PacifiCorp Iron Gate Project

Turbine Performance and Air Admission Tests

Prepared for

CH2M HILL
Portland, Oregon

Revision B

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Revision History

Rev A October 2008	Initial release.
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1. OVERVIEW AND SCOPE

1.1. Overview

This report describes performance and air admission testing on the generating unit at PacifiCorp's Iron Gate Project powerhouse on the Klamath River near Hornbrook, California. These tests were conducted in conjunction with a water quality assessment program conducted by PacifiCorp and the Portland office of CH2M-Hill. Testing took place the week of August 18 - 22, 2008.

This testing is part of a program to evaluate methods for improving the dissolved oxygen DO) in the river downstream of the powerhouse during the low-DO season that runs from summer to early fall. Like many turbines of similar design, the Iron Gate unit is equipped with an air admission system which normally admits air into the draft tube at low wicket gate openings to smooth out rough operation due to cavitation and draft tube swirl. As the induced air travels through the draft tube and into the tailwater, a fraction of the oxygen (and nitrogen) goes into solution, increasing dissolved oxygen (and dissolved nitrogen), providing a potentially low-cost method of improving DO. By configuring the air valve to remain open at all gate openings, the range of potential DO enhancement is increased.

While the initial costs of this type of aeration are typically modest, a potentially significant cost is the loss of generating efficiency and the loss of power.

The objectives of the testing reported here were to determine the effect of air admission on the efficiency of the generating unit, and to quantify the amount of air drawn into the draft tube through the air admission system over a range of turbine flow rates. This report covers only these aspects of the test program and does not present data or conclusions related to the water quality data collection effort conducted concurrent to these tests.

1.2. Description of the Generating Unit

A transverse section through the generating unit centerline and a plan view of the unit are shown in Figures 1.1 and 1.2, respectively. The turbine is a vertical-axis Francis-type rated at 25,000 hp under 154 feet of head. At the rated conditions, the generator output is 18.1 MW with a discharge of about 1,550 cfs. The turbine is supplied from an exposed steel penstock connected to the reservoir headworks. At the lower end, the penstock bifurcates (as shown in Figure 1.2), with one leg of the bifurcation supplying the turbine, and the other leg going to a Howell-Bunger valve. This arrangement allows the powerhouse discharge to be controlled or increased beyond what is possible with the turbine alone.

The penstock is equipped with an Accusonic acoustic time-of-flight flowmeter system which measures the entire penstock flow before the bifurcation. Winter-Kennedy flowmeter taps are installed in the turbine spiral case, although they are presently unused. These taps were put into service for these tests and were calibrated against the acoustic flowmeter, allowing the portion of the total flow passing through the turbine to be determined.

The bellmouth inlet for the turbine air admission system is located on the powerhouse wall at the taildeck, and feeds the air piping which connects to the headcover in the wheelpit. The air flows from the headcover to the draft tube through holes in the runner crown at the downstream edge of the buckets. Air flow is driven by the vacuum which exists in the draft tube; the strength of the vacuum depends on the flow through the turbine.

The airflow is controlled by a valve which is actuated by a linkage to the gate ring. Between 0 and 38% gate opening, the valve is fully open. At 38% the valve begins closing and is fully closed at gate openings greater than 65%.

1.3. Scope of Testing

For these tests, the linkage connecting the air valve to the gate ring was removed, allowing for independent control of the valve position. Turbine testing was performed over a range of gate openings with the air valve fully open and with the air valve fully closed.

Because the total powerhouse discharge is tightly regulated, the range of test conditions possible was limited. On August 20, the turbine efficiency and air admission testing was conducted with the total powerhouse discharge maintained at approximately 1500 cfs, corresponding to a tailwater elevation of about 2171.75 ft. Constant powerhouse flow was achieved by using the Howell-Bunger bypass valve to balance the flow as the turbine was operated at different gate openings.

Testing was conducted at gate openings from 30% to about 85% at 5% increments. 86% was the highest gate opening achievable under the flow constraint of 1500 cfs. Tests over the full operating range were conducted with the air valve open and the air valve closed. Powerhouse and PRC instrumentation monitored the performance of the generating unit and the airflow being admitted to the headcover through the bellmouth inlet at the taildeck.

In addition to the turbine testing described above, air flow was monitored on August 19 when the turbine discharge was a constant 1000 cfs. Turbine performance and air flow were monitored during steady operation on the afternoon of August 21. In-stream water quality monitoring in the river downstream of the powerhouse was being conducted on these days.

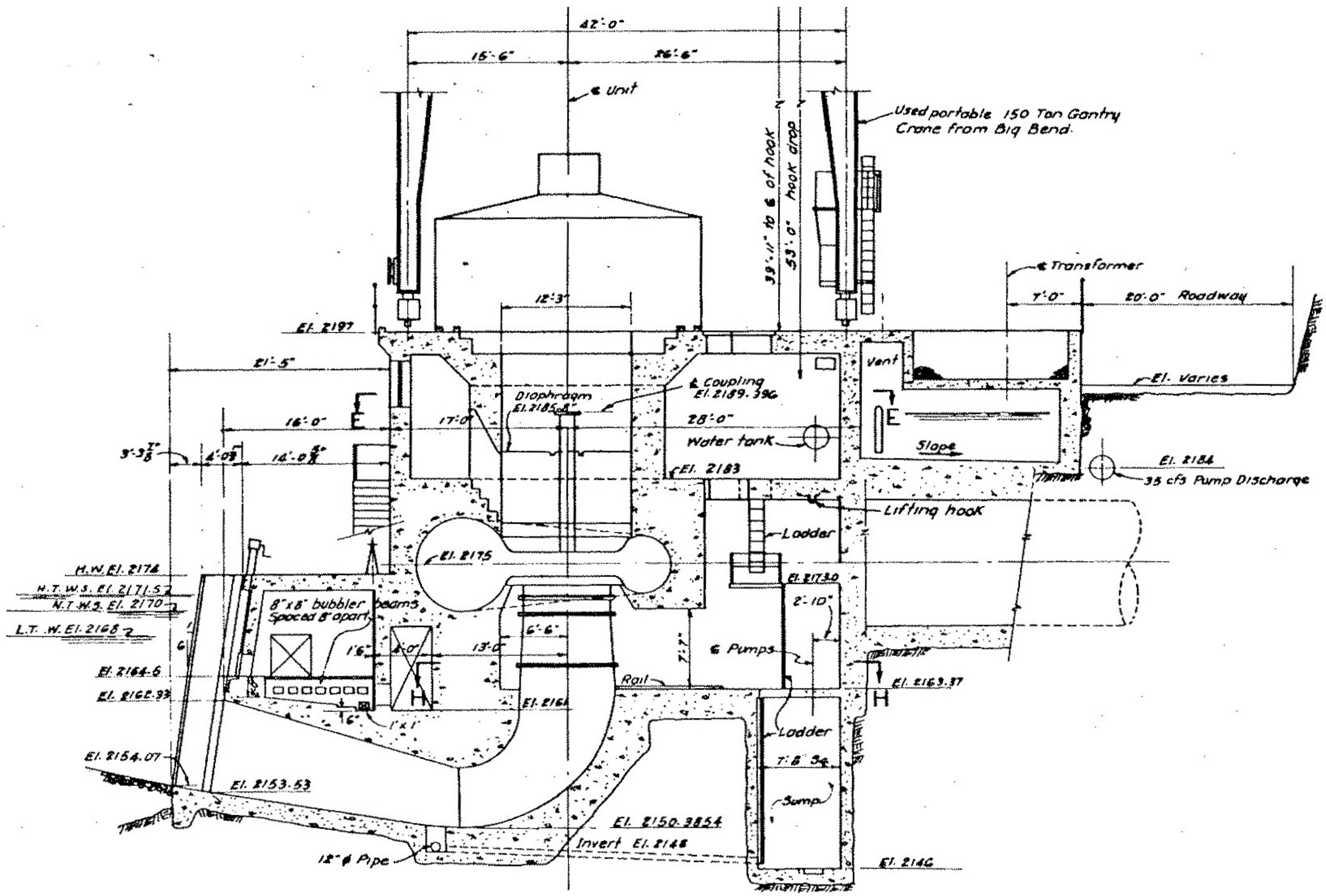


Figure 1.1: Transverse Section Through Unit Centerline

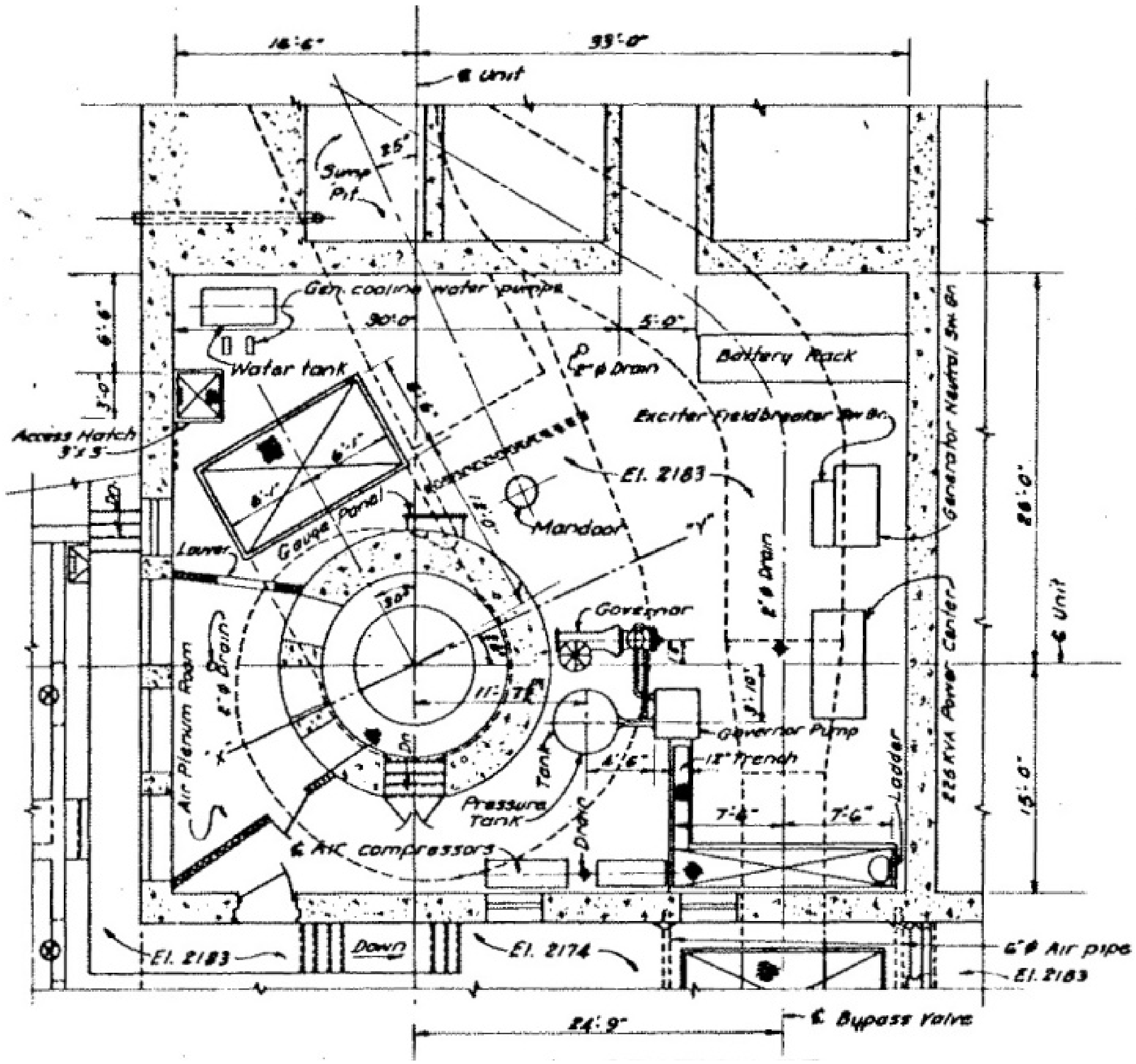


Figure 1.2: Plan View Showing Generating Unit and Bypass Line

2. PERSONNEL

The following personnel had principal responsibilities during the testing. Numerous other support personnel also participated.

Test Personnel

Name	Title	Responsibility
PacifiCorp		
Norm Etling	Maintenance Supervisor	Site preparations and coordination
Terry Riley	Lead Mechanical Engineer	Test planning and coordination
Linda Prendergast	Principal Aquatic Scientist	Water quality investigations
Larry Castle	Operator	Unit operations
CH2M-Hill Portland		
Kenneth Carlson	Project Manager	Test planning and oversight
Principia Research Corporation		
Charles Almquist	Principal Engineer	Test planning and execution

3. INSTRUMENTATION

3.1. General Description

A summary of the instrumentation used is presented in Table 3.1. Most of the instruments were temporarily installed by Principia Research Corporation (PRC) for these tests. These included instruments for determination of inlet pressure, turbine flowrate (Winter-Kennedy differential), wicket gate servomotor stroke, air flow in the vent pipe, draft tube pressure, air temperature, relative humidity, atmospheric pressure, and water temperature. Powerhouse instruments recorded included headwater and tailwater elevation, total powerhouse discharge, and generator power output.

Instrumentation specifications for those instruments supplied by PRC are found in Appendix A. Calibrations for instruments provided by PRC are found in Appendix B.

3.2. Data Acquisition

Test data were acquired by a Hewlett-Packard 34970A data acquisition system, located in the office building, and controlled by HP's Benchlink software. All of the instruments employed 4 – 20 mA current loop outputs. 250 ohm precision resistors were used to convert the 4-20 mA current loops to 1 – 5 V.

3.3. Instrumentation Installations

3.3.1. Inlet Head

The locations of the inlet head piezometer taps in the turbine inlet section are shown in Figure 3.1. The four taps are equally spaced around the circumference of the inlet section. The piezometer (pressure) lines from the taps are combined by a manifold located at the piezometer bay at the upstream side of the turbine pedestal. A Rosemount 3051CG gage pressure cell was use to measure the inlet pressure. A photograph of the manifold and pressure cell installation is shown in Figure 3.2.

3.3.2. Winter-Kennedy Differential Pressure

The locations of the Winter-Kennedy (W-K) pressure taps in the spiral case are shown in Figure 3.1. The three flowmeter pressure lines were accessed at the piezometer bay. Two Rosemount differential pressure cells were employed, with one cell measuring the R3-R1 differential, and the other measuring the R3-R2 differential, providing two W-K flow measurements. Figure 3.2 shows the installation.

3.3.3. Wicket Gate Position

The wicket gate servo stroke was measured using a cable extension transducer ("pull-pot") mounted on the servomotor at the governor outside the wheel pit. The transducer was attached to a mounting bracket clamped to the servo cylinder housing. The free end of the cable was attached to a pointer on servo shaft. The cable was level and parallel to the axis of motion. A photograph of the installation is shown in Figure 3.3.

3.3.4. Air Flow

Air flow was determined from measurement of the pressure drop from atmospheric at the throat of the bellmouth inlet to the air admission piping located on the downstream wall of the powerhouse. Two pressure taps were installed at the bellmouth throat. These taps were combined by a tee, and the difference between the throat pressure and the atmospheric pressure was measured by a Rosemount 3051C-D1differential pressure cell. A schematic of the bellmouth inlet is shown in Figure 3.4 and a photograph of the installation is shown in Figure 3.5.

3.3.5. Draft Tube Pressure

Draft tube pressure was measured by a Rosemount 3051C-D4 differential pressure cell connected to a pressure tap at the exposed section of the draft tube liner near the mandoor. A photograph of the installation is shown in Figure 3.6.

3.3.6. Air Temperature and Relative Humidity

Air temperature and relative humidity were measured by an Omega HX-90 transmitter located just inside the door to the powerhouse, near the bellmouth inlet.

3.3.7. Atmospheric Pressure

Air pressure was measured by a Rosemount 3051CA absolute pressure transmitter located near the data acquisition equipment in the office building.

3.3.8. Water Temperature

Water temperature was measured using a Dwyer 3-wire RTD transmitter immersed in water continuously drawn from a tap on the raw cooling water line near the turbine pedestal.

3.3.9. Generator Output

Generator output was obtained from a 4-20 mA analog output on the powerhouse’s Siemens wattmeter located in the control room.

3.3.10. Total Powerhouse Discharge

The total powerhouse discharge was obtained from a 4-20 mA analog output on the Accusonic flowmeter located in the office building.

3.3.11. Headwater Elevation

Headwater elevation is measured by a submersible pressure cell at the headworks. The instrument reading was obtained from a 4-20 mA analog located in the control room

3.3.12. Tailwater Elevation

Tailwater elevation was measured from a temporarily-installed installation provided by PacifiCorp. The measurement was made using a Druck submersible pressure cell suspended in a PVC pipe serving as a stilling well attached to the taildeck near the existing staff gage. The 4-20 output from the pressure cell was recorded by the data acquisition system in the office building. A photograph of the installation is shown in Figure 3.7.

Table 3.1:
Instrumentation

Parameter	Location	Units	Instrument	Model
PRC Instrumentation				
WK flowmeter differential	Spiral case	in H_2O	Differential pressure cell	Rosemount 3051C
WK flowmeter differential	Spiral case	in H_2O	Differential pressure cell	Rosemount 3051C
Inlet head	Turbine inlet	ft H_2O	Gage pressure cell	Rosemount 3051C
Gate position	Governor	inches	Cable extension xducer	Celesco PT420-30
Air flow differential	Bellmouth inlet	in H_2O	Differential pressure cell	Rosemount 3051C
Draft tube pressure	Draft tube liner	in H_2O	Gage pressure cell	Rosemount 3051C
Water temperature	Cooling water line	Deg F	RTD	Dwyer 650
Air temperature	Powerhouse entrance	Deg F	RTD	Omega HX-10
Relative humidity	Powerhouse entrance	%	RH transducer	Omega HX-10
Atmospheric pressure	Office	psia	Absolute pressure cell	Rosemount 3051C
Data acquisition	Office	-	Data acquisition system	HP34970A
Plant Instrumentation				
Generation	Control room	MW	Plant wattmeter	Seimens
Total plant discharge	Accusonic cabinet	cfs	Acoustic flowmeter	Accusonic
Forebay elevation	Control room	feet	Submersible press. cell	Druck
Tailwater elevation	Taildeck @ staff gage	feet	Submersible press. cell	Druck

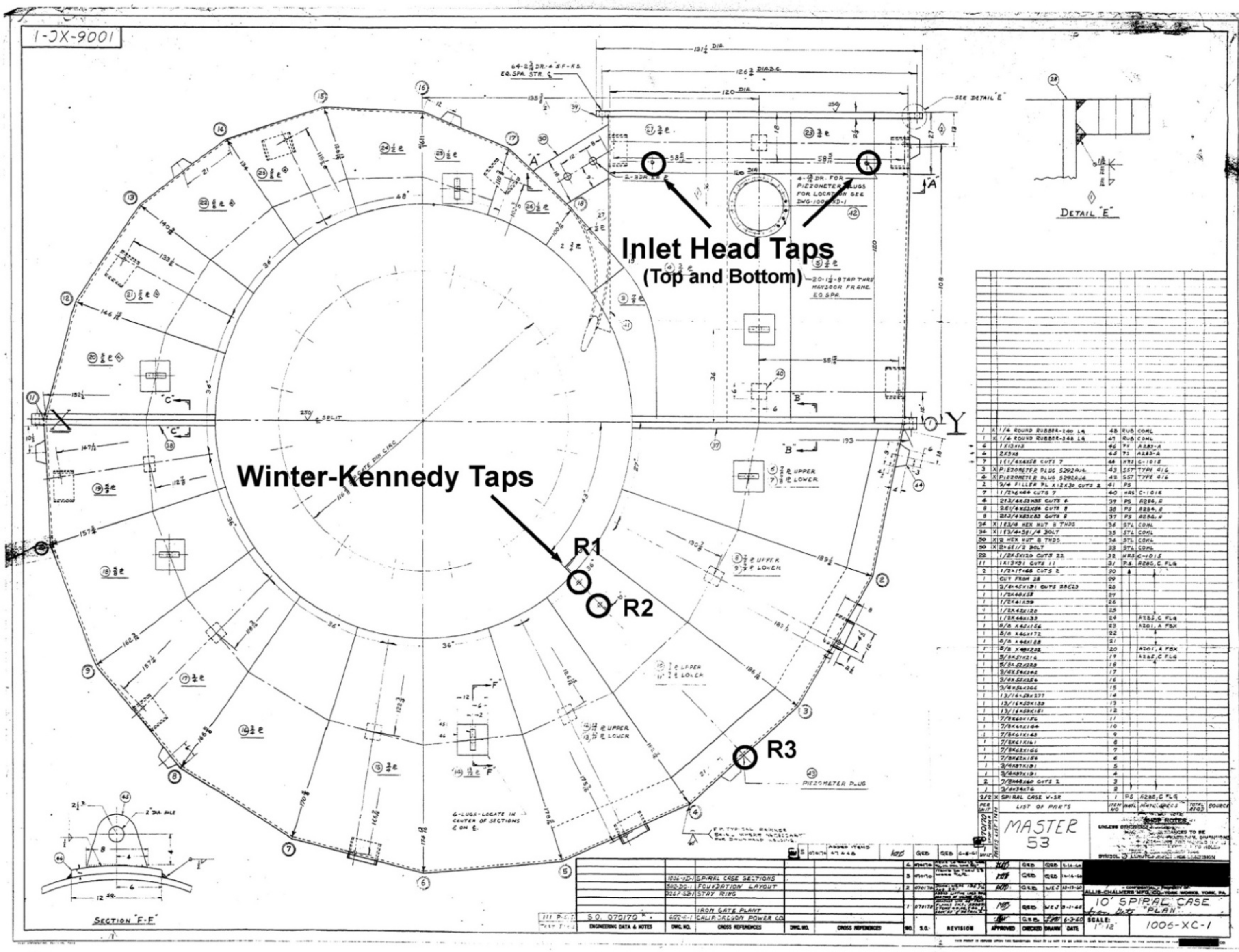


Figure 3.1: Inlet Head and Winter-Kennedy Piezometer Taps

Figure 3.2: Inlet and Winter-Kennedy Pressure Cell Installation

Figure 3.3: Servo Gate Stroke Measurement

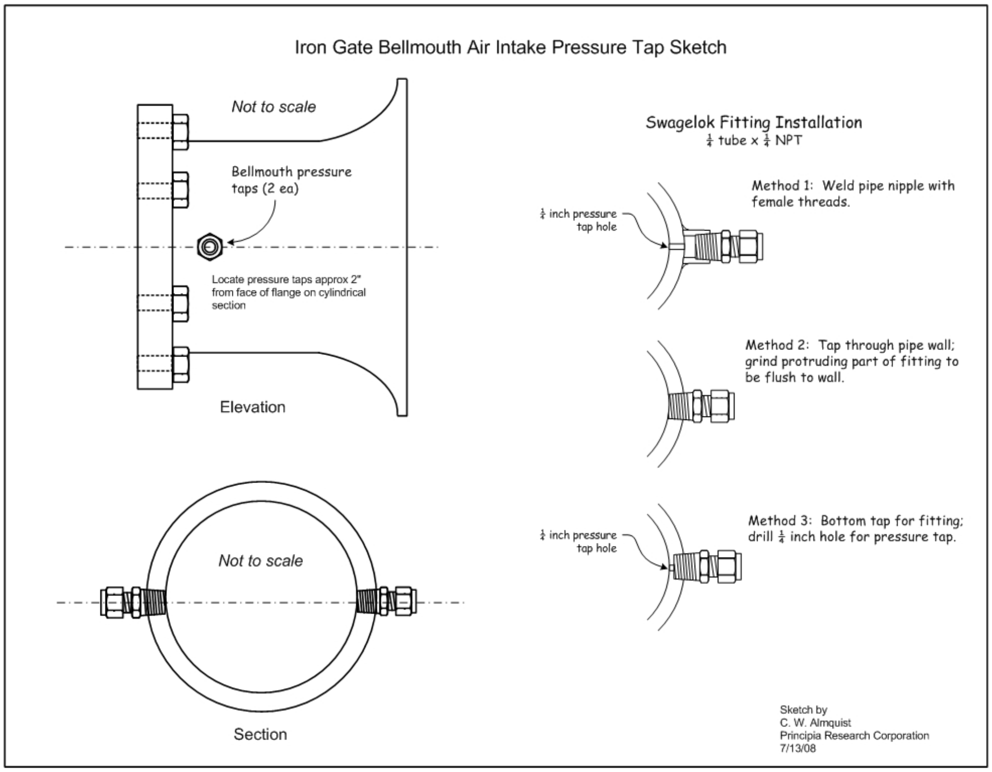


Figure 3.4: Schematic of Bellmouth Inlet

Figure 3.5: Bellmouth Inlet

Figure 3.6: Draft Tube Pressure Measurement

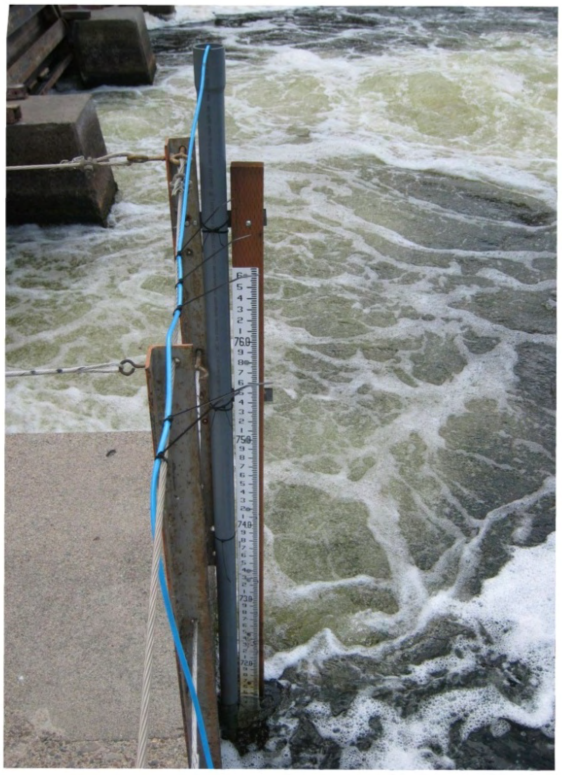


Figure 3.7: Tailwater Measurement

4. Test Conditions and Procedures

4.1. Test Conditions

The tests described in this report were run in general accordance with ASME PTC 18-2002 [ASME, 2002], the American National Standard test code for hydroturbine testing.

Because the total powerhouse discharge from the Iron Gate project is tightly regulated, the range of test conditions possible was very limited. During the test week the powerhouse discharge was constant at 1000 cfs on August 18 – 19, transitioned to a flow of 1500 cfs early afternoon on August 20, and remained constant at 1500 cfs for the testing on August 20 – 21. The turbine efficiency testing was conducted on the afternoon of August 20 at a total powerhouse discharge of 1500 cfs.

In addition, air flow data, Winter-Kennedy differential pressures, and the total powerhouse discharge measured by the acoustic flowmeter were recorded on August 19 at a powerhouse discharge of 1000 cfs. This gave an additional point for calibrating the Winter-Kennedy flowmeters.

Complete air flow and turbine performance data was also recorded during in-stream water quality surveys conducted on the afternoon of August 21. The powerhouse and turbine discharges were constant during this period.

4.2. Test Procedures

The turbine performance and air flow tests on August 20 were performed at a nominal net head of 150 ft. Because the total powerhouse discharge was held constant at 1500 cfs, the tailwater elevation showed very little change during the tests, averaging about 2171.75 ft elevation.

Constant powerhouse flow was achieved by using the Howell-Bunger bypass valve to balance the flow as the turbine was operated at different gate openings. The Winter-Kennedy flowmeter taps in the spiral case were calibrated against the penstock acoustic flowmeter, allowing the portion of the flow passing through the turbine to be directly measured.

Testing was conducted at gate openings from 30% to about 85% at 5% increments. 86% was the highest gate opening achievable under the flow constraint of 1500 cfs. Tests over the full operating range were conducted with the air valve open and the air valve closed. Powerhouse and PRC instrumentation monitored the performance of the generating unit and the airflow being admitted to the headcover through the bellmouth inlet at the taildeck.

The linkage connecting the air valve to the gate ring was disconnected so that the air valve could be operated independently of gate position. The air-on tests were all conducted with air valve fully open.

The general test procedure was as follows:

1. The unit was set to the desired gate opening or power output, with MVARs (Volt-Amps Reactive) held as close to zero as possible. The Howell-Bunger valve

automatically compensated for the change in turbine flow to maintain the powerhouse discharge at a constant 1500 cfs.

2. Power output was allowed to stabilize, usually taking two to three minutes.
3. Data collection was initiated and continued for a minimum 200 scans of all instruments. All measurement points were scanned once every second.
4. The unit was set to the next desired gate opening, and this procedure was repeated.

Between test runs, preliminary analysis and plotting of the data just acquired were performed to assess the reasonableness and quality of the results.

5. DATA REDUCTION PROCEDURES

Data reduction procedures and equations are presented in this section. The test results are summarized in subsequent sections.

5.1. Linearization

All voltages read by the data acquisition system were converted to engineering units by the linear equation

$$E = mV + b \tag{5.1}$$

where *E* is the value in engineering units, *V* is the measured voltage, *m* is the slope and *b* is the offset. The values of *m*, *b*, and the engineering units used are found in Appendix A.

5.2. Turbine Performance Computations

5.2.1. Winter-Kennedy Flow Rate

The measured flow rate Q_m is determined from the Winter-Kennedy differential h_{WK} by

$$Q_m = C_{WK}\sqrt{h_{WK}} \tag{5.2}$$

where C_{WK} is the Winter-Kennedy coefficient, determined by calibration against the acoustic flowmeter.

5.2.2. Turbine Net Head

Turbine net head is computed as follows:

<u>Inlet static head</u>, h_i:

$$h_i = h_{gs} + Z_{gs} \tag{5.3}$$

where

h_{gs} = inlet static head measured by inlet pressure cell (ft H_2O)
Z_{gs} = elevation of pressure cell (ft elevation)

<u>Inlet velocity head</u>, h_{Vi}:

$$h_{Vi} = \frac{1}{2g}\left(\frac{Q_m}{A_i}\right)^2 \tag{5.4}$$

where

Q_m = total measured flow rate (cfs)
A_i = penstock area at the spiral case entrance (ft^2)
g = acceleration of gravity (ft/s^2)

Inlet total head, H_i:

$$H_i = h_i + h_{Vi} \tag{5.5}$$

Discharge static head, h_d:

$$h_d = h_{ds} + Z_{ds} \tag{5.6}$$

where

h_{ds} = pressure measured by tailwater submersible pressure cell (ft H_2O)
Z_{gs} = elevation of submersible pressure cell (ft elevation)

Discharge velocity head, h_{Vd}:

$$h_{Vd} = \frac{1}{2g}\left(\frac{Q_m}{A_d}\right)^2 \tag{5.7}$$

A_d = total area at the draft tube opening to the tailrace (ft^2)

Discharge total head, H_d:

$$H_d = h_d + h_{Vd} \tag{5.8}$$

Turbine net head at test conditions, H_T:

$$H_T = H_i - H_d \tag{5.9}$$

Constants and areas used in the above equations are summarized in Table 5.1.

5.2.3. Generator Efficiency and Loss

The generator efficiency curve was obtained from PacifiCorp Drawing C-8893. A plot of this curve along with the associated generator loss as a function of generator output is given in Figure 5.1. Generator loss was calculated from generator efficiency by

$$L_G = P_e\left(\frac{1}{\eta_G} - 1\right) . \tag{5.10}$$

For ease of computation, the following quadratic curve fit was developed for generator loss:

$$L_g = 6.60499 \times 10^{-4} P_e^{\,2} - 6.19880 \times 10^{-4} P_e + 0.303554 . \tag{5.11}$$

Graphs of the generator efficiency and derived generator loss are shown in Figure 5.1.

Table 5.1:
Constants and Parameters Used in Analyses

General Parameters

Latitude	41.93	deg N
Distributor CL elevation	2175.00	2175
Water temperature	72	deg F
Local gravity	32.1564	ft/s^2
Water density	62.2960	lbm/ft^3
Air density	0.0666	lbm/ft^3
Sp. Wt. of water in air	62.270	lbf/ft^3
Spiral case inlet area	78.53	ft^2
Draft tube exit area	220.91	ft^2

Elevations

Turbine floor	2183.00	ft
Inlet pressure cell	2183.13	ft
Tailwater pressure cell	2170.04	ft
Draft tube pressure cell	2165.04	ft

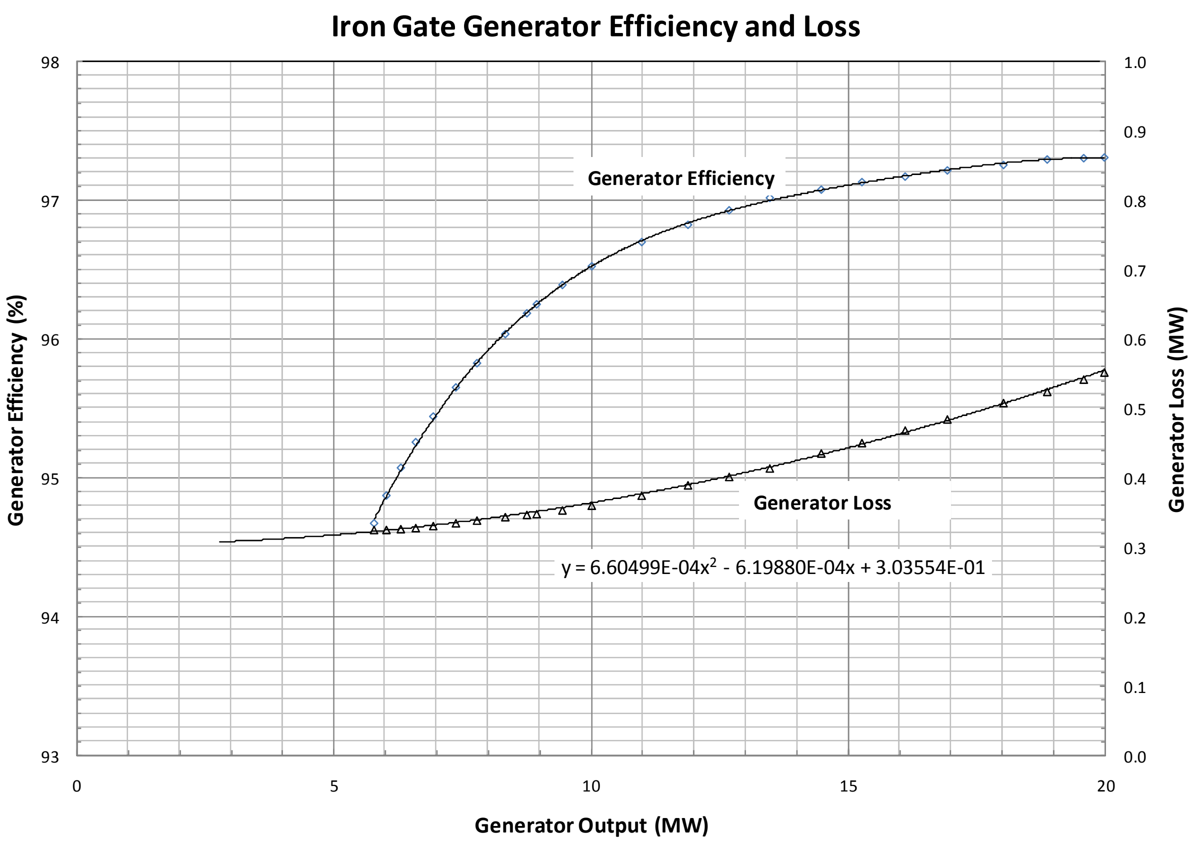


Figure 5.1: Generator Efficiency and Loss

5.2.4. Turbine output

Turbine power output at test conditions is computed from the sum of the measured generator output and the generator losses:

$$P_T = P_e + L_g \quad . \tag{5.12}$$

Note: 1 MW = 1,341 hp.

5.2.5. Turbine Efficiency

Turbine efficiency η_t is computed from

$$\eta_t = 550 \frac{P_{Thp}}{(\rho / g_c) Q_m H_T} \tag{5.13}$$

where

P_{Thp} = turbine output (hp)
ρ = density of water (lbm/ft^3)
g_c = gravitational constant = 32.174

Water density is computed from water temperature, station elevation, and station latitude according to equations found in ASME PTC 18 [ASME, 2002]. Note that the term ρ/g_c is the water density in terms of slugs.

5.2.6. Unit Efficiency

Unit efficiency is defined here as the efficiency of the turbine-generator, from the spiral case inlet to the draft tube exit:

$$\eta = 737.6 \frac{P_e}{(\rho / g_c) Q_m H_T} \tag{5.14}$$

5.3. Air Flow Calculations

Air flow calculation procedures described here generally follow those found in ASME *Fluid Meters* [ASME, 1971].

The equation relating the air velocity at the bellmouth inlet to the pressure difference between the inlet throat and the surrounding atmosphere is

$$V_a = CY \left(2 \frac{\Delta p}{\rho_a} \right)^{1/2} \tag{5.15}$$

where, in any dimensionally consistent set of units,

V_a = air velocity
C = nozzle discharge coefficient
Y = gas expansion factor
Δp = pressure drop at inlet throat
ρ_a = air density outside the bellmouth

When the velocity is in ft/sec, the pressure drop is in inches of water h_w, and the density of air is in lbm/ft^3, this equation reduces to

$$V_a = 18.28CY\left(\frac{h_w}{\rho_a}\right)^{1/2} \tag{5.16}$$

Air density is computed from the perfect gas relation:

$$\rho_a = \frac{144 p_a}{R_a (T_a + 459.67)} \tag{5.17}$$

where

T_a = air temperature (deg F)
R_a = gas constant for air (53.343)
p_a = atmospheric pressure (psia)

The gas expansion factor can be closely approximated by

$$Y = 1 - 0.5559\frac{h_w}{p_a} \tag{5.18}$$

The discharge coefficient is a function the Reynolds Number Re and can be approximated by

$$C = 1 - 34.60\,\mathrm{Re}^{-2/3} \tag{5.19}$$

The Reynolds Number is defined by

$$\mathrm{Re} = \frac{\rho_a V_a D}{\mu} \tag{5.20}$$

where D is the diameter of bellmouth inlet throat (ft) , and μ is the kinematic viscosity of the air (lbm/ft-sec).

The kinematic viscosity of air can be approximated by

$$\mu = 1.102 \cdot 10^{-5} + 1.618 \cdot 10^{-8} T_a \tag{5.21}$$

Because the discharge coefficient C used to compute the velocity at the bellmouth throat depends itself on the velocity, the equations above must be solved iteratively for each test.

The air flow Q_a (ft^3/s) at test conditions is then computed by

$$Q_a = V_a \pi D^2 / 4 \tag{5.22}$$

Although relative humidity was measured, the effect of moisture on air density is small at the low relative humidities observed during testing, and is neglected in the computations.

5.4. Correction of Efficiency Test Results to Common Head

The measured flow rate and turbine power output at the test head is corrected to a common head, H_c, by:

$$Q = Q_T \left(\frac{H_c}{H_T} \right)^{0.5} \tag{5.23}$$

$$P = P_T \left(\frac{H_c}{H_T} \right)^{1.5} \tag{5.24}$$

No correction is required for efficiency.

6. Performance and Air Admission Results

6.1. Winter-Kennedy Flowmeter Calibration

Figure 6.1 shows the calibration of the both of the Winter-Kennedy tap pairs against the acoustic flow meter. Because of the discharge restrictions, only calibrations at 1000 and 1500 cfs were possible. However, when the measured flow is plotted against the square root of the Winter-Kennedy differentials, the resulting points lie along a line passing through the origin, as would be expected. The Winter-Kennedy coefficients are determined to be:

- Tap Pair R3-R1 C_{WK} = 139.76
- Tap Pair R3-R2 C_{WK} = 166.63

The turbine flow rate is calculated from:

$$Q_m = C_{WK}\sqrt{h_{WK}} \quad . \tag{6.1}$$

For analyses of test data, the R3-R1 tap pair was used for the determination of the turbine discharge.

The Winter-Kennedy calibrations show that the Winter-Kennedy taps can be used to determine the portion of the powerhouse flow which is passing through the turbine.

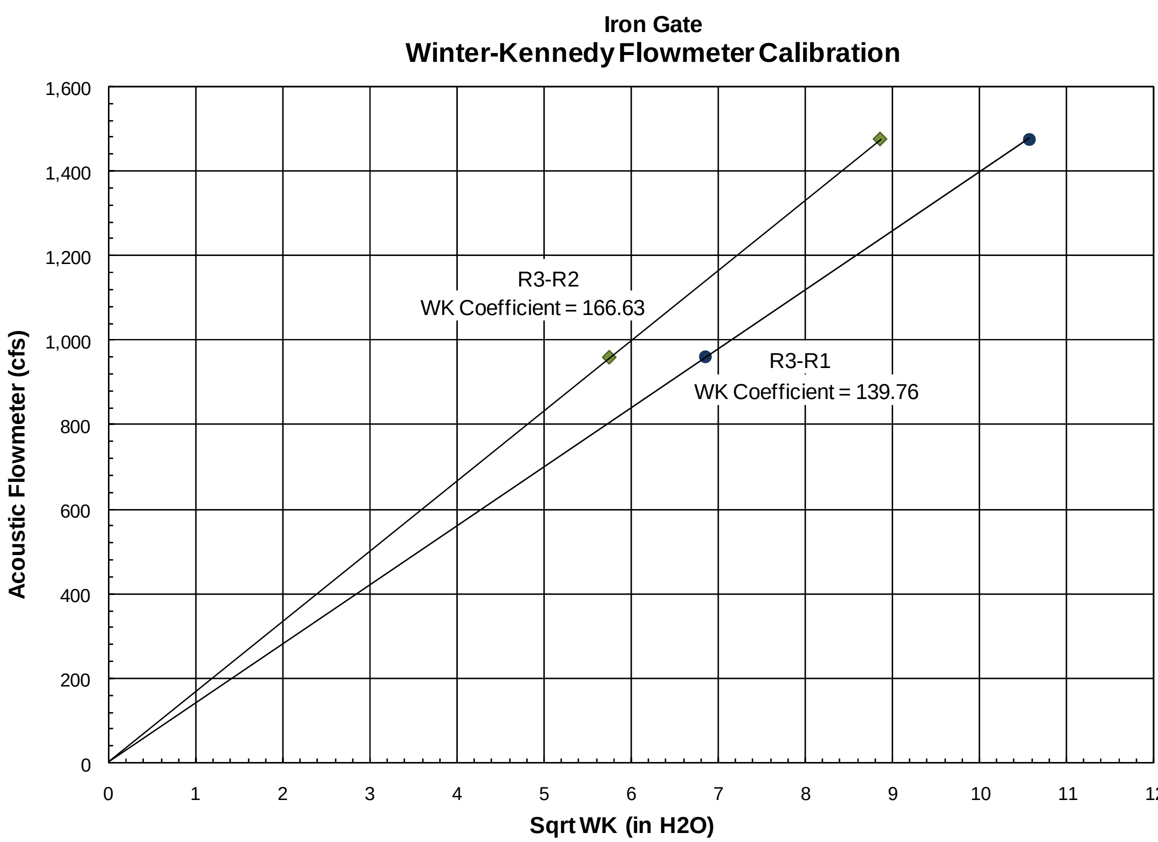


Figure 6.1: Winter-Kennedy Flowmeter Calibrations

6.2. Basic Data and Calculations

Tabular results of the performance and air admission tests are presented in Tables 6.1 – 6.4:

- Table 6.1 Raw Data
- Table 6.2 Basic Calculations
- Table 6.3 Unit and Turbine Efficiency Calculations
- Table 6.4 Air Admission Calculations

The calculations in these tables are based on the data reduction procedures described in Section 5.

6.3. Performance Results

Figure 6.2 shows the unit (combined turbine and generator) efficiency as a function of power output for both the air-on and the air-off tests. The effect of air admission on efficiency is typical for units of this type: At lower power outputs, where the unit tends to cavitate and run roughly, the addition of air improves efficiency, by up to about 5%. At about 8 MW generator output (corresponding to a gate opening of about 50%), air admission has no effect on efficiency, and at higher power outputs, air admission causes a drop in efficiency.

The peak unit efficiency occurs at the maximum power output of about 16 MW achieved for these tests. With air on, peak efficiency is 85.5% whereas with air off, it drops to 83.3%, a decrease of 2.2%. The maximum power output at the 1500 cfs limit is reduced by about 0.8 MW.

Figure 6.3 presents the same information, but considers the efficiency of the turbine alone. With air off, the peak efficiency is 88.0%, dropping to 85.8% with the air on, again a drop of 2.2%. Air admission reduces the maximum power output at 1500 cfs by about 850 hp or about 0.6 MW.

The effect of air admission on unit efficiency as a function of generator output is shown in Figure 6.4. It is seen that air admission improves efficiency by about 4.6% at 2 MW, dropping to a loss of efficiency of about 2% at 16 MW.

Curves of unit discharge as a function of generator output for the air-on and air-off cases are shown in Figure 6.5. These curves (and the shown curvefit equations) are useful for analysis and operational purposes.

6.4. Air Flow Results

Figure 6.6 shows the air flow rate to the turbine plotted against turbine power ouput over the range of test conditions. Figure 6.7 shows the air flow rate plotted against the turbine flow rate. The air flow rate does not vary greatly, ranging from about 25 cfs at the lowest gate opening (30% gate, 260 cfs turbine discharge, 2.1 MW) to a maximum of about 35 cfs at the higher gate openings.

The ratio of air flow to water flow, which is measure of the relative potential for aeration, is shown in Figure 6.8 as a function of generator power, and in Figure 6.9 as a function of turbine flow. The air-water flow ratio is at a maximum at the lowest gate openings, with a maximum of about 7.5%, and drops steadily to a value of about 2.4% at the maximum test gate opening.

In general, the 2.4% air-water flow ratio at the higher gate openings is relatively small and may lead to only a modest (but possible significant) increase in dissolved oxygen in the tailrace. The water quality studies conducted in conjunction with the testing reported here will determine the actual improvement observed.

Raw Data																	
Run	Time	Num Scans	Air Vent	Gate	Acoustic Flow	Plant MW	W-K R3-R1	W-K R3-R2	Inlet Head	Tail-water	Plant HW	Air Flow	DT Press.	Atm. Press.	Air Temp	Rel. Humidity	Water Temp
	PDT			in	cfs	MW	in H2O	in H2O	ft H2O	ft	ft	in H2O	ft H2O	psia	deg F	%	deg F
IG14	8/20/08 16:30	201	Off	6.55	1503	16.25	116.46	81.61	133.15	1.72	2325.59	-0.06	0.43	13.58	86.59	42.33	71.62
IG15	8/20/08 16:44	201	Off	19.32	1488	2.76	9.62	7.01	137.82	1.44	2325.60	-0.06	9.25	13.58	86.74	42.74	71.61
IG16	8/20/08 16:53	202	Off	18.32	1483	3.64	12.84	9.20	137.79	1.48	2325.61	-0.07	10.11	13.59	86.81	42.65	71.59
IG17	8/20/08 17:00	201	Off	17.25	1487	4.68	17.07	12.17	137.61	1.54	2325.61	-0.06	10.82	13.58	87.04	42.71	71.60
IG18	8/20/08 17:06	202	Off	16.09	1484	5.87	22.65	16.18	137.45	1.60	2325.61	-0.06	10.77	13.58	87.07	42.50	71.59
IG19	8/20/08 17:12	225	Off	14.87	1476	7.26	29.54	21.20	137.29	1.65	2325.62	-0.06	9.60	13.58	86.93	42.39	71.58
IG20	8/20/08 17:18	208	Off	13.84	1482	8.57	36.75	26.47	136.97	1.68	2325.62	-0.06	8.04	13.58	86.77	42.66	71.60
IG21	8/20/08 17:24	202	Off	12.61	1481	9.93	46.31	33.22	137.06	1.72	2325.62	-0.06	5.06	13.58	86.96	42.47	71.64
IG22	8/20/08 17:30	203	Off	11.63	1478	10.93	55.78	39.84	136.19	1.71	2325.62	-0.06	4.90	13.58	86.88	42.56	71.54
IG23	8/20/08 17:39	202	Off	10.30	1474	12.26	68.87	48.92	135.89	1.69	2325.63	-0.06	6.30	13.58	86.55	43.30	71.54
IG24	8/20/08 17:47	201	Off	9.07	1474	13.68	83.41	59.12	135.36	1.66	2325.64	-0.06	5.45	13.58	86.40	44.14	71.61
IG25	8/20/08 17:53	218	Off	7.95	1487	14.92	97.32	68.71	134.36	1.68	2325.64	-0.06	2.68	13.58	86.25	44.31	71.53
IG26	8/20/08 18:00	275	Off	6.68	1496	16.18	114.71	80.54	133.42	1.73	2325.65	-0.07	0.30	13.58	86.03	44.57	71.53
IG01	8/20/08 14:57	216	On	21.11	1502	2.10	6.03	4.63	137.67	1.36	2325.54	3.48	13.52	13.59	86.13	42.64	71.64
IG02	8/20/08 15:03	316	On	21.16	1496	2.10	6.08	4.69	137.70	1.35	2325.54	3.53	13.52	13.58	86.30	42.76	71.63
IG03	8/20/08 15:10	201	On	17.04	1505	5.00	17.87	12.78	137.30	1.55	2325.53	4.88	13.48	13.58	86.58	41.84	71.63
IG04	8/20/08 15:18	212	On	18.33	1517	3.93	13.04	9.30	137.45	1.50	2325.55	4.04	13.41	13.58	86.80	42.17	71.63
IG05	8/20/08 15:26	202	On	16.14	1490	5.87	22.08	15.90	137.24	1.59	2325.55	5.72	9.58	13.58	86.84	42.46	71.61
IG06	8/20/08 15:32	203	On	15.01	1477	7.10	28.29	20.31	137.09	1.63	2325.55	5.76	8.21	13.58	86.64	42.87	71.62
IG07	8/20/08 15:37	201	On	13.69	1496	8.39	36.29	26.15	136.75	1.68	2325.55	6.14	6.11	13.58	86.48	43.54	71.62
IG08	8/20/08 15:44	206	On	12.53	1490	9.57	45.26	32.41	136.44	1.71	2325.56	6.79	4.21	13.58	86.41	43.15	71.61
IG09	8/20/08 15:51	211	On	11.28	1480	10.82	55.98	40.01	136.02	1.72	2325.57	7.02	2.45	13.58	86.29	43.10	71.60
IG10	8/20/08 15:58	209	On	10.33	1470	11.79	65.65	46.76	135.62	1.72	2325.57	7.12	1.45	13.59	86.46	43.07	71.58
IG11	8/20/08 16:06	214	On	9.04	1472	13.10	80.34	56.96	134.99	1.71	2325.57	6.84	0.34	13.58	86.74	43.37	71.61
IG12	8/20/08 16:13	207	On	7.98	1465	14.20	93.15	65.78	134.38	1.71	2325.58	6.71	-0.63	13.58	86.90	43.54	71.62
IG13	8/20/08 16:22	205	On	6.57	1479	15.56	112.23	78.77	133.50	1.70	2325.59	6.33	-1.73	13.58	86.64	43.37	71.61
WKCal_1500	8/20/08 14:39	153	On	6.56	1475	15.52	111.79	78.61	133.29	1.69	2325.51	6.37	-	13.59	86.36	41.94	71.65
WKCal_1000	8/20/08 10:42	98	On	12.70	961	9.61	46.92	33.04	138.01	1.30	2325.45	7.33	-	-	83.43	47.49	79.31
Pretest_8-19	8/19/08 18:40	138	On	12.65	963	9.72	-	-	138.02	1.28	2325.47	7.11	-	-	82.50	36.84	72.20
8-21_AllDay	8/21/08 12:38	1939	On	6.97	1114	15.12	106.59	74.99	133.14	1.68	2325.33	6.48	-1.39	13.63	83.79	40.11	71.73

Table 6.1: Raw Data

Run	Gate Stroke	Gate Stroke	WK41 Flow	WK42 Flow	Flow Used in Calcs	HW El	Inlet Vel	Inlet Vel Head	Exit Vel	Exit Vel Head	Inlet Static Head	Inlet Total Head	Disch Static Head	Disch Total Head	Net Head	Gross Head	Gen Loss	Gen Effic'y	Turbine Output
	%	in	cfs	cfs	cfs	ft	ft/s	ft	ft/s	ft	ft	ft	ft	ft	ft	ft	MW	%	hp
IG14	85.8	19.80	1508	1505	1508	2325.59	19.21	5.74	6.83	0.72	2316.27	2322.01	2171.75	2172.48	149.53	153.83	0.47	97.20	22,425
IG15	30.5	7.03	434	441	434	2325.60	5.52	0.47	1.96	0.06	2320.95	2321.42	2171.47	2171.53	149.89	154.13	0.31	89.99	4,113
IG16	34.8	8.02	501	505	501	2325.61	6.38	0.63	2.27	0.08	2320.92	2321.55	2171.52	2171.60	149.95	154.09	0.31	92.16	5,303
IG17	39.5	9.10	577	581	577	2325.61	7.35	0.84	2.61	0.11	2320.73	2321.57	2171.58	2171.68	149.89	154.03	0.32	93.69	6,694
IG18	44.5	10.26	665	670	665	2325.61	8.47	1.12	3.01	0.14	2320.57	2321.69	2171.63	2171.77	149.92	153.98	0.32	94.79	8,305
IG19	49.8	11.48	760	767	760	2325.62	9.67	1.45	3.44	0.18	2320.41	2321.87	2171.68	2171.87	150.00	153.94	0.33	95.60	10,181
IG20	54.2	12.51	847	857	847	2325.62	10.79	1.81	3.84	0.23	2320.10	2321.91	2171.71	2171.94	149.97	153.91	0.35	96.11	11,952
IG21	59.6	13.74	951	960	951	2325.62	12.11	2.28	4.31	0.29	2320.18	2322.46	2171.75	2172.04	150.42	153.87	0.36	96.48	13,803
IG22	63.8	14.72	1044	1052	1044	2325.62	13.29	2.75	4.72	0.35	2319.31	2322.06	2171.75	2172.09	149.97	153.88	0.38	96.68	15,162
IG23	69.6	16.04	1160	1165	1160	2325.63	14.77	3.39	5.25	0.43	2319.02	2322.41	2171.73	2172.16	150.25	153.90	0.40	96.88	16,977
IG24	74.9	17.28	1276	1281	1276	2325.64	16.25	4.11	5.78	0.52	2318.48	2322.59	2171.69	2172.21	150.38	153.95	0.42	97.03	18,907
IG25	79.8	18.39	1379	1381	1379	2325.64	17.56	4.79	6.24	0.61	2317.48	2322.28	2171.72	2172.33	149.95	153.92	0.44	97.13	20,597
IG26	85.3	19.66	1497	1495	1497	2325.65	19.06	5.65	6.78	0.71	2316.54	2322.19	2171.76	2172.48	149.72	153.88	0.47	97.20	22,325
IG01	22.7	5.23	343	358	343	2325.54	4.37	0.30	1.55	0.04	2320.80	2321.09	2171.40	2171.43	149.66	154.14	0.31	87.33	3,230
IG02	22.5	5.19	345	361	345	2325.54	4.39	0.30	1.56	0.04	2320.83	2321.13	2171.38	2171.42	149.71	154.15	0.31	87.33	3,230
IG03	40.3	9.30	591	596	591	2325.53	7.52	0.88	2.67	0.11	2320.43	2321.31	2171.59	2171.70	149.61	153.95	0.32	94.04	7,136
IG04	34.8	8.01	505	508	505	2325.55	6.43	0.64	2.28	0.08	2320.57	2321.21	2171.54	2171.62	149.59	154.01	0.31	92.67	5,693
IG05	44.2	10.20	657	664	657	2325.55	8.36	1.09	2.97	0.14	2320.37	2321.46	2171.62	2171.76	149.69	153.93	0.32	94.79	8,298
IG06	49.2	11.34	743	751	743	2325.55	9.47	1.39	3.36	0.18	2320.21	2321.61	2171.66	2171.84	149.77	153.89	0.33	95.53	9,968
IG07	54.9	12.65	842	852	842	2325.55	10.72	1.79	3.81	0.23	2319.87	2321.66	2171.72	2171.94	149.71	153.84	0.34	96.05	11,716
IG08	59.9	13.82	940	949	940	2325.56	11.97	2.23	4.26	0.28	2319.56	2321.79	2171.75	2172.03	149.76	153.81	0.36	96.39	13,320
IG09	65.3	15.06	1046	1054	1046	2325.57	13.32	2.76	4.73	0.35	2319.14	2321.90	2171.76	2172.11	149.79	153.81	0.37	96.66	15,014
IG10	69.5	16.02	1132	1139	1132	2325.57	14.42	3.23	5.13	0.41	2318.75	2321.98	2171.76	2172.16	149.82	153.82	0.39	96.81	16,325
IG11	75.0	17.30	1253	1258	1253	2325.57	15.95	3.96	5.67	0.50	2318.12	2322.08	2171.74	2172.24	149.83	153.83	0.41	96.97	18,109
IG12	79.6	18.36	1349	1351	1349	2325.58	17.18	4.59	6.11	0.58	2317.50	2322.09	2171.74	2172.32	149.77	153.84	0.43	97.07	19,620
IG13	85.7	19.77	1481	1479	1481	2325.59	18.85	5.53	6.70	0.70	2316.62	2322.15	2171.74	2172.44	149.71	153.85	0.45	97.17	21,475
WKCal_1500	85.8	19.79	1478	1477	1478	2325.51	18.82	5.51	6.69	0.70	2316.41	2321.92	2171.72	2172.42	149.50	153.79	0.45	97.16	21,421
WKCal_1000	59.2	13.65	957	958	957	2325.45	12.19	2.31	4.33	0.29	2321.14	2323.45	2171.33	2171.63	151.82	154.11	0.36	96.40	13,368
Pretest_8-19	59.4	13.69	-	-	963	2325.47	12.27	2.34	4.36	0.30	2321.14	2323.48	2171.32	2171.61	151.87	154.15	0.36	96.43	13,514
8-21_AllDay	84.0	19.38	1443	1443	1443	2325.33	18.37	5.25	6.53	0.66	2316.26	2321.51	2171.72	2172.38	149.13	153.61	0.45	97.14	20,870

Table 6.2: Basic Calculations

	Combined Turbine-Generator Calculations								Turbine Calculations			
	Test Values		At 150 ft Net Head			At 150 ft Gross Head			At 150 ft Net Head			
Run	Net Effic'y	Gross Effic'y	Power	Flow	Effic'y	Power	Flow	Effic'y	Test Effic'y	Power	Flow	Effic'y
	%	%	MW	cfs	%	MW	cfs	%	%	hp	cfs	%
IG14	85.38	82.99	16.33	1511	85.38	15.65	1489	82.99	87.56	22531	1511	87.83
IG15	50.32	48.93	2.76	434	50.32	2.65	428	48.93	55.87	4117	434	55.91
IG16	57.50	55.95	3.65	501	57.50	3.50	494	55.95	62.36	5306	501	62.39
IG17	64.02	62.30	4.68	578	64.02	4.49	570	62.30	68.28	6702	578	68.33
IG18	69.75	67.91	5.88	665	69.75	5.64	656	67.91	73.54	8312	665	73.58
IG19	75.46	73.53	7.26	760	75.46	6.98	750	73.53	78.93	10181	760	78.93
IG20	79.87	77.82	8.57	847	79.87	8.24	836	77.82	83.07	11955	847	83.09
IG21	82.23	80.39	9.89	950	82.23	9.56	939	80.39	85.47	13746	950	85.23
IG22	82.73	80.63	10.93	1044	82.73	10.52	1031	80.63	85.55	15168	1044	85.57
IG23	83.37	81.39	12.23	1159	83.37	11.80	1145	81.39	86.20	16934	1159	86.05
IG24	84.43	82.48	13.63	1275	84.43	13.16	1260	82.48	87.23	18835	1275	87.01
IG25	85.48	83.27	14.93	1379	85.48	14.35	1361	83.27	87.97	20607	1379	88.00
IG26	85.54	83.22	16.23	1498	85.54	15.57	1478	83.22	87.83	22389	1498	88.00
IG01	48.52	47.11	2.11	343	48.52	2.02	338	47.11	55.43	3241	343	55.56
IG02	48.30	46.91	2.11	345	48.30	2.02	340	46.91	55.20	3239	345	55.31
IG03	67.07	65.18	5.02	592	67.07	4.81	583	65.18	71.12	7164	592	71.31
IG04	61.74	59.96	3.95	505	61.74	3.78	498	59.96	66.44	5717	505	66.62
IG05	70.69	68.74	5.88	657	70.69	5.64	648	68.74	74.42	8323	657	74.57
IG06	75.56	73.54	7.12	744	75.56	6.83	734	73.54	78.97	9991	744	79.10
IG07	78.88	76.76	8.42	843	78.88	8.08	831	76.76	81.96	11750	843	82.11
IG08	80.55	78.43	9.60	941	80.55	9.22	929	78.43	83.43	13352	941	83.56
IG09	81.85	79.71	10.84	1046	81.85	10.42	1033	79.71	84.56	15046	1046	84.68
IG10	82.30	80.16	11.81	1133	82.30	11.35	1118	80.16	84.90	16354	1133	85.00
IG11	82.65	80.51	13.12	1253	82.65	12.61	1237	80.51	85.13	18139	1253	85.23
IG12	83.29	81.09	14.24	1350	83.29	13.67	1332	81.09	85.66	19666	1350	85.79
IG13	83.16	80.93	15.61	1482	83.16	14.98	1462	80.93	85.42	21537	1482	85.58
WKCal_1500	83.23	80.91	15.60	1480	83.23	14.95	1459	80.91	85.37	21529	1480	85.66
WKCal_1000	78.33	77.16	9.44	952	78.33	9.23	944	77.16	82.23	13127	952	81.24
Pretest_8-19	78.69	77.52	9.54	957	78.69	9.33	950	77.52	82.61	13266	957	81.60
8-21_AllDay	83.23	80.80	15.25	1447	83.23	14.59	1426	80.80	85.18	21053	1447	85.67

Table 6.3: Unit and Turbine Efficiency Results

Air Flow Data									
Run	Gate	Atm. pressure	Air temp	Rel. humidity	Bell-mouth Diff'al	Bell Coeff	Air Vel	Air Flow	Air:Water Ratio
	%	psia	deg F	%	in H2O	-	ft/s	cfs	%
IG14	85.8	13.58	86.59	42.33	0.00	0.0	0.0	0.0	0.0
IG15	30.5	13.58	86.74	42.74	0.00	0.0	0.0	0.0	0.0
IG16	34.8	13.59	86.81	42.65	-0.01	0.0	0.0	0.0	0.0
IG17	39.5	13.58	87.04	42.71	0.00	0.0	0.0	0.0	0.0
IG18	44.5	13.58	87.07	42.50	0.00	0.0	0.0	0.0	0.0
IG19	49.8	13.58	86.93	42.39	0.00	0.0	0.0	0.0	0.0
IG20	54.2	13.58	86.77	42.66	0.00	0.0	0.0	0.0	0.0
IG21	59.6	13.58	86.96	42.47	0.00	0.0	0.0	0.0	0.0
IG22	63.8	13.58	86.88	42.56	0.00	0.0	0.0	0.0	0.0
IG23	69.6	13.58	86.55	43.30	0.00	0.0	0.0	0.0	0.0
IG24	74.9	13.58	86.40	44.14	0.00	0.0	0.0	0.0	0.0
IG25	79.8	13.58	86.25	44.31	0.00	0.0	0.0	0.0	0.0
IG26	85.3	13.58	86.03	44.57	-0.01	0.0	0.0	0.0	0.0
IG01	22.7	13.59	86.13	42.64	3.54	0.993	131.7	25.9	7.5
IG02	22.5	13.58	86.30	42.76	3.59	0.993	132.6	26.0	7.6
IG03	40.3	13.58	86.58	41.84	4.94	0.994	155.3	30.5	5.2
IG04	34.8	13.58	86.80	42.17	4.10	0.993	141.6	27.8	5.5
IG05	44.2	13.58	86.84	42.46	5.78	0.994	167.9	33.0	5.0
IG06	49.2	13.58	86.64	42.87	5.82	0.994	168.4	33.1	4.4
IG07	54.9	13.58	86.48	43.54	6.20	0.994	173.7	34.1	4.1
IG08	59.9	13.58	86.41	43.15	6.85	0.994	182.6	35.8	3.8
IG09	65.3	13.58	86.29	43.10	7.08	0.995	185.5	36.4	3.5
IG10	69.5	13.59	86.46	43.07	7.18	0.995	186.7	36.7	3.2
IG11	75.0	13.58	86.74	43.37	6.90	0.994	183.2	36.0	2.9
IG12	79.6	13.58	86.90	43.54	6.77	0.994	181.5	35.6	2.6
IG13	85.7	13.58	86.64	43.37	6.39	0.994	176.3	34.6	2.3
WKCal_1500	85.8	13.59	86.36	41.94	6.43	0.994	176.9	34.7	2.4
WKCal_1000	59.2	-	83.43	47.49	7.39	0.995	189.5	37.2	3.9
Pretest_8-19	59.4	-	82.50	36.84	7.17	0.995	186.6	36.6	3.8
8-21_AllDay	84.0	13.63	83.79	40.11	6.54	0.994	178.4	35.0	2.4

Table 6.4: Air Flow Results

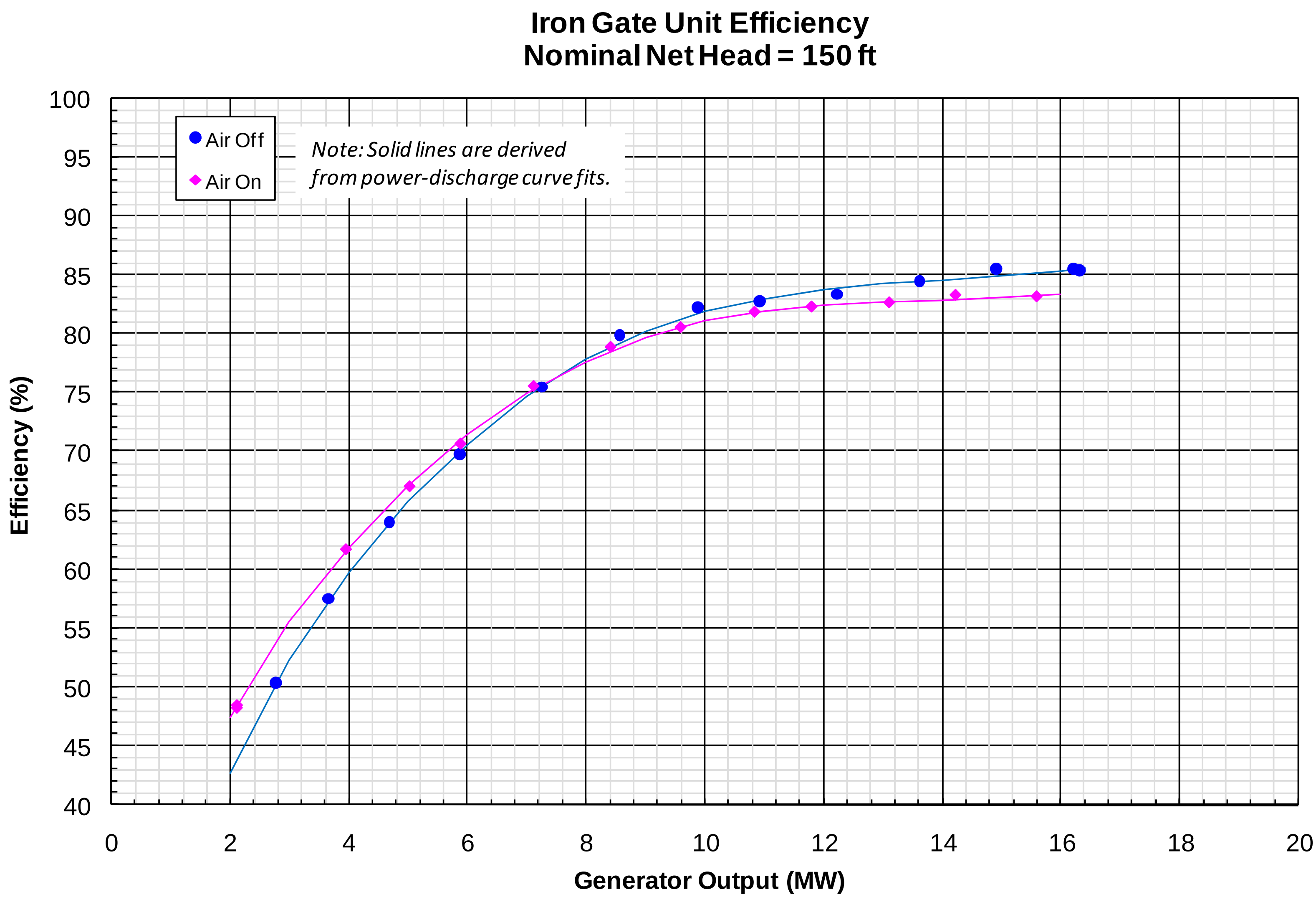


Figure 6.2: Unit Efficiency With and Without Air Admission

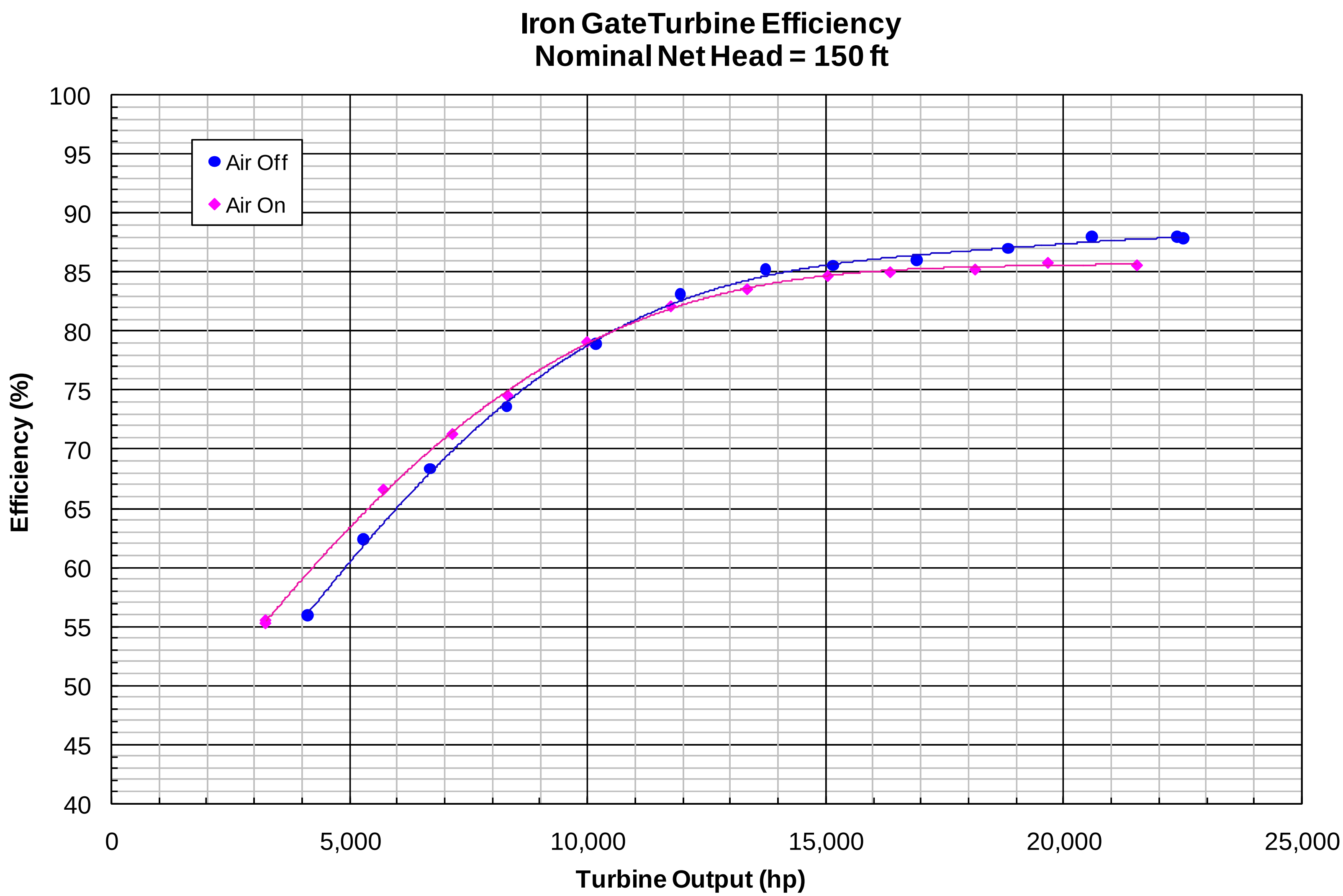


Figure 6.3: Turbine Efficiency With and Without Air Admission

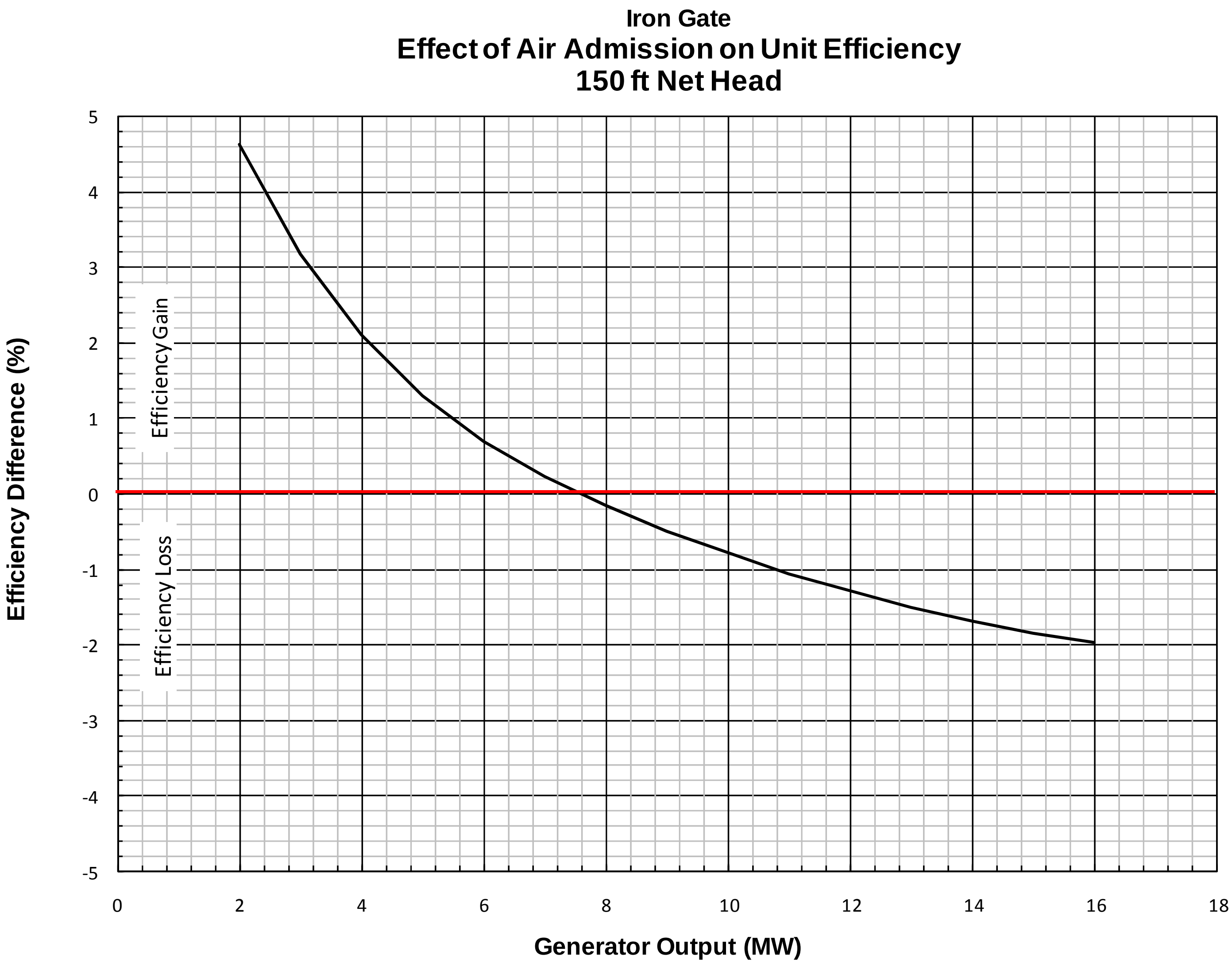


Figure 6.4: Effect of Air Admission on Unit Efficiency

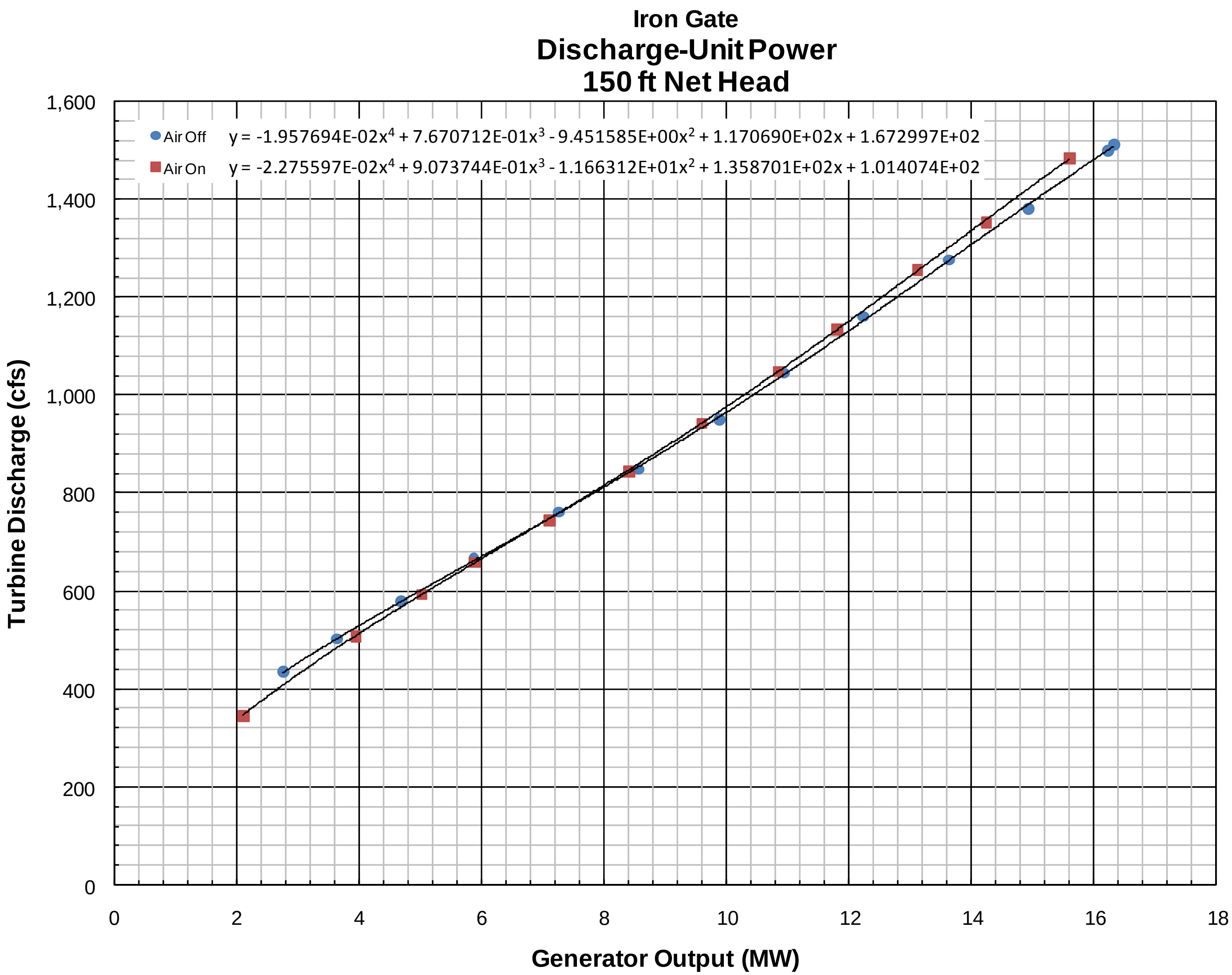


Figure 6.5: Unit Discharge-Power Curves With and Without Air Admission

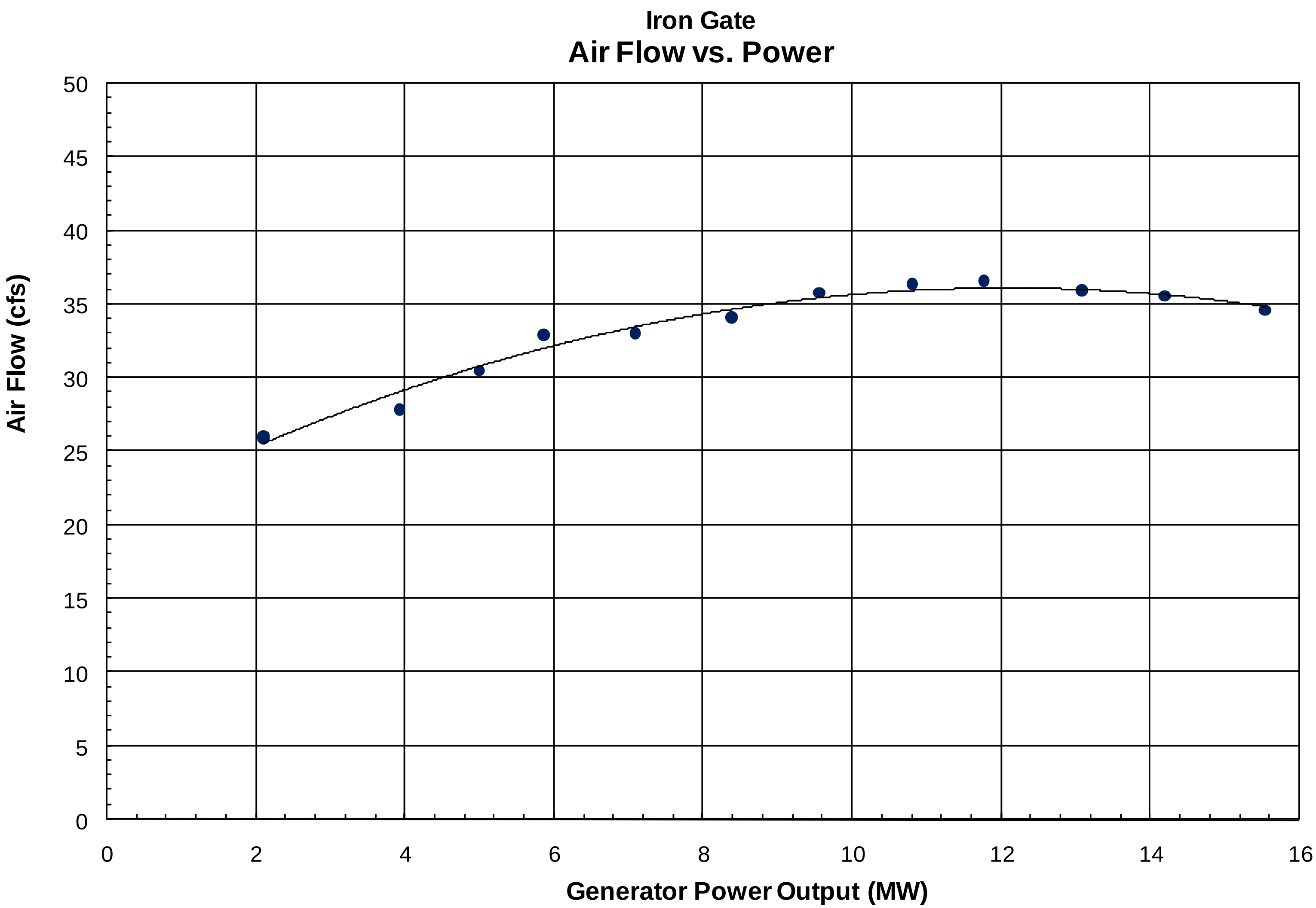


Figure 6.6: Air Flow vs. Generator Power Outut

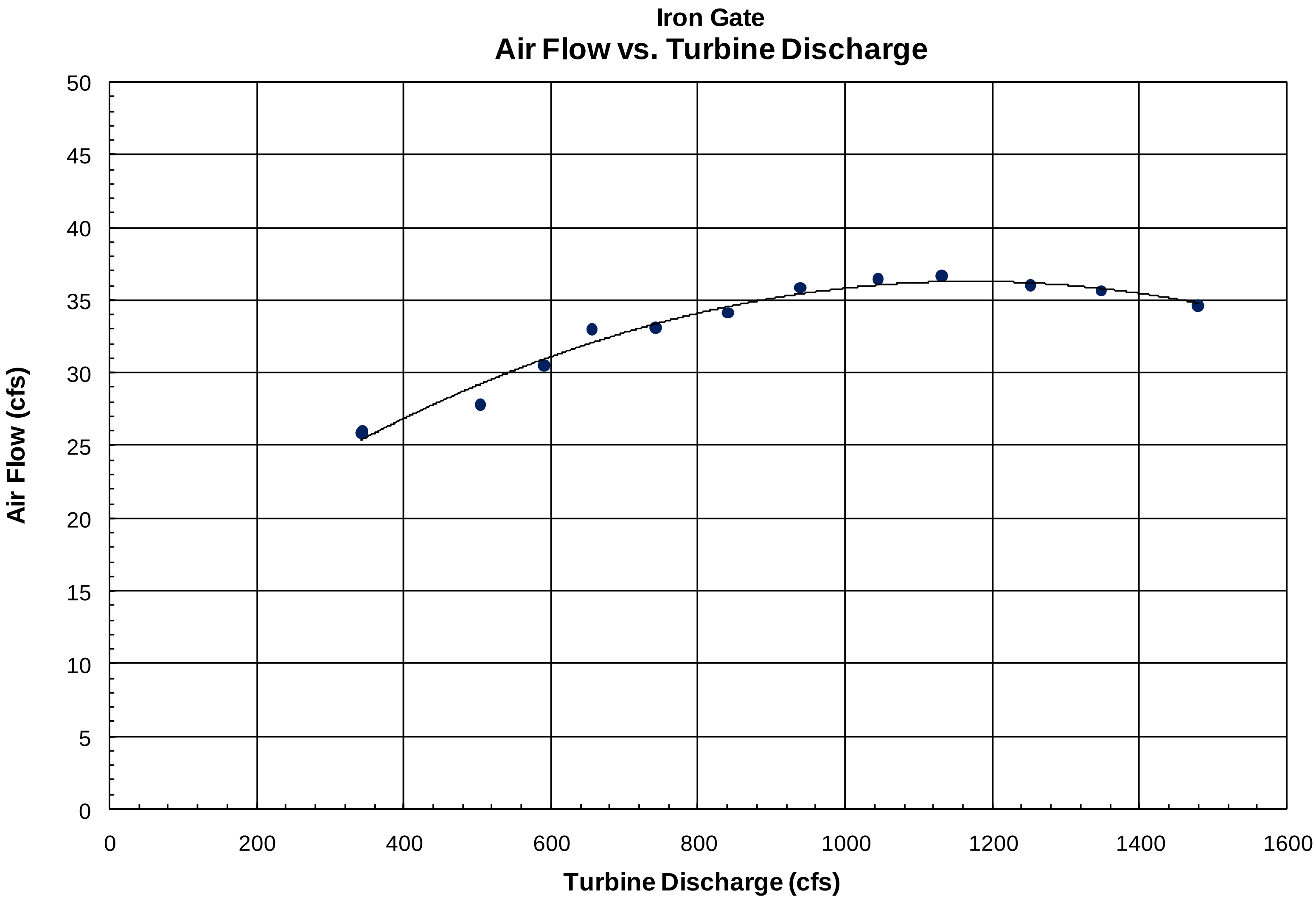


Figure 6.7: Air Flow vs. Turbine Discharge

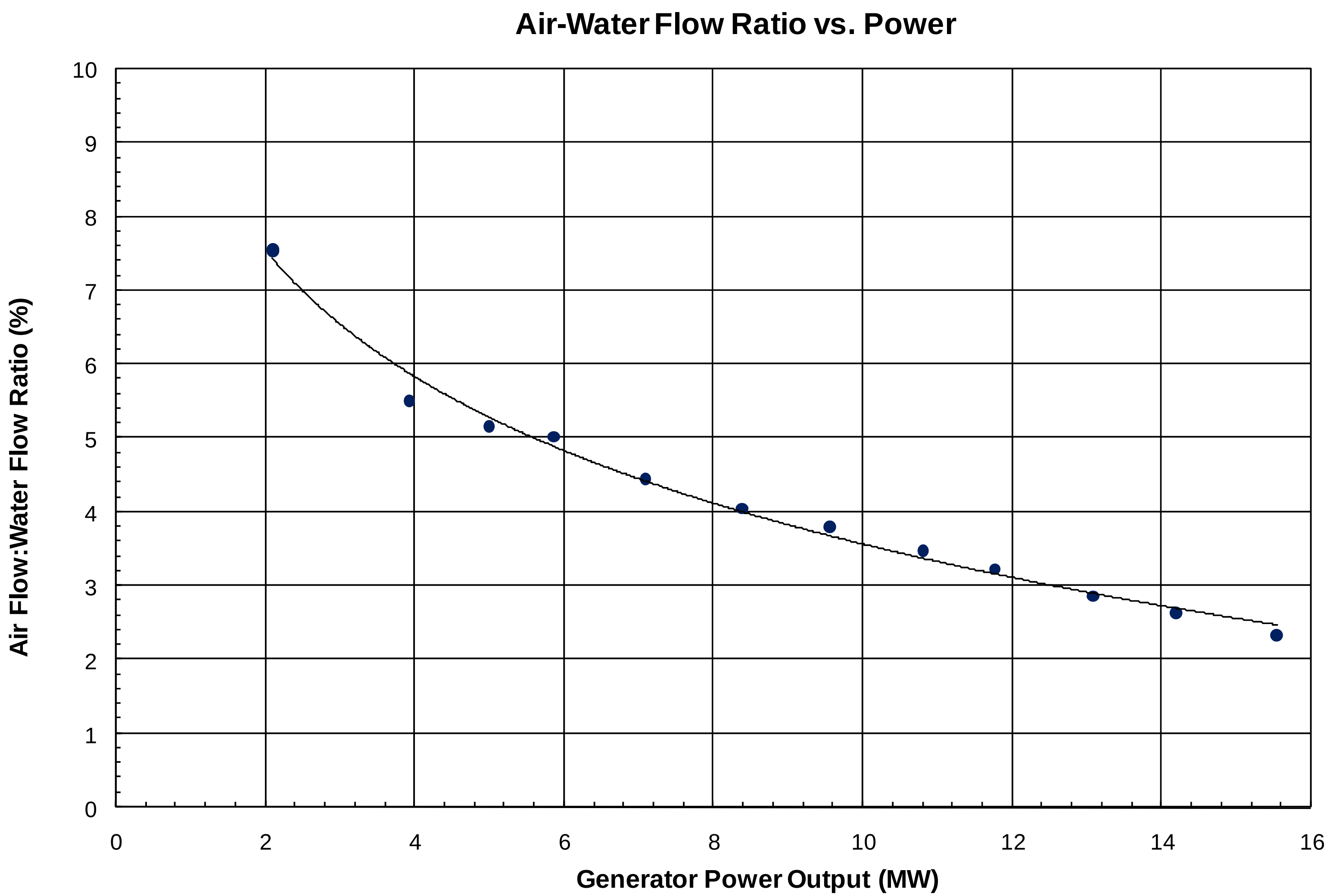


Figure 6.8: Air-Water Flow Ratio vs. Generator Power Output

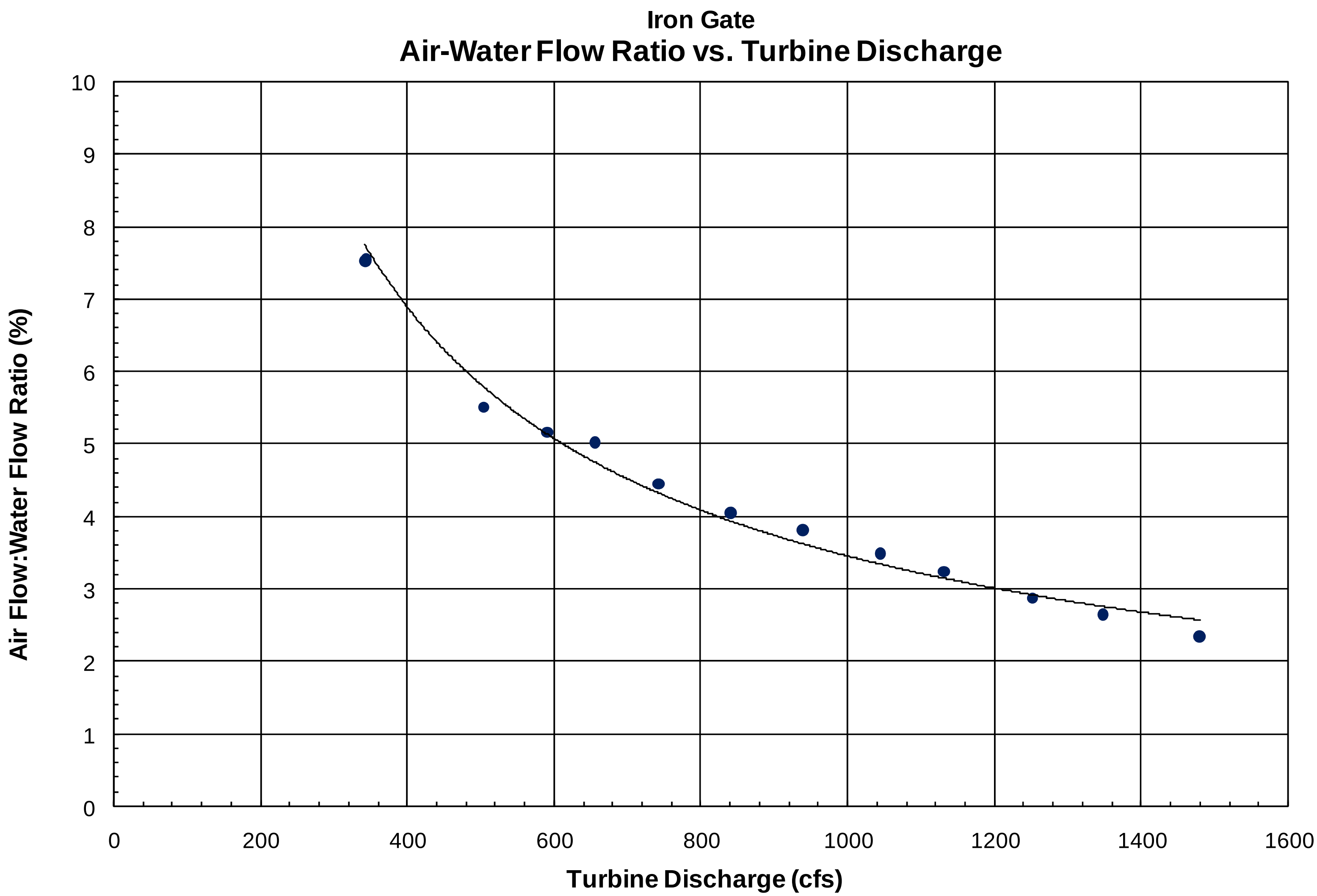


Figure 6.9: Unit Air-Water Flow Ratio vs. Turbine Discharge

7. SUMMARY AND CONCLUSIONS

The generating unit at PacifiCorp's Iron Gate Project powerhouse on the Klamath River has demonstrated that it is capable of drawing air through its air admission system over the entire range of operation. Although testing was conducted only at a total powerhouse discharge of 1500 cfs, this capability will likely be achievable at total powerhouse discharges up to the turbine capacity because the tailwater elevation (which heavily influences the air flow) varies little with powerhouse discharge.

The total air flow rate into the turbine remains relative constant at 25 – 35 cfs over the range of operating conditions. As a result, the air-water flow ratio decreases from a high of about 7.5% at the lowest gate openings to about 2.4 % at the maximum tested gate opening of 86%. Previous experience indicates that the increase in DO due to a 2.4% air-water flow ratio will be modest but measureable. The water quality surveys conducted concurrently with these tests will provide quantification of the DO improvement.

Air admission results in an increase in unit efficiency at gate openings below about 50% and a decrease at larger gate openings. At the maximum tested gate opening of 86%, the loss in efficiency was about 2%. Air admission also results in a decrease in maximum power output of about 0.8 MW.

8. References

1. ASME, *Performance Test Code 18 – Hydraulic Turbines*, American Society of Mechanical Engineers, New York, 2002.
2. ASME, *Fluid Meters*, 6th Edition, American Society of Mechanical Engineers, New York, 1971.

APPENDICES

A. INSTRUMENTATION SPECIFICATIONS

B. CALIBRATION DATA

Appendix A
Instrumentation Specifications

User's Guide

Publication Number 34970-90003 (*order as 34970-90101 manual set*)
Edition 3, March 2003

For Safety information, Warranties, and Regulatory information, see the pages following the Index.

Agilent 34970A
Data Acquistion/Switch Unit

DC, Resistance, and Temperature Accuracy Specifications

± (% of reading + % of range) [1]
Includes measurement error, switching error, and transducer conversion error

Function	**Range [3]**	**Test Current or Burden Voltage**	**24 Hour [2] 23 °C ± 1 °C**	**90 Day 23 °C ± 5 °C**	**1 Year 23 °C ± 5 °C**	**Temperature Coefficient /°C 0 °C – 18 °C 28 °C – 55 °C**
DC Voltage	100.0000 mV		0.0030 + 0.0035	0.0040 + 0.0040	0.0050 + 0.0040	0.0005 + 0.0005
	1.000000 V		0.0020 + 0.0006	0.0030 + 0.0007	0.0040 + 0.0007	0.0005 + 0.0001
	10.00000 V		0.0015 + 0.0004	0.0020 + 0.0005	0.0035 + 0.0005	0.0005 + 0.0001
	100.0000 V		0.0020 + 0.0006	0.0035 + 0.0006	0.0045 + 0.0006	0.0005 + 0.0001
	300.000 V		0.0020 + 0.0020	0.0035 + 0.0030	0.0045 + 0.0030	0.0005 + 0.0003
Resistance [4]	100.0000 Ω	1 mA current source	0.0030 + 0.0035	0.008 + 0.004	0.010 + 0.004	0.0006 + 0.0005
	1.000000 kΩ	1 mA	0.0020 + 0.0006	0.008 + 0.001	0.010 + 0.001	0.0006 + 0.0001
	10.00000 kΩ	100 µA	0.0020 + 0.0005	0.008 + 0.001	0.010 + 0.001	0.0006 + 0.0001
	100.0000 kΩ	10 µA	0.0020 + 0.0005	0.008 + 0.001	0.010 + 0.001	0.0006 + 0.0001
	1.000000 MΩ	5 µA	0.002 + 0.001	0.008 + 0.001	0.010 + 0.001	0.0010 + 0.0002
	10.00000 MΩ	500 nA	0.015 + 0.001	0.020 + 0.001	0.040 + 0.001	0.0030 + 0.0004
	100.0000 MΩ	500 nA || 10 MΩ	0.300 + 0.010	0.800 + 0.010	0.800 + 0.010	0.1500 + 0.0002
DC Current *34901A Only*	10.00000 mA	< 0.1 V burden	0.005 + 0.010	0.030 + 0.020	0.050 + 0.020	0.002 + 0.0020
	100.0000 mA	< 0.6 V	0.010 + 0.004	0.030 + 0.005	0.050 + 0.005	0.002 + 0.0005
	1.000000 A	< 2 V	0.050 + 0.006	0.080 + 0.010	0.100 + 0.010	0.005 + 0.0010
Temperature	**Type**	**Best Range Accuracy [5]**		**Extended Range Accuracy [5]**		
Thermocouple [6]	B	1100°C to 1820°C	1.2°C	400°C to 1100°C	1.8°C	0.03°C
	E	-150°C to 1000°C	1.0°C	-200°C to -150°C	1.5°C	0.03°C
	J	**-150°C to 1200°C**	**1.0°C**	**-210°C to -150°C**	**1.2°C**	**0.03°C**
	K	-100°C to 1200°C	1.0°C	-200°C to -100°C	1.5°C	0.03°C
	N	-100°C to 1300°C	1.0°C	-200°C to -100°C	1.5°C	0.03°C
	R	300°C to 1760°C	1.2°C	-50°C to 300°C	1.8°C	0.03°C
	S	400°C to 1760°C	1.2°C	-50°C to 400°C	1.8°C	0.03°C
	T	-100°C to 400°C	1.0°C	-200°C to -100°C	1.5°C	0.03°C
RTD	R_0 from 49Ω to 2.1 kΩ	-200°C to 600°C	0.06°C			0.003°C
Thermistor	2.2 k, 5 k, 10 k	-80°C to 150°C	0.08°C			0.002°C

[1] Specifications are for 1 hour warm up and 6½ digits
[2] Relative to calibration standards
[3] 20% over range on all ranges except 300 Vdc and 1 Adc ranges
[4] Specifications are for 4-wire ohms function or 2-wire ohms using Scaling to remove the offset.
Without Scaling, add 4Ω additional error in 2-wire ohms function.
[5] 1 year accuracy. For total measurement accuracy, add temperature probe error.
[6] Thermocouple specifications not guaranteed when 34907A module is present

DC Measurement and Operating Characteristics

DC Measurement Characteristics [1]

DC Voltage	
Measurement Method:	Continuously Integrating, Multi-slope III A/D Converter
A/D Linearity:	0.0002% of reading + 0.0001% of range
Input Resistance:	
100 mV, 1 V, 10 V ranges	Selectable 10 MΩ or >10 GΩ
100 V, 300 V ranges	10 MΩ ±1%
Input Bias Current:	< 30 pA at 25 °C
Input Protection:	300 V on all ranges
Resistance	
Measurement Method:	Selectable 4-wire or 2-wire Ohms, Current source reference to LO input
Offset Compensation:	Selectable on 100Ω, 1 kΩ, 10 kΩ ranges
Max. Lead Resistance:	10% of range per lead for 100Ω and 1 kΩ ranges. 1 kΩ on all other ranges
Input Protection:	300 V on all ranges
DC Current	
Shunt Resistance:	5Ω for 10 mA, 100 mA; 0.1Ω for 1A.
Input Protection:	1.5A 250 V fuse on 34901A module
Thermocouple	
Conversion:	ITS-90 software compensation
Reference Junction Type:	Internal, Fixed, or External
Open T/C Check:	Selectable per channel. Open > 5 kΩ
RTD	α = 0.00385 (DIN/IEC 751) using ITS-90 software compensation or α = 0.00391 using IPTS-68 software compensation.
Thermistor	44004, 44007, 44006 series

Measurement Noise Rejection 60 Hz (50 Hz) [2]

DC CMRR: 140 dB

Integration Time	Normal Mode Rejection [3]
200 PLC / 3.33s (4s)	110 dB [4]
100 PLC / 1.67s (2s)	105 dB [4]
20 PLC / 333 ms (400 ms)	100 dB [4]
10 PLC / 167 ms (200 ms)	95 dB [4]
2 PLC / 33.3 ms (40 ms)	90 dB
1 PLC / 16.7 ms (20 ms)	60 dB
< 1 PLC	0 dB

DC Operating Characteristics [5]

Function	Digits [6]	Readings/s	Additional Noise Error
DCV, DCI, and	6½	0.6 (0.5)	0% of range
Resistance:	6½	6 (5)	0% of range
	5½	60 (50)	0.001% of range
	5½	300	0.001% of range [7]
	4½	600	0.01% of range [7]

Single Channel Measurement Rates [8]

Function	Resolution	Readings/s
DCV, 2-Wire Ohms:	6½ (10 PLC)	6 (5)
	5½ (1 PLC)	57 (47)
	4½ (0.02 PLC)	600
Thermocouple:	0.1 °C (1 PLC)	57 (47)
	(0.02 PLC)	220
RTD, Thermistor:	0.01 °C (10 PLC)	6 (5)
	0.1 °C (1 PLC)	57 (47)
	1 °C (0.02 PLC)	220

Autozero OFF Operation
Following instrument warm-up at calibration temperature ±1 °C and < 10 minutes, add 0.0002% range additional error + 5 µV.

Settling Considerations
Reading settling times are affected by source impedance, low dielectric absorption characteristics, and input signal changes.

[1] 300 Vdc isolation voltage (ch-ch, ch-earth)
[2] For 1 kΩ unbalance in LO lead
[3] For power line frequency ±0.1%
[4] For power line frequency ±1%, use 80 dB.
For power line frequency ±3%, use 60 dB.
[5] Reading speeds for 60 Hz and (50 Hz) operation; autozero OFF
[6] 6½ digits=22 bits, 5½ digits=18 bits, 4½ digits=15 bits
[7] Add 20 µV for DCV, 4 µA for DCI, or 20 mΩ for resistance
[8] For fixed function and range, readings to memory, scaling and alarms off, autozero OFF

Reference Manual
00809-0100-4001, Rev EA
December 2002

Model 3051 Pressure Transmitter

with HART protocol®

www.rosemount.com

Stability

±0.125% of URL for 5 years for ±50 °F (28 °C) temperature changes, and up to 1000 psi (6,9 MPa) line pressure

Dynamic Performance Total Response Time (T_d + T_c)

100 ms

Model 3051L—Liquid Level

Reference Accuracy

±0.075% of span

Model 3051H—High Process Temperature

Reference Accuracy

±0.075% of span

Stability

±0.1% of URL for 12 months for Ranges 2 and 3

±0.2% of URL for 12 months for Ranges 4 and 5

DETAILED PERFORMANCE SPECIFICATIONS

For zero-based spans, reference conditions, silicone oil fill, SST materials, Coplanar flange (Model 3051C) or 1/2 in.- 18 NPT (Model 3051T) process connections, digital trim values set to equal range points.

Reference Accuracy

Stated reference accuracy includes hysteresis, terminal-based linearity and repeatability.

Model 3051CD Ranges 2–5 and 3051CG

±0.075% of span for spans less than 10:1, accuracy =

$\pm\left[0.025 + 0.005\left(\frac{URL}{Span}\right)\right]$% of Span

Model 3051CD Range 1

±0.10% of span for spans less than 15:1, accuracy =

$\pm\left[0.025 + 0.005\left(\frac{URL}{Span}\right)\right]$% of Span

Model 3051CD Range 0

±0.10% of span for spans less than 2:1, accuracy = ±0.05% of URL

Model 3051T/CA Ranges 1–5

±0.075% of span for spans less than 10:1, accuracy =

$\pm\left[0.0075\left(\frac{URL}{Span}\right)\right]$% of Span

Model 3051CA Range 0

±0.075% of span for spans less than 5:1, accuracy =

$\pm\left[0.025 + 0.01\left(\frac{URL}{Span}\right)\right]$% of Span

Model 3051H/3051L

±0.075% of span for spans less than 10:1, accuracy =

$\pm\left[0.025 + 0.005\left(\frac{URL}{Span}\right)\right]$% of Span

Model 3051P

±0.05% of span

Ambient Temperature Effect per 50 °F (28 °C)

Model 3051CD/CG

Range 2 - 5: ±(0.0125% URL + 0.0625% span) from 1:1 to 5:1
±(0.025% URL + 0.125% span) from 5:1 to 100:1

Range 1: ±(0.1% URL + 0.25% span) from 1:1 to 30:1
±(0.147% URL + 0.15% span) greater than 30:1

Range 0: ±(0.25% URL + 0.05% span)

Model 3051CA

Range 1 - 4: ±(0.025% URL + 0.125% span) from 1:1 to 30:1
±(0.035% URL + 0.125% span) from 30:1 to 100:1

Range 0: ± (0.1% URL +0.25% span)

Model 3051P

All ranges: ±(0.006% URL + 0.03% span)

Model 3051H

All ranges: ±(0.025% URL + 0.125% span + 0.35 inH_2O)

For spans below 30:1 rangedown:
±(0.035% URL + 0.125% span + 0.35 inH_2O)

Model 3051L

See Rosemount Inc. Instrument Toolkit™ software.

Model 3051T

Ranges 2- 4: ±(0.025% URL + 0.125% span) from 1:1 to 30:1
±(0.035% URL + 0.125% span) from 30:1 to 100:1

Range 5: ±(0.1% URL + 0.15% span)

Range 1: ±(0.025% URL + 0.125% span) from 1:1 to 10:1
±(0.05% URL + 0.125% span) from 10:1 to 100:1

Mounting Position Effects

Model 3051C/P
Zero shifts up to ±1.25 inH_2O (3,11 mbar), which can be calibrated out. No span effect.

Model 3051H
Zero shifts up to ±5 inH_2O (127 mmH_2O), which can be calibrated out. No span effect.

Model 3051L
With liquid level diaphragm in vertical plane, zero shift of up to 1 inH_2O (25,4 mmH_2O).
With diaphragm in horizontal plane, zero shift of up to 5 inH_2O (127 mmH_2O) plus extension length on extended units. All zero shifts can be calibrated out. No span effect.

Model 3051T/CA
Zero shifts up to 2.5 inH_2O (63,5 mmH_2O), which can be calibrated out. No span effect.

Vibration Effect

All Models
Measurement effect due to vibrations is negligible except at resonance frequencies. When at resonance frequencies, vibration effect is less than ±0.1% of URL per g when tested between 15 and 2000 Hz in any axis relative to pipe-mounted process conditions.

Power Supply Effect

All Models
Less than ±0.005% of calibrated span per volt.

RFI Effects

All Models
±0.1% of span from 20 to 1000 MHz and for field strength up to 30 V/m. Shielded cable needed for 30 V/m.

Transient Protection (Option Code T1)

All Models
Meets IEEE Standard 587, Category B

1 kV crest (10 × 1 000 microseconds)
3 kV crest (8 × 20 microseconds)
6 kV crest (1,2 × 50 microseconds)

Meets IEEE Standard 472, Surge Withstand Capability

SWC 2,5 kV crest, 1 MHz wave form

General Specifications:

Response Time: < 1 nanosecond
Peak Surge Current: 5000 amps to housing.
Peak Transient Voltage: 100 V dc.
Loop Impedance: < 25 ohms
Applicable Standards: IEC 801-4, IEC 801-5

NOTE:
Calibrations at 68 °F (20 °C) per ASME Z210.1 (ANSI)

Cable-Extension Position Transducer

- Short to Medium Range
- 4...20 mA Output

CE

PT420

The PT420 is available with full-scale measurement ranges from 2 to 100 inches, providing a 0/4-20 mA feedback signal that is linearly proportional to the position of a traveling stainless-steel extension cable. Use the PT420 to provide position feedback on hydraulic cylinders in factories and utilities, gate position in fresh or wastewater distribution systems, or valve opening in process-related applications.

The PT420 installs in minutes by mounting its base to a fixed surface and attaching its cable to the movable object. The PT420 works without perfect parallel alignment, and when its stainless steel cable is retracted, its height is less than 5".

Specifications:

GENERAL

Full Stroke Ranges .... 0-2 to 0- 100 inches, see ordering info.
Output Signal .... 4 - 20 mA (2-wire), 0 - 20 mA (3-wire), see ordering info.
Accuracy
  2 and 5 Inch Ranges .... ±0.28% full stroke
  10, 15, 25 Inch Ranges .... ±0.18% full stroke
  20, 30 Inch Ranges and Greater .... ±0.15% full stroke
Repeatability .... greater of ±0.001 inches or 0.02% full stroke
Resolution .... essentially infinite
Measuring Cable .... 0.019-in. dia. nylon-coated stainless steel
Cable Fitting .... crimp and swivel
Enclosure Material .... powder coated and anodized aluminum
Sensor .... plastic-hybrid precision potentiometer
Weight .... 2 lbs., max.

ELECTRICAL

Input Voltage .... 12 to 40 VDC
Input Current .... 20 mA, max.
Loop Resistance (Load) .... (loop supply voltage - 12) / 0.02, max.
Circuit Protection .... 38 mA maximum
Impedance .... 100 MΩ @ 100 VDC, min.
Zero and Span Adjustment .... 2:1 turndown
Electrical Connector MS3102E-14S-6P
Mating Plug (included) MS3106E-14S-6S

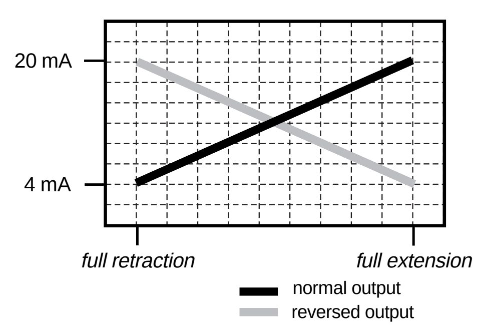
ENVIRONMENTAL

Enclosure Design .... NEMA 1
Operating Temperature .... -40° F to 180°F
Thermal Effects
  Zero .... 0.01% full stroke / °F, max.
  Span .... 0.01% / °F, max.
Vibration .... up to 10 G's to 2000 Hz max.

MECHANICAL

Measurement Range (Inches)	Cable Tension (Ounces, ±30%)	Max. Cable Acceleration (Gravities)
0- 2, -10, -20	12	11
0- 5, -25, -50	5	2
0-15, -30	8	3
0-40	6	4
0-60	13	4
0-75	10	3
0-100	13	2

Electrical Output:



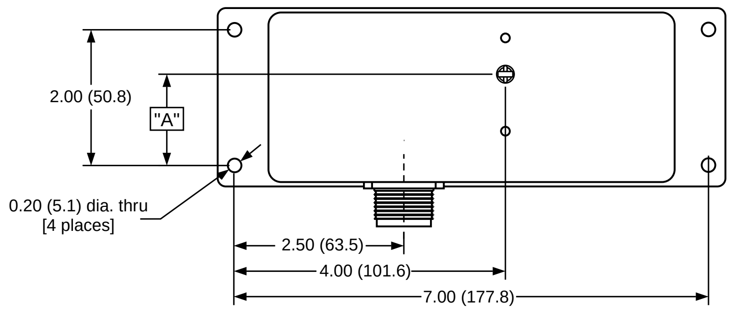
celesco
www.celesco.com
Celesco Transducer Products, Inc.
20630 Plummer Street • Chatsworth, CA • 91311
tel: (800) 423-5483 • (818) 701-2750
fax: (818) 701-2799
e-mail: info@celesco.com

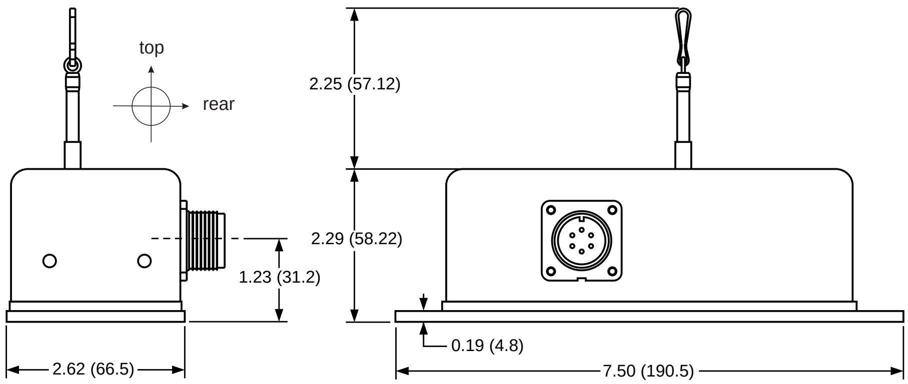
PT420 Short to Medium Range • 4...20 mA Output Signal

outline drawing (2 thru 50 inch f.s. ranges)

"A" DIMENSION	
RANGE	INCHES (MM)
2", 10", 20"	1.34 (34.0)
5", 25", 50"	1.83 (46.8)
15", 30"	1.56 (39.6)
40"	1.63 (41.4)

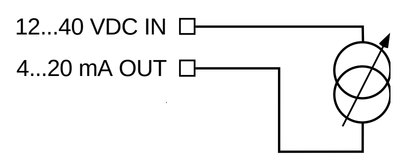
ALL DIMENSIONS ARE IN INCHES (MM)
tolerances are ±0.02 in. (+0.5mm) unless otherwise noted



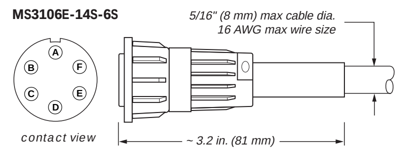


Electrical:

Sensing Circuit



Mating Plug



Ordering Information / Model Number:

PT420 -____ - __ 1 __ - 1 __ 1 0

order code: □ A B C D E F G

sample: PT420-0025-111-1110

□ Full Stroke Range

0002 = 2 inches	**0030** = 30 inches
0005 = 5 inches	**0040** = 40 inches
0010 = 10 inches	**0050** = 50 inches
0015 = 15 inches	**0060** = 60 inches
0020 = 20 inches	**0075** = 75 inches
0025 = 25 inches	**0100** = 100 inches

A Measuring Cable Tension

1 = standard *(see MECHANICAL specifications)*

NOTE: options 2, 3, and 7 below are available for RE-ORDER only!

2 = increased *(approx. 4 x standard cable tension, 0.024 inch dia. measuring cable)**

3 = high *(approx. 8 x standard cable tension, 0.024 inch dia. measuring cable)**

7 = decreased *(same as standard cable tension)*

C Measuring Cable Exit

NOTE: options 2, 3, and 4 below are available for RE-ORDER only!

1 = top exit **2** = front exit **3** = rear exit **4** = bottom exit

E Output

1 = 4-20 mA, 2-wire, output increasing with cable extension

2 = 20-4 mA, 2-wire,output decreasing with cable extension

3 = 0-20 mA, 3-wire, output increasing with cable extension

4 = 20-0 mA, 3-wire, output decreasing with cable extension

F Electrical Connection

1 = 6-pin plastic connector and mating plug

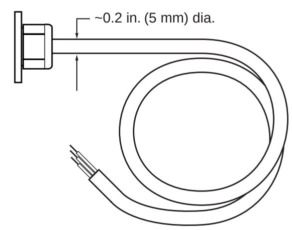
2 = terminal strip

3 = 6-pin metal connector and mating plug

4 = 25 ft. instrumentation cable

** note: mechanical dimensions may vary from outline drawing above*

Instrumentation Cable



Electrical Connections

		2-wire	3-wire
6-pin conn.	A	12...40 VDC	12...40 VDC
	B	4...20 mA out	common
	C		0...20 mA out
	D	case ground	
	E		
	F		
instr. cable	RED	12...40 VDC	12...40 VDC
	BLK	4...20 mA out	0...20 mA out
	WHT	n/a	common
	GRN	case ground	n/a

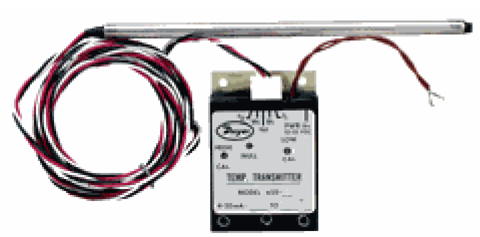
celesco

tel: (800) 423-5483 • (818) 701-2750
fax: (818) 701-2799

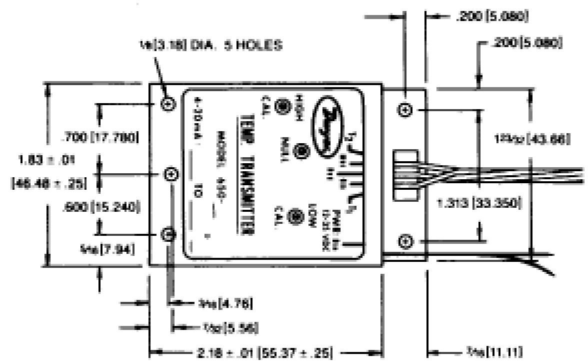
DWYER INSTRUMENTS, INC.
102 Highway 212, P.O. Box 373, Michigan City, IN 46361
Phone: (219) 879-8000 Fax: (219) 872-9057

Series 650 Temperature Transmitter

4-20 mA signal. Two wire operation. Temperatures from -55° to +180°C.



Catalog Page



Dimensional Enlargement

The Dwyer Series 650 Temperature Transmitter combines low cost with small size making it ideal for a wide variety of HVAC, industrial and commercial multi-point temperature monitoring applications. Non-polarized terminals simplify connection to any 12-35 VDC power supply. Capable of operation with long cable runs, Series 650 Transmitters are well suited for monitoring air or water temperatures at remote locations. Three models are stocked in popular ranges factory calibrated within 0.3% of span. All are linear within 0.25% of span and may be recalibrated within low range and span limits shown in chart. Low Range is temperature corresponding to 4 mA output. Span is temperature difference between Low and High Ranges corresponding to 4-20 mA output signal. Refer to Bulletin E-62 for complete details.

All **Series 650** models listed
A-325 Duct Mounting Kit with flange, fitting and hardware
Ⓑ Items subject to Schedule B discounts

PHYSICAL DATA

Power Supply: 12-35 volts DC
Output Signal: 4-20 mA DC
Voltage Stability: Output error less than 0.01% of span over the specified supply voltage range
Linearity: Within 0.25% of span
Thermal Drift: Less than 0.5% of span over ambient temperature range of 0-50°C (32°-122°F)
Ambient Operating Temperature (Electronics): 0-70°C (32°-158°F)
Maximum Temperature (Probe): 204°C (400°F)
Probe Construction: 6" long, 0.25" O.D. Type 304 Stainless Steel
Probe Cable Length: 7 feet
Initial Calibration: Within 0.3% of span at 20°C (68°F) ambient

STOCKED MODELS in bold

Model Number	Range As Stocked	Low Range Limits		Span Limits	
		Min.	Max.	Min.	Max.
650-1	-23° to +10°C	-32° C	-14° C	24° C	48°C
650-2	-7° to +49°C	-12° C	+6°C	37° C	150° C
650-3	0° to +100°C				

Consult factory for special ranges calibrated

Relative Humidity/ Temperature Transmitter

Model HX93

$225

- 4-20mA or 0-1V Output
- RH and Temperature Output
- Compact Size for Mounting Versatility
- Watertight Enclosure
- Accurate to 2.5% RH and 0.6°C

The HX93 transmitter provides remote or on-site monitoring of relative humidity and temperature. The HX93 outputs a linearized current or voltage signal proportional to the measured humidity or temperature. RH outputs are temperature compensated. Current output models enable placing of the transmitter at a remote location virtually any distance away from the readout or datalogging device. HX93 utilizes a thin-film polymer capacitor to sense relative humidity, and a Platinum 1100 OHM RTD to accurately sense temperature. A stainless steel mesh type filter protects the sensors, which is easily removable for cleaning. Mounting screws are easily accessible inside the rugged, ABS enclosure, which houses and protects the electronics to NEMA 13 specifications. An unregulated power supply providing a voltage of 6-30V powers the HX93.

1 YEAR WARRANTY — MADE IN USA

Model TX82B
Sold Separately, See Section N for More Details

Works with loop powered indicators!

Specifications

Input Voltage Range:
24 Vdc nominal (6 to 30Vdc)
MEASURING RANGE
RH: 3 to 95%
Temperature:
-20 to 75°C (-4 to 167°F)
ACCURACY
RH: ±2.5% @75°F with temperature coefficient of -.06 RH/°F
Temperature: 0.6°C (±1°F)
OUTPUT
HX93C: 4 to 20mA for 0 to 100% RH and -20 to 75°C (-4 to 167°F)
HX93V: 0 to 1Vdc for 0 to 100% RH and -20 to 75°C (-4 to 167°F)
RH Temperature Compensation:
-20 to 75°C (-4 to 167°F)
RH Time Constant (90% response at 25°C, in moving air at 1m/s):
>10 seconds, 10 to 90% RH;
>15 seconds, 90 to 10% RH
Repeatability: ±1% RH, 0.5°F
Housing: ABS plastic watertight enclosure; meets NEMA 1, 2, 3, 3R, 4, 4X, 5, 12 and 13 specifications
Connections: Liquid-tight nylon with neoprene gland, for 0.09 to 0.265" diameter cable; internal 4-pin terminal block accepts 14-22 gauge wire
Dimensions: 3.14" x 3.22" x 2.16"
Weight: 8 oz (226.8 grams)

To Order ***(Specify Model Number)***

Model No.	Price	Description
HX93(*)	$225	Relative Humidity and Temperature Transmitter
HX92-CAL	65	Calibration Kit, 11 and 75% RH Standards
PSU-93	40	Unregulated Power Supply, 16 to 23Vdc, 300mA max
TX4-100	28.50	4 conductor shielded transmitter cable (100 ft)
CAL-3-Hu	125	NIST Traceable Calibration

**To order, Specify "C" for 4 to 20mA output(s), or "V" for 0-1 Vdc output(s)*
Ordering Example: HX93C**, humidity transmitter with 4-20mA output, with HX92-CAL Calibration kit $225 + 65 = **$290.

Appendix B
Calibration Data

Calibration

Instrument Identification

Company ID: 76911
PRINCIPIA RESEARCH CORPORATION
CHARLIE ALMQUIST
826 CLAYTON AVENUE
NASHVILLE, TN 37204

PO Number: CC-CHARLES ALMQUIST

Instrument ID: **N0513**
Manufacturer: HEWLETT PACKARD
Description: DATA ACQUISITION UNIT

Model Number: 34970A
Serial Number: US37004387

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: NORMAL
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: HP34970AV2

Remarks:

Technician: WILLIAM KENNEY
Cal Date: 24Apr2008
Cal Due Date: 24Apr2009
Interval: 12 MONTHS
Temperature: 70.0 F
Humidity: 32.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Inotek Instruments Calibration Laboratory is certified to ISO 9001:2000 by QMI (certificate # 010576). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1315 within the scope for which the lab is accredited.
All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.

Approved By: WILLIAM KENNEY
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
1997321	H044026	FREQUENCY COUNTER	53132A	06Sep2007	06Sep2008
1924143	H048972	TEMP/HUM RECORDER	31061221-001	27Nov2007	27Feb2009
2041863	H099536	DMM	3458A	23Jan2008	23Jan2009
1980680	Z01968	CALIBRATOR	5700A	16Nov2007	16Nov2008

Davis Calibration

Hewlett Packard 34970A Data Acquisition Unit

1 year specifications

Procedure: HP34970AV2 Work Order: 206744

ID Number: N0513 Date Calibrated: 4/24/2008

All calculations and data transfers have been reviewed for accuracy and completeness

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Section 1 - Zero Offset Verification

Function/Range	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
DCI / 10mA	.0000000A	-.0000020A	.0000001A		.0000020A	PASS
DCI / 100mA	.0000000A	-.0000050A	.0000000A		.0000050A	PASS
DCI / 1A	.0000000A	-.0001000A	.0000047A		.0001000A	PASS
DCV / 100mV	.0000000V	-.0000040V	.0000004V		.0000040V	PASS
DCV / 1V	.0000000V	-.0000070V	.0000005V		.0000070V	PASS
DCV / 10V	.0000000V	-.0000500V	.0000000V		.0000500V	PASS
DCV / 100V	.0000000V	-.0006000V	.0000260V		.0006000V	PASS
DCV / 300V	.0000000V	-.0090000V	.0001300V		.0090000V	PASS
2W / 100ohm	.0000Ohms	-1.0040Ohms	-.1943Ohms		1.0040Ohms	PASS
2W / 1Kohm	.0000Ohms	-1.0100Ohms	-.1953Ohms		1.0100Ohms	PASS
2W / 10Kohm	.000Ohms	-1.100Ohms	-.191Ohms		1.100Ohms	PASS
2W / 100Kohm	.000Ohms	-2.000Ohms	-.220Ohms		2.000Ohms	PASS
2W / 1Mohm	.00Ohms	-11.00Ohms	-.26Ohms		11.00Ohms	PASS
2W / 10Mohm	.00Ohms	-101.00Ohms	-7.70Ohms		101.00Ohms	PASS
2W / 100Mohm	0Ohms	-10001Ohms	0Ohms		10001Ohms	PASS
4W / 100ohm	.0000Ohms	-.0040Ohms	-.0008Ohms		.0040Ohms	PASS
4W / 1Kohm	.0000Ohms	-.0100Ohms	.0000Ohms		.0100Ohms	PASS
4W / 10Kohm	.000Ohms	-.100Ohms	-.003Ohms		.100Ohms	PASS
4W / 100Kohm	.000Ohms	-1.000Ohms	-.052Ohms		1.000Ohms	PASS
4W / 1Mohm	.00Ohms	-10.00Ohms	.00Ohms		10.00Ohms	PASS
4W / 10Mohm	.00Ohms	-100.00Ohms	-7.70Ohms		100.00Ohms	PASS
4W / 100Mohm	0Ohms	-10000Ohms	0Ohms		10000Ohms	PASS

ID Number: N0513

Section 2 - DC Voltage Accuracy

Range	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
100mV	100.0000mV	99.9910mV	100.0018mV		100.0090mV	PASS
1V	1.0000000V	.9999530V	1.0000142V		1.0000470V	PASS
10V	10.00000V	9.99960V	10.00004V		10.00040V	PASS
100V	100.00000V	99.99490V	100.00037V		100.00510V	PASS
300V	300.00000V	299.97750V	299.99810V		300.02250V	PASS

Section 3 - AC Voltage Accuracy

Range / Freq	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
100mV / 1KHz	10.0000mV	9.9540mV	9.9867mV		10.0460mV	PASS
100mV / 1KHz	100.0000mV	99.9000mV	100.0104mV		100.1000mV	PASS
100mV / 50KHz	100.0000mV	99.8300mV	99.9527mV		100.1700mV	PASS
1V / 20Hz	1.000000V	.999000V	.999911V		1.001000V	PASS
1V / 1KHz	1.000000V	.999000V	1.000082V		1.001000V	PASS
1V / 20KHz	1.000000V	.999000V	1.000000V		1.001000V	PASS
1V / 50KHz	1.000000V	.998300V	.999457V		1.001700V	PASS
1V / 100KHz	1.000000V	.993200V	.998855V		1.006800V	PASS
1V / 300KHz	1.000000V	.955000V	1.001050V		1.045000V	PASS
10V / 1KHz	.10000V	.08600V	.10060V		.11400V	PASS
10V / 1KHz	1.00000V	.99540V	.99993V		1.00460V	PASS
10V / 10Hz	10.00000V	9.99000V	10.00036V		10.01000V	PASS
10V / 1KHz	10.00000V	9.99000V	10.00016V		10.01000V	PASS
10V / 50KHz	10.00000V	9.98300V	9.99417V		10.01700V	PASS
100V / 1KHz	100.0000V	99.9000V	99.9814V		100.1000V	PASS
100V / 50KHz	100.0000V	99.8300V	99.9420V		100.1700V	PASS
300V / 1KHz	300.000V	299.580V	299.949V		300.420V	PASS
300V / 50KHz	200.000V	199.400V	199.997V		200.600V	PASS

Section 4 - Four Wire Resistance Accuracy

Range	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
100 ohm	100.00000	99.98600	100.00063		100.01400	PASS
1 Kohm	1.0000000	0.9998900	1.0000031		1.0001100	PASS
10 Kohm	10.000000	9.998900	9.999949		10.001100	PASS
100 Kohm	100.00000	99.98900	99.99983		100.01100	PASS
1 Mohm	1.0000000	0.9998900	0.9999818		1.0001100	PASS
10 Mohm	10.000000	9.995900	9.998491		10.004100	PASS

ID Number: N0513

Section 5 - Two Wire Resistance Accuracy

Range	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
100 ohm	100.00000	98.98600	100.20932		101.01400	PASS
1 Kohm	1.0000000	0.9988900	1.0001864		1.0011100	PASS
10 Kohm	10.000000	9.997900	10.000233		10.002100	PASS
100 Kohm	100.00000	99.98800	100.00017		100.01200	PASS
1 Mohm	1.00000000	0.99988900	0.99998338		1.00011100	PASS
10 Mohm	10.0000000	9.9958990	9.9979367		10.0041010	PASS
100 Mohm	100.000000	99.190000	100.790430		100.810000	PASS

Section 6 - Frequency Accuracy

Range	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
100 Hz	100.0000 Hz	99.9000 Hz	99.9929 Hz		100.1000 Hz	PASS
100 KHz	100.0000 KHz	99.9900 KHz	99.9999 KHz		100.0100 KHz	PASS

Section 7 - DC Current Accuracy

Range	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
10mA	10.00000mA	9.99300mA	10.00044mA		10.00700mA	PASS
100mA	100.00000mA	99.94500mA	99.99958mA		100.05500mA	PASS
1A	1.000000A	.998900A	.999668A		1.001100A	PASS

Section 8 - AC Current Accuracy

Range / Freq	Nominal	Lower Limit	As Found	As Left	Upper Limit	Result
10mA / 1KHz	10.00000mA	9.98600mA	9.99883mA		10.01400mA	PASS
100mA / 1KHz	100.00000mA	99.40000mA	99.75795mA		100.60000mA	PASS
1A / 1KHz	.010000A	.008590A	.009148A		.011410A	PASS
1A / 1KHz	.200000A	.199400A	.199827A		.200600A	PASS

Unless otherwise noted
As Found = As Left

Principia Research Corporation

Calibration Record

Cal ID	Serial/Tag No	Cal Posn	Mfr/Model	Transducer Type
	N0414		RM 3051C G4	Pressure transmitter

Standards Used
- S2801 GE Druck IPC6 readout
- S2803 GE Druck 100 psi module
- N0404 HP 34970A

Nominal Range

Location/ID: Inlet Head

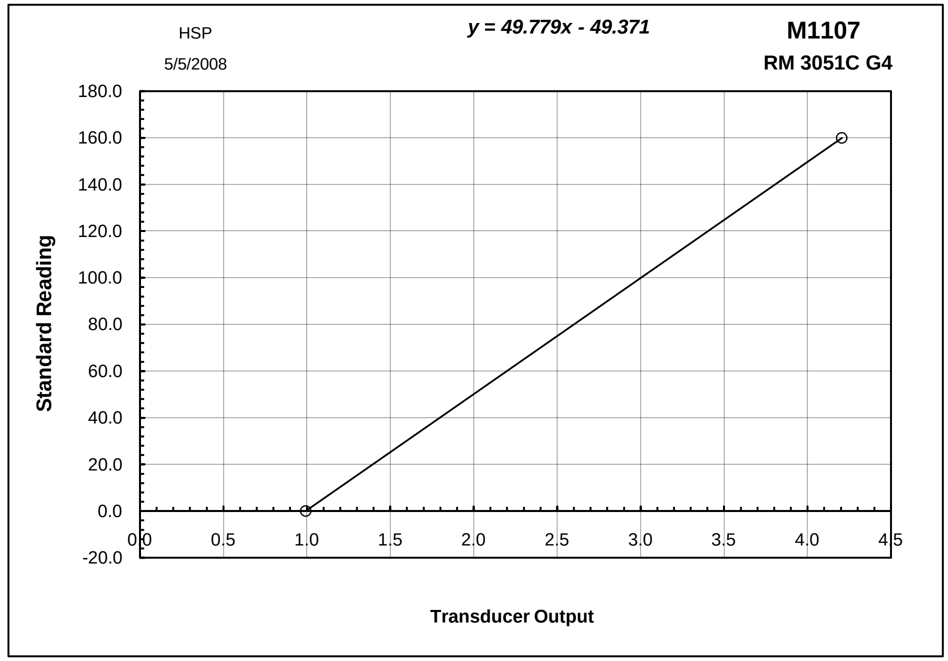
Project Calibrated For	Loop Resistor		Cal by	Date
Iron Gate August 2008	250 Ohm	0.01%	CWA	8/19/2008

Statistics

Num Pts	2		**Uncertainty**	-	ft H20
Slope	49.7791	ft H20/DCV	**% Uncertainty**	-	%
Intercept	-49.3709	ft H20			

Notes

	Calibration Data		Calibration Curve			
Run	Standard	UUT	Pred. Value	Deviation	% Dev.	
	ft H20	DCV	ft H20	ft H20	% F.S	
1	0.000	0.9918	0.000	0.000	0.000	
2	160.000	4.2060	160.000	0.000	0.000	



Principia Research Corporation

Calibration Record

Cal ID	Serial/Tag No	Cal Posn	Mfr/Model	Transducer Type
	R2702		RM 3051 CD2	Pressure transmitter

Standards Used
- S2801 GE Druck IPC6 readout
- S2807 GE Druck 30 psi module
- N0404 HP 34970A

Nominal Range

Location/ID: Winter-Kennedy R3-R1

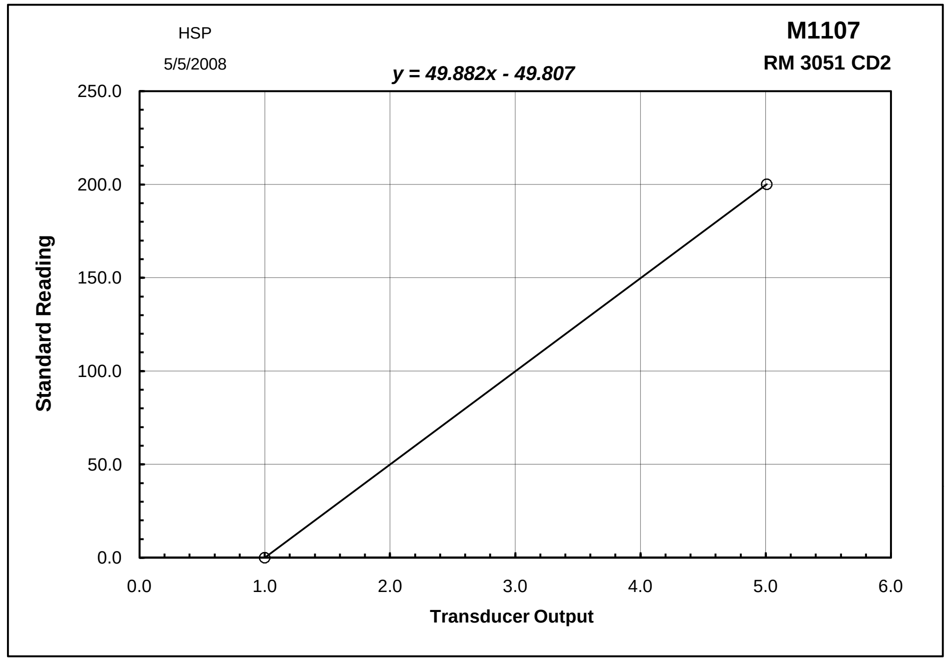
Project Calibrated For	Loop Resistor		Cal by	Date
Iron Gate August 2008	250 Ohm	0.01%	CWA	8/19/2008

Statistics

Num Pts	2		**Uncertainty**		in H20
Slope	49.8815	in H20/DCV	**% Uncertainty**		%
Intercept	-49.8067	in H20			

Notes

	Calibration Data		Calibration Curve			
Run	Standard	UUT	Pred. Value	Deviation	% Dev.	
	in H20	DCV	in H20	in H20	% F.S	
1	0.000	0.9985	0.000	0.000	0.000	
2	200.000	5.0080	200.000	0.000	0.000	



Principia Research Corporation

Calibration Record

Cal ID	Serial/Tag No	Cal Posn	Mfr/Model	Transducer Type
	M1104		RM 3051 CD2	Pressure transmitter

Standards Used
- S2801 GE Druck IPC6 readout
- S2807 GE Druck 30 psi module
- N0404 HP 34970A

Nominal Range

Location/ID: Winter-Kennedy R3-R2

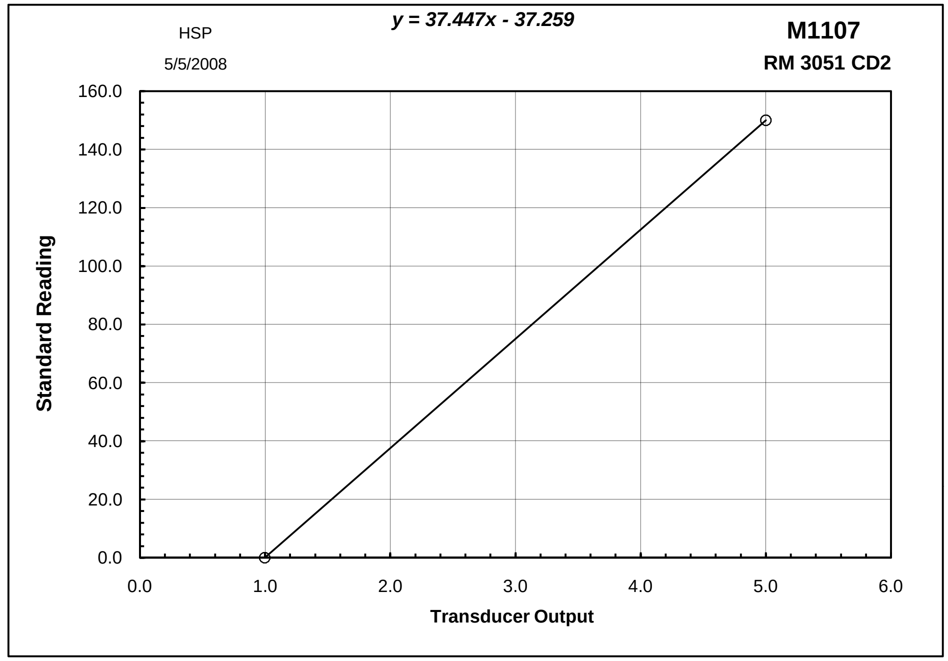
Project Calibrated For	Loop Resistor		Cal by	Date
Iron Gate August 2008	250 Ohm	0.01%	CWA	8/19/2008

Statistics

Num Pts	2		**Uncertainty**	in H20
Slope	37.4466	in H20/DCV	**% Uncertainty**	%
Intercept	-37.2594	in H20		

Notes

	Calibration Data		Calibration Curve			
Run	Standard	UUT	Pred. Value	Deviation	% Dev.	
	in H20	DCV	in H20	in H20	% F.S	
1	0.000	0.9950	0.000	0.000	0.000	
2	150.000	5.0007	150.000	0.000	0.000	



Principia Research Corporation

Calibration Record

Cal ID	Serial/Tag No	Cal Posn	Mfr/Model	Transducer Type
	P0802		RM 3051 CD1	Pressure transmitter

Standards Used
- S2801 GE Druck IPC6 readout
- S2802 GE Druck 5 psi module
- N0404 HP 34970A

Nominal Range

Location/ID: Air Flow

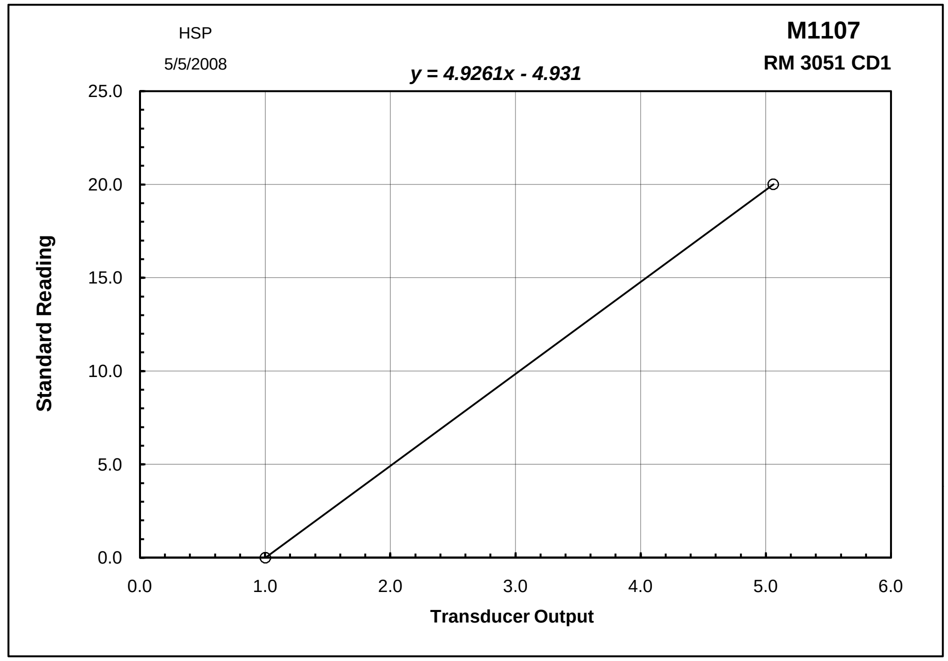
Project Calibrated For	Loop Resistor		Cal by	Date
Iron Gate August 2008	250 Ohm	0.01%	CWA	8/19/2008

Statistics

Num Pts	2		**Uncertainty**	in H20
Slope	4.9261	in H20/DCV	**% Uncertainty**	%
Intercept	-4.9310	in H20		

Notes

	Calibration Data		Calibration Curve			
Run	**Standard**	**UUT**	**Pred. Value**	**Deviation**	**% Dev.**	
	in H20	**DCV**	**in H20**	**in H20**	**% F.S**	
1	0.000	1.0010	0.000	0.000	0.000	
2	20.000	5.0610	20.000	0.000	0.000	



Principia Research Corporation

Calibration Record

Cal ID	Serial/Tag No	Cal Posn	Mfr/Model	Transducer Type
	M1106		RM 3051 CD2	Pressure transmitter

Standards Used
- S2801 GE Druck IPC6 readout
- S2807 GE Druck 30 psi module
- N0404 HP 34970A

Nominal Range

Location/ID: Draft Tube

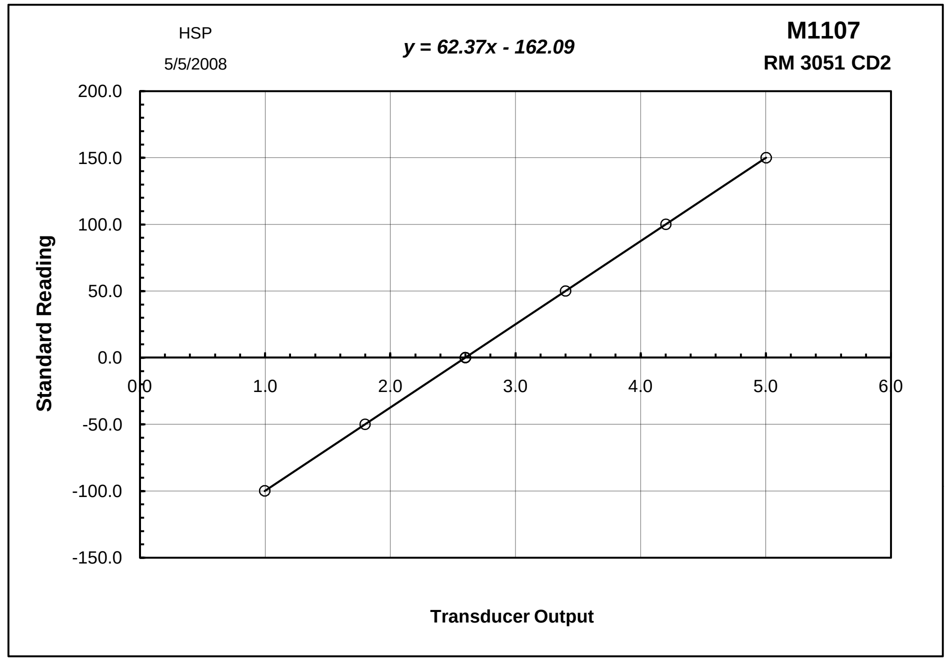
Project Calibrated For	Loop Resistor		Cal by	Date
Iron Gate August 2008	250 Ohm	0.01%	CWA	9/8/2008

Statistics

Num Pts	8		Uncertainty	0.023	in H20
Slope	62.3701	in H20/DCV	% Uncertainty	0.009	%
Intercept	-162.0906	in H20			

Notes

	Calibration Data		Calibration Curve			
Run	Standard	UUT	Pred. Value	Deviation	% Dev.	
	in H20	DCV	in H20	in H20	% F.S	
1	0.000	2.5991	0.016	0.016	0.006	
2	50.000	3.4002	49.980	-0.020	-0.008	
3	100.000	4.2018	99.976	-0.024	-0.010	
4	150.000	5.0040	150.009	0.009	0.004	
5	0.000	2.5995	0.041	0.041	0.016	
6	-50.000	1.7976	-49.974	0.026	0.010	
7	-100.000	0.9950	-100.032	-0.032	-0.013	
8	0.000	2.5986	-0.016	-0.016	-0.006	



Principia Research Corporation

Calibration Record

Cal ID	Serial/Tag No	Cal Posn	Mfr/Model	Transducer Type
	S0302		Celesco PT420-30	Pull-pot

Standards Used	Nominal Range	Location/ID
X0002 Starett steel rule		Servo Stroke

Project Calibrated For	Loop Resistor	Cal by	Date
Osage Unit 7 / Unit 1 Testing	250 Ohm 0.01%	HSP	5/6/2008

Statistics

Num Pts	15		Uncertainty	0.006	in
Slope	-7.4636	in/DCV	% Uncertainty	0.021	%
Intercept	37.6105	in			

Notes

	Calibration Data		Calibration Curve			
Run	Standard	UUT	Pred. Value	Deviation	% Dev.	
	in	DCV	in	in	% F.S	
1	1.000	4.905	1.001	0.001	0.005	
2	2.000	4.769	2.016	0.016	0.054	
3	4.000	4.501	4.016	0.016	0.055	
4	6.000	4.236	5.998	-0.002	-0.008	
5	8.000	3.969	7.986	-0.014	-0.049	
6	10.000	3.702	9.984	-0.016	-0.055	
7	12.000	3.432	11.996	-0.004	-0.013	
8	14.000	3.163	14.004	0.004	0.013	
9	16.000	2.897	15.992	-0.008	-0.027	
10	18.000	2.627	18.005	0.005	0.017	
11	20.000	2.362	19.984	-0.016	-0.056	
12	22.000	2.092	21.997	-0.003	-0.009	
13	26.000	1.555	26.003	0.003	0.011	
14	28.000	1.286	28.012	0.012	0.040	
15	30.000	1.019	30.007	0.007	0.023