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SPECIAL STUDIES IN ELECTROLYSIS MITIGATION

III. A REPORT ON CONDITIONS IN SPRINGFIELD, OHIO, WITH INSULATED FEEDER SYSTEM INSTALLED

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SPECIAL STUDIES IN ELECTROLYSIS MITIGATION:

3. A REPORT ON CONDITIONS IN SPRINGFIELD, OHIO, WITH INSULATED FEEDER SYSTEM INSTALLED

By Burton McCollum and George H. Ahlborn

I. INTRODUCTION

A. PREVIOUS SURVEYS

In an earlier report[1] there was given a brief discussion of the subject of electrolysis mitigation and a description of the negative feeders which the Springfield Railway Co. had already installed, and recommendations were made concerning the methods to be pursued in Springfield. These included improvement of the Springfield Railway Co.'s system of insulated return feeders, redistribution and addition of negative copper, one crosstie between tracks, the installation of one cable at the Ohio Electric Railway Co.'s substation (chart No. III, opposite p. 49 of above report), careful testing and bonding of track and thorough interconnection of tracks at all intersections whether of the same or different railways.

The insulated return feeder system installed in Springfield was designed and built by the American Railways Co., which operates the Springfield city railway system. During a joint investigation carried on by the utilities and the Bureau of Standards in December, 1913, and January, 1914, certain changes were made, including the disconnection of pipe drainage copper from the pipes and its connection to the tracks on North Street as negative return feeders, and the installation of a cable on East Main Street between Sycamore Street and Belmont Avenue. As pointed out in a special report,[2] other work remained to be done, including the installa-

[1] Technologic Paper No. 27, Bureau of Standards.

[2] Joint Investigation Report on Electrolysis Conditions in Springfield, Ohio.

tion of pressure wires running to the end of every trolley line or the point where the line crossed the city limits, and a considerable amount of track repair work.

B. REASONS FOR PRESENT SURVEY

Because the condition of the track was unsatisfactory at the time of the previous survey and the weather had interfered with measurements and probably affected the values, more detailed measurements were made by the Bureau in July and August of 1914. It is the purpose of this report to discuss the results obtained in these measurements, to describe the insulated return feeder system as finally installed, to make comparison between the conditions shown by the various surveys, to present certain recommendations regarding the improvement and maintenance of the track network, and to draw conclusions as to the effectiveness of the mitigation system in its present form.

II. DISCUSSION OF GENERAL CONDITIONS OF THE VARIOUS SYSTEMS

Before taking up the discussion of the data, a brief description of the conditions existing in Springfield, Ohio, which affect the electrolysis situation will be of interest. Springfield is a city of varied manufacturing interests, having a population of 50 000 and a riding habit of 0.55 per inhabitant, the number of passengers per car mile being 6 and the power required 0.17 kwhrs. per ton mile on the city lines. The country is rolling, there being no very steep grades on either city streets or interurban right of way.

A. RAILWAY SYSTEMS OF SPRINGFIELD

Five railway companies operate within the city limits of Springfield. The Springfield Railway Co. operates 33 miles of single track and normally 29 cars weighing from 12 to 16 tons with an average running current of 35 amperes each. The Ohio Electric Railway Co. operates heavy interurban cars weighing 34 to 43 tons and using an average current of 300 amperes, running on an hourly schedule in three directions and carried by the substation

in Springfield on a total of 18½ miles of line. Freight service, irregular schedule, is handled on these lines. The single-track mileage within the city is 11.6 miles. The power stations of these two lines are fortunately situated, viewed from the electrolysis standpoint, as has been pointed out in previous reports, since they are toward opposite ends of the city load area, and since the interconnection of tracks interchange of current on the negative side takes place very effectively. The other three interurban lines, the Springfield, Troy & Piqua Railway Co., the Springfield & Washington Railway Co., and the Springfield & Xenia Railway Co., have a combined length of 5.3 miles of single track, have no power houses within the city, and the cars (generally only one to each line in the city at any one time) run on an hourly schedule and draw an average current of about 75 amperes per car. Considerable freight service and motor load, especially on the Springfield, Troy & Piqua line, increase the load on these lines.

1. DETAILS OF CONSTRUCTION

The tracks are mainly T rails of weight varying from 35 to 100 pounds per yard, on wooden ties embedded in rock ballast or concrete, new construction being mainly 90 or 100 pounds per yard. A new type of construction already laid on West Pleasant Street and at several other points consists of 100-pound girder rails, laid on steel channels and I sections with a beam of concrete underneath the rail. The joints are connected by an electric pencil weld, and are also welded to the channels at the joints. This provides frequent and effective cross bonding. The stray current leakage from this type of construction will probably be greater than with wooden ties, but the steel ties are spaced 6 feet, and the drainage from the concrete beams should be good. A small amount of track on private right of way is raised above the surface, so that only the ties are in contact with the earth or ballast.

2. REPAIRED SECTIONS

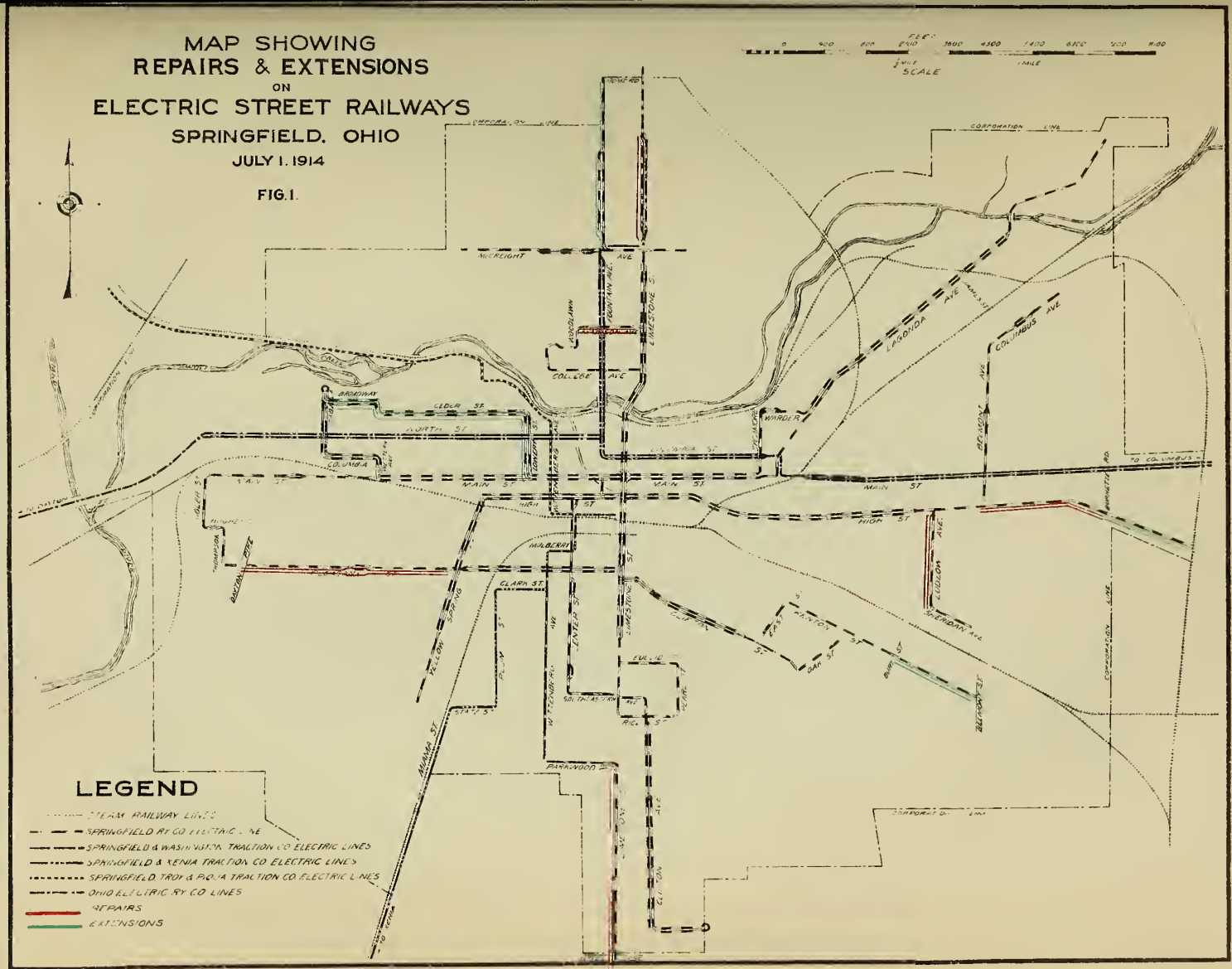
All sections of track mentioned in the second report as defective, except on Limestone Street between McCreight Avenue and Grube Road and on High Street between Belmont Avenue and Burnett

Road have been repaired. Work on these two sections was in progress during this survey, and the discussion of the data will have to include consideration of the effect of these sections. Track repair work is so necessary that it seems undesirable to delay or interrupt it on account of a survey, and some track work will be in progress on a system of this size at all times. To get consistent results there should be a minimum number of disconnected tracks. In addition to the above, new work and repairs were planned or in progress at the following points: East High Street from Burnette Road to the Detroit, Toledo & Ironton tracks; West Pleasant Street from Yellow Springs Street to Dayton Road; on Cedar Street and Broadway to Isabella Street; Yellow Springs Street from State Street south; and on North Fountain Avenue from McCreight Avenue to Home Road. These sections are shown by colors on the accompanying map (Fig. 1, opposite p. 10).

B. OTHER UTILITIES

The underground structures consist of cast-iron mains with lead joints and services operated by the city water department, cast-iron and steel mains with lead, screw, and Dresser joints, and steel or wrought iron service pipes belonging to the Springfield Gas Co., and lead sheath cables of the Central Union Telephone Co. and the Springfield & Xenia Telephone Co.

Gas mains are laid from 2 to 4 feet below the surface, and the ratio of the mileage of cast iron to that of wrought iron and steel is about 1 to 2. The many lead joints showing gas leaks may indicate high resistance joints as on the steel mains do the frequent Dresser couplings, the location of which is very irregular and uncertain. The mains lie in the streets rather than in the alleys, and there is only one supply main to each street, the services crossing under the car tracks. This is also true of the water mains which are all cast iron laid at a depth from 3 to 5 feet. Frequent water heaters make good metallic connections between the gas and water systems. No regular attempt to protect the surfaces by paints, other than the standard practice by the manufacturers, has been made, although some special preparations have been tried. The



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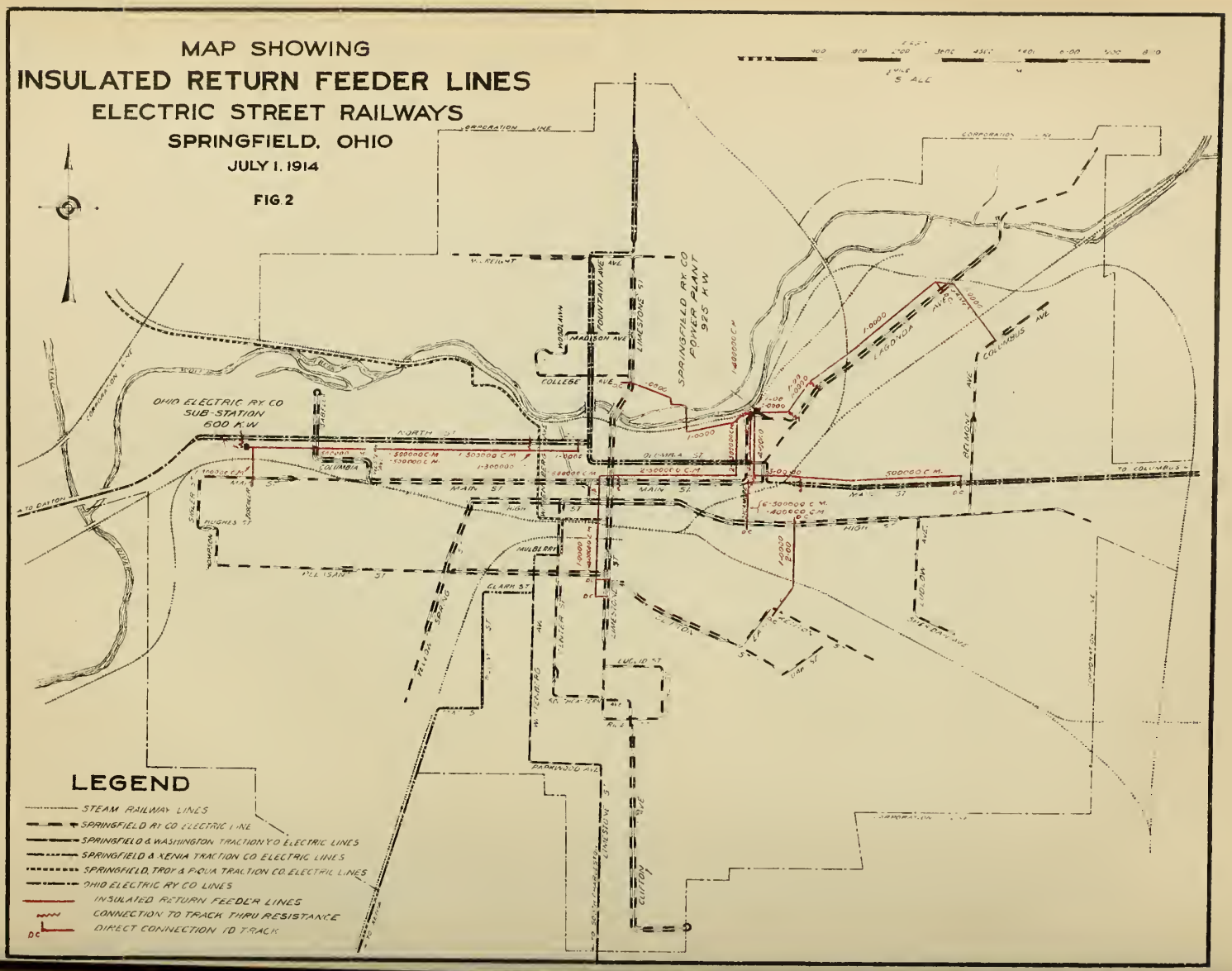

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lead sheath cables are in tile conduit varying from 2 to 26 ducts per run and the total amount of underground run is 14 400 feet. The manholes and ducts seem to be generally clear of water, but frequent springs in the subsurface keep some sections of earth very wet around both cables and pipes.

III. DESCRIPTION OF INSULATED RETURN FEEDER SYSTEMS

A. CONSTRUCTIONAL DETAILS

The insulated return feeder systems are shown on the map in Fig. 2, which shows the location of the feeders, their size and length, and the location and kind of rail connections. It will be noted from the map and table that two stations are equipped with feeders, the Springfield Railway Co. having the more extensive system and the Ohio Electric Railway Co. substation having lines in two directions. The power stations of the three other interurbans are situated well outside the city limits and their loads are too light to require insulated feeders. The map (Fig. 2, opposite p. 11) and Table 1 show certain feeders not specifically recommended by Technologic Paper No. 27, as follows: The No. 0000 feeder to College Avenue and Limestone Street, erected before the first survey, has been left in place as has that on East Street from Kenton to High Streets. A 500 000 circular mil cable was erected on Main Street from Lincoln to Belmont Avenues and connected to the Springfield Railway return feeders to take care of the current until this track was relaid and rebonded, it being planned to repave this street soon. The feeders on North Street, extending from the substation to Fountain Avenue, were originally installed to drain the underground pipes of current. These have been cut over to the rails as shown. The feeders are chiefly copper-strand cable with weatherproof insulation strung on the same poles with the positive feeders.

The rail taps are soldered to cross bonds connecting all rails at the point of connection. In places where resistance taps were necessary $\frac{5}{16}$ inch steel-strand cable was would around a wooden "squirrel cage" with asbestos-covered bars, making a very low-

cost unit but with a large temperature coefficient of resistance. In a single resistance unit at the Ohio Electric Railway substation motor-starting grids were used, they being reassembled in series multiple to give the desired resistance and these are dissipating about 2 kw with a considerable temperature rise. Such a unit is very satisfactory for indoor service and has a smaller temperature coefficient than the steel cable, the most obvious objection to the use of grids for outdoor service being the possibility of change of resistance due to oxidation of the contacts between the grids. The larger temperature coefficient of the stranded cable would be useful in automatically distributing the current between tap points should the load be temporarily concentrated near one feeder terminal.

B. CURRENT, RESISTANCE, AND LOSSES IN FEEDERS

The conditions under which the insulated return feeders are operating are of interest and some of the facts are set forth in the tables following. Table 1 gives a name which distinguishes each feeder, the location of each section, the cross section, weight, length, calculated resistance, current, and watts lost, in the order given. The cross section is the manufacturer's rated circular mils; the length was measured along the track, introducing slight discrepancies at corners. The weight is based on a value of 3090 pounds per 1000 feet of million circular mils; the resistance is based on a unit resistance of 11 ohms per circular mil foot, a value correct within 1 per cent at 28° to 32° C, this temperature being a reasonable mean annual value for a feeder carrying an average load. The current is based on measurements of millivolt drop on a definite length of the cable at the tap points with the recording millivoltmeters, and the power lost is calculated from the resistance and current readings. Since the current used is an all-day average value and the losses in the conductors are proportional to the square of the effective value of the current, a ratio of 1.25 between effective and average is applied in calculating the power lost in the cables.

It is interesting to note the relative amount of negative and positive copper on the Springfield Railway system. The positive feeders weigh 83 200 pounds and the trolley wire 82 400 pounds.

The total negative copper applied for the purpose of reducing gradients amounts to 51 500 pounds, excluding the cable connected to the Main and Sycamore feeder installed temporarily by the Ohio Electric Railway Co. to take care of the East Main Street track until relaid. The weight of the negative copper is 61 per cent of the positive feeders, or 31 per cent of the total positive copper including trolley wire. The Ohio Electric Co. feeder consists of one No. 0000 cable paralleling all tracks for the distance within the city limits, about 32 200 feet weighing 21 000 pounds, and the trolley amounts to about 53 000 feet of No. 0000 and 5000 feet of No. 000, or 37 200 pounds, making the total positive copper 58 200 pounds. The negative feeder mentioned above on East Main Street should be excluded, but if the copper on North Street is included, the negative copper will weigh 16 600 pounds, which is 79 per cent of the positive feeders and 28 per cent of the total positive copper. For both railway systems the total negative copper is 30 per cent of the total positive.

The power loss in the negative feeders, as seen from Table 1, amounts to a total of 11.0 kw, or 264 kwhrs. per day, of which the Springfield Railway station supplies 216 kwhrs. and the Ohio Electric Railway substation 48 kwhrs. These losses are of greater interest when compared with the losses occurring before the insulated return feeder system was installed, which comparison is made below.

TABLE 1

Insulated Return Feeder Data

SPRINGFIELD RAILWAY CO.

Feeder and location of section	Cross-section	Length	Weight	Resist	Current	Power loss
Main and Sycamore feeder:						
Main Street, Belmont to Lincoln Avenue	Cir. mils	Feet	Pounds	Ohms	Amp.	Watts
	500 000	4200	6490	0.0924	15.6	35.2
Main Street, Lincoln Avenue to Sycamore Street	635 000	900	1770	0.0156	49	58.5
Sycamore Street, Main to High Street	3 400 000	1000	10 500	0.0032	50	12.7
Sycamore Street, Main to Warder Street	846 400	1900	4970	0.0247	246	2340
Lagonda Avenue feeder:						
James Street, Columbus to Lagonda Avenue	211 600	1800	1180	0.0936	8.9	11.6
Lagonda Avenue, James to Nelson Street	211 600	3900	2550	0.203	31.3	310
Lagonda Avenue, Nelson to Warder Street	344 700	1000	1060	0.0319	61.8	190
Warder Street, Lagonda Avenue to Sycamore Street	768 000	1000	2370	0.0143	115.8	300
College Avenue feeder:						
Power house to College Avenue and Limestone Street	211 600	3800	2480	0.198	73	1650
Main and Limestone feeder:						
Limestone Street, Clifton to Clark Street	211 600	200	130	0.0104	18.6	56.2
Limestone Street, Clifton to Main Street	611 600	1800	3400	0.0324	95.6	652
Main and Sycamore Streets	500 000	600	930	0.0132	.....	.....
Limestone to Warder Street	1 000 000	5000	15 450	0.055	190.6	3120
Columbia and Sycamore feeder:						
Sycamore Street, Columbia to Warder Street	400 000	1400	1730	0.0385	64	246
East Street feeder:						
East Street, High to Kenton Street	477 600	2000	2950	0.0460	15.2	16.6
Total	.....	.....	57 960	.....	.....	8998.8

OHIO ELECTRIC RAILWAY CO.

Main and Zischler feeder:						
Zischler Street, Main to North Street	300 000	800	742	0.0294	71	232
North Street feeder:						
North Street, Fountain to Wittenberg Avenue	211 600	500	330	0.0260	37.9	108
	300 000	600	560	0.0220	.....	.....
North Street, Wittenberg Avenue to Zischler Street	300 000	1100	1020	0.0403	101	1670
	500 000	300	460	0.0066	.....	.....
	800 000	2200	5440	0.0302	.....	.....
	1 000 000	2600	8040	0.0286	.....	.....
Total	.....	.....	16592	.....	.....	2010

C. RESISTANCE TAPS

It might be well to show some details of the resistance grids. All are on the squirrel-cage supports with the exception of No. 3, as pointed out in Table 2, at Main and Sycamore Streets, No. 8 at North Street and Wittenberg Avenue, and the last at the Ohio Electric Railway substation; and two of these three are dissipating more energy than any of the others. That at Main and Sycamore Streets is drawn in a horizontal loop, which is probably the best position for the rapid radiation of heat, while the last is made up of grids which will withstand a very high temperature. The resistances vary from 0.02 to 0.3 ohm, and the potential drops across them vary from 3 to 12 volts.

TABLE 2

Insulated Return Resistance Taps

Location	Description	Resistance	Current	Potential	Power loss
		Ohms	Amp.	Volts	Watts
Main and Limestone Streets	10 double turns of $\frac{5}{16}$-inch steel strand.	0.0278	95	2.6	390
Main Street and Lincoln Avenue	18 turns of $\frac{5}{16}$-inch steel strand	0.109	33.4	3.6	190
Main and Sycamore Streets	Loop 41 feet 6 inches, double $\frac{5}{16}$-inch steel strand.	0.0385	147	5.7	1300
Columbia and Sycamore Streets	25 turns $\frac{5}{16}$-inch single steel strand.	0.147	64	9.4	940
Warder Street and Lagonda Avenue	31.5 turns, $\frac{5}{16}$-inch steel strand	0.182	54	9.8	830
Nelson Street and Lagonda Avenue	38.5 turns of 200 mil. (solid) iron	0.303	30.5	9.2	440
Main and Zischler Streets	18 turns of 3 foot $3\frac{3}{8}$ inch, $\frac{5}{16}$-inch steel strand 7, No. 12s.	0.0925	71	6.6	730
North Street and Wittenberg Avenue.	Loop 12 feet 10 inches, $\frac{5}{16}$-inch steel strand.	0.0193	56	1.08	95
Substation	Grids	0.044	150	6.6	1550

D. OPERATING COSTS WITHOUT RETURN FEEDER SYSTEMS

In considering any system of electrolysis mitigation it is necessary to consider not alone the electrolysis conditions that are brought about by the installation, but it is important also to take into account the cost of securing the improved conditions. In the present case this cost is affected by two factors, namely, the proper charge to be made against the insulated feeders installed and the change in the power losses caused by changing from the original

conditions of operation to the present system. We, accordingly, give below some estimates of the power losses and feeder costs that would exist without the insulated feeder systems installed, and compare these with the losses and feeder costs under the existing installation. The figures on which these estimates are based are shown in tables.

In order to calculate the losses under either system of distribution it is necessary first to determine the distribution of load in the different sections of the railway tracks. In order to do this we have taken the complete car schedules as furnished by all of the railway companies operating in Springfield and for each independent car routing we have taken the total number of cars operating on that particular routing and divided this by the length of the routing in thousands of feet. This gives the number of cars per thousand feet of track due to this particular line. The number of cars in each section of track between intersections or branches is then determined by multiplying the number of cars per thousand feet by the length of each section. This gives the number of cars in each section in question due to one line of cars only. Similar calculations are made for all car lines running over each section and by summing these up we get the total average number of cars in the section under consideration. Multiplying this number by the average number of amperes consumed per car gives the number of amperes originating in each section of track. Then by a careful analysis of the track network the approximate distribution of the current flowing from outlying sections into the sections near the power house can be determined, and in this way the actual current flowing in any particular portion of the track network can be estimated with sufficient accuracy for present purposes. Knowing the approximate value of the current in any section of track and the size and weight of the rails, the energy loss is readily calculated. An examination of the load curve in Fig. 5 shows that the total average load on the Springfield Railway system is 725 amperes, or 25 amperes per car for the 29 cars in normal operation, and this figure has been used throughout in calculating the energy losses. The data used as the basis of these calculations are shown in Table 3, which table gives the current

flow in each section of the track, the length of the section, the number and weight of rails, the calculated resistance of the track, and the calculated power loss. The resistance of the track is calculated on the basis of a resistivity of 0.00033 ohm per pound foot, which allows 10 per cent for joint resistance. In calculating the power losses under the old system of distribution the current on each railway system is assumed to be confined to the tracks of that particular railway company's tracks, no allowance being made for leakage or interconnection of the tracks.

The reason why no allowance is made for interchange of current due to the interconnection of tracks is that, prior to the installation of the present insulated feeder system it was planned to insulate the tracks of the Ohio Electric and Springfield Railway lines at intersections, and this had actually been done in at least one instance. This means that all current supplied to the Springfield Railway cars from the west, north, and south, and even a portion of East High Street, must return by way of East Main Street from Limestone to Sycamore Streets, and it is here that the greatest loss occurs. Table 3 giving the data on which the calculations are based is self-explanatory, and from an examination of this table it will be seen that the total losses on the Springfield Railway line within the district under consideration amount to about 15.5 kw. It will be seen that the track sections included in this calculation embrace only those lying between the power house and the extreme ends of the various feeder lines. The reason for this is that we are interested only in the changes of power losses and it will be evident that the current flow, and consequently the power losses in the track sections lying beyond the ends of the feeders, will not be materially changed, and can therefore be neglected in making a comparison of the losses under the two systems.

5696°—16——3

TABLE 3

Power Losses Uninsulated Return

SPRINGFIELD RAILWAY CO.

Location of section		Length	Weight of rail	Resistance	Current	Power loss
From—	To—					
		Feet	Lbs.yds.	Ohms	Amp.	Watts
Clark and Limestone Streets..	Limestone and High Streets...	2200	4–60	0.0091	175	437
Main and Sycamore Streets...	Sycamore and Warder Streets.	1800	2–60	0.0149	450	4720
Lagonda Avenue and Warder Street.	Sycamore and Warder Streets.	800	2–60	0.0066	275	781
College Avenue and Limestone Street.	Limestone and Main Streets..	2600	4–60	0.011	100	172
Limestone and Main Streets..	Main and Sycamore Streets...	3100	4–60	0.013	650	8580
Lagonda Avenue and James Street.	Lagonda Avenue and Warder Street.	4900	4–60	0.020	50	78
Columbus Avenue and James Street.	High Street and Belmont Avenue.	4000	2–60	0.033	25	32.3
High Street and Belmont Avenue.	High and Limestone Streets...	8000	4–60	0.033	75	290
Kenton and East Streets.....	Clifton and Limestone Streets.	4300	4–60	0.018	25	17.6
Main and Zischler Streets.....	Main and Limestone Streets..	5500 2100	4–60 2–60	0.040	75	351
Limestone and High Streets...	Limestone and Main Streets..	500	4–90	0.0014	200	87.5
Total.....	.....	.....	.....	.....	.....	15 546

OHIO ELECTRIC RAILWAY CO.

Belmont Avenue and Main Street.	Lincoln Avenue and Main Street.	4200	4–71	0.0146	130	386
Lincoln Avenue and Main Street.	Columbia and Sycamore Streets.	1400	2–71	0.0098	130	259
Columbia and Sycamore Streets.	Fountain Avenue and North Street.	3800	4–90	0.010	130	264
Fountain Avenue and North Street.	North and Zischler Streets....	5900 1500	4–90 4–71	0.021	213	1495
Total.....	.....	.....	.....	.....	.....	2404
Grand total.....	.....	.....	.....	.....	.....	17 950

On the Ohio Electric Railway lines the losses on East Main and Columbia Streets are included, since there will be no interchange such as occurs with interconnections. The total current on the substation is 300 amperes and this is proportioned between the

lines on the basis of schedule and feeding distances, which indicates 130 amperes from the east and 83 from the north. The average loss is 2400 watts, or 57.6 kwhrs. daily.

E. OPERATING COSTS WITH RETURN FEEDER SYSTEMS

The losses within the same limits as those included in the foregoing calculations were determined by actual measurement under the insulated return feeder system. This was done by measuring the drop of potential between the negative bus and the various tap points by means of telephone lines. These potential drops varied between 15 and 13.2 volts, the average being 13.88 volts. Using the same ratio of effective to average current, namely, 1.25 and taking the average value of current for the Springfield Railway lines to be 725 amperes as before, we find the average loss to be 15 700 watts, or 377 kwhrs., daily as compared with 373 kwhrs. with the uninsulated return, an increase of 4 kwhrs. per day.

Following the same method on the Ohio Electric Railway the average current is 300 amperes and the average potential drop 6.63 volts. The watts lost are 3100, or 74.4 kwhrs. per day, as compared with 57.6 kwhrs. with the uninsulated return, giving an increase of 16.8 kwhrs. Thus, the total loss is greater by 20.8 kwhrs. with insulated return feeder system or a cost of 20.8 cents a day on the basis of 1 cent per kwhr., or $75.90 annually. This discussion on losses is summarized in Table 4.

F. ANNUAL CHARGES ON INSULATED NEGATIVE FEEDERS

The investment in negative copper must be charged against this insulated feeder system. As shown by Table 1, the weight of negative copper on the Springfield Railway lines is 51 500 pounds, and on the Ohio Electric Railway 23 000 pounds, the totals in the table differing because the weight of the East Main Street cable has been shifted to the Ohio Electric. Figuring the value of copper erected at 25 cents a pound this represents a value of $18 600, and taking the annual charges as interest 5 per cent, taxes 1 per cent, and depreciation 2 per cent, we get an annual charge of $1490 paid by the two railways for negative copper.

TABLE 4

Power Losses—Insulated Return Feeder Systems

Springfield Railway Co.:
- Average station current, 725 amperes
- Average voltage drop on feeders, 13.88 volts
- Effective value of current or voltage=average×1.25
- 725×13.88×1.56=15 700 watts
- 15 700×24=377 kwhrs. daily
- 377×365=137 600×0.01 kwhr.=$1376 annual cost

Ohio Electric Railway Co.:
- Average station current, 300 amperes
- Average voltage drop on feeders, 6.63 volts
- 300×6.63×1.56=3103 watts
- 3103×24=74.4 kwhrs. daily
- 74.4×365×0.01=$271.50 annual cost
- Total, 377+74.4=451.4 kwhrs. daily

Power losses in same district without insulated feeders 430.6 kwhrs. per day

Difference in power losses:
- 451.4−430.6=20.8 kwhrs. per day
- 20.8×0.01×365=$75.90 annual cost of increase in power lost due to insulated return feeders

The annual charge rate on the pressure wire system would be somewhat higher, namely, 10 per cent, and 10 per cent on $1080 equals $108.

Totaling the charges, we see that the reduction of potential difference is costing the railways $1670 annually. This will be reduced by 10 per cent due to the saving in copper when the East Main Street feeder is no longer necessary because of track rehabilitation. The removal of this feeder will not only obviate the loss in this cable, but will make possible the readjustment of the resistance taps, which will reduce the losses therein considerably, and when these changes are made the power loss under the insulated feeder system will be somewhat less than before this system was installed. It is estimated that after these changes are made the annual cost chargeable to the insulated feeder system will be about $1500.

The track maintenance cost will be somewhat higher if the bonding is kept in the condition recommended, especially during the next few years, but the track depreciation will be less as a result and the riding qualities will be better, due to improved joints. The car operation and lighting will be improved by a more constant voltage over the track network.

The cost of the return feeders is considerably greater than advised in the first report in Technologic Paper, No. 27, due to

several circumstances. In the first place, the load is larger, the load on the Springfield Railway system being now 725 amperes for the all-day average, as against 600 amperes at the time the first estimates were made. In the second place the feeder already in place running from the Springfield Railway Co.'s power plant to College Avenue and Limestone Street was allowed to remain. Also the cable mentioned above, running from the Ohio Electric Railway substation to North Street and Fountain Avenue, which had previously been used as a pipe drainage cable, was left in place and converted to a track feeder, thus further improving electrolysis conditions. In addition to these changes, the bad track conditions which were found on East Main Street and which were not immediately remedied on account of plans for street paving, as explained elsewhere in this report, made it necessary to run a temporary feeder along this street, thereby considerably increasing the apparent cost. Notwithstanding these increases, however, the present annual operating cost is below that existing at the time of the first report. The power losses on the insulated return installed at that time are shown to be valued at $3817 while the interest on copper was $420, giving a total of $4237 annually for the Springfield Railway alone as compared with $1648 for all the present power losses, and $1600 investment charges. The present annual cost is then $3248, leaving a balance of $969 in favor of the present system, and this saving will be increased by the removal of copper as pointed out above.

IV. PRESSURE WIRE SYSTEM

The pressure wires were recommended in order to determine the electrolysis conditions conveniently and thus show whether the insulated feeder system and track return is being properly maintained.

A. LOCATION OF PRESSURE WIRES

These wires radiate from three centers and each is connected to the track at the extreme end or at the city limits if the track extends beyond. There are 11 wires running from the Springfield Railway Co.'s power house at Warder and Sycamore Streets. The reference point is at Main and Sycamore Streets, which is the

point of lowest potential, as explained below. The outlying points are enumerated in Table 6, giving the pressure wire resistance. The over-all potentials are shown in Tables 13 and 14 and shown on the map in Fig. 12 (opposite p. 41). The Ohio Electric Co. has four pressure wires extending from the waiting station at Columbia Street and Fountain Avenue to the tracks at North and Zischler Streets and to the city limits on the east, north, and west. The reference point of other interurban lines is at their waiting station at Washington Street and Fountain Avenue, and the other wires extend from this station to the track intersection with the corporation line.

B. CONSTRUCTION OF PRESSURE WIRE SYSTEM

There are three switchboards bearing the terminals of the pressure wires leading from the tracks. That at the Springfield Railway Co. station is a panel on the main switchboard, while those in the two waiting stations are lighter and less expensive. The essential features are binding posts to which a meter can be connected conveniently and labels indicating the terminating points of the wires.

The permanent pressure wires consist of 12 B. W. G. single-strand iron wire covered with double or triple braid weather-proof insulation. The wires are mounted on glass or porcelain insulators on poles, except where trees or other conditions interfere, when the wires are suspended from the trolley spans. The cost averaged about $30 per mile and the total length is about 36 miles on all lines, of which the Springfield Railway Co. have 22 miles.

V. RESULTS OF MEASUREMENTS

A. METHODS OF MEASUREMENT

The readings were taken chiefly with five Bristol smoked chart millivolt meters each having 5–0–5 millivolt scale, a resistance of about 2.5 ohms, corresponding to 500 ohms per volt, multiplying ranges of 5–20–500–2000–10 000– and 30 000 and a period of about 30 seconds. Typical 24-hour and 1-hour charts are reproduced in Figs. 3 and 4. The first chart (Fig. 3) is a 24-hour record of the millivolt drop on a length of copper bus carrying the total load of

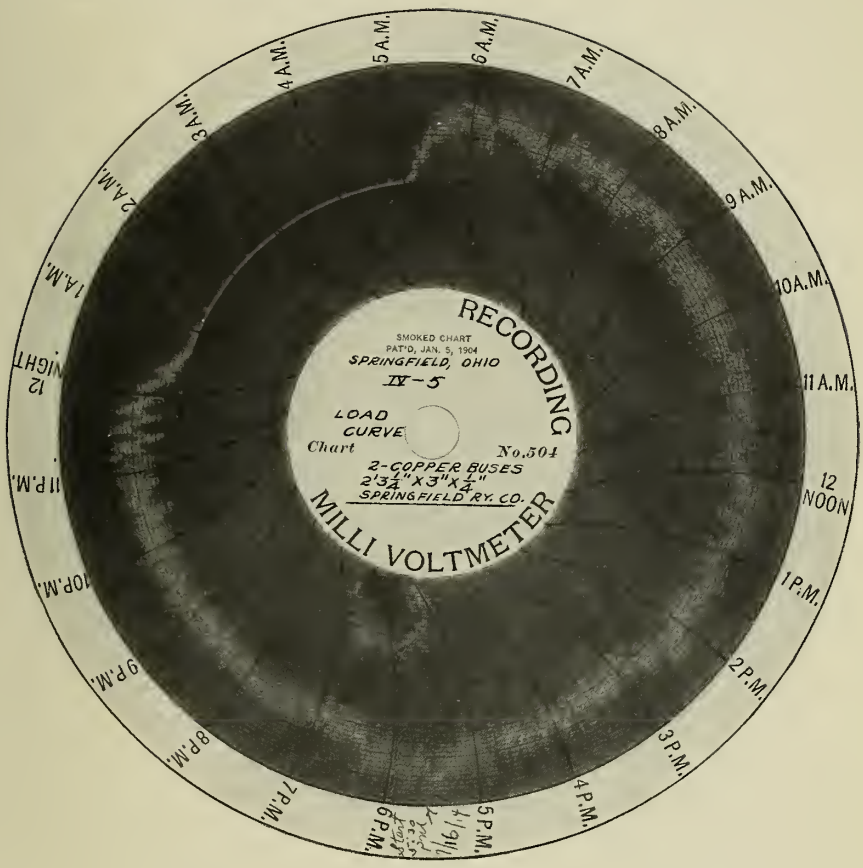
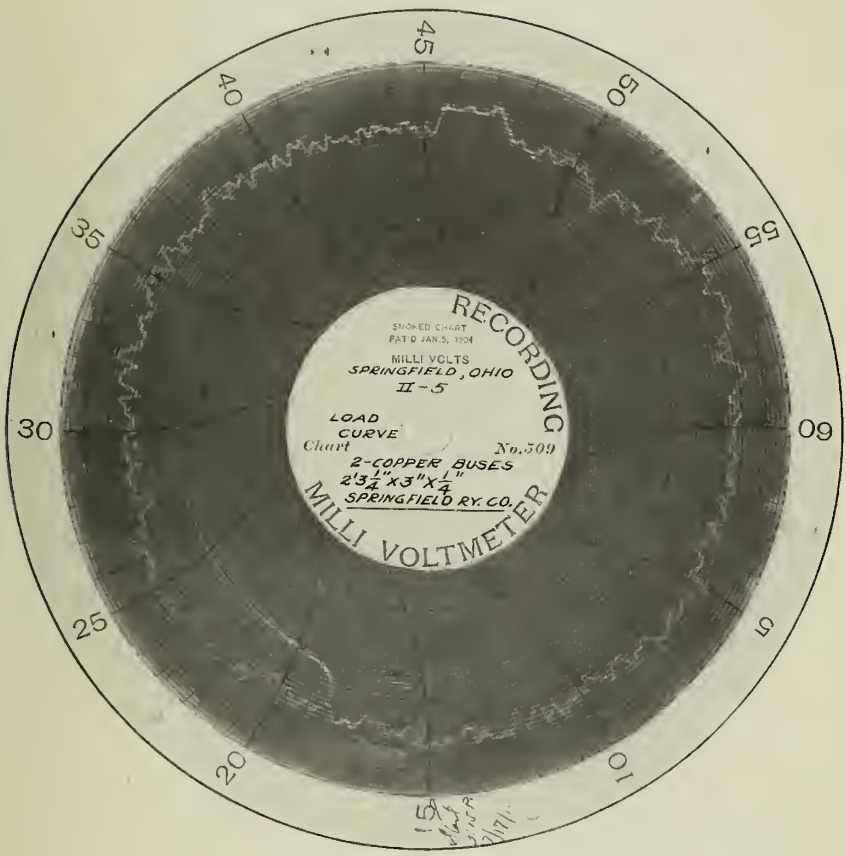

RECORDING
MILLI VOLTMETER
SMOKED CHART
PAT'D, JAN. 5, 1904
SPRINGFIELD, OHIO
IV-5
LOAD
CURVE
Chart
No.504
2-COPPER BUSES
2'3/4" X 3" X 1/4"
SPRINGFIELD RY. CO.
12
NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.
12
NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.

FIG. 3


45
40
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35
55
30
60
25
5
20
10
RECORDING
SMOKED CHART
PAT'D JAN. 5, 1904
MILLI VOLTS
SPRINGFIELD, OHIO
II-5
LOAD
CURVE
Chart
No. 509
2-COPPER BUSES
1"
2 3/4" X 3" X 1/4"
SPRINGFIELD RY. CO.
MILLI VOLTMETER

FIG. 4

Springfield Railway Co. The width of the band on the record shows the difficulty in getting an accurate average of each hour or quarter hour. In order to assist in averaging the 24-hour charts several 1-hour charts were taken of the same potential during the same day, one of which is reproduced (Fig. 4, opposite p. 22). The fine sharp line of this record may be very closely followed with a planimeter and an accurate average obtained. This makes clear one reason why chiefly 1-hour records were obtained, another reason also is the larger number of 1-hour charts that can be made in a given time. The values in millivolts are obtained from the 24-hour charts by inspection while the 1-hour charts are integrated with a polar planimeter by means of which results checking to within 1 or 2 per cent on the higher readings may be obtained, which is better than is possible by inspection, and the integrating process is also much faster. Indicating instruments were used where momentary simultaneous values were desired or where the sensitivity of the recorders was not sufficient. For example, in taking the current readings by the method of measuring a voltage drop on a solid length of main the voltages were universally so low as to require a portable galvanometer to give a readable deflection.

The leads used in the case of potential differences were short lengths of wire between fire hydrant and rail or other conductors under test. For potential gradients, telephone lines extending from the telephone exchange to all tap points were used, while the permanent pressure wires, consisting of No. 12 B. W. G. iron wire, served as leads in the over-all measurements taken. In current readings on water and gas mains two leads were attached to a solid length of the main varying from 3 to 10 feet, and these were brought to the curb and terminated in an iron box. Current readings on copper feeders and busses were made by using the leads with which the instruments were calibrated.

B. CORRECTIONS AND REDUCTION FACTORS

Since the readings were mainly one hour or less in duration and the railway load fluctuated widely throughout the day, it is necessary to reduce all readings to some common bases, two being used in this report, namely, the maximum-hour average and the

all-day average. The all-day average is the average of all values for the 24-hour period, while the maximum-hour average is the average of all values for the hour of heaviest load. These two values are very commonly used in electrolysis surveys and are given here to make easier comparison with conditions in other cities. The use of the short time readings, a few minutes only taken at different hours of the day, as a basis of survey or comparison is not satisfactory, since very discordant results may be obtained by their use. Load curves for the Springfield Railway Co. and the Ohio Electric Railway Co. are given in Figs. 5 and 6, the curves being smoothed out by using the average value of load for the hour at each point. The all-day average value is indicated by the straight line, and the ratio of the average for any hour to the all-day average is also shown by the dotted curve. It is by the use of this ratio curve that readings taken during any particular hour are reduced to a common basis, e. g., the all-day average. Experience has shown that with hour readings a satisfactory average can be obtained, but the fluctuation from moment to moment is so great that reduction of readings taken for a much shorter period is not reliable. The variation in load in case of the Ohio Electric Railway substation was so great that the load ratio curve was further smoothed out by averaging several hours for each point, it seeming probable that the fluctuations would not be repeated at exactly the same time each day and this average would give a more reasonable value; in other words, a reading taken at one of these light load periods but reduced by a peak load value would show too low all-day and maximum-hour values, while the average ratio would reduce this error by 50 per cent.

The resistance of leads requires another correction in case of over-all potentials and gradients, but not in the case of the potential difference and current measurements, because in the latter the resistance of the circuit is comparable with that with which the instruments have been calibrated. The resistance of each telephone lead was measured by a Wheatstone bridge as the loop resistance, and since each lead consisted of the two wires of a pair, one-fourth of the loop resistance was the lead or pressure wire resistance. The resistance of each lead extending from the telephone exchange to the point named is shown in Table 5. Since

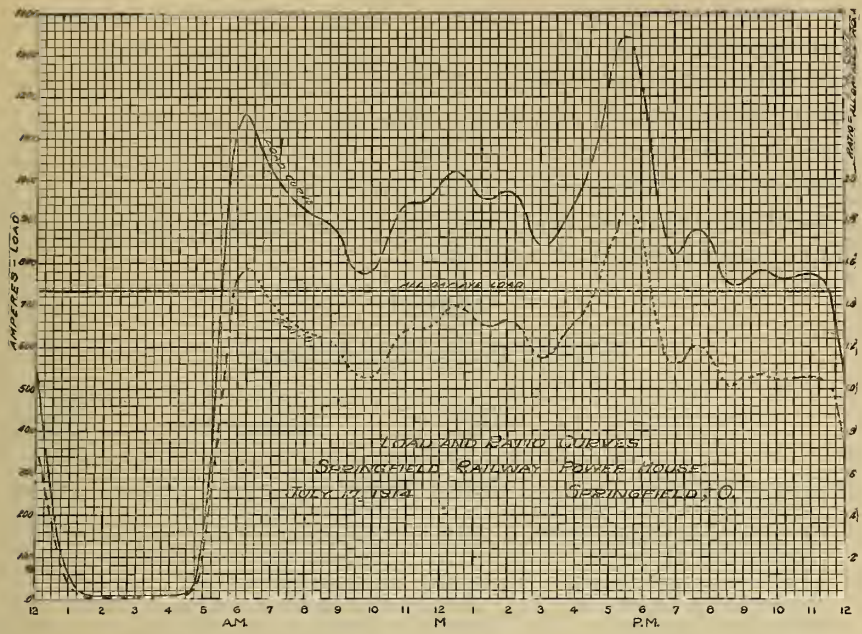

AMPERES-LOAD
LOAD AND RATIO CURVES
SPRINGFIELD RAILWAY POWER HOUSE
JULY 17, 1914
SPRINGFIELD, O.
A.M.
M
P.M.

FIG. 5

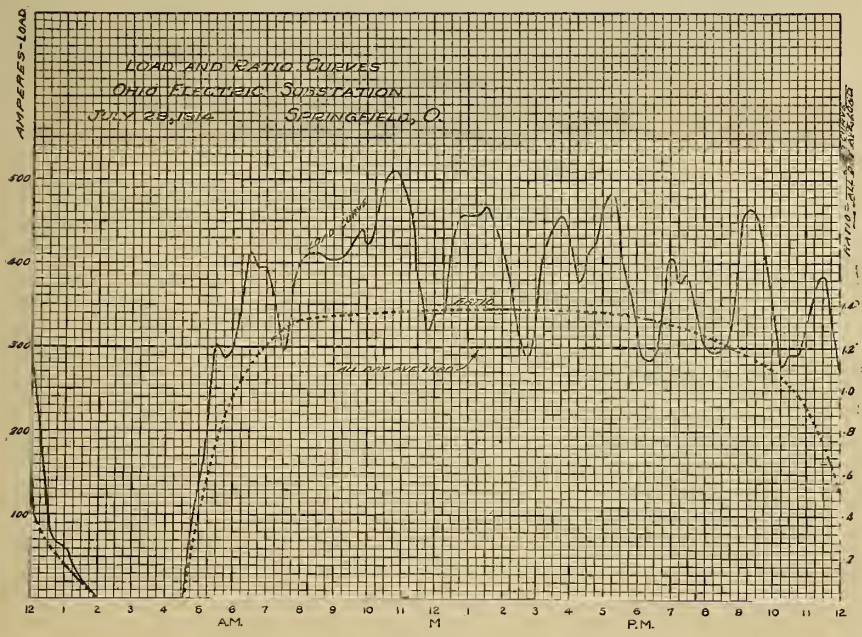

AMPERES-LOAD
LOAD AND RATIO CURVES
OHIO ELECTRIC SUBSTATION
JULY 28, 1914
SPRINGFIELD, O.
A.M.
M
P.M.

FIG. 6

the permanent pressure wires are single wires, their resistance was calculated from the length and specific resistance of the wires, and these values are shown in Table 6. It will be noted that only one of these exceeds 100 ohms, while the resistance of the instrument is from 6000 to 30 000 ohms. Since the resistance of the pressure wires makes only a small percentage correction necessary, a slight inaccuracy in this resistance would influence the result by only a small fraction of 1 per cent.

TABLE 5

Telephone Pressure Wire Resistance

Terminal locations	Resistance	Terminal locations	Resistance
Telephone central station to—	Ohms	Telephone central station to—Continued.	Ohms
Springfield Railway Co.'s negative bus.	87.0	Clark and Limestone Streets	24.9
Warder Street and Lagonda Avenue	87.3	College Avenue and Limestone Street	37.1
Sycamore and Warder Streets	43.2	Columbus Avenue and James Street	97.0
Columbia and Sycamore Streets	34.1	Main and Zischler Streets	74.2
Main and Sycamore Streets	33.5	North Street and Wittenberg Avenue	33.4
High and Sycamore Streets	30.2	Fountain Avenue and North Street	14.9
Lagonda Avenue and Nelson Street	52.3	North and Zischler Streets	50.0
James Street and Lagonda Avenue	87.2	Lincoln Avenue and Main Street	35.0
Main and Limestone Streets	6.6	Belmont Avenue and Main Street	50.0

TABLE 6

Permanent Pressure Wire Resistance

SPRINGFIELD RAILWAY CO.

Terminal locations	Length	Resistance
Sycamore and Warder Streets to—	Feet	Ohms
McCreight Avenue and St. Paris Pike	9700	61.2
Isabella Street at Snyder Park loop	13 500	85.0
Main and Sigler Streets	14 000	88.2
Yellow Springs and State Streets	13 400	84.5
Spring Grove Park	16 750	105.0
Kenton and Burt Streets	8900	56.1
Belmont and Sheridan Avenues	9600	60.5
High Street and Burnette Road	10 600	66.8
Main and Sycamore Streets	1850	11.7
Columbus Avenue and Wheel Street	8650	54.5
Lagonda Avenue and Hilltop Street	10 500	66.2

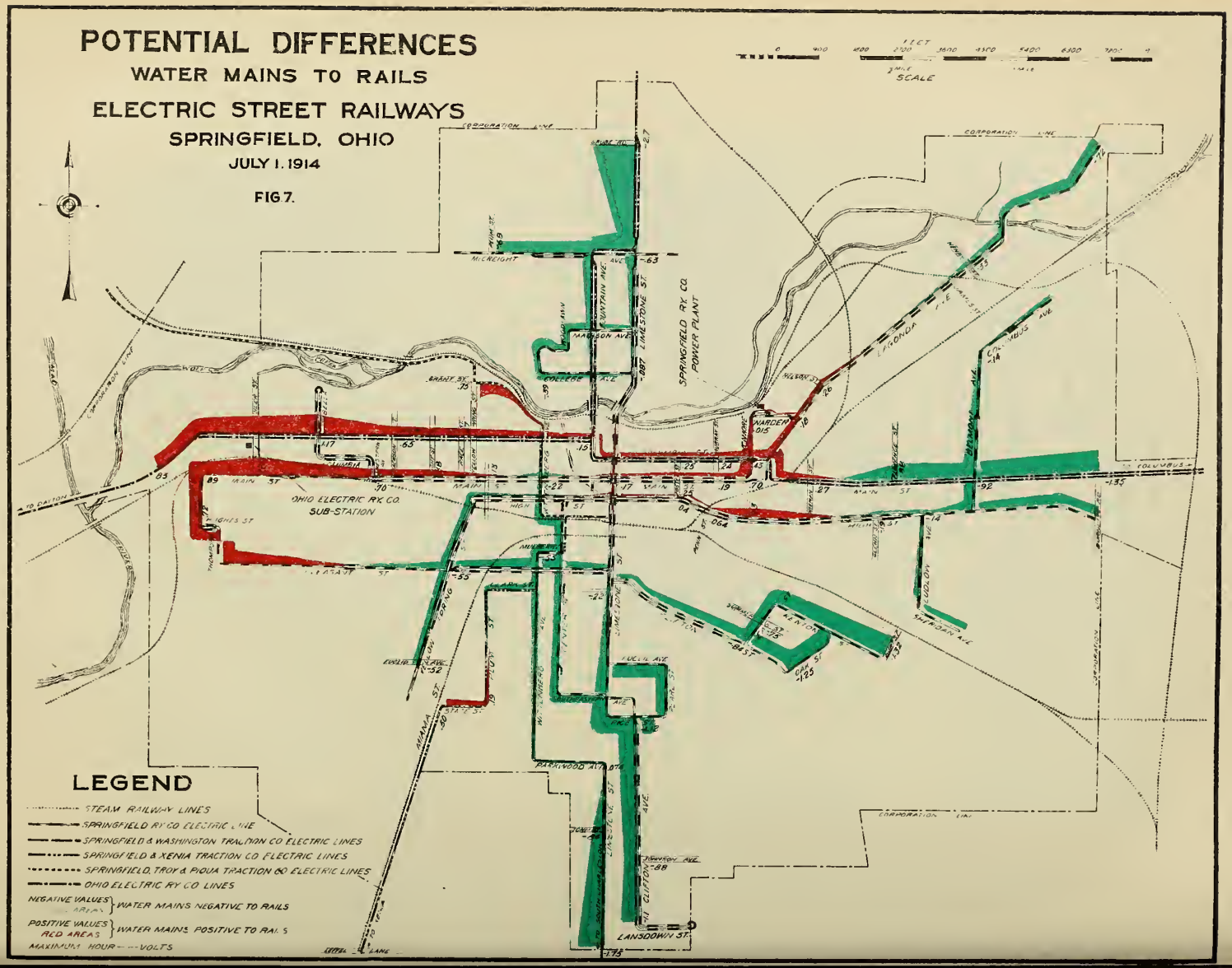

POTENTIAL DIFFERENCES
WATER MAINS TO RAILS
ELECTRIC STREET RAILWAYS
SPRINGFIELD, OHIO
JULY 1. 1914
FIG 7.
SCALE
LEGEND
STEAM RAILWAY LINES
SPRINGFIELD RY CO ELECTRIC LINE
SPRINGFIELD & WASHINGTON TRACTION CO ELECTRIC LINES
SPRINGFIELD & XENIA TRACTION CO ELECTRIC LINES
SPRINGFIELD, TROY & PIQUA TRACTION CO ELECTRIC LINES
OHIO ELECTRIC RY CO LINES
NEGATIVE VALUES BLUE AREAS
WATER MAINS NEGATIVE TO RAILS
POSITIVE VALUES RED AREAS
WATER MAINS POSITIVE TO RAILS
MAXIMUM HOUR --- VOLTS
CORPORATION LINE
SPRINGFIELD RY. CO. POWER PLANT
OHIO ELECTRIC RY. CO. SUB-STATION
MAIN ST
HIGH ST
LIMESTONE ST
MADISON AVE
COLLEGE AVE
GRANT ST
WILSON ST
MARDER
LAGONDA
COLUMBUS AVE
EUDLOW
SHERMAN AVE
MANOR
EAST
PARKWOOD AVE
LANSDOWN ST
MIAMI ST
TO DAYTON
TO COLUMBUS

TABLE 6—Continued

Permanent Pressure Wire Resistance—Continued

OHIO ELECTRIC RAILWAY CO.

Terminal locations	Length	Resistance
Fountain Avenue and North Street to—	Feet	Ohms
Main Street and Burnette Road	14 200	89.5
Limestone Street and Home Road	11 180	70.5
Main Street and Ohio Electric Co. tracks	11 130	70.2
Substation (North and Zischler Streets)	8130	51.3
Main Street and Lagonda Avenue	4260	26.2
OTHER INTERURBANS		
Fountain Avenue and Washington Street to—		
Waiting station track	50	0.31
Sp. and Washington at John Street	7900	49.8
Sp. and Xenia at 100 feet south of State and Miami Streets	7900	49.8
Sp. Troy and Piqua at Bechtle Street	10 200	64.4

C. DESCRIPTION OF TABLES

1. POTENTIAL DIFFERENCES

(*a*) *Water Mains to Rails.*—Potential difference readings between pipes and rails are made the data basis of many reports and the magnitude of these differences has an important relation to the situation but is perhaps over emphasized, there being other measurements of equal or even greater significance; for example, the potential gradients in track or earth, the over-all potentials or the stray currents flowing in the various structures. The potential difference readings taken in this survey are shown in Table 7, and the map (Fig. 7, opposite p. 27). The table shows the hour and location of readings in succeeding columns and following this the average potential difference for the entire day and for the maximum hour. The direction of flow or the polarity is indicated by the sign, a negative sign meaning that the water main is negative to the rails. Columns showing the processes of reduction from the recorder chart area as obtained by the planimeter, the range of the instrument, and the load ratios are omitted in this and succeeding tables as incidental and confusing. The map shows the location of the railways and presents the figures for this last survey in red, the average value for the maximum

hour being given, and that the reader may get a vivid picture of the value and polarity they are indicated by colored areas, the red indicating pipe positive to rail and green pipe negative to rail, the magnitude being shown by the figures.

It will be noted that the readings are scattered over the entire railway area and the region in which the pipes are negative to rail covers a greater per cent of the territory than that in which the pipes are positive to rail, and the values of potential difference are larger in the negative area. From Table 7 it will be seen that with two exceptions all positive values, reduced to the hour of peak load, are less than 1 volt. Of these two readings the highest value of 1.17 volts is found at Isabella and North Streets and the other of 1.05 volts is at Main and Zischler Streets. All the higher positive values are near the Ohio Electric Railway substation, several exceeding one-half volt for the all-day average, but none reaching 1 volt. It should be noted that the momentary swings of potential are much larger than the average values and these are sometimes stated, giving an inaccurate impression of the situation. It is encouraging to note that all negative values are also low, the largest value noted being −1.75 volts at Limestone Street and Leffel Lane where, as already mentioned, the track had not been completely repaired.

TABLE 7

Potential Differences—Water Mains to Rails

[One-hour charts. These data were obtained in July and August, 1914]

Hour	Location	Potential difference, volts	
		All-day	Max.-hr.
11.32 a. m.	End of Lagonda line	−0.39	−0.72
2.25 p. m.	Sycamore and Warder Streets	0.008	0.015
12.00 m.	Lagonda Avenue and Nelson Street	0.14	0.26
11.38 a. m.	Lagonda Avenue and Water Street	0.095	0.18
9.34 a. m.	Columbia and Sycamore Streets	0.24	0.43
9.09 a. m.	Main and Limestone Streets	0.088	0.16
10.55 a. m.	Main and Sigler Streets	0.49	0.89
9.16 a. m.	North and Isabella Streets	0.69	1.17
9.14 a. m.	Main and Zischler Streets	0.57	1.05
11.27 a. m.	Plum Street and McCreight Avenue	−0.37	−0.68
11.17 a. m.	College and Wittenberg Avenues	−0.28	−0.39
10.50 a. m.	College Avenue and Limestone Street	−0.047	−0.087

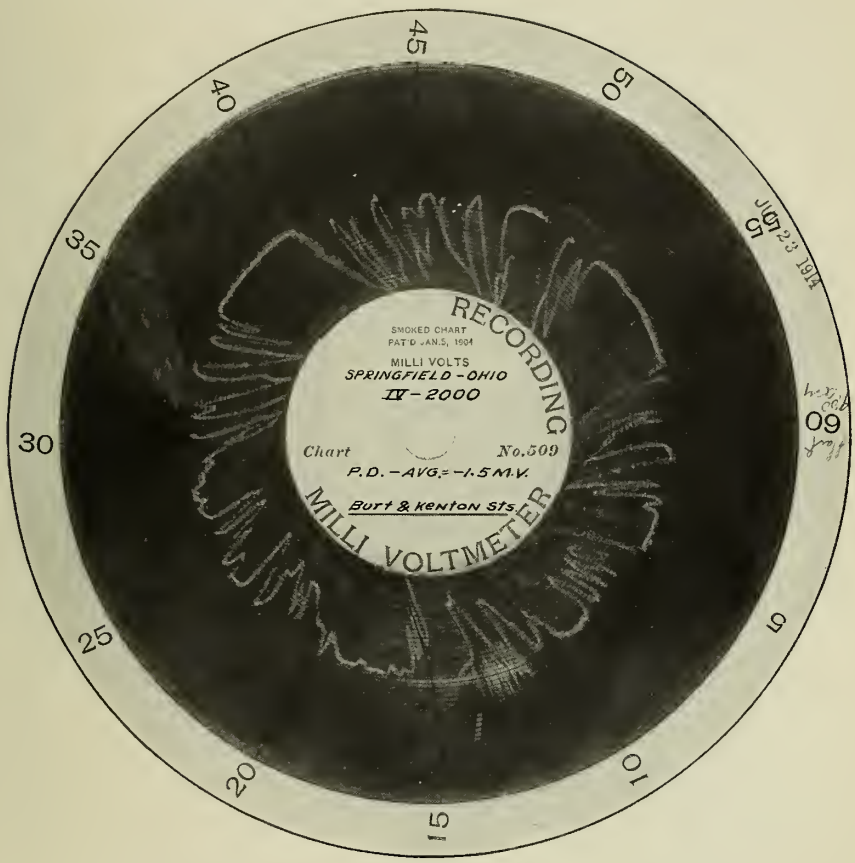
TABLE 7—Continued

Potential Differences—Water Mains to Rails—Continued

Hour	Location	Potential difference, volts	
		All-day	Max.-hr.
9.35 a. m.	Fountain Avenue and North Street	0.089	0.15
10.00 a. m.	McCreight Avenue, 500 feet East of Limestone Street	−0.34	−0.63
10.15 a. m.	Grube Road and Limestone Street	−1.57	−2.7
1.27 p. m.	Main Street and Wittenberg Avenue	−0.12	−0.22
2.00 p. m.	Columbia and Foster Streets	0.13	0.25
1.40 p. m.	Limestone and Main Streets	0.092	0.17
1.50 p. m.	Foster and Main Streets	0.14	0.25
2.20 p. m.	High and Penn Streets	0.35	0.64
2.50 p. m.	Main and Murray Streets	0.103	0.19
3.06 p. m.	Columbia and Murray Streets	0.13	0.24
3.18 p. m.	Foster and High Streets	0.023	0.04
3.33 p. m.	Freeman and Main Streets	0.15	0.27
5.35 p. m.	Henry Street and Lagonda Avenue	−0.18	−0.33
5.15 p. m.	Belmont and Columbus Avenues	−0.08	−0.14
4.05 p. m.	Clark and Limestone Streets	−0.12	−0.22
3.35 p. m.	Plum and State Streets	0.11	0.19
3.45 p. m.	Mulberry Street and Wittenberg Avenue	−0.30	−0.55
3.10 p. m.	Euclid Avenue and Yellow Springs Street	−0.28	−0.52
2.35 p. m.	Pleasant and Yellow Springs Streets	−0.3	−0.55
2.18 p. m.	Hughes and Sigler Streets	0.39	0.72
12.51 p. m.	Jackson and North Streets	0.38	0.65
12.40 p. m.	North and Race Streets	0.28	0.47
12.40 p. m.	Main Street and Western Avenue	0.38	0.70
12.15 p. m.	Light and Main Streets	0.21	0.38
11.25 a. m.	Main and Plum Streets	0.07	0.13
10.50 a. m.	High and Sycamore Streets	0.23	0.43
10.40 a. m.	Glenn and High Streets	−0.10	−0.19
9.39 a. m.	Burnett Road and Main Street	−0.8	−1.35
9.27 a. m.	Belmont Avenue and Main Street	−0.50	−0.92
9.05 a. m.	High Street and Ludlow Avenue	−0.08	−0.14
9.15 a. m.	Florence and Main Streets	−0.48	−0.88
10.20 a. m.	Limestone Street and Parkwood Avenue	0.04	0.07
8.35 a. m.	East and Summer Streets	−0.41	−0.75
9.50 a. m.	Clifton Avenue and Rice Street	−0.61	−1.12
10.40 a. m.	Clifton and Johnson Avenues	−0.48	−0.88
10.55 a. m.	Clifton and Lansdown Avenues	−0.59	−1.10
8.10 a. m.	Main and Sycamore Streets	0.38	0.70
1.20 p. m.	State and Miami Streets	0.35	0.50
11.05 a. m.	Columbia Street and Lagonda Avenue	0.27	0.50
2.36 p. m.	Limestone and John Streets	−0.46	−0.84
11.32 a. m.	Burt and Kenton Streets	−0.72	−1.32
10.12 a. m.	Oak and Clifton Streets	−0.68	−1.25
10.06 a. m.	Clifton and East Streets	−0.46	−0.84
2.00 p. m.	Limestone Street and Leffel Lane	−1.38	−1.75
11.30 a. m.	Grant and Yellow Springs Streets	0.55	0.75
12.09 p. m.	West Main Street and Ohio Electric tracks	0.49	0.83

The effect of track bonding is well shown on the two charts of potential difference, Figs. 8 and 9. As seen by the first chart (Fig. 8, opposite p. 30), the reading was taken at Burt and Kenton Streets on July 23, 1914, at 9 a. m., and the range was 2000 or multiplied by the primary range of the instrument equals 10 volts. The instrument swung off scale several times and the average for the hour is over 3 volts, the pipe being negative to the rail. The track was evidently in bad condition, and the track on this line, including Kenton, Oak, and Clifton Streets, was tested and repaired, and when the chart (Fig. 9, opposite p. 30), dated August 6, 1914, at 11.32 a. m., was taken, using the same instrument range, it will be noted that none of the swings reach 3 volts and the average is less than 1 volt. Reduced to all-day average the preceding value is −2.4 volts and the succeeding value −0.72 volts. This emphasizes the importance of track maintenance. Similar conditions still exist at several points in Springfield where larger negative values may be observed and these of course increase the positive values in the territory about the station supplying the line in question.

(*b*) *Gas to Water Mains.*—Only a small number of readings were made between gas and water mains, the purpose being to supplement previous readings which indicated the gas and water mains to be intimately connected and at practically the same potential. It will be noted in Table 8 that the difference exceeds one-tenth volt at only one point and this during the maximum hour. Zero readings noted incidentally at a number of other points in the course of the survey are not given, these values although higher than the average, being deemed sufficient to show that the potential differences of either gas or water mains against rails or ground are practically the same, and that the two sets of mains must be treated as a common system. The reason for this is the intimate contact between the systems chiefly through gas-water heaters which are scattered over the city.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RECORDING
SMOKED CHART
PAT'D JAN.5, 1904
MILLI VOLTS
SPRINGFIELD - OHIO
IV - 2000
Chart
No.509
P.D. - AVG.= -1.5 M.V.
Burt & Kenton Sts.
MILLI VOLTMETER

FIG. 8

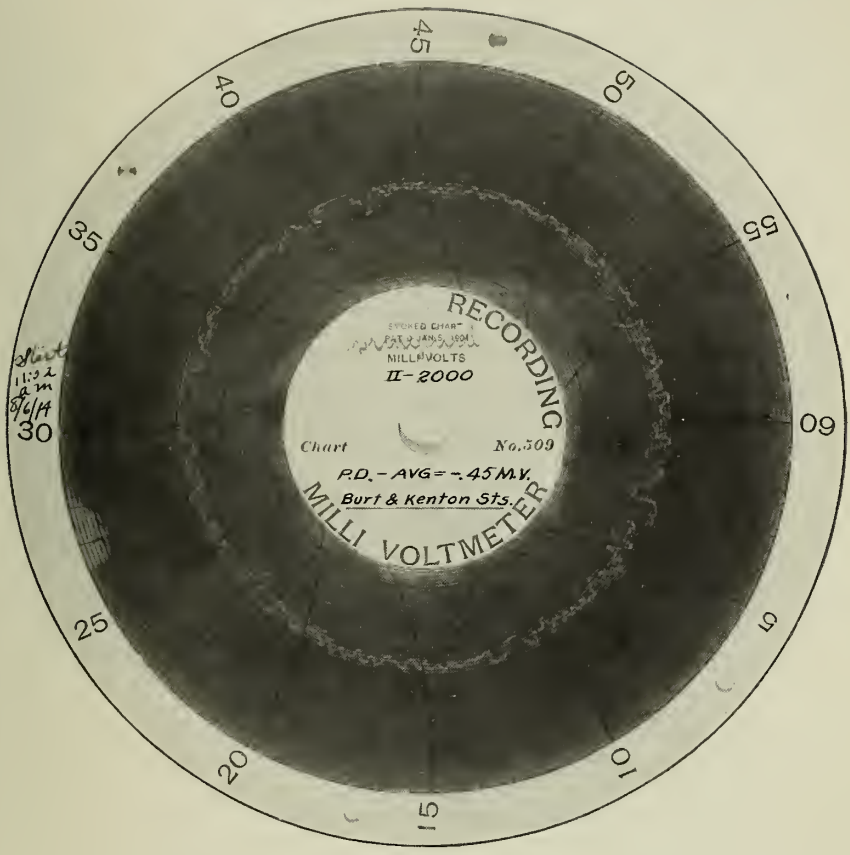

45
50
55
60
5
10
15
20
25
30
35
40
RECORDING
MILLIVOLTS
II-2000
Chart
No.509
P.D. - AVG = -.45 M.V.
Burt & Kenton Sts.
MILLI VOLTMETER

FIG. 9

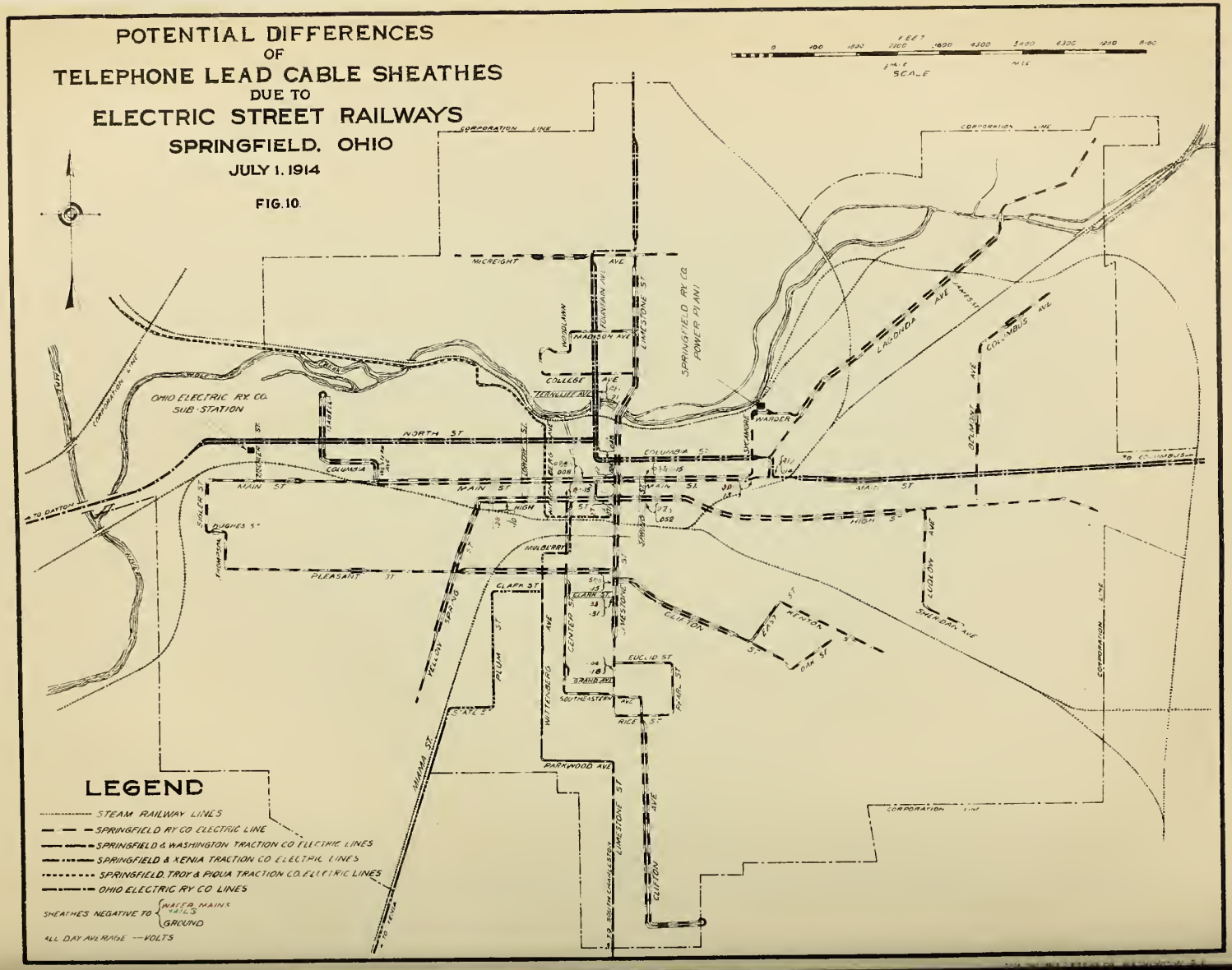

POTENTIAL DIFFERENCES
OF
TELEPHONE LEAD CABLE SHEATHES
DUE TO
ELECTRIC STREET RAILWAYS
SPRINGFIELD, OHIO
JULY 1, 1914
FIG. 10.
SCALE
CORPORATION LINE
MCREIGHT AVE
MADISON AVE
COLLEGE AVE
TERRYCLIFF AVE
OHIO ELECTRIC RY. CO. SUB-STATION
SPRINGFIELD RY. CO. POWER PLANT
LAGONDA AVE
COLUMBUS AVE
WARDER
NORTH ST
COLUMBIA ST
MAIN ST
HIGH ST
MULBERRY
PLEASANT ST
CLARK ST
CLIFTON
EUCLID ST
GRAND AVE
SOUTHEASTERN AVE
RICE ST
PARKWOOD AVE
SHERIDAN AVE
LUDLOW
LIMESTONE ST
TO DAYTON
TO COLUMBUS
LEGEND
STEAM RAILWAY LINES
SPRINGFIELD RY. CO. ELECTRIC LINE
SPRINGFIELD & WASHINGTON TRACTION CO. ELECTRIC LINES
SPRINGFIELD & XENIA TRACTION CO. ELECTRIC LINES
SPRINGFIELD, TROY & PIQUA TRACTION CO. ELECTRIC LINES
OHIO ELECTRIC RY. CO. LINES
SHEATHES NEGATIVE TO WATER MAINS, RAILS, GROUND
ALL DAY AVERAGE — VOLTS

TABLE 8

Potential Differences—Gas to Water Mains

[One-hour charts. These data were obtained in July, 1914]

Hour	Location	Potential difference, volts	
		All-day	Max.-hr.
4.20 p. m.	Lagonda Avenue and Warder Street	0	0
9.50 a. m.	Fountain Avenue and North Street	−0.043	−0.073
10.13 a. m.	Grube Road and Limestone Street	−0.065	−0.11
3.35 p. m.	High Street west of Spring Street	−0.014	−0.026
1.30 p. m.	Isabella and North Streets	0.0018	0.003
4.55 p. m.	Henry Street and Lagonda Avenue	0.005	0.009
8.25 a. m.	Limestone and Clark Streets	−0.005	−0.009

(*c*) *Lead Sheaths to Other Structures.*—Potential difference readings were taken on the Central Union Telephone Co.'s lead sheaths at 14 different manholes, distributed over a system having about 50 such locations. One-half hour readings, using an indicating voltmeter between the sheath and water mains and recorders between sheath and rail and sheath and ground are given in Table 9 and Fig. 10 (opposite p. 31) and show the sheath to be negative to these structures at all points, the values varying from 1.4 volts to almost zero for the maximum hour. The lower values were noted between sheath and ground, where the magnitude is quite an indefinite quantity due to earth gradients, chemical potentials, and high-resistance contacts. An additional column is added showing the portion of the time that the sheath is positive. At Main and Sycamore Streets the sheath is positive to rails for 16 out of 30 minutes with an average of 0.10 volt, but at the same point it was not positive to pipe or ground for any portion of the period so that it can hardly be considered a dangerous condition. The all-day average potential to rail is −0.32 volt, to water mains −0.28, and to ground −0.12, all values low enough to create no serious hazard to other structures, as is the case where sheaths are overdrained, but safe also from the standpoint of the cables. This has been accomplished with three drainage points taking somewhat more current from the cables than formerly, as will be shown later, but giving much better potential conditions with no extremes.

These potential differences are reproduced on map (Fig. 10, opposite p. 31), which will assist in giving an idea of the extent of the underground cable system as the readings cover the area quite completely.

TABLE 9

Potential Differences—Lead Sheaths to Other Structures

[One-half-hour charts or indicating-instrument readings. These data were obtained in July, 1914]

Hour	Location	Potential, volts		Positive reading, volts
		All-day	Max.-hr.	
	To water pipe:			
2.05 p. m.	Main and Sycamore Streets	−0.38	−0.70	None
12.03 p. m.	Main Street and alley west of Fountain Avenue	−0.09	−0.17	None
11.05 a. m.	Fountain and Ferncliffe Avenues	−0.41	−0.75	+0.1 for 1 min.
4.35 p. m.	Main and Spring Streets	−0.07	−0.13	+0.1 for ⅔ min.
3.35 p. m.	Main Street and Lagonda Avenue	−0.41	−0.75	None
10.10 a. m.	Columbia Street and alley west of Limestone Street	−0.20	−0.37	None
9.20 a. m.	Main Street and alley west of Limestone Street	−0.12	−0.22	None
12.25 p. m.	Clifton and Limestone Streets	−0.51	−0.94	None
11.20 a. m.	High and Spring Streets	−0.27	−0.50	None
10.25 a. m.	High Street and alley west of Limestone Street	−0.27	−0.50	None
3.35 p. m.	Limestone Street and alley north of Grand Avenue	−0.44	−0.81	None
1.09 p. m.	High Street between Lowry and Plum Streets	−0.28	−0.52	None
10.55 a. m.	Center and High Streets	−0.18	−0.33	None
4.35 p. m.	Limestone and Clark Streets	−0.33	−0.61	None
	Average	−0.28	−0.52	
	To rail:			
1.28 p. m.	Main and Sycamore Streets	−0.005	−0.009	+0.10 for 16 min.
12.01 p. m.	Main Street and alley west of Fountain Avenue	−0.08	−0.15	+0.05 for 1 min.
11.05 a. m.	Fountain and Ferncliffe Avenues	−0.21	−0.39	+0.11 for 6 min.
4.38 p. m.	Main and Spring Streets	−0.05	−0.08	+0.02 for 4 min.
3.28 p. m.	Main Street and Lagonda Avenue	−0.12	−0.22	+0.013 for 11 min.
10.09 a. m.	Columbia Street and alley west of Limestone Street	−0.13	−0.24	+0.1 for 1 min.
9.20 a. m.	Main Street and alley west of Limestone Street	−0.11	−0.20	+0.04 for 3 min.
12.25 p. m.	Clifton and Limestone Streets	−0.76	−1.40	None
11.20 a. m.	High and Spring Streets	−0.43	−0.79	None
10.32 a. m.	High Street and alley west of Limestone Street	−0.43	−0.79	None
3.34 p. m.	Limestone Street and alley north of Grand Avenue	−0.97	−1.80	None
1.09 p. m.	High Street between Lowry and Plum Streets	−0.50	−0.92	None
10.52 a. m.	Center and High Streets	−0.32	−0.59	None
4.33 p. m.	Limestone and Clark Streets	−0.49	−0.90	None
	Average	−0.32	−0.61	

TABLE 9—Continued

Potential Differences—Lead Sheaths to Other Structures—Continued

Hour	Location	Potential, volts		Positive reading, volts
		All-day	Max.-hr.	
	To ground:			
1.28 p. m.	Main and Sycamore Streets	−0.13	−0.24	None
12.04 p. m.	Main Street and alley west of Fountain Avenue	−0.008	−0.02	None
11.05 a. m.	Fountain and Ferncliffe Avenues	−0.21	−0.39	+0.087 for 5 min.
4.38 p. m.	Main and Spring Streets	−0.15	−0.28	None
3.00 p. m.	Main Street and Lagonda Avenue	−0.14	−0.26	None
10.10 a. m.	Columbia Street and alley west of Limestone Street	−0.05	−0.09	None
9.18 a. m.	Main Street and alley west of Limestone Street	−0.02	−0.04	None
12.25 p. m.	Clifton and Limestone Streets	−0.15	−0.28	None
11.22 a. m.	High and Spring Streets	−0.05	−0.10	None
10.25 a. m.	High Street and alley west of Limestone Street	−0.07	−0.13	None
3.33 p. m.	Limestone Street and alley north of Grand Avenue	−0.18	−0.33	None
1.09 p. m.	High Street between Lowry and Plum Streets	−0.10	−0.18	None
10.50 a. m.	Center and High Streets	−0.15	−0.28	None
4.33 p. m.	Limestone and Clark Streets	−0.31	−0.57	None
	Average	−0.12	−0.23	

2. POTENTIAL GRADIENTS

(*a*) *Springfield Railway Co.'s Lines.*—A small number of potential gradients, obtained chiefly to determine the condition of balance of the insulated return feeder system, were taken along the tracks inside the feeder area and between points where insulated feeders are connected to track. These gradients on the Springfield Railway Co.'s tracks are arranged in Table 10, and on the Ohio Electric Railway Co. lines in Table 11. The first two columns show the locations of the two terminals between which the potentials were observed, the first being positive unless the sign indicates otherwise. In addition to the potential difference for all day and maximum hour between the two points, the distance between them via tracks or feeder is given, the unit being 1000 feet, and the last two columns show the gradient for this unit of length for the all-day average and the maximum hour. The gradients are toward the station with the exception of the two terminating at Sycamore and Warder Streets, where the flow is from the station. Thus, the tracks are assisting in returning the

current to the plant on all other lengths and, as previously pointed out, there is no track connection where the track is in low ground, where large potential differences would be most serious. In the potential differences (Table 7) the effect of these connections is noted, a value of +0.015 volt existing at Sycamore and Warder Streets, with +0.18 volt at Lagonda Avenue and Warder Street and +0.7 volt at Main and Sycamore Streets, the two latter values existing farther from the station but having the advantage of being on higher ground than the first at the station.

TABLE 10

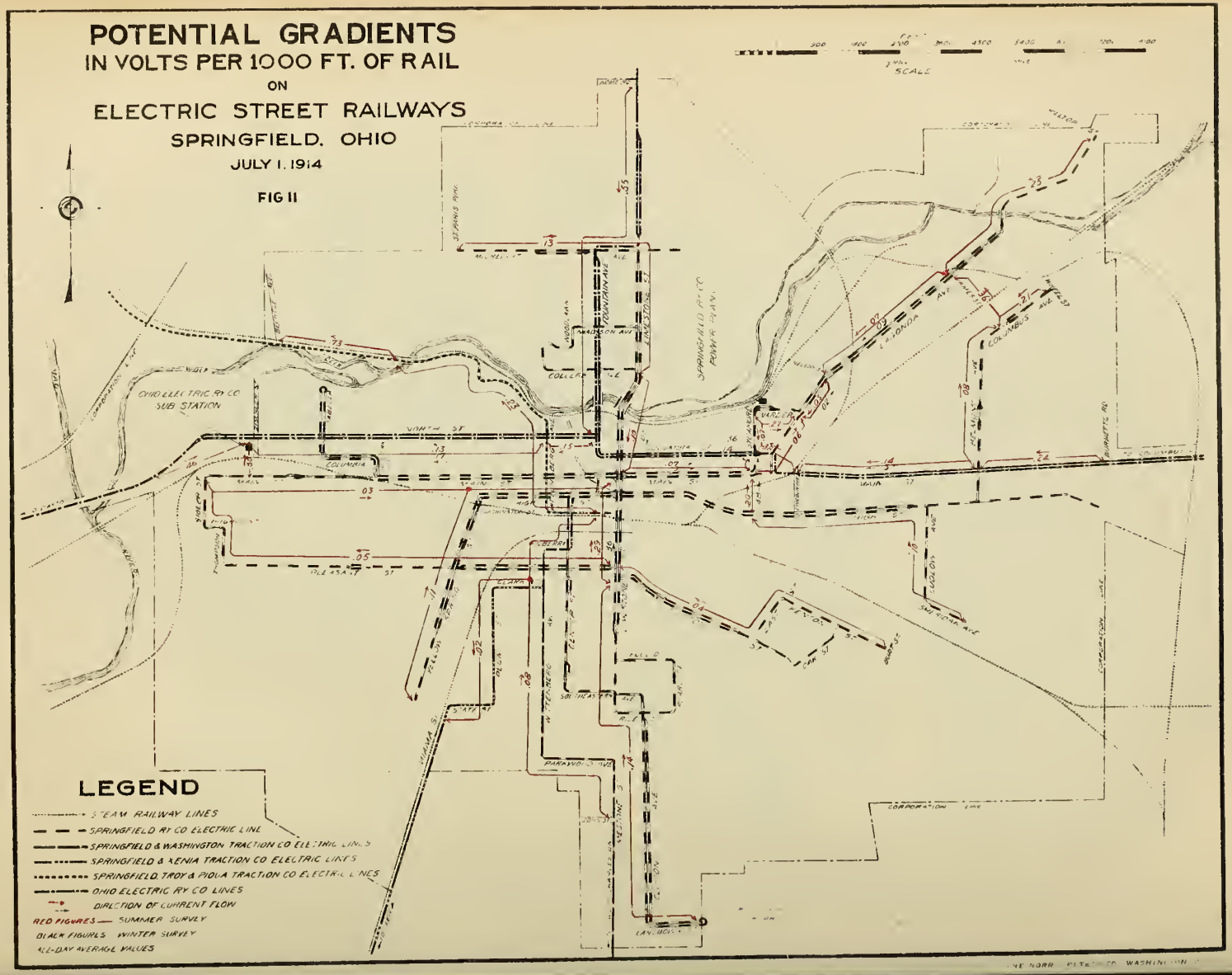
Potential Gradients Between Tap Points, Springfield Railway Co.

[One-hour charts. These data were obtained in July, 1914]

Location		Potential difference, volts		Distance between tap points	Potential gradient, volts per 1000 feet	
From—	To—	All-day	Max.-hr.		All-day	Max.-hr.
				Thousand feet		
Clark and Limestone Streets..	Limestone and Main Streets.	0.76	1.41	2.6	0.29	0.54
Columbia and Sycamore Streets	Sycamore and Warder Streets	−0.10	−0.26	1.4	−0.07	−0.19
Main and Sycamore Streets...	Columbia and Sycamore Streets	0.07	0.13	0.5	0.14	0.26
Do.....	Lagonda Avenue and Warder Street	0.18	0.33	2.9	0.06	0.11
Lagonda Avenue and Warder Street	Sycamore and Warder Streets	−0.27	−0.49	1.0	−0.27	−0.49
Columbus Avenue and James Street	James Street and Lagonda Avenue	0.64	1.17	1.8	0.36	0.65
College Avenue and Limestone Street	Limestone and Main Streets.	0.25	0.47	2.6	0.10	0.18
High and Sycamore Streets...	Main and Sycamore Streets.	0.20	0.36	1.0	0.20	0.36
Limestone and Main Streets..	.....do.....	0.22	0.40	3.1	0.07	0.13
Lagonda Avenue and Nelson Street	Lagonda Avenue and Warder Street	0.05	0.10	1.0	0.05	0.10
James Street and Lagonda Avenue	Nelson Street and Lagonda Avenue	0.28	0.52	3.9	0.07	0.13
Warder and Sycamore Streets.	Main and Sycamore Streets.	0.14	0.24	1.9	0.07	0.13
Average.....	.....	.....	.....	.....	0.15	0.26

POTENTIAL GRADIENTS
IN VOLTS PER 1000 FT. OF RAIL
ON
ELECTRIC STREET RAILWAYS
SPRINGFIELD, OHIO
JULY 1, 1914

FIG 11



Referring again to the potential gradient measurements shown in Table 10, the highest value is on James Street between Columbus and Lagonda Avenues along an insulated cable serving as a crosstie between tracks, the value being 0.65 volt for the maximum hour. The average of all values for the 12 sections measured is 0.26 volt. This value may be considered very satisfactory as reducing leakage and still making a reasonable use of the track as return.

(*b*) *Ohio Electric Railway Co.'s Lines.*—Potentials on six sections are shown in Table 11, and of these two on East Main Street are carrying current to the Springfield power house. The highest gradient is on Zischler Street between North and Main Streets, where an insulated feeder runs from the substation to Main Street and where the tracks on North Street are insulated from ground. The all-day average value is 0.50 and maximum hour 0.83 volt per 1000 feet, which under average conditions is approaching the limits of safe gradients, but need not be considered dangerous on this short distance, 800 feet, particularly because of the conditions mentioned before. The average gradient for the Ohio Electric Railway Co.'s lines is 0.39 volt for the maximum hour and 0.23 for the all-day average. This is greater than for the Springfield Railway Co.'s lines, but is considered safe enough for conditions existing in this district. These values are shown on the map in Fig. 11 (opposite p. 35), the red lines connecting the points between which the potentials were read, the value being in volts per thousand feet and not the total potential between the points. The arrow indicates the direction of the gradient.

TABLE 11

Potential Gradients Between Tap Points, Ohio Electric Railway Lines

[One-hour charts. These data were obtained in July, 1914]

Location		Potential difference, volts		Distance between tap points	Potential gradient, volts per 1000 ft.	
From—	To—	All-day	Max.-hr.		All-day	Max.-hr.
				Thousand feet		
Main Street and Lincoln Avenue	Columbia and Sycamore Streets	0.53	0.90	1.4	0.38	0.64
Belmont Avenue and Main Street	Lincoln Avenue and Main Street	0.60	1.02	4.2	0.14	0.24
Fountain Avenue and North Street	North and Zischler Streets...	0.93	1.57	7.3	0.13	0.22
Main and Zischler Streets.....	North and Zischler Streets...	0.40	0.68	0.8	0.50	0.85
North Street and Wittenberg Avenue	Main and Zischler Streets...	0.51	0.87	7.0	0.07	0.12
Fountain Avenue and North Street	North Street and Wittenberg Avenue	0.17	0.29	1.1	0.15	0.26
Average.....	.....	.....	.....	.....	0.23	0.39

(*c*) *Outside Tap Points.*—In addition to the potential gradients measured directly on the sections of track inside the insulated return feeder area, potential gradients for practically all sections of track lying outside this area may be deduced from the above gradients and the over-all potential values. The all-day average values of these gradients are shown in Table 12 and by the red figures on map in Fig. 11 (opposite p. 35). The highest value noted on the Springfield Railway Co.'s lines is 0.25 volt and is found on the extreme section of the Lagonda line which, as will be pointed out later, has some electrically defective joints and many mechanically poor ones. The average for all the values on the Springfield Railway Co.'s lines beyond the return feeder terminals is 0.11 volt, which is very satisfactory.

TABLE 12

Rail Gradients Outside of Tap Points

[All-day average values]

SPRINGFIELD RAILWAY CO.

Location		Distance	Potential, volts	
From—	To—		Total	Per 1000 feet
		Thousand feet		
Sheridan and Belmont Avenues	Main and Sycamore Streets	6.75	0.65	0.10
Lagonda Avenue and Hilltop Street	Lagonda Avenue and James Street	4.7	1.17	0.25
Spring Grove Park	Clark and Limestone Streets	10.2	1.42	0.14
Columbus Avenue and West Wheel Street	Columbus Avenue and James Street	1.3	0.27	0.21
Main Street and Belmont Avenue	Columbus Avenue and James Street	3.4	0.27	0.08
Main and Sigler Streets	Main and Limestone Streets	9.0	0.26	0.03
Burt and Kenton Streets	Clark and Limestone Streets	7.2	0.32	0.04
Yellow Springs and State Streets	Main and Limestone Streets	8.0	0.85	0.11
McCreight Avenue and Saint Paris Pike	Limestone Street and College Avenue	6.5	0.82	0.13
Pleasant and Limestone Streets	Main and Sigler Streets	10.8	0.50	0.05
Average				0.11
INTERURBAN				
Main Street and Burnett Road	Main Street and Belmont Avenue	2.8	0.68	0.24
Limestone Street and Home Road	North Street and Fountain Avenue	8.8	4.87	0.55
West Main Street and Ohio Electric tracks	North and Zischler Streets	2.4	1.1	0.46
Springfield, Troy & Piqua at Bechtle Street	Springfield, Troy & Piqua at Buck Creek	2.7	−1.96	−0.73
Springfield, Troy & Piqua at Buck Creek	Washington Street and Fount. Avenue	7.0	−1.6	−0.23
State and Miami Streets	do	7.2	−0.16	−0.02
Limestone and John Streets	do	9.0	0.71	0.08
Average				0.33

The Ohio Electric Railway lines show higher values of potential gradients beyond the return feeder terminals, but the highest value (0.55 volt) is on track in process of repair and the next highest (0.46 volt) is on track on private right of way and substantially insulated from ground. This is also true of the other high value on the interurbans, namely, 0.73 volt between Bechtle

Avenue and Buck Creek on the Springfield, Troy & Piqua Railway. This value, while not particularly serious, owing to the character of track construction as above mentioned is, nevertheless, too large and is partly due to the presence of some bad joints which should be repaired.

3. OVER-ALL POTENTIALS

(*a*) *Springfield Railway Co.'s Lines.*—The over-all potentials on the Springfield Railway Co.'s tracks, taken with the permanent pilot wires already described, are presented in Table 13, which is arranged in the same manner as the tables previously described, and the corrected values for the all-day and maximum-hour potentials appear in the last two columns. A 24-hour chart and one or more 1-hour charts as check readings were taken on each length. The track at Main and Sycamore Streets is taken as the reference point, although it will be noted from the gradients (Table 10) that Lagonda Avenue and Warder Street is slightly lower (0.06 volt for all-day and 0.11 volt for the maximum hour) and these figures may be added but are too small to make any material change in results having the magnitude of these over-all potentials. The highest values were found to Spring Grove Park loop where 2.4 volts for the all-day average was recorded and 4.33 for the maximum-hour. The lowest values are at Main and Sigler Streets where the interchange between power stations has the greatest influence, the values being 0.48 volt for the all-day average and 1.26 volts for the maximum-hour. The average of all reading is 1.25 volts for the all-day period and 2.35 for the maximum-hour. The individual values are low enough to be considered very satisfactory and safe, and compare very favorably with the limits set by the frequently mentioned German regulation and the English Board of Trade provisions.

TABLE 13

Over-all Potential Differences

[24-hour charts. Negative terminal, Main and Sycamore Streets. These data were obtained in August, 1914]

Location of positive terminal	Over-all potential, volts	
	All-day	Max.-hr.
Belmont and Sheridan Avenues	0.85	1.28
Lagonda Avenue and Hilltop Street	1.32	2.43
Snyder Park Loop	1.52	3.40
Spring Grove Park	2.40	4.33
Columbus Avenue and Wheel Street	1.06	1.68
Main and Sigler Streets	0.48	1.26
Burt and Kenton Streets	1.30	2.38
Yellow Springs and State Streets	1.07	1.97
McCreight Avenue and St. Paris Pike	1.29	2.40
Average	1.25	2.35

(*b*) *Interurban Lines.*—The over-all potentials on the interurban lines, shown in Table 14, are much more irregular and in some cases considerably higher than those just discussed, e. g., all-day averages of 5.8 volts on the North Limestone Street line and 3.05 volts on the East Main Street line with respective maximum-hour values of 13.9 volts and 8.6 volts. As stated above, bad bonding exists on both these lines, which is chiefly responsible for the high voltages observed, and in fact one of the tracks on North Limestone Street was entirely open when the measurement was made on this line. Work is in progress or planned on these sections, however, which should put them in satisfactory condition. Since the feeding distances on the north and east branches are rather long (6 and 7½ miles, respectively), these tracks will always be well loaded, but it does not appear that considerations of economy would justify decreasing these feeding distances at the present time. As pointed out in the earlier reports, the rails as laid on interurban private right of way of these lines are, for the most part, in poor contact with the soil and leakage is thereby greatly reduced. If, however, these over-all potentials become too large, they may produce some trouble on both telephone and pipe systems, and they should be kept as low as possible by bonding and cross bonding and making an effort to keep rails clear of soil wherever possible.

TABLE 14

Over-all Potential Differences, Interurban Lines

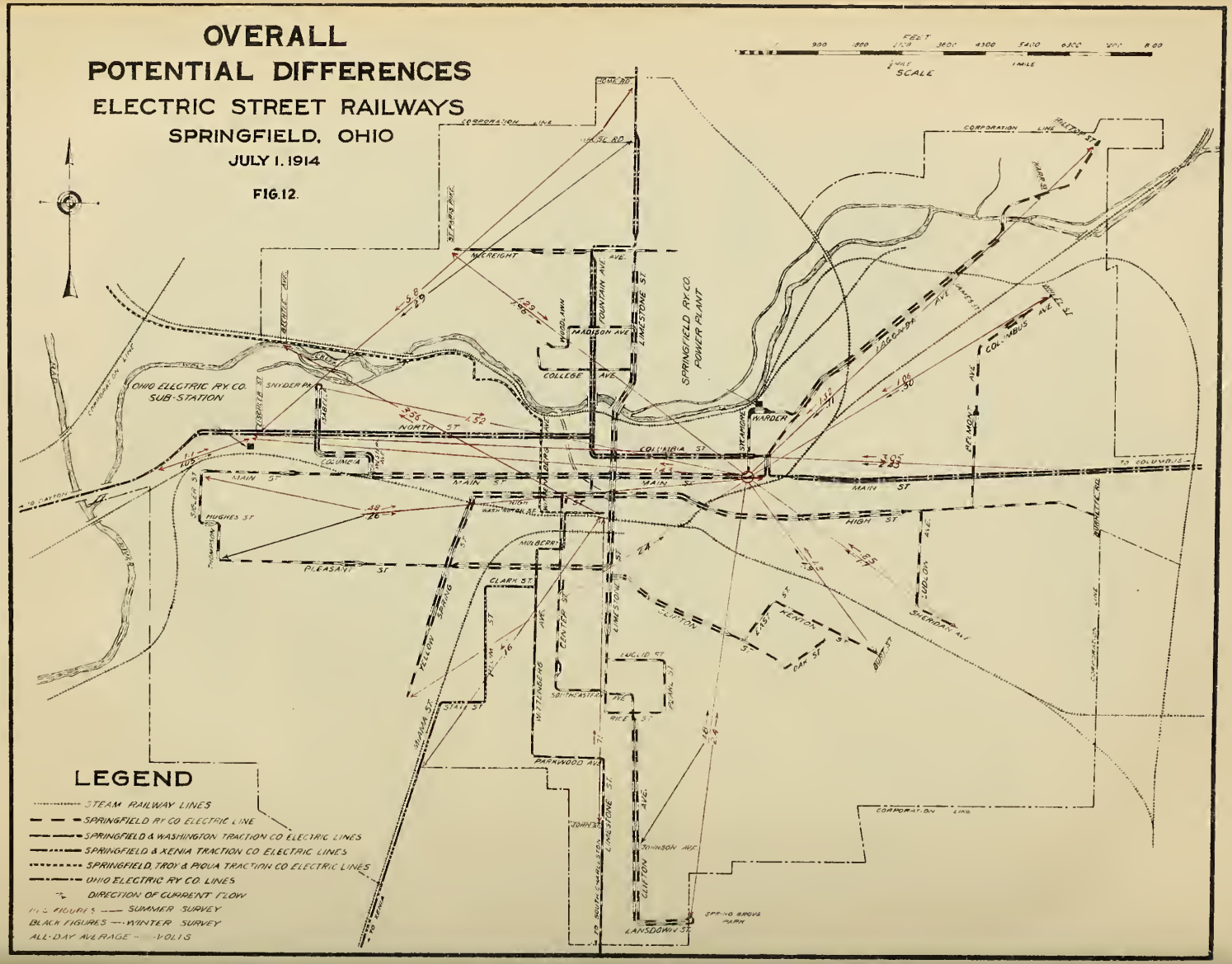
[24-hour charts. These data were obtained in August, 1914]

Location	Over-all potential, volts	
	All-day	Max.-hr.
OHIO ELECTRIC RAILWAY CO.[a]		
Limestone Street and Home Road	5.8	13.9
West Main Street and Ohio Electric tracks	1.10	2.36
Main Street and Lagonda Avenue	1.43	3.65
Main Street and Burnett Road	3.05	8.6
SPRINGFIELD, TROY & PIQUA RAILWAY CO.[b]		
Buck Creek Branch	1.6	3.8
Bechtle Avenue	3.56	5.62
SPRINGFIELD & XENIA RAILWAY CO.[b]		
State and Miami Streets	+0.16	+0.24
SPRINGFIELD & WASHINGTON RAILWAY CO.[b]		
Limestone and John Streets	−0.71	−1.7

[a] Negative terminal at substation, North and Zischler Streets.
[b] Positive terminal at Fountain Avenue and Washington Street.

The over-all potential on the Springfield, Troy & Piqua Railway line is also rather high—3.56 volts for the all-day and 5.62 volts for the maximum-hour—although considerable effort has been made to put this track in good condition. A few bonds are probably defective, and the load is continuous and rather heavy on this line, due to extra freight service and to motor and lighting load at the car barn.

The greater part of this line within the city is on private right of way and fairly well insulated, so that the voltages here observed are not dangerous. The other two interurban lines have very satisfactory values of over-all potentials, as will be seen from Table 14, but the Springfield & Washington Railway line was only



THE NORRIS PETERS CO., WASHINGTON, D.C.

measured to John Street, it still requiring some bonding and repairs south of that point. On the whole, the interurban lines do not furnish a serious menace to underground structures wherever they are raised above the ground, and the voltage limitations on such sections need not be as severe as on urban tracks embedded in the highway. The map in Fig. 12 (opposite p. 41) shows the over-all potentials between the extreme points of the various systems, the figures in red being all-day average values, obtained in the recent survey, and the figures in black those taken during the previous winter. Both sets of data, however, were taken after the insulated negative feeder systems had been installed.

4. STRAY CURRENTS ON UNDERGROUND STRUCTURES

The magnitude of the currents which are flowing in the underground structures and which are properly called "stray" currents is shown in Tables 15, 16, 17, and 18, which give readings at about 80 different points or current stations on water and gas mains and lead-sheathed cables. The stations are numbered in each table and the hour of reading and location of station follow, then the size and kind of pipe. If indicated as C. I. (cast iron), in the water main table, the class (C) has been used in the calculations and for the gas main tables the class for gas standard, approximately Class A of the A. W. W. A. standard. The length of section and the calculated resistance of the section are omitted, but the observed potential across it and two values of current are given, the algebraic average being the average of all readings observing the plus and minus signs, or direction of current flow, and the arithmetical average not taking the sign into consideration, as though the current flowed in one direction. Where the current reverses at frequent intervals, as in this case, the algebraic average value is more nearly proportional to the electrolytic damage since the efficiency of corrosion is reduced by the frequent reversals. The direction of current flow is indicated by the letters N., E., S., or W. The currents are not reduced to all-day or maximum-hour values, because the readings are of only a half hour duration and because it is quite uncertain which load curve ratio should be applied in the case of these stray currents. The map in Fig. 13

(opposite p. 42) shows the location of the current stations by the position of the circles and the magnitude of the currents by the length of the arrows when these are greater than 1 ampere.

(*a*) *Current on Water Mains.*—Nineteen observations were made on the water system each on a solid length for pipe, 4 feet long in practically every case. These values are given in Table 15, and it will be noted that the potential differences are small fractions of millivolts, the largest being 0.29 millivolt at station No 7 at Isabella Street, north of Main Street, indicating a current flow of 3.5 amperes on an 8-inch cast-iron pipe. There are several points where the current is of about this value and the average for all stations is 1.5 amperes, and it will be noted that where there is any current (there are only two zero currents in this table) the values are generally between 1 and 3 amperes. The algebraic and arithmetic values are approximately the same, indicating few reversals in direction of current during test. Currents of this small magnitude when discharged from a large network of pipes will produce practically negligible damage.

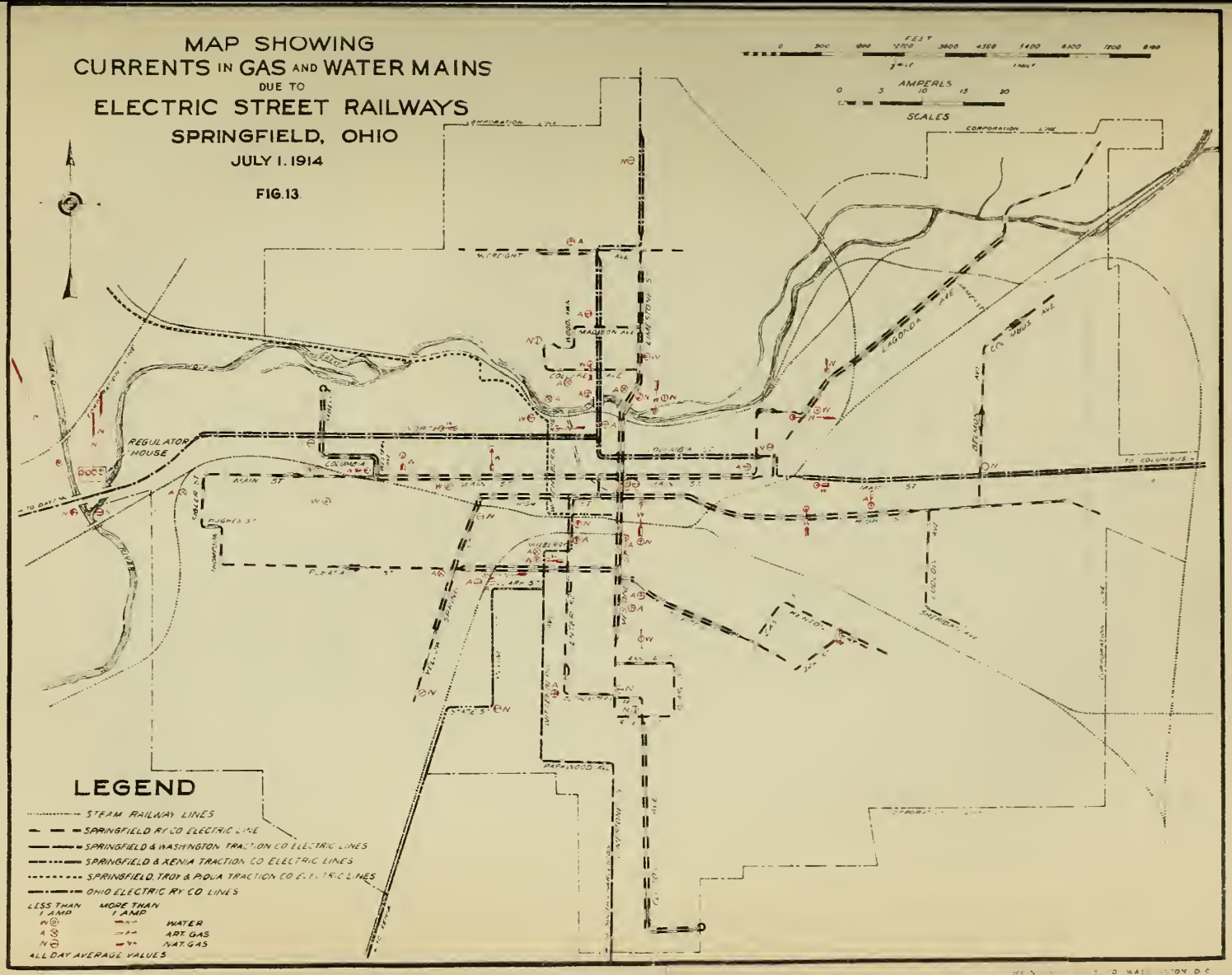

MAP SHOWING
CURRENTS IN GAS AND WATER MAINS
DUE TO
ELECTRIC STREET RAILWAYS
SPRINGFIELD, OHIO
JULY 1. 1914
FIG. 13.
FEET
AMPERES
SCALES
CORPORATION LINE
MCCREIGHT AVE
MADISON AVE
LINCOLN AVE
LAGONDA AVE
COLUMBUS AVE
REGULATOR HOUSE
COLUMBIA ST
MAIN ST
HIGHES ST
FLORA ST
WILLBURN
PARKWOOD AVE
TO COLUMBUS
LEGEND
STEAM RAILWAY LINES
SPRINGFIELD RY CO ELECTRIC LINE
SPRINGFIELD & WASHINGTON TRACTION CO ELECTRIC LINES
SPRINGFIELD & XENIA TRACTION CO ELECTRIC LINES
SPRINGFIELD, TROY & PIQUA TRACTION CO ELECTRIC LINES
OHIO ELECTRIC RY CO LINES
LESS THAN 1 AMP
MORE THAN 1 AMP
WATER
ART. GAS
NAT. GAS
ALL DAY AVERAGE VALUES

TABLE 15

Current in Water Mains

[30-minute galvanometer readings. These data were obtained in July, 1914]

No.	Hour	Location	Mains		Poten. drop, alg. av.	Current, amp.		Direction
			Size	Kind		Alg. av.	Arith. av.	
			Inches		M. V.			
1	4.37 p. m.	Lincoln Street north of High Street..	16	CI	0.14	3.2	3.5	N
2	12.15 p. m.	Cedar and Cliff Streets.....	16	CI	0.04	0.26	0.69	W
3	4.50 p. m.	Spring Street, on Buck Creek Bridge.	12	CI	0.18	3.7	4.1	S
4	10.36 a. m.	Plum Street north of Columbia Street.	10	CI	0.18	2.6	2.7	N
5	12.55 p. m.	Shaffer Street north of Columbia Street	8	CI	0.15	1.6	1.7	N
6	9.45 a. m.	Dayton Avenue and High Street.....	10	CI	0.02	0.35	0.49	
7	10.30 a. m.	Isabella Street north of Main Street.	8	CI	0.29	3.5	3.5	N
8	5.22 p. m.	East Main Street east of Freeman Avenue	24	CI	0.02	1.2	8.0	E
9	4.48 p. m.	Chestnut Avenue east of Limestone Street	10	CI	0.03	0.39	0.73	W
10	2.40 p. m.	Clifton Avenue north of Liberty Street.	8	CI	0.19	2.0	2.1	
11	1.35 p. m.	North Street west of Race Street.....	8	CI	0.11	1.1	1.6	W
12	4.15 p. m.	Fountain Avenue south of College Avenue	8	CI	0.17	1.8	2.8	N
13	10.30 a. m.	Pleasant Street west of Wittenberg Avenue	8	CI	0.15	1.6	2.1	W
14	11.28 a. m.	Spring Street north of High Street...	20	CI	0.09	3.8	4.1	N
15	2.55 p. m.	West High and Race Streets.....	6	CI	0.03	0.19	0.25	E
16	12.00 m.	Main Street and Western Avenue...	10	CI	0.08	1.1	1.1	E
17	5.35 p. m.	Main Street east of Spring Street....	24	CI	0.0	0.0	0.0	
18	5.15 p. m.	West Main Street east of Light Street.	6	CI	0.05	0.35	0.38	E
19	11.17 a. m.	Lagonda Avenue north of Warder Street	20	CI	0.0	0.0	0.0	
		Total.....	.....	.....	.....	28.74	39.84	
		Average.....	.....	.....	.....	1.51	.....	

(*b*) *Current in Natural Gas Mains.*—In measuring current flow on the gas mains potential drops were taken for the most part on 10-foot sections of pipe. The data are shown in Table 16, and it will be seen that only one of the potentials on the gas mains exceeds 1 millivolt. Only two are over a half, while there are six where no potential could be observed, and nine on which only a few hundredths of a millivolt were observed. Since some mains are wrought iron these small values still indicate appreciable currents; that is, 0.01 millivolt on an 8-inch W. I. main indicates ¼

ampere. The highest algebraic average value of current observed is 13.9 amperes, but all but three values are less than 5 amperes, while the algebraic average of all values is 1.7 amperes. This is raised decidedly by three readings on the main which comes from the gas fields, and if these are omitted the average is only 0.69 ampere, a value comparable with the current on the artificial gas system having mains only within the city. The lower value of current on all gas mains, as compared with water mains, can be ascribed to the presence of rubber gasket joints, since otherwise the current would generally be greater on a wrought-iron system due to the lower specific resistance of that metal and the high resistance of lead-calked joints on cast mains.

TABLE 16

Current in Natural Gas Mains

[30-minute galvanometer readings. These data were obtained in July, 1914]

No.	Hour	Location	Mains		Poten. drop, alg. av.	Current, amp.		Direction
			Size	Kind		Alg. av.	Arith. av.	
			Inches		M. v.			
1	4.55 p. m.	Clifton and East Streets	6	CI	0.38	0.94	2.2	W
2	9.50 a. m.	Main Street and Belmont Avenue	6	WI	0.00	0.00	0.00	
3	1.30 p. m.	Clifton Avenue and Rice Street	3	WI	0.01	0.05	0.05	S
4	11.42 a. m.	Warder Street and Lagonda Avenue	4	WI	0.80	4.70	4.70	E
5	11.20 a. m.	North Street and Wittenberg Avenue	6	CI	1.39	3.40	3.40	W
6	2.45 p. m.	Columbia Street east of Sycamore Street	4	WI	0.01	0.01	0.01	E
7	3.30 p. m.	Yellow Springs and Washington Streets	4	CI	0.34	0.54	0.72	W
8	11.08 a. m.	Wittenberg Avenue and Pleasant Street	6	CI	0.29	0.71	0.75	N
9	1.53 p. m.	Southern Avenue and Limestone Street	6	CI	0.26	0.63	0.75	W
10	4.40 p. m.	Spring Street north of Monroe Street	6	WI	0.08	0.79	0.79	N
11	11.15 a. m.	Isabella and North Streets	3	WI	0.00	0.00	0.00	
12	10.00 a. m.	Plum and State Streets	4	WI	0.04	0.24	0.24	W
13	9.30 a. m.	Southern Avenue and Yellow Springs Street	4	WI	0.00	0.00	0.00	
14	9.30 a. m.	High Street and Burnett Road	4	WI	0.00	0.00	0.00	
15	4.20 p. m.	Wittenberg Avenue and Ward Street	4	CI	0.34	0.54	0.56	S
16	3.55 p. m.	Kenton and Oak Streets	6	WI	0.29	3.04	4.4	W

TABLE 16—Continued

Current in Natural Gas Mains—Continued

No.	Hour	Location	Mains		Poten. drop, alg. av.	Current, amp.		Direction
			Size	Kind		Alg. av.	Arith. av.	
			Inches		M. v.			
17	3.00 p. m.	Limestone and Third Streets	2	WI	0.00	0.00	0.00	
18	2.05 p. m.	Limestone Street and Home Road	4	WI	0.06	0.34	0.43	N
19	3.35 p. m.	Center Street between Mulberry and Jefferson Streets	8	CI	0.02	0.06	0.06	N
20	10.22 a. m.	Lagonda Avenue and Nelson Street	6	WI	0.14	1.46	1.60	S
21	10.27 a. m.	South of West Main Street registration house	10	WI	0.00	0.00	0.00	
22	9.18 a. m.	40 feet west of West Main Street registration house	10	WI	0.63	13.9	15.8	E
23	10.05 a. m.	Main Street at Buck Creek Bridge	3	WI	0.01	0.05	0.05	W
24	10.35 a. m.	Main Street registration house, second pipe from east side	8	WI	0.01	0.29	0.29	S
25	10.42 a. m.	Main Street registration house, third pipe from east side	8	WI	0.18	7.0	8.3	S
26	11.12 a. m.	Main Street registration house, fourth pipe from east side	8	WI	0.25	9.5	9.5	S
27	10.40 a. m.	Spring Street at Buck Creek Bridge	8	WI	0.02	0.30	0.30	N
28	10.10 a. m.	Limestone Street at Buck Creek Bridge	4	WI	0.01	0.01	0.01	S
29	2.37 p. m.	Eleventh Street and railroad bridge	10	WI	0.19	0.05	0.05	W
		Average				1.7		

(*c*) *Current in Artificial Gas Mains.*—The 22 readings of Table 17 on artificial gas mains show no potential readings as great as a millivolt, and the largest current is 9 amperes on a 6-inch wrought-iron main at Center Avenue north of Mulberry Street. The algebraic values are slightly lower than the arithmetical but the currents are mostly unidirectional. The algebraic average of all values is only 0.68 ampere and the arithmetical average is 0.76 ampere with six zero current values and six in the hundredths place, so low as to be negligible. In general the values are very low, due chiefly to the low over-all voltage drops which prevail and to some extent to the presence of insulating joints which are distributed somewhat irregularly and at infrequent intervals.

TABLE 17

Current in Artificial Gas Mains

[30-minute galvanometer readings. These data were obtained in July, 1914]

No.	Hour	Location	Mains		Poten. drop, alg. av.	Current, amp.		Direction
			Size	Kind		Alg. av.	Arith. av.	
			Inches		M. v.			
1	1.50 p. m.	North Fountain Avenue, opposite gas office	6	CI	0.02	0.04	0.04	S
2	3.30 p. m.	Clifton Street and Clifton Avenue...	4	WI	0.08	0.47	0.47	N
3	10.07 a. m.	High and Sigler Streets	12	WI	0.00	0.00	0.00	
4	4.20 p. m.	Yellow Springs and Pleasant Streets	12	WI	0.00	0.00	0.00	
5	9.00 a. m.	High and Lowry Streets.....	2	CI	0.02	0.01	0.01	N
6	1.35 p. m.	High and Sycamore Streets	3	CI	0.00	0.00	0.00	
7	11.50 a. m.	High Street and Greenmount Avenue	8	WI	0.13	2.00	3.20	S
8	3.45 p. m.	Fountain and Madison Avenues....	2	CI	0.03	0.02	0.02	E
9	4.00 p. m.	Woodlawn and College Avenues....	8	WI	0.00	0.00	0.00	
10	9.45 a. m.	Limestone Street at Buck Creek bridge	3	WI	0.00	0.00	0.00	
11	10.50 a. m.	Wittenberg and Southern Avenues.	4	WI	0.06	0.38	0.56	E
12	10.00 a. m.	Mulberry Street and Wittenberg Avenue	2	CI	0.00	0.00	0.00	
13	4.22 p. m.	Plum and Pleasant Streets.....	3	CI	0.16	0.17	0.17	N
14	10.37 a. m.	Main and Florence Streets	4	CI	0.05	0.08	0.34	N
15	3.30 p. m.	Woodlawn and McCreight Avenues	5	WI	0.02	0.31	0.31	N
16	4.35 p. m.	Limestone and Monroe Streets	6	CI	0.65	1.62	1.6	N
17	3.25 p. m.	Limestone Street at high school	4	CI	0.17	0.27	0.37	N
18	3.15 p. m.	Main and Sycamore Streets	6	CI	<0.01	<0.1	0.11	E
19	9.25 a. m.	Center Avenue north of Mulberry Street	6	WI	0.86	8.95	8.95	N
20	2.25 p. m.	Wittenberg Avenue on Buck Creek bridge	8	WI	<0.01	<0.01	0.18	N
21	2.10 p. m.	Fountain Street on Buck Creek bridge	6	WI	0.02	0.21	0.21	S
22	2.18 p. m.	WestPleasant Street at A. A. Bridge.	10	WI	0.11	0.30	0.30	E
		Average.....	.....	.....	.....	0.68	.....	

(*d*) *Current in Lead Cable Sheaths.*—In order to make the lead sheaths uniformly negative to surrounding structures they were connected to the negative return at three different points and resistances inserted and adjusted until satisfactory potential conditions were reached. The current flowing in these three bonds represents all the stray current in the sheaths. Table 18 shows the hour of reading, the location of the bond, and the average

currents for all-day and maximum-hour taken off the sheaths. Most of the current, amounting to 11 amperes for the all-day average, is being taken to the Springfield Railway power house, through the tap at Main and Limestone Streets quite distant from either station, while the currents on the bonds near the two stations are much smaller, being 3.08 amperes at the Ohio Electric substation tap at Main and Zischler Streets, and 1.94 amperes at the Springfield Railway power house tap at Main and Sycamore Streets. The total current taken from all these taps is about 16 amperes for the all-day average and 29.4 amperes for the maximum-hour. In all probability these currents can be materially reduced when the bad track conditions on North Limestone Street and East Main Street are improved. When the tracks are put in good condition, as urged elsewhere in this report, the current drained from the telephone cables should be reduced as much as possible, not so much for the further protection of the cables themselves, which are considered quite safe under present conditions, but to prevent drawing any more current than necessary from other underground structures which might be prejudicial to the latter.

TABLE 18

Current in Telephone Sheaths

[One-hour charts. These data were obtained in July and August, 1914]

No.	Hour	Location	Current, amp.	
			All-day	Max.-hr.
1	10.10 a. m.	Main and Limestone Streets	10.0	20.3
2	9.33 a. m.	Main and Zischler Streets	3.08	5.67
3	2.10 p. m.	Main and Sycamore Streets	1.94	3.58
		Total	16.02	29.45

5. CROSS CONNECTIONS

The data indicate the need of crossties or connection between tracks where a long circuit or loops exist before they intersect. Some of these will be short underground bonds while others will have to be overhead cables for a greater distance. At Main Street and Lagonda Avenue an average potential of 0.1 volt exists with

swings to 2 volts between the two tracks, which are about 10 feet apart. There is a track loop or the distance around the metallic circuit of about 500 feet. A bond of 0000 copper between these tracks is desirable, especially since telephone lead sheaths lie directly across this gap. At Limestone Street and McCreight Avenue a similar condition exists with swings of 2.5 volts between the two tracks and an average of about 0.1 volt. The separation is about 8 feet and the loop about 2000 feet and a 0000 bond here is needed. An overhead cable of 300 000 circular mils is desirable between Miami and Yellow Springs Streets, between the Springfield & Xenia Railway line and the Springfield Railway Co., a distance of 700 feet since the current is flowing in opposite directions in the two lines and pipe potential differences are positive on one and negative on the other. A similar cable on Washington Street, between the interurban terminal tracks and Limestone Street, would relieve rather high local potentials found to exist thereon, a distance of about 400 feet, also on Lansdown Avenue between Clifton Avenue and Limestone Street, a distance of 600 feet, where potential swings of 3 volts occur. The total cost of these ties amounts to $400 and every one is a joint tie connecting two different companies' tracks.

6. COST DATA

In discussing data showing the electrolytic conditions, the question of the safety of the underground structures is not the only one to be considered, the economies of the mitigation system also being an important factor. The data indicates the pipes and cables to be substantially safe and gradients and over-all potentials to be reasonably low at most points. The discussion of cost data presented elsewhere in this report shows that these conditions have been brought about with annual cost to the railways somewhat greater than that before any mitigation system was installed, but with very high potentials existing. However, the annual cost is less than with the original mitigation system owing to the reduced power loss under the present installation.

7. SIGNIFICANCE OF DATA

To determine the meaning of conditions found in Springfield, especially their effect on the safety of the subsurface structures, they must be compared with those in other places where the same conditions have prevailed long enough to enable one to draw conclusions from the results. The potentials existing in Springfield before the mitigation systems were installed were about the same as those prevailing in most American cities where damage has been practically universal and damage was progressing in a similar manner. In England where the over-all potentials have been limited to 7 volts during the maximum half-hour and in Germany where a 2½-volt limit during average scheduled traffic has been set, there has been freedom from electrolysis. Although the bases of measurement are not exactly the same, they are comparable in a general way. All over-all potential values on the Springfield Railway Co. lines are below these limits, and this is true of those on all sections of interurban lines except those still unrepaired or practically insulated from earth.

Gradients have been limited in England by a provision permitting a maximum current density of 9 amperes per square inch of rail cross section. This corresponds to a gradient of about 0.9 volt per 1000 feet, for the maximum half-hour allowing no drop on joints, or 0.3 or 0.4 volt per 1000 feet for the all-day average gradient. On this basis all sections in Springfield are not creating any serious hazard to subsurface structures due to leakage from short sections of track. Since only two or three unrepaired sections of track remain and there is promise of these being taken care of before this paper goes to press, while at the beginning of this work a very large percentage of the track was in bad condition, and since the all-day average over-all potentials have been generally reduced to 3 volts, no all-day average gradient exceeds 0.4 volt per 1000 feet, potential differences are less than 1 volt even for the maximum hour, with the exception of two points, and the current flow in the underground pipes is negligible, it is evident that conditions in Springfield are very satisfactory and the pipes may be considered safe. Maintenance

of track bonding has been frequently mentioned and it is the real essential for continued satisfactory conditions.

It should be pointed out that there is a large amount of damaged pipes in certain districts which may be exposed at times and that breaks or leaks may occur at previously weakened points. Such instances should be looked into carefully to determine existing potential conditions and whether soil conditions are such as to give rise to any appreciable trouble.

D. COMPARATIVE DATA—WINTER AND SUMMER SURVEYS

It would be of interest to compare conditions in Springfield before and after the installation of the insulated return feeders and the accompanying track interconnection and improvement. We have only a few readings taken prior to the changes, but certain over-alls and potential differences indicate a great change of conditions have taken place. More complete data, taken during the winter survey mentioned in the early part of this report and during the summer survey, the data for which have just been given, give an opportunity to compare the effect of varying temperatures and frost on electrolysis conditions.

During the winter survey the ground was frozen to a depth of 4 to 10 inches, thus making a considerable part of the current leaking from the rails go through this frozen ground, and experimental data indicate that such freezing of the ground should reduce the leakage current very materially, due to the high resistance of frozen soil. The low temperatures should also make all metallic structures better conductors, especially the rails, which have a large temperature coefficient of resistance and are exposed to temperature changes much greater than the pipes. The comparative data for the winter and summer survey presented below bear out these conclusions in a very definite manner.

1. POWER-HOUSE LOADS

In comparing the electrical measurements made in winter and summer it is necessary to take account of the difference in railway loads during the two seasons. The summer and winter loads on the interurban lines are practically the same, as shown by the

schedule on three of the interurbans and by the kilowatts, daily and weekly demand, on the Ohio Electric Railway Co. Table 19 gives the power consumption by the Ohio Electric Railway Co. and shows that the average load per week varied more between January and December than January and July, and the variation from day to day was even greater in many instances. These figures, while indicating no great difference between winter and summer, show the impossibility of repeating readings within a few per cent on this system; e. g., the greatest variation shown on succeeding days is between Monday and Tuesday, December 15 and 16, when a change of almost 50 per cent occurred. During the summer the maximum variation was considerably less than this, namely, about 38 per cent, and that on succeeding days less than 30 per cent.

TABLE 19

Load Data—Ohio Electric Railway Co., Springfield Substation

[Watthour meter]

	Output in kwhrs.
Output for week December 15 to 21, 1913:	
December 15	3827
December 16	5640
December 17	3800
December 18	4980
December 19	3854
December 20	4490
December 21 (Sunday)	3760
Total	30351
Average	4336
Output for week January 15 to 21, 1914:	
January 15	3830
January 16	4620
January 17	5780
January 18 (Sunday)	3960
January 19	5620
January 20	4490
January 21	4650
Total	32950
Average	4707
Output for week July 15 to 21, 1914:	
July 15	5990
July 16	4640
July 17	4240
July 18	5430
July 19 (Sunday)	4620
July 20	4540
July 21	5680
Total	35140
Average	5020

In Table 20, showing the Springfield Railway Co. load, it will be noted that the variation for week days is decidedly less, being about 20 per cent for winter and 16 per cent for summer. Owing to electric heating and increased traffic, the city line has a load of 56 per cent greater in the winter than in the summer, the average daily kilowatthours being 9300 for one week in July and about 15 500 per week in December and January. This would have the tendency to increase both the current in the pipes and the potential differences between pipe and rail, and must be taken into consideration in comparing potential and current readings.

TABLE 20

Load Data—Springfield Railway Co.

[Watthour meter]

	Output in kwhrs.
Output for week December 15 to 21, 1913:	
December 15	15 890
December 16	16 180
December 17	14 630
December 18	15 640
December 19	16 000
December 20	17 320
December 21 (Sunday)	13 590
Total	109 250
Average	15 607
Output for week January 15 to 21, 1914:	
January 15	15 410
January 16	14 650
January 17	17 650
January 18 (Sunday)	13 020
January 19	15 480
January 20	15 210
January 21	16 770
Total	108 190
Average	15 456
Output for week July 15 to 21, 1914:	
July 15	9080
July 16	9570
July 17	9340
July 18	10 540
July 19 (Sunday)	9040
July 20	8990
July 21	8840
Total	65 400
Average	9343

2. COMPARISON OF WINTER AND SUMMER ELECTRICAL MEASUREMENTS

(a) *Comparative Potential Differences.*—At many of the points where potential differences between water and rail were observed during the summer survey readings were also taken during the winter survey. These have been reduced to a comparative basis by applying a correction factor derived from the load curves based on the hours at which the two readings were taken. It will be noted that of the 47 readings in Table 21, 30 are of about the same magnitude, but there are a number of decided differences, especially near the neutral area, where a slight change in the relation of the load on the two stations will reverse the polarity. This has evidently occurred at Florence and Main Streets, Hughes and Sigler Streets, and Main Street and Wittenberg Avenue. The differences on Limestone Street at Parkwood Avenue and Landsdown Avenue, where the polarity changed from positive to negative, are evidently due to a change in power distribution on the Springfield and Washington line. The arithmetical average potential difference for all points compared is 0.51 volt during the winter and 0.34 volt in the summer, an increase of 50 per cent during the winter. The total load on all stations increased 39 per cent at the same time and the track resistance due to temperature coefficient has decreased 15 per cent, leaving 26 per cent to be ascribed to the effect of frost, a very definite effect even when it is considered that considerable track improvement had been made since the winter readings. This tends to prove that frost increases the potential differences. As would be expected, the current in the pipe discussed later also points quite definitely to this higher resistance effect.

TABLE 21

Comparative Potential Differences—Water Mains to Rails

[One-hour charts]

Location	Potential difference, volts		Location	Potential difference, volts	
	Winter	Summer		Winter	Summer
Belmont Avenue and Main Street	−0.6	−1.03	Lagonda Avenue and Nelson Street	+0.2	+0.19
Clark and Limestone Streets	−0.3	−0.13	Lagonda Avenue and Warder Street	+0.36	+0.11
Clifton and East Streets	−0.64	−0.56	Light and Main Streets	+0.08	+0.24
Clifton Avenue and Johnston Street	−1.3	−0.49	Limestone Street and Landsdown Avenue	+1.5	−0.48
Clifton and Oak Streets	−1.15	−0.39	Limestone Street and Madison Avenue	−0.01	−0.06
Clifton Avenue and Rice Street	−0.8	−0.84	Limestone and Main Streets	+0.32	+0.11
College and Wittenberg Avenues	−0.2	−0.31	Limestone Street and McCreight Avenue	−2.1	−0.63
Columbia and Foster Streets	+0.2	+0.17	Limestone Street and Parkwood Avenue	−1.12	+0.04
Columbia and Sycamore Streets	+0.43	+0.32	Main Street (West) and Ohio Electric tracks	+0.14	+0.06
Columbus and Belmont Avenues	−0.2	−0.14	Main and Plum Streets	+0.11	+0.08
Florence and Main Streets	+0.02	−0.66	Main and Sigler Streets	+0.36	+0.58
Foster and High Streets	+0.05	+0.03	Main and Sycamore Streets	+0.66	+0.53
Foster and Main Streets	+0.24	+0.18	Main Street and Western Avenue	+0.25	+0.48
Fountain Avenue and North Street	+0.32	+0.12	Main Street and Wittenberg Avenue	+0.02	−0.16
Freeman Avenue and Main Street	+0.73	+0.21	Main Street and Zischler Avenue	+0.60	+0.59
Glenn and High Streets	+0.08	−0.13	McCreight Avenue and Plum Street	−0.65	−0.46
Grant and Yellow Springs Streets	+0.6	+0.74	Mulberry Street and Wittenberg Avenue	−0.42	−0.42
High Street and Ludlow Avenue	−0.58	−0.09	North and Race Streets	+0.48	+0.36
High and Penn Streets	+0.09	+0.04	Pleasant and Yellow Springs Streets	−0.9	−0.40
High and Sycamore Streets	+0.24	+0.29	Plum and State Streets	−0.1	+0.14
Hughes and Sigler Streets	−0.6	+0.50	Power and Sycamore Streets	−0.25	−0.01
North and Isabella Streets	+1.0	+0.92	Arithmetical average	0.51	0.34
North and Jackson Streets	+0.4	+0.51			
Karr Street and Lagonda Avenue	−0.7	−0.48			
Kenton and Oak Streets	−0.75	−0.50			
Lagonda Avenue and Henry Street	−0.09	−0.23			

The positive values around the Springfield power house were much smaller (0.36 to 0.11 volt at Lagonda Avenue and Warder Street, 0.43 to 0.32 volt at Columbia and Sycamore Streets, and

0.66 to 0.53 volt at Main and Sycamore Streets) in the summer survey, but there is little change at the Ohio Electric station (0.60 to 0.59 volt at Main and Zischler Streets and 1.0 to 0.92 volts at Isabella and North Streets), which is about what would be expected from the load curves, there being an increase of 10 per cent in the summer load.

A number of readings taken during the winter survey (Table 22) show the water and gas system to be practically at the same potential, most of the readings being a few millivolts. There is one notable exception, at 1712 North Limestone Street, where the gas was negative to the water main 1.92 volts. This indicates the presence of a high-resistance joint at some point on this natural-gas main. At the next service south the potential difference dropped to 5 millivolts. This, in general, supports the practice of measuring from water main to rails, since fire hydrants furnish more convenient connection points than are found on the gas mains.

TABLE 22

Potential Differences—Gas to Water Mains

[Indicating instrument readings. These data were obtained in January, 1914.]

Hour	Location	Potential difference	Hour	Location	Potential difference
		M. V.			M. V.
3.43 p. m.	1906 West Main Street.....	+52	10.38 a. m.	1352 West Pleasant Street .	+ 0.130
10.59 a. m.	31 South Limestone Street .	− 1.2	11.30 a. m.	1901 West Main Street.....	+ 0.3
10.00 a. m.	1819 Lagonda Avenue.....	− 0.05	1.20 p. m.	563 South Limestone Street	− 4.3
4.24 p. m.	518 North Limestone Street.	+ 1.43	3.18 p. m.	1519 Clifton Avenue.....	+ 1.5
2.55 p. m.	1712 North Limestone Street	− 1.92 V.	2.06 p. m.	531–533 East Street.....	+ 5.58
	1708 North Limestone Street	− 5		805 East High Street.....	− 2

(b) *Comparative Current on Mains.*—The Tables 15, 16, and 17, containing the current readings on water and gas mains, have been rearranged and data obtained during the preceding winter survey added in the last two columns. A correction factor has been applied to the summer readings, based on the load curve of the nearest power station, reducing the figure to the same hour at which the winter reading was taken. Of the 17 readings on the water mains Table 23, which were taken in both surveys, 10 of

the summer readings were larger than the corresponding winter readings and 4 others are practically the same. The average for summer is 1.81 amperes and 1.55 for winter. Since the total winter load is 39 per cent greater than the summer load, a correction must be applied in making a comparison, and when this is made the ratio of currents for similar load conditions would be 1.81 amperes to 1.11, or the summer current is 63 per cent larger.

TABLE 23

Comparative Currents in Water Mains

[One-half-hour galvanometer readings]

No.	Location	Mains		Current			
				Summer		Winter	
		Size	Kind	Amp.	Direction	Amp.	Direction
		Inches					
1	Lincoln Street north of High Street	16	CI	3.58	N	3.45	N
2	Cedar and Cliff Streets	16	CI	0.27	W	0.42	E
3	Spring Street, on Buck Creek Bridge	12	CI	4.49	S	0.86	S
4	Plum Street north of Columbia Street	10	CI	2.65	N	0.58	N
5	Shaffer Street north of Columbia Street	8	CI	1.54	N	1.72	N
6	Dayton Avenue and High Street	10	CI	0.25	.....	0.79	E
7	Isabella Street north of Main Street	8	CI	3.78	N	2.06	N
8	Main Street east of Freeman Avenue	24	CI	1.75	E	3.72	E
9	Chestnut Avenue east of Limestone Street	10	CI	0.49	W	0.25	W
10	Clifton Avenue north of Liberty Street	8	CI	2.67	.....	0.87	
11	North Street west of Race Street	8	CI	1.15	W	0.93	W
12	Fountain Avenue south of College Avenue	8	CI	1.83	N	0.80	N
13	Pleasant Street west of Wittenberg Avenue	8	CI	1.62	W	1.68	W
14	Spring Street north of High Street	20	CI	3.66	N	5.85	N
15	High and Race Streets	6	CI	0.17	E	0.01	E
16	Main Street and Western Avenue	10	CI	1.06	E	0.69	W
17	Main Street east of Spring Street	24	CI	0.00	.....	1.65	E
	Total	.....	.....	30.76	.....	26.33	
	Average	.....	.....	1.81	.....	1.55	

On the natural-gas mains (Table 24) 6 summer readings are larger but the average is practically the same, the 1 winter reading of common magnitude, 8.15 amperes, being ⅔ of the winter

total of 11 readings. Again, considering the season load ratio the summer readings are practically 40 per cent larger than the corresponding winter values. In case of the artificial-gas mains (Table 25) the currents are too small to be considered as conclusive. The values obtained here, however, indicate the same general effect, the summer average being 0.29 ampere on the 10 common stations as compared to 0.16 ampere in winter, and if the load ratio is applied the summer current is relatively two and one-half times larger. While individual readings are not entirely consistent, the general tendency is quite definite and it is evident that there is a reduction of current flow on underground pipes due to the high resistance accompanying freezing temperatures in the earth.

TABLE 24

Comparative Currents in Natural-Gas Mains

[One-half-hour galvanometer readings]

No.	Location	Mains		Current			
				Summer		Winter	
		Size	Kind	Amp.	Direction	Amp.	Direction
		Inches					
1	Clifton and East Streets	6	CI	1.50	W	0.20	W
2	Main Street and Belmont Avenue	6	WI	0.00	.....	0.25	N
3	Clifton Avenue and Rice Street	3	WI	0.05	S	0.20	S
4	Warder Street and Lagonda Avenue	4	WI	4.73	E	8.15	E
5	North Street and Wittenberg Avenue	6	CI	3.08	W	1.46	W
6	Columbia Street, 50 feet east of Sycamore Street	4	WI	0.01	E	0.00	
7	Yellow Springs and Washington Streets	4	CI	0.53	W	0.03	W
8	Wittenberg Avenue and Pleasant Street	6	CI	0.52	N	0.29	N
9	Southern Avenue and Limestone Street	6	CI	0.56	W	1.14	W
10	Spring Street north of Monroe Street	6	WI	1.01	N	0.39	N
11	Isabella and North Streets	3	WI	0.00	.....	0.04	N
	Total	.....	.....	11.99	.....	12.15	
	Average	.....	.....	1.09	.....	1.10	

TABLE 25

Comparative Currents in Artificial-Gas Mains

[One-half-hour galvanometer readings]

No.	Location	Mains		Current			
				Summer		Winter	
		Size	Kind	Amp.	Direction	Amp.	Direction
		Inches					
1	North Fountain Avenue, opposite gas office	6	CI	0.04	S	0.01	S
2	Clifton Street and Clifton Avenue	4	WI	0.45	N	0.17	N
3	High and Sigler Streets	12	WI	0.00	.....	0.12	W
4	Yellow Springs and Pleasant Streets	12	WI	0.00	.....	0.01	E
5	High and Lowery Streets	2	CI	0.01	N	0.00	
6	High and Sycamore Streets	3	CI	0.00	.....	0.03	N
7	High Street and Greenmount Avenue	8	WI	2.41	S	1.14	S
8	Fountain and Madison Avenues	2	CI	0.02	E	0.00	E
9	Woodlawn and College Avenues	8	WI	0.00	.....	0.09	S
10	Limestone Street at Buck Creek Bridge	3	WI	0.00	.....	0.00	
	Total	.....	.....	2.93	.....	1.57	
	Average	.....	.....	0.29	.....	0.16	

(*c*) *Current in Lead Sheaths.*—The change since the early mitigation work in the current on the telephone lead sheaths is not great, but current is being taken off at one more point, the extent of underground cables has increased, and potentials are smaller and more evenly distributed. It is anticipated that the repairs on North Limestone and East Main Streets when completed will permit a reduction of the drainage current from the sheaths and at the same time permit these cables to be maintained at smaller negative potentials with respect to neighboring underground structures.

(*d*) *Comparative Rail Gradients.*—The rail gradients were taken with entirely different objects in view in the two surveys, those in the winter being taken with the purpose of determining the condition of the track return, and based on these readings recommendations were made to improve defective sections of track. Since this was known to have been done in most places it was not considered necessary to install the many pressure wires required

to repeat all of these values in the summer survey and only those necessary to determine the condition of the insulated feeder system were taken. On the gradient map, Fig. 11, the winter values are shown in black wherever one was taken over the same length as during the summer. On North Limestone Street, West North Street, and Lagonda Avenue gradients are practically the same in both surveys with quite an increase on South Limestone Street, and decrease on East Main Street, in the summer survey. The change on South Limestone is probably due to the development of defective joints on this line while the improvement on East Main Street must be due to rebonding in this section. As noted before, all uninsulated track gradients are well below 0.4 volt per 1000 feet and are considered very satisfactory.

(*e*) *Comparative Over-All Potentials.*—The winter survey values of over-all potentials as shown by the second report are not exactly comparable, since the tables and maps contain values for the average schedule traffic and not the all-day average, and the points of pilot wire connection were not always the same, having been extended to the end of the line in some instances. The winter values are shown on the map in Fig. 12 in black figures and the black lines indicate differences in points of connection of pressure wires. On the Springfield Railway lines the two values appear for every line except the winter reading to Snyder Park, which was not obtained. Only four of the winter values are larger than the summer but the winter average for all points is slightly higher, 1.38 to 1.35 volts; also two winter lengths were shorter, i. e., Lagonda Avenue and Clifton Avenue. However, when the load decrease is considered it indicates that sections on Lagonda, Belmont, and Clifton Avenues have deteriorated somewhat since the winter survey. This is also true of North Limestone and East Main Street, on the Ohio Electric Railway lines, where the summer values are considerably larger. Since the load here is practically constant, the temperature coefficient would increase the drop in summer from 10 or 15 per cent and on Limestone a greater length is included. This track was undergoing repairs at the time of survey, as pointed out before. A different reference point was used on the other interurbans so that an

exact comparison is not possible, although it may be noted that the over-all potentials on these lines are of the same order of magnitude.

VI. RECOMMENDATIONS

Electrolysis conditions in Springfield are, on the whole, good at the present time, but as indicated above there are certain places where improvement in the tracks is required. Certain standards of operation and maintenance must be agreed upon and these enforced through the medium of inspection and reports. In view of the fact that the prevention of electrolysis is not essential to the operation of a railway system, it is very often neglected and for that reason some method of supervision is generally desirable. In order to assure the maintenance of satisfactory electrolysis conditions through succeeding years, we wish to make the following recommendations dealing with construction and administration based on the experimental data presented above.

A. INSULATED RETURN FEEDERS

It is earnestly recommended that the insulated return feeder system be maintained in good operating condition. No changes are necessary at present and few extensions will be required for a number of years, but the cables and resistance units should be inspected periodically.

B. IMMEDIATE RAIL BONDING

With a new roadbed and new rails on East Main Street, the 500 000 circular mils cable extending from Lincoln Street to Belmont Avenue may be re-covered, which will reduce the losses to a certain extent in the insulated return feeders and should improve conditions around the Ohio Electric Railway substation as well as along East Main Street. There are other sections which require additional bonding, notably on Limestone Street south of John Street which is, like the East Main Street section, awaiting permanent street paving.

C. INTERCONNECTIONS

Certain points where high local gradients may be reduced and the general situation improved by cross connections were described in detail on page 47 of this report. They are simply enumerated here:

At Main Street and Lagonda Avenue.

At Limestone Street and McCreight Avenue.

From Miama Street to Yellow Springs Street end of Springfield Railway line.

On Washington Street from interurban tracks to Limestone Street.

On Landsdown Avenue from Clifton Avenue to Limestone Street.

As pointed out, these may be installed at a small cost which should in each case be borne jointly by the two railway lines connected, since each connects two different lines and each derives certain benefits especially in increased conductivity in its return.

D. EXTENSION AND MAINTENANCE OF PRESSURE WIRE SYSTEMS

With the exception of the one pressure wire on South Limestone Street, which should be extended to Leffel Lane, the system is complete and it is urged that this be maintained and made of regular use. It should be inspected and a simple test applied to the wires to determine their continuity and insulation. Additional wires will be necessary only when new railway lines are constructed in new directions and when existing railways are extended.

E. DRAINAGE METHODS

Pipe drainage should not be permitted in Springfield, one of the most evident local objections being due to the high resistance and insulating joints in the pipe system.[3] The lead sheaths permit a small amount of drainage because of their continuity and rather small extent but must not be overdrained or made extremely negative because of the excessive currents resulting and the hazard produced to pipes.

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[3] For general discussion, see Technologic Paper No. 52.

F. UNDERGROUND STRUCTURES

The owners of pipe systems can improve the electrolysis conditions by several methods—chiefly by laying new mains and services as far from existing tracks as possible,[3] and installing insulating joints in new mains and services with sufficient fre quency to assure no high potential differences across them.

G. VOLTAGE LIMITATIONS

Since the measurement of over-all potential difference is one of the most convenient methods of determining the danger of the underground systems from electrolysis, limits of this voltage should be set to define the values permissible. An inspection of the over-all potential table indicates that all of these could be limited to an all-day average of 4 volts, and when necessary repair work is completed a limit of 3 volts all-day average would be reasonable and this value is recommended for all lines except the North Limestone Street line of the Ohio Electric Railway, and the Springfield, Troy & Piqua line. On these lines, owing to the semi-insulated character of the track construction, a limit of 4 volts is permissible.

H. STANDARDS OF BONDING

In order to insure good electrolysis conditions not only will the over-all potential differences have to be limited but gradients over shorter lengths must not become excessive. Since high gradients are due to tracks overloaded with current or having bad bonds, and since the insulated feeder systems and track interconnection should provide good current distribution, even with considerable growth, only the bonding needs to be specified to maintain low gradients.

The standard of bonding which should be maintained can be reached by annual tests and repair of all bad bonds; e. g., those exceeding the resistance of 10 feet of rail, providing the rail or joint foundation is in good condition. Bonds on joints that are vibrating badly under traffic will fail rapidly and there are certain sections of track in Springfield which must be watched and bonds replaced frequently until the roadbed is thoroughly repaired.

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[3] For general discussion, see Technologic Paper No. 52.

The East Street and Lagonda Avenue lines are examples of sections over which supervision should be very close.

On all new track cross bonds should be installed every 300 feet with 60-foot rail construction. An exception may be made in the case of steel tie construction where the ties are electric welded to the rails at the joints. In interurban construction cross bonds should be used as frequently as recommended above. Since loss due to theft is common with exposed copper bonds, a ½-inch steel strand cross bond with copper terminals welded to the rails will often be more permanent and is effective and of sufficient conductivity.

I. ANNUAL TESTS AND REPORTS

The companies operating the railway lines should be required to submit annual reports showing the location and resistance in equivalent feet of rail of all bad joints. Since such resistances expressed in equivalent feet of rail can be obtained with any of the standard bond-testing instruments on the market, they should be given and not the drop across the joint which is a function of the current flowing as well as the resistance of the joint.

J. SUPERVISION OF TESTS AND REPORTS

It is very desirable that the city retain some one competent to pass on these bonding reports, check up the values given in the report, to measure the over-all potentials, and suggest any other desirable tests. This would greatly assist in maintaining good electrolysis conditions, and the employment of such an expert is recommended.

VII. SUMMARY

The foregoing report discusses previous electrolysis surveys and the physical conditions which affect electrolysis conditions of the city and public utilities. The present insulated return feeder system is described in considerable detail showing size, location, etc., of feeders, resistance taps, power losses, and the cost of operation of the railways as affected by this mitigation system. It is shown that the cost of operation is slightly greater than before any system was installed but less than with the first insulated

return system. The pressure wires by which the over-all potential differences may be measured are described and resistance given.

The data of the most recent survey are given in detail showing the potential differences between the various structures and along the tracks, and the stray current in the underground pipes and cable sheaths. These data are also compared with those taken the preceding winter, and it is noted that low temperatures, slightly below the freezing point, do affect conditions considerably, reducing the amount of stray current and increasing the potential differences between the tracks and the pipes, both these effects being due to the increased soil resistance.

Recommendations are made concerning the constructional details of the utilities and the administration of electrolysis regulations by the city. It is recommended that the insulated feeder system be continued in operation, that certain improvement in track bonding and interconnection be made, that the pressure wires be maintained, that no pipe drainage be resorted to, and that the pipes laid in the future be kept as far as practicable from railway tracks and have enough insulating joints to materially increase their resistance.

Definite over-all voltage limits are suggested as a reasonable requirement and also a suitable standard of bond maintenance, these conditions to be determined by annual tests and reports to an expert employed by the city.

In connection with the work in Springfield, the Bureau wishes to acknowledge the cooperation and assistance of the city manager and other city authorities, including the water department; also of the Springfield Gas Co., Central Union Telephone Co., Springfield Railway Co., Ohio Electric Railway Co., Springfield, Troy & Piqua Railway Co., Springfield & Washington Railway Co., Springfield & Xenia Railway Co., and of Prof. E. O. Weaver, professor of physics, Wittenberg College.

WASHINGTON, July 17, 1915.