THESIS

TESTS OF EFFICIENCY

OF THE URBANA AND CHAMPAIGN ELECTRIC STREET RAILWAY.

By

CHAS. TREGO. O. E. GOLDSCHMIDT.

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Test of the Efficiency of the Urbana and Champaign Electric Street Railway.

The object of the tests made was to obtain the conditions under which this road operates. The tests made consisted of special car tests to obtain data concerning the operation of the cars under ordinary conditions, and also a general test of the entire system to determine the power distribution, accounting for all losses so far as we can ascertain them, and finally to obtain information on the practical operation of an electric street railway. These tests were made at different times between January and June, 1894.

This is a single track road connecting the cities of Champaign and Urbana, Ill. and has branches running into different parts of Champaign. The east end of the
road in Urbana is near the crossing of the Wabash R.R. on Main St. It is about one block west of the C. C. C. & St.L. R.R. shops and about four blocks east of the Champaign County Court House. The extreme west end of the line is on West Church St in Champaign, about four blocks west of the new West End Park, which has lately been opened by the Electric Street Railway Co to induce travel on its line.

The total length of the main line is about 4 1/2 miles.

A loop of about 7/8 miles leaves the main line at Third St and University Ave. in Champaign, running south to the Fair Grounds, and thence east, connecting with the main line at the corner of Wright and Green Sts on the line between the two cities. Another branch leaves the main line at New and Church Streets, running south on New St. to Thomas Ave. This is about 1/2 mile long. Still another branch runs north on Neil St. from the corner of Church and Main streets. This passes the Wabash and Big Four Depots and
continues a short distance beyond to the car barn and
pours house. This branch is about a half mile in length.
A short piece of old track on Railroad St. connects the
Main line at Wright St and at Goodwin Ave. but is not now
in use.

The main line runs through the wealthiest and
most thickly settled part of Champaign on West Church St,
then through the business portion of the city, passing
within one block of the Illinois Central Depot and crossing
the tracks of this road on University Ave. It runs on
University Ave to Wright St, the former being the principal
street of the east side of Champaign. On Wright St it passes
the University Athletic Park, and on both Wright and Green
streets it passes all the buildings of the University of
Illinois. In Urbana the line runs along Railroad St.
This is midway between Main and Green streets, which are
the best residence streets in this city. All the hotels in both
cities are on the line of the road or but a short distance from it. The Walker Opera House in Champaign is within one block of the road. All churches in the two cities are within easy reach of the cars. The accompanying map shows the location of the road and the principal points in the two cities.

The elevation of the different points of the road and also the grades are shown by the profile map. This is drawn so as to be continuous from the west end of the line in Champaign to the Wabash R.R. in Urbana, by way of Wright St. All other parts of the line are shown as branches of this same line.

The usual route of the cars is from the west end of the line, east on Church St. and University Ave to Wright St. and south on Wright to Green, then east on Green and Railroad Stree to the east end of the road in Urbana. Every third car in each direction, however, goes around by
the Fair Ground line. The schedule time for the round trip by either of these routes is one hour. The cars require twenty minutes to make the trip from Neil St in Champaign to the east end in Urbana, and twenty minutes to return, while the other twenty minutes are required to run out and return on Church St. The distance out and back is 2.4 miles. According to the time card two cars leave Neil St, and one leaves Urbana at the even hour, and at twenty and forty minutes after. Of the two cars leaving Neil St one goes west on Church and the other east to Urbana. The first car leaves Champaign at 6 A.M. and the last car leaves Urbana at 10:20 A.M. Special cars and trailers are run on special occasions. A car is kept on the New St branch making connections with the Church St car both ways, requiring ten minutes for the run. The average number of passengers carried per day is 1700, and as many as 14000 passengers have been carried.
The cars make about 16 round trips per day, making about 140 miles per day. There have been no serious accidents on the road since its establishment, speaking well for the excellent management of the road.

The Line.

In most places the construction is of the ordinary type, with span wires and wooden side poles. At the crossing of the Illinois Central tracks, in front of the University, and about ¼ mile on Railroad St, the construction is of the side bracket type. Poles are placed 125 ft apart.

The main feeder for the line runs from the Fourth Station following the line to the old right of way on Wright St where it is connected to the trolley. This feeder is No. 00. Connections between trolley and this feeder are also made at Main and Neil Sts and at 3rd St, and University Ave. This is to equalize the pressure along this line. A sub-feeder runs from the large feeder on Wright St along Railroad St to North St in Urbana.
where it is connected to the trolley. This is No. 0 wire. Another feeder, size No. 1, runs from the corner of Main and Neil Sts to New St. These feeders are all of the "Shield Brand" wire. The Trolley wire in Champaign is all No. 0, while from Wright and Railroad Sts to the east end in Urbana it is No. 1.

The rails are bonded with $\frac{5}{6}$ inch tinned copper wire. The rails were newly drilled and reamed, and the bond wire which has a projection for riveting at each end, is inserted and riveted to the rail. On all new work every other rail is cross bonded.

For grounds along the line several rails were buried in each case where the road crosses the creek and these are connected to the rail by means of both copper and iron wire (galvanized). Wherever it was possible a ground connection was made with a water pipe. At the station a number of car wheels were buried in a well and connected to the track by
both copper and galvanized iron wire. Another ground is
here made by means of a spiral coil of galvanized iron wire
which was buried in the ground in a bed of charcoal.

The dynamos and lightning arresters are also connected
to these grounds. Three Keystone, six West, and six Swing Base
lightning arresters are distributed along the line.

As a general rule the road shuts down during heavy
thunder storms, taking no risk of lightning arresters
refusing to act.
GRADE AT SOUTH END OF THIRD STREET
STEEPEST GRADE ON LINE.
The Road.

The road was originally a horse railway and when it was changed into the present electric system, only a small part of the old route was retained. The route in Champaign was entirely changed; in Urbana the old road led east of Goodwin Ave was retained. The route was selected in such a way, that the road should pass through the most thickly settled parts of the two cities, at the same time being convenient to the University. There are very few heavy grades on the line, as may be seen from the profile. The grades on Third St are the worst but are not very long, the maximum being 4.1% and this for a distance of 500 feet only. The grade on Church St is the longest but it is only about a 1% grade. This is for a distance of 2200 feet.

In the construction of the road no cutting was necessary and but little filling. The roadbed on the old line in
Urbana was filled from 3 to 8 feet which was done when
the horse railway was built. This old road was ballasted
with gravel, while the new tracks are ballasted only in
a few places and there with cinders. Along most of the
dike in Champaign the street is paved. Some parts of
the road where no ballast is used have sunk out of
sight in long spells of wet weather.
All turn-outs are shown on the map.
Pomer House.

The power house is located in the northern part of Champaign, near the intersection of the Illinois Central and Big Four R.R., a side track of the former running directly to the power house. The length of line from the power house to main and Neil St's is about 0.5 miles; from the power house to the extreme west end of the line, 1.97 miles; from power house to extreme east end in Urbana 3.33 miles; and from the power house to the south end of new St is 1.5 miles.

The building is of brick 72 x 54, with slate roof supported by wooden trusses. The boiler house, at present is a rough frame structure, but is to be rebuilt of brick. A view of the power house is shown in the accompanying blueprint. The arrangement of machinery is shown in the two interior views, the one showing the dynamos, the other the engines; and also by the general plan of the station and
Boiler House:

Boilers - There are three Babcock and Wilcox water tube boilers, rated at 750 H.P. each, carrying steam at from 90 to 125 lbs. pressure. Two of these boilers were put in lately having been removed from the boiler plant of the Intermural Railway at the World's Columbian Exposition at Chicago. They are of a later type than the other boiler but are rated the same.

The feed water is obtained from the Champaign City Water works and is heated by an exhaust steam feed water heater. A Duplex pump is used to feed the boilers.

The coal used is a medium quality of soft coal and is shovel'd from the cars directly into the boiler room.

The steam is carried into the engine room by a 10 inch pipe 50 feet long, and from this main it branches to the several engines. The pipe supplying the street railway engine is 8 inches in diameter and 70 feet long.
Engines - There are four engines in the station, only one of them being used for the street railway; the others are used for the lighting plant.

The railway engine is a Porter-Allen. High speed automatic engine with 16 x 16 cylinder and runs at 280 revolutions.

It has a six foot driving pulley with 20 inch face. This engine is "No.1" on plan of station.

Engine No.2 is an Ideal 14 x 14 running at 280 revolutions.
The drive is six feet in diameter with 12 inch face; the governor pulley is of the same size. The third engine is also an Ideal. It has 12 x 12 cylinder and runs at 275 revolutions.

It drives from governor pulley 6 ft in diameter and 18 inch face, the fly wheel is 6 ft in diameter and 10 inch face.

The fourth engine is a Russell side crank engine with 14 x 20 cylinder, 207 revolutions. It has 6 ft drive wheel with 20 inch face.

The two Ideal engines run over while the Porter-Allen
and Russel are turned in the other direction and run under so as to get a longer belt. All of these engines take steam from the same boilers. The boiler is sufficient to run either the railway or the lights alone but two must be used when both railway and lighting dynamos are in operation at the same time.

The line shaft extends the entire length of the engine room. It is divided in the middle, the ends having flange couplings, so they may be connected if necessary. Both parts run at 420 revolutions. The south end is driven by the Porter Allen engine and is a 5-inch shaft. The north end is driven by the Russel engine and is 3 3/4 inches in diameter. The north end is also so arranged that it can be belted to the 14 x 14 Ideal engine, if necessary.

The pulleys for driving the south end of shaft are all friction clutch pulleys. All the other pulleys are plain pulleys, a number of extra ones being on this shaft.
Dynamons.

There are in all nine dynamons in the station. Two of these are for the railway, two more are alternators for incandescent lighting and the rest are arc lighting machines. We will take them up here as they are numbered in the drawings of the station.

Nos. 1 and 2 are the railway generators. They are Westinghouse machines having a capacity of 46.8 K.W. each. They are compound wound and run at 525 revolutions. The normal output is about 90 amperes at 520 volts. The entire current of one machine does not go through anyone of its series coils. The upper set of coils are connected in series, and also the lower set. These two sets are connected in parallel so that the main current divides between them. An equalizing wire connects the two dynamons being connected to a point between the armature and the series coils of each machine. This is
to prevent one machine overpowering the other and driving it as a motor if the voltage should be very different. If the voltage of one machine should be too low, current will flow to it through the equalizing wire from the other machine and pass out through the series coils, thus magnetizing the fields more highly and raising the voltage. At the same time the voltage on the other machine will fall as the current in the series coils is less. In this way the two machines will keep each other balanced so that they may be run in parallel. On the switch board, between each machine and the bus-bar, is an automatic circuit breaker set to open circuit at 125 amperes. There are a number of lightning arresters of different types on the switchboard to protect the dynamos.

No. 3 is a 60 K.W. Westinghouse Alternator and it is belted direct to the 14 x 14 Ideal engine.
No 4 is a 45 K.W. Westinghouse Alternator and is belted
direct to the 12 x 12 Ideal engine.

All the arc dynamos are made by the Western Electric Co. No's 5, 8 and 9 are 18 ampere 45 light machines.
No 6 is a 30 light and No 7 a 40 light 10 ampere machine.

Car Barn

The car barn is a brick structure 50 x 100 ft.

The exterior view is shown in the accompanying photograph and a plan in the accompanying drawing. It has 6 tracks connected by a transfer table. Two of the tracks are over a pit for a distance of one car length. It was intended to hold 25 cars but comes far short of that. The company has no machinery to do repair work, but does some armature winding.
The company has 7 motor cars and 4 trailers. The electrical equipment is made by the Westinghouse Co. Brick trucks are used on all but No. 16, which has a McGuire truck. The car bodies were built by the Brownell and Wright Co. and the LaCled Car Co., both of St. Louis. All of the cars have but one motor.

No. 10 is a 16 ft. closed car with 25 H.P. single reduction motor.

No. 11 is a 16 ft. closed car; it has a 16 H.P. double reduction motor. This motor is an old type but still gives good satisfaction. This car is often used as a work car, the top being fitted with a platform in order to work on the trolley wire.

No. 12 is an open car 20 ft. long. It is equipped with a 25 H.P. single reduction motor. Until recently the field coils of this motor were badly burnt, allowing the current...
WIRING DIAGRAM OF WESTINGHOUSE SINGLE-REDUCTION SINGLE-MOTOR CAR.
to pass through without exciting the fields very strongly. In consequence of this the motor took from two to three times as much current as any other motor on the road and the car ran at such a high speed that they never dared to turn the controller on to the last notch.

No 14. This is a 16 ft closed car. The truck of this car is put under No 15 for summer use.

No 15 is a 20 ft open car. The motor is 25 H.P. single reduction.

No 16 is a 20 ft closed car. It has a 30 H.P. single reduction motor. It has a McQuire truck.

No 17 is like No 16 with the exception that it has a 25 H.P. motor.

The trailers are Nos 18, 19, and 20 and one not numbered. The latter is a home-made affair while the others are 16 ft closed cars.
All cars are equipped with 33 inch wheels except No. 12 which has 36 inch wheels. The former have been found to give the best satisfaction.

The wiring diagrams of both single and double reduction motors are shown in accompanying drawings.

The company has tried a number of different kinds of resistances for use with the motors but the later style gotten out by the Westinghouse Electric Company seems to be most satisfactory.

The information in regard to H.P. of motors was obtained from man in charge of car barn.
25 H.P. SINGLE REDUCTION WESTINGHOUSE MOTOR

CONTROLLER
Special Car Test No. 1.

This test was made on Jan. 12, 1894. The temperature on that day was 10° below zero, and the ground was covered with about three inches of fresh snow. The object of this test was to obtain records to show the effect of frozen ground, and the power required to run through snow.

The car used was No. 16. It is a 20 ft. closed car. We had no means of weighing the car but from tables giving the weights of the different parts of car we estimated the weight at 11,000 lbs. It is mounted on a single 7½ ton truck having 33 inch wheels. The car has one 30 HP. single reduction Westinghouse motor.

To measure the current supplied to the motor we placed a Weston 100 amp. Ammeter in the circuit between the motor and the ground connection so as to receive all the current going through the motor. The voltage was measured by a Weston volt-meter connected.
between wire on Trolley pole and the ground. We placed another voltmeter where we thought it would measure the volta lost in the controlling resistance but owing to a mistake in the connections this could not be used. The speed was measured by taking the number of revolutions indicated by a Tachometer belted to the front axle, and reducing the readings to miles per hour.

We had one man for each instrument and another to call the time for taking readings. Readings were taken every ten seconds while the car was in motion. The car was run by the manager of the street railway. The car was run West on Church St. from the corner of Church and Neil Sts. to Prospect Ave. Beyond this the snow had not been cleared from the tracks. We tried running the car through this snow but found it would only go a few feet on the snow before stopping. As soon as it would run on to the snow the wheels would slip and
the voltage would fall much below the normal value. After
the car had stopped, the wheels still turning would wear
through the snow to the rails when the voltage would in-
stantly rise to its normal value, as shown in the curves
for the special car test No. 1. P. This shows that the drop
was due to the increased resistance caused by the snow
between the wheels and the rail. After several attempts
to run on the snow to make certain of this result, we ran
the car over the line to Urbana and back. This run was
made to determine the power and speed of the car under
ordinary conditions. The curves plotted for special car
test No. 1. P. show the variations of voltage on different parts
of the line as well as the Amperes and HP required by the
car. All the regular cars were running and these
caused some of the variations of the voltage as this de-
defends, to some extent, on the current used.
The maximum voltage along the line was
520 volts, while at one place near Eastern end of line it fell to 480 volts. At this time, however, another car was following us closely, and it remained at this point for but an instant. The average for the East line seems to be about 480 volts and on the rest of the line about 500 volts. The highest speed we obtained was 23 miles per hour which was obtained going down grade on Church St. About 15 miles per hour seems to be an average speed.

We stopped on several of the curves and noted the current required to start the car on the curve. This at times would run up to 70 amperes but would go down to 50 amperes in the first 10 seconds. In general, the slower the speed, the greater was the current required to run it. This of course shows that the H.T. at the motor was very great, as most of the voltage was lost in the resistance at such times.

When the car is running at very high speed
The counter E.M.F. is so great that not much current can go through the motor. As an example of this we find that when the speed was 10½ miles per hour the average current was 63 amp, and when the speed was 18 miles per hour, the average current was about 17 amperes. The H.P. for these two cases were 33 and 11 respectively. The average current for a car is about 25 amperes, corresponding to 17 H.P. The current is much greater of course on some of the steeper grades. This test was not as complete as it might have been as we were not well prepared for the work. In the next test we renew what to expect and were prepared for it.
Special Car Test No 2
Apr 15 1894

This test was to secure more accurate data concerning the operation of the cars than we obtained from our first test. We were more careful about locating the position of the car at each reading. The same car, No 16, was used and the readings were taken every ten seconds. To get the speed of the car we had a pulley on the car axle of such size as would make the tachometer show just three times as many revolutions as the axle was actually making. This enabled us to get readings of the speed down to 1 1/2 miles per hour, while with the belt running upon the car axle we could get nothing under 7 miles. We also had a voltmeter connected across the controlling resistance, so as to measure the power lost there.

The total voltage and current were measured as before. The route was from Neil St west to West End Park, then back again and east on University Ave to 3d St.
then south to the Fair Grounds. The car was run back and forth on John St with the controller at different notches, to determine the speed, power, etc for these notches. Then from John St the car was run to the east end of the line in Urbana. The return trip was by Wright St, instead of Third St, and University Ave to Neil St. The curves for this run are plotted on the sheet headed, "Special Car Test No 2."

In plotting these curves we have plotted the distance horizontally, instead of the time as in the first test. It seems to us to show the conditions under which the car operates at the different points on the road better than the other way. We have plotted these curves as though the first part of the run from Neil St to the first end was the last part to make the curves represent a round trip. In the curves for the run going east there is a break for the time the car was on John St; the curves for this time being plotted separately. The profile of the road is shown under the other curves. It is useful in
making comparisons. The parts of the curves west of the
Champaign city limits are not drawn, as there was nothing
by which we could locate the car.

We have plotted the observed amperes, volts, and
speed of the car, and the calculated applied electrical horse
power, lift horse power, and propelling horse power.
The lift horse power is found from the speed of the car and the
grade by means of the formula

$$\text{Lift H. P.} = \frac{\text{Car weight (in pounds)} \times \text{Lift (ft per minute)}}{33000}$$

As we could not get the exact lift per minute for each of
our 10 second readings, we have taken an average for the
length of time we find it to be nearly constant, and have
plotted this as a straight line. Sometimes the lift horse
power is positive, and sometimes negative; it is positive
when extra power is required to overcome it, and negative
when it helps the motor. If it is positive going one way it
will be negative going the other way. The amount of this
lift H.P. will depend both upon the speed of the car, and the steepness of the grade, but ordinarily it does not make a difference of more than 5 H.P.

The propelling H.P. is found by taking the power lost in the resistance from the applied electrical H.P. and taking the percentage of this remainder that represents the efficiency of the motor for this speed and current, as the output of the motor. To this output is added or subtracted the lift H.P. for that time and the result is called the propelling H.P. This method does not take account of the power required to accelerate the car or that given out by the car in stopping.

This propelling H.P. is not as large as would be expected from the applied H.P., but this is accounted for by the low efficiency of street car motors, which is seldom above 70% or at most 75% after allowing for the loss in gearing. When the speed is low and the current large the efficiency
will not be one third of this.
The current ran up to 60 amperes several times during the run, but the average was only about 17.5 amperes. The voltage was a little higher than when we made the first test, the average being 500 volts. It was lowest at the eastern end of the road. The speed of course varied greatly, the maximum being 22 miles per hour, and the average about 17. The maximum electrical horse power was 43, while the average was 11.7. We noticed nothing more about either current, voltage, or speed than was spoken of in the first test.

The horse power has the same sudden changes that the current has, and is much the smallest when the car can run steadily at a good uniform speed. It would seem as if most of the power is used to start the car, so little is used to keep them running. The lift horse power helps the car quite a good deal when going east, but opposes more
than it helps when going west. This is because the general
elevation of the road is towards the east. The maximum lift 4 H.P.
was 9 H.P. and was when the car went up a steep grade
at a high speed; it only lasted for a short time. There is
a large saving of power in taking the grades at a high
speed, for while it takes more power for the time, the
total work, in horse power hours, is really less than
if it had been taken more slowly.
The propelling horse power is not large except when
starting a car or in a few cases when in going down
hill the lift horse power brings it up. The average is
about 8 H.P. There is very little difference in the average
for going east and west, though the lift horse power brings
the average up for the eastern trip, a little above the other.
Car Tests with Controller at Different Notches.

These tests were made during the test just described, while the car was on John St. They were made to determine the speed and power required, as well as the power lost in the resistance when the car was run with the controller in different positions.

The car was first run from Third to Wright St. with the controller on the 3rd notch; then from Wright to Third St. on the first notch, and thence alternately East and West with the controller at a different notch each time. The car was first brought up to speed, for fear of burning out the resistance, and then the controller was thrown to the desired notch.

The curves for each notch are shown separately. The same scale being used for each. They are plotted on the sheet marked "Special Car Test with Controller at Different Notches". The profile is plotted under each set of curves, it being the same, of course, for each of these curves.
The amperes, volts, volts at motor, speed, and applied, lift and propelling horse powers are plotted. The area between the total volts and volts at motor is shaded, representing the volts lost in the resistances. The lift and propelling horse powers were found as before. The time is shown by the short vertical dotted lines below the profile, each division representing 10 seconds; the even minutes being marked with the time.

The curve for the 5th notch is not shown, owing to some uncertain points in it. It would be the same as the ordinary curves after the car is up to speed, it being the notch at which the car is ordinarily run.

The connections to the motor and the resistances is shown in the diagrams of car wiring. When the handle of the controller is thrown to the first notch, connection is made from the trolley to the resistance and then through the motor to the ground. At the second notch, the first resistance
coil is cut out, the current still passing through the second and third and fourth coils, through the motor and thence to the ground. At the third notch the first and second coils are cut out, leaving only the third and fourth coils in circuit. The third coil is cut out at the fourth notch, and the fourth coil at the fifth notch, there being no extra resistance in circuit at the last named notch.

The following table gives the average value of the current, volts lost, speed, and total horse power for each notch. These figures can not be very reliable, for the test was too short to get the actual values to which these would finally come.

The current should be about the same for the different notches, though after the speed is steady the notches with the least resistance should take a little more current than the others. The torque at the motor depends directly upon the current, and as the torque required is nearly the same for all the low speeds, the current ought to be
about the same. For various causes, one of which being the
shortness of the runs, our results do not agree very closely
with the above theory. The speed should increase as resis-
tance is cut out, but it did not do so. In some cases it
was even less than for lower notches. It is on account
of these that we do not think the results are reliable. If
the runs could have been longer they would have been
very different. The loss in voltage shown is all right,
but it is the only thing of any value we can get from
this test. We did not measure these resistances, but it
seems that each time a coil is cut out the resistance
is made half what it was formerly. So great loss
of efficiency would result if the current was sent
through these resistances all the time, for they are not
large enough to make any appreciable difference. With
the large starting currents of course the drop is very large,
often 400 volts or 50%, but this serves to protect the motor.
Table of Average Values for Car Test with Controller at Different Notches.

<table>
<thead>
<tr>
<th>Notch</th>
<th>Ampere</th>
<th>Volt</th>
<th>Speed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>70 = 14%</td>
<td>15.5</td>
<td>9.2</td>
</tr>
<tr>
<td>2</td>
<td>19.3</td>
<td>40 = 8%</td>
<td>13.8</td>
<td>13.5</td>
</tr>
<tr>
<td>3</td>
<td>20.3</td>
<td>20 = 4%</td>
<td>13.8</td>
<td>13.5</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>10 = 2%</td>
<td>14.5</td>
<td>15</td>
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<tr>
<td>5</td>
<td>16</td>
<td>0</td>
<td>13.5</td>
<td>10</td>
</tr>
</tbody>
</table>
The Station Output.

On April 28 we took readings of the electrical output at the station during the entire run from 6:00 A.M. to 11:30 P.M. We did this principally to find the power we had to allow for in the general test.

We placed a Wilton ammeter in the circuit between each dynamo and the bus bar on the switch board, and a Wilton Voltmeter between the trolley and ground bus bars. The readings were taken every minute, those of the two ammeters being added together.

The voltage was not constant, but did not vary much from 520 volts. When a heavy load was suddenly thrown off, the engine would run considerably faster and thus bring the voltage up; at times it would go up to 600 volts. Again when a heavy load was on long enough for the engine to recover from the first shock the voltage would rise to about 540 or 550 volts due to the series turns
on the dynamo when compounding them. This last effect was not noticed, however, if the load was only on for a short time, for the engine would blow up, and did not have time to recover its speed, so the volts would fall to 500 or 510. Only once did they get below 500 and then only for a short time.

The current was very irregular, often changing instantly over 100 amperes. It varied from 10 to 250 amperes. At the beginning of the hour the average current was usually high, and it then decreased until 20 minutes past the hour, when it again became high, and again decreased until 40 minutes past the hour, when this was repeated. This was caused by the cars all starting at about the same time, the current at starting being greater than at any other time.

From 6:00 to 7:00 AM, 12:00 to 1:00 PM, and 6:00 to 7:00 PM. the current averaged the lowest. This was probably because
the stationary motors were not running during these hours. After 7:00 P.M. the current became much greater, causing the circuit breakers on the switchboard to act several times. All the extra cars had been put on for the evening to accommodate the crowd for a special attraction at the West End Park.

As the different cars were taken out in the morning we had an opportunity to find roughly the current taken by each car. No 12 took nearly three times as much as any of the others. We afterwards examined the motor on this car and found the field coils badly burnt.

The station machinery is large enough to run double the number of cars usually operated, so it cannot run at near its highest efficiency much of the time.
The General Test

On May 17, 1894 we made a test of the whole system to determine its working conditions and efficiency. Then were assigned to make as regular boiler test; others to take indicator cards and speed from the engine, and readings of the volts and amperes at the dynamos. Two men were placed on each car and at all the stationary motors to take similar readings. We did not have enough voltmeters to put one at each stationary motor, but we distributed what we had so that the volts at these motors could be found from those at some other motor not far away. Readings were taken every minute from 6 A.M. until 5 P.M. except at the boilers where they were taken whenever coal or water was used.

We had a voltmeter and ammeter on each car, except for about an hour and a half in the morning when car No. 11 had to be taken out before the instru-
ments could be put on it. One of the other cars had an accident just as it was starting out, and No. 11. had to be taken out in its place. As soon as possible No. 16 was wired up and sent out, No. 11. being sent in. After the damaged car had been repaired it replaced No. 16. The results of this test are plotted on the sheets headed "General Test." The first sheet shows the electrical horsepowers taken by each car and stationary motor at every minute, and also the power furnished by the generator at the station. We have dotted a line to show the estimated power used by the car without instruments. This car is exactly like No. 13, and the power is estimated from that used by 13. Car No. 13 was on New St. and only ran about half the time.

At most of the stationary motors the power was so nearly constant, only varying by a few tenths of a horse-power, that it is plotted as straight lines for long
intervals. Most of these motors take very little power except that at the elevator, which takes about 15 to 20 H.P. The motor in Bevis Bros planing mill takes about 5 H.P. most of the time, but occasionally runs up to 10 or 15 H.P. The motor in the “News” printing office takes more power than any in the other printing offices, and only does about the same work. The trouble is probably in the motor itself. The motor in Russell’s Laundry takes considerable power, for it runs at a good load all the time. The total power used by all the stationary motors except the motor at the elevator is about 14 H.P.

Cars No 10 & 13, which are 16 ft cars, take much less power than No 15 and 17, which are 22 and 20 ft long. It is hard to compare No 10 with No 13, because No 13 runs so little. It seems, however, as though No 10 took a little more power. No 10 has a 25 H.P. single reduction motor and No 13 has a 16 horse power double reduction motor. The 25 horse power motor seems
to be larger than is needed for their light cars. Car No. 15 is a 22 ft. open car, while No. 17 is a 20 ft. closed car. Both have the 25 H.P. single reduction motor. These cars take almost exactly the same current. No. 17 is probably some what heavier than No. 15.

Some of the motormen shut the current off while the car is running down hill, or when it has a good start, thinking that this saves power. Others use the current most of the time. There is but little difference in the power used however, as far as we can see. If current is used all the time the car gets to the end of the run sooner and cars then stand still for awhile. The average of the total power used by the cars is about 31 H.P. and the average of the total power taken by the stationary motor is about 19 H.P. making a total average of 50 motor H.P.

The station E.H.P. was not as large as on the other day we took readings. Indeed the load on this day
<table>
<thead>
<tr>
<th>HOUR</th>
<th>CAR No10</th>
<th>CAR No11</th>
<th>CAR No13</th>
<th>CAR No15</th>
<th>CAR No16</th>
<th>CAR No17</th>
<th>TOTAL FOR CARS</th>
<th>TOTAL FOR STATION</th>
<th>TOTAL FOR ALL MOTORS</th>
<th>STATION E.H.P</th>
<th>ENGINE I.H.P.</th>
<th>COAL BURNED</th>
<th>WATER EVAPORATED</th>
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<td>5.1‡</td>
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<td>5.4</td>
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</table>

† CAR ONLY OUT SMALL PART OF THE HOUR
‡ THIS CAR ONLY RUNS HALF OF THE TIME
†† 508 LBS. OF COAL FIRED BEFORE 6:00 A.M.
‡‡ 1200 LBS. OF WATER PUMPED IN AFTER 5:00 P.M.
† THIS DOES NOT INCLUDE THE FIRST HOUR NOR PARTS OF HOURS.
was little less than usual. The average station E H. S. was 55°. The engine horse power is not plotted, as there seems to be no good place to put it. The average for each hour is given in the table of H. P., coal and water per hour, which also gives the average horse power for the hour or the horse power hours of each car and for the sum of the cars and of the stationary motion. The coal fired and water fed into the boiler each hour are given also.

This table was made by taking the sum of the readings for each place during the given hour, and dividing by 60, or the number of readings taken, if some were missed. Zeros readings were counted in with the rest. We think from the way in which it is made out, that this table is quite accurate. The quantities of coal and water given must not be supposed to be the quantities actually burned or evaporated, which we could not get at in any way. No notes were made of the condition of the fire, and we do not
know the quantity of water in the boiler for the different depths in the water gauge.

The engine horse power is much larger than the output of the dynamos. Cards taken before the dynamos were giving any current, showed a friction load of near 80%, and this will probably account for the difference here. The dynamo output averages 10% higher than the power accounted for at the motors, which shows the average loss in the line to be small.

These average values for the total motor, dynamos and engine horse powers, and the weights of coal and water, are plotted for each hour on the sheets marked "General Test: Coal, Water and Average Horsepower."

From these curves there does not seem to be any particular relation between the coal burned and the water evaporated, but the curves on the sheet headed "General Test: Data of Boiler Test" show that ther
These curves are plotted in a different way. The abscissas represent time and the ordinates the total coal burned or water evaporated up to that time. The total horse power hours of work as given by the engine, dynamos and motor readings, are also plotted in the same way. The scale to which the coal is plotted is 1/2 as large as the scale for the water, the zeros being at the same places. The curves run along very close together and cross in many places, showing that only about 5 lbs of water is evaporated by each pound of coal. This is very poor; the builders of the boilers claim about 9 lbs as common practice.

The other curves on this sheet give all the other data, as temperatures, pressures, moisture in steam etc., that were obtained in the boiler test. A detailed statement of the results of the boiler test is given on the printed form enclosed. This shows the evaporation to have been too low. The coal consumed is a fair amount.
for the size of the boilers, both as to the amount per sq ft of grate surface, and per sq ft of heating surface. The boiler was worked much below its rated capacity, so this makes the water evaporated per sq ft of grate surface, and per sq ft of heating surface, and per pound of coal, all too low.

These boilers are said to be rated at 250 H.P. each and they will undoubtedly give even more than that, but when we computed the capacity from the heating surface we only made it 193 H.P. This is on a basis of 11.5 sq ft of heating surface per H.P., which is the usual amount for such boilers.

The poor results of the boiler test can be partly accounted for by the great variations in the load. The boiler has to be ready to supply a large quantity of steam at all times, and the fires kept as as to furnish this, while during a large part of the time only as little steam will be used. Such conditions are
a pretty effectual bar to a high plant efficiency.

The builders claim there are 2388 sq ft of heating surface on this boiler. Our figures are from our own calculations, that were based on the sizes of parts given on blueprints of the boilers. We had figured out the test before finding what the builders rating was, and we do not care to change the figures without more certain information. This would make little difference in any of the results where heating surface is used.

The following tables show in a condensed form all we have been able to determine about the coal, water, and cost of fuel, for the different quantities usually given for comparison. The only thing we can find to compare with any of these is the coal used per dynamo HP; at the 1894 convention of the American Street Railway Association it was found that for 66 different roads the average of the coal used per dynamo horse power was 8.1 lbs. We find that
**GENERAL TEST TABLES**

### 1. Total Water Evaporated
- Total Water Evaporated: 40.000 LBS.
- Coal Burned: 7.900 LBS.
- Engine H.P. Hours: 8.33.
- Dynamo: 578.
- Motor: 521.
- Car Motor: 327.
- Round trips of cars: 32.
- Of 8.6 miles each: 3-1/2.
- Car Miles Run: 297.
- No. of Passengers Carried: Estimated from daily avg. of 1700-1100.
- Passengers per car mile: 4.
- Round trip: 32.

### 2. Coal per Eng. H.P. Hour
- Coal per Eng. H.P. Hour: 9.48 LBS.
- Dynamo: 13.67.
- Motor: 15.16.
- Car Round Trip: 144.2.
- Car Mile: 16.7.
- Passenger Carried: 4.52.

### 3. Water Evaporated by 1 lb of Coal per Engine H.P. Hour
- 1 lb of Coal: 5.06 LBS.
- Dynamo: 48.02.
- Motor: 69.20.
- Car Round Trip: 76.77.
- Car Mile: 730.
- Passenger Carried: 85.

### 4. Cost of Coal, Per Ton
- Cost of Coal, Per Ton: $1.43.
- Total Cost of Coal Burned: $5.65.
- Cost of Fuel Per lb of Water Evaporated: .0141 cts.

### Notes:
- 3D. 5K Car reduced to round trip runs of 8.6 miles each.
- + Equal 63% of total motor H.P.
This road takes 13.67 lbs, which shows that the station
efficiency is much below the average. We can find nothing
to compare with any of the other quantities, but as they are
all closely connected the same results would probably be
found in the other cases.

The number of passengers carried was taken from the
daily average of 1700. The car ran 17 hours a day so this
makes an average of 100 per hour. Our test lasted 11 hours
as we may assume that 1100 people were carried. The
pounds used by the car motors is 63% of the total motor
H.P. hours, so that we might get the coal, water, etc. per
car run, car mile, x passengers carried, we have only taken
63% of the total coal, water, etc. to figure on. The runs of
Car No. 13 were reduced to equivalent round trips.

We can find no way to give the efficiency of the
road in per cent. There seems to be no place to start, as would
be the case with a road run by water power, for it is not
usual to charge the engine the heat lost in the exhaust steam. This would have to be accounted for in some way if we started with the heat in the fuel, and as there is no other place to start we do not attempt to give this efficiency. The greatest losses are found in the station. The engine cannot have a cut off later than 2/3, so to have it large enough to handle the heavy loads, it must cut off very early for the average loads. This makes a great loss by condensation in the cylinder which reduces the efficiency. Then the method of driving dynamos from a countershaft makes a great loss, the total friction load being near 30 H.P. Much of this would be saved by putting direct to the engine. The dynamos being underloaded makes them also run at a lower efficiency than they should.

A railway is a difficult place to get a high plant efficiency, because the load changes so much. In the large roads there are so many cars that the station load does
not vary much, consequently these roads have a higher plant efficiency than the smaller ones. This road can not be expected to do as well as the larger roads, but it should give better results than our tests indicate.