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INFORMATIONAL ROUTING

HYDRAULICS BRANCH
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Memorandum

Denver, Colorado
August 18, 1975

Chief, Mechanical Branch

Acting Chief, Division of Design FE, 8/20

ACTING Chief, Division of General Research WP Simmons 8/20/75

Chief, Hydraulics Branch

Test Results with Vortex Entrained Airflow through the 9-inch Model Turbine of Units 19, 20, and 21 for Grand Coulee Third Powerplant (My Memorandum to You Dated July 28, 1975, Copy Attached)

Tests have recently been performed at the Estes Powerplant Test Facility to determine effect of penstock intake vortex entrained air passing through the model turbine and draft tube. The tests were performed in accordance with a request made by Mr. Carlos Bates during a meeting with Hydraulics Branch personnel on June 24, 1975.

The following materials are attached to graphically and numerically illustrate test conditions and results:

Page	Item
1A	Speed coefficient, phi, versus gate angle with efficiency contours, draft tube throat flow swirl curves, and net head lines (phi hill curves). Run numbers are shown on the right side of this page with leaders to the test points.
2A	Test facility diagram to illustrate locations of performance test measurements and to identify corresponding column headings on the data acquisition and results sheets, pages 3A through 9A.
3A	Run 442, 28° gate, phi = 0.82, no vortex air at penstock intake. Printout of basic transducer voltages, averages, equivalent engineering units, and calculated results of turbine performance. Does not include draft tube surge pressure amplitudes or runner deflection measurements; these are shown on photograph pages 10A through 14A.
4A	Same, except run 443, with a continuous air entraining vortex at the penstock intake.
5A	Printout of run 444, phi = 0.78, 18° gate, no vortex air at the penstock intake.

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6A	Same, except run 445, with a continuous air entraining vortex at the penstock intake.
7A	Printout of run 446, phi = 0.91, 18° gate, no vortex entrained air at the penstock intake.
8A	Same, except run 447, with a continuous air entraining vortex of variable size at the penstock intake.
9A	Printout of run 448, same as run 447, except the air entraining vortex at the penstock intake was intermittent. The vortex was fully established until available air was exhausted, then as compressed air flowed into the head tank, the vortex reestablished itself and continued to cycle in this manner.
10A	Runs 442 and 443, 28° gate, photographs of analog signals on oscilloscope display to show comparative magnitude of draft tube throat pressure fluctuations and runner deflection values without and with vortex entrained air passing through the turbine when operating free of draft tube surges. Note the difference in vertical sensitivity of the draft tube throat pressure traces in the two photographs. The grid pattern of the oscilloscope display is composed of 1-cm squares. The draft tube throat pressure tap is on the tailrace side of the throat. The proximity sensor faces the runner band 180° from the throat pressure tap. The analog signals were routed through a band pass electronic filter that passed frequencies of 15 hertz or less. This range includes draft tube throat vortex rotational frequencies and related runner deflection frequencies but eliminates signals due to turbine rotational speed.
11A	Runs 444 and 445, 18° gate, photographs of oscilloscope display to show comparative draft tube surge and runner deflection values without and with vortex entrained air passing through the turbine when operating at nonperiodic draft tube surge conditions.
12A	Runs 446 and 447, 18° gate, photographs to show comparative draft tube surge and runner deflection values without and with vortex entrained air, from a variable size vortex, passing through the turbine when operating at periodic draft tube surge (rough operation) conditions.
13A	Runs 446 and 448, same as above, except the photograph from run 448 illustrates the effect of air entrained by an intermittent vortex. Note the change in vertical sensitivity for the upper traces in the photograph.

14A	Repeat photograph from run 448 with an oscilloscope display horizontal sweep time of 1 cm/s instead of 10 cm/s used for all previous photographs. This photograph illustrates a null condition in draft tube throat surge pressure as air entrained by a reocurring vortex initially reaches the draft tube throat. Greater than original amplitude draft tube surge pressure reoccurs almost immediately as air continues to pass through the turbine.

Operating conditions for test runs performed to determine effects of penstock intake vortex entrained air are shown by run numbers, along the right side of page 1A, and leaders to the test points. Runs 442 and 443 were performed near rated head, at rated speed, 106 percent of rated power, and near 0 draft tube swirl. Under these conditions, the model turbine operates extremely smooth with very low amplitude random draft tube throat pressure fluctuations as illustrated by the top photograph on page 10A. When vortex entrained air was passing through the turbine, the draft tube throat pressure fluctuations and runner deflections changed to the values shown by the bottom photograph on page 10A. Note the change in the vertical sensitivity scale of the draft tube throat pressure traces. The grid of the photographed oscilloscope display is composed of 1-cm squares. The signal sweep time from the left side of the grid to the right side is 1 second.

The photographs on page 10A show significant increases in draft tube pressure fluctuations and runner deflections due to penstock intake vortex entrained air passing through the turbine. The maximum amplitude of pressure fluctuations increased from 0.8 foot of water without vortex airflow to 10 feet of water with vortex airflow through the turbine. Runner deflection increased from practically 0 to about 0.4 of a mil due to vortex airflow. However, maximum draft tube throat pressure fluctuations due to vortex air during run 443 are not as large as those that occurred during run 446, photograph at top of page 12A, when these fluctuations were due to periodic surging and attained an amplitude of 15 feet.

Turbine runner deflection values were greater with vortex entrained air during run 443 than they were during any runs made with or without air. Runs 446 and 447 in the fully developed draft tube surge range revealed runner deflections of about 0.25 of a mil that were not appreciably modified by vortex entrained air. Note the change of vertical sensitivity of the runner deflection signal between runs 445 and 446, page 11A and 12A.

A vortex was created at the penstock intake by feeding compressed air into the top of the head tank through a pressure regulator, an airflow meter and a manual rate-of-flow control valve. Intermittent vortices were created while adjusting the airflow to create a constant vortex.

Observations of the intermittent airflow in the draft tube throat and the oscilloscope display revealed that the intermittent airflow momentarily decreased draft tube throat pressure surges to about one-fourth original amplitude, then the surges returned at greater than original amplitude. This phenomenon occurred in about one-half second and is shown by the lower photograph on page 13A taken during run 448 with turbine operation in the periodic draft tube surge (rough operation) range. The photograph on page 14A which covers a 10-second time period, further illustrates this phenomenon. The intermittent flow of vortex entrained air through the turbine was accompanied by change from a thumping-type typical rough operation sound to a mechanical rattle sound.

The water discharge during run 442, without vortex airflow, was 17.30 ft^3/s and the turbine efficiency was 91.05 percent. During run 443, the water discharge was nearly the same at 17.23 ft^3/s and the efficiency was also nearly the same at 91.03 percent when vortex entrained airflow through the turbine was 2.8 percent of the waterflow. These values are shown on printout pages 3A and 4A. Apparently, the most significant problems created by vortex entrained airflow through this turbine, when operating free of draft tube surges are creation of pressure surges, especially in the draft tube throat, and fluctuating forces on rotating components of the turbine. No pressure fluctuation measurements were obtained between the spiral case inlet and the draft tube throat and significant pressure fluctuation occurrences in this portion of the flow system are unknown.

There are numerous interrelated results of these tests that might be discussed. However, it is left to the reader to pursue those that are of concern through study of the attached test results.

D. L. KING

Attachments

Copy to: Chief, Division of Power Engineering, E&R Center
(with attachment)

[illegible] 251
254
(with attachment to each)
1532

INFORMATIONAL ROUTING

Memorandum

Chief, Mechanical Branch

Denver, CO
July 28, 1975

Chief, Division of Design
Chief, Division of General Research UGc 7/29/75

Chief, Hydraulics Branch

Potential Adverse Effects of Vortex Formation During Startup of Unit 19, Grand Coulee Third Powerplant

The three hydraulic model studies for features of Grand Coulee Third Powerplant all indicated that air-entraining vortices may occur in the prototype. Because vortex modeling is uncertain in predicting prototype vortex size, there may be potential for vortices large enough to cause structural damage.

Danger signals for impending vortex damage are implicit. Whether or not air is drawn through the trashrack into the penstock, a large vortex should be regarded as a potential threat. The trashrack is the upstream-most hydraulic structure exposed to vortex action. Fast rotational vortex velocities acting on the trashrack may produce vibration and noise, and thus be a cautioning influence in progressing with the startup. Rotational velocities of the vortex should be somewhat reduced after passing through the trashrack, but could persist downstream to the turbine. Model turbine test data from the Estes Park facility should be beneficial for providing information about detection of vortex danger signals in the vicinity of the turbine.

It is recommended that vortex observations be made, with continuous communication between the observers and the operator. If a large vortex forms then observations of increased noise, vibrations, and pressure surges can be made, and if necessary the system could be immediately shut down.

Enclosed are two sections from the draft report "Hydraulic Model Vortex Study - Grand Coulee Third Powerplant" that refer to the matter of vortex formation and potential adverse effects.

D. L. KING

Enclosures

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1532

NECESSITY FOR, AND COMMENTS ABOUT, PROTOTYPE OBSERVATIONS

Results of the model tests did not produce a reliable and definite answer to whether there will be a vortex problem near the intakes of the Grand Coulee Third Powerplant. The model test results did, however, indicate the possible danger of a vortex problem developing. Therefore, prototype operation should be closely observed to determine if a vortex problem exists, and if the vortex is of sufficient magnitude to be potentially harmful to the trashracks, turbines, or other parts of the hydraulic structure. Because the magnitude of a possible vortex is unknown and considering the huge size of the hydraulic structures, it is imperative that observations be made at the very onset of operation for the first unit. If the vortex appears "dangerous" then the system could immediately be shut down. These observations should also be made at the initial operation of each new unit and repeated with all installed units operating.

It should be kept in mind that the first unit will probably not exhibit the most severe vortex action. The hydraulic model tests indicated that the vortex severity increased as the number of operating units increased. The greatest change in vortex severity occurred with an increase from one to three operating units. Further increase in the number of operating units only slightly increased the vortex severity.

The increase of vortex severity is especially significant with respect to the installation sequence of the first three units. Installation of the units were planned at 6-month intervals. A beneficial factor of this installation sequence is that the worst vortex conditions will not occur during the initial operation of the Grand Coulee Third Powerplant. There should be time for observation and study to determine if raft installation will be necessary. Estimating flow conditions for a more severe vortex while observing less severe conditions will be difficult. Rafts that work well for the less severe conditions may be inadequate for the more severe conditions.

The prototype observations may also provide the means for verifying guidelines for the rafts, as obtained from the model tests. The information should prove or disprove: (1) location where raft coverage is needed, (2) dimensions of the raft, and (3) velocity acting upon the raft. Rahm8/, gives some description about making prototype velocity measurements and observations.

8/Rahm, L., Flow Problems with Respect to Intakes and Tunnels of Swedish Hydro-Electric Power Plants, Bulletin No. 36, of the Institution of Hydraulics at the Royal Institute of Technology, Stockholm, Sweden, 1953.

CONCLUSIONS AND RECOMMENDATIONS

1. There is insufficient information to define unacceptable vortex conditions at the Grand Coulee Third Powerplant. The effect of vortex action upon the prototype trashrack structures and turbines is unknown.

2. There are no hydraulic model similitude laws that accurately correlate hydraulic model vortices to the prototype operation. Test results from the hydraulic model were primarily qualitative.

3. The hydraulic model test indicated there may be danger of air-entraining vortices occurring in the forebay channel near the intakes of the Grand Coulee Third Powerplant.

4. Without model trashracks, vortices were generally the most severe in the region immediately in front of the intake. This region was very susceptible in vortex development or the continuation of a developed vortex. The model trashracks occupied and restrained a portion of this vortex prone region from contributing to vortex action.

5. Hydraulic model tests indicate that the vortex severity increased as the number of operating units increased.

6. Rafts placed in the hydraulic model were successful in eliminating formation of air-entraining vortices.

7. Operation of the prototype structure will be needed to verify the results obtained from the hydraulic model vortex study.

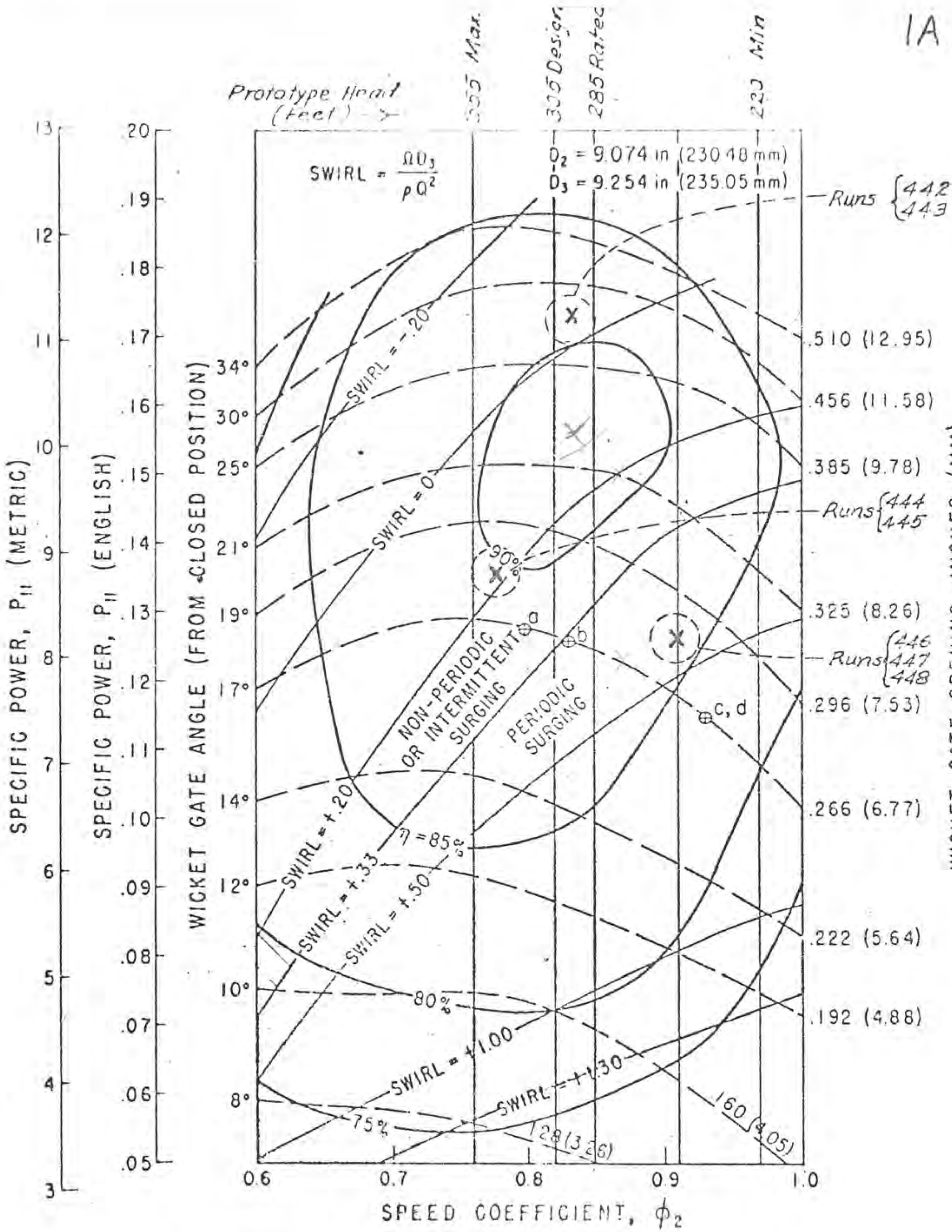
8. Observation of vortex conditions is recommended during prototype operation. Three types of observations are necessary.

   a. Prototype observations to determine the extent of a vortex problem and to determine if rafts are needed.

   b. If rafts are needed, then further vortex observations are required to verify adequacy of the raft design guidelines.

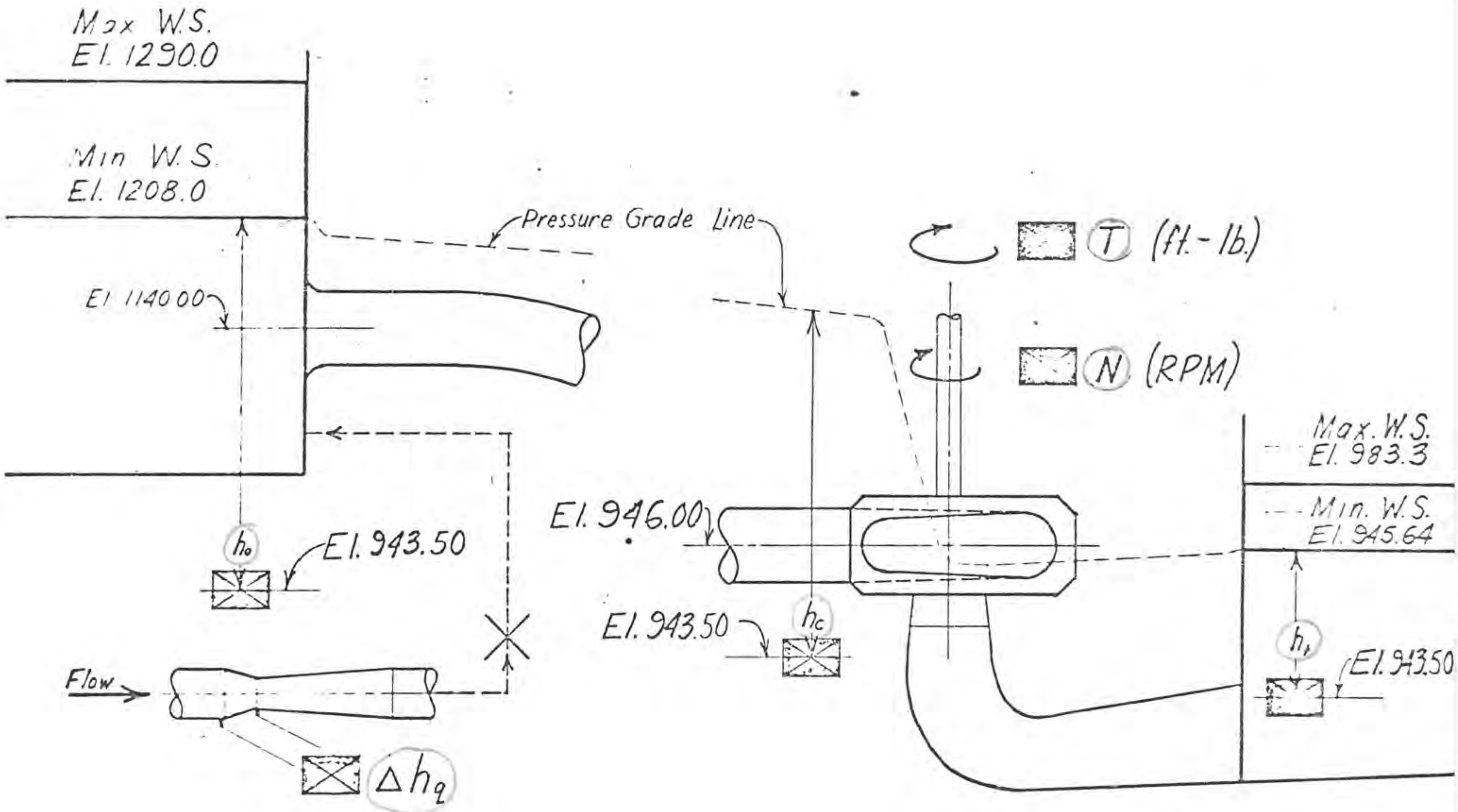
   c. As a safety precaution, observations to insure that structural damage does not occur. These observations should be made during initial operation of each newly installed unit and with all other units operating.

1A



9-inch D.F.W. Model Turbine at Estes Powerplant Test Facility

Runs 442 through 448 for Intake Vortex Entrained Air Tests


Max W.S.
El. 1290.0
Min W.S.
El. 1208.0
Pressure Grade Line
El 1140.00
T (ft.-lb.)
N (RPM)
Max. W.S.
El. 983.3
Min. W.S.
El. 945.64
El. 946.00
h_o
El. 943.50
El. 943.50
h_c
h_t
El. 943.50
Flow
Δh_q

GRAND COULEE [illegible] MODEL OF [illegible]

DATE: 750709 H(ATM)= 26.17 H(V)= .44

****

RUN NR. 442 - No Air
GATE ANGLE= 28

H(D)	H(C)	H(T)	HG(Q)	RPM	TORQUE	
3.5000	3.4290	1.5720	2.0180	8.0310	3.0470	VOLTS
3.5130	3.4230	1.5590	2.0150	8.0350	3.0550	VOLTS
3.5170	3.4340	1.5670	2.0160	8.0320	3.0760	VOLTS
3.4990	3.4320	1.5650	2.0190	8.0310	3.0510	VOLTS
3.5050	3.4360	1.5650	2.0200	8.0330	3.0690	VOLTS
3.5110	3.4400	1.5650	2.0150	8.0300	3.0550	VOLTS
3.5070	3.4490	1.5750	2.0140	8.0400	3.0530	VOLTS
3.5080	3.4440	1.5710	2.0130	8.0370	3.0260	VOLTS
3.5090	3.4350	1.5710	2.0150	8.0250	3.0500	VOLTS
3.4980	3.4470	1.5680	2.0150	8.0300	3.0320	VOLTS
3.5067	3.4370	1.5679	2.0160	8.0324	3.0519	AVERAG
324.159	317.323	36.198	1.865	2902.452	947.701	ENG.

TEST POINT

PHI= .8232 N11= 126.0 H(P)= 303.5
SIGMA= .2026 T.W.= 979.70

MODEL MEASUREMENTS

-BHP_p = 851,900.

H= 293.30 RPM= 2902.5 Q= 17.30 T= 947.7 BHP= 523.7

MODEL RESULTS

E= 91.05 HP11= .1834 Q11= 1.825

SWIRL= -.06

D.T. SURGE

FREQ.= 0.00
RMS PRES.= 1.1 FT .4% OF H
F. PAR.= 0.00
P. PAR.= .04

****

****
RUN NR. 443 With Air, Constant Vortex
GATE ANGLE= 28

H(O)	H(C)	H(T)	HG(Q)	RPM	TORQUE	
3.5270	3.4570	1.5780	2.0060	8.0290	2.9550	VOLTS
3.5380	3.4710	1.6010	2.0030	8.0290	3.0310	VOLTS
3.5320	3.4590	1.6310	2.0010	8.0270	3.0660	VOLTS
3.5210	3.4410	1.5970	2.0020	8.0230	3.0380	VOLTS
3.5320	3.4620	1.5970	2.0000	8.0310	3.0660	VOLTS
3.5220	3.4460	1.5890	2.0010	8.0310	3.0520	VOLTS
3.5150	3.4510	1.5940	2.0020	8.0230	3.0360	VOLTS
3.5230	3.4340	1.5900	2.0000	8.0330	3.0580	VOLTS
3.5210	3.4530	1.5830	2.0050	8.0310	3.0360	VOLTS
3.5390	3.4510	1.6020	1.9970	8.0290	3.0500	VOLTS
3.5270	3.4525	1.5962	2.0017	8.0285	3.0438	AVERAGE
326.036	318.754	36.851	1.852	2901.042	946.739	ENG. VAL.

TEST POINT

PHI= .8210   N11= 125.0   H(P)= 304.6
SIGMA= .2043   T.W.= 980.35

MODEL MEASUREMENTS

H= 294.05   RPM= 2901.0   Q= 17.23   T= 946.7   BHP= 522.9

$BHP_p = 850,600.$

MODEL RESULTS

E= 91.03   HP11= .1375   Q11= 1.817

$\bar{Q}_{Air} = 0.49\ cfs$ (free air)

SWIRL= -.06

$\frac{Q_{Air}}{Q_{water}} = 2.8\%$

D.T. SURGE

FREQ.= 0.00
RMS PRES.= 3.0 FT   1.0% OF H
F. PAR.= 0.00
P. PAR.= .11

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[illegible] 9-IN MODEL AT [illegible]

DATE: 750710 H(HIM)= 26.24 H(V)= .44

CAL. FACTORS

92.4400 92.4770 23.8996 .9300 361.5680 310.7000

RUN NR. [illegible] — *No Air*
GATE ANGLE= 10

H(O)	H(C)	H(T)	HG(Q)	RPM	TORQUE	
3.8460	3.8020	1.5410	1.2060	7.9250	2.6270	VOLTS
3.8400	3.7880	1.5410	1.2060	7.9270	2.6350	VOLTS
3.8420	3.7920	1.5530	1.2030	7.9270	2.6220	VOLTS
3.8370	3.8110	1.5420	1.2040	7.9240	2.6330	VOLTS
3.8490	3.8020	1.5420	1.2050	7.9250	2.6350	VOLTS
3.8370	3.7930	1.5510	1.2050	7.9260	2.6200	VOLTS
3.8490	3.8170	1.5400	1.2070	7.9260	2.6230	VOLTS
3.8350	3.7970	1.5390	1.2020	7.9250	2.6270	VOLTS
3.8450	3.7920	1.5470	1.2090	7.9300	2.6280	VOLTS
3.8440	3.8070	1.5470	1.2040	7.9320	2.6290	VOLTS
3.8424	3.8001	1.5443	1.2051	7.9267	2.6285	AVERAGE
355.191	351.422	35.673	1.121	2866.041	816.675	ENG. VALUES

USE PANEL RPM = 2863

TEST POINT

PHI= .7737 N11= 118.5 H(P)= 343.6
SIGMA= .1825 T.W.= 979.17

MODEL MEASUREMENTS

$BHP_p = 724,200.$

H= 323.10 RPM= 2863.0 Q= 13.41 T= 816.7 BHP= 445.2

MODEL RESULTS

E= 90.67 HP11= .1366 Q11= 1.348

SWIRL= .17

D.T. SURGE

FREQ.= [illegible]
RMS PRES.= .9 FT .% OF H
F. PAR.= 0.00
P. PAR.= [illegible]

RUN NR. 145 - Constant Vortex
GATE ANGLE= 18

H(0)	H(C)	H(T)	HG(Q)	RPM	TORQUE	
3.8530	3.8050	1.5400	1.2030	7.9140	2.6570	VOLTS
3.8480	3.8080	1.5410	1.2010	7.9170	2.6480	VOLTS
3.8360	3.8040	1.5330	1.2040	7.9170	2.6350	VOLTS
3.8470	3.7950	1.5410	1.2040	7.9170	2.6360	VOLTS
3.8440	3.8010	1.5390	1.2040	7.9180	2.6380	VOLTS
3.8600	3.8080	1.5450	1.2010	7.9160	2.6520	VOLTS
3.8560	3.7970	1.5550	1.2050	7.9150	2.6390	VOLTS
3.8500	3.7920	1.5330	1.2010	7.9170	2.6510	VOLTS
3.8450	3.8020	1.5420	1.2020	7.9150	2.6480	VOLTS
3.8470	3.8130	1.5440	1.2050	7.9170	2.6520	VOLTS
3.8486	3.8028	1.5413	1.2030	7.9163	2.6456	AVERAGE
355.765	351.672	35.603	1.119	2862.281	821.988	ENG. VALUES

USE PANEL RPM = 2860

TEST POINT

PHI= .7726 N11= 118.3 H(P)= 344.6
SIGMA= .1822 T.W.= 979.10

MODEL MEASUREMENTS

$BHP_p = 728,100.$

H= 323.41 RPM= 2860.0 Q= 13.39 T= 822.0 BHP= 447.6

MODEL RESULTS

$Q_{air} = 0.42$ cfs (free air)

E= 91.15 HP11= .1391 Q11= 1.346

$\frac{Q_{air}}{Q_{water}} = 3.1\%$

SWIRL= .16

D.T. SURGE

FREQ.= 0.00
RMS PRES.= 1.4 FT .4% OF H
F. PAR.= 0.00
P. PAR.= .09

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****
RUN NR. 446 – No Air
GATE ANGLE= 10

H(O)	H(C)	H(T)	HG(O)	RPM	TORQUE	
2.9660	2.9340	1.5600	.8280	8.0370	1.5330	VOLTS
2.9690	2.9320	1.5690	.8270	8.0390	1.5350	VOLTS
2.9790	2.9480	1.5740	.8300	8.0420	1.5230	VOLTS
2.9700	2.9430	1.5720	.8280	8.0460	1.5200	VOLTS
2.9770	2.9260	1.5510	.8270	8.0420	1.5050	VOLTS
2.9700	2.9330	1.5600	.8260	8.0430	1.5270	VOLTS
2.9720	2.9460	1.5670	.8290	8.0360	1.5360	VOLTS
2.9740	2.9400	1.5590	.8270	8.0410	1.5260	VOLTS
2.9590	2.9190	1.5590	.8230	8.0420	1.5220	VOLTS
2.9790	2.9350	1.5560	.8250	8.0430	1.5210	VOLTS
2.9715	2.9355	1.5527	.8270	8.0410	1.5242	AVERAGE
274.685	271.466	36.098	.769	2907.368	473.569	ENG. VALUES

TEST POINT

PHI= .9109   N11= 139.5   H(P)= 247.9
SIGMA= .2471   T.W.= 979.60

MODEL MEASUREMENTS

$BHP_p = 426,400.$

H= 240.41   RPM= 2907.4   Q= 11.10   T= 473.-   BHP= 262.1

MODEL RESULTS

E= 86.62   HP11= .1271   Q11= 1.295

SWIRL= .45

D.T. SURGE

FREQ.= 12.10
RMS PRES.= 3. ~~3~~ FT   1% ~~1%~~ OF H
F. PAR.= .50
F. PAR.= .02

****

RUN NR. 447 – Nearly constant Vortex, variable in size
GATE ANGLE= 18

H(O)	H(C)	H(T)	HG(Q)	RPM	TORQUE	
2.9790	2.9500	1.5600				
H(O)	H(C)	H(T)	HG(Q)	RPM	TORQUE	
2.9830	2.9480	1.5630	.8190	8.0370	1.5140	VOLTS
2.9760	2.9480	1.5520	.8220	8.0410	1.5280	VOLTS
2.9710	2.9390	1.5650	.8230	8.0400	1.5270	VOLTS
2.9710	2.9430	1.5620	.8220	8.0400	1.5220	VOLTS
2.9750	2.9450	1.5500	.8240	8.0420	1.5330	VOLTS
2.9790	2.9410	1.5640	.8220	8.0430	1.5320	VOLTS
2.9830	2.9460	1.5660	.8230	8.0410	1.5270	VOLTS
2.9840	2.9460	1.5750	.8270	8.0430	1.5380	VOLTS
2.9830	2.9460	1.5620	.8260	8.0390	1.5250	VOLTS
2.9790	2.9450	1.5740	.8230	8.0400	1.5310	VOLTS
2.9784	2.9447	1.5643	.8231	8.0406	1.5282	AVERAGE
275.323	272.317	36.135	.765	2907.224	474.812	ENG. VALUES

TEST POINT

PHI= .9063 H11= 139.2 H(P)= 248.8
SIGMA= .2464 T.W.= 979.63

MODEL MEASUREMENTS

$BHP_p = 427{,}500.$

H= 241.20 RPM= 2907.2 Q= 11.08 T= 474.8 BHP= 262.8

MODEL RESULTS

$Q_{air} = 0.37$ cfs (free air)

E= 86.76 HP11= .1268 Q11= 1.289

$\frac{Q_{air}}{Q_{water}} = 3.3\%$

SWIRL= .44

D.T. SURGE

FREQ.= 12.40
RMS PRES.= 8.0 FT 3.3% OF H
F. PAR.= .51
P. PAR.= .74

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RUN NO. 48 - Intermittent Vortex
GATE ANGLE= 18

H(O)	H(C)	H(T)	HC(Q)	RPM	TORQUE	
2.7760	2.7370	.1960	.8740	8.2450	1.6320	VOLTS
2.7850	2.7410	.1900	.8810	8.2430	1.6260	VOLTS
2.7810	2.7420	.1970	.8770	8.2560	1.6470	VOLTS
2.7810	2.7380	.1940	.8750	8.2440	1.6380	VOLTS
2.7810	2.7440	.1870	.8800	8.2440	1.6180	VOLTS
2.7770	2.7410	.1930	.8780	8.2470	1.6410	VOLTS
2.7790	2.7360	.1930	.8780	8.2460	1.6210	VOLTS
2.7770	2.7400	.1920	.8780	8.2460	1.6270	VOLTS
2.7810	2.7440	.1760	.8770	8.2430	1.6300	VOLTS
2.7830	2.7400	.1910	.8780	8.2410	1.6280	VOLTS
2.7801	2.7403	.1909	.8776	8.2455	1.6308	AVERAGE
256.992	253.415	4.410	.816	2991.309	506.690	ENG. [illegible]

TEST POINT

PHI= .9081   N11= 139.0   H(P)= 249.5
SIGMA= .1090   T.W.= 947.91

MODEL MEASUREMENTS

$BHP_p = 467,900.$

H= 254.36   RPM= 2991.3   Q= 11.44   T= 506.7   T= 287.6

MODEL RESULTS

$Q_{air} = 0.28$ cfs (free air)

E= 87.19   HP11= .1282   Q11= 1.297

SWIRL= .44

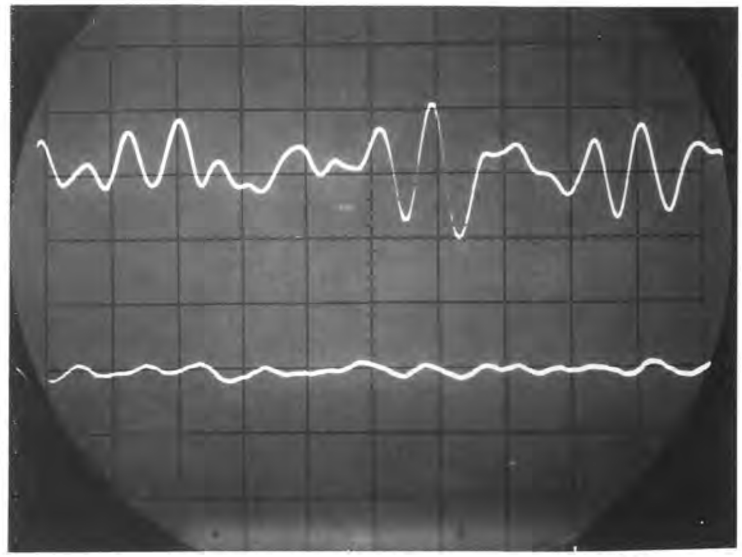
$$\frac{Q_{air}}{Q_{water}} = 2.4\%$$

D.T. SURGE

FREQ.= [illegible].6U
RMS PRES.= 3.5 FT   1.4% OF H
F. PAR.= .51
P. PAR.= .30

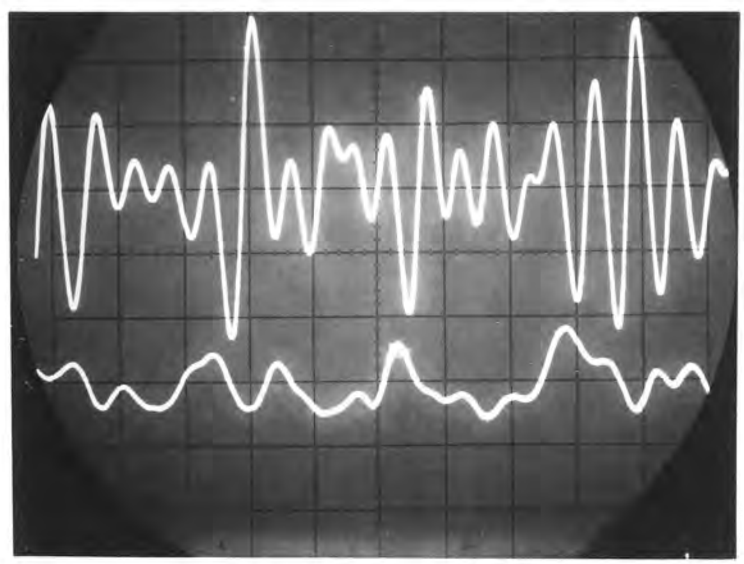
****

Run # 442
Gate Opening 28 °
Phi .82
Net head 293. Ft.
Tailwater El. 980.
Power 851,900. HP
635.3 MW
No penstock intake vortex



Upper trace - Draft tube throat pressure (tailrace side).
Vertical sensitivity 0.4 Ft. H_2O/cm.
Lower trace - Runner proximity transducer (upstream side).
Vertical sensitivity 0.25 Mils deflection/cm.
Sweep speed 10 cm/sec., 15 Hz Low pass filter (both traces).

Run # 443
Gate Opening 28 °
Phi .82
Net head 294. Ft.
Tailwater El. 980.
Power 850,600. HP
634.3 MW
Penstock intake vortex
constant ✓ intermit____
$\frac{\text{Q free air}}{\text{Q water}} \times 100 = 2.8\ \%$



Upper trace - Draft tube throat pressure (tailrace side).
Vertical sensitivity 2 Ft. H_2O/cm.
Lower trace - Runner proximity transducer (upstream side).
Vertical sensitivity 0.25 Mils deflection/cm.
Sweep speed 10 cm/sec., 15 Hz Low pass filter (both traces).

GRAND COULEE THIRD PP UNITS 19, 20, 21. 9-inch MODEL TURBINE

Run # 444

Gate Opening 18 °

Phi .77

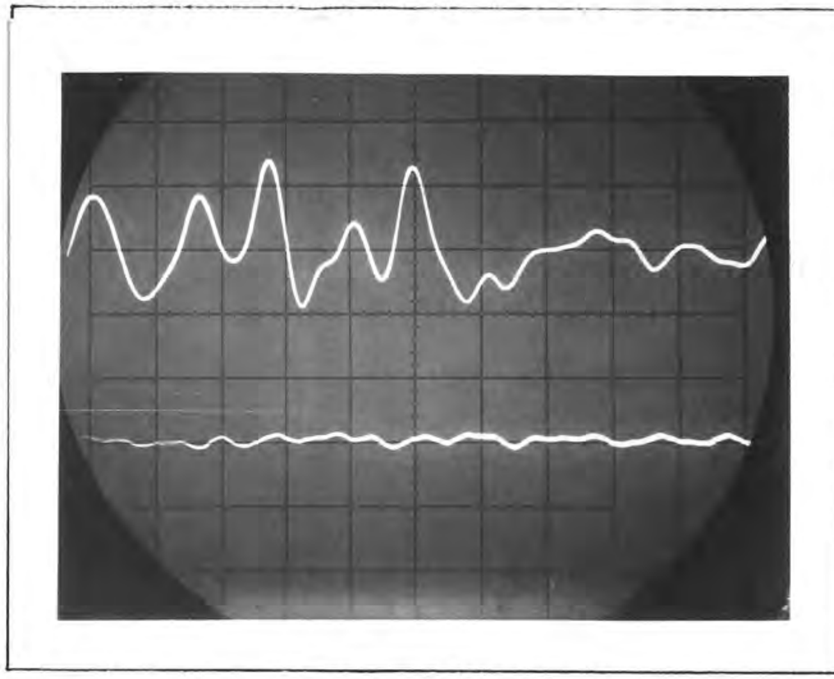
Net head 323. Ft.

Tailwater El. 979.

Power 724,200. HP

540.0 MW

No penstock intake vortex



Upper trace - Draft tube throat pressure (tailrace side).

Vertical sensitivity 0.8 Ft. H_2O/cm.

Lower trace - Runner proximity transducer (upstream side).

Vertical sensitivity 0.25 Mils deflection/cm.

Sweep speed 10 cm/sec., 15 Hz Low pass filter (both traces).

Run # 445

Gate Opening 18 °

Phi .77

Net head 323. Ft.

Tailwater El. 979.

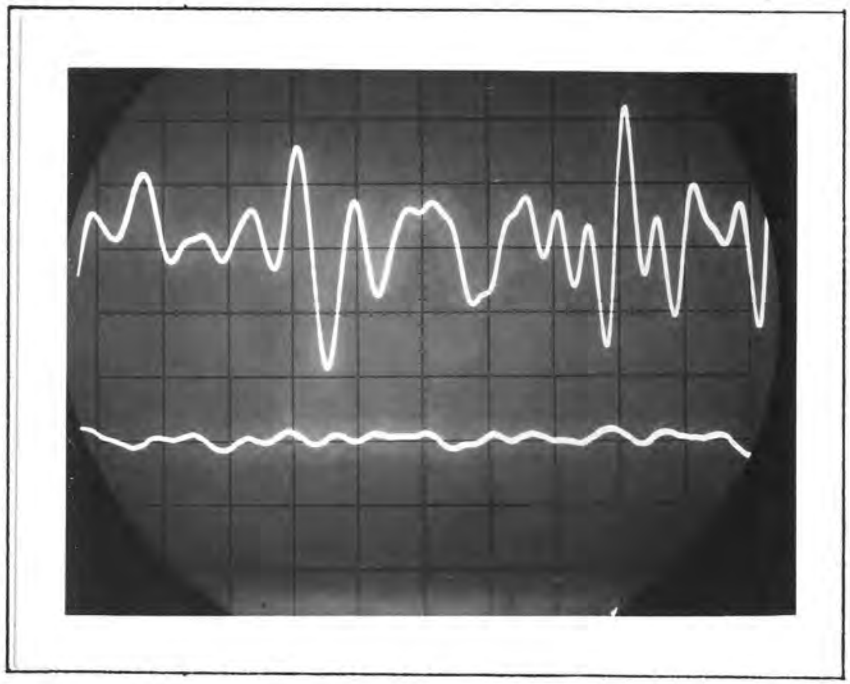
Power 728,100. HP

542.9 MW

Penstock intake vortex

constant ✓ intermit____

$\frac{\text{Q free air}}{\text{Q water}} \times 100 = 3.1$ %



Upper trace - Draft tube throat pressure (tailrace side).

Vertical sensitivity 0.8 Ft. H_2O/cm.

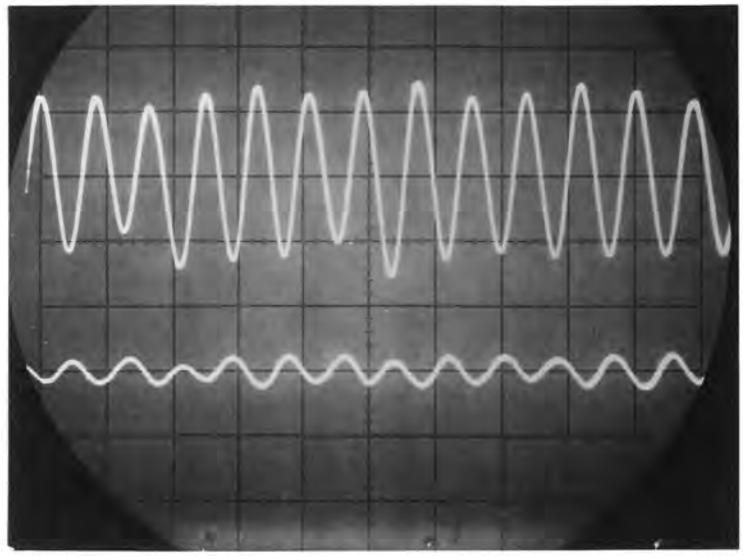
Lower trace - Runner proximity transducer (upstream side).

Vertical sensitivity 0.25 Mils deflection/cm.

Sweep speed 10 cm/sec., 15 Hz Low pass filter (both traces).

GRAND COULEE THIRD PP UNITS 19, 20, 21. 9-inch MODEL TURBINE

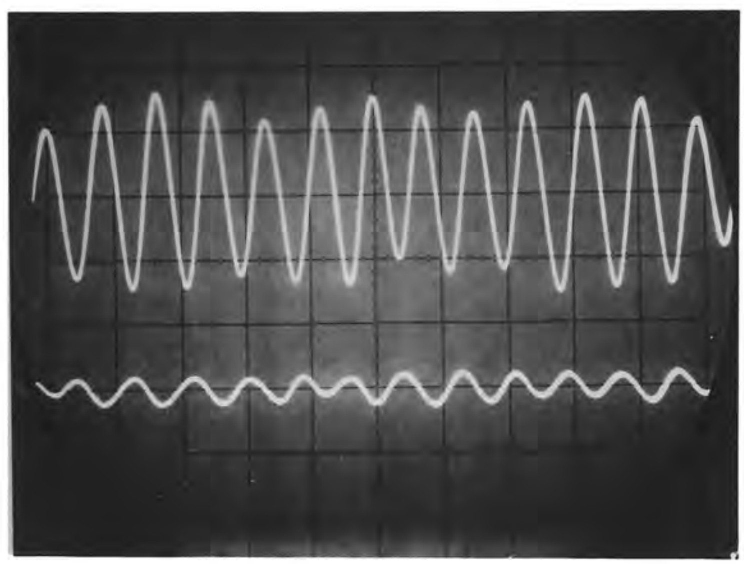
Run # 446
Gate Opening 18 °
Phi .91
Net head 240. Ft.
Tailwater El. 980.
Power 426,400 HP
318.0 MW
No penstock intake vortex



Upper trace - Draft tube throat pressure (tailrace side).
Vertical sensitivity 5 Ft. H_2O/cm.
Lower trace - Runner proximity transducer (upstream side).
Vertical sensitivity 0.5 Mils deflection/cm.
Sweep speed 10 cm/sec., 15 Hz Low pass filter (both traces).

Run # 447
Gate Opening 18 °
Phi .91
Net head 241. Ft.
Tailwater El. 980.
Power 427,500. HP
318.8 MW
Penstock intake vortex
constant ✓ Variable size intermit

$\frac{Q \text{ free air}}{Q \text{ water}} \times 100 = 3.3 \pm \%$



Upper trace - Draft tube throat pressure (tailrace side).
Vertical sensitivity 5 Ft. H_2O/cm.
Lower trace - Runner proximity transducer (upstream side).
Vertical sensitivity 0.5 Mils deflection/cm.
Sweep speed 10 cm/sec., 15 hz Low pass filter (both traces).

Run # 446

Gate Opening 18 °

Phi 0.91

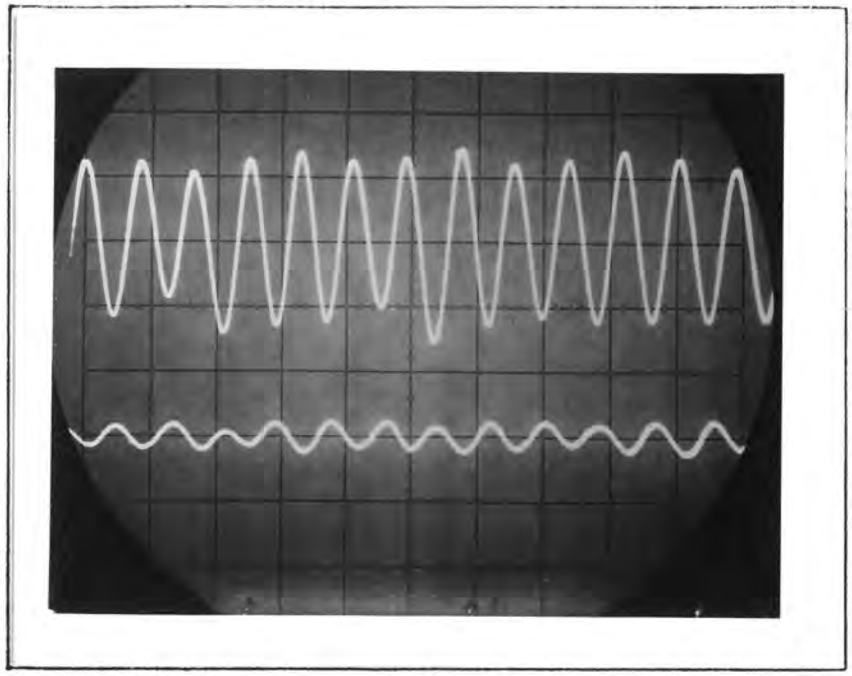
Net head 240 Ft.

Tailwater El. 980

Power 426,000 HP

318.0 MW

No penstock intake vortex



Upper trace - Draft tube throat pressure (tailrace side).

Vertical sensitivity 5 Ft. H_2O/cm.

Lower trace - Runner proximity transducer (upstream side).

Vertical sensitivity 0.5 Mils deflection/cm.

Sweep speed 10 cm/sec., 15 Hz Low pass filter (both traces).

Run # 448

Gate Opening 18 °

Phi .91

Net head 254. Ft.

Tailwater El. 948.

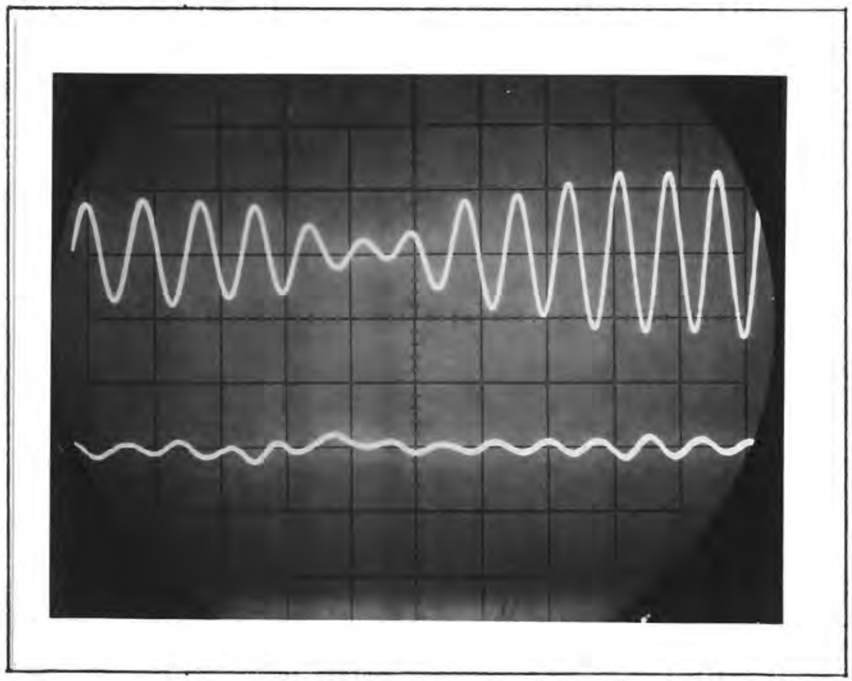
Power 467,900. HP

348.9 MW

Penstock intake vortex

constant ____ intermit ✓

$\frac{\text{Q free air}}{\text{Q water}} \times 100 = 2.4 \pm \%$



Upper trace - Draft tube throat pressure (tailrace side).

Vertical sensitivity 10 Ft. H_2O/cm.

Lower trace - Runner proximity transducer (upstream side).

Vertical sensitivity 0.5 Mils deflection/cm.

Sweep speed 10 cm/sec., 15 Hz Low pass filter (both traces).

GRAND COULEE THIRD PP UNITS 19, 20, 21. 9-inch MODEL TURBINE

Run # 448

Gate Opening 18 °

Phi 0.91

Net head 254 Ft.

Tailwater El. 948

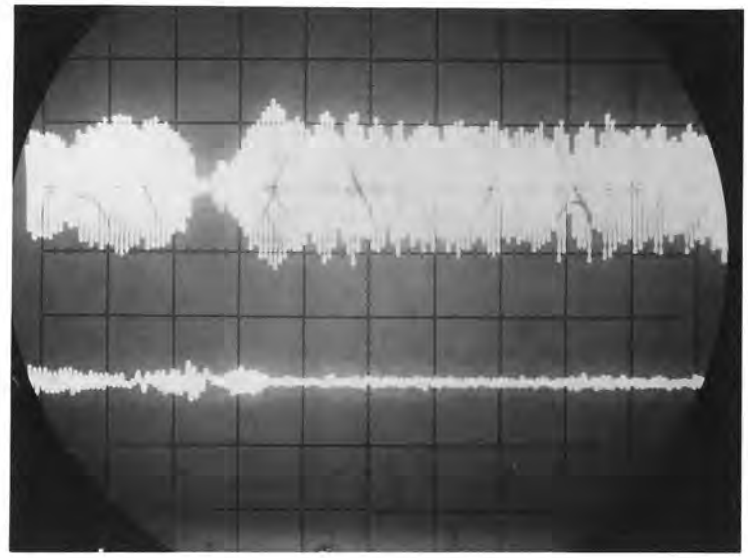
Power 467,900 HP

348.9 MW

Penstock intake vortex

constant____ intermit ✓

$\frac{\text{Q free air}}{\text{Q water}}$ x 100 = 2.4± %



Upper trace - Draft tube throat pressure (tailrace side).

Vertical sensitivity 10 Ft. H_2O/cm.

Lower trace - Runner proximity transducer (upstream side).

Vertical sensitivity 0.5 Mils deflection/cm.

Sweep speed 1 cm/sec., 15 Hz Low pass filter (both traces).

GRAND COULEE THIRD PP UNITS 19, 20, 21. 9-inch MODEL TURBINE