the watt-meter.disc. Runs were made in both directions as in test No. 2 to eliminate errors. For each different weight of the Limit switch trials were made in both directions and the acceleration and power readings for the two were averaged to obtain points on the curve. Curve No. 1 shows that the power consumption increased as the rate of acceleration was increased.

(4) POWER REQUIRED TO GET UP SPEED ON CURVES WITH DIFFERENT RATES OF ACCELERATION.

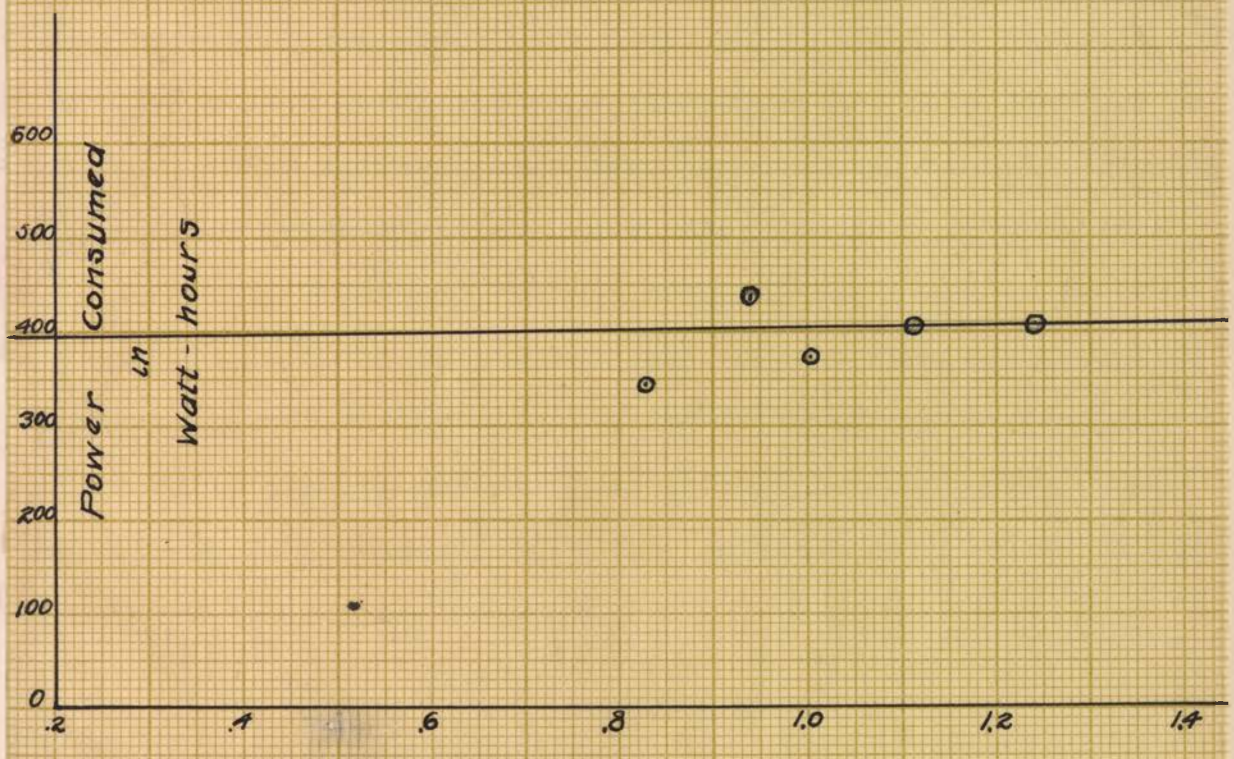
For these trials a piece of curved track of considerable length was chosen and data taken similar to that in test N^{o}. 3 for a stretch 500 feet long. The rates of acceleration were varied as before by changing the weight on the limit switch., and the data collected is embodied in table No. 3. As before a curve was plotted. The results obtained would seem to indicate that very little or no more power is required for higher than for lower rates of acceleration. That is, the power required to run between two points on a curve is practically constant regardless of the rate of acceleration.

POWER CONSUMED IN STARTING CAR ON CURVES.

Time in Seconds	Maximum Speed Attained	Weight on Limit Switch	Average Rate of Acceleration	Power Required Watt-hours	Average of Accelerations	Average Watt-hours.
17.5	23.4	5.00	1.336	360	1.240	409
22.0	25.2	5.00	1.144	458		
21.0	23.3	4.50	1.110	405	1.110	405
22.0	20.7	4.00	0.940	435	0.940	435
22.0	22.8	3.50	1.035	368	1.020	375
19.5	19.8	3.50	1.015	382		
18.0	21.4	2.75	1.188	375	0.828	342
30.0	14.0	2.75	0.467	308		

TABLE NO. 3.

Curve No.2.
Showing Relation
between
Power Consumed in Starting Car
on a Curve,
and
Rate of Acceleration.



(5) POWER LOST ON THE MIDDLE FORK GRADES.

In this test which was made on the Middle Fork grades, the heaviest on the line, two poles were chosen 10000 feet apart, which distance takes in both grades. As may be seen from the profile the track descends rapidly to the bridge and ascends to the same height on the other side. The current and voltage curves were integrated between the reference points for several different runs and the power consumption calculated. These values were then averaged. The power which would be consumed if the track were level was calculated from the data obtained in test No. 1. The difference between the average value as actually found and the value found for level track shows the power lost on account of the grades. This difference was found to be 836 watt-hours. Probably the largest part of the loss is accounted for by the fact that the motorman had to apply the brakes in going down to prevent the car from attaining a dangerous speed. The rest may be accounted for by the curves on both sides of the bridge near the top of the grades.

POWER LOST ON MIDDLE FORK GRADES.

Direction of Run.	Time in Seconds.	Average Voltage.	Average Current.	Kilo-watt-hours.	Direction of Wind.	Velocity of Wind.
East	236	403	117	3.015	S.E.	10
West	245	470	108	3.458	N.	4
East	265	477	112	3.935	N.	4
West	227	400	107	2.700	S.W.	11.5
East	264	421	100	3.082	S.E.	8.5
Average Kilowatt-hours Required						3.236
Kilowatt-hours Required for Level Track						2.400
Power Lost Due to Grades 836 Watt-hours						

TABLE NO. 4.

(6) POWER LOST PER STOP OF CAR.

In this test it was assumed that in making a stop and start the car passed over about 1250 feet, this value being chosen as about the average from observations taken with different motormen. From the first test the power required by the car in running this distance at average speed without a stop was obtained. This was found to be 270 watt-hours. Subtracting this value from that obtained for a start in test No. 2, 470 watt-hours, the additional power required for each additional stop was obtained. This power was found to be 200 watt-hours.

(7) POWER CONSUMPTION PER TON-MILE.

The data for this test was obtained from several complete runs between Urbana and Danville. The number of stops was noted on each trip and also the number of passengers carried. Eight stops was assumed to be the average number for one trip, and all of the watt-meter readings were corrected by means of the data obtained in test No. 6 for this number of stops. After correcting for the number of stops the number of passengers was considered. The average weight of a passenger was assumed to be 150 pounds. This was multiplied by the number of passengers and added to the weight of the car which was found to be 54500 pounds. Dividing the power for the trip by this weight and by the distance gave the power per ton-mile. Dividing this by 2000 and multiplying by 150 gave the power per passenger-mile, for each added passenger. The data for this test and the results may be found in table No. 5. The corrected values of the total power for the trips showed that the power consumption was greater going from Danville to Urbana than from Urbana to Danville. The average power required for the trip in each direction was obtained and the difference calculated. The average watt-hours per ton-mile and the average watt-hours per added passenger-mile were calculated. The profile of the track shows a difference in level between Urbana and Danville of 112 feet, Urbana being the higher. The average weight of the car and passengers was found to be 56500 pounds. Using this value the power required to lift the car 112 feet is $\frac{56500 \times 112 \times .746}{33000 \times 60}$ = 2.385 Kilowatt-hours. The difference in power actually required for the runs is 6.43 kilowatt-hours, this however must be divided by 2 to obtain the power required to lift the car. This gives 3.22 kilowatt-hours. This value is 1.35 times the actual power required to lift the car 112 feet, or an error of 35%. This error may be accounted for to a great extent by the fact that the prevailing winds during the runs were from the South-east.

POWER CONSUMPTION PER TON-MILE AND PER PASSENGER-MILE.

Direction of Run.	Number of Starts	Number of Passengers	Power Consumed K.W.-hours	K.W.-hours Corrected for 8 Starts	Watt-hours per Ton-mile	Watt-hours per Pass-mile	Direction of Wind.	Velocity of Wind.
U - D	12	13	50.30	49.50	55.0	0.413	S.W.	10
D - U	12	13	59.00	58.20	64.7	0.485	S.W.	10
U - D	10	18	44.40	44.00	46.6	0.350	N.E.	12
D - U	2	18	57.26	56.06	61.5	0.461	N.E.	12
U - D	9	8	49.76	49.56	55.9	0.419	N.	5
D - U	10	8	61.60	60.80	68.6	0.515	N.	5
U - D	6	24	55.16	55.56	60.5	0.454	S.E.	7
D - U	6	24	56.08	56.48	60.9	0.456	S.E.	7
U - D	11	12	53.48	52.88	58.9	0.441	W.	10
D - U	10	12	62.32	61.92	69.0	0.518	W.	10
U - D	9	14	48.40	48.20	53.3	0.400	N.E.	6
D - U	15	14	54.80	53.40	59.1	0.444	N.E.	6
U - D	2	7	48.22	49.42	55.8	0.418	S.E.	10
D - U	2	7	45.20	46.40	52.5	0.394	S.E.	10
U - D	6	10	51.20	51.60	57.7	0.433	S.E.	10
D - U	2	10	65.50	66.70	74.7	0.560	S.E.	10

Averages.

Average Power Consumed, U - D	50.90 K.W.-hours.
Average Power Consumed, D - U	57.47 K.W.-hours.
Average Watt-hours per Ton-mile	57.1
Average Watt-hours per Passenger-mile	0.428
Average Weight of Car and Passengers	56500 #

TABLE NO. 5.

(8) POWER CONSUMED BY AIR-COMPRESSOR PER CAR-MILE.

An integrating wattmeter was placed in the compressor circuit and during several of the runs readings were taken to obtain data on the power required for braking and operating the pneumatic switches in the switch group. Taking the total watt-hours per run and dividing by the distance gives the value of the power required per car-mile. The average of several such sets of readings shows a consumption of about 64.8 watt-hours per mile. While no accurate determination can be made due to the varied character of the runs and the difference in motormen the average values obtained may serve as a basis for comparison with the total power required per car-mile. According to the data obtained the power consumed was about 4.05% of the total power per car-mile.

GENERAL CONCLUSIONS.

From an economic standpoint fast running with the cars full, and with few stops is the ideal condition for an interurban system. In test No. 6 it may be seen that the power required for an additional stop is 200 watt-hours, and from table No. 5 that the power required for an additional passenger-mile is .43 watt-hours. That is, more power is lost in making a single stop than is required to carry 14 passengers from Urbana to Danville on a regular trip. For example, if two cars started from Urbana, car A and car B car A carrying 14 more passengers than B and making eight stops, B making nine, the two cars would consume the same amount of power. While this result is rather startling, it is not so important as might be thought at the first glance. The cost of all the power used on the system is a small part of the expense of conducting an interurban system, probably not more than 15%, so that a material increase or decrease in the power required for one car would make an almost inappreciable difference in the expense account. The comparison serves to show, however, that the power per passenger-mile is so small in proportion to the operating expenses that an increase in the number of passengers carried makes a much greater increase in the earnings.

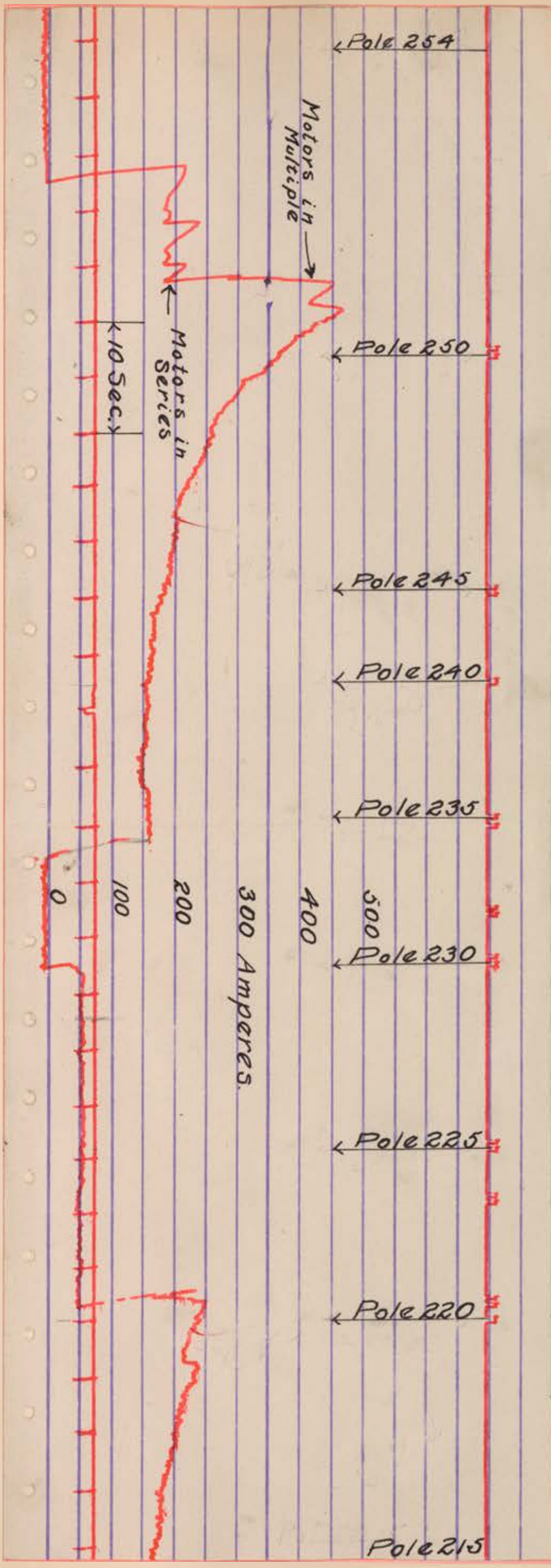
Some interesting and useful data may be deduced from the preceeding tables in connection with the extension of interurban systems. In estimating the increased load upon the power plant it is desirable to know the relative weights of the different factors influencing the power consumption. In order to have something on which to base an estimate the following table is appended:

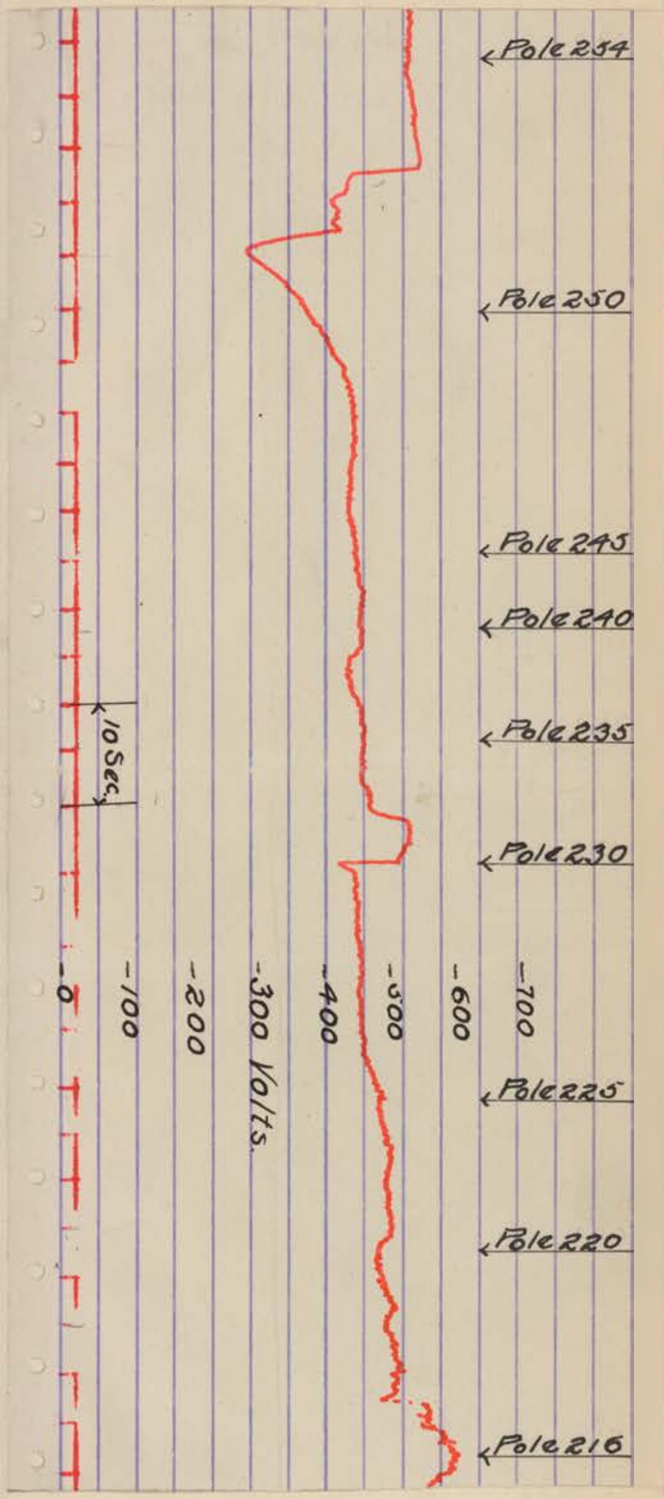
For each added ton-mile	add 47.10	watt-hours.
For each added passenger-mile........	add .43	watt-hours
For each added car-stop..............	add 200.00	watt-hours
For each added 100 feet difference in elevation.	add 84.00	watt-hours

The first and second items were taken from table No.5 and are assumed to be for average track conditions, and for an average distance of 4 miles between stops.

The third item was taken from test No.6

The fourth item was taken from test No. 7. This refers to difference in elevation between terminals, and is for a car weighing approximately 28 tons.


Pole 254
Motors in Multiple
Motors in Series
10 Sec.
Pole 250
Pole 245
Pole 240
Pole 235
Pole 230
Pole 225
Pole 220
Pole 215
0
100
200
300 Amperes.
400
500


Pole 254
Pole 250
Pole 245
Pole 240
Pole 235
Pole 230
Pole 225
Pole 220
Pole 216
10 Sec.
-0
-100
-200
-300 Volts.
-400
-500
-600
-700


Voltage
Elevation
Speed
Current
Current in Amperes.
Speed in miles per hour.
Pressure in volts.
Elevation in feet.
Curves for Complete Run
Urbana to Danville.
May 24. '06.
Danville Station