Turbine Index Test
Ice Harbor U6
Runner Blades in Fixed Position

Executive Summary:

An abbreviated index test was conducted for Unit 6 at Ice Harbor Dam on 03 March 2019 to determine the operating range of the unit with the runner blades in a fixed position. Fish screens were not installed during the test. Unit 6 has recently been converted to a fixed blade turbine due to inspection results showing excessive oil leaking at the runner hub. The testing process used to identify the turbine performance consisted of using discrete fixed wicket gate positions at selected outputs while power and relative flow was collected to produce an operating table for this unit, which is included in this report.

Background:

An inspection of Unit 6 revealed questionable excessive oil leak at the runner hub. While in-place repair option are explored, the option to hydraulically lock the blades to return the unit to service was selected. However, the operating range of the unit, and its lower and upper operating limits would have to be determined. This test is an abbreviated index test to determine the best operating range for the unit with the now fixed blade angle.

Test Scope:

The Index method using Winter-Kennedy (W-K) taps was used to determine relative flows and relative efficiencies. The abbreviated index test was performed at the fixed blade position near a gross head of 95 feet. This test, the 2006 U6 with and without screens index test, and the original turbine model test for this family of runners were used to develop an operating tables for the operating head range of the plant. The HDC test team performed testing with the support of project staff.

Test Procedure:

The general test procedure consisted of the selection of a test condition, collection of 2.5 minutes of steady state data, and repeating this data collection 2-3 times for that condition. After data was collected for a test condition, all information was reviewed prior to moving on to the next test condition to provide a quality check of recorded data. The unit was then moved to the next test condition and data collection was repeated.

Discharge Measurements:

The W-K method was used to monitor a relative discharge during the test. This method of measurement does not measure actual discharge unless the W-K readings are calibrated against an absolute method of measurement. The W-K piezometer system measures the difference in angular momentum across a radial plane and any difference in velocity heads at the taps due to non-uniform velocity distribution across the radial plane. By placing piezometer taps at the inside and outside radius and measuring the piezometer differential, a relative index or measurement of discharge can be made.

Unit 6 has two low-pressure taps located at the top of the distributor above the leading edge of the stay vanes and one high-pressure tap located on the outside wall of the semi-spiral case at the centerline elevation of the distributor. The differential pressure transducer (see Photo 1) was connected to the high

pressure tap and the low pressure tap located immediately above stay ring to obtain a differential pressure. A precision scaling resistor was used to place the transducers 4-20 mA output in an appropriate voltage range for logging. Transducer outputs in volts were recorded using a National Instruments Data Acquisition 6225 System.

Power Measurements:

For measurement of power, three single-phase watt transducers as well as current and voltage transducers were connected to the secondary side of the metering instrument transformers. The potential transformers have a ratio of 14,400/120 and the three current transformers have a ratio of 6000/5. During testing, the power, voltage, and current transducer output was routed to the National Instruments Data Acquisition 6225 System.

Head Measurements:

Gross head is the difference between the forebay and tailwater surface elevations. Gross head measurements were logged manually from the digital governor cabinet display during each test run. Prior to testing, head values displayed on the governor HMI of neighboring Unit 5 and the plant head were compared to Unit 6 to ensure that they were all within a reasonable range of each other.

Unit 6 Shutdown Gross Head (ft)	Unit 5 Shutdown Gross Head (ft)	Plant Gross Head (ft)
96.30	95.37	95.13

Unit 6 head reading was 0.93 feet higher than Unit 5 and 1.17 feet higher that the plant head. There was spillway work being completed which caused the tailwater transducer nearest to the work (Unit 6) to read lower than the actual tailwater level. A correction of 0.93 ft was applied to the Unit 6 head readings. Periodic checks of plant head and Unit 5 readings were made to validate Unit 6 corrected head readings.

During testing, the gross head varied from 95.09 feet to 95.48 feet, with an average gross head of 95.25 feet. Test results presented are normalized to a common gross head of 95 feet.

Gate Position Measurements:

During testing, the permanently installed linear transducer mounted on top of the gate servomotor assembly was used to measure gate servostroke. The signal output of this transducer is fed to the digital governor. The signal from the transducer was manually logged from the digital governor display.

Data Reduction:

The index test data was collected by adjusting the gate to a fixed opening, then collecting two or three 2.5-minutes of data. These were then averaged to a final value and reported on the spreadsheet included at the end of this report. The WK data was collected at about 200 points per second so it represented about 30000 points per run. Data collection for the index test required approximately 3 hours to complete. Averaged readings from the W-K and power modules transducers were converted to real engineering values by using previously obtained calibration constants.

Results:

A summary of the test results using the W-K method to compute a relative flow and relative turbine efficiency is presented in Table 1. Table 1 shows the results of each test run, the test run reference number, percent wicket gate servomotor stroke, gross head, generator output and relative discharge. The generator input, turbine output, and relative discharge adjusted to a common gross head of 95 feet are also presented. The relative turbine efficiencies in Figure 1 and Table 1 are adjusted to a peak efficiency of 91.8% to match the turbine model peak efficiency for the blade angle tested.

The target blade angle setting is 23.85 degree. The results were compared to the 2006 Unit 6 without screens index test to determine the blade set position. During this test, the digital governor display showed a blade percentage 42.1%[1] (23.92 degrees) and the oil head scale showed a blade angle setting of 24.0 degrees. The test results indicate an actual blade setting of 23.8 degrees based on the power output at the peak efficiency. Unit 6's flat over-travel was not measured directly prior to testing, rather it was assumed to be the same as the Unit 5's flat over-travel measurement of 16.0 degrees.

[1] 0% and 100% corresponds to flat overtravel (16.0 degrees) and steep overtravel (34.82 degrees) as measured during the 2016 Unit 5 Blade Calibration.

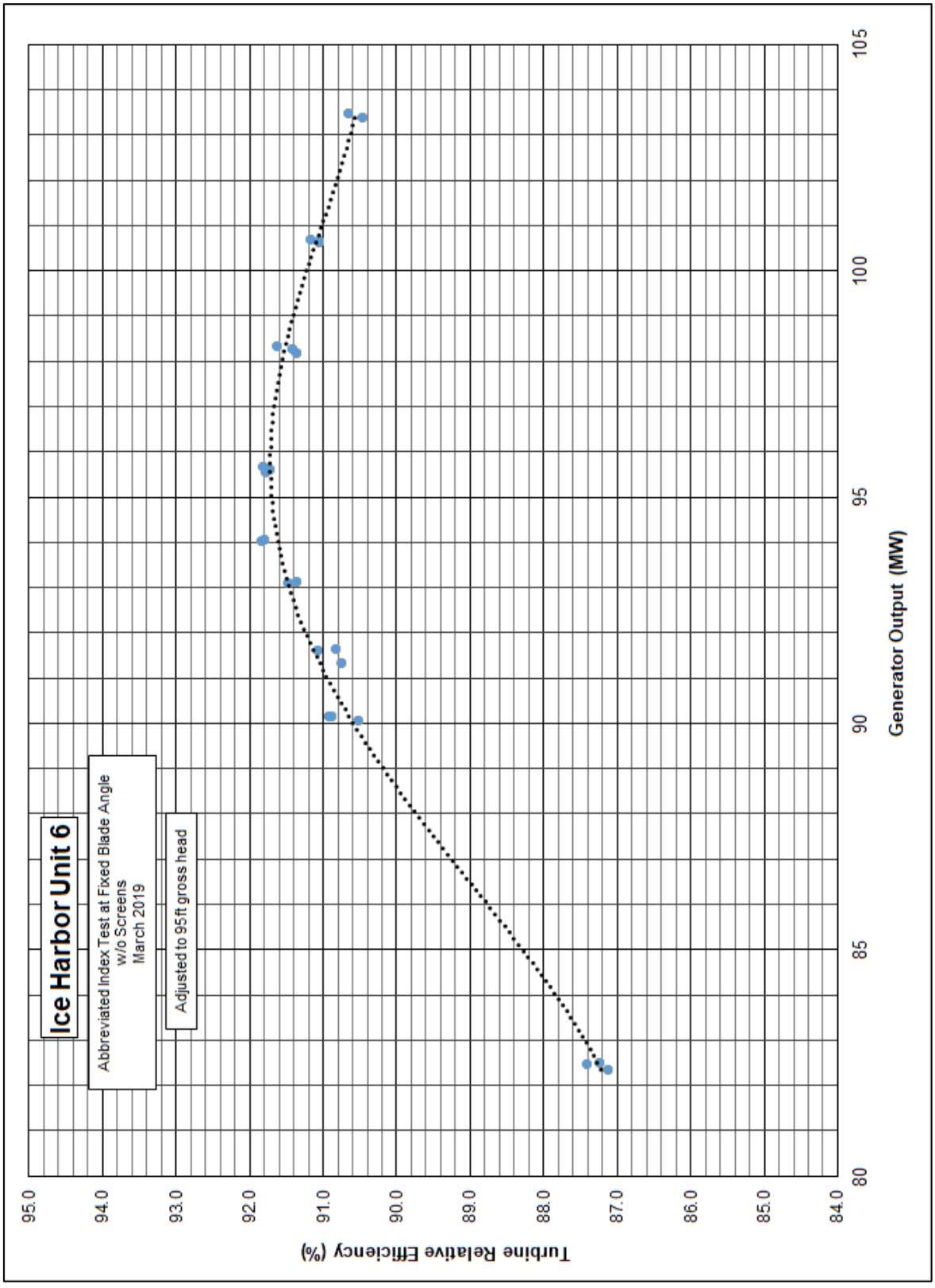

Figure 1 – Results of U6 Index Test at 95 ft Head Presented as Power (MW) vs Efficiency (%)

Table 1 - Index Test Results - Ice Harbor, Unit 6 - March 2019

Run No.	Measured values				Values adjusted to a gross head of 95 ft			
	Servo Stroke (%)	Generator output (kW)	Gross head (ft)	W-K Relative Discharge (cfs)	Generator input (MW)	W-K Relative Discharge (cfs)	Turbine output (hp)	Relative efficiency (%)
1	60.00	82,909	95.48	12,031	82.35	12,001	112,688	87.13
2	60.00	82,915	95.37	12,031	82.50	12,008	112,892	87.23
3	60.00	82,905	95.38	12,004	82.48	11,980	112,859	87.41
4	65.00	90,641	95.39	12,616	90.16	12,590	123,372	90.92
5	65.00	90,408	95.24	12,610	90.14	12,594	123,346	90.88
6	65.00	90,412	95.30	12,651	90.06	12,631	123,234	90.53
7	70.00	95,949	95.24	13,246	95.66	13,229	130,904	91.82
8	70.00	95,997	95.35	13,242	95.55	13,218	130,744	91.78
9	70.00	95,891	95.23	13,253	95.62	13,237	130,846	91.72
10	75.00	98,447	95.13	13,635	98.32	13,626	134,546	91.62
11	75.00	98,461	95.24	13,660	98.17	13,643	134,332	91.36
12	75.00	98,468	95.18	13,661	98.27	13,648	134,469	91.42
13	80.00	100,885	95.20	14,050	100.65	14,035	137,726	91.05
14	80.00	100,741	95.13	14,040	100.62	14,030	137,681	91.06
15	80.00	100,743	95.09	14,027	100.68	14,021	137,771	91.18
16	90.00	103,562	95.17	14,520	103.37	14,507	141,448	90.47
17	90.00	103,643	95.15	14,504	103.48	14,493	141,602	90.66
18	68.00	94,228	95.16	13,022	94.07	13,011	128,719	91.80
19	68.00	94,230	95.18	13,012	94.04	13,000	128,681	91.85
20	66.00	91,938	95.27	12,792	91.62	12,774	125,374	91.07
21	66.00	91,875	95.42	12,807	91.34	12,779	124,993	90.76
22	66.00	91,927	95.25	12,828	91.64	12,811	125,398	90.82
23	67.00	93,384	95.25	12,939	93.09	12,922	127,385	91.47
24	67.00	93,415	95.24	12,961	93.14	12,944	127,448	91.36

Development of the Operating Tables for Unit 6:

Using the model test for this family of units, 2006 Unit 6 index test, and this abbreviated index test, it was possible to develop operating limits for Unit 6 as a fixed blade turbine without STS's installed. It was necessary to adjust the data for the with screens condition since this testing was performed without fish screens installed. The adjustment was made by comparing results from the Unit 6, 2006 with screen installed index test. Unit 6's resulting operating tables are similar to the operating tables provided for Unit 5. HDC is recommending sharing operating tables for Unit 5 and 6 to reduce the number of unique operating tables. The following tables were developed for project's operation of Unit 5 and 6.

Ice Harbor, Unit 5-6, Operating Table without Screens Installed

Based on the 1962 Model Test, 2006 Unit 6 Index Test, and
Unit 5 (2017) and Unit 6 (2019) Abbrev. Index Test

Gross Head (ft)	Lower Operating Limit		Best Turbine Operating Efficiency		Upper Operating Limit	
	Generator Power (MW)	Discharge (cfs)	Generator Power (MW)	Discharge (cfs)	Generator Power (MW)	Discharge (cfs)
75	**70.1**	12,538	**72.9**	12,888	**79.2**	14,153
76	71.2	12,550	74.0	12,893	80.3	14,160
77	72.3	12,560	75.0	12,898	81.5	14,167
78	73.3	12,570	76.1	12,903	82.7	14,173
79	74.4	12,580	77.2	12,907	83.8	14,179
80	**75.4**	12,589	**78.2**	12,911	**85.0**	14,184
81	76.3	12,565	79.2	12,906	86.2	14,193
82	77.2	12,542	80.3	12,900	87.1	14,148
83	78.0	12,519	81.3	12,895	87.9	14,105
84	78.9	12,497	82.3	12,890	88.8	14,062
85	**79.8**	12,475	**83.3**	12,884	**91.0**	14,224
86	81.1	12,527	84.6	12,914	92.0	14,208
87	82.5	12,578	85.8	12,943	93.1	14,191
88	83.8	12,627	87.1	12,971	94.1	14,175
89	85.2	12,675	88.3	12,998	95.1	14,159
90	**86.5**	12,721	**89.6**	13,024	**96.2**	14,143
91	87.5	12,724	90.6	13,032	97.4	14,159
92	88.6	12,726	91.7	13,040	98.6	14,174
93	89.6	12,728	92.8	13,047	99.9	14,190
94	90.6	12,730	93.9	13,054	101.1	14,204
95	**91.6**	12,732	**95.0**	13,061	**102.3**	14,219
96	92.4	12,698	96.0	13,054	103.6	14,237
97	93.2	12,665	97.0	13,047	104.8	14,254
98	93.9	12,632	98.0	13,039	106.1	14,271
99	94.7	12,600	99.0	13,032	107.4	14,287
100	**95.5**	12,568	**100.0**	13,025	**108.7**	14,302
101	96.6	12,583	101.1	13,023	109.9	14,322
102	97.7	12,597	102.1	13,021	111.2	14,341
103	98.8	12,611	103.1	13,019	112.5	14,360
104	99.8	12,624	104.1	13,018	113.7	14,378
105	**100.9**	12,637	**105.1**	13,016	**115.0**	14,396

Ice Harbor Unit 5-6, Operating Table with STS Installed

ased on the 1962 Model Test, 2006 Unit 6 Index Test, and
Unit 5 (2017) and Unit 6 (2019) Abbrev. Index Test

Gross Head (ft)	Lower Operating Limit		Best Turbine Operating Efficiency		Upper Operating Limit	
	Generator Power (MW)	Discharge (cfs)	Generator Power (MW)	Discharge (cfs)	Generator Power (MW)	Discharge (cfs)
75	**72.5**	13,198	**74.6**	13,432	**76.1**	13,866
76	73.6	13,210	75.7	13,437	77.2	13,872
77	74.7	13,221	76.8	13,442	78.4	13,878
78	75.8	13,231	77.9	13,447	79.5	13,884
79	76.9	13,241	79.0	13,451	80.6	13,889
80	**77.9**	13,250	**80.0**	13,454	**81.7**	13,894
81	78.8	13,225	81.1	13,456	82.9	13,903
82	79.7	13,201	82.2	13,457	83.8	13,869
83	80.6	13,176	83.3	13,458	84.7	13,836
84	81.5	13,152	84.4	13,458	85.6	13,804
85	**82.4**	13,129	**85.5**	13,458	**87.5**	13,933
86	83.8	13,184	86.6	13,470	88.5	13,916
87	85.2	13,237	87.8	13,482	89.5	13,900
88	86.6	13,288	88.9	13,492	90.5	13,884
89	88.0	13,339	90.1	13,503	91.5	13,867
90	**89.4**	13,387	**91.2**	13,513	**92.5**	13,851
91	90.4	13,390	92.4	13,524	93.7	13,867
92	91.5	13,392	93.5	13,534	94.9	13,883
93	92.5	13,394	94.6	13,545	96.0	13,897
94	93.6	13,396	95.8	13,555	97.2	13,912
95	**94.6**	13,397	**96.9**	13,564	**98.4**	13,926
96	95.5	13,362	98.0	13,569	99.6	13,943
97	96.3	13,327	99.1	13,574	100.8	13,960
98	97.1	13,292	100.3	13,578	102.1	13,976
99	97.9	13,258	101.4	13,582	103.3	13,991
100	**98.7**	13,225	**102.5**	13,586	**104.5**	14,007
101	99.8	13,240	103.6	13,588	105.7	14,026
102	100.9	13,255	104.6	13,590	106.9	14,044
103	102.0	13,269	105.7	13,592	108.1	14,063
104	103.2	13,283	106.8	13,594	109.4	14,081
105	**104.3**	13,297	**107.8**	13,596	**110.6**	14,098

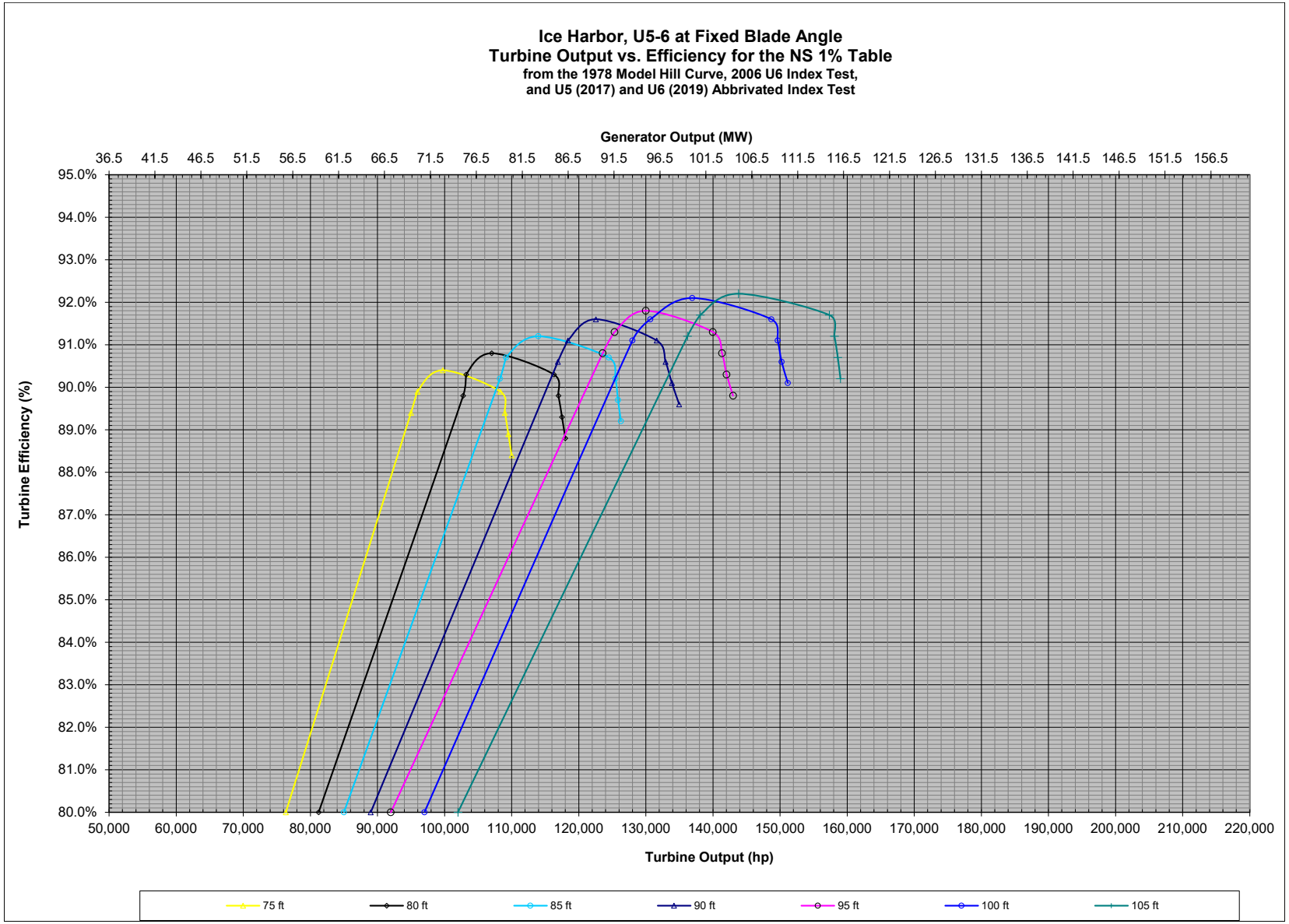

Figure 2 - Plot Showing Turbine Output vs. Efficiency without Fish Screens for Operational Head Range

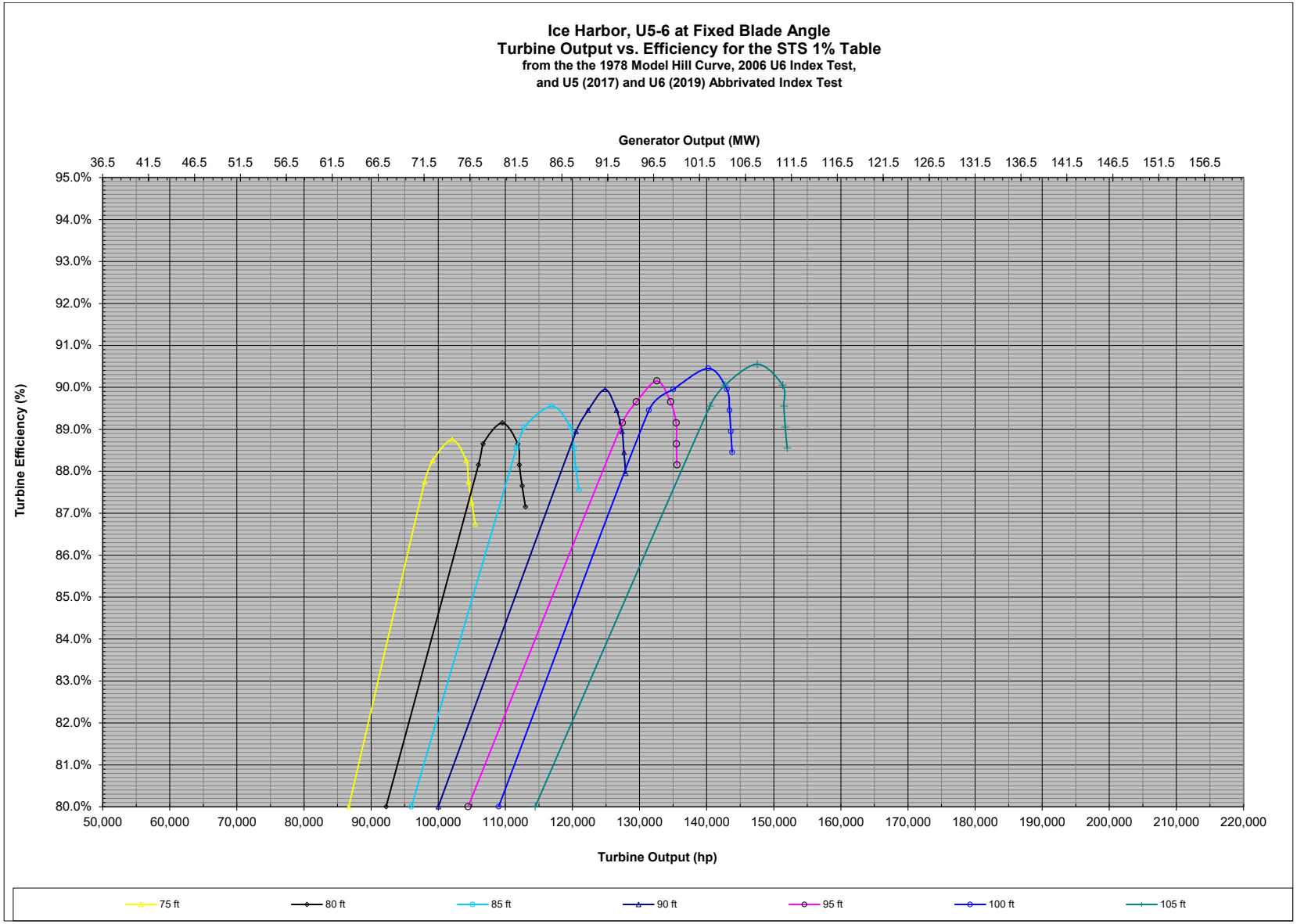

Figure 3 - Plot Showing Turbine Output vs. Efficiency with Fish Screens for Operational Head Range

Test Photos:

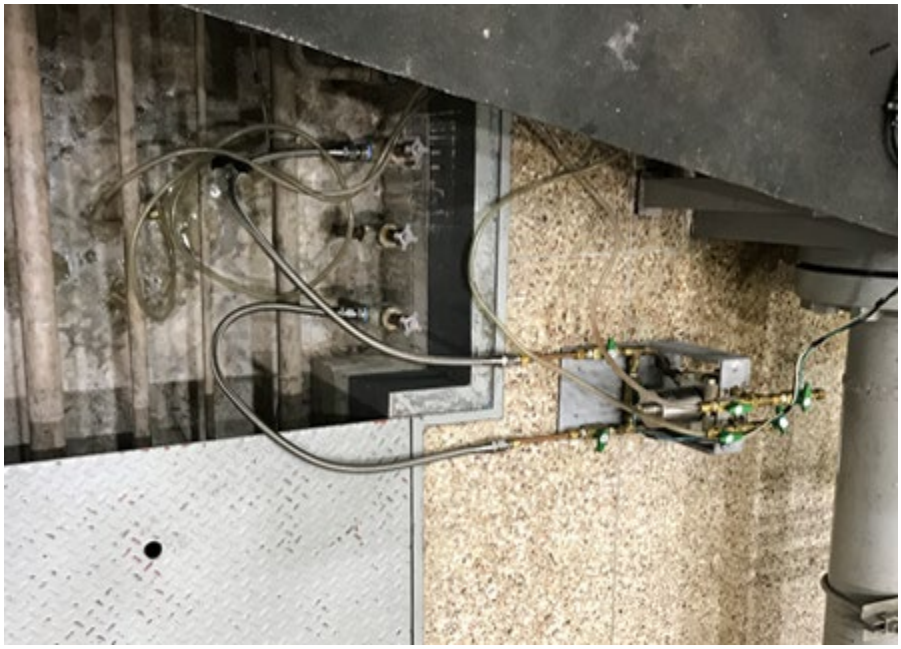

Photo 1 - Winter-Kennedy Transducer Setup

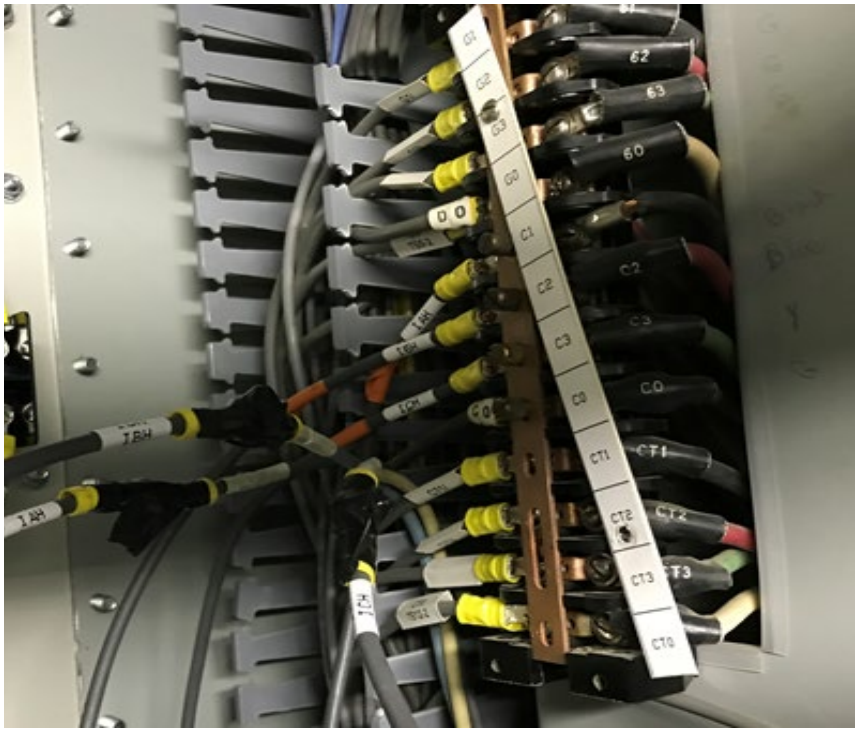

Photo 2 - CT Connection on Governor Cabinet

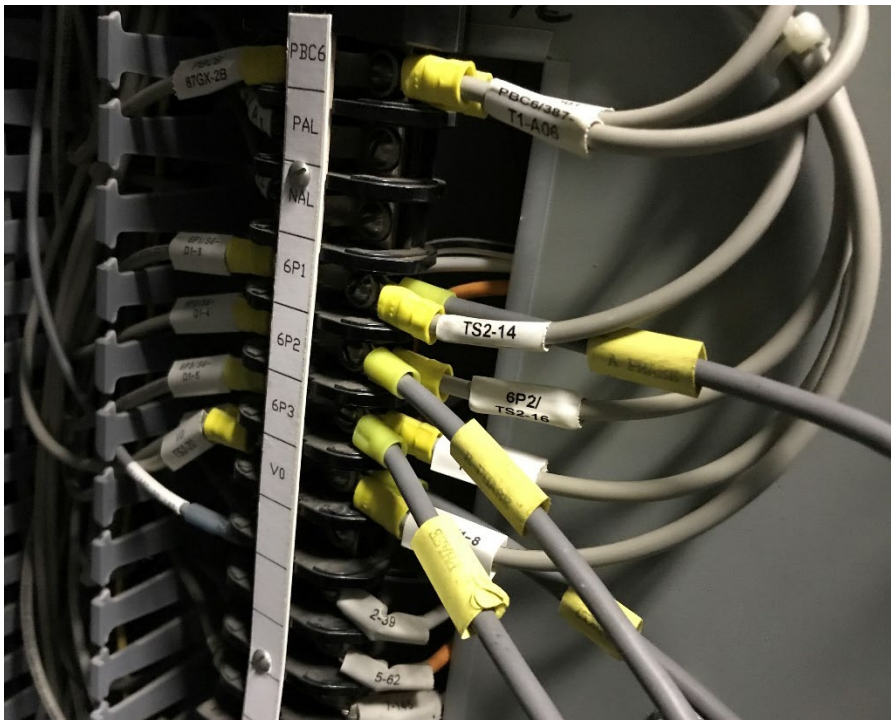

Photo 3 - PT Connection on Governor Cabinet

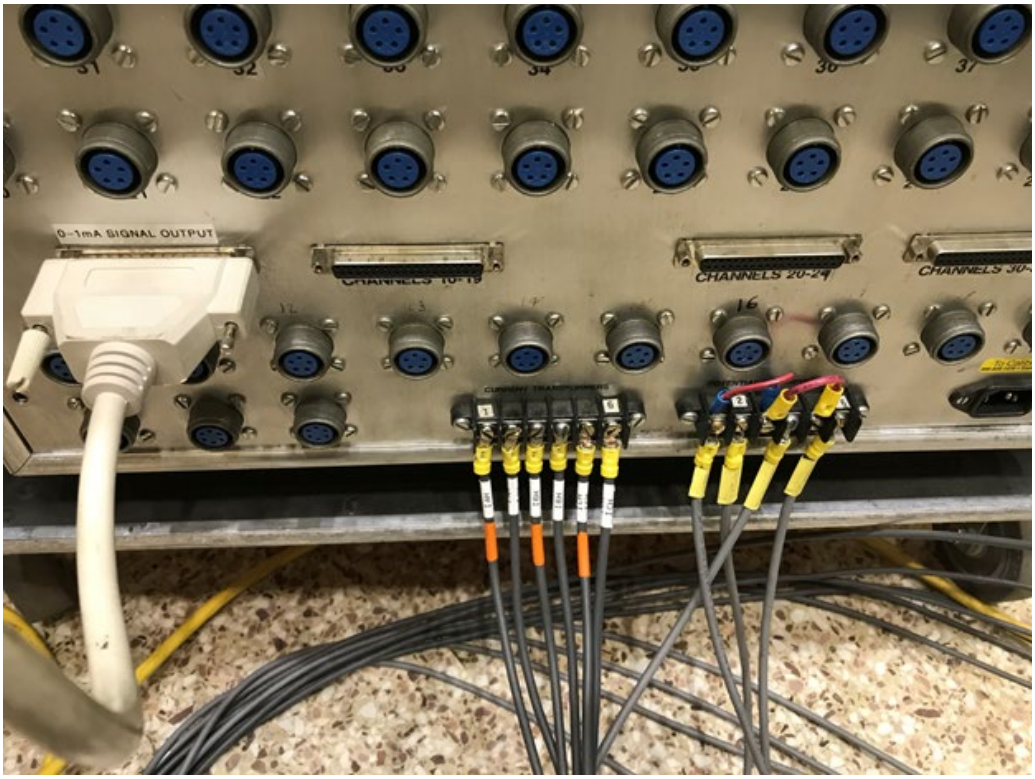

Photo 4 - Potential, Current, and Watt Transducer Wiring Setup

Photo 5 - Photo of Oil Head Blade Angle Indicator

Photo 6 - Photo of Digital Governor Display