

THESIS.

COMBINED EFFICIENCY TEST OF UNIT No.4

in the

HYDROELECTRIC STATION OF THE EASTERN TENNESSEE POWER CO.

on the

OCONEE RIVER AT PARKSVILLE, TENNESSEE.

For the degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

under

DR.C.A.PERKINS and PROF.J.A.SWITZER

by

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1913

The Ocoee river rises in Northern Georgia and between its head-waters and Parksville Tennessee it drains an area of about 600 square miles. At Parksville it passes through a narrow gorge and at this point a dam has been built by the Eastern Tennessee Power Company. Work was commenced on this dam in February 1911 and in April 1912 the power developed there was being used in several distant cities.

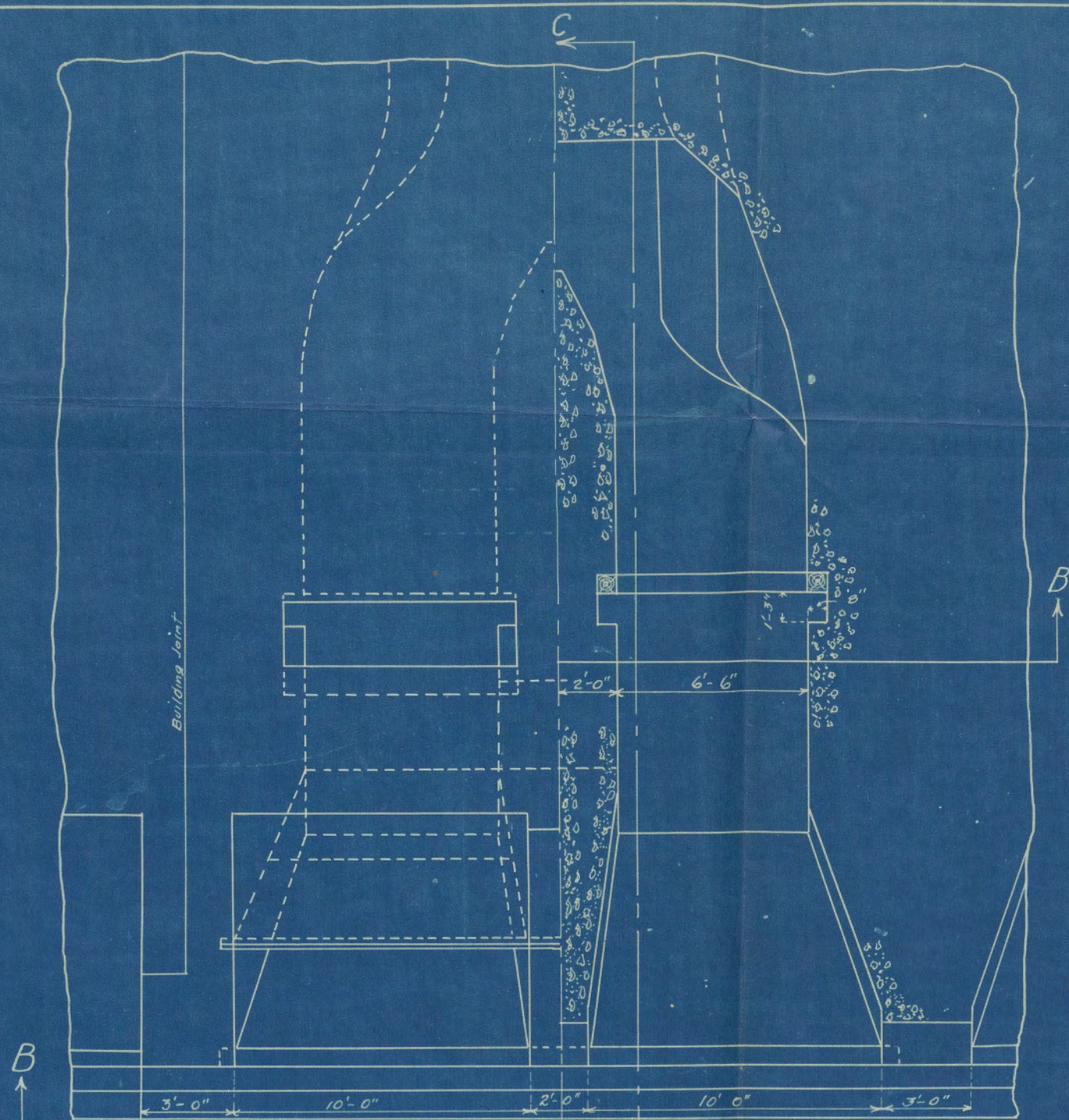
The dam is built of solid concrete with no steel reinforcement, 125 feet high, 840 feet long at the crest, from 115 to 125 feet thick at its base with a spillway 362 feet long capable of passing a flood of 45,000 second feet. It backs up the river for a distance of eight miles forming a lake which covers $3\frac{1}{2}$ square miles containing 100,000 acre feet of water. Only the top layer of this however can be used for storage as the intake for the turbines is located in the dam 20 feet below the crest of the spillway. The penstocks are formed in the dam itself as are the wheel-chambers and draft tubes. The power house has for its foundation part of the dam but the upper portion is of brick and steel. It is 165 feet long by 35 feet wide and contains five

main units, four of which are now in operation, the fifth being almost completely installed. There are two exciter units driven either by water power or induction motors. These exciter units are Westinghouse 120 K.W. at 125 volts and 960 amperes running at 580 R.P.M. Only one exciter is necessary for five main units.

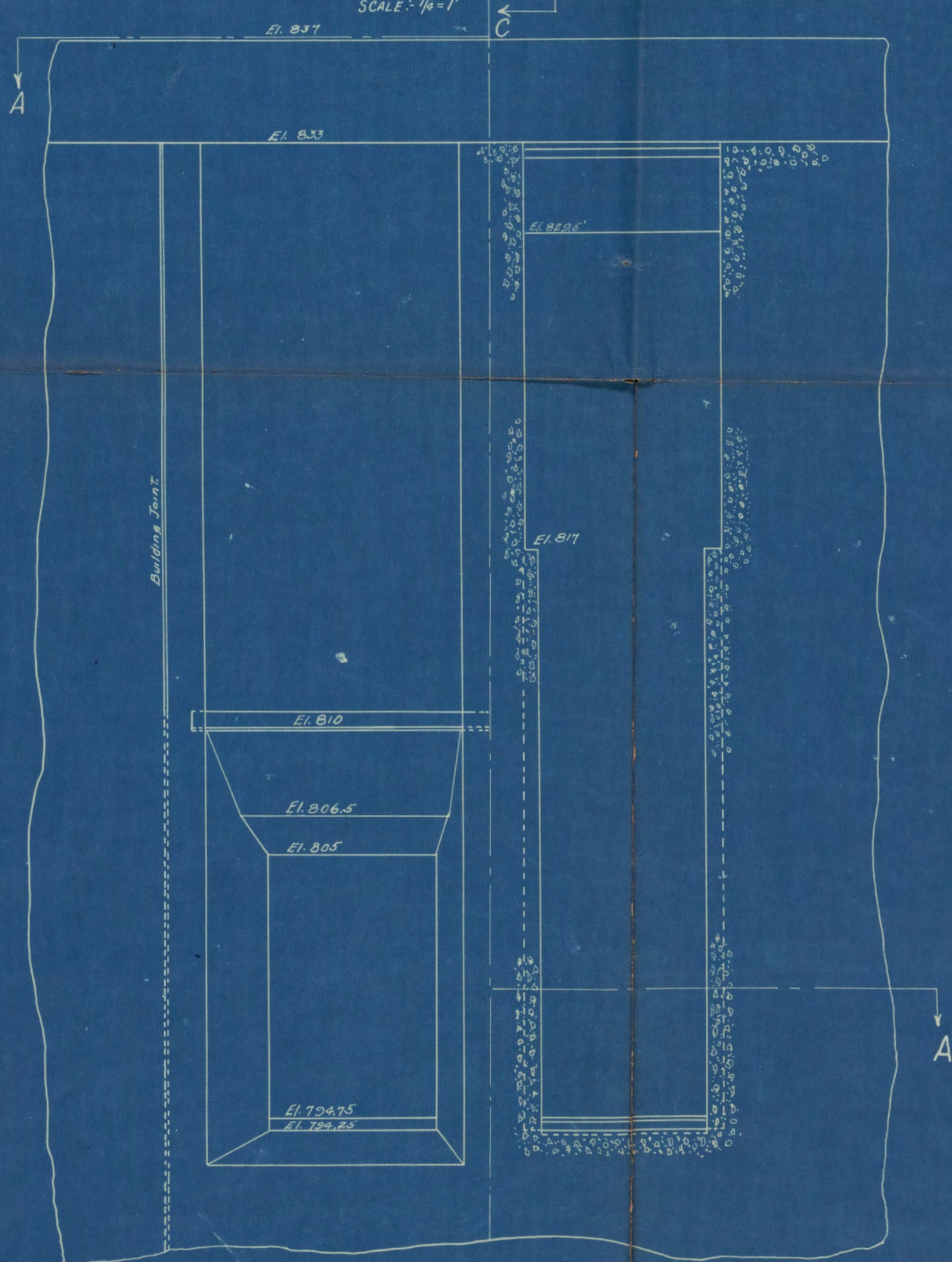
The main units are Westinghouse three phase alternators with a rated output of 3750 K.V.A. at 2300 Volts and 944 Amperes per terminal. These alternators are driven by S. Morgan Smith twin horizontal turbines of the American type (inward and downward flow) running at 360 R.P.M. The turbines have wicket gates and are controlled by Lombard governors, type NS.

The switch-board is of the remote control type having on it no voltage higher than 110 Volts. The voltmeters are connected to potential transformers of ratio 2300 / 110 and the current transformation is 1600 / 5. The board is equipped with all necessary instruments of the latest type.

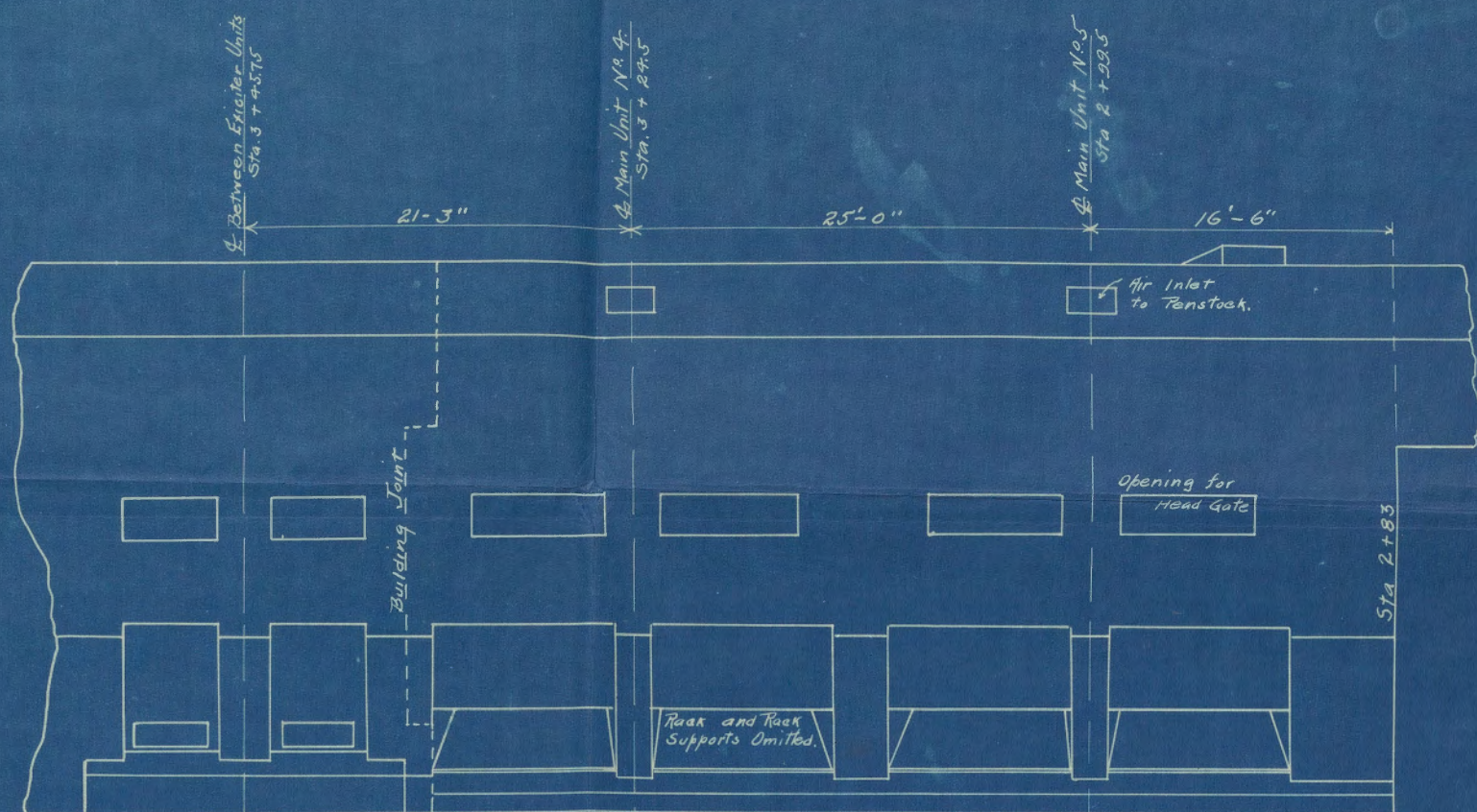
Power is transmitted to Rome Ga., Chattanooga, Cleveland, Athens, Lenoir City, Knoxville and Mascot Tennessee at 66000 Volts. A transmission line is also being built to Nashville, Tennessee



SECTIONAL PLAN A-A
SCALE: $\frac{1}{4}" = 1'$

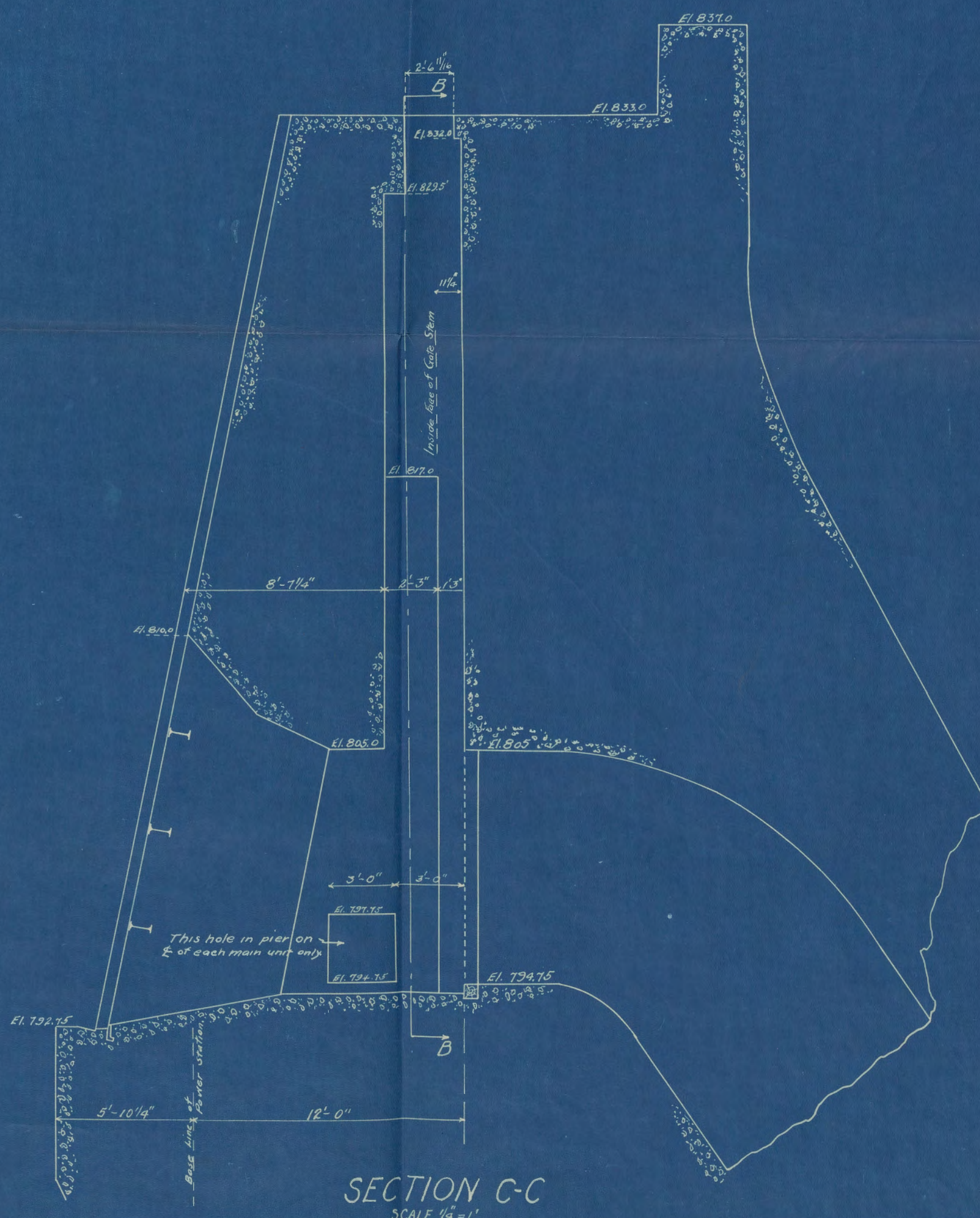


SECTIONAL ELEV. B-B
SCALE: $\frac{1}{4}" = 1'$



PLAN
SCALE: $\frac{1}{8}" = 1'$

INTAKE FOR MAIN UNIT
FOR
POWER HOUSE ON OCOEE RIVER
EASTERN TENNESSEE POWER CO.
PARKVILLE, TENN. MAR. 20, 1913.



SECTION C-C
SCALE: $\frac{1}{4}" = 1'$

which will be used to transmit power from the Parksville station but also will be connected with the other developments on the Ocoee river.

DESCRIPTION OF THE TEST.

Measurement of the Input.

As there was no wier by which the discharge could be obtained it was necessary to find the velocity of the water and calculate the discharge by knowing the area of the section at which the measurements were made. The tail race could not be considered for this purpose as the discharge from all the turbines combines before the eddies and swirls subside. Therefore it was necessary to measure the velocity at the entrance to the penstock.

There are two intakes for each penstock, it being divided so as to lessen the size of a single head-gate. It was therefore necessary to place a current meter in each intake just in front of the head - gate for it was impossible to obtain entrance to the penstock at a point below the head - gates.

The top of the dam from which the meters were lowered was 38.8 feet above the bottom of the intakes. The meters were

A meter was attached to a 1" pipe, 45' long with a swivel joint and lowered to the desired level by a small block and tackle.

The pipe was held in the desired vertical line by a cross brace.

This brace was slipped through a cross in the pipe 15 feet above the current meter and held in place by a set screw as shown in the accompanying sketch.

The method of measuring the discharge through a section with a current meter is to divide the section into a number of smaller areas and determine the mean velocity in each. Then the total discharge through the section is the sum of the products of the small areas by the mean velocity in each or

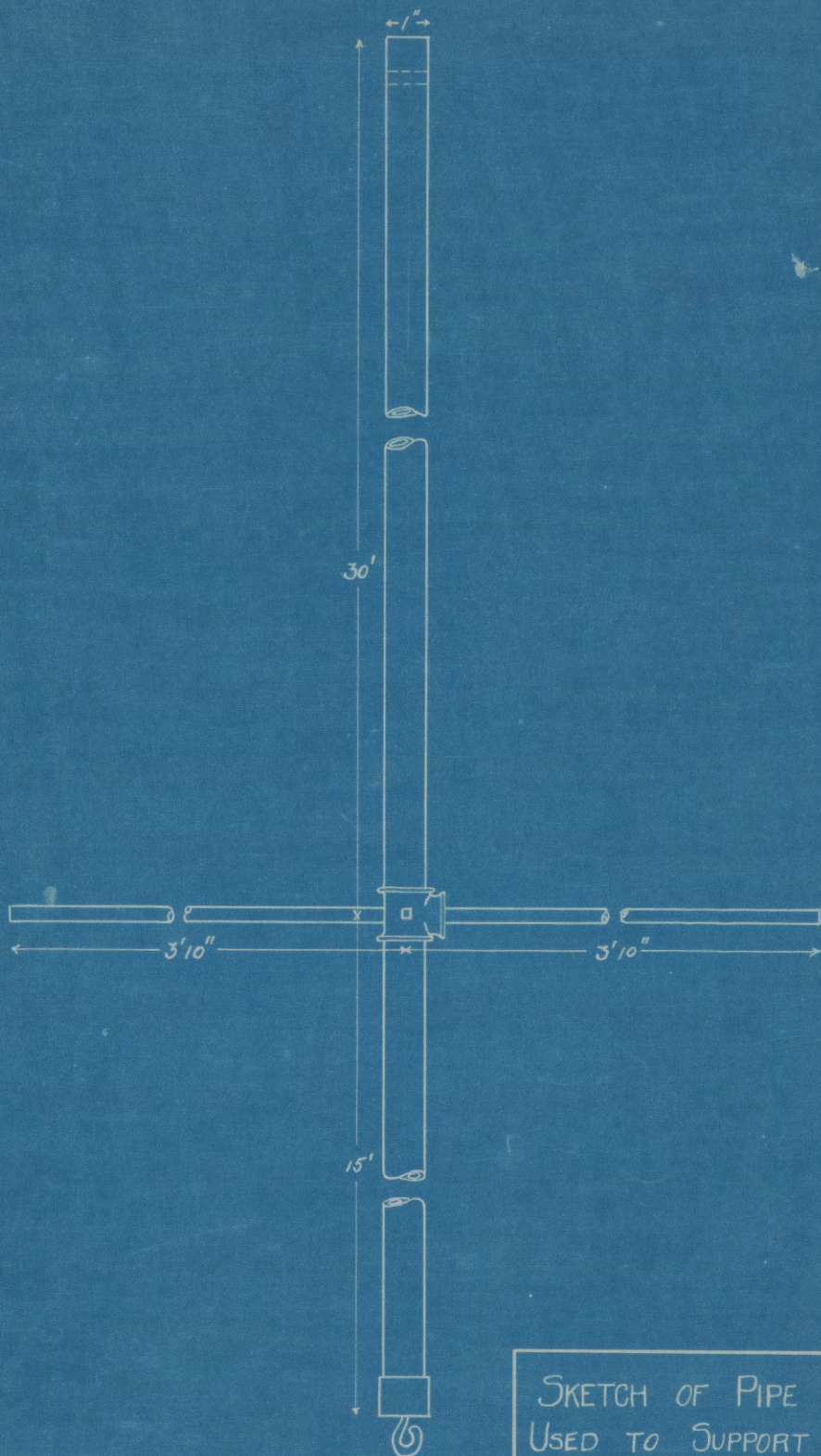
$$Q = a_1 v_1 + a_2 v_2 + a_3 v_3 + a_4 v_4 + \text{etc.}$$

The methods of determining the mean velocity in a section with a current meter are the vertical velocity curves method, the integrating method and the point method.

The vertical velocity curve method is the most accurate when the flow is constant but as it takes longer than either of the other methods, there is more chance of error when the flow is liable to change during the time the points for the curve are

being obtained. With this method the meter is placed successively at various points on a vertical line and the velocity determined. These values are then plotted as abscissa with the depths as ordinates. The mean abscissa as obtained with a planimeter is taken as the mean velocity along that vertical. By determining the mean velocity along a number of verticals, the mean velocity of the entire section may be obtained by averaging the mean velocities along the verticals.

The integrating method may be used to obtain either the mean velocity in a vertical or the mean velocity of the entire section. When used to obtain the mean velocity in the entire section, the meter is moved with uniform speed throughout the section in a zigzag manner, the time required for the entire section to be covered as well as the revolutions of the meter being recorded. It is not possible to obtain good results by this method with a Price differential ^{current} meter for the vertical and horizontal motion causes the wheel to revolve and hence the number of revolutions observed is not the true number caused by the current.



SKETCH OF PIPE
USED TO SUPPORT
CURRENT METER.
PARKSVILLE, TENN. MAR. 20, 1913.

The point method ^{depends} upon either of the other methods. It has been found in the measurement^e of velocity in pipes that the ratio of the mean velocity in the section considered to the velocity at some one point (as for example the geometrical o center of the section) is a constant and is independent of the rate of flow. This fact is made use of extensively by users of Pitot tubes. This relation has also been found by the Water Resource Branch of the U.S. Geological Survey to be fairly constant in open streams so that after the relation has been established for a given point and section, the mean velocity in that section can be obtained knowing the velocity at the point. The relation is established either by vertical velocity curves or by the integrating method. Its accuracy^a then depends on the care with which the mean velocity is determined by the other methods. The constancy of the relation for a permanent cross section depends on the uniformity of flow pass that section.

The chief advantage of the point method is that a close approximation to the true mean velocity can be obtained in a much shorter time than by any of the more accurate methods. It

was on account of the quickness with which this method could be used that it was selected, for the time during which the load could be held constant, was limited, at the larger gate openings. The generator could not be disconnected from the commerical load so there were flucations in the load. These were reduced to a minimum by blocking the governor of Unit No. 4 and thereby causing the other three units to take care of the variations as the four operate in parallel. But it was not thought wise to block the gonernor for a long enough time to make a traverse of the intake at any gate opening above $\frac{5}{8}$ since the variation in load might be too great for the other three units ~~to~~ handle alone. Hence it was decided ^{to} ~~^~~ measure the discharge with all possible accuracy by the vertical velocity curve method at $\frac{1}{4}$ gate and at $\frac{5}{8}$ gate. From these curves obtain the mean velocity in the section as described. Then knowing the velocity at the center of the intake, the relation between this and the mean velocity could be established. At the larger gate openings the governor need be blocked only for a short time while the center velocity was measured and with the mean

velocity coefficient known, the discharge could be found for those gate openings. The assumption then on which the measurement of the discharge is based at gate openings other than $\frac{1}{4}$ and $\frac{5}{8}$ is that the mean velocity coefficient remains constant regardless of the rate of flow.

MEASUREMENT OF OUTPUT.

As stated above, the generator could not be disconnected from the commercial load, so a water rheostat could not be used. However the load was held fairly constant as can be seen from the graphic meter record. At $\frac{1}{4}$ gate the load varied only slightly but at $\frac{5}{8}$ gate there were large fluctuations. At the other gate openings the load was held practically constant for a short while.

The output was measured by the switch board instruments. There were three phase indicating wattmeters, ammeters, voltmeters and power factor meters on the circuit of each unit. These instruments on the circuit of generator No. 4 checked with themselves, that is, the power as indicated by the wattmeter was equal to that as calculated by the formula

$$P = 1.73 E I \cos \theta.$$

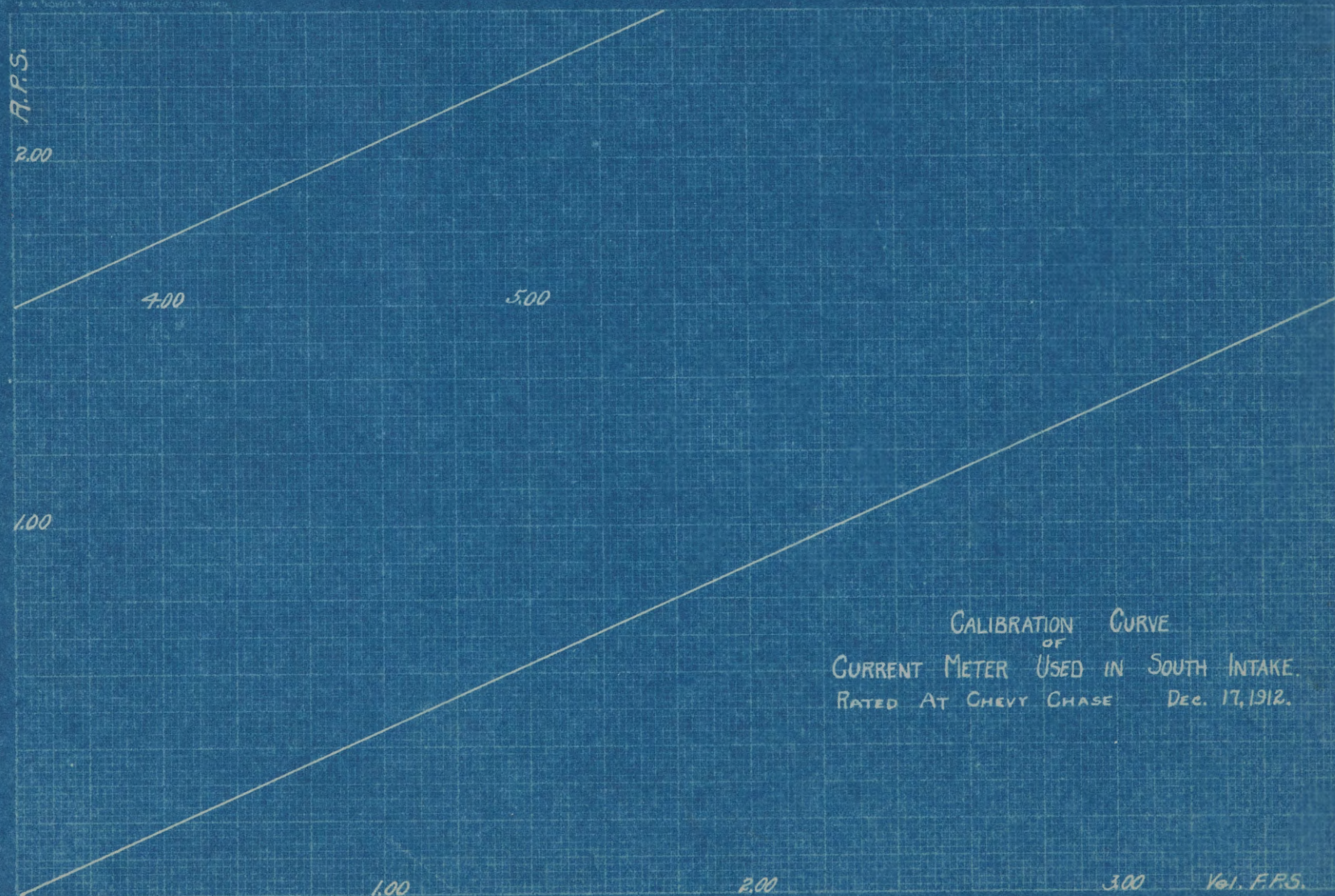
using the values of E, I, and $\cos \theta$ as obtained from the volt-

meter, ammeter, and power factor meter respectfully.

As a further check, a single phase wattmeter, calibrated in the University Laboratory was connected in series with the switch board wattmeter. This instrument however was not provided with a damping device that would prevent the needle from oscillating with the slight variations in load so that it was not possible to read it with accuracy. So the output as indicated by the switch board instruments is used in the calculations.

CALCULATION OF THE MEAN VELOCITY RATIO.

As stated above it was decided to obtain the mean velocity curves at $\frac{1}{4}$ gate and at $\frac{5}{8}$ gate. These curves were obtained along three verticals in each intake at both gate openings. One vertical was the center line, the other two were 20" from the sides. Besides these, one traverse was made along a vertical 6" from the wall in the south intake at $\frac{1}{4}$ gate. The head gate stems and guides interfered so with moving the meter along this vertical that it was decided to get the velocity near the walls by an indirect method as described



CALIBRATION CURVE
OF
CURRENT METER USED IN SOUTH INTAKE.
RATED AT CHEVY CHASE DEC. 17, 1912.

Rev. of Meter - R.P.S.

4.00

3.00

2.00

1.00

CALIBRATION CURVE

OF
CURRENT METER USED IN NORTH INTAKE.
RATED AT CHILHOWEE PARK APR. 9. 1913.

1.00

2.00

3.00

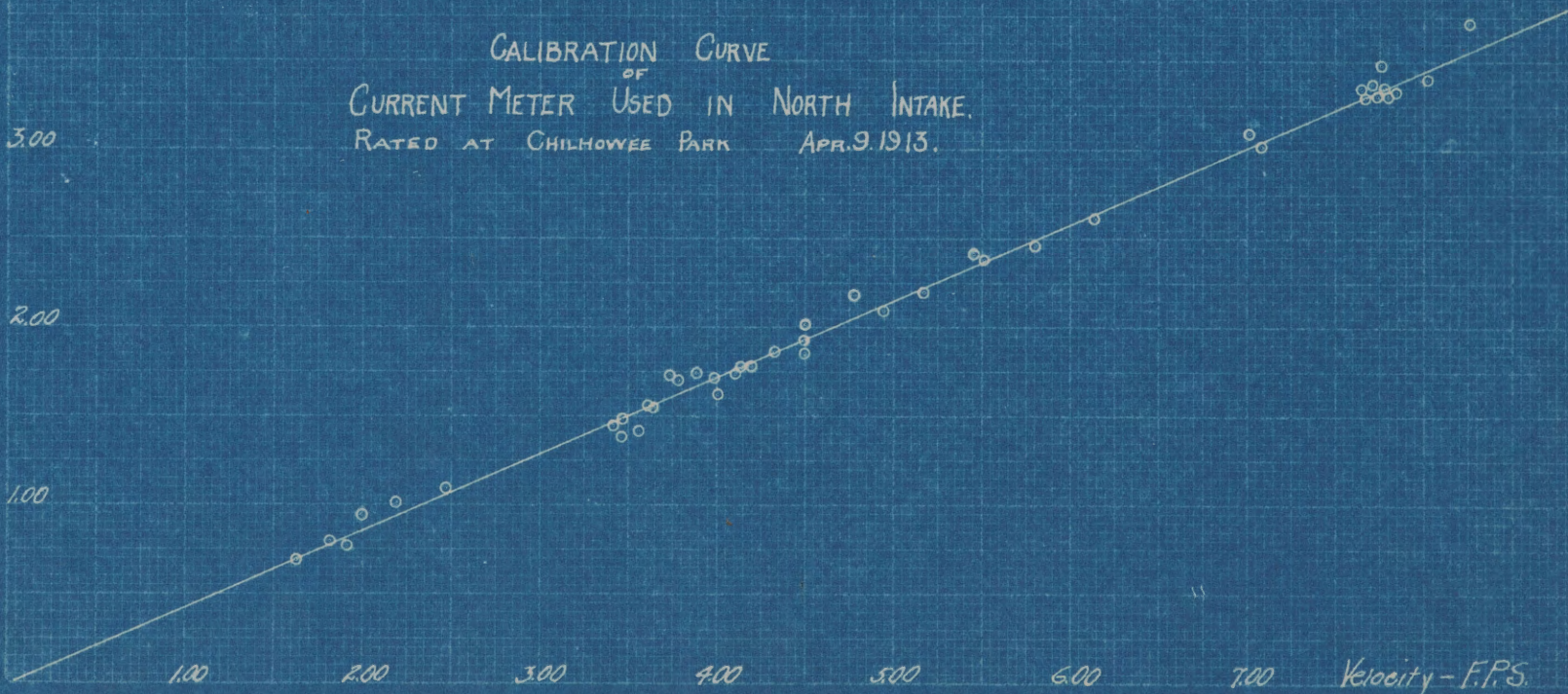
4.00

5.00

6.00

7.00

Velocity - F.P.S.



later. Small Price differential meters were used in both intakes.

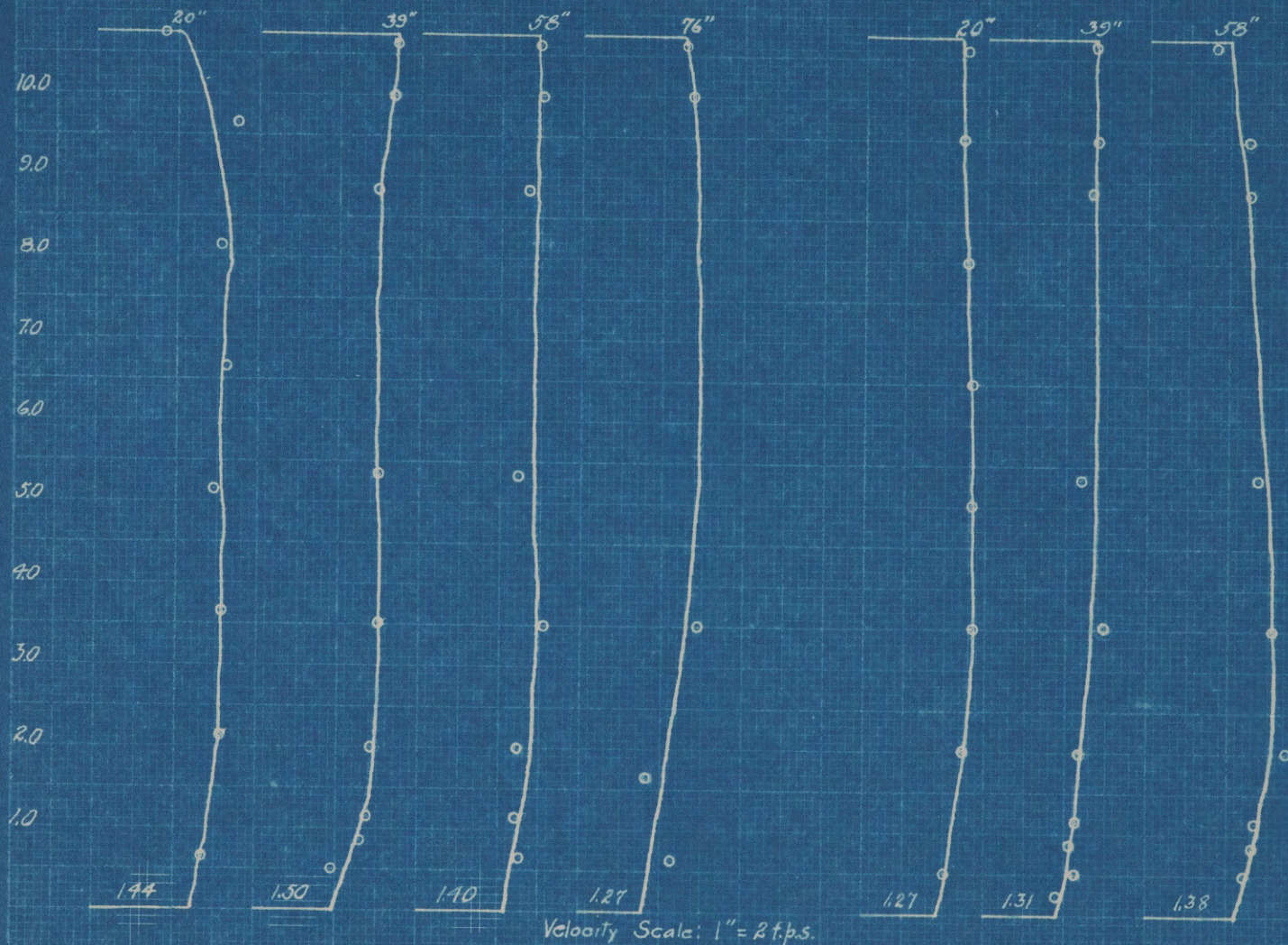
Observations were taken about two feet apart on each vertical.

The meter used in the south intake belonged to the Tennessee Power Company and had been calibrated Dec. 17, 1912 at the U.S. Government Rating Station in Chevy Chase, Md. so that its rating curve was taken as correct. The meter used in the north intake belonged to the University of Tennessee and no calibration of it had recently been made. In order to obtain its rating curve, before it was used again, a course 200 feet long was accurately laid off on the lake in Chilhowee Park in Knoxville. This distance was marked by two wires stretched across the lake just high enough for the boat and occupants to pass under. The meter was attached to the bow of the boat by a pipe at a sufficient distance in front so that the disturbances of the water by the prow of the boat would not affect the meter. The course was traversed at various speeds, the time and number of revolutions during this distance being recorded. The result of this calibration is shown on the accompanying curve. Both this curve and that of the other

VERTICAL VELOCITY CURVES AT 1/4 GATE.

SOUTH INTAKE.

NORTH INTAKE.

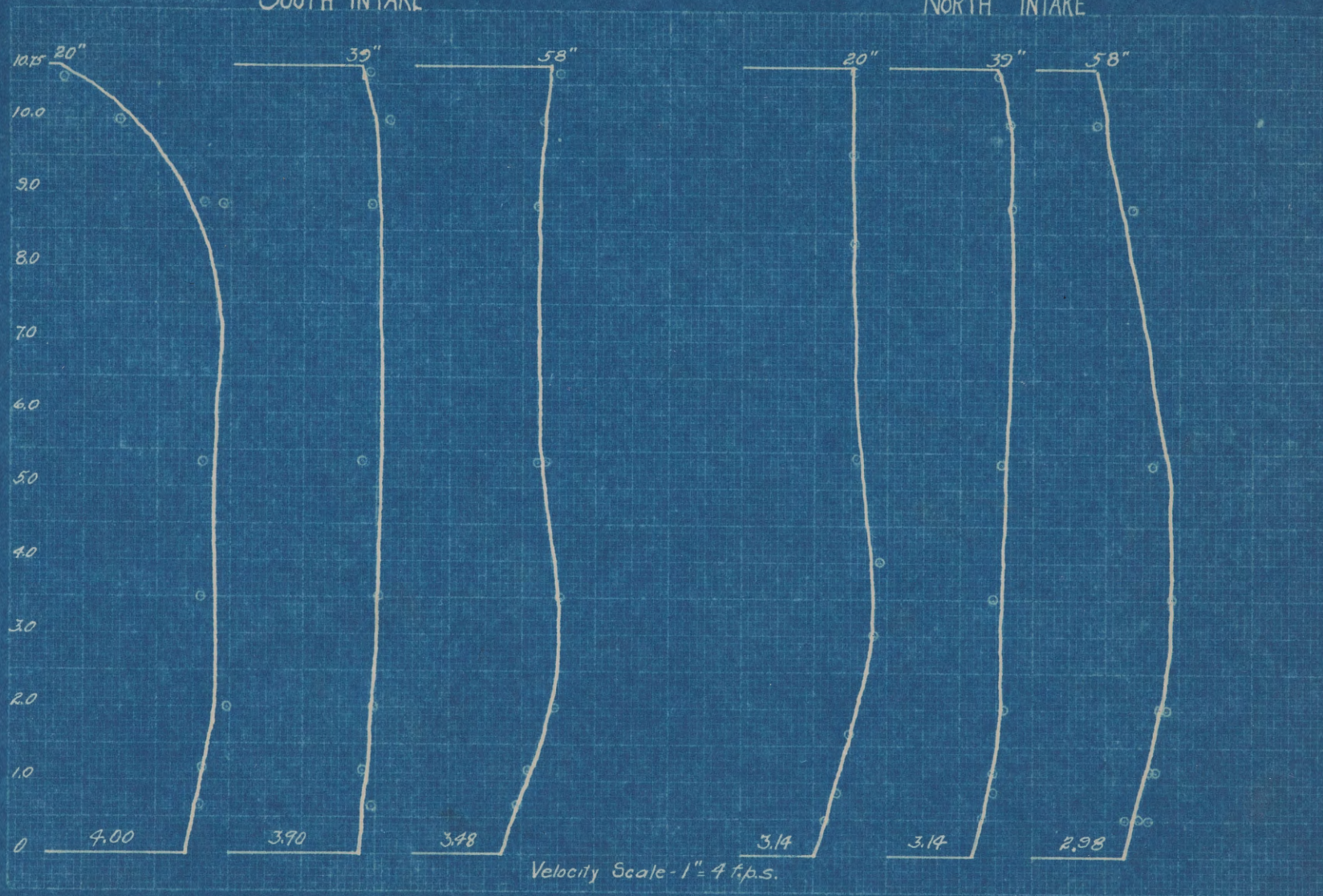


Note: Numbers at top of curves denote distance of vertical from south wall of intake. Numbers at bottom of curves indicate mean velocity in the vertical.

VERTICAL VELOCITY CURVES AT $\frac{5}{8}$ GATE.

SOUTH INTAKE

NORTH INTAKE



meter were drawn to a larger scale and the velocity as obtain at the different points in the intake taken from them. The The vertical velocity curves were then plotted and the mean velocity obtained by a planimeter.

After obtaining the mean velocity in the vertical, the mean velocity for the section included between the two verticals was taken as the average of the two values. The velocity along the walls was secured by plotting the velocities obtained in each vertical on the same level, as horizontal velocity curves. The values from these curves, when extended to the walls, were taken as the velocities at those points. They were then plotted as vertical velocity curves and the mean value of the velocity along the walls obtained from them. This velocity was found to be about .2 of a foot per second less than the mean velocity along the 20" vertical. As the areas between the verticals were nearly equal, the mean velocity for the intake was taken as the average of the velocities in these sections. The mean velocity coefficient for the section was then obtained, it being as stated above

the ratio of the mean velocity to the center velocity.

The value of the ratio as obtained by the traverse in the south intake at $\frac{1}{4}$ gate is 8% less than the ratio as obtained in the same intake at $\frac{5}{8}$ gate. In the north intake the ratio is 5% more at $\frac{1}{4}$ gate than at $\frac{5}{8}$ gate. (See sketch accompanying). At first glance it would appear that this result disproves the assumption that the ratio is a constant for a given section regardless of the velocity but on consideration of the conditions under which the traverse was made at $\frac{5}{8}$ gate, it will be seen that there is reasonable room for still holding the assumption to be true.

It will be noticed that the vertical velocity curves obtained with the gate $\frac{1}{4}$ open are much more regular than those obtained with the gate $\frac{5}{8}$ open. There are several apparent reasons for this. First, the load was more nearly constant when the traverse was made at $\frac{1}{4}$ gate than when the gate was $\frac{5}{8}$ open. The influence ^{of} ~~in~~ the variation in load on the velocity at the intake can be observed by refering to the graphic meter record. At 3:20 P.M. the output was 3300

SOUTH INTAKE.

1/4 GATE

	20"	19"	19"	14"	6"
10.75'	Area - 17.91	17.03	17.03	12.54	5.37
	Av. Vel. - 1.34	1.47	1.45	1.34	1.17
	Disch. - 23.99	25.03	24.69	16.80	6.29
	Total Disch. - 96.8				
	Ratio M.V.:C.V. - .942				

NORTH INTAKE.

1/4 GATE

	20"	19"	19"	20"
	Area - 17.91	17.03	17.03	17.91
	Av. Vel. - 1.17	1.29	1.34	1.28
	Disch. - 20.98	21.96	22.80	21.80
	Total Disch. - 87.54			
	Ratio M.V.:C.V. - 1.016			

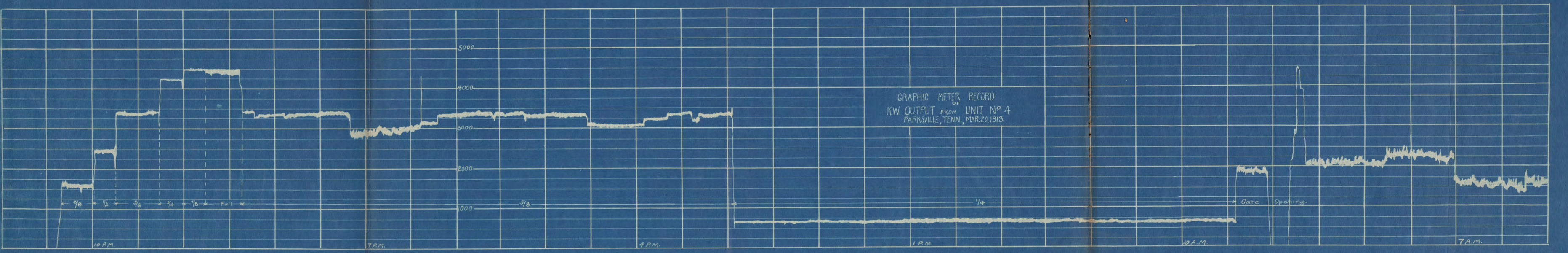
5/8 GATE.

Area - 17.91	17.03	17.03	17.91
Av. Vel. - 3.90	3.95	3.69	3.38
Disch. - 69.90	67.27	62.50	60.05
Total Disch. - 259.72			
Ratio M.V.:C.V. 1.020			

5/8 GATE.

Area - 17.91	17.03	17.03	17.91
Av. Vel. - 3.04	3.14	3.06	2.88
Disch. - 54.50	53.43	52.15	51.65
Total Disch. - 211.73			
Ratio M.V.:C.V. - .968			

DISCHARGE AT 1/4 AND 5/8 GATE
AND
MEAN VELOCITY COEFFICIENT.



K.W. At 3:25 P.M. the velocity at a point along the 58" vertical, 42" from the bottom of the intake, was 3.9 feet per second. At 4:00 P.M. the output had dropped to 3050 K.W., a change of 8%. At about the same time, the velocity was measured along the same vertical at a point 14" from the bottom and was found to be 3.1 feet per second, a change of 20%. This is partly due to the different location of the points but the chief cause was the change in load for the velocity was measured along the same vertical at the 14" point at 3:08 P.M. when the load was 3300 K.W. and was 3.4 feet per second, a difference between the velocity at the 42" point of only 12%, making a difference due to the change in load of 8%.

The traverse at $\frac{5}{8}$ gate was also probably affected by the swirls caused by the walls of the intake being irregular.

The grooves in which the head gate travels and the bottom block against which it sets cause eddies that influence the revolutions of the current meter. These irregularities doubtless cause disturbances at all gate openings but the

effect of such would not seriously interfere^e with the accuracy of the current meter except at comparatively high velocities.

While this traverse was being made some trouble was experienced with the meter in the south intake. Several times the contact spring failed to record the revolutions.

Although it seems very improbable that any error have been introduced by such a failure of the meter, still the readings obtained just before the spring gave away, are subject to suspicion. The meter was finally adjusted so that it worked properly when the later measurements were made.

For these reasons it is believed that the variation in the mean velocity coefficient as obtained at $\frac{5}{8}$ gate opening is due to the fact that the traverse did not give the value of the mean velocity in the section within the probable limit of error of the test. It seems very probable that the swirls at $\frac{1}{4}$ gate when the velocity was only about 30% of the velocity at $\frac{5}{8}$ gate were not sufficient to impair the accuracy^a of the current meter readings and as the load was practically constant when this traverse was being made, the value of the

coefficient as obtained at $\frac{1}{4}$ gate is used in the calculations

It will be noticed that the velocity in the north intake is less at all gate openings than that in the south intake. This difference could be caused by a reduction in area of the north intake by trash being caught on the intake rack. Or if the trash rack were clear, the difference could be accounted for by the head gate being lower in the north intake than in the south. There might also be a difference in the smoothness of the two intakes that would affect the velocity to some extent. It was not possible to examine the intakes and the possibility of there being trash on the intake racks was overlooked.

CALCULATION OF THEORETICAL HORSE POWER AND EFFICIENCY

At all gate openings except $\frac{1}{4}$ and $\frac{5}{8}$ the center velocity only was obtained in the two intakes. From this the mean velocity for the section was obtained by the mean velocity coefficient as found by the $\frac{1}{4}$ gate traverse. Knowing the area of each intake to be 69.9 square feet, the total discharge in cubic feet per second was found. The theoretical horse power is

CALCULATION OF THEORETICAL HORSE-POWER AND EFFICIENCY.

PARKSVILLE, TENN.

MAR. 20, 1913.

GATE	CENTER VELOCITY.		MEAN VELOCITY.		DISCHARGE.		TOTAL DISCHARGE.	QH.	THEO. H.P. $\left[\frac{QH}{8.8}\right]$	KW. OUTPUT.	H.P. OUTPUT.	EFF.
	SOUTH INTAKE.	NORTH INTAKE.	SOUTH INTAKE.	NORTH INTAKE.	SOUTH INTAKE.	NORTH INTAKE.						
1/4	1.48	1.23	1.39	1.25	96.8	87.5	184.4	20100	2284	722	967	42.3
3/8	2.12	1.80	2.00	1.83	139.8	127.8	267.6	29190	3308	1650	2214	67.0
1/2	2.85	2.44	2.68	2.48	187.5	173.3	360.8	39380	4475	2490	3338	74.4
5/8	3.65	3.13	3.44	3.19	240.5	223.0	463.5	50600	5750	3345	4480	78.0
3/4	4.32	3.84	4.06	3.91	284.0	273.0	557.0	60750	6910	4232	5675	82.2
7/8	4.70	4.22	4.43	4.29	310.0	300.0	610.0	66500	7560	4466	5990	79.3
FULL.	5.12	4.55	4.82	4.63	336.5	324.0	660.5	72000	8185	4440	5950	72.7

MEAN VELOCITY COEFFICIENT - SOUTH INTAKE - .945

" " " " - NORTH " - 1.016

AREA OF EACH INTAKE - 69.875 sq'

HEAD - 109.0'

horse power is

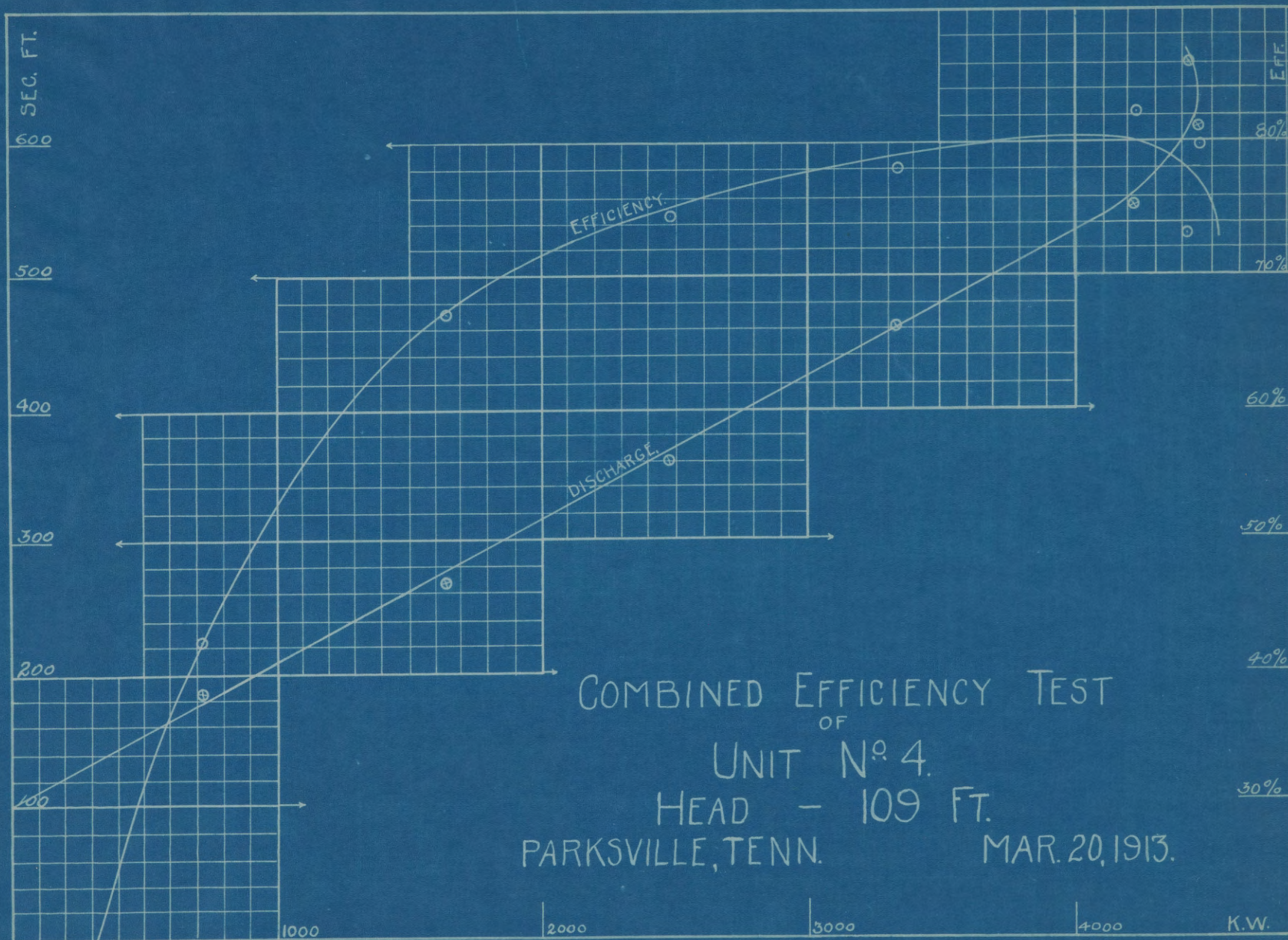
$$\text{T.H.P.} = \frac{QH}{8.8}$$

where "H" is the total head on the plant or the difference between head water and tail water. This head staid practically constant at 109 feet during the test. It was determined by gages in the pool and in the tail race. The output was measured at the switch board and the combined efficiency of the unit was calculated as shown on accompanying sheet.

CONCLUSION.

It was found that the unit operates at the highest efficiency, at the head under which the test was made, at $\frac{3}{4}$ gate opening. The efficiency is well sustained between $\frac{1}{2}$ gate and $\frac{3}{4}$ gate but drops off after $\frac{3}{4}$ gate is passed and more rapidly beyond $\frac{7}{8}$ gate. The output of the unit is less at full gate than it is at $\frac{7}{8}$ gate, which accounts for the rapid dropping off of efficiency beyond $\frac{7}{8}$ gate.

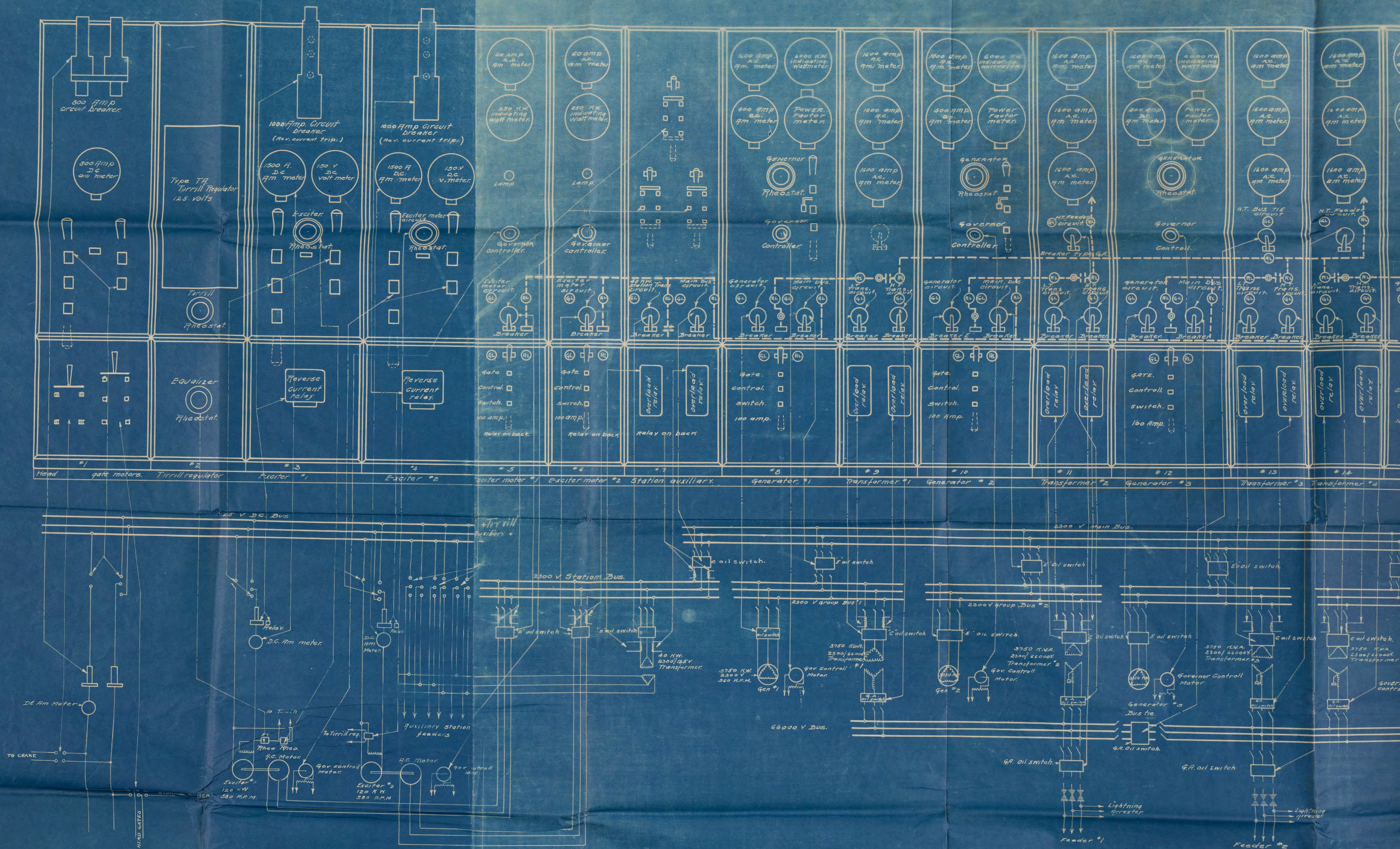
The discharge is directly proportional to the gate opening until $\frac{3}{4}$ gate is reached. After that it increases only a small amount; the discharge at $\frac{3}{4}$ gate being only 15% less



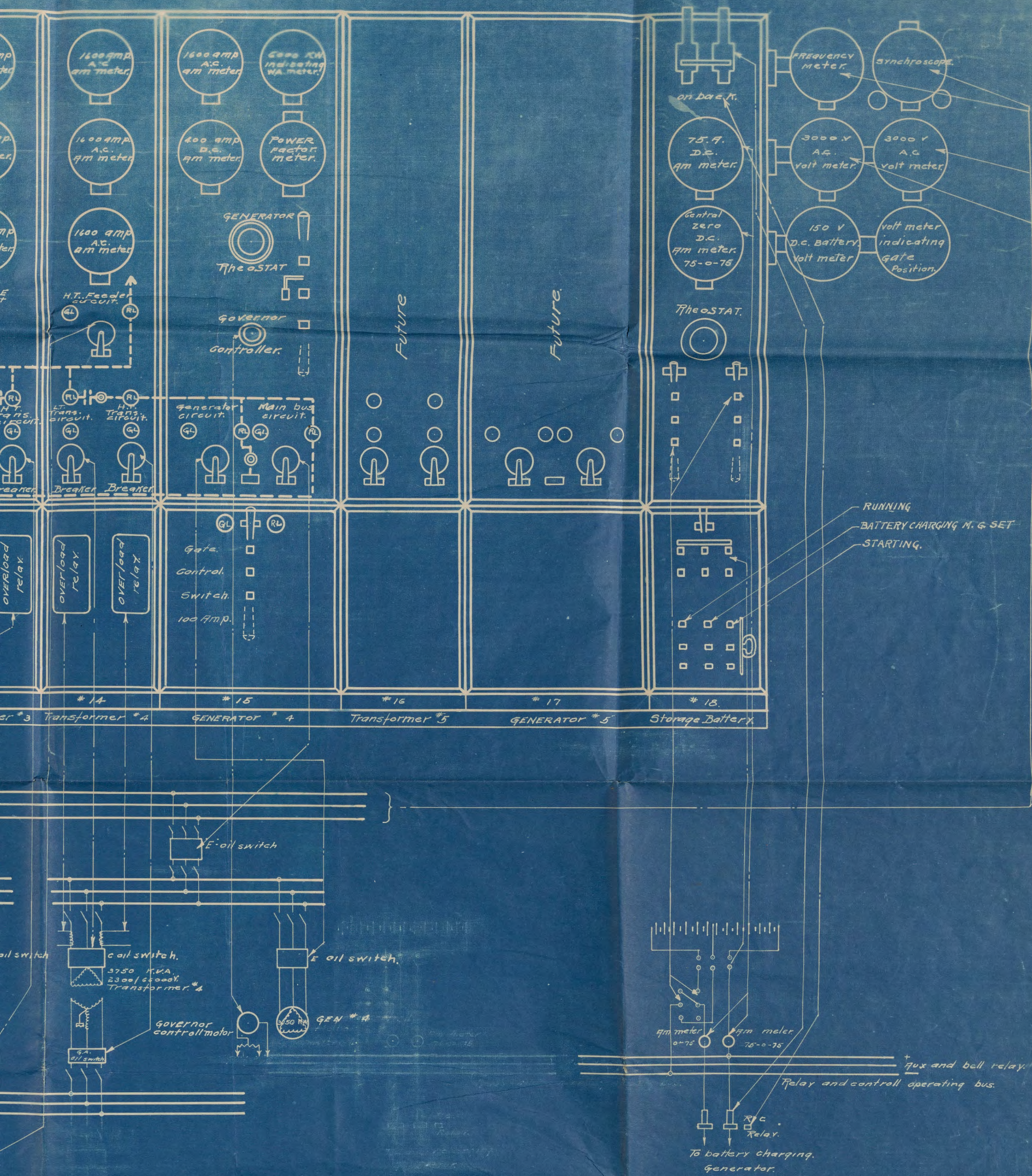
than the discharge at full gate.

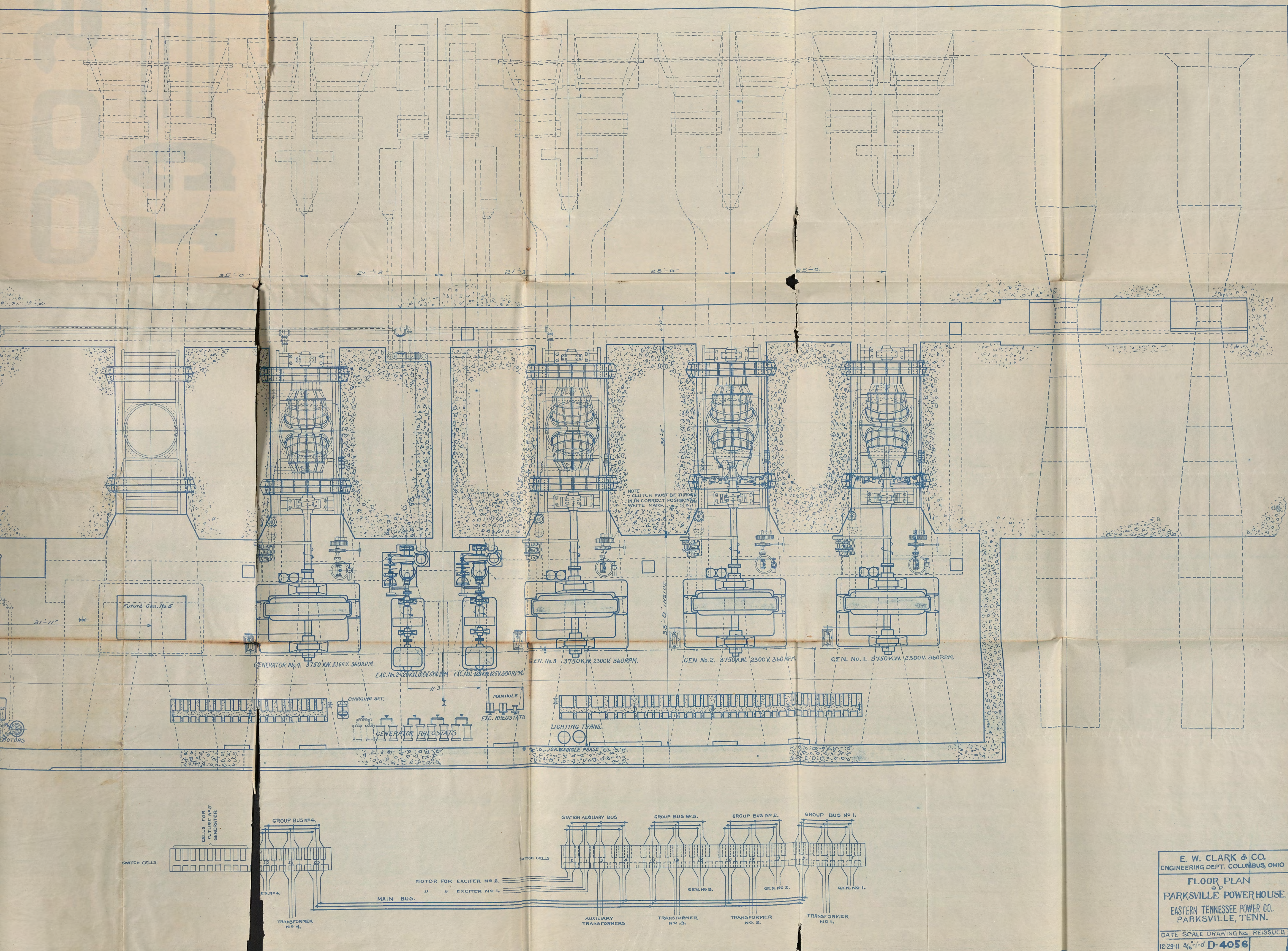
It will be noticed from the discharge - output curve that the unit takes 100 second feet at no load. This point was not definitely located by the test but the probable curve at this point seems to indicate that this quantity of water is necessary to run the unit at no load.

The most probable cause of error in the test is found in the assumption that the mean velocity coefficient was constant for different velocities. The results did not verify the assumption. However the variation in the value of the ratio was not serious enough to vitiate the assumption but rather justifies the discarding of the value as found by the $\frac{5}{8}$ gate traverse. This conclusion was reached after considering the conditions which gave rise to errors in measuring the mean velocity at that gate opening and which were not present when the traverse was made at $\frac{1}{4}$ gate opening. It is believed that the error introduced by the assumption of a constant mean velocity ratio is less than would have resulted from measuring the discharge by any other method under the conditions of the test



NOTE:
 6400 KW
 400 KW
 40 KW
 6000 KW
 500-0
 MAIN
 No Volt





E. W. CLARK & CO.
 ENGINEERING DEPT. COLUMBUS, OHIO
FLOOR PLAN
PARKVILLE POWERHOUSE.
 EASTERN TENNESSEE POWER CO.
 PARKVILLE, TENN.
 DATE 12-29-11 SCALE 3/16"=1'-0" DRAWING No. D-4056 REISSUED.

