FINAL REPORT

MANUAL INDEX TEST OF PORTLAND HYDRO PLANT #2

MAY 1988

PORTLAND GENERAL ELECTRIC
AND
GENERATION PROGRAMS BRANCH
BONNEVILLE POWER ADMINISTRATION

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Introduction

On May 27-28, 1988, a manual index test was conducted on the single Kaplan hydraulic turbine at Portland Hydro Plant #2, operated by Portland General Electric. The primary purpose of this test was to obtain an independent evaluation of the optimum blade to gate cam curve to compare with the results of the installed Index Test Box (ITB). This device, developed by Woodward Governor Company, is attached to new, electronic 3-D governors and is designed to determine the optimum blade to gate cam curve while the unit remains in normal operation. The first commercially available ITB had just been installed and operated on this unit. Now, to verify the accuracy of its results, an independent index test was required in order to compare the results.

Secondary purposes of this manual index test were twofold. The first was to demonstrate the efficiency improvements typically available from prototype Kaplan turbines which, even though new, had not been previously field index tested. The second was to mutually calibrate the various powerhouse measuring instruments.

The results showed this manual index test to have been extremely accurate and all the test objectives were met.

Test Personnel

PGE - Bert Evans
- Terry Hansen, operator

BPA - Lee Sheldon, RMG
- William Beebe, RMG
- Calvin Ek, ELMM

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Instrumentation

A. Wicket Gate Servomotor Stroke

The primary measure of wicket gate servomotor stroke for the manual index test was taken directly on the servomotor push rod itself. A steel rule, read to the nearest 1/16", was fastened on a fixed surface in the pit liner, and a pointer on the push rod. The rule was zero positioned at exactly the 10" mark when the gates were closed with full squeeze from the governor. The turbine manufacturer's drawings show the full or 100% servomotor stroke to be 13.31".

It is noted that the gate servo position indicated to the governor and hence the ITB is from the gate servo restoring cable. Hence, any stretch or drag of the cable would cause a different indication of gate servo position. Two other gages indicating gate servo position monitored during this test were on the panel in the control room and on the governor cabinet.

B. Blade Angle

The primary measure of blade servomotor stroke was from the mechanical rotating pointer on the oil head. An arc scale with divisions of 1% was drawn and fastened behind the oil head pointer. It was zero positioned so that the full steep was at exactly 100%. Subsequently, it turned out that the full flat position was at 4 1/2%. Consequently, all oil head blade servomotor stroke valves were converted to actual blade values by the following calibration equation:

actual blade = (indicated blade - 4 1/2)(100/95.5)

It is noted again that the blade position indicated to the governor and the ITB is from the blade servo restoring cable. As with the gates, any stretch or drag of this cable would cause a different indication of blade position. The gage on the governor cabinet indicating blade position was also monitored during these tests.

C. Power

The primary measure for generator output was the rotating standard on the panel in the control room. An electronic counter was temporarily attached to automatically time a specified number of revolutions of the disk. Then, the ratio of these revolutions per second was converted to MW by multiplying by this project's conversion factor of 82.944.

Two other power readings were also monitored. The first was the MW meter in the control room and the second was the value input to the Index Test Box. Since the ITB conducts its test runs at constant power, accuracy of this value is immaterial. In fact, the ITB was arbitrarily programmed so that 100% power was 13 MW.

D. Discharge

The primary measure of relative flow was the Winter-Kennedy piezometers. Readings were taken with the use of an old manometer borrowed from the Corps of Engineers. The piezometer lines were bled of any entrained air frequently and station service air was used to pressurize both manometer legs and position the water surfaces at convenient reading levels.

Two other flow readings were also monitored. The first was a flow meter in the control room and the second was the value input to the Index Test Box. The control room flow meter had been supplied by the turbine manufacturer and used the same Winter-Kennedy piezometers as used in this manual index test. The Index Test Box also used the same pair of piezometers to input a linear scale from 0% to 100%. The 100% value had been equated, for convenience, to 2,000 cfs.

E. Tailwater

The primary measure for the tailwater elevation was the tailwater gage in the control room. This had been previously compared with the downstream powerhouse staff gage at three different elevations and was found to be extremely accurate.

The other tailwater elevation value monitored was that input to the Index Test Box. The 0% to 100% tailwater scale in the ITB had been set for a 10 ft spread from 745 ft msl to 755 ft msl.

F. Inlet Pressure

The inlet pressure was the only parameter that was not measured independent of the Index Test Box. This is because the project has a long penstock and only one set of two diagonal pairs of piezometers manofolded together to use to measure the penstock pressure at the turbine inlet. Consequently, the penstock pressure value was read directly from that input to the Index Test Box. The 0% to 100% forebay scale in the ITB had been set for a 45 ft spread from 825 ft msl to 870 ft msl.

It is specifically pointed out that by virtue of this measurement, the head values in this manual index test are not total net energy heads but are net piezometric heads. That is, they do not account for the energy in the velocity head entering the spiral case. However, since both the Index Test Box and this manual index test use the same inlet pressure readings, it should not effect the accuracy of comparing the results of the two tests. Since the governor also uses this same piezometric head, the results can also still be utilized to optimize the performance of this Kaplan turbine. There would be an inaccuracy, however, if some aspects of these test results were compared with the model test results which are based on total net energy head or the total difference in the energy levels between the fluid entering and leaving the turbine.

Data Acquisition

This manual index test was conducted in the standard manner. First, a series totaling 16 runs were made without any adjustment to the governor. These were made in the gate opening direction at about 5% gate increments and then in the gate closing direction. These runs measured the existing "as found" or the "on cam" performance. Next, the blades were put in the full flat position and a series of runs in the gate opening position begun. However, after the second run, it was observed that the blades were, in fact, drifting a little. After readjusting the governor, the blades were able to be placed in a fixed position at a corrected angle of 4.2%, and the runs in the gate opening direction started again. After that, the blades were placed in 5 more successively steep fixed angles and a series of runs in the gate opening direction made for each blade angle.

Data Reduction

The data and data reduction from this manual index test are presented on Table 1, sheets 1 and 2. In the process of reducing the head data, it was noted that the resulting piezometric grade line was higher than the forebay elevation. This meant that the scale factors for the inlet pressure in the Index Test Box of 825 ft msl to 870 ft msl for 0% to 100% were too high and that a constant correction factor had to be computed. Fortunately, this was quite easy for the reservoir elevation was virtually unchanged. During the entire two days of testing it did not vary from an average value of 858.99 ft msl by more than $\pm$ 0.08 ft. Consequently, since both head loss and velocity head are proportional to the square of the flow, a linear regression program of piezometric elevations versus the flow squared was calculated for all the test runs and the resulting equation extrapolated to zero flow. From this, the value input to the ITB at zero flow is predicted to have been 868.79 ft msl. However, at zero flow it should have been identical to the reservoir elevation, showing the constant correction factor for the inlet piezometric elevation to be -10.35 ft.

Next, subtracting tailwater from this corrected piezometric elevation at the inlet gave the correct net piezometric head. This value was used to reduce the power readings from the rotating standard and the relative flow from the Winter-Kenedy's for each run to a common net piezometric test head of 105 ft. Power was corrected by the head ratio of the common head to individual test head raised to the 3/2 exponent while flow was corrected by the square root of the same ratio.

The relative efficiency was computed by dividing the power in MW by the relative flow in $\sqrt{D}$, both corrected to the common test head.

Finally, a head loss value was calculated for each test run. This was done by first computing a velocity head for this 10.5 ft diameter penstock based on the flow meter values. Then this was added to the corrected piezometric head to give the hydraulic grade line and the difference between this value and the constant forebay elevation was the head loss.

Graphs

The data from Table 1 was plotted in the conventional manner. First, on Graphs 1 and 2 the head corrected values of power in MW and relative flow in $\sqrt{D}$ were both plotted against the gate servo stroke in percent for each fixed blade angle. These two graphs are commonly referred to as the "smooth curves" because of their continuous positive slopes. At this point, it became evident that this test must have been exceptionally accurate, for there is virtually no scatter in any of the data points. Only in the relative flow and at the highest blade angle is there any evidence of scatter.

Next, the two smooth curves were interrogated in increments of 1% of servo stroke for the values of power and relative flow to compute the relative efficiencies for each fixed blade angle. These computed relative efficiency curves are plotted versus power on the upper portion of Graph 3. Then the actual , individual, test points are added after the fact as the solid circles. Thus, although the efficiency curves appear to be drawn through the data points they are actually computed form the smooth curves and then the data points added only for comparison. This technique allows the actual peak of the efficiency curve to be drawn to a higher degree of accuracy. Next, the tangent curve connecting these peaks is drawn so that it just touches at a singular point. It may be observed that this point where the tangent curve just touches is not necessarily at the exact efficiency peak. Finally, the individual data points from the "as found" test runs in both the gate opening and closing directions are plotted and connected by straight line segments.

On the lower portion of this Graph, the power versus gate servo stroke relation for each fixed blade angle is replottedfrom Graph 1. These are used as interpolating curves for now the point of tangency above may be projected directly down and the interception is the exact gate servo stroke corresponding with the point of tangency. The values for these six points are given in the first two columns of Table 2.

Table 2

Actual Optimum		ITB Optimum	
Gate %	Blade %	Gate %	Blade %
27.0	4.2	27.6	4.2
36.9	19.9	37.6	19.9
50.7	41.4	51.6	41.2
57.5	52.9	58.4	52.7
65.0	68.6	66.0	68.3
67.6	80.1	68.6	79.7

These six points are plotted on Graph 4, and the connecting line becomes the actual unit's optimum blade to gate cam curve, labeled "actual optimum". The term actual denotes that this curve is based on the primary measures of the actual wicket gate servomotor push rod and blade servomotor stroke at the oil head. The fact that these points form such a perfectly straight line in the lower gate openings attests to the extreme accuracy with which this test was conducted.

Next, the existing cam curve is plotted on Graph 4 from the "as found" test runs. It is noted that there is a slight difference in the opening and closing directions due to a mechanical hysteresis. The amount of this hysteresis is only about 1% in terms of either gate servo movement or blade angle, which basically shows good and fairly tight gate-blade linkages. This Graph also shows that at the larger gate openings there is a significant difference between the existing and optimum cam curves. Therefore, a significant efficiency improvement should be available to this unit by changing to the optimum cam curve.

Returning to Graph 3, the lower right hand corner depicts the amount of this efficiency improvement. This evaluation was obtained by computing the percent difference in relative efficiency between the tangent curve and the "as found" existing cam curve in the opening direction. Only the opening direction was used because the tangent curve is tangent to the fixed blade peak efficiencies, which were determined in the opening direction. It is noted that between 2 and 5 MW there is about a 1% improvement, then no improvement until powers greater than 10 MW at which point an improvement of several percent becomes available. The area between 5 and 6.5 MW where the improvement is negative is due to a single "as found" data point. This actually represents a test error and in fact there is probably an error band of about ± 1/2% associated with the individual "as found" data points used for this efficiency improvement evaluation. However, even deducting this probable error, there is still an improvement of several percent available at the higher powers. The amount of error attributable to the relative efficiency curves computed from the smooth curves is, of course, significantly less than this amount from an individual test point.

Calibration

An aside advantage of indexing a Kaplan turbine is the calibration of many of the powerhouse instruments. For instance, since the actual movement of the wicket gate servomotor push rod was read on every run, it could be used to calibrate the gate reading in the control room which was also read on every run. A linear regression analysis between the two produced the following equation:

(a) actual gate servo = 0.9743 (gate servo in control room) + 0.96

From the value of the intercept, the actual gate servo is open about 1% when the reading in the control room is zero. On the other end of the scale, if the control room is reading 100%, the gate servo is actually open 98.4%. In this same manner, all the following calibration equations were obtained:

(b) Gate reading on governor cabinet
actual gate servo = 0.9796 (gate servo on governor cabinet) - 0.27

(c) Gate reading on Index Test Box
actual gate servo = 0.9889 (ITB) - 0.28

(d) Blade angle reading on governor cabinet
actual blade angle = 1.0630 (blade angle on governor cabinet) - 1.05

(e) Blade angle reading on Index Test Box
actual blade angle = 1.0057 (ITB) - 0.07

(f) MW power meter in control room
actual MW = 1.0165 (MW in control room) - 0.115

(g) MW power reading on ITB
actual MW = 0.9096 (ITB) - 0.172

It is noted that the power values on the Index Test Box are actually a linear scale of 0% to 100% and that for reading purposes on this test, 100% had been set equal to 13 MW. In addition, since the method used by the ITB to conduct an index test is to use the governor to maintain constant power, an error in this reading has no effect on accuracy. However, in the future, for this unit, a value of - 0.172 MW for 0% and 11.653 MW [0.9096(13) - 0.172] for 100% would be the most representative.

(h) Flow meter in control room

$$\sqrt{D}_{\text{Winter-Kennedy}} (\text{in ft}^{1/2}) = 0.001087 \text{ (flow meter in control room in cfs)} - 0.310$$

The slope value of 0.001087 is the "k" factor of the Winter-Kennedy piezometers.

RUN #	TIME 4-28-88	GATE IN CONTROL ROOM (%)	GATE ON GOVERNOR CABINET (%)	GATE ON ITB (%)	GATE SERVO PUSH ROD INCHES	(%) ÷13.31	BLADE ON GOVERNOR CABINET (%)	BLADE ON ITB (%)
36	9:44	38.5	38.9	38.5	5	37.6	39	41.2
37	9:47	44.0	44.5	44.3	5 13/16	43.7	39	40.8
38	9:49	48.5	49.0	49.1	6 7/16	48.4	39	40.9
39	10:00	54.0	55.0	54.7	7 3/16	54.0	39	40.8
40	10:03	60.5	61.5	61.1	8	60.1	39	40.9
41	10:08	65.0	65.5	65.1	8 1/2	63.9	39	40.8
42	10:13	70.0	72.5	71.0	9 5/16	70.0	39	40.9
43	10:22	45.0	45.5	45.3	5 15/16	44.6	51	52.9
44	10:26	50.0	50.5	50.2	6 9/16	49.3	51	53.0
45	10:29	55.0	56.5	56.1	7 5/16	54.9	51	53.0
46	10:32	60.0	60.2	60.1	7 7/8	59.2	51	52.9
47	10:35	67.0	69.5	67.8	8 15/16	67.1	51	52.9
48	10:37	71.0	72.3	71.4	9 3/8	70.4	51	53.0
49	10:47	50.0	50.5	50.4	6 9/16	49.3	65	67.5
50	10:51	55.0	56.5	56.4	7 3/8	55.4	65	67.6
51	10:56	59.5	60.1	59.9	7 7/8	59.2	65	67.6
52	10:58	66.5	67.1	67.4	8 3/4	65.7	65	67.5
53	11:01	70.0	71.1	70.4	9 1/4	69.5	65	67.5
54	11:04	75.0	77.0	76.5	10 1/16	75.6	65	67.5
55	11:06	80.0	80.0	79.7	10 7/16	78.4	65	67.6
56	11:15	55.0	55.5	55.3	7 1/4	54.5	76	79.6
57	11:18	60.0	60.1	59.7	7 13/16	58.7	76	79.6
58	11:22	65.0	66.0	65.7	8 9/16	64.3	76	79.5
59	11:24	70.0	70.0	69.9	9 3/16	69.0	76	79.6
60	11:27	77.0	79.0	77.9	10 1/4	77.0	76	79.6
61	11:29	80.0	81.0	80.5	10 9/16	79.4	76	79.5
62	11:32	90.0	90.5	88.4	11 5/8	87.3	76	79.5

BLADE ON OIL HEAD READING (%)	CORRECTED (%) (%-4½) x (100/95.5)	MW METER IN CONTROL ROOM (MW)	POWER ON ITB READING	(MW) x 13	ROTATING STANDARD IN CONTROL ROOM (REVS)	(SEC)	(MW) (R/S) x (82.944)	FLOW METER IN CONTROL ROOM (CFS)	$v^2/2g$ (ft)
44	41.4	5.55	47.5	6.175	5	76.56	5.417	935	1.81
44	41.4	6.40	55.2	7.176	6	78.47	6.342	1030	2.20
44	41.4	7.00	60.1	7.813	6	71.61	6.950	1100	2.51
44	41.4	7.40	64.0	8.320	6	66.99	7.429	1160	2.79
44	41.4	7.70	66.6	8.658	6	64.46	7.721	1230	3.14
44	41.4	7.85	67.6	8.788	6	63.41	7.848	1255	3.26
44	41.4	7.95	68.8	8.944	6	62.24	7.996	1300	3.50
55	52.9	6.75	58.0	7.540	6	74.45	6.685	1160	2.79
55	52.9	7.60	65.5	8.515	6	65.80	7.563	1235	3.14
55	52.9	8.35	72.0	9.360	6	59.44	8.373	1305	3.53
55	52.9	8.70	75.0	9.750	6	57.01	8.729	1365	3.86
55	52.9	9.05	78.2	10.166	6	54.49	9.133	1430	4.24
55	52.9	9.15	79.1	10.283	6	54.18	9.185	1480	4.54
70	68.6	7.75	67.3	8.749	6	63.70	7.813	1375	3.92
70	68.6	8.95	79.2	10.296	6	55.37	8.988	1460	4.42
70	68.6	9.50	82.0	10.660	6	51.78	9.611	1540	4.92
70	68.6	10.35	89.2	11.596	8	63.54	10.443	1645	5.61
70	68.6	10.50	90.7	11.791	8	62.48	10.620	1680	5.85
70	68.6	10.80	92.5	12.025	8	61.29	10.826	1750	6.35
70	68.6	10.85	93.4	12.142	8	60.97	10.883	1790	6.64
81	80.1	8.85	82.1	10.673	8	74.62	8.892	1575	5.14
81	80.1	9.80	84.3	10.959	8	67.68	9.804	1650	5.64
81	80.1	10.75	92.7	12.051	10	76.15	10.892	1745	6.31
81	80.1	11.25	96.9	12.597	10	73.14	11.340	1805	6.75
81	80.1	11.75	100.9	13.117	10	70.00	11.849	1900	7.48
81	80.1	11.80	101.6	13.208	10	69.65	11.909	1950	7.88
81	80.1	12.00	102.9	13.377	10	68.96	12.028		

FLOW ON ITB (%)	FLOW ON ITB (CFS) x2000	WINTER-KENNEDY PIEZOMETERS DIFFER-ENTIAL	WINTER-KENNEDY PIEZOMETERS $\sqrt{D}$ ($ft^{1/2}$)	TAILRACE ELEVATION ITB READING (%)	TAILRACE ELEVATION ITB ELEV (FT MSL)	TAILRACE ELEVATION CONTROL ROOM (FT MSL)	PENSTOCK PRESS ITB READING (%)	PENSTOCK PRESS ITB ELEV (FT MSL)	PENSTOCK PRESS CORRECT ELEV (FT MSL) -10.35	PIEZO-METRIC HEAD (FT)
47.0	940	0.995	0.997	50.1	750.01	750.10	92.7	866.72	856.37	106.27
51.4	1028	1.195	1.093	51.3	750.13	750.30	91.8	866.31	855.96	105.66
55.0	1100	1.365	1.168	52.6	750.26	750.30	90.6	865.77	855.42	105.12
58.5	1170	1.525	1.235	53.7	750.37	750.40	90.0	865.50	855.15	104.75
61.1	1222	1.710	1.308	54.1	750.41	750.45	89.0	865.05	854.70	104.25
62.9	1258	1.795	1.340	54.6	750.46	750.45	88.8	864.96	854.61	104.16
64.3	1286	1.915	1.384	54.6	750.46	750.45	88.0	864.60	854.25	103.80
58.2	1164	1.520	1.233	53.0	750.30	750.30	89.0	865.05	854.70	104.40
61.7	1234	1.715	1.310	53.3	750.33	750.40	88.8	864.96	854.61	104.21
65.9	1318	1.965	1.402	54.1	750.41	750.50	87.6	864.42	854.07	103.57
68.5	1370	2.120	1.456	55.2	750.52	750.60	86.5	863.93	853.58	102.98
72.1	1442	2.405	1.551	56.0	750.60	750.60	85.2	863.34	852.99	102.39
74.0	1480	2.470	1.572	56.4	750.64	750.65	84.8	863.16	852.81	102.16
68.8	1376	2.125	1.458	53.6	750.36	750.40	86.7	864.02	853.67	103.27
74.9	1498	2.465	1.570	55.3	750.53	750.50	84.7	863.12	852.77	102.27
76.8	1536	2.705	1.645	55.5	750.55	750.55	83.5	862.58	852.23	101.68
81.8	1636	3.080	1.755	57.2	750.72	750.70	81.6	861.72	851.37	100.67
83.9	1678	3.220	1.794	57.5	750.75	750.75	80.6	861.27	850.92	100.17
87.3	1746	3.470	1.863	58.8	750.88	750.80	79.4	860.73	850.38	99.58
89.2	1784	3.590	1.895	58.1	750.81	750.80	78.8	860.46	850.11	99.31
78.7	1574	2.820	1.679	55.6	750.56	750.60	83.8	862.71	852.36	101.76
82.5	1650	3.020	1.738	56.0	750.60	750.60	81.6	861.72	851.37	100.77
87.5	1750	3.480	1.865	58.1	750.81	750.80	79.1	860.60	850.25	99.45
90.7	1814	3.745	1.935	58.4	750.84	750.80	77.6	859.92	849.57	98.77
95.8	1916	4.105	2.026	59.1	750.91	750.95	75.5	858.98	848.63	97.68
97.6	1952	4.305	2.075	60.3	751.03	751.00	74.8	858.66	848.31	97.31
101.2	2024	4.623	2.150	59.5	750.95	751.00	73.3	857.99	847.64	96.64

MW CORRECTED FOR HEAD (MW)	$\sqrt{D}$ CORRECTED FOR HEAD ($FT^{1/2}$)	RELATIVE EFFICIENCY	h_L (FT)
5.320	0.991	5.368	0.81
6.283	1.090	5.766	0.83
6.938	1.167	5.944	1.06
7.456	1.236	6.030	1.05
7.804	1.313	5.945	1.15
7.943	1.345	5.904	1.12
8.135	1.392	5.844	1.24
6.743	1.237	5.453	1.50
7.649	1.315	5.817	1.24
8.547	1.412	6.055	1.39
8.987	1.470	6.113	1.55
9.484	1.571	6.039	1.76
9.571	1.594	6.005	1.64
8.010	1.470	5.448	1.40
9.350	1.591	5.878	1.80
10.086	1.672	6.033	1.84
11.124	1.792	6.206	2.01
11.397	1.837	6.205	2.22
11.722	1.913	6.127	2.26
11.832	1.949	6.072	2.24
9.320	1.706	5.465	1.49
10.482	1.774	5.878	1.98
11.816	1.916	6.166	2.43
12.430	1.995	6.230	2.67
13.206	2.101	6.287	2.88
13.348	2.155	6.193	2.80
13.622	2.241	6.078	----

TABLE 1
SHEET 2

RUN #	TIME 4-27-88	GATE IN CONTROL ROOM (%)	GATE ON GOVERNOR CABINET (%)	GATE ON ITB (%)	GATE SERVO PUSH ROD INCHES	GATE SERVO PUSH ROD (%) ÷13.31	BLADE ON GOVERNOR CABINET (%)
1	11:15	15.0	16.5	16.2	2 1/8	16.0	1
2	11:28	23.8	25.5	25.4	3 5/16	24.9	6
3	11:38	30.0	30.5	30.5	3 15/16	29.6	11
4	11:44	37.5	37.8	37.8	4 15/16	37.1	19
5	11:49	44.5	44.9	44.7	5 13/16	43.7	25
6	11:53	52.0	53.5	53.1	6 15/16	52.1	34
7	12:00	60.0	60.0	59.8	7 13/16	58.7	44
8	12:06	67.0	67.0	67.0	8 3/4	65.7	. 57
9	12:12	75.0	75.5	75.2	9 7/8	74.2	72
10	12:18	79.5	79.0	78.8	10 5/16	77.5	78
11	12:25	71.0	----	----	9 1/4	69.5	--
12	12·29	60.0	60.1	59.9	7 13/16	58.7	43
13	12:37	50.0	51.0	50.7	6 5/8	49.8	32
14	12:47	39.0	39.0	39.4	5 1/8	38.5	20
15	12:51	30.0	29.0	28.7	3 3/4	28.2	10
16	12:56	17.0	18.0	17.2	2 3/16	16.4	2
19	2:22	20.0	21.5	20.7	2 3/4	20.7	4
20	2:28	15.0	----	16.2	2 1/8	16.0	4
22	2:42	24.5	26.0	25.9	3 3/8	25.4	4
23	2:45	30.5	32.5	31.8	4 3/16	31.5	4
24	2:48	35.0	36.5	35.7	4 11/16	35.2	4
25	2:54	42.0	44.5	43.3	5 5/8	42.3	4
26	2:57	46.0	48.5	48.0	6	45.1	5
27	3:01	49.0	50.0	50.0	6 9/16	49.3	5
28	3:11	24.5	----	25.9	3 5/16	24.9	19
29	3:14	33.5	34.5	34.3	4 1/2	33.8	19
30	3:18	41.0	41.5	41.1	5 7/16	40.9	19
31	3:21	46.5	47.5	46.9	6 3/16	46.5	19
32	3:24	50.5	52.5	51.2	6 3/4	50.7	20
33	3:28	58.0	61.5	58.4	7 3/4	58.2	20
34	3:30	65.0	66.0	64.4	8 1/2	63.9	20
35	3:36	28.0	29.5	29.3	3 13/16	28.6	20

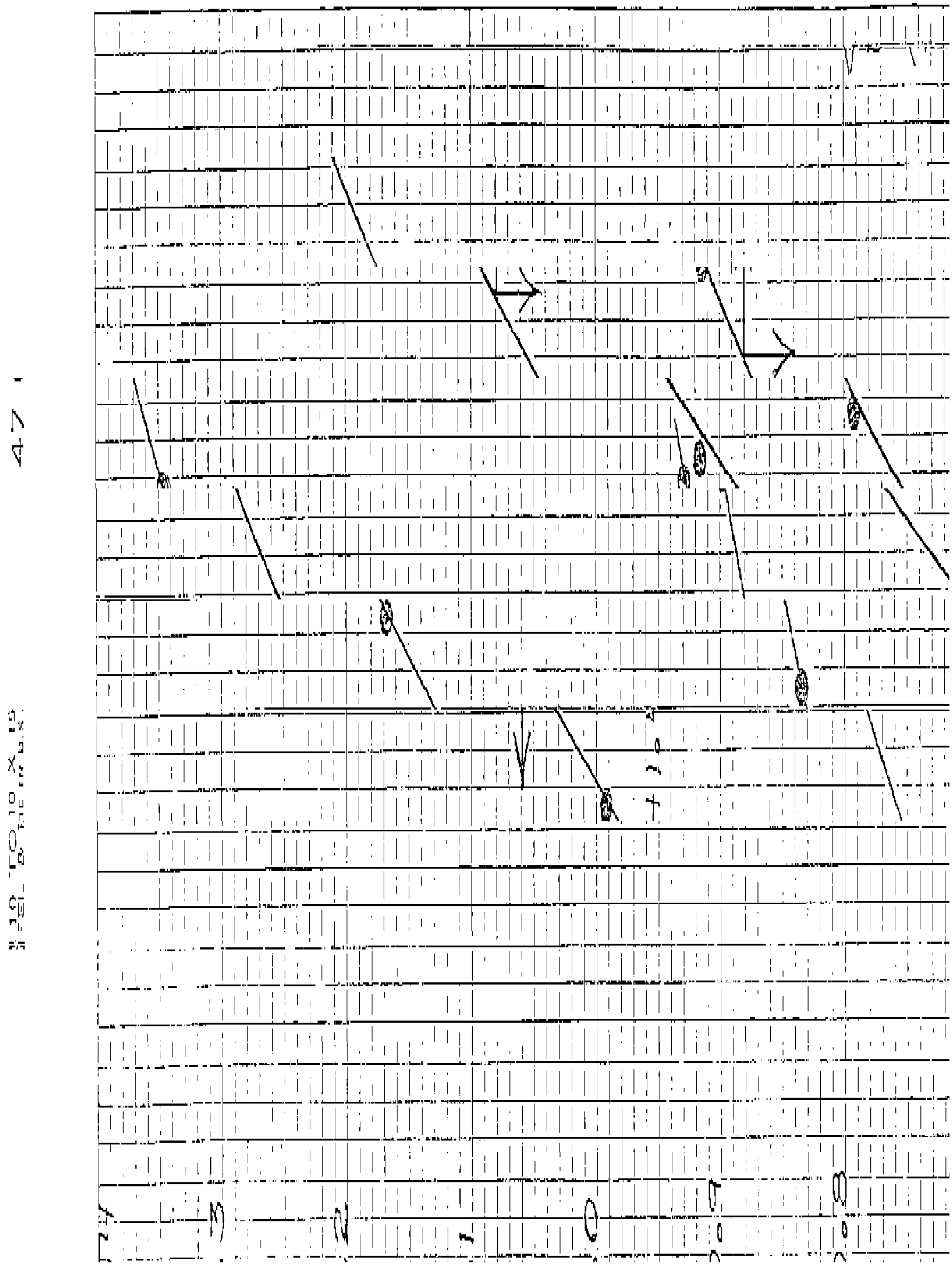
BLADE ON ITB (%)	BLADE ON OIL HEAD READING (%)	CORRECTED (%) (%-4½) x (100/95.5)	MW METER IN CONTROL ROOM (MW)	POWER ON ITB READING	(MW) x 13	ROTATING ST IN CONTROL (REVS)	(SEC)
[illegible].2	4 1/2	0.0	----	14.6	1.898	2	106.02
5.0	9 1/2	5.2	----	23.4	3.042	3	95.61
[illegible].3	15	11.0	----	29.8	3.874	4	98.74
[illegible].0	22 1/2	18.8	----	39.1	5.083	5	93.58
[illegible].7	29	25.7	----	47.9	6.227	7	106.10
[illegible].1	39 1/2	36.6	----	59.5	7.735	8	96.77
[illegible].8	49	46.6	----	71.0	9.230	9	90.85
[illegible].4	60 1/2	58.6	----	83.9	10.907	11	93.82
[illegible].9	77	75.9	----	97.8	12.714	14	101.86
[illegible].9	81	80.1	----	104.2	13.546	15	102.94
----	65 1/2	63.9	----	----	-----	13	104.91
[illegible].5	47 1/2	45.0	----	70.4	9.152	10	101.50
[illegible].1	35 1/2	32.5	6.55	56.6	7.358	7	89.10
[illegible].4	23	19.4	----	40.9	5.317	6	106.88
[illegible].1	12 1/2	8.4	3.20	27.8	3.614	4	106.83
[illegible].6	4 1/2	0.0	1.70	15.3	1.989	2	99.58
[illegible]	8 1/2	4.2	2.10	19.4	2.522	2	77.48
[illegible]	8 1/2	4.2	1.60	15.0	1.950	1	51.17
[illegible].4	8 1/2	4.2	2.65	23.1	3.003	2	64.77
[illegible].5	8 1/2	4.2	2.90	25.4	3.302	2	58.35
[illegible].5	8 1/2	4.2	3.05	26.4	3.432	2	56.04
[illegible].6	8 1/2	4.2	3.20	27.8	3.614	2	53.22
[illegible].6	8 1/2	4.2	3.20	28.1	3.653	2	52.26
[illegible].6	8 1/2	4.2	3.25	28.3	3.679	2	52.17
[illegible].8	23 1/2	19.9	3.20	28.4	3.692	3	79.01
[illegible].8	23 1/2	19.9	4.25	37.1	4.823	3	58.46
[illegible].7	23 1/2	19.9	4.80	41.2	5.356	3	53.00
[illegible].7	23 1/2	19.9	5.00	43.2	5.616	3	50.29
[illegible].7	23 1/2	19.9	5.10	44.3	5.759	3	49.09
[illegible].8	23 1/2	19.9	5.25	45.4	5.902	3	48.30
[illegible].8	23 1/2	19.9	5.35	46.0	5.980	3	47.27
[illegible].6	23 1/2	19.9	3.75	32.4	4.212	2	45.44

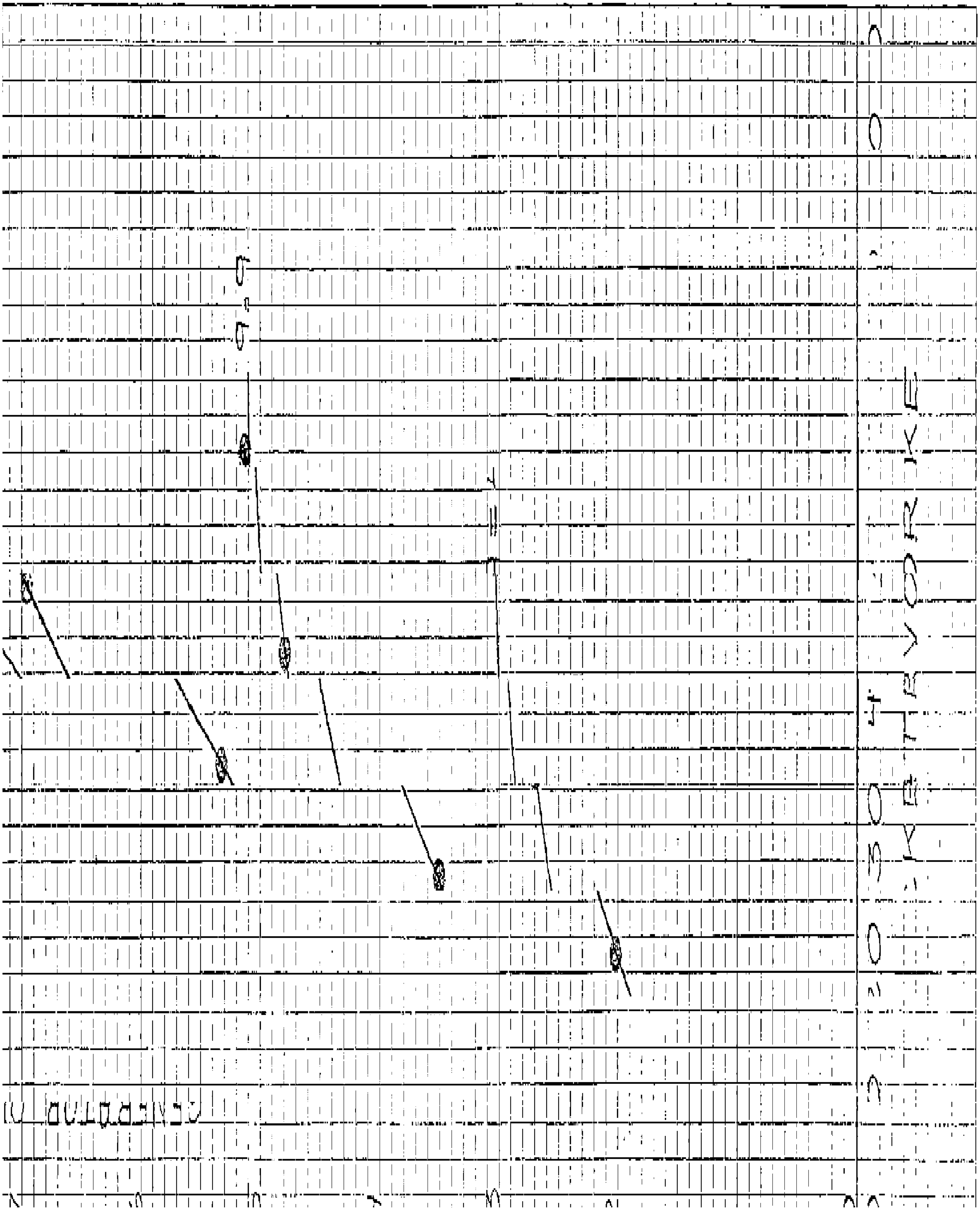
ANDARD ROOM (MW) (R/S) x (82.944)	FLOW METER IN CONTROL ROOM (CFS)	$v^2/2g$ (ft)	FLOW ON ITB (%)	(CFS) x2000	WINTER-KENNEDY PIEZOMETERS DIFFER-ENTIAL	$\sqrt{D}$ ($ft^{1/2}$)	TAILRACE ELEVATION ITB READING (%)	ELEV (FT MSL)	TAILRACE ELEVATION CONTROL ROOM (FT MSL)
1.565	350	0.25	17.7	354	0.115	0.339	34.7	748.47	748.60
2.603	475	0.47	23.7	474	0.232	0.482	33.3	748.33	748.40
3.360	580	0.70	29.3	586	0.355	0.596	38.9	748.89	749.00
4.432	730	1.10	36.7	734	0.580	0.762	46.0	749.60	749.65
5.472	870	1.57	43.9	878	0.835	0.914	49.1	749.91	750.00
6.857	1080	2.42	54.2	1084	1.305	1.142	52.2	750.22	750.25
8.217	1290	3.45	65.2	1304	1.880	1.371	54.6	750.46	750.50
9.725	1530	4.85	77.0	1540	2.670	1.634	56.5	750.65	750.65
11.400	1820	6.87	91.3	1826	3.940	1.985	59.1	750.91	750.85
12.086	1960	7.96	98.4	1968	4.430	2.105	60.1	751.01	751.05
10.278	1650	5.64	----	----	3.105	1.762	----	------	750.80
8.172	1300	3.50	64.9	1298	1.845	1.358	65.9	751.59	750.60
6.516	1030	2.20	51.7	1034	1.190	1.091	53.5	750.35	750.40
4.656	770	1.23	38.7	774	0.655	0.809	50.0	750.00	750.10
3.106	560	0.65	28.8	576	0.330	0.574	48.1	749.81	749.90
1.666	370	0.28	18.4	368	0.125	0.354	44.0	749.40	749.50
2.141	410	0.35	20.3	406	0.180	0.424	43.7	749.37	749.40
1.621	360	0.27	18.4	368	0.130	0.361	41.7	749.17	749.30
2.561	470	0.46	23.7	474	0.225	0.474	43.7	749.37	749.45
2.843	510	0.54	25.9	518	0.270	0.520	44.8	749.48	749.60
2.960	535	0.59	26.8	536	0.295	0.543	45.5	749.55	749.60
3.117	560	0.65	28.4	568	0.335	0.579	45.9	749.59	749.65
3.174	570	0.67	29.1	582	0.355	0.596	46.0	749.60	749.65
3.180	580	0.70	29.6	592	0.370	0.608	45.8	749.58	749.65
3.149	605	0.76	30.1	602	0.385	0.620	46.1	749.61	749.70
4.256	700	1.02	35.1	702	0.530	0.728	47.5	749.75	749.80
4.695	760	1.20	38.3	766	0.640	0.800	48.7	749.87	749.95
4.948	800	1.33	40.4	808	0.710	0.843	49.4	749.94	750.00
5.069	820	1.39	41.8	836	0.750	0.866	49.7	749.97	750.00
5.152	860	1.53	43.5	870	0.820	0.906	49.7	749.97	750.05
5.264	890	1.64	44.7	894	0.880	0.938	49.7	749.97	750.05
3.651	635	0.84	32.3	646	0.445	0.667	47.4	749.74	749.80

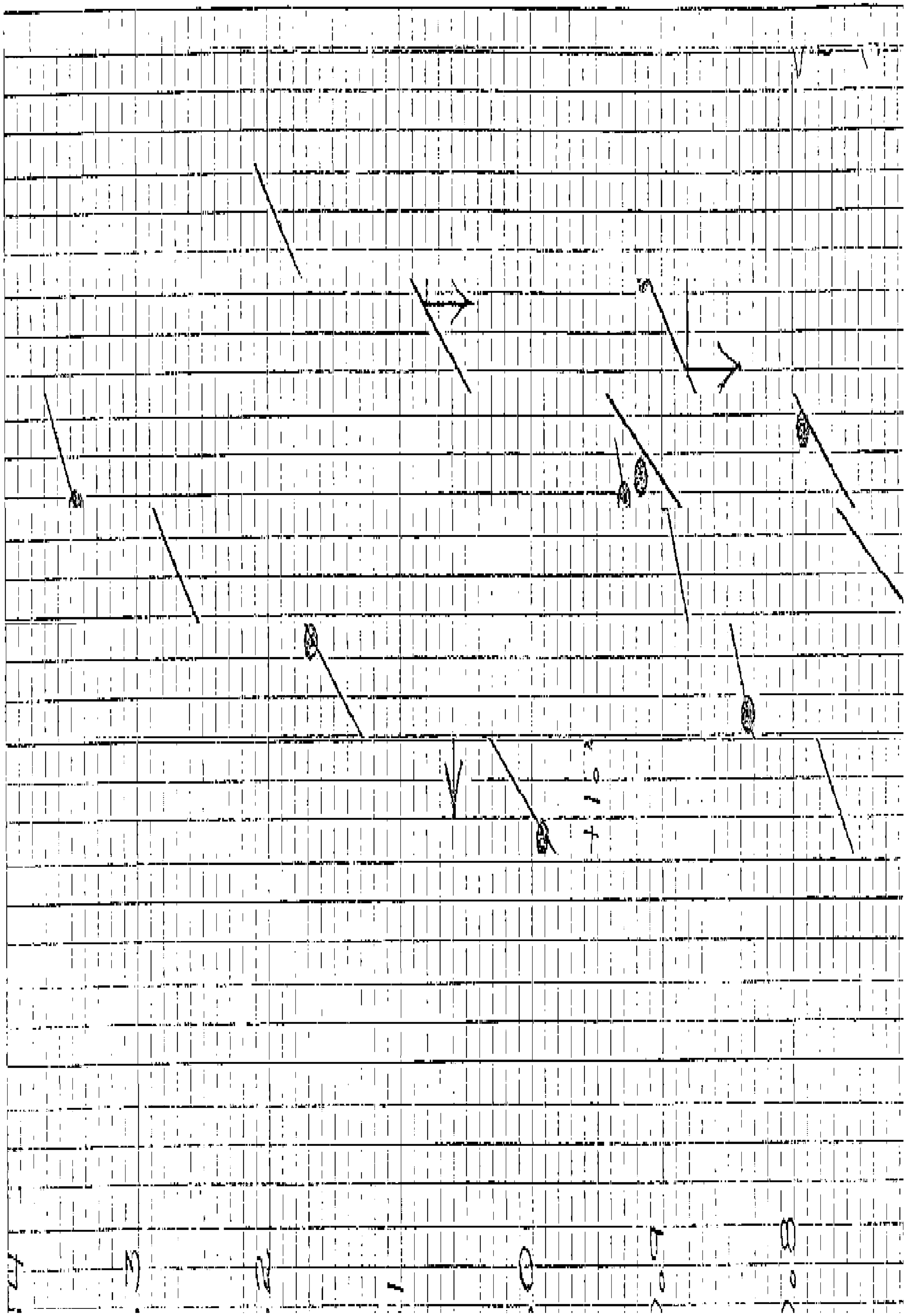
PENSTOCK PRESS READING (%)	ITB ELEV (FT MSL)	CORRECT ELEV (FT MSL) -10.35	PIEZO-METRIC HEAD (FT)	MW CORRECTED FOR HEAD (MW)	$\sqrt{D}$ CORRECTED FOR HEAD ($FT^{1/2}$)	RELATIVE EFFICIENCY	h_L (FT)
97.3	868.79	858.44	109.84	1.463	0.331	4.413	0.30
96.6	868.47	858.12	109.72	2.437	0.472	5.168	0.40
95.9	868.16	857.81	108.81	3.185	0.585	5.440	0.48
95.1	867.80	857.45	107.80	4.260	0.752	5.665	0.44
93.5	867.08	856.73	106.73	5.339	0.907	5.890	0.69
91.1	866.00	855.65	105.40	6.818	1.140	5.982	0.92
88.2	864.69	854.34	103.84	8.355	1.379	6.060	1.20
84.0	862.80	852.45	101.80	10.187	1.659	6.139	1.69
78.2	860.19	849.84	98.99	12.454	2.044	6.092	2.28
74.8	858.66	848.31	97.26	13.557	2.187	6.198	2.72
----	------	------	------	------	-----	-----	
88.1	864.65	854.30	103.70	8.326	1.366	6.093	1.19
91.7	866.27	855.92	105.52	6.468	1.088	5.943	0.87
94.5	867.53	857.18	107.08	4.521	0.801	5.643	0.58
96.0	868.20	857.85	107.95	2.980	0.566	5.263	0.49
97.3	868.79	858.44	108.94	1.576	0.348	4.536	0.27
97.6	868.92	858.57	109.17	2.020	0.416	4.857	0.07
97.7	868.97	858.62	109.32	1.526	0.354	4.313	0.10
97.4	868.83	858.48	109.03	2.420	0.465	5.203	0.05
97.5	868.88	858.53	108.93	2.691	0.511	5.270	-0.08
96.9	868.61	858.26	108.66	2.812	0.534	5.268	0.14
96.9	868.61	858.26	108.61	2.963	0.569	5.204	0.08
96.8	868.56	858.21	108.56	3.019	0.586	5.151	0.11
96.8	868.56	858.21	108.56	3.025	0.598	5.059	0.08
96.8	868.56	858.21	108.51	2.997	0.610	4.915	0.02
95.8	868.11	857.76	107.96	4.082	0.714	5.686	0.21
95.2	867.84	857.49	107.54	4.530	0.790	5.730	0.30
94.8	867.66	857.31	107.31	4.789	0.834	5.743	0.35
94.7	867.62	857.27	107.27	4.909	0.857	5.729	0.33
94.2	867.39	857.04	106.99	5.009	0.898	5.581	0.42
94.1	867.35	857.00	106.95	5.121	0.929	5.510	0.35
95.9	867.16	857.81	108.01	3.499	0.658	5.321	0.34

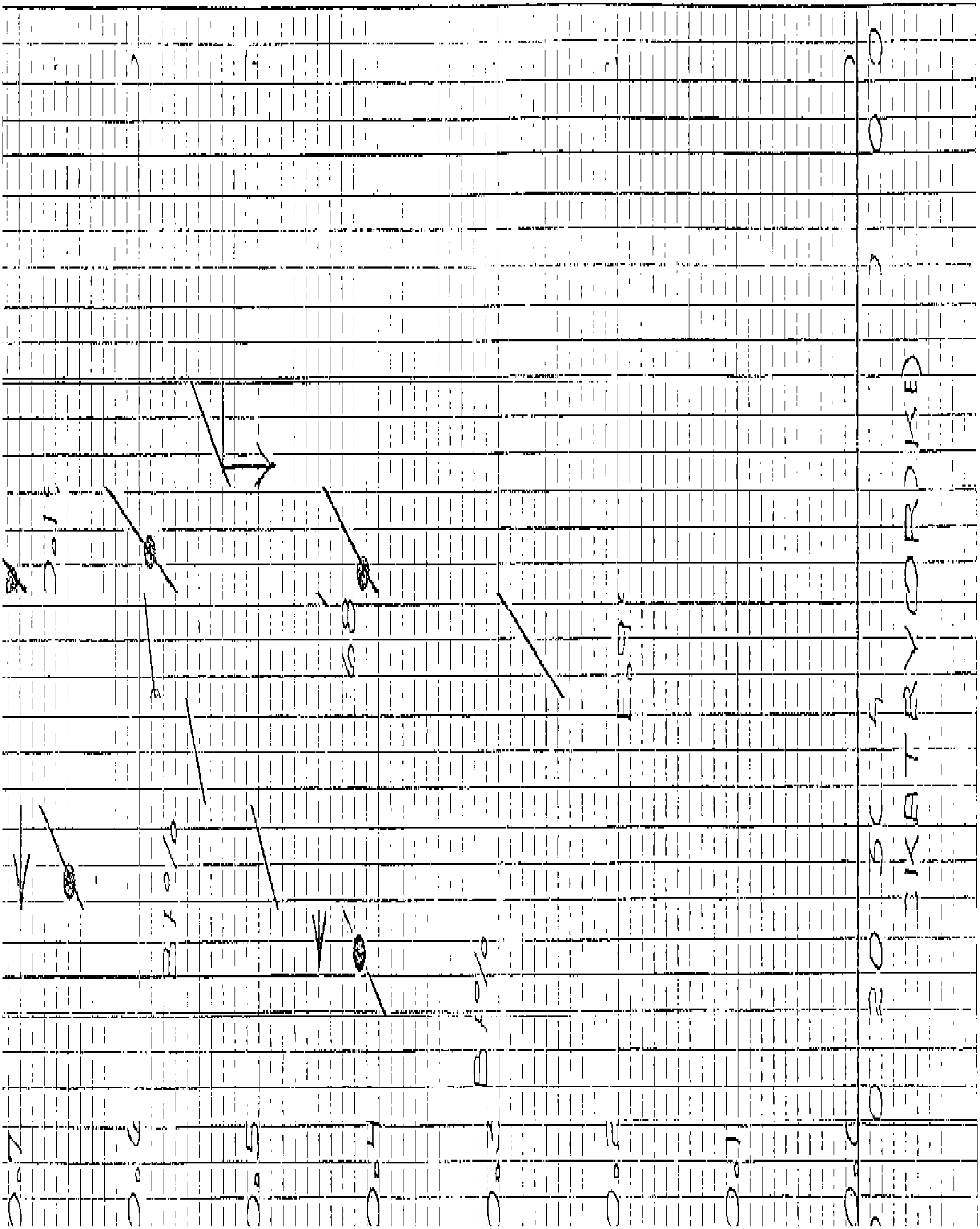
(VS1-5237T)

TABLE 1
SHEET 1



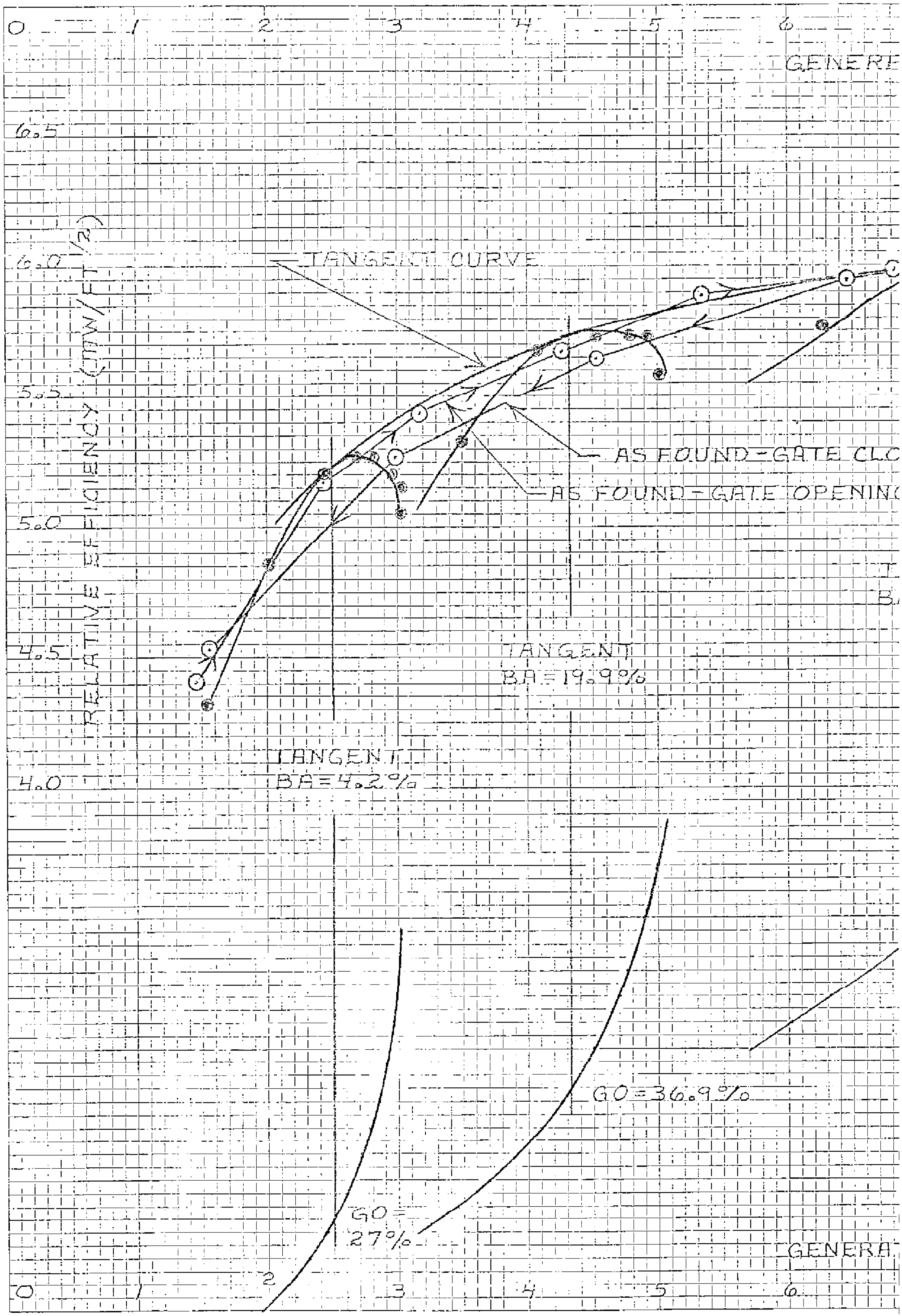


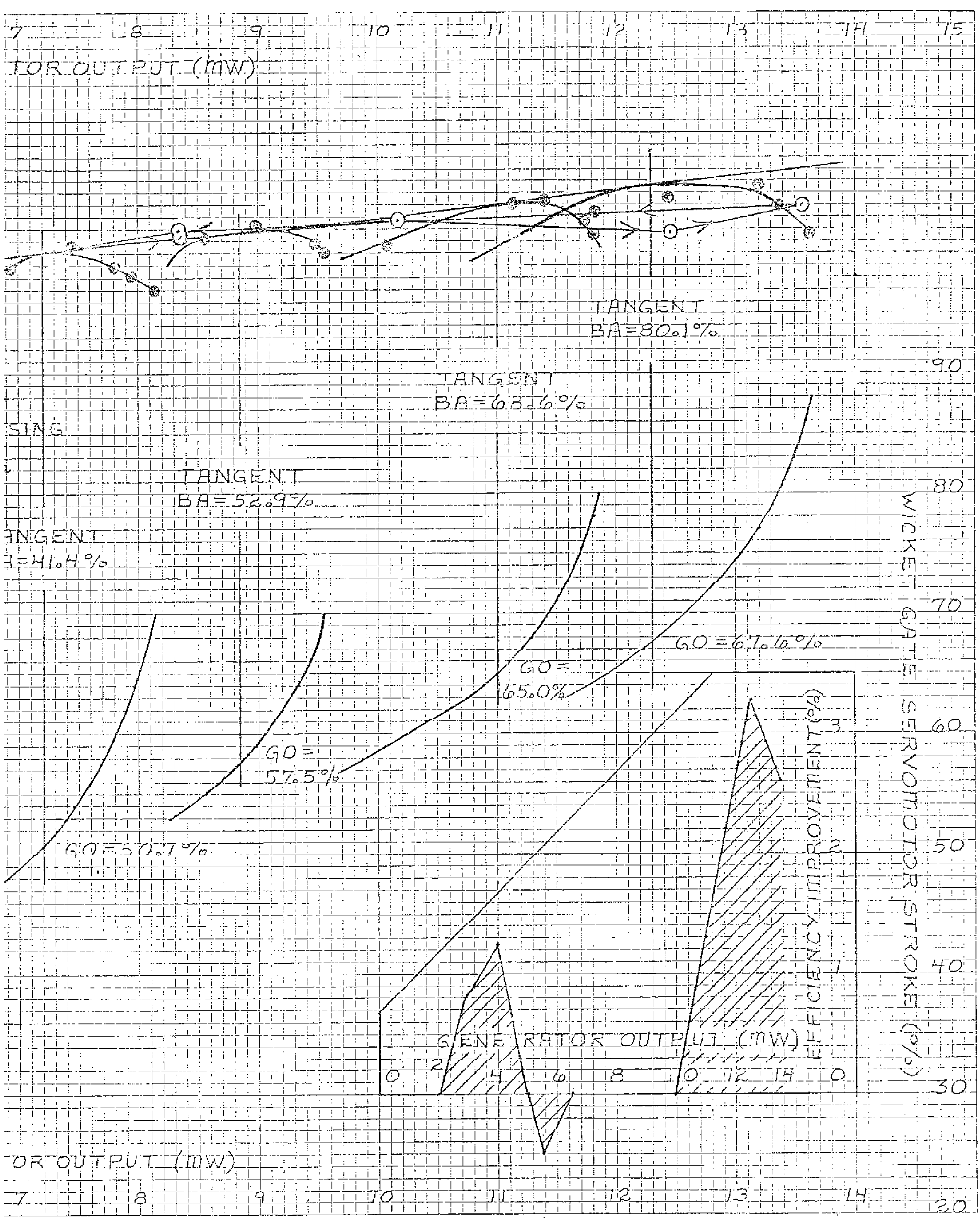




47 0703

K&E 10 X 10 TO THE INCH • 10 X 15 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.





TOR OUTPUT (MW)
TANGENT
BA=80.1%
TANGENT
BA=68.6%
SING
TANGENT
BA=52.9%
ANGENT
=41.4%
GO=67.6%
GO=
65.0%
GO=
57.5%
GO=50.7%
WICKET GATE SERVOMOTOR STROKE (%)
EFFICIENCY IMPROVEMENT (%)
GENERATOR OUTPUT (MW)
OR OUTPUT (MW)

GRAPH 3