

AN ACCEPTANCE TEST OF A HYDRAULIC TURBINE

A THESIS

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SAMUEL EDWARD MYRICK

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INTRODUCTION

The primary purpose of this thesis, as here written, was to make an acceptance test upon a horizontal singled discharge spiral casing five hundred and twenty-five horse power reaction turbine. This turbine was furnished to the City of Cookeville for public utility purposes in connection with the electric lighting of that city by the Wellman-Seaver-Morgan Co. of Cleveland Ohio.

This thesis was written for the purpose of producing the results of this test in an engineering statement and to furnish information in regard to the possible methods that may be employed in the performance of such a test. It was also intended to reveal some facts regarding the practicability of the brine method for determination of the velocity of flow in closed penstocks.

As there is not available, at the present time, much written material bearing on the subject of the testing of hydraulic turbine units, with complete accompanying data and computations, it is hoped that this presentation will be of some practical value to the prospective tester as a comprehensive reference.

It should be remembered when reading this thesis that the final results as regards the efficiency of the turbine were the basis for the acceptance of the wheel subject to the contract between the Wellman-Seaver-Morgan Co. and the City of Cookeville, which contract specifies a guarantee of certain maximum efficiency.

GENERAL SURVEY OF THE FIELD

On December 2, 1921 a trip was made to Cookeville, Tennessee for the purpose of making a preliminary survey of the field of the test. The plant was found to be located about twelve miles from Cookeville at Burgess Falls on the Falling Water River in White County. The plant at this time was in the process of construction and about sixty percent complete.

In the general layout of this development a wood stave penstock led from a re-enforced concrete dam, following the general course of the river and crossing the stream twice on suspension bridges, to a surge tank located at the brink of the main falls. Between the two suspension bridges the penstock passed through a tunnel cut in solid rock. From the surge tank it led downward, close to the face of a rock cliff, to the power house about 115 below and about 400 down the stream. The total length of the penstock was about 2600 feet and the total static head on the turbine was about 240 feet.

The re-enforced concrete dam was 20 feet high to the crest of the spillway section, which was 100 feet long. The bulk-head section of the dam was about 225 feet in length and was tied into solid rock on each bank and re-enforced with earth fills. Through the dam there was a 6'X10' sluice way fitted with a cast iron sluice gate and hand hoisting apparatus. The penstock intake was of rectangular section 4.0 ft. X 5.0 ft. properly protected by a sloping trash rack made of rectangular bars. This intake led through the dam to a reducing fitting which con-

nected to the wood stave pipe through a 30" hand operated gate valve. At the down-stream end of the gate valve the penstock was fitted with a three inch vent pipe for the release or admission of air in filling and draining the pipe line.

The penstock was 30" inside diameter and made of one and one-half inch Douglas Fir staves banded with one-half inch wrought iron bands spaced according to the head of the section. The supports for the penstock as it followed the river were concrete saddles moulded to fit the contour of the pipe and held down by rods grouted into solid rock. At the two points where the penstock crossed the river it was supported on suspension bridges. Just before entering upon the first and immediately after leaving the second bridge the penstock was fitted with 30" steel ells. Below this latter point the penstock entered the surge tank and from there dropped to the power house below at a sharp angle with the horizontal.

The suspension bridges were made of two inch stranded steel cables supported by concrete pillars and grouted anchors and in one instance, by a steel tower. To the cables were fastened adjustable suspender rods supporting horizontal members which formed a cradle upon which the penstock was carried. In expanding and contracting the cables were allowed to move on rollers supported on top of the tower.

The surge tank was six feet in diameter and made of 5/16 inch boiler plating erected in sections to a height

of 120 feet. The top of the tank rose about ten feet above the level of the crest of the spillway section of the dam. The tank was supported on a concrete foundation bedded in solid rock and was anchored by four e inch anchor bolts. Passage into the tank at the base was permitted by a man hole and a steel ladder led to the top.

The house for the power plant was a steel structure 18 ft by 20 ft. located about 400 feet down stream from the main falls. This falls was the last of a series of three falls which lay between the site of the dam and the power house.

The power installation consisted of a 525 H. P. horizontal reaction turbine direct connected to a 450 KVA alternator and exciter. The governor, pressure regulator, and oil pump were arranged in the house as shown by Plate No. 14.

STATEMENT OF PURPOSE

The purpose of this thesis was to secure complete information concerning the performance of the turbine as to efficiency, under various loads and gate openings, when running at rated speed and operating under specified head. As a secondary consideration, an attempt was made to secure some facts regarding the process of velocity determination by the brine method and to establish some relation between the velocities as thus obtained and the actual velocity of flow in closed penstocks. It is intended that this thesis will be of sufficient value to merit reference

as a practical work on the subject of the testing of small hydro-electric units and that it will, in some measure, portray the results that are probable when using the salt brine method in connection with velocity determination.

GENERAL THEORY

In order to arrive at the determination of the turbine efficiency it was necessary to collect data indicating the power input and output under the various conditions of operation as regards loading. In computing the applied power in connection with a water power investigation there are two fundamental determinations that must be accurately made. First, the total head on the plant must be determined. This total head includes the pressure head, the head due to velocity in the penstock, and the draft head or the head recovered by the use of a draft tube or regainer. Then, the quantity of water required by the turbine at various stages of operation must be determined from the product of the cross-sectional area of the penstock and the mean velocity of flow. From the results of these two determinations the power applied to the turbine can be determined from the relation,

$$H. P. = q H / 8.8.$$

The total head on the turbine is obtained by taking the sum of the component heads just mentioned. In the first place, the pressure head is measured by means of a pressure gage attached to the scroll case of the turbine.

It is more convenient if this gage can be attached on a level with the center of the turbine runner as this relieves the necessity of using a constant to transfer the readings of this datum. The draft head is measured by a scale which shows the difference in elevation between the level of the tail water and the turbine center. The velocity head being a function of the mean velocity of flow in the conduit, may be added only after the proper velocity determinations have been made.

In the determination of the discharge of the turbine there are various methods by which the mean velocity of flow may be ascertained, the local conditions of the test determining the feasibility of any one of the methods. The A. S. M. E. Testing Code recommends the following methods as practical in connection with this type of test:

1. Measurement by means of standard weir.
2. " " " " current meter.
3. " " " " pitometer.
4. " " " " chemical titration method.

There are several methods which are not mentioned in the above, all of which are practical and lead to accurate results provided they are used only where they applicable to the particular conditions of the test. Among these may be mentioned:

1. The volumetric method.
2. Venturimeters.
3. The salt solution method.
4. The brine velocity method.
5. The color density method.

The two methods decided upon were the brine velocity method and the pitometer method, the latter of which is probably the most accurate method applicable to this installation.

The pitometer is an improved or modified pitot tube, the theory of which is explained by the fundamental relation expressed by $V^2 = 2gh$. In the arrangement of the pitometer there are two pitot tubes on a common stem extending through a gland into the penstock or pipe. This gland is attached to the penstock by means of a corporation cock and the point of one tube is pointed directly up the stream of flow while the other is in the exact opposite direction or pointing down stream. The former is then subject to the action of both the pressure head and velocity head while the latter is acted upon by the difference between these two heads. When both of these tubes are connected to a differential gage the deflection indicates twice the velocity head. The scale, however, is so graduated that the velocity head may be read in inches of the indicator. The actual velocity is then computed from this deflection, the specific gravity of the indicator used and the pitometer constant, which is a figure determined from actual calibration of the particular instrument.

The determination of velocity by the salt brine method depends upon the fact that a quantity of salt brine, when injected into a penstock, moves forward with the velocity of the water and increases it's conductivity. The velocity of the water may be ascertained by determining the rate at which the salt brine solution moves and this may be done by observing

the passage of the solution through a section of the penstock and noting the time required. The rate of movement of the brine, computed from the time required for the passage and the length of the section, is an indication of the velocity of the water. The arrival of the brine solution at a section of the penstock may be detected by an arrangement wherein it becomes a part of an electrical circuit upon it's arrival at this section. If a galvanometer is connected in series with a battery and a pair of electrodes arranged in the penstock as shown in Plate No. 2, there will be only a small deflection of the instrument because of the high resistance of the water in the space between the two electrodes. Upon the arrival of a charge of the brine at a section marked by a pair of these electrodes, the conductivity of the water in the space between the electrodes is immediately increased allowing an increase in the current of the battery circuit. This, in turn, causes a sudden increase of the galvanometer deflection which signals the arrival of the charge. The time required for the passage of a charge of the brine solution from one section of the penstock to another may be ascertained by noting the lapse of time between deflections of galvanometers located at the respective sections. From the length of the penstock between the two sections and the time noted between galvanometer deflections, the rate of travel of the brine charge and the velocity of the water may be computed.

DESCRIPTION OF THE METHOD AND APPARATUS.

The power delivered by the turbine was determined from the output of the alternator used as an electrical dynamometer. Due consideration was taken of the power delivered to the exciter and of the efficiency of the alternator. See Plates 8 and 9. - The efficiencies used in the thesis are those certified by the General Electric Co. The figures for excitation were also furnished by this company. The power output of the alternator was absorbed by a water rheostat, built by us in the stream adjacent to the power house. The water rheostat was made up of three electrodes of corrugated metal roofing suspended from a triangular support and the load on the alternator was regulated by varying the depth to which these electrodes were lowered in the water. Each electrode was about four feet long and exposed about twelve square feet of area to the water. The support was made in the form of an equilateral triangle with sides eighteen inches in length and an electrode was suspended at each vertex. It was found that a rheostat of these dimensions would absorb only about two hundred and fifty kilowatts, and for higher loads two rheostats were used in parallel.

The current from the alternator was taken through the switch board to the test instruments. The voltage was stepped down by potential transformers in a twenty to one ratio. The current was also reduced by current transformers in the same ratio. Wattmeters were provided measuring the

output in watts, the connection known as the "two wattmeter method" being employed. Voltmeters and ammeters were used for the purpose of checking the power observations. A multiple board was provided and the instruments so connected as to give duplicate readings of the power, voltage, and current in each phase. In compliance with the A. S. M. E. Code for testing hydraulic turbines all instruments were calibrated both before and after the test in the electrical laboratory of the University of Tennessee. See Plates 4, 5, and 6. The speed of the turbine was held constant at the rating of nine hundred revolutions per minute throughout the entire test. The speed was checked by both tachometer and revolution counter.

The power applied to the turbine was computed from the total head applied and the quantity of water discharged. Previous to running the actual test a preliminary test was run wherein both pitometer and salt brine apparatus were used to determine the velocity of flow. From the data of this test a curve was plotted showing the relationship between the velocities as determined by the two methods.

The brine measurement apparatus was installed in a straight section of the penstock. The brine solution was injected into the penstock by the use of a high pressure grease gun at a point about a hundred feet above the upper set of electrodes. The electrodes were made of No. 6 hard drawn brass wire inserted diametrically into the penstock about six inches apart in a plane perpendicular to the direction of the flow. This set of electrodes was connected in series with a dry cell battery and a millivoltmeter, the

circuit being completed through the water in the space between the two electrodes as previously explained. At a section three hundred feet further down stream there was installed another such set of electrodes connected with a battery and galvanometer as the first. The two galvanometers were placed side by side and near the point of injection of the brine solution, making it possible for one observer to watch both and, at the same time, to supervise the injection. In order to make a velocity determination a charge of concentrated salt solution was injected and the time lapsing between the deflections of the two galvanometers noted as the time required for the passage of the brine through the intervening three hundred foot section. From this time observation the velocity of flow was computed in feet per second. This, however, was not the actual mean velocity of flow in the penstock as has been shown by the relationship between the velocity determined by the brine method and the actual velocity, illustrated by the brine calibration curve on Plate No. 3. In order to obtain data for the construction of this brine calibration curve simultaneous determinations of the velocity of flow in the penstock were made by both the brine velocity method and the pitometer. The pitometer observations were corrected to actual mean velocity of flow in feet per second and the calibration curve was plotted between these values as ordinates and the corresponding velocity determinations by the brine method as abscissa. The actual mean velocity corresponding to any velocity determination by the brine method was taken from this curve as the

ordinate of a point the abscissa of which was the velocity as determined by the brine method. In this manner the velocities as obtained by the brine method were corrected to the actual mean velocities of flow. Communication between the brine station and the power house was effected by means of field signal device.

The actual inside diameter of the penstock was determined the mean of a number of circumferential measurements of different points and the actual dimensions of the wood staves. From this was determined the mean cross-sectional area of the penstock. The discharge of the turbine was computed from the product of this cross-sectional area and the mean velocity of flow as determined from the salt brine time observations and corrected by the salt brine calibration curve.

In the determinations for the total head, the pressure head was measured by means of a standard test gage attached to the turbine casing with it's center three tenths of a foot below the center of the runner. This gage was calibrated both before and after the test and the mean calibration curve plotted. See Plate No. 7. In arriving, then, at the actual pressure head on the turbine the gage readings were corrected to standard by the use of this curve and proper allowance was made for the displacement of the gage from the center of the turbine runner. The draft head was measured by an arrangement of a float and a scale to indicate the distance between the center of the turbine runner and the level of the water in the tail race. The velocity head at the gage section was computed from the mean velocity of flow in the pen-

stock.

The total applied power was computed from the total head and the discharge of the turbine. The net applied power was computed from the total by deducting the power lost in the tail race. The power lost in the tail race was computed from the discharge and the velocity head at exit from the draft tube.

The efficiency of the turbine was computed from the ratio of the power delivered to the alternator to the net applied power. At each load on the turbine about ten observations were made and all computations were based on the mean of these readings. Before starting each series of readings the turbine was run at the proper load long enough to allow conditions to become adjusted.

IDENTIFICATION AND RATING OF UNIT

THE TURBINE

One 525 horse power single horizontal hydraulic turbine with cast iron spiral casing, to operate at 900 RPM under 200 ft. head, including a 2500 ft. lb. type LR Woodward governor and accessories, Steel draft tube, and pressure regulator.

THE GOVERNOR

One Woodward Water Wheel Governor No. 4683;

Type -- LR

Ft. lbs. 2500

Size -- 5X9

THE ALTERNATOR

One General Electric Three Phase Alternator No. 3748458.

Type-----ATB, 8-450 M-900

Form-----S

Amperes-----113

Speed-----900

KW-----360, PF 0.8

Cycles-----60

Volts-----2300

450 KVA continuous -- Stator 50 deg. C. rise

Rotor 60 " " "

THE EXCITER

One General Electric Direct Current Generator No. 1158003

Type-----MP-6-8.5-900

Form-----B

IDENTIFICATION AND RATING OF UNIT
(Contd)

Amperes-----68

Speed-----900

No load Voltage-----125

Full load Voltage-----125

8.5 KW continuous-----50 deg. C. rise.

IDENTIFICATION OF INSTRUMENTS.

One G. E. wattmeter No. 198719 Type P-3

One Thomson Indicating wattmeter No. 43104

One Thomson A. C. ammeter No. 42221 Type P.

One Weston A. C. ammeter No. 17396 Mod. 155

One Thomson A. C. voltmeter No. 145086 Type P.

One Weston A. C. voltmeter No. 6202 Mod. 155.

One G. E. current transformer No. 668365 Type S - Form P.

One G. E. current transformer No. 651259 Type S - Form P.

One G. E. potential transformer No. 231421 Type H - Form A.

One G. E. potential transformer No. 177183 Type H - Form PA.

All electrical instruments supplied from the electrical
engineering laboratory of the University of Tennessee.

The Bourdon Standard Test Gage of Hydraulic Laboratory.

One Veeder revolution counter No. _____

One U. S. Air Service tachometer No. _____

One Weston millivoltmeter No. _____

One Weston millivoltmeter No. _____

TABLE No. 1.

PITOMETER TRAVERSE DATA.

LEGEND

Column A -- Distance from bottom of penstock in inches.

" B -- Deflection on left scale of "U"tube.

" C -- Deflection on right scale of "U"tube.

" D -- Mean deflection in inches.

" E -- Mean deflection in feet.

" F -- Velocity in feet per second.

Pitometer constant - 0.84

Specific gravity of indicator - 1.245

A	B	C	D	E	F
0.00	3.50	3.50	3.50	0.291	1.80
0.50	4.75	5.00	4.87	0.406	2.12
1.00	5.25	5.25	5.25	0.438	2.20
2.00	7.00	6.75	6.87	0.573	2.52
4.00	7.25	7.50	7.37	0.615	2.61
6.00	7.75	8.00	7.87	0.656	2.70
8.00	9.25	8.75	9.00	0.750	2.89
10.00	9.50	9.25	9.37	0.780	2.95
12.00	10.00	10.00	10.00	0.833	3.04
15.00	10.75	10.50	10.62	0.885	3.14
18.00	10.50	10.25	10.37	0.865	3.10
20.00	10.00	9.75	9.87	0.823	3.03
22.00	9.62	9.50	9.56	0.797	2.98
24.00	8.75	8.75	8.75	0.730	2.85

TABLE No.1 (contd.)

A	B	C	D	E	F
26.00	7.75	7.87	7.81	0.651	2.69
28.00	6.25	6.50	6.37	0.531	2.43
29.00	5.00	5.00	5.00	0.416	2.15
29.69	2.50	2.50	2.50	0.208	1.52

TABLE No.2.

PIPE COEFFICIENT DATA.

LEGEND

Column A -- Annulus as shown by Plate No. 1.

" B -- Inside diameter of annulus.

" C -- Area corresponding to diameter in column B.

" D -- Area of annulus in square inches.

" E -- Area of annulus in square feet.

" F -- Mean velocity from vertical velocity curve.

" G -- Discharge in cubic feet per second.

A	B	C	D	E	F	G
-	30.2	716.31	---	---	--	---
H	28.2	624.58	91.73	0.637	1.87	1.191
G	26.2	539.13	85.45	0.593	2.27	1.346
F	24.0	452.39	86.74	0.602	2.47	1.489
E	21.3	356.33	96.06	0.667	2.62	1.749
D	18.5	268.80	87.53	0.608	2.74	1.666
C	15.1	179.08	89.72	0.623	2.84	1.770

TABLE No. 2 (contd.)

A	B	C	D	E	F	G
B	10.6	88.25	90.83	0.631	2.96	1.870
A	---	----	88.25	0.613	3.08	1.888

Total cross-sectional area of penstock as obtained by addition of areas of annulae -- 4.98 sq. ft. Total discharge as obtained by addition of discharges of annulae -- 12.969 cubic feet per second. Mean velocity = $Q/A = 12.969/4.98 = 2.60$ feet per second. Velocity at center of penstock as obtained from the pitometer traverse -- 3.14 ft. per second. Pipe coefficient = $2.60/3.14 = 0.828$

TABLE No. 3

DATA FOR DETERMINATION OF VELOCITY BY BRINE METHOD.
(PRELIMINARY TEST)

LEGEND

Column A -- Turbine gate opening.

" B -- Time of observation.

" C -- Time between instrument deflections in seconds.

" D -- Velocity in feet per second.

Distance between electrodes -- 300 feet of straight section. Electrodes made of No. 6 hard-drawn brass wire arranged as shown in Plate No.2.

A	B	C	D
0.20	11:09	170	1.76
0.20	11:14	171	1.75
0.20	11:15	169	1.77

TABLE No. 3 (contd.)

A	B	C	D
0.20	11:16	170	1.76
	Mean velocity --		1.76
0.30	11:20	130	2.31
"	11:23	127	2.36
"	11:27	124	2.42
	Mean velocity --		2.36
0.40	2:40	97	3.09
"	2:41	98	3.06
"	2:42	96	3.12
"	2:45	94	3.19
"	2:46	93	3.23
"	2:47	95	3.16
	Mean velocity --		3.14
0.50	2:19	78	3.85
"	2:24	84	3.57
"	2:25	83	3.62
"	2:29	79	3.80
	Mean velocity --		3.71
0.60	4:36	66	4.55
"	4:38	65	4.62
"	4:40	66	4.55
"	4:42	66	4.55
"	4:43	65	4.62

TABLE No. 3 (contd.)

A	B	C	D
0.60	4:44	65	4.62
"	4:45	65	4.62
"	4:46	65	4.62
	Mean velocity	---	4.59
0.70	8:03	60	5.00
"	8:04	60	5.00
"	8:05	58	5.17
"	8:07	58	5.17
"	8:08	59	5.09
"	8:10	59	5.09
"	8:11	60	5.00
"	8:13	59	5.09
"	8:14	58	5.17
; "	8:15	59	5.09
"	8:17	60	5.00
	Mean velocity	---	5.08
0.80	8:26	56	5.36
"	8:27	54	5.55
"	8:29	55	5.45
"	8:31	53	5.67
"	8:33	54	5.55
"	8:37	54	5.55
"	8:38	53	5.66

TABLE No. 3 (contd.)

A	B	C	D
0.80	8:40	54	5.25
"	8:42	54	5.25
"	Mean velocity --		5.54
0.90	8:49	50	6.00
"	8:50	51	5.90
"	8:51	54	5.55
"	8:52	49	6.13
"	8:54	49	6.13
"	8:56	46	6.53
"	8:58	52	5.77
"	9:00	50	6.00
"	9:02	49	6.13
	Mean velocity --		6.01
1.00	9:45	47	6.39
"	9:47	48	6.26
"	9:49	49	6.13
"	9:50	48	6.26
"	9:51	50	6.00
"	9:52	50	6.00
"	9:54	48	6.26
"	9:56	48	6.26
"	9:57	50	6.00
"	10:00	49	6.13
"	10:01	50	6.00
	Mean velocity --		6.15

TABLE No. 4

DATA FOR DETERMINATION OF VELOCITY BY PITOMETER.
(PRELIMINARY TEST)

LEGEND

Column A -- Turbine gate opening.

" B -- Time of observation.

" C -- Pitometer deflection.

" D -- Velocity in feet per second.

The relation between the two velocities as obtained by the different methods is shown by Brine Calibration Curve , Plate No. 3 .

A	B	C	D
0.20	11:07	3.50	1.49
"	11:08	3.75	1.54
"	11:09	3.50	1.49
"	11:10	3.50	1.49
"	11:11	3.50	1.49
"	11:12	3.75	1.54
"	11:13	3.50	1.49
"	11:14	3.50	1.49
"	11:15	3.50	1.49

Mean velocity -- 1.50

Specific gravity of indicator- 1.255

0.30	11:21	6.00	1.95
"	11:22	7.25	2.14
"	11:23	6.50	2.03
"	11:24	6.75	2.07
"	11:25	6.75	2.07

TABLE No. 4 (contd.)

A	B	C	D
0.30	11:26	6.50	2.03
"	11:27	6.50	2.03
Mean velocity	---		-- 2.04
Specific gravity of indicator			-- 1.255
0.40	2:38	11.50	2.66
"	2:39	11:25	2.63
"	2:40	11.25	2.63
"	2:41	11.25	2.63
"	2:42	11.25	2.63
"	2:43	11.50	2.66
"	2:44	11.50	2.66
"	2:45	11.50	2.66
"	2:46	11.50	2.66
"	2:47	11:50	2.66
"	2:48	11.50	2.66
"	2:49	11.50	2.66
"	2:50	11.50	2.66
Mean velocity	---		--- 2.65
Specific gravity of indicator			--- 1.255
0.50	2:19	18.00	3.34
"	2:20	17.75	3.31
"	2:21	18.00	3.34
"	2:22	18.00	3.34
"	2:23	18.00	3.34

TABLE No. 4 (contd.)

A	B	C	D
0.50	2:24	17.75	3.31
"	2:25	18.00	3.34
"	2:26	18.25	3.36
"	2:27	18.00	3.34
"	2:28	17.75	3.31
"	2:29	18.00	3.34
Mean velocity ---			3.33
Specific gravity of indicator ---			1.255
0.60	4:25	11.75	4.29
"	4:26	11.75	4.29
"	4:27	11.75	4.29
"	4:28	11.75	4.29
"	4:29	11:50	4.24
"	4:30	11.75	4.29
"	4:31	12.00	4.33
"	4:32	11.75	4.29
"	4:33	11.75	4.29
"	4:34	11.75	4.29
"	4:35	11.75	4.29
"	4:36	11.75	4.29
"	4:37	11.75	4.29
"	4:38	11.75	4.29
Mean velocity ---			4.30
Specific gravity of indicator ---			1.600

TABLE No. 4 (contd.)

A	B	C	D
0.70	8:02	14.00	4.67
"	8:03	14.00	4.67
"	8:04	14.00	4.67
"	8:05	14.00	4.67
"	8:06	14.00	4.67
"	8:07	13.50	4.58
"	8:08	13.25	4.55
"	8:09	13.50	4.58
"	8:10	13.50	4.58
"	8:11	13.25	4.55
"	8:12	13.25	4.55
"	8:13	13.25	4.55
"	8:14	13.25	4.55
"	8:15	13.25	4.55
"	8:16	13.25	4.55
"	8:17	13.50	4.58
"	8:18	13.50	4.58
Mean velocity ---			4.60
Specific gravity of indicator ---			1.600
0.80	8:25	16.00	5.00
"	8:26	16.00	5.00
"	8:27	15.75	4.97
"	8:28	15.50	4.94
"	8:29	15.50	4.94

TABLE No. 4 (contd.)

A	B	C	D
0.80	8:30	15.50	4.94
"	8:31	15.25	4.90
"	8:32	15.00	4.85
"	8:33	15.25	4.90
"	8:34	15.25	4.90
"	8:35	15.50	4.94
"	8:36	15.50	4.94
"	8:37	15.25	4.90
"	8:38	15.00	4.85
"	8:39	15.00	4.85
"	8:40	15.25	4.90
"	8:41	15.25	4.90
"	8:42	15.25	4.90
Mean velocity ---			4.91
Specific gravity of indicator ---			1.600
0.90	8:48	17.75	5.29
"	8:49	18.00	5.31
"	8:50	17.75	5.29
"	8:51	18.00	5.31
"	8:52	18.00	5.31
"	8:53	18.00	5.31
"	8:54	18.00	5.31
"	8:55	18.00	5.31
"	8:56	18.00	5.31
"	8:57	18.00	5.31
"	8:58	18.00	5.31

TABLE No. 4 (contd.)

A	B	C	D
0.90	8:59	18.00	5.31
"	9:00	18.25	5.35
"	9:01	18.25	5.35
"	9:02	18.25	5.35
Mean velocity ---			--- 5.31
Specific gravity of indicator --			1.600
0.97	9:43	20.00	5.58
"	9:44	20.25	5.61
"	9:45	20.00	5.58
"	9:46	20.25	5.61
"	9:47	20.00	5.58
"	9:48	19.75	5.55
"	9:49	20.00	5.58
"	9:50	20.50	5.65
"	9:51	20.25	5.61
"	9:52	20.00	5.58
"	9:53	20.00	5.58
"	9:54	19.75	5.55
"	9:55	19.75	5.55
"	9:56	20.00	5.58
"	9:57	19.75	5.55
"	9:58	19.75	5.55
"	9:59	19.75	5.55
"	10:00	20.00	5.58
"	10:01	20.00	5.58
Mean velocity ---			-- 5.58

TABLE No. 5.

DATA FOR DETERMINATION OF VELOCITY BY BRINE METHOD.

LEGEND.

Column A -- The turbine gate opening.

" B -- The clock time of observation.

" C -- Time between instrument deflections in sec.

" D -- The velocity in feet per second.

A	B	C	D
0.40	10:33	92	3.26
"	10:34	90	3.34
"	10:36	89	3.39
"	10:37	88	3.41
"	10:39	91	3.30
"	10:40	88	3.41
"	10:41	87	3.45
"	10:42	94	3.19
"	10:45	86	3.49
"	10:46	87	3.45
"	10:49	87	3.45
"	10:50	80	3.76
"	10:56	94	3.19
Mean velocity --			3.39
0.50	11:06	70	4.29
"	11:07	71	4.23

TABLE No. 5 (contd.)

A	B	C	D
0.50	11:09	71	4.23
"	11:11	70	4.29
"	11:13	70	4.29
"	11:15	70	4.29
"	11:17	69	4.35
"	11:19	69	4.35
"	11:23	69	4.35
"	11:25	70	4.29
Mean velocity	---	---	4.29
0.60	11:30	60	5.00
"	11:31	58	5.17
"	11:33	58	5.17
"	11:35	59	5.09
"	11:36	60	5.00
"	11:38	60	5.00
"	11:40	58	5.17
"	11:41	60	5.00
"	11:43	59	5.09
"	11:45	58	5.17
"	11:46	59	5.09
"	11:48	59	5.09
"	11:50	60	5.00
Mean velocity	---	---	5.08

TABLE No. 5 (contd.)

A	B	C	D
0.70	1:51	54	5.56
"	1:52	52	5.76
"	1:54	52	5.76
"	1:57	53	5.66
"	1:58	53	5.66
"	1:59	53	5.66
"	2:00	52	5.76
"	2:02	53	5.66
"	2:03	48	6.25
"	2:05	53	5.66
Mean velocity ---			---5.73
0.80	2:13	47	6.38
"	2:14	49	6.12
"	2:16	49	6.12
"	2:18	47	6.38
"	2:19	49	6.12
"	2:20	48	6.25
"	2:22	49	6.12
"	2:24	48	6.25
"	2:25	47	6.38
"	2:28	49	6.12
"	2:29	49	6.12
Mean velocity ---			--- 6.21

TABLE No. 5 (contd.)

A	B	C	D
0.88	2:45	44	6.82
"	2:47	47	6.39
"	2:48	43	6.98
"	2:50	45	6.67
"	2:52	44	6.82
"	2:53	45	6.67
"	2:55	45	6.67
"	2:56	45	6.67
"	2:59	44	6.82
Mean velocity	---		---6.71
0.97	3:09	44	6.82
"	3:10	46	6.53
"	3:13	44	6.82
"	3:15	43	6.98
"	3:17	42	7.14
"	3:18	43	6.98
Mean velocity	---		---6.87

TABLE No. 6.

CALIBRATION OF INSTRUMENTS.

G.E. Wattmeter No. 198719 - Type - P-3.

LEGEND

Column A -- Reading of voltmeter No. 145086 corrected.

" B -- Reading of standard ammeter.

" C -- Reading of wattmeter under calibration.

" D -- Watts as computed from volts and amperes.

" E -- Error of wattmeter in watts.

A	B	C	D	E
110.3	0.30	35	33	2
110.3	0.40	47	44	3
110.3	0.50	57	55	2
110.3	0.60	66	66	0
110.3	0.94	104	104	0
110.3	1.00	112	110	2
110.3	1.10	123	121	2
110.3	1.17	131	129	2
110.3	1.55	173	171	2
113.8	1.70	194	193	1
114.3	1.90	218	217	1
114.3	2.29	262	262	0
114.0	2.32	262	263	-1
114.4	2.29	261	262	-1
114.3	3.12	357	356	-1
115.3	2.90	332	334	-2

For wattmeter calibration curves see Plate No. 4.

TABLE No. 6 (contd.)

Thomson Indicating Wattmeter No. 43104.

LEGEND

Column A -- Reading of voltmeter No. 145086 corrected.

" B -- Reading of standard ammeter.

" C -- Reading of wattmeter under calibration.

" D -- Watts as computed from volts and amperes.

" E -- Error of wattmeter in watts.

A	B	C	D	E
106.3	0.79	88	84	4
106.1	1.10	122	118	4
107.1	1.17	132	126	6
108.6	1.50	161	163	-2
106.6	1.80	196	192	4
106.2	2.51	266:	267	-1
105.9	4.03	425	426	-1
104.4	4.55	472	475	-3
104.7	4.90	508	513	-5
103.6	5.55	577	575	2
105.6	3.28	346	346	0
106.1	4.16	438	443	-5
105.2	2.66	276	280	-4
105.3	194	205	205	0
105.9	1.50	162	159	3

For wattmeter calibration curve see Plate No. 4.

TABLE No. 6 (contd.)

Thomson Voltmeter No. 145086 -- Type P.

LEGEND

Column A -- Reading of standard voltmeter.

" B -- Average reading of voltmeter 145086.

" C -- Error in volts.

A	B	C	A	B	C
115.5	115.1	-0.4	116.6	116.5	-0.1
116.2	115.9	-0.3	115.0	114.6	-0.4
114.0	113.7	-0.3	113.0	112.7	-0.3
111.9	111.4	-0.5	109.8	109.1	-0.7
106.5	106.2	-0.3	105.9	105.7	-0.2
101.5	101.4	-0.1	102.5	102.2	-0.3
103.5	103.0	-0.5	104.1	103.9	-0.2

For voltmeter calibration curve see Plate No. 5.

A.C Comparison of Voltmeter No. 6202 with Voltmeter No.
145086 Corrected to Standard.

LEGEND

Column A -- Reading of voltmeter No. 145086 corrected.

" B -- Average reading of voltmeter No. 6202.

" C -- Error in watts.

A	B	C	A	B	C
90.3	89.1	-1.2	93.7	93.0	-0.7
95.4	94.5	-0.9	97.1	96.0	-1.1
100.8	99.2	-1.6	102.0	100.5	-1.5
103.4	102.0	-1.4	106.3	105.0	-1.3

TABLE No. 6 (contd.)

A	B	C	A	B	C
107.9	107.0	-0.9	110.3	109.4	-0.9
112.7	112.0	-0.7	114.1	113.2	-0.9

For voltmeter calibration curves see Plate No. 5.

Calibration of Ammeters.

LEGEND

Column A -- Reading of standard ammeter in amperes.

" B -- Reading of ammeter No. 42221.

" C -- Error of ammeter No. 42221.

" D -- Reading of ammeter No. 17396.

" E -- Error of ammeter No. 17396.

A	B	C	D	E
1.83	1.80	-0.03	1.75	-0.08
2.27	2.20	-0.07	2.18	-0.09
2.44	2.44	0.00	2.42	-0.02
2.86	2.87	-0.01	2.86	0.00
3.32	3.31	-0.01	3.30	-0.02
3.42	3.43	0.01	3.41	-0.01
3.60	3.58	-0.02	3.60	0.00
3.90	3.90	0.00	3.92	0.02
4.35	4.32	-0.03	4.35	0.00
4.55	4.53	-0.02	4.55	0.00
4.67	4.67	0.00	4.68	0.01
4.79	4.78	-0.01	4.80	0.01

TABLE No. 6 (contd.)

A	B	C	D	E
4.94	4.90	-0.04	4.93	-0.01
5.04	5.03	-0.01	--	--
5.21	5.21	0.00	--	--
5.61	5.59	-0.02	--	--

For ammeter calibration curves see Plate No. 6.

Calibration of Burbon Standard Test Gage.

LEGEND

Column A -- Weight applied to tester.

" B -- Gage reading decreasing.

" C -- Gage reading increasing.

" D -- Average gage reading.

A	B	C	D
50	50.9	50.7	50.8
70	70.7	70.5	70.6
80	80.9	80.7	80.8
90	90.4	90.0	90.2
100	100.7	100.5	100.6
90	90.3	90.2	90.2
80	80.9	80.8	80.8
70	70.9	70.8	70.8
50	50.8	50.7	50.7

Gage calibrated on the American Dead-weight Tester of the Steam Engineering Laboratory. Plate No.7. Readings - lb.

TABLE No. 7.

POWER OBSERVATIONS.

LEGEND.

Column A -- Time of observation.

" B -- Reading of wattmeter No.198719 in phase two.

" C -- Reading of wattmeter No.43104 in phase two.

" D -- Reading of wattmeter No.198719 in phase one.

" E -- Reading of wattmeter No.43104 in phase one.

Wattmeter readings as shown are corrected to standard.

0.40 GATE.

A	B	C	D	E
10:34	235	229	250	244
10:36	235	230	250	248
10:38	237	232	250	248
10:40	237	231	252	248
10:42	237	231	252	248
10:44	237	231	242	248
10:46	237	231	258	248
10:48	236	231	250	247
10:50	236	231	248	247
10:52	237	231	250	248
10:54	237	232	250	248
Mean --	236	231	251	248

Total average watts -- 484

TABLE No. 7 (contd.)

0.50 GATE.

A	B	C	D	E
11:06	303	293	329	319
11:08	303	294	329	320
11:10	303	293	331	322
11:12	303	292	331	325
11:14	303	293	331	324
11:16	303	292	331	325
11:18	302	293	328	324
11:20	303	292	329	325
11:22	301	292	331	325
11:24	301	292	331	323
11:26	301	292	331	323
Mean --	302	292	330	323

Total average watts -- 624

0.60 GATE.

11:30	370	366	406	402
11:32	370	365	405	397
11:34	374	366	405	399
11:36	374	366	406	398
11:38	374	366	403	399
11:40	373	366	406	402
11:42	372	365	408	402
11:44	372	366	406	402
11:46	372	366	408	402

TABLE No. 7 (contd.)

0.60 GATE (contd.)

A	B	C	D	E
11:48	372	365	407	402
11:50	372	366	408	407
Mean --	372	366	406	401

Total average watts -- 773

0.70 GATE.

1:50	433	423	465	455
1:52	433	423	465	458
1:54	433	424	463	458
1:56	431	426	463	458
1:58	431	424	463	458
2:00	431	423	463	458
2:02	432	423	463	457
2:04	432	423	463	458
2:06	432	423	463	457
Mean --	432	424	463	458

Total average watts -- 889

0.80 GATE.

2:13	473	465	499	494
2:15	475	465	499	493
2:17	476	466	499	492
2:19	475	466	497	491
2:21	475	466	499	493
2:23	475	467	501	493

TABLE No. 7 (contd.)

0.80 GATE (contd.)

A	B	C	D	E
2:25	475	468	499	492
2:27	475	468	499	494
2:29	475	468	500	493
Mean --	475	467	499	493

Total average watts -- 967

0.88 GATE.

2:45	---	500	---	521
2:47	---	501	---	521
2:49	---	502	---	522
2:50	---	500	---	523
2:51	---	534	---	523
2:53	---	532	---	524
2:55	---	504	---	523
2:57	---	504	---	524
2:59	---	501	---	523
3:00	---	501	---	524
Mean --	---	508	---	523

Total average watts -- 1031

0.97 GATE.

3:09	---	514	---	541
3:10	---	515	---	543
3:11	---	514	---	543
3:12	---	516	---	545

TABLE No. 7 (contd.)

0.97 GATE (contd.)

A	B	C	D	E
3:13	---	517	---	541
3:14	---	517	---	542
3:15	---	517	---	542
3:16	---	517	---	542
3:17	---	517	---	543
3:18	---	517	---	543
3:19	---	517	---	543
Mean	---	516	---	543

Total average watts -- 1059

VOLTAGE OBSERVATIONS.

LEGEND.

Column A -- Time of observation.

" B -- Reading of voltmeter No.145086 in phase 2.

" C -- Reading of voltmeter No.6202 in phase 2.

" D -- Reading of voltmeter No.145086 in phase 1.

" E -- Reading of voltmeter No.6202 in phase 1.

Voltmeter readings as shown are corrected to standard.

0.40 GATE.

A	B	C	D	E
10:34	113.3	114.4	112.8	113.9
10:36	113.3	113.8	112.3	113.6
10:38	112.8	113.2	111.8	113.3

TABLE No. 7 (contd.)

0.40 GATE (contd.)

A	B	C	D	E
10:40	112.5	113.3	111.3	112.2
10:42	112.5	113.5	111.1	112.1
10:44	111.7	113.8	111.0	112.2
10:46	111.2	112.6	110.7	112.6
10:48	111.5	112.5	110.7	112.2
10:50	111.5	112.6	110.3	112.2
10:52	111.3	111.8	110.3	111.4
10:54	111.1	111.8	110.1	111.8
Mean --	112.1	113.3	111.1	112.6

Average phase 2 -- 112.7 Average phase -1 -111.9

0.50 GATE.

11:06	111.3	112.2	110.8	111.3
11:08	111.3	112.1	109.6	111.1
11:10	110.5	112.2	109.5	111.1
11:12	110.5	111.8	109.3	111.1
11:14	110.7	111.8	109.1	110.9
11:16	109.8	111.2	109.1	110.9
11:18	109.7	110.9	109.1	109.9
11:20	109.3	110.9	109.1	109.9
11:22	109.6	110.9	108.3	109.7
11:24	109.3	110.7	108.3	109.7
11:26	109.3	110.7	108.3	109.7
Mean --	109.7	111.4	109.1	110.5

Average phase 2-- 110.5 Average phase 1-- 109.8

TABLE No. 7 (contd.)

0.60 GATE.

A	B	C	D	E
11:30	113.8	115.0	112.7	113.8
11:32	114.0	115.0	112.1	113.6
11:34	113.4	114.6	112.1	113.8
11:36	113.3	114.6	111.6	113.3
11:38	113.3	114.5	111.3	113.0
11:40	113.1	114.1	111.1	112.8
11:42	112.7	113.8	111.3	112.8
11:44	112.6	114.0	111.3	112.8
11:46	112.3	113.8	111.3	112.5
11:48	112.3	113.3	111.1	112.3
11:50	112.3	113.5	110.9	112.8
Mean --	113.0	114.2	111.5	113.0

Average phase 2 -- 113.6 Average phase 1 - 112.3

m 0.70 GATE.

1:50	114.3	114.8	111.7	114.3
1:52	113.8	114.8	111.8	113.6
1:54	113.9	114.8	111.8	113.7
1:56	113.5	114.7	111.5	112.8
1:58	113.5	114.7	111.3	113.0
2:00	113.8	114.4	111.7	113.0
2:02	113.2	114.2	111.9	113.0
2:04	113.3	114.5	111.3	112.8

TABLE No. 7 (contd.)

0.70 GATE (contd.)

A	B	C	D	E
2:06	113.6	114.8	111.3	112.8
Mean --	113.6	114.6	111.6	113.2
Average phase 2-- 114.1 Average phase 1 -- 112.4				

0.80 GATE.

2:13	114.4	115.8	111.3	113.3
2:15	114.3	115.3	111.3	113.6
2:17	113.9	115.1	111.3	112.8
2:19	113.9	115.1	111.3	112.8
2:21	113.3	115.1	111.3	112.9
2:23	114.1	115.0	110.8	112.7
2:25	113.9	114.6	111.3	112.1
2:27	113.7	114.8	111.3	112.8
2:29	114.0	114.6	111.3	112.8
Mean --	113.2	115.0	111.3	112.9
Average phase 2-- 114.1 Average phase 1 - 111.6				

0.88 GATE.

2:45	113.5	114.6	110.7	112.2
2:47	113.8	114.8	110.7	112.3
2:49	113.3	114.3	110.8	112.2
2:50	113.5	114.5	110.8	112.3
2:51	113.3	114.8	110.8	112.8
2:53	113.3	114.7	110.5	112.3
2:55	113.3	114.7	110.3	112.0

TABLE No. 7 (contd.)

0.88 GATE (contd.)

A	B	C	D	E
2:57	113.6	113.9	109.8	111.8
2:59	112.9	113.8	109.8	111.8
3:00	112.7	113.8	109.8	111.8
Mean --	113.3	114.4	110.4	112.2

Average phase 2 -- 113.8 Average phase 1 - 111.3

0.97 GATE.

3:09	113.6	114.8	111.1	112.6
3:10	113.6	115.2	111.1	112.9
3:11	114.1	115.2	111.1	113.3
3:12	114.2	115.0	111.1	112.8
3:13	114.3	115.0	111.3	112.9
3:14	114.3	115.0	111.3	112.9
3:15	114.3	114.9	111.3	112.9
3:16	114.3	114.9	111.3	112.9
3:17	114.3	114.9	111.3	112.9
3:18	114.2	114.9	111.3	112.9
3:19	113.9	114.9	111.3	112.9
Mean --	114.1	114.9	111.2	112.9

Average phase 2 - 114.5 Average phase 1 - 111.6

TABLE No. 7 (contd.)

CURRENT OBSERVATIONS.

LEGEND.

Column A -- Time of observation.

" B -- Reading of ammeter No. 42221 in phase two.

" C -- Reading of ammeter No. 17396 in phase two.

" D -- Reading of ammeter No. 42221 in phase one.

" E -- Reading of ammeter No. 17396 in phase one.

0.40 GATE.

A	B	C	D	E
10:34	2.31	2.41	2.45	2.54
10:36	2.30	2.42	2.46	2.56
10:38	2.31	2.44	2.46	2.57
10:40	2.31	2.44	2.56	2.60
10:42	2.31	2.44	2.49	2.60
10:44	2.31	2.44	2.49	2.61
10:46	2.31	2.44	2.49	2.60
10:48	2.32	2.44	2.47	2.59
10:50	2.33	2.44	2.49	2.59
10:52	2.34	2.47	2.50	2.60
10:54	2.34	2.40	2.50	2.60
Mean --	2.32	2.44	2.48	2.59

Average amperes - phase 2- 2.39 - phase 1-2.59

0.50 GATE.

11:06	3.05	3.08	3.33	3.39
11:08	3.05	3.18	3.33	3.39
11:10	3.05	3.19	3.35	3.40

TABLE No. 7 (contd.)

0.50 GATE (contd.)

A	B	C	D	E
11:12	3.06	3.18	3.37	3.40
11:14	3.07	3.18	3.35	3.40
11:16	3.07	3.18	3.36	3.40
11:18	3.08	3.18	3.36	3.40
11:20	3.08	3.19	3.36	3.42
11:22	3.06	3.19	3.38	3.43
11:24	3.10	3.19	3.38	3.42
11:26	3.09	3.19	3.38	1.45
Mean --	3.07	3.18	3.36	3.41

Average amperes -- phase 2 - 3.13

phase 1 - 3.39

0.60 GATE.

11:30	3.65	3.70	4.01	4.02
11:32	3.65	3.70	4.01	4.02
11:34	3.69	3.74	3.99	4.01
11:36	3.71	3.73	4.04	4.03
11:38	3.68	3.72	4.04	4.02
11:40	3.69	3.73	4.06	4.04
11:42	3.71	3.74	4.05	4.04
11:44	3.72	3.74	4.06	4.05
11:46	3.71	3.75	4.06	4.06
11:48	3.71	3.78	4.06	4.06
11:50	3.71	3.78	4.06	4.08

TABLE No. 7 (contd.)

0.60 GATE (contd.)

A	B	C	D	E
Mean --	3.69	3.74	4.04	4.04
Average amperes -- phase 2 - 3.69				
phase 1 -- 4.04				

0.70 GATE.

1:50	4.27	4.27	4.59	4.60
1:52	4.31	4.28	4.59	4.58
1:54	4.29	4.28	4.59	4.60
1:56	4.30	4.29	4.60	4.60
1:58	4.29	4.27	4.61	4.60
1:59	4.29	4.28	4.59	4.61
2:02	4.30	4.30	4.60	4.61
2:04	4.31	4.30	4.61	4.61
2:06	4.29	4.27	4.61	4.61
Mean --	4.29	4.23	4.60	4.60
Average amperes -- phase 2 4.26				
phase 1 4.60				

0.80 GATE.

2:13	4.62	4.61	4.96	4.96
2:15	4.65	4.63	4.97	4.96
2:17	4.64	4.63	4.98	4.97
2:19	4.65	4.64	4.98	4.98
2:21	4.66	4.66	4.98	4.99
2:23	4.65	4.64	4.99	5.00

TABLE No. 7 (contd.)

0.80 GATE (contd.)

A	B	C	D	E
2:25	4.66	4.64	4.98	4.99
2:27	4.67	4.65	4.99	4.99
2:29	4.67	4.68	4.98	4.99
Mean --	4.64	4.64	4.98	4.98

Average amperes -- phase 2, 4.64

phase 1, 4.98

0.88 GATE.

2:45	---	5.00	---	5.32
2:47	---	5.02	---	5.31
2:49	---	5.02	---	5.30
2:50	---	5.02	---	5.30
2:51	---	5.49	---	5.30
2:53	---	5.49	---	5.30
2:55	---	5.02	---	5.30
2:57	---	5.08	---	5.32
2:59	---	5.09	---	5.33
3:00	---	5.07	---	5.32
Mean --	---	5.13	---	5.31

Average amperes -- phase 2 -- 5.13

phase 1 -- 5.31

0.97 GATE.

3:09	---	5.20	---	5.46
3:10	---	5.18	---	5.45

TABLE No. 7 (contd.)

0.97 GATE (contd.)

A	B	C	D	E
3:11	---	5.14	---	5.44
3:12	---	5.12	---	5.45
3:13	---	5.12	---	5.43
3:14	---	5.15	---	5.44
3:15	---	5.16	---	5.44
3:16	---	5.16	---	5.44
3:17	---	5.17	---	5.48
3:18	---	5.17	---	5.48
3:19	---	5.16	---	5.47
Mean --	---	5.16	---	5.45

Average amperes -- phase 2 -- 5.16

phase 1 -- 5.45

TABLE No. 8.

DETERMINATION OF APPLIED POWER.

TOTAL HEAD

LEGEND.

Column A -- The turbine gate opening.

- " B -- Standard gage reading - lbs./sq. in. corrected.
 " C -- Pressure head on center of turbine runner in feet.
 " D -- The draft head in feet.
 " E -- Velocity head at entrance to turbine case- ft./sec.
 " F -- The total head in feet.

A	B	C	D	E	F
0.40	88.6	204.7	11.4	0.2	216.3
0.50	88.1	203.6	11.2	0.2	215.0
0.60	87.1	201.3	11.2	0.3	212.8
0.70	86.1	199.0	11.0	0.4	210.4
0.80	85.3	197.2	11.0	0.5	208.7
0.88	84.3	194.9	11.0	0.6	206.5
0.97	83.7	193.4	11.0	0.6	205.0

Diameter of penstock -- 30.2 inches. Area of cross-section of penstock -- 4.97 square feet.

Center of standard gage 0.3 ft. above center of turbine runner.

TABLE No. 8 (contd.)

DISCHARGE.

LEGEND.

Column A -- Turbine gate opening.

- " B -- Velocity as determined by brine method.
 " C -- Velocity correction from brine calibration curve.
 " D -- Actual velocity.
 " E -- Velocity at discharge end of draft tube.
 " F -- Discharge.

All velocities recorded in feet per second.

Discharge recorded in cubic feet per second.

A	B	C	D	E	F
0.40	3.39	0.43	3.27	1.96	16.25
0.50	4.29	0.50	3.79	2.28	18.84
0.60	5.08	0.60	4.48	2.69	22.26
0.70	5.73	0.70	5.06	3.04	25.15
0.80	6.21	0.71	5.50	3.30	27.33
0.88	6.71	0.80	5.91	3.54	29.37
0.97	6.87	0.80	6.07	3.64	30.17

Diameter of draft tube at discharge end-----

39 inches. Area of cross-section of draft tube at discharge
 end -- 8.29 square feet.

TABLE No. 8 (contd.)

APPLIED POWER

LEGEND.

Column A -- Turbine gate opening.

- " B -- Power as computed from $qh/8.8$
- " C -- Power loss in tail race - H.P.
- " D -- Net applied power in H.P.
- " E -- Net applied power in KW.

A	B	C	D	E
0.40	399.41	0.11	399.30	297.8
0.50	460.29	0.17	460.12	343.2
0.60	538.29	0.29	538.00	401.3
0.70	601.31	0.41	538.00	448.2
0.80	646.15	0.53	645.60	481.6
0.88	689.64	0.65	689.00	513.9
0.97	702.82	0.70	702.12	523.7

TABLE No. 8 (contd.)
POWER OUTPUT AND EFFICIENCY.

LEGEND.

Column A -- The turbine gate opening.

- " B -- The net output of the alternator in Kw.
" C -- The efficiency of the alternator in percent.
" D -- Power output of the turbine less excitation.
" E -- The necessary excitation in Kw.
" F -- The total output of the turbine in Kw.
" G -- The efficiency of the turbine in percent.

A	B	C	D	E	F	G
0.40	193.6	94.6	205.0	2.68	207.7	69.7
0.50	249.6	95.1	262.9	2.86	265.8	77.4
0.60	309.2	95.5	324.0	3.14	327.1	81.6
0.70	355.6	95.8	371.2	3.30	374.5	83.6
0.80	386.8	96.0	404.1	3.40	407.5	84.5
0.88	412.4	96.1	430.0	3.58	433.6	84.5
0.97	423.6	96.1	440.8	3.59	444.4	85.0

TABLE No. 9.

THE RELATION BETWEEN VELOCITY AS DEDUCED BY THE BRINE METHOD AND THAT DETERMINED BY THE PITOMETER.

LEGEND.

Column A -- The turbine gate opening.

" B -- The velocity at center of penstock in feet per second.

" C -- The mean velocity in feet per second.

" D -- Velocity in feet per second as deduced by brine velocity method.

" E -- The ratio of D to C -- D/C

" F -- The ratio of D to B -- D/B .

A	B	C	D	E	F
0.20	1.81	1.50	1.76	1.172	0.972
0.30	2.46	2.04	2.36	1.158	0.960
0.40	3.20	2.65	3.14	1.186	0.980
0.50	4.02	3.33	3.71	1.114	0.923
0.60	5.23	4.33	4.59	1.059	0.878
0.70	5.55	4.60	5.08	1.104	0.915
0.80	5.94	4.91	5.54	1.138	0.933
0.90	6.41	5.31	6.01	1.131	0.937
1.00	6.75	5.58	6.15	1.101	0.911
Mean				1.131	0.926

CONCLUSIONS.

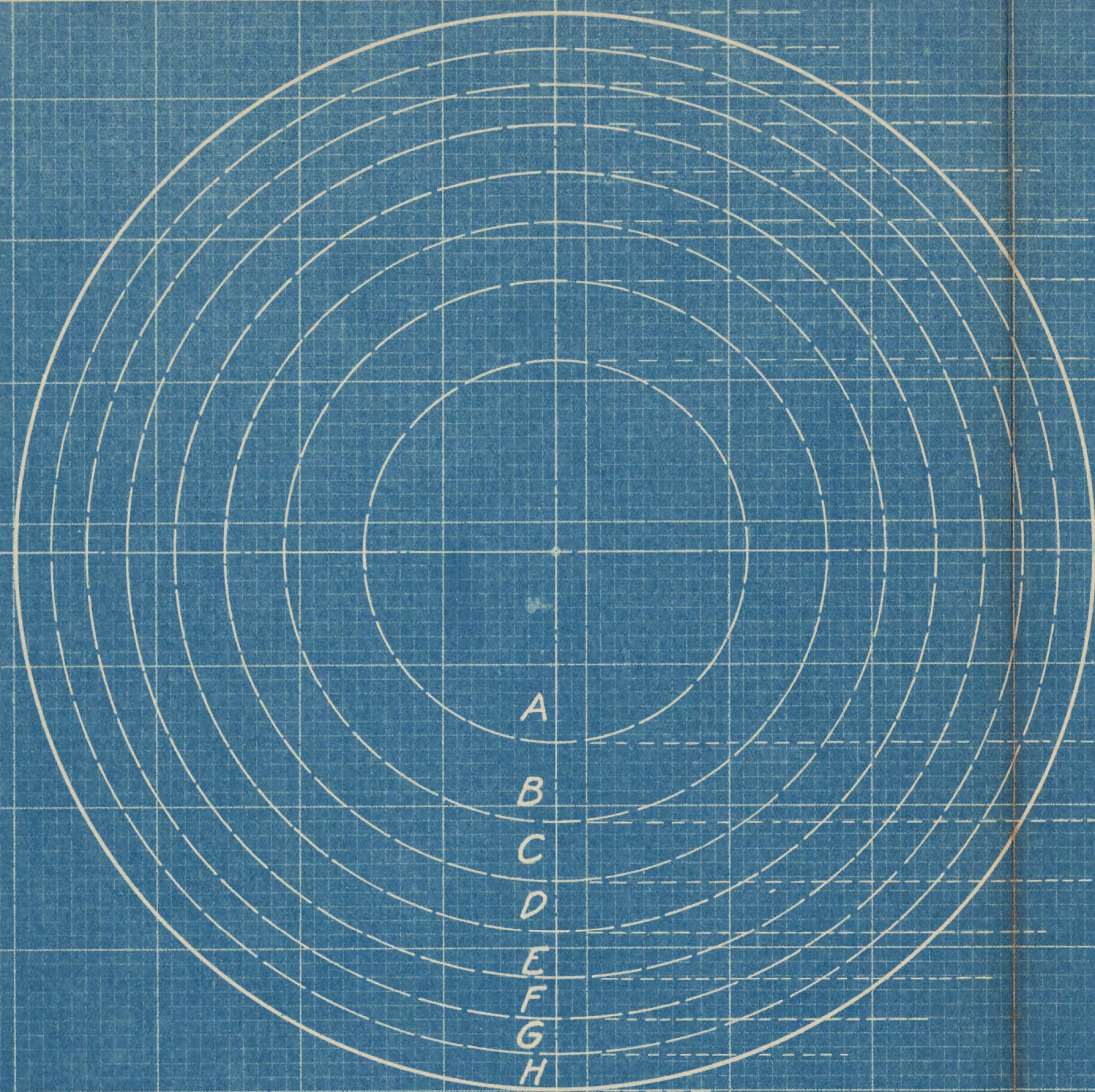
From the results of the test and the specifications set forth in the contract it was concluded that the turbine was acceptable in so far as maximum efficiency at best gate is concerned. The efficiencies guaranteed by the Wellman-Seaver-Morgan Co. for this wheel operating under a net effective head of two hundred feet at a speed of nine hundred revolutions per minute are as follows:

<u>Power</u>	<u>Efficiency</u>
1.00 Load -----	79% Efficiency.
Best Gate -----	85% "
0.75 Load -----	84.8% "
0.50 Load -----	80% "

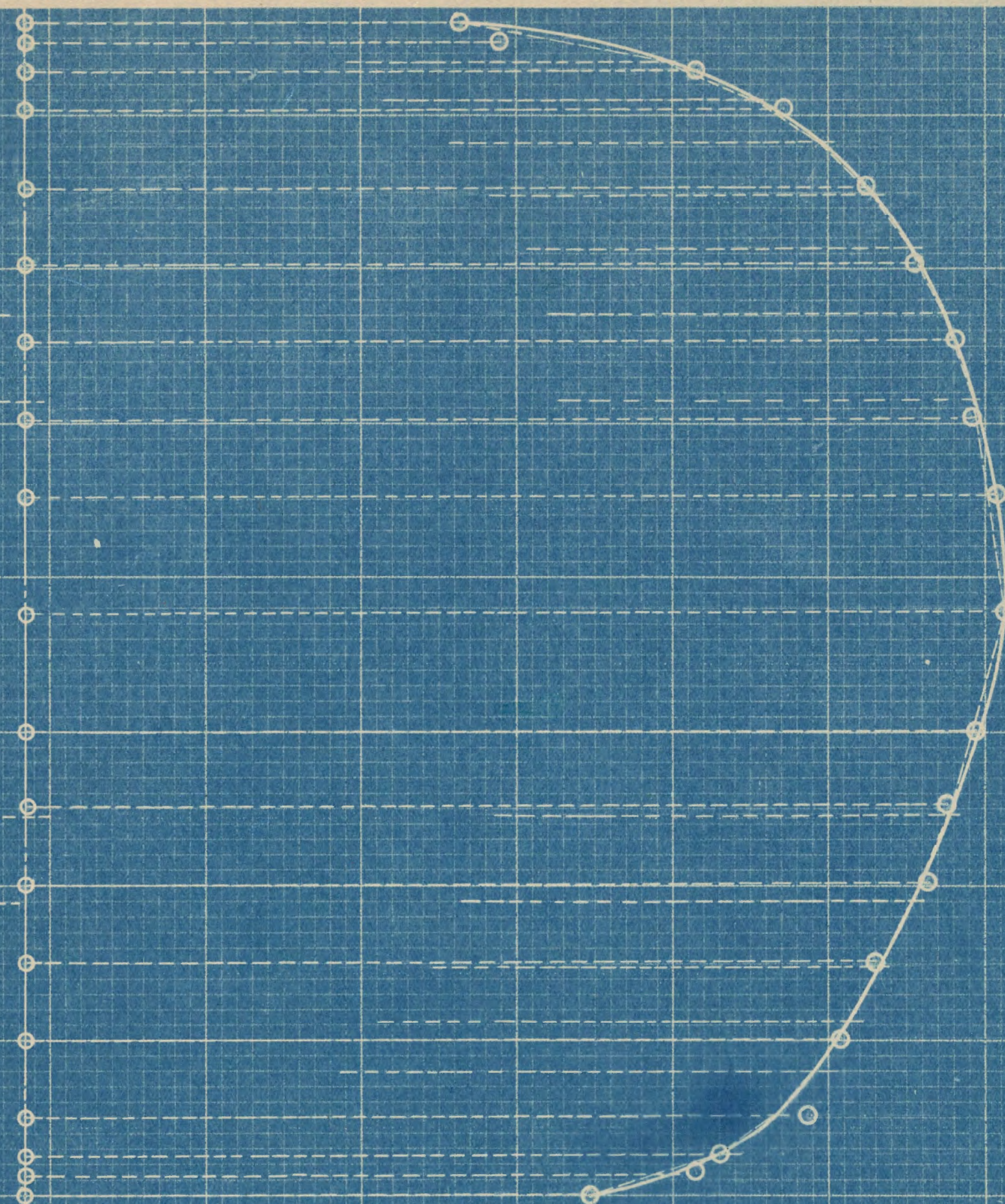
At 0.97 gate, which was the dial reading corresponding to the maximum gate opening, the turbine showed an efficiency quite a bit above the guarantee but at lower gates a slight deficiency was noted. This gave indication of some discrepancy between the actual opening of the gates and that which was indicated on the governor dial. After making a study of Plates 11 and 12 it was further concluded that such was the case. For comparison of the efficiency delivered by the turbine and that guaranteed, see table No. 8, page 52.

In so far as the salt brine velocity method is concerned it was concluded that this method as applied in the test does not indicate the actual mean velocity of flow in a closed penstock. Verifications of this statement may be found in the results as tabulated in Table No. 9 which show that this method measures neither the center velocity nor the actual

mean velocity but, in reality, a velocity between these two. It was noted that the velocity as deduced from the salt brine method agreed more closely with the mean than with the central velocity. It was further concluded that, in order to arrive at the mean velocity of flow in a closed penstock by the salt brine velocity method, a pipe coefficient must be determined and used.



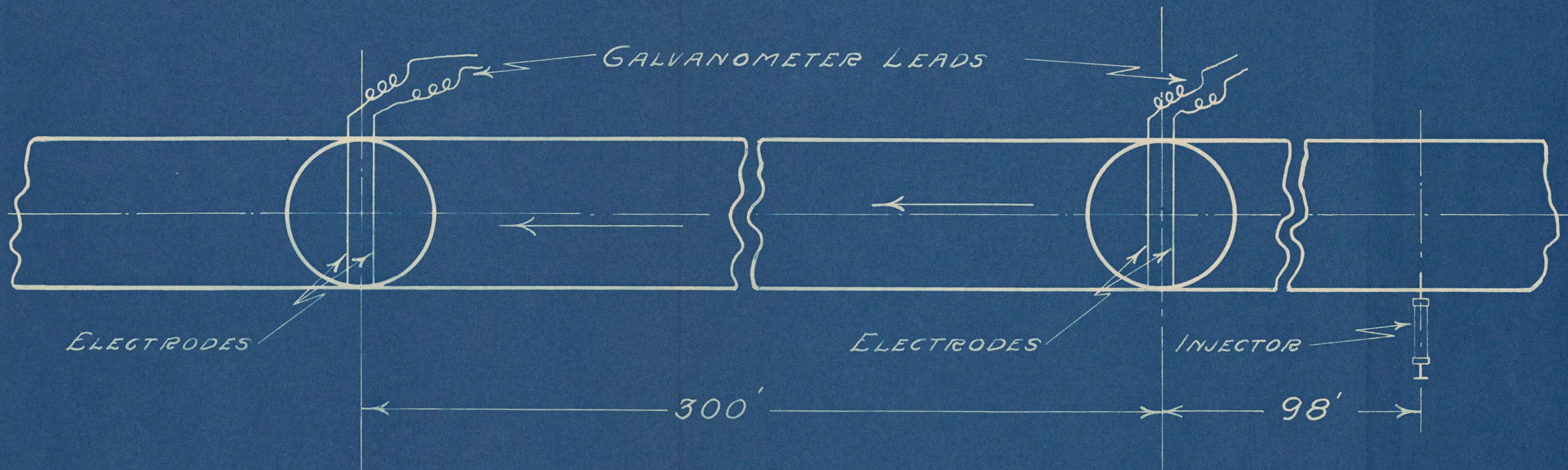
CROSS-SECTION OF PENSTOCK



SCALE: 1" = 0.5 FT. PER SEC.

VERTICAL VELOCITY CURVE

PLATE - 1
DIAGRAM OF PIPE TRAVERSE



ARRANGEMENT OF EQUIPMENT USED IN THE
DETERMINATION OF VELOCITIES BY THE
BRINE METHOD

PLATE-2

ACTUAL VELOCITIES - FT. PER SEC.

NOTE: ACTUAL VELOCITIES
DETERMINED BY PITOMETER.

BRINE CALIBRATION CURVE

PLATE - 3

0

1

2

3

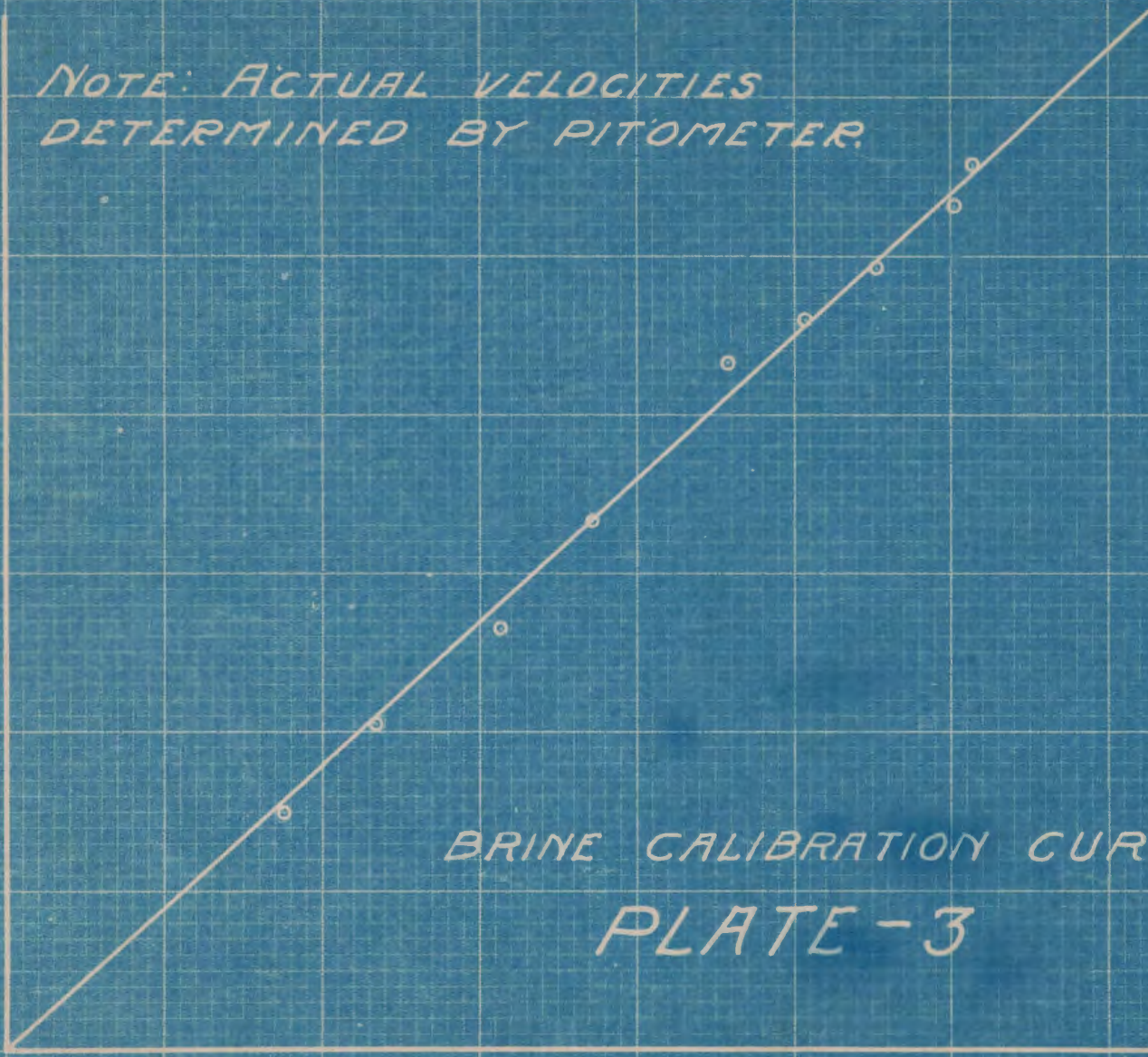
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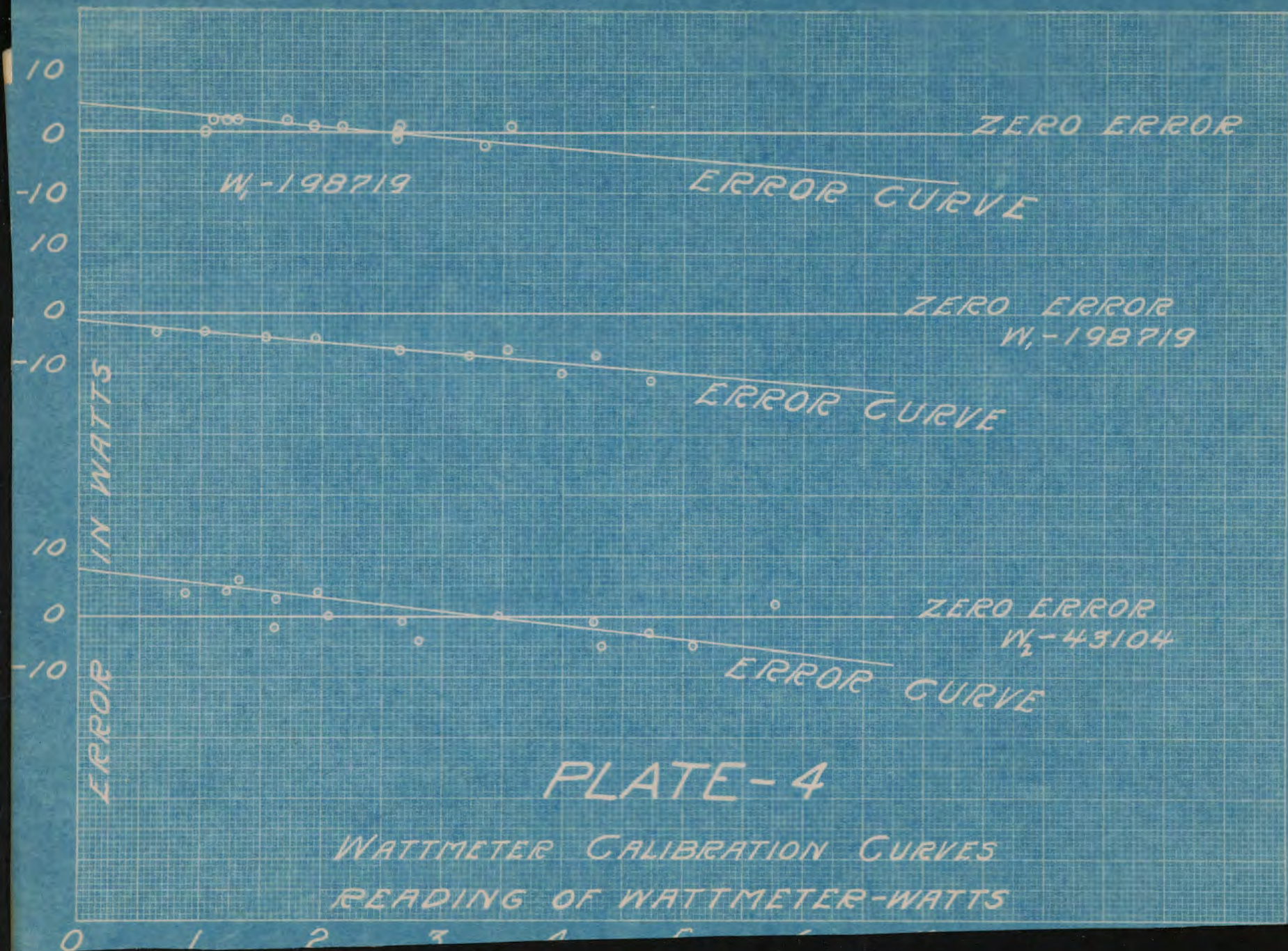
5

6

7

VELOCITIES BY BRINE METHOD IN FT PER SEC





APPENDIX.

	Plate.
Alternator efficiency curve-----	9
Ammeter calibration curves-----	6
Brine calibration curve-----	3
Equipment used in brine velocity determinations--	2
Exciter input curves-----	8
Gage calibration curve-----	7
Over all plant efficiency curve-----	13
Pitometer traverse-----	1
Turbine efficiency -- Alternator load -----	10
Turbine efficiency -- Gate opening -----	11
Turbine efficiency -- Turbine load -----	12
Unit assembly, W-S-M-Co. Drwng. -----	14
Voltmeter calibration curves -----	5
Wattmeter calibration curves -----	4



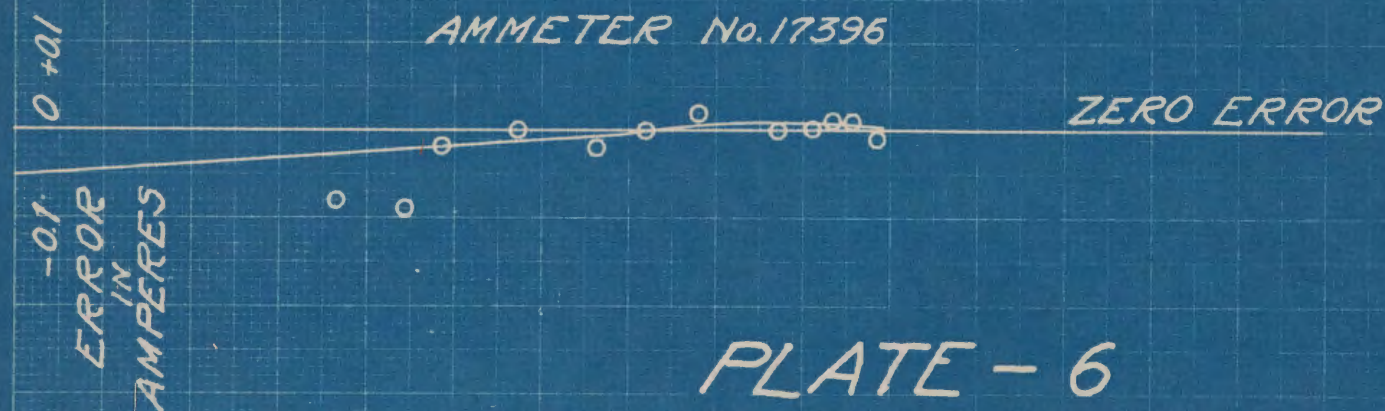
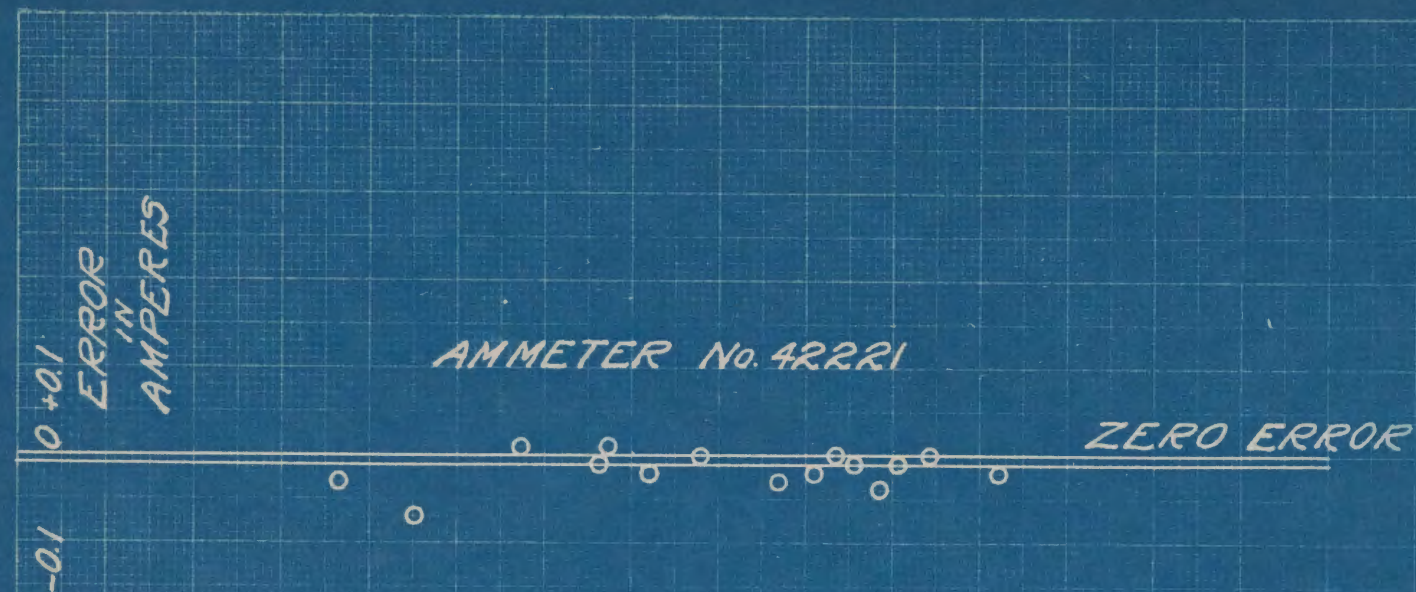


PLATE - 6

AMMETER CALIBRATION CURVES

READING OF INSTRUMENT-AMPERES

0 1 2 3 4 5 6

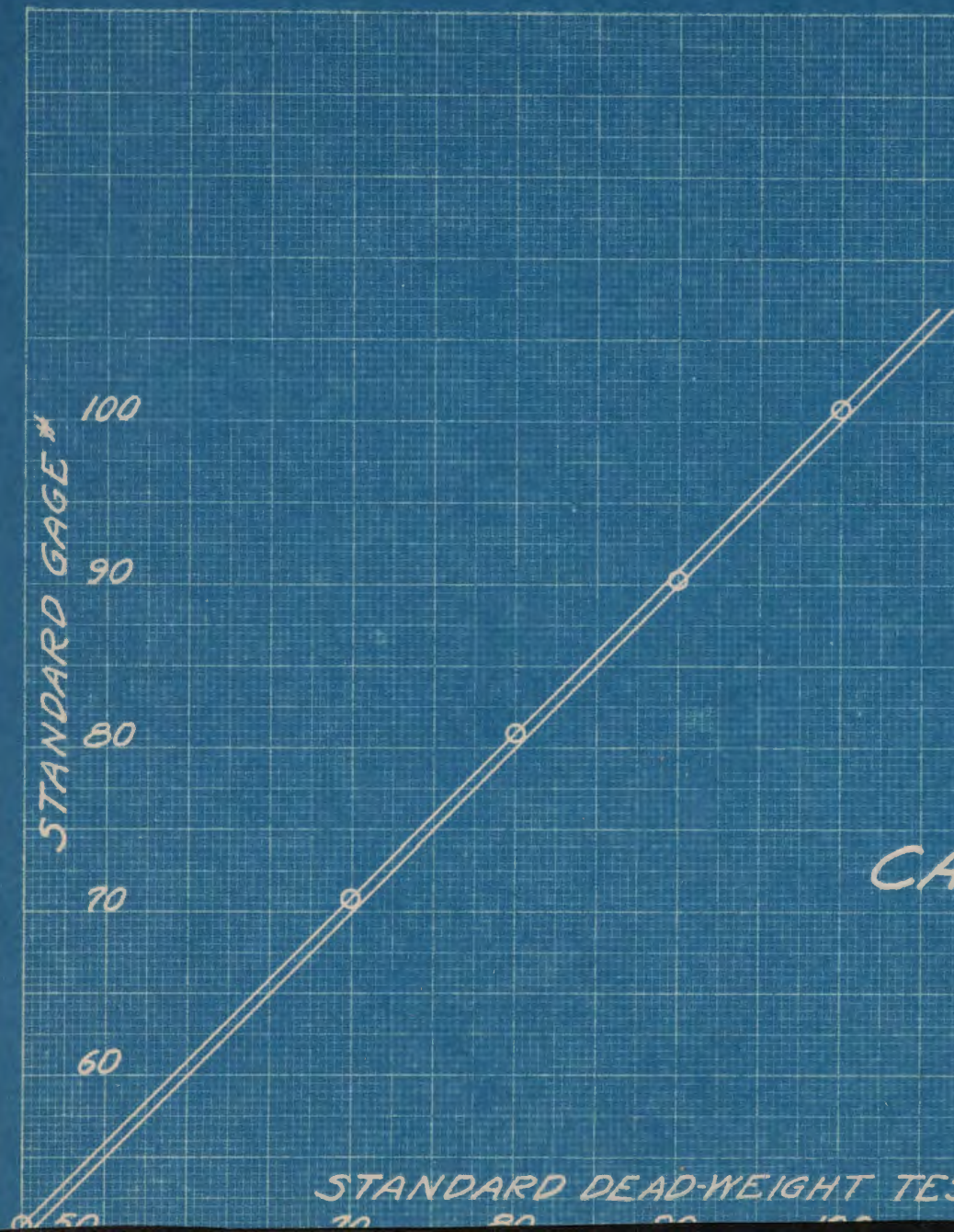


PLATE-7
STANDARD GAGE
CALIBRATION CURVE

EXCITER INPUT CURVE
UNITY POWER FACTOR

PLATE-8

EXCITATION IN KILOWATTS

4.0

3.5

3.0

2.5

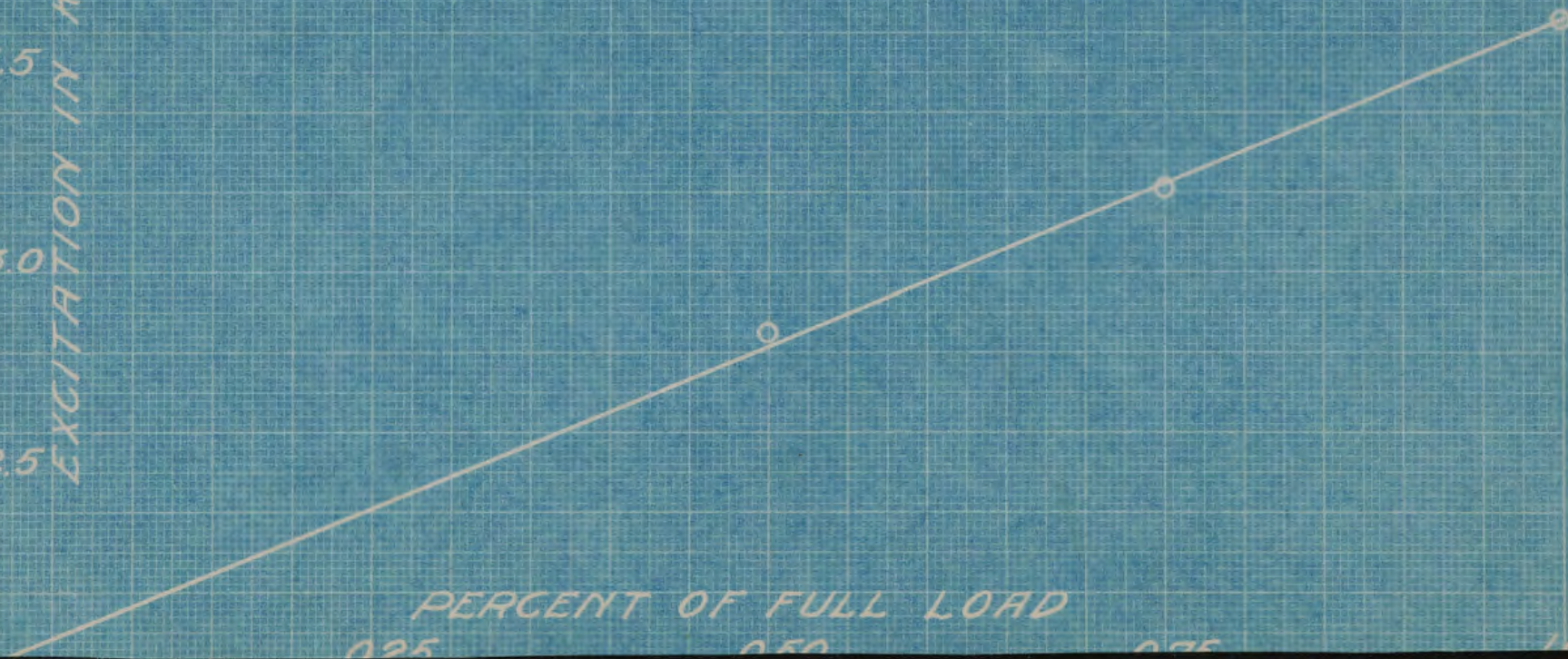
PERCENT OF FULL LOAD

0.25

0.50

0.75

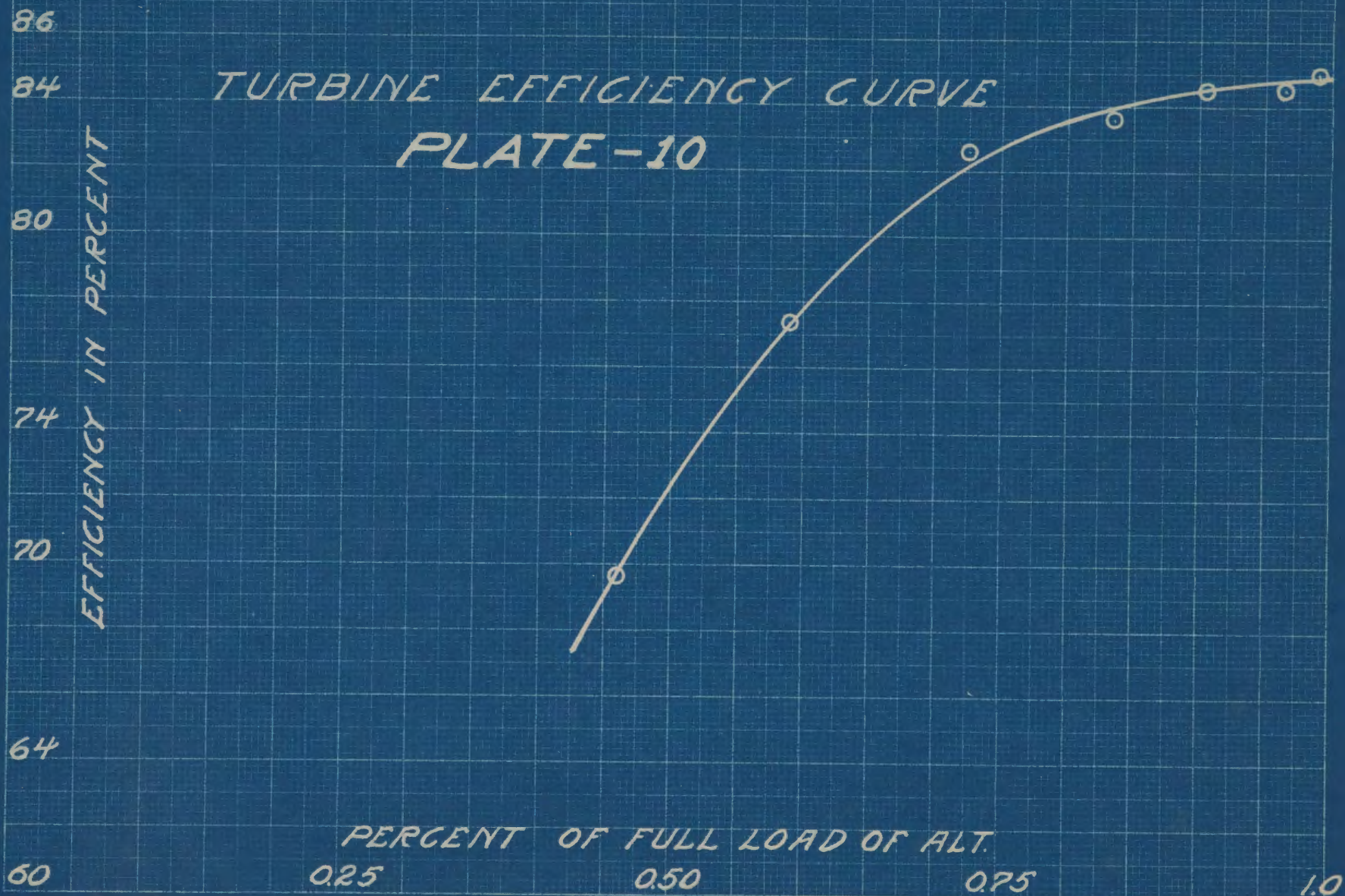
1.0

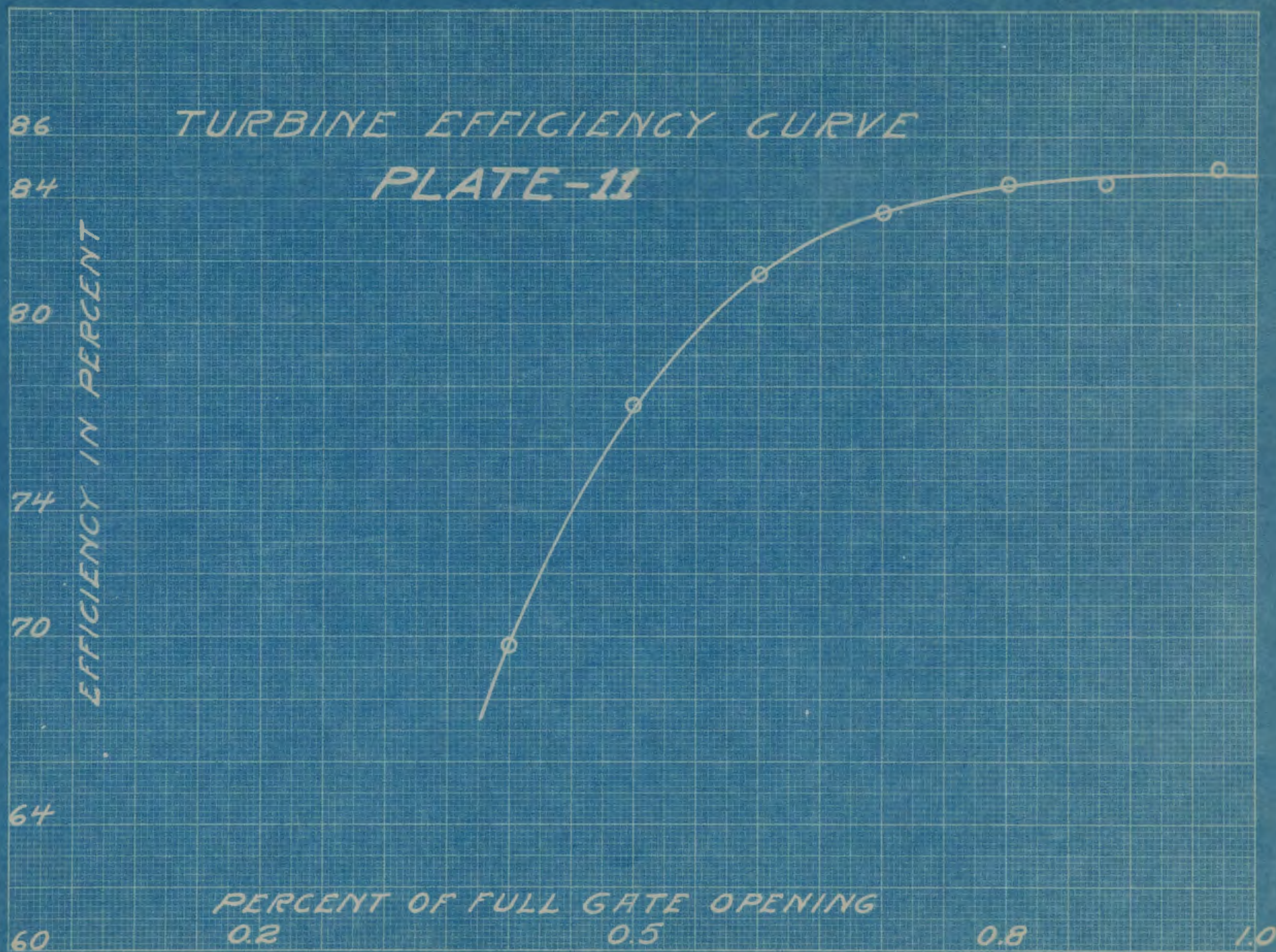


ALTERNATOR EFFICIENCY CURVE
UNITY POWER FACTOR

PLATE-9







EFFICIENCY IN PERCENT

85
80
75
72
65
50

PERCENT OF FULL LOAD OF TURBINE

75

100

125

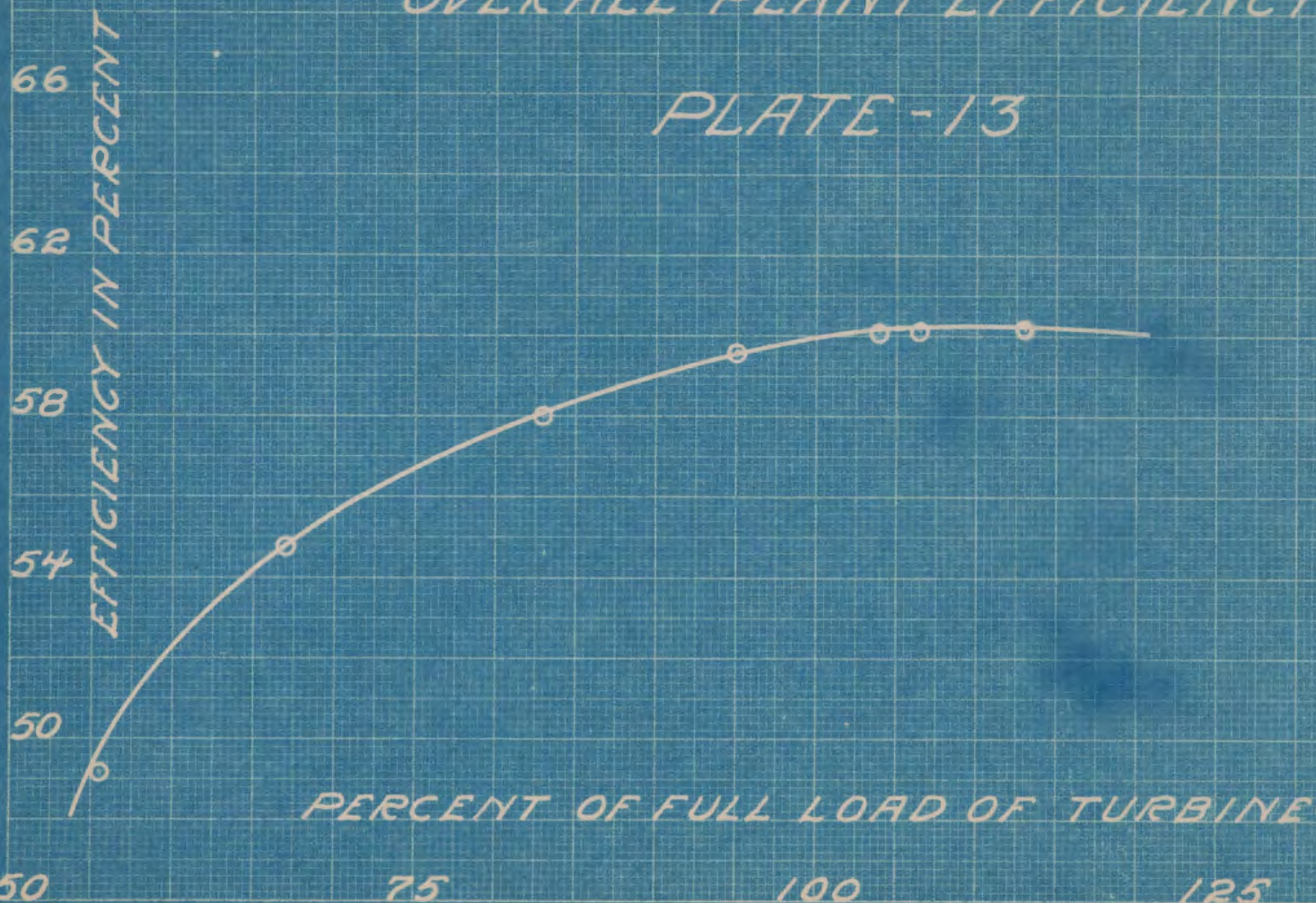
TURBINE EFFICIENCY CURVE

PLATE-12



CURVE
OF
OVERALL PLANT EFFICIENCY

PLATE-13



APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily indorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.
