DESIGN, CONSTRUCTION, AND OPERATIONAL PROCEDURES FOR A RECIRCULATING LABORATORY FLUME AT IOWA STATE UNIVERSITY

by

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1. INTRODUCTION

The University of Iowa's IIHR-Hydroscience & Engineering (IIHR) was contracted by Iowa State University's (ISU's) Agricultural & Biosystems Engineering (ABE) department for the design, fabrication and installation of a research-grade laboratory flume. The flume was designed and fabricated at IIHR, deconstructed, transported to ISU, re-assembled and commissioned in the designated laboratory space in ABE's Sukup Hall on the ISU main campus.

2. FLUME DESIGN

2.1 Flume Dimensions

The laboratory flume consists primarily of a 2 feet high by 4 feet wide by 38 feet long open channel of uniform cross-section. Additional length on both ends for head and tail tanks results in an overall length of approximately 48 feet. A clear space of approximately 4 feet between the flume structure and existing laboratory walls was maintained. Engineering drawings of the flume are included in Figure 2 - 1 and Figure 2 - 2. Figure 2 - 3 shows isometric renderings of the final flume design generated from the fully 3-dimensional CAD model created in Creo Parametric.

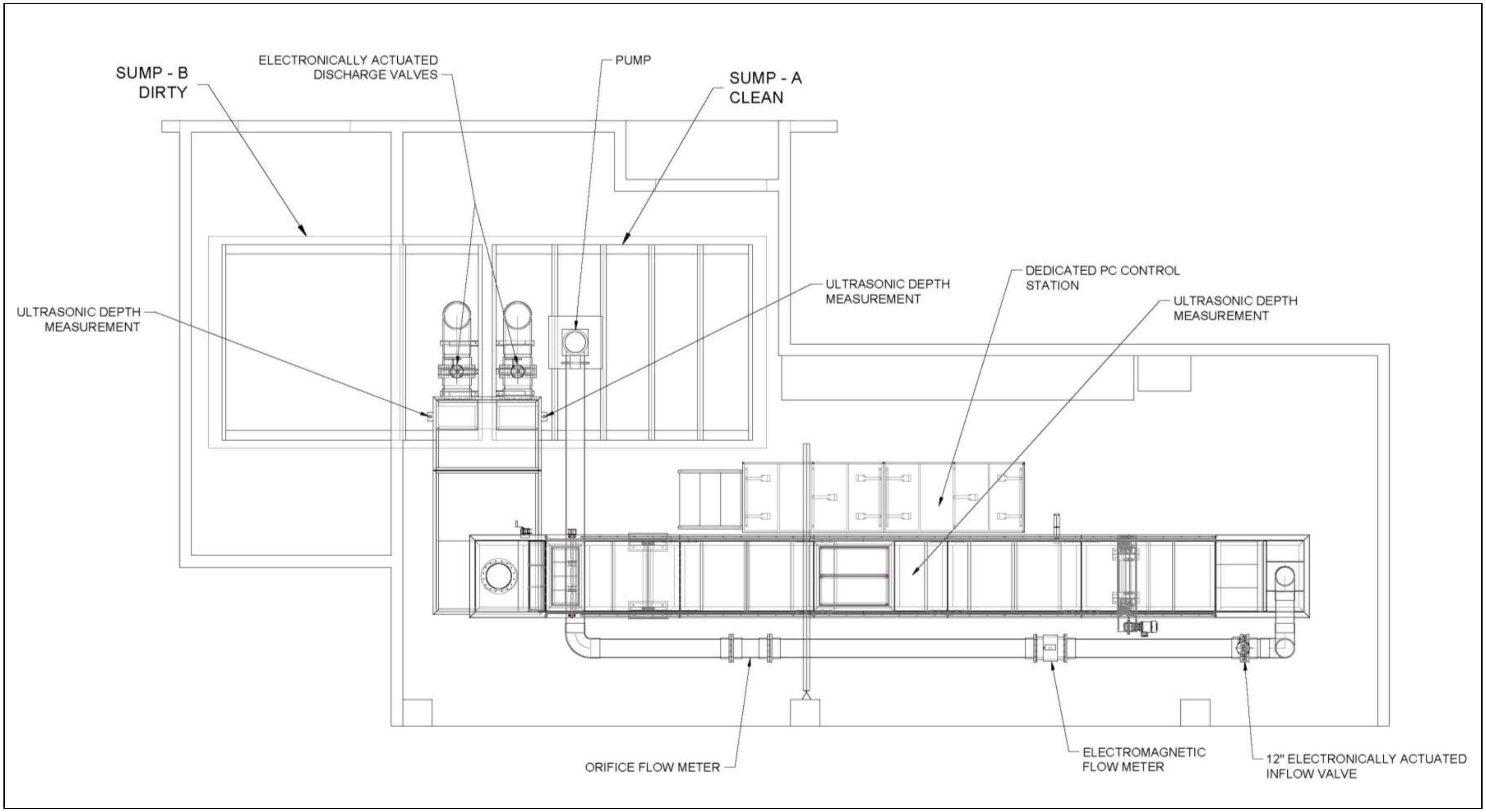


Figure 2 - 1. Plan view of flume and laboratory

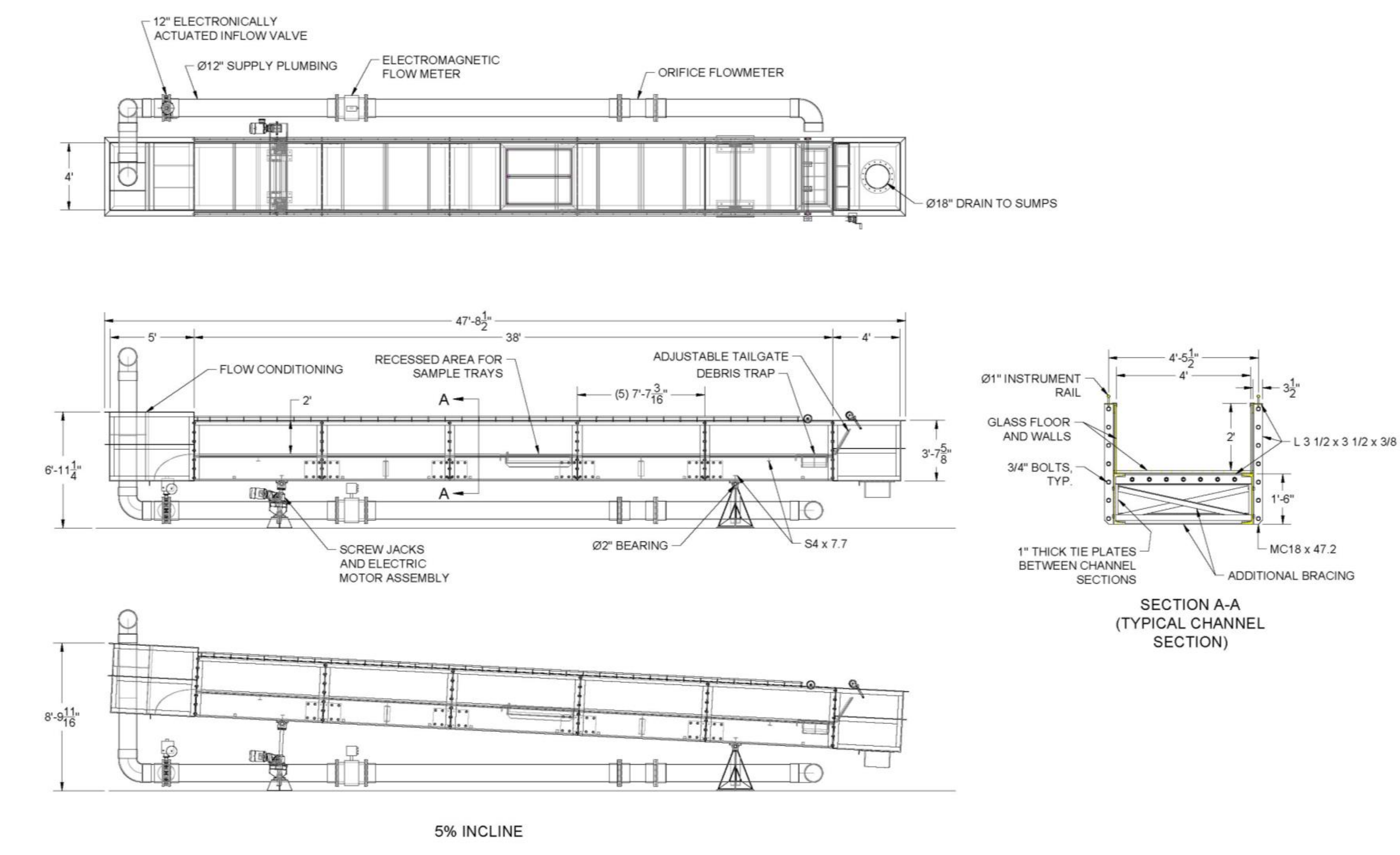


Figure 2 - 2. Plan, elevation and section views of flume

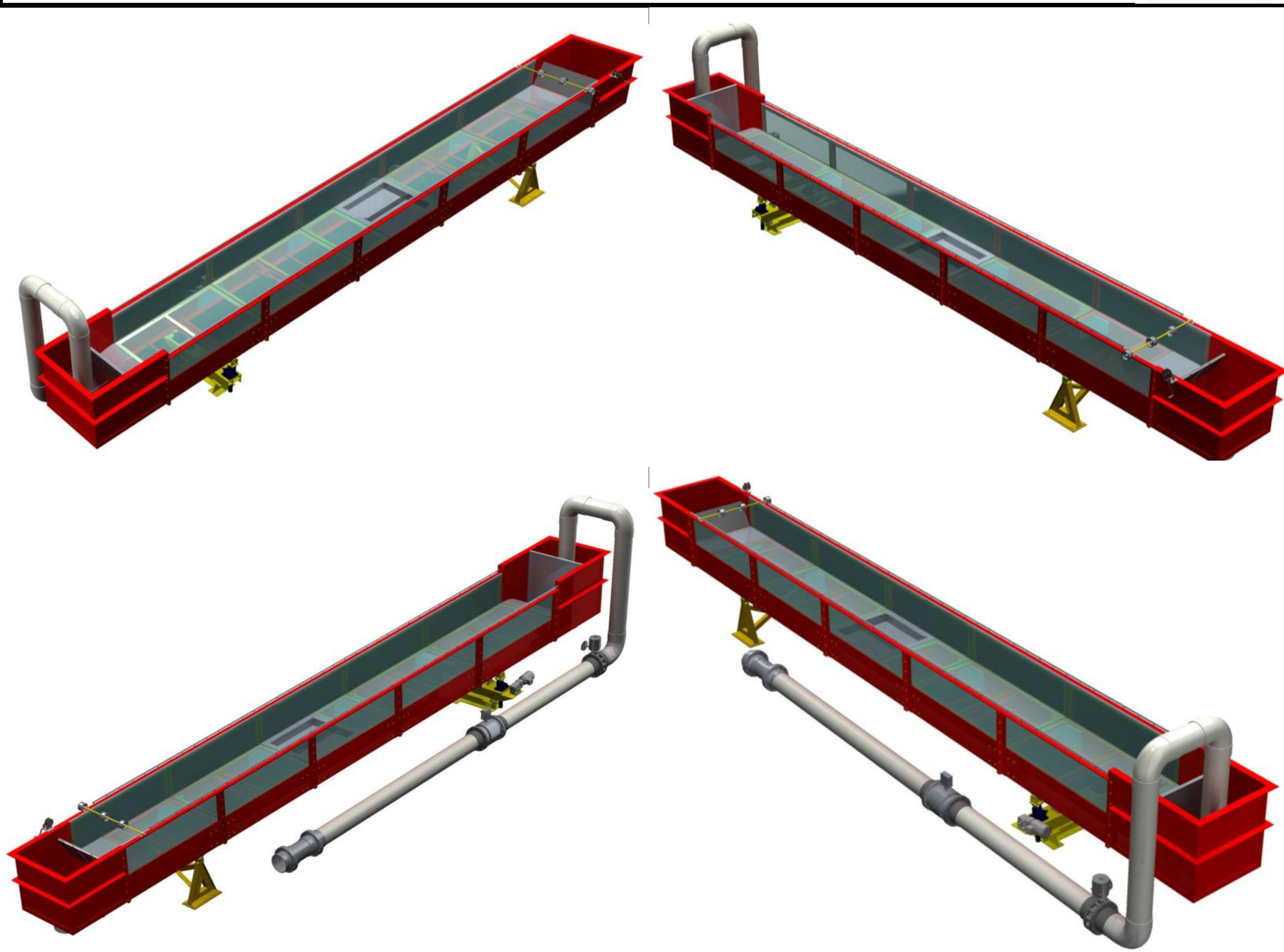


Figure 2 - 3. 3-D renderings

2.2 Structural Design

The flume was constructed from carbon steel, stainless steel, and tempered glass to achieve a flume structure that will deflect no more than L/3000, where L is section length, along the total length of the flume and within any flume member/section per IIHR's flume design standards. Figure 2 - 4 shows the shear, moment, and deflection calculated for two continuous MC18x42 support beams with a water depth of 20 inches (note that the head and tail boxes are considered point loads at the ends of the beams).

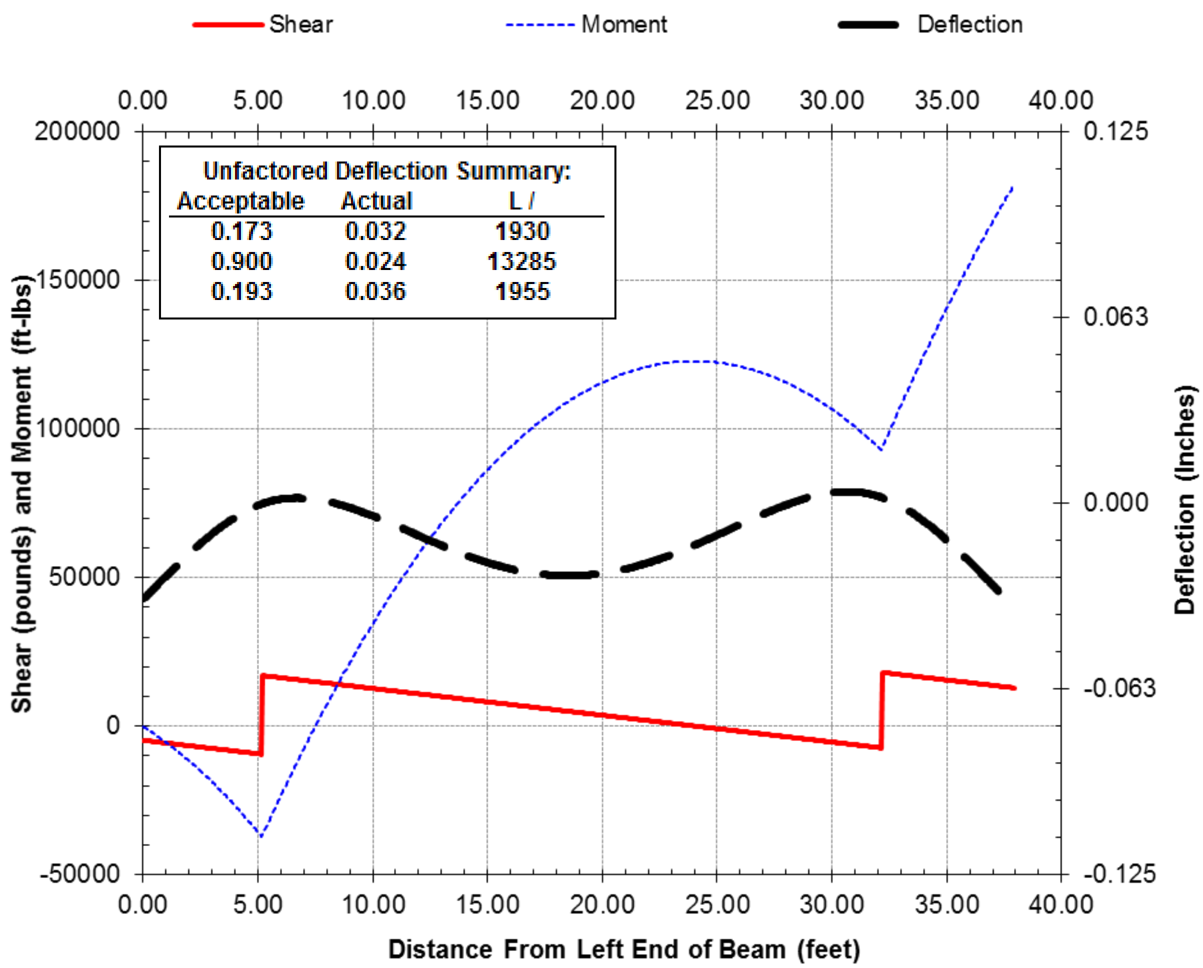


Figure 2 - 4. Structural performance of the continuous MC18x42 flume support members

The flume was built in sections (non-continuous) in order to fit inside the elevator in Sukup Hall. The sections were fastened together along flange connections and 1-inch thick plates were laminated across the C-channel joints to recreate beam continuity and provide adequate structural integrity. A full 3-dimensional finite element analysis (FEA) was performed using Creo Simulate to verify that the stresses and deflections were acceptable. Resultant stresses and displacements from analysis with the flume filled with 20 inches of water are shown in Figure 2 - 5 and Figure 2 - 6, respectively. Results were satisfactory and consistent with the continuous beam results.

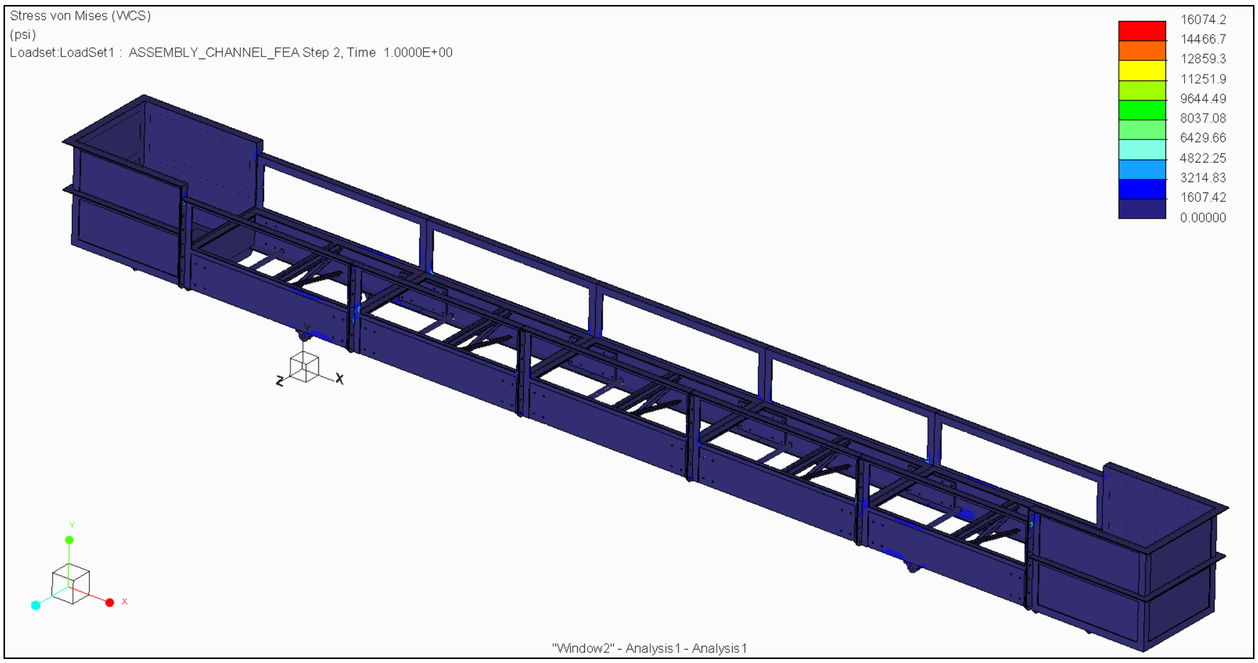


Figure 2 - 5. Stress contours from Creo Simulate FEA

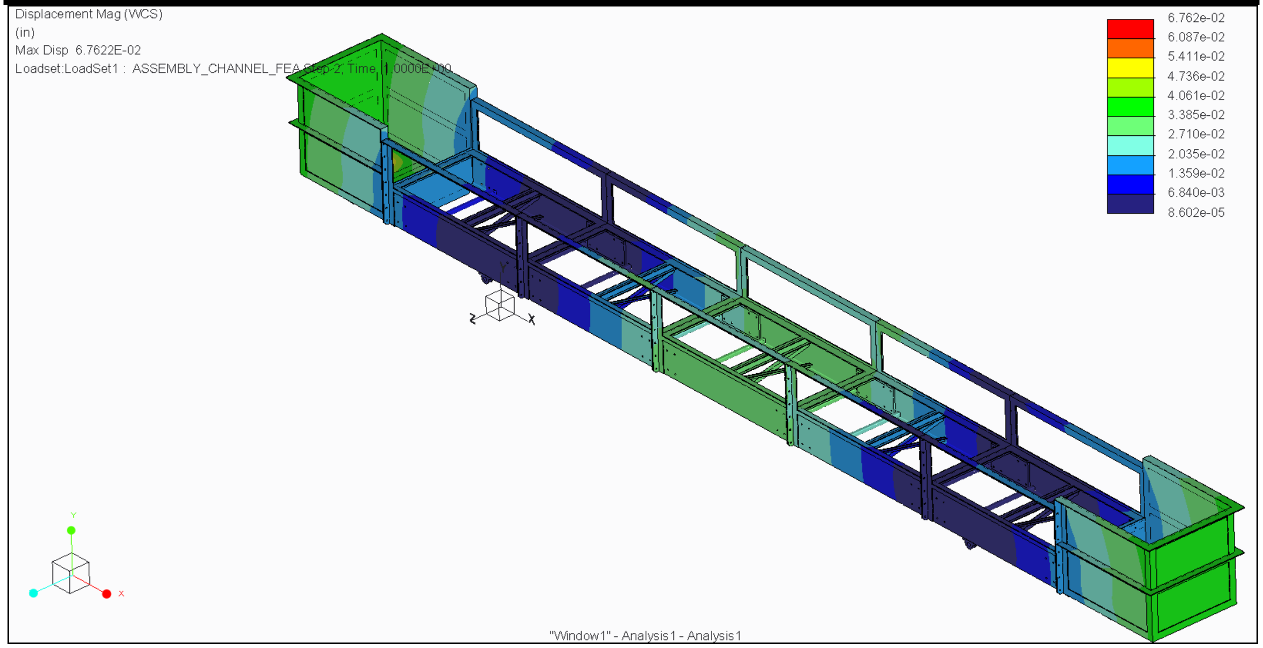


Figure 2 - 6. Displacement contours from Creo Simulate FEA

2.3 Flow Control and Measurement

The flume is equipped with a Hydroflo two-stage mixed flow vertical turbine pump and 60 horsepower motor that draws water from a clean sump (sump A) with a peak flow rate of about 4,000 gallons per minute (gpm) or 9.0 cubic feet per second (cfs) through a 12-inch inflow line to the flume's headbox. Water is discharged from the flume's tailbox either into the "clean" sump (sump A) or to a designated "dirty" sump (sump B). The peak flow rate provides an average velocity within the flume of about 1.35 feet per second (fps) with a water depth of 20-inches (1.67 ft) with the flume in a level position. The pump curve is shown in Figure 2 - 7.

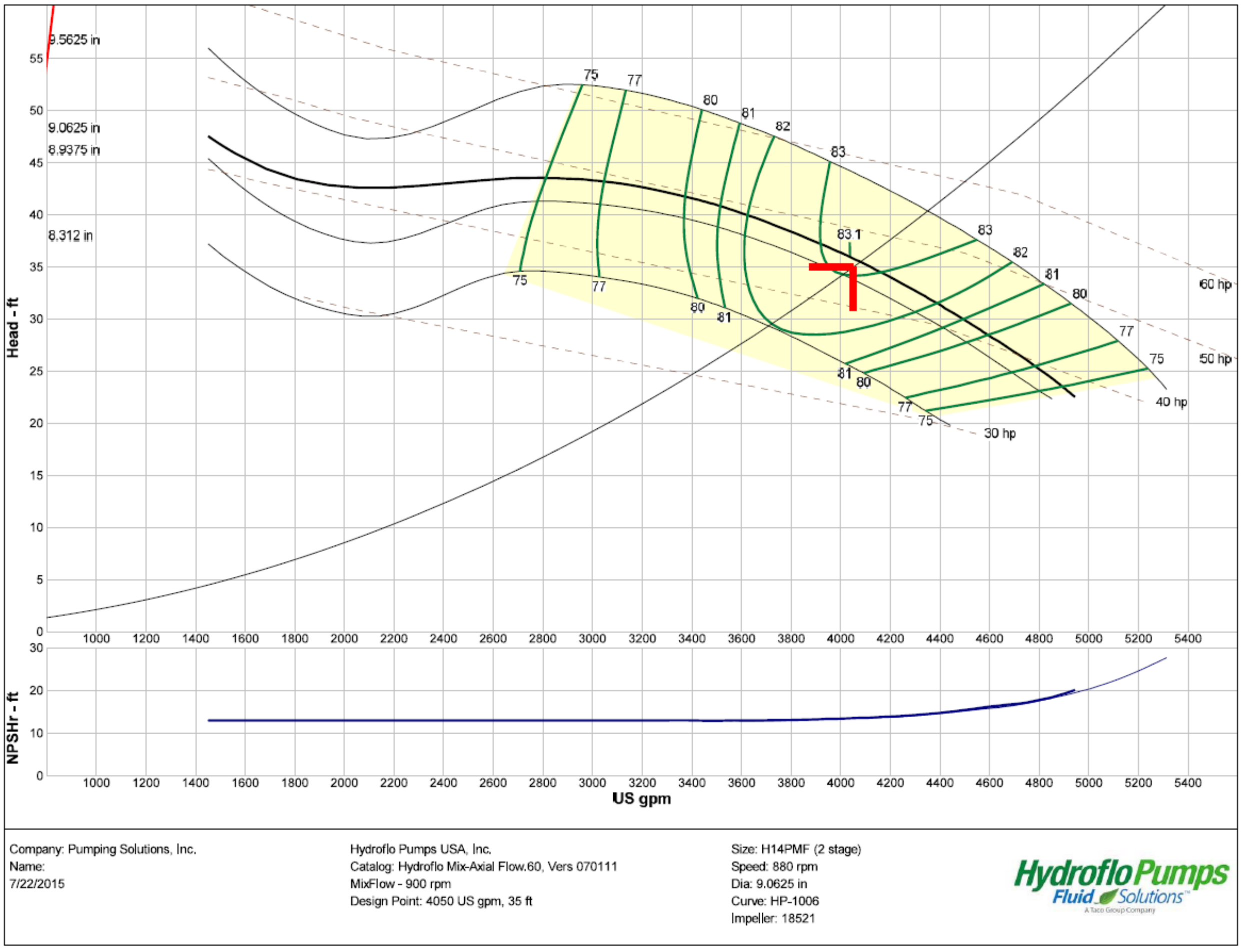


Figure 2 - 7. Hydroflo pump curve

The flow rate can be measured with either an electromagnetic flow meter (magflow) or with a traditional orifice-type flow meter. Manual flow rate control is provided by a variable frequency drive (VFD) and electronically actuated butterfly valves (1 in supply line, 2 in discharge line for sump A/B selection – see Appendix A for details).

The magflow meter also provides electronic feedback between the VFD and a custom proportional controller in LabVIEW (see Appendix B for details) that allows a constant flow rate to be specified and maintained in the case where there may be water drawn from one sump and discharged into another. This provides a way for the pump to compensate for the falling head in the supply sump and maintain a constant flow rate during such tests.

2.4 Tilting Capabilities

The flume has the capability to be set at any sloped position between 0 and 5% (0 – 2.86 degrees). Two electronically actuated screw jacks provide lifting at a point near the flume headbox to achieve the desired slope. The slope/angle is measured with an electronic inclinometer. Details on the actuated screw jacks, jack motor, and inclinometer are provided in Appendix A. The slope can be altered either manually with momentary push-button control or by specifying a desired slope in a standalone LabVIEW program (see Appendix B).

2.5 Depth Control and Measurement

Water levels within the flume are controlled with a manually adjusted hinged weir (tailgate) near the downstream end of the flume section. Water levels within the flume and the two sumps are measured with ultrasonic level sensors which output to the dedicated PC. The depth measurement within the flume can be used in combination with the flow rate to determine the average velocity, Froude number, bed shear stress, Reynolds Number, as well as many other useful flow parameters in the flume test section. Details on the ultrasonic level sensors are provided in Appendix A.

2.6 Sediment Test Section

A sediment test section consisting of a recessed floor with removable sediment inserts/trays was incorporated into the flume design. Various sediment tray insert configurations were also included. A jib crane with an electronic chain hoist was installed to assist in manipulating/installing/removing sediment tray inserts. A false floor cover insert was designed to fit over the sediment test section for test cases that do not require the recessed section. A sediment trap just upstream of the tailgate was incorporated in the design to assist with sediment control and removal.

2.7 Sediment Feeder

A Gandy 4 ft drop spreader (Figure 2 - 8) equipped with dual 12 volt electric drive motors was adapted for installation at the upstream end of the test section to serve as a controlled sediment feeder for sediment transport related studies. It is partitioned into two reservoirs, each half the width of the flume. A calibration tray is included to aid in setting desired feed rates or sediment concentrations. The feeder is operated manually with on/off toggle switches.

Figure 2 - 8. Gandy drop spreader/sediment feeder

2.8 Instrumentation Platform and Linear Rails

Instrumentation rails made from 0.7500 ± 0.0005 inch diameter T-303 stainless round rail were installed along the length of the flume above each side wall. The rails are supported on T-304 stainless steel threaded rod with stainless washers and nuts to allow leveling and parallel alignment.

A generic instrument platform was provided consisting of rectangular frame made from 80/20 T-slot aluminum members and a transparent acrylic platform.

2.9 Flume Control Station

Along the side of the flume, an elevated control station was developed to aid in convenient operation and monitoring of the flume. The control station is equipped with the controls needed to operate the flume either in a standalone mode or from a dedicated PC utilizing LabVIEW software.

The standalone controls consist of the pump VFD, actuated valve controls, and tilt/angle control. Standalone operation allow users to control the flume across the full spectrum of conditions without the use of the PC.

In addition to the standalone mode, a dedicated PC with custom LabVIEW software was incorporated to enhance the range of control and functionality of the flume. The custom software programs allow for the following:

- Depth display in the flume channel and in sumps A and B
- Flow rate display from the magflow meter
- Actuated valve position display
- Flume slope/angle display
- Actuated jack control for specified slope setting
- Display of variables such as average velocity, bed shear stress, Froude Number, Reynolds Number, etc.
- “Flow Tracking” mode that utilizes internal LabVIEW proportional controller function to set and maintain target flow rate.

Detailed descriptions of the LabVIEW virtual instrument programs are provided in Appendix B.

APPENDIX A: ELECTRONIC INSTRUMENTATION

A.1 VFD Description

One Yaskawa P1000 variable frequency drive (VFD), shown in Figure A-1, powers and controls the US Motors, 60HP, 900RPM, MODEL 15411 electrical motor attached to the flume water pump. A VFD is a type of controller that varies the frequency and voltage supplied to an electric motor. For this application the Yaskawa P1000 VFD can be remotely operated through LabVIEW using low voltage DC signals allowing the user to vary the motor (i.e. pump) speed and thus the flow of water through the flume.

Figure A-1 Yaskawa P1000 variable frequency drive

A.1.1 Specifications

Table A-1 lists the key information of main interest for the P1000, for more specifications please see the supplied user manual. For this application the VFD is connected to three-phase, 208 Volts AC power.

Table A-1. VFD specifications

Model	CIMR-PU2A0169FAA
Input power	3 phase, 200 to 240 Volts AC
Amperage	169 A
Input/Output	Analog and Digital

A.1.2 Output signals utilized

The user manual for P1000 notes in several locations of the inherent noise coupled to peripheral devices connected to the VFD. These peripheral devices are typically used for both monitoring and controlling the VFD. Table A-2 lists the VFD terminals and signal description used in controlling the VFD remotely through LabVIEW. Large noise spikes were observed in LabVIEW readings when the VFD was wired directly to the National Instruments Data Acquisition device (DAQ). To isolate the noise generated by VFD on the DAQ, a pair of B&B Electronics Zlinx Wireless I/O RF modules (i.e., Master and Slave) Model ZZ24D-NC-SR were used to wirelessly transfer signal levels between the P1000 VFD and DAQ/LabVIEW. The Zlinx I/O Base Modules operate at 2.4GHz and have 2 Analog Inputs, 2 Analog Outputs, 2 Digital Inputs, and 2 Digital Outputs. Pull-up resistors were added to the RF modules as needed since the RF units can only sink current. Both analog and digital control and feedback signals travel between LabVIEW software and the VFD using the Zlinx master and slave wireless units. For a wiring diagram of the RF module and the VFD, see Figure A-14. For wiring diagram from RF module to DAQ see Figure A-12. The B&B Electronics Zlinx RF modules were configured using the built-in encryption functionality using a unique code to eliminate the possibility of signal corruption if other Zlinx RF modules are operating in the area. A complete list of the configuration settings for the Zlinx modules is available in the user manual folder in the file *B&B_Zlinx.doc.*

Table A-2. Yaskawa P1000 I/O signals utilized for systems control

Terminal	Description
S1	Pump motor Start / Stop Control from external terminals (Digital input)
SN	Pump motor Start / Stop Control from external terminals (Common)
A1	Adjust pump motor speed from external terminal (0-10VDC) (Analog input)
AC	Adjust pump motor speed from external terminal (Common)
M1	Feedback to LabVIEW (Digital output)
M2	Feedback to LabVIEW (Common)
FM	VFD output frequency % (0-10VDC) (Analog Output)

A.1.3 Pump VFD Modified Parameter Settings Report

After connecting the VFD and electrical motor, the motor specific parameter ***E2*** (Motor rated Current) was set in the P1000 to 75.5 A, and the P1000's built in Auto-Tune function was performed. The Auto-Tune function optimizes the P1000 to efficiently control a specific motor. Disabling the Reverse Operation functionality, ***b1***, of the VFD eliminates the possibility of the pump motor accidentally being driven in the wrong direction for the pump. The default deceleration rate, ***C1***, of 10 seconds was modified to a value of 20 seconds. This is the amount of time it takes for the VFD to ramp the motor down from 100% operation to 10% before automatically shutting the motor down. The final parameter edited was ***o1-03*** (Digital Operator Display Selection) which changed the VFD display units from frequency (0-60 Hz) to percentage (0-100%) to allow for a better understanding of the system operation. The full complement of edited parameters from factory default settings is available in Table A-3.

Note: all internal factory jumpers on the VFD to control functionality were left in factory default positions.

Table A-3. Modified VFD Parameters

Parameter	Value	Default
A1 Initialization		
A1-06 Application Preset	8	0
b1 Operation Mode Selection		0
b1-04 Reversion Operation Selection	1	0
C1 Acceleration and Deceleration Times		
C1-02 Deceleration Time 1	20.0 sec	10.0 sec
C6 Carrier Frequency		
C6-02 Carrier Frequency Selection	6	7
d1 Frequency Reference		
d1-01 Frequency Reference 1	25.67%	0.00%
d1-17 Jog Frequency Reference	10.00%	6.00%
E2 Motor 1 Setup		
E2-01 Motor Rated Current	75.7 A	79.7A
L5 Fault Reset		
L5-05 Auto restart selection	1	0
o1 Display Settings		
o1-03 Digital Operator Display Selection	1	0

A.2 Magnetic Flow Meter Description

One Badger M2000 electromagnetic flow meter (Figure A-2) is used to provide fluid metering capabilities for the flume. For this application, the M2000 provides output data for pipe flow velocities and volumetric flow rates as well as empty pipe detection features.

Figure A-2 Badger M2000 electromagnetic flow meter

A.2.1 Factory specs summary

Table A-4 lists the key specifications for the magflow meter. For additional details, refer to the supplied user manual. For this application, the magflow meter was connected to 120V single-phase AC input supply power.

Table A-4. Specifications for Magflow Meter

Model	M2000
Input power	85…265 Volts AC
Power	20 W
Accuracy	±0.25 percent of rate for velocities greater than 1.64 ft./s (0.50 m/s) ± 0.004 ft./s (± 1mm/s) for velocities less than 1.64 ft./s (0.50 m/s)
Pulse Width	Scalable up to 10 kHz, open collector up to 1 kHz, solid-state relay
Output	Analog and Digital

A.2.2 Output signals utilized

The magflow meter signals are used with the Proportional-Integral-Derivative (PID) controller functionality embedded within the custom LabVIEW software application installed on the control PC. Terminals 15 (-) and 16 (+) on the magflow output a 0-20 mA current loop (this value was modified from the default 4-20 mA factory setting) signal and is converted into a voltage signal by a 250 ohm resistor located on the custom I/O printed circuit board, Figure A-15. Terminals 1 (+) and 2 (-) have been set to enable the Empty Pipe Alarm signal. The Empty Pipe Alarm digital signal is sent from the magflow to the DAQ using a 10 kΩ pull-up resistor located on the custom I/O printed circuit board inside the electronics enclosure, Figure A-15. All digital outputs on the magflow implement internal open collector circuits and the manufacturer recommends using 10 kΩ pull-up resistors. Table A-5 lists the output signals utilized from the magflow meter.

Note: The Analog Output factory default settings for terminals 16 (+) and 15 (-) have been changed from 4-20 mA Resistive Load <800 Ω, to 0-20 mA. The Empty Pipe Alarm detection used on terminals 1(+) and 2(-) have been modified from factory default.

Table A-5. Mag Flow Meter utilized output signals

Terminal	Description
1 (+)	Empty pipe alarm (Open Collector Digital signal)
2 (-)	Empty pipe alarm (common)
15 (-)	Flow Unit – flow rate set to cubic feet per second (common)
16 (+)	Flow Unit – flow rate set to cubic feet per second (0-20mA)

A.3 Ultrasonic Level Sensors Description

Three Senix ToughSonic Level and Distance sensors are used to monitor water depths in the system (Figure A-3). ToughSonic sensors are IP68 waterproof rated and contain a rugged transducer potted in a stainless steel housing to provide long life. The Senix sensor is a non-contact Time of Flight (ToF) measuring device, measuring the distance (air space) to the target. To provide an accurate ToF measurement, the sensors internal temperature compensation was enabled to account for changes in the speed of sound with changes in temperature. The factory default setting is to disable internal temperature compensations.

Figure A-3. Senix ToughSonic ultrasonic level transducer

A.3.1 Factory Specs summary

Table A-6 lists the key specifications for the Senix ultrasonic transducers. For additional details, refer to the supplied user manual. For this application, the Senix sensors are connected to regulated 24 VDC power supplies located in the electronics enclosure shown in Figure A-11.

Table A-6. Senix ToughSonic Specifications

Models	TSPC-30S1 TSPC-15S
Input power	10-30 VDC @ 70 mA maximum; Typical: 45 mA @ 24 VDC
Amperage	70 mA; 45 mA
Accuracy	Nominal 0.3% of range @ constant temp. Affected by target, distance, environment
Resolution	Digital: 0.0034 in. (0.086 mm) TSPC-30S1 Digital: 0.0068 in. (0.172 mm) TSPC-15S Analog:4099 steps (0-10 VDC), 3279 steps (4-20 mA) Both models
Output	0-10, 0-5 VDC or PC customized, 10 mA max
Range	0.5 – 10 ft TSPC-30S1 1 – 20 ft TSPC-15S

A.3.2 Output signals utilized

One Senix ToughSonic 14 sensor is used to determine water depth in the flume test section. Two Senix ToughSonic 30 sensors are used to determine water depth in sump A and sump B. The ToughSonic 14 outputs a voltage that equates to the distance to the water's surface or "air space". LabVIEW then converts this value to water depth and displays it in the Test Section Depth measured in feet. Both of the ToughSonic 30 sensors output a voltage that equates to the distance to the water's surface or "air space". Those voltages are interpreted by the LabVIEW software application installed on the control PC that displays the Depth Sump A and Depth Sump B values in feet for the end user to view. If the water level in the Sump A is less than 2.5 feet (7.5 feet of measured air space), the ToughSonic sensor triggers a relay which turns on a strobe light mounted on top of the Sump A's 18-inch actuated valve, Figure A-13. Flume operators will be made aware of low water level in Sump A due to the strobe lights automatically powering on when a low water level condition is present. This warning is to aid in preventing the user from running the pump dry when the water level in the sump is low. The ultrasonic sensor in Sump B is programmed to turn on its warning strobe light when the water level in Sump B is less than 12 inches from the top of the sump. This warning is to aid in preventing the system from overflowing the sump and flooding the floor of the room. The Sump B warning strobe is mounted on top of the Sump B's 18-inch actuated valve.

A.4 <u>Actuated Valves Description</u>

Three Promation actuated valves are used to control water flow within the flume system, Figure A-4. One 12-inch actuated valve is used to control inflow to the flume. Two 18-inch actuated valves control water flow for Sump A and Sump B. All three valves can be operated both manually and electronically using the valve control panel located at the workstation.

Figure A-4. Promation actuated valve

A.4.1 Factory specifications summary

Table A-7 lists the key specifications. For additional details, refer to the supplied user manual. For this application, all Promation actuated valves were connected to 120V single-phase AC input supply power.

Table A-7. Specifications for Pomation actuated valves.

12 inch Model 18 inch Model	P5-120N4-ED P7-120N4-ED
Input power	120 VAC
Amperage	2.1 A 12 inch Model 3.1 A 18 inch Model
Manual Override	7.6" Hand wheel 12 inch model 11.6" Hand wheel 18 inch model
Motor Protection	230°F/110°C Thermal F* Class *Totally Enclosed Non-Ventilated Motors
Output	4-20 mA

A.4.2 Momentary controls

The three valves are electronically adjustable over the full range from fully open to fully closed position using momentary toggle switches mounted within the red enclosure at the PC control station (Figure A-5). Each valve includes factory limit switches that stop the valve motor from turning once it reaches the maximum position in the open or closed state. Green and red LED lights indicate the valve full open and full closed positions, respectively.

Figure A-5. Valve Control Toggle Switch Box

A.4.3 Output signals utilized (valve % open indicator)

Each actuated valve outputs a 4-20 mA signal that is converted into a voltage signal by a 250-ohm resistor located the custom I/O printed circuit board (Figure A-15). LabVIEW software displays each valve's position in terms of percentage open. Table A-8 lists the signals used to control and monitor the actuated valves.

Table A-8. Signals for Promation actuated valves

Terminal	Description
4-20 OUT	Milliamp output for valve position
SIG RTN	Milliamp output for valve position
RUN OPEN	Control to open valve
OPEN PILOT	Signal to green LED that valve is full open
RUN CLSD	Control to close valve
CLSD PILOT	Signal to red LED that valve is full closed

A.5 Tilting Actuator Description

The tilting mechanism (Figure A-6) installed on the flume consists of two actuator jacks, Nord electric motor, gearbox, and Yaskawa V1000 VFD (Figure A-8). The gearbox is coupled to a drive shaft connected to the jacks. The system is designed to provide tilting of the flume from 0 to 5% slope. The assembly uses a unique double pivoting system to maintain a proper lifting angle to the structure. The system can be controlled either from LabVIEW (see Appendix B) or by using the manual push-button control switch connected to the V1000 VFD.

Figure A-6. Tilting actuator for raising and lowering the flume.

A.5.1 Motor and Jacks

The Nord electric motor (model SK 132S/4 CUS) is used to power the gearbox (SK 96272). The 7.5hp motor and gear ratio of 1:8.71 provide approximately 2300 in-lbs of torque. This system powers the Nook Action Jacks (model 15-MSJ-U 8:1). The jacks are capable of lifting 15 tons each, with a range of 0-18" of total actuation.

A.5.2 Limit Switches

Four limit switches (Figure A-7) are mounted to the flume structure near the lifting assembly. Two pairs of limit switches control the upper and lower stop positions. One set of switches act as the main limit switch set, limiting the flume travel from 0-5% slope. The second set of limit switches acts as a failsafe if the main set of limit switches fail to stop the upward or downward travel. The failsafe set of limit switches are connected to the VFD in series with the emergency stop button. In the highly unlikely event that the main set of limit switches fails to stop flume travel, the failsafe set of switches will stop the system as if the emergency stop button had been pressed. The failsafe limit switches are offset 1/2-inch from the main limit switches and engage 1/2-inch after the flume travel beyond the 0% lower limit, or 5% upper limit.

Figure A-7. Limit switch used to stop upward and downward motion of the flume.

A.5.3 VFD / Momentary controller bundle

One Yaskawa V1000 VFD (Figure A-8) is used to power the flume tilt motor. Four limit switches are wired to this VFD for controlling the lower and upper limits of flume tilt as described above. A momentary pushbutton controller located at the PC control station allows for manual control of flume tilting. A momentary reset pushbutton clears VFD fault situations. An emergency stop button places the VFD in Safe Disable mode.

Figure A-8. Yaskawa V1000 VFD used for controlling the motion in tilting the flume.

A.5.4 Specifications

Table A-9 shows the key specifications for the V1000. For additional details, refer to the supplied user manual. For this application, the VFD is connected to three-phase, 208 Volts AC power.

Table A-9. Yaskawa V1000 VFD main specifications.

Model	CIMR-VU2A0030FAA
Input power	3 phase, 200 to 240 Volts AC
Amperage	37 A
Input/Output	Analog and Digital
Operator Controls	Keypad Included

A.5.5 Output signals utilized

The following Yaskawa VFD I/O connections utilized for system control signals are shown in Table A-10. A 1:6 voltage divider installed between terminals V+, A1 and AC provides constant input voltage of 1.75 V on terminal A1 Figure A-9). This input voltage on terminal A1 sets the V1000 VFD to fixed 10 Hz when operating the Nord electric motor. A complete wiring diagram for the V1000, limit switches, push button control and DAQ connections is provided in Figure A-16.

Figure A-9. Voltage divider resistors installed in the Yaskawa V1000 VFD terminals

Table A-10. Yaskawa V1000 I/O signals utilized for systems control

Terminal	Description
S1	Tilt motor forward run / stop (Digital)
S2	Tilt motor reverse run / stop (Digital)
HC	Safe disable input power supply (Common)
SC	Multi-Function Digital Inputs signal level sequence (Common)
H1	Safe disable input; Open: Output disabled, Closed: Normal operation (Digital)
V+	Input power supply 10.5 Vdc (Analog)
A1	Multi-function input 2 (frequency reference 0-10V) (Analog)
AC	Frequency reference (Common)

A.5.6 Tilt VFD Modified Parameter Settings Report

After the VFD was wired to the Nord electric motor, the motor specific parameter ***E2*** (Motor rated Current) was set in the V1000 to 19.8 A. The V1000's built in Auto-Tune function was performed as per the setup instructions in the V1000 manual. The Auto-Tune function optimizes the V1000 to efficiently control a specific motor. Disabling LOCAL operation ***o2,*** eliminates the possibility of the tilt motor being driven by the V1000's internal control panel.

Parameter ***d1-01***, as configured, sets the output operating frequency to 10 Hz to match the input applied to terminal A1 (Multi-function input 2). This setting allows the VFD to control the motor at a fixed rate and considered optimal for travel speeds while raising and lowering the flume. The acceleration and deceleration rates, ***C1***, were modified from the default of 10 seconds to a value of 1 second. This is the amount of time it takes for the VFD to ramp up/down the motor over the range of 10- 100%. Since the VFD is locked in at a rate of 10 Hz, this setting allows the user to efficiently and quickly stop motion. The full complement of edited parameters from factory default settings is available in Table A-11.

Table A-11. Modified parameters set in V1000 VFD

Parameter	Value	Default
b8 Energy Saving		
b8-04 Energy-saving coefficient	94.75	72.69
C1 Acceleration and Deceleration Times		
C1-01 Acceleration time 1	1.0 Sec	10.00 sec
C1-02 Deceleration time 1	1.0 sec	10.00 sec
C1-03 Acceleration time 2	1.0 sec	10.00 sec
C1-04 Deceleration time 2	1.0 sec	10.00 sec
C1-05 Acceleration time 3 for motor2	1.0 sec	10.00 sec
C1-06 Deceleration time 3 for motor2	1.0 sec	10.00 sec
C1-07 Acceleration time 4 for motor2	1.0 sec	10.00 sec
C1-08 Deceleration time 4 for motor2	1.0 sec	10.00 sec
C1-09 Emergency stop time	1.0 sec	10.00 sec
d1 Frequency Reference		
d1-01 Frequency Reference 1	10.00 Hz	0.00 Hz
E2 Motor 1 Setup		
E2-01 Motor rated current	19.80 A	26.60 A
E2-03 Motor no-load current	5.15 A	8.00 A
E2-05 Motor line-to-line resistance	1.948 Ohm	0.288 Ohm
E2-11 Motor rated output	5.50 kW	7.50 kW
o2 Key Selections		
o2-01 LOCAL/REMOTE key enable/disable	0	1

A.6 Inclinometer Description

The Level Developments VS Series inclinometer (Figure A-10) is a high performance dual-axis output device designed for use in tough environments. The inclinometer is mounted to the inside web of a C-channel under the test section of the flume to sense the degree of tilt.

Figure A-10. Inclinometer used for measuring the tilt angle of the flume

A.6.1 General Specifications

Table A-12 shows the key specifications for the VS Series inclinometer. For additional information, refer to the supplied user manual. For this application, the VS Series inclinometer is connected to a regulated 24 VDC power supply located in the electronics enclosure (Figure A-11).

Table A-12. Specifications of VS series inclinometer

Model	VS-10-C-1-3
Input power	12-30 Volts DC
Amperage	68 mA
Range	±10°
Accuracy	±0.03° (@20°C)
Resolution	0.001° (@1Hz BW)
Output	RS232 & 0-5VDC

A.6.2 Ouput Signals

The range of operation for this model sensor is ±10 degrees. Output data from the inclinometer is communicated to the control PC via the RS232 connection and can be viewed using the vendor-supplied software installed on the control PC. In addition, LabVIEW programs utilize the voltage output from the sensor and translate the output voltage to an angle measurement. A summary of the signals utilized from the inclinometer is provided in Table A-13.

Table A-13. Signals utilized on VS Series Inclinometer

Terminal	Description
Red	Power Supply +ve
Black	Power Supply GND
Brown	Transmit Serial: DB9 Pin 2
Blue	Receive Serial: DB9 Pin 3
Green	Signal GND and Serial: DB9 Pin 5 GND
Orange	X-axis analogue output 0-5 V (Analog)

A.7 Schematics and Wiring Diagrams

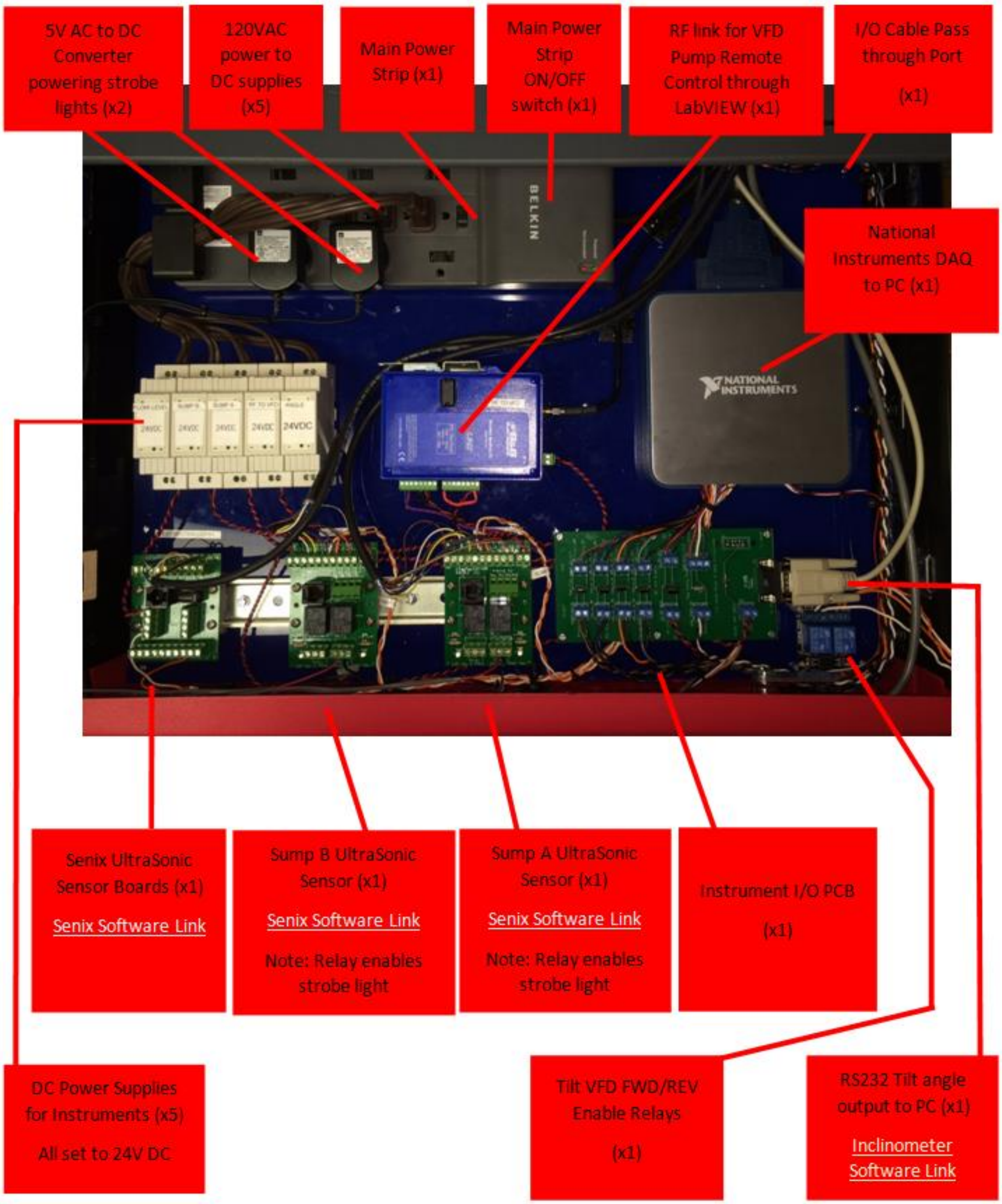


Figure A-11. Electronics control enclosure

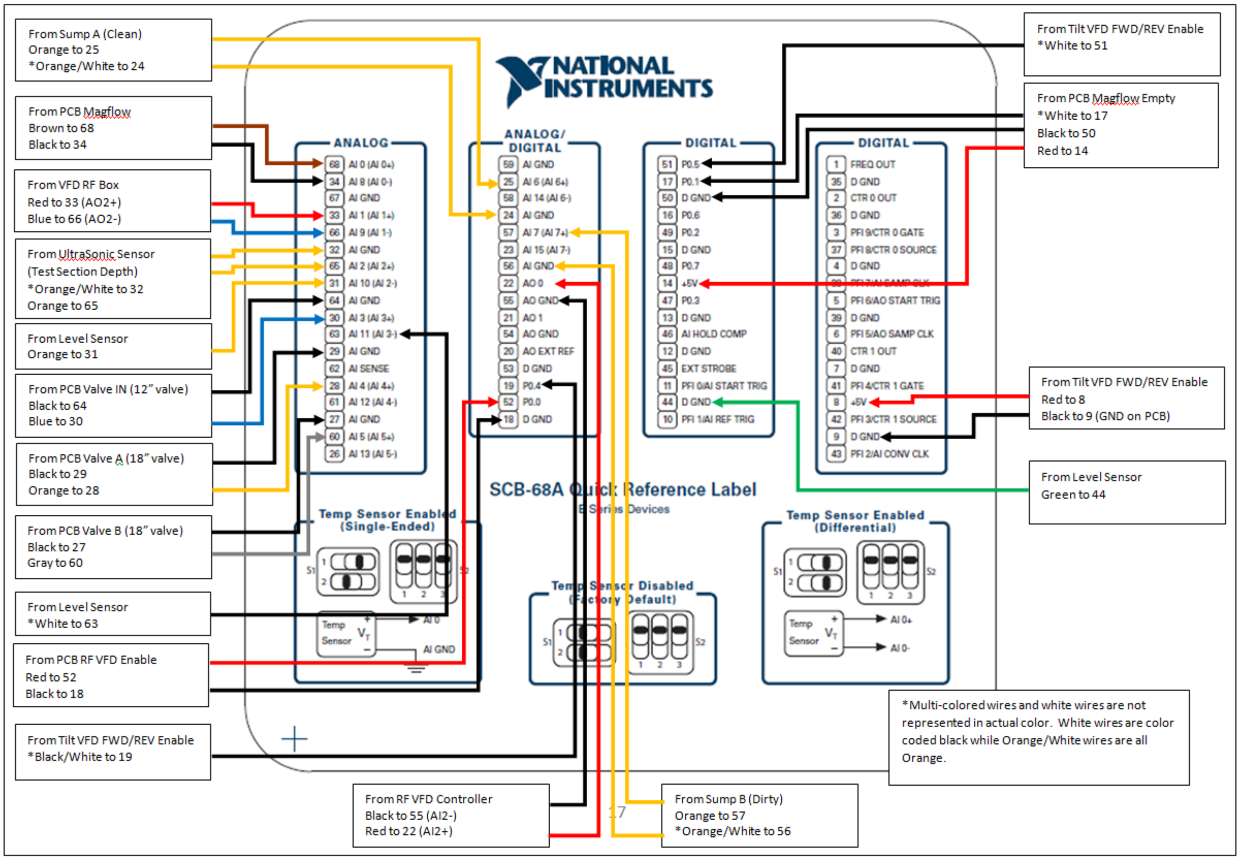


Figure A-12. Wiring diagram for all DAQ connections

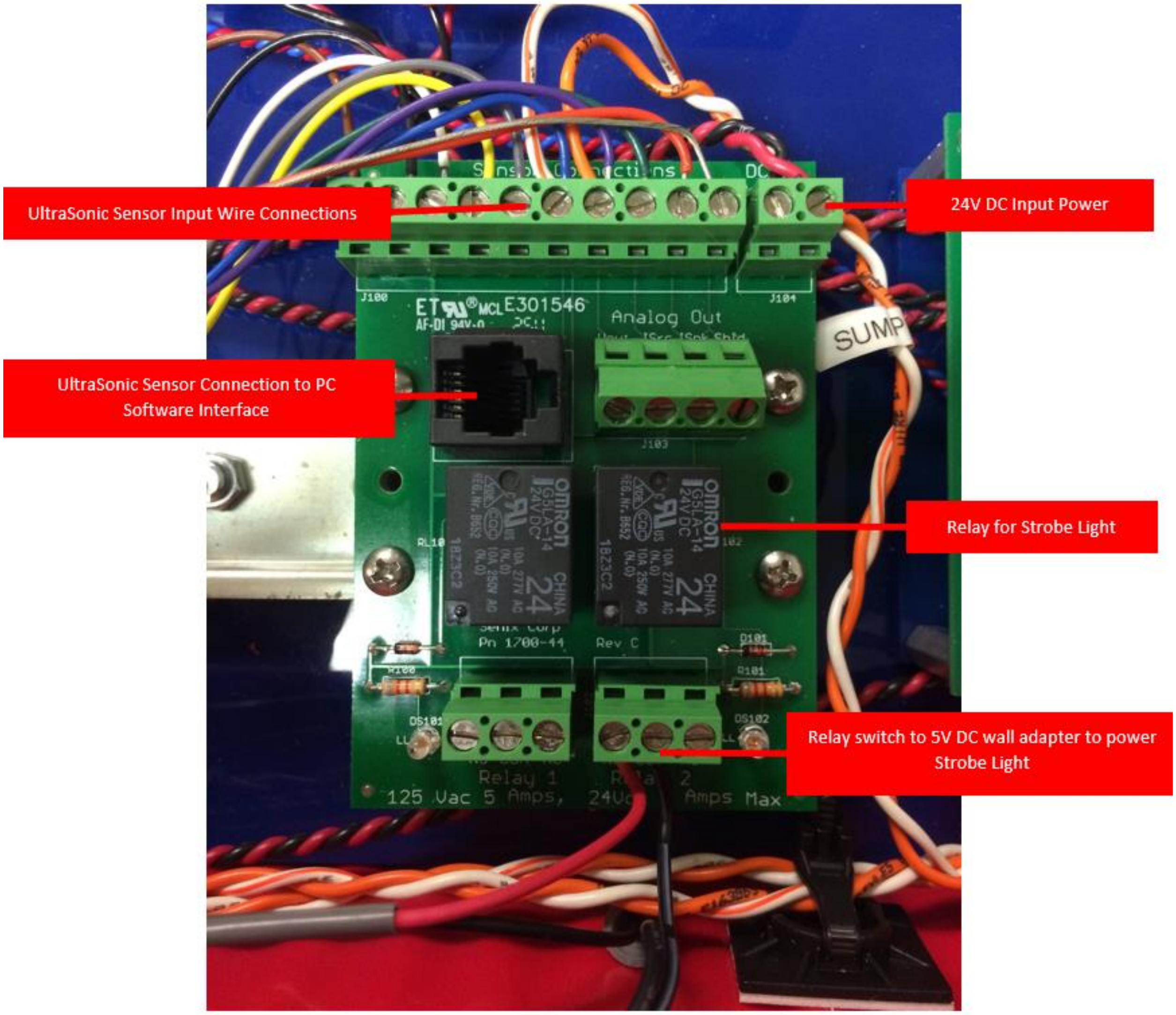


Figure A-13. Senix manufactured ultrasonic termination board used to power and interface with Senix ultrasonic transducers, one board per transducer

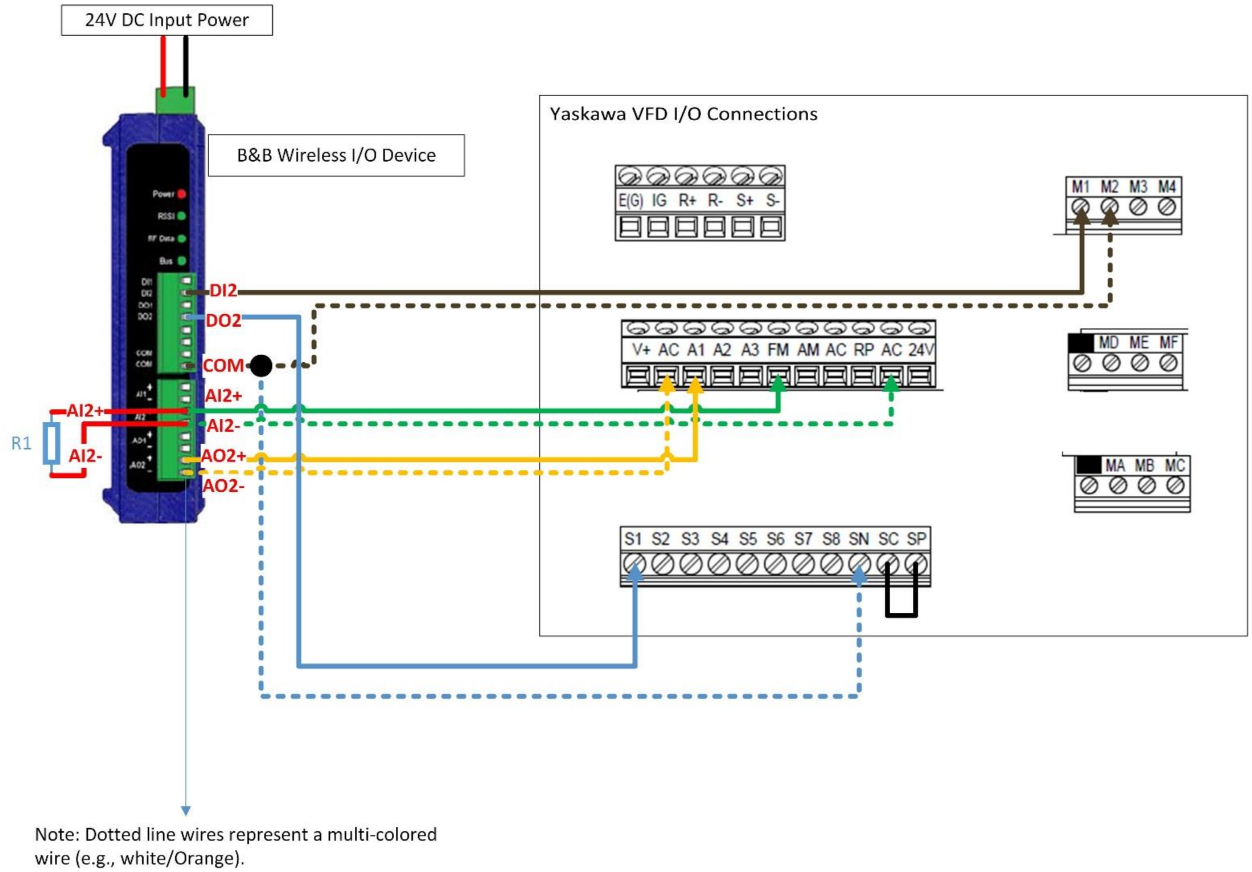


Figure A-14. Wiring diagram between pump VFD and B&B wireless I/O system

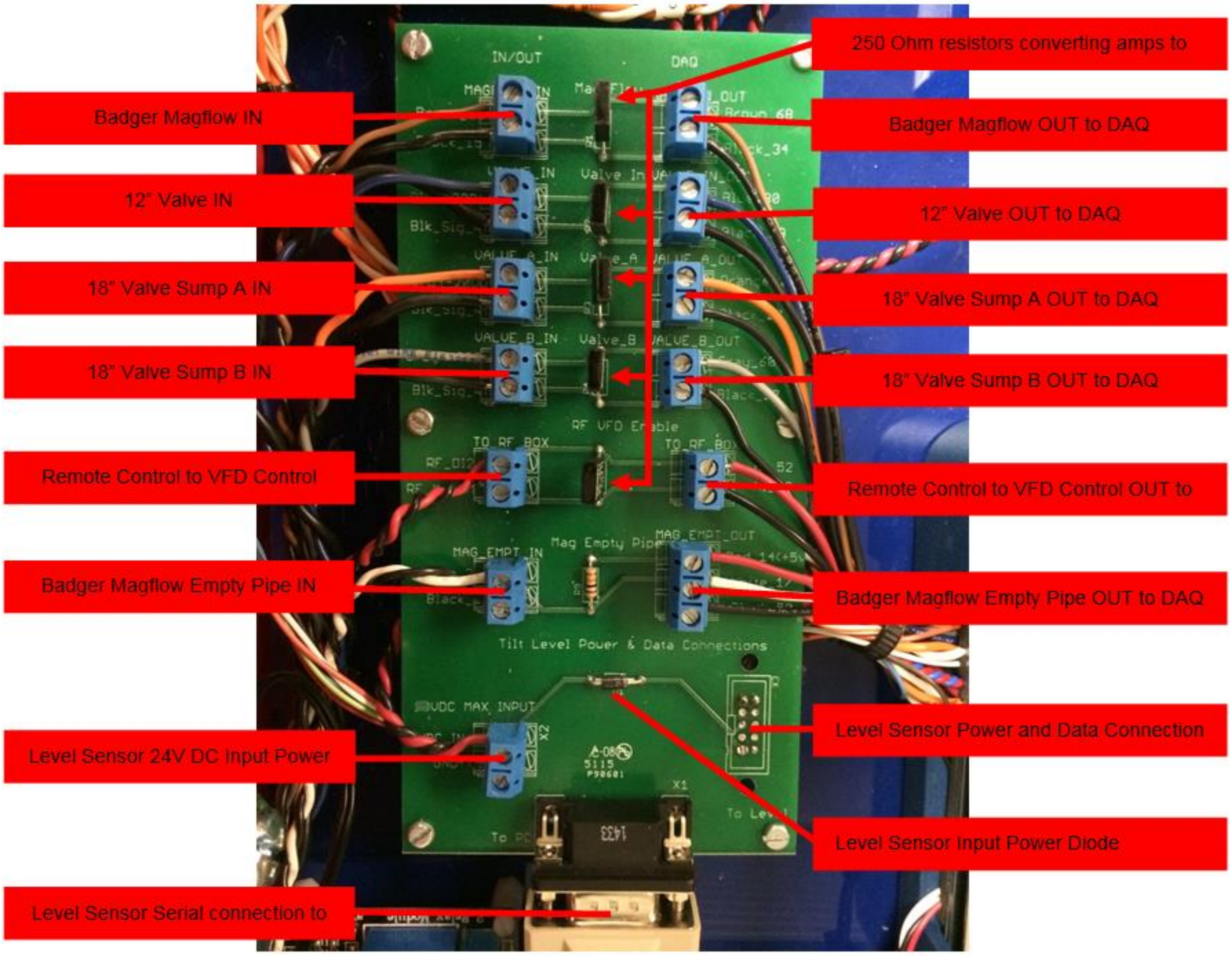


Figure A-15. Flume electronics I/O printed circuit board used to translate sensor current outputs to voltage outputs. The board provides power to the inclinometer sensor and communications to the control PC

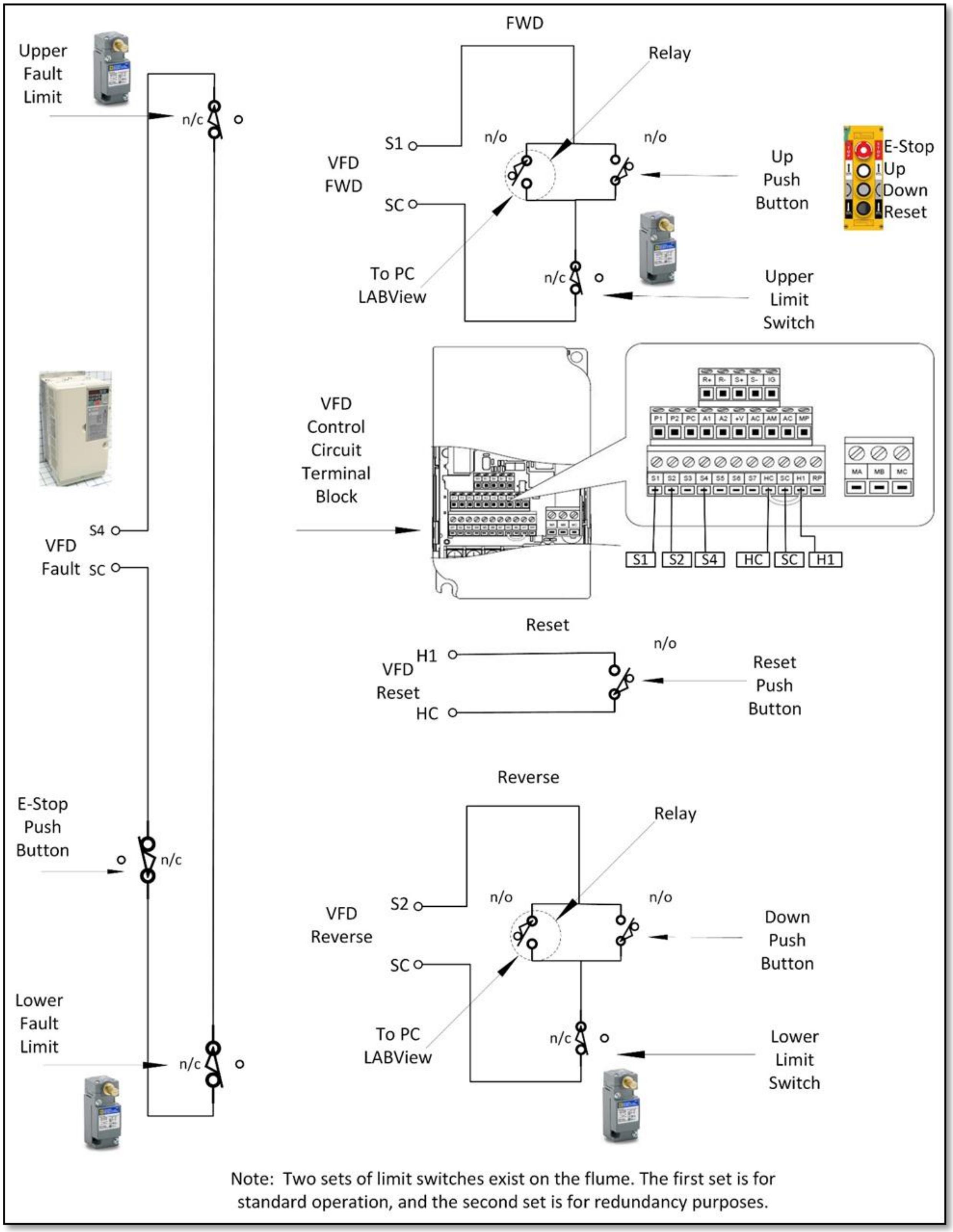


Figure A-16. Wiring diagram for tilting VFD, limit switches and pushbutton control which control the tilt angle of the flume

A.8 System Software & Hardware Links

Senix UltraSonic Sensor: https://senix.com/wp-content/uploads/2015/08/senixview-3-3-450.zip

Level Developments Inclinometer: https://www.leveldevelopments.com/wp/wp-content/uploads/software/Inclinometer_App.zip

B&B Remote Control: http://www.bb-elec.com/getattachment/a969801b-42c3-4ae4-a009-d4575f659a40/ZlinxMgr-3-2-16.zip.aspx

Yaskawa VFD Drive Wizard Industrial: https://www.yaskawa.com/pycprd/products/industrial-ac-drives/software-tools/drivewizard-industrial/tab1/link10

National Instruments DAQ Card: http://sine.ni.com/nips/cds/view/p/lang/en/nid/207409

National Instruments DAQ Connector Block: http://sine.ni.com/nips/cds/view/p/lang/en/nid/210777

National Instruments DAQ Cable: http://sine.ni.com/nips/cds/view/p/lang/en/nid/201628

APPENDIX B: COMPUTER CONTROLS AND DATA ACQUISITION

B. COMPUTER CONTROLS AND DATA ACQUISITION

B.1 Graphical User Interface (GUI) and LabVIEW Description

While there is no better documentation of a program than the illustrated source code, descriptions of the various routines are provided here for convenience and quick access. Most controls, indicators, variables, and algorithms are well commented in LabVIEW and are best viewed in that environment.

The source code was written in LabVIEW 2015 and down versioned to 2012 for use at ISU. There are two top-level virtual instruments (VI's) and a number of sub-VI's. In addition, a large number of standard LabVIEW library routines are called. These are not altered in any way and should be part of any LabVIEW installation so they are not documented here.

The hardware interface code uses the DAQMx libraries supplied with LabVIEW. These handle the low-level analog signal acquisition, analog output, and the digital input/output duties.

The code should be easily transportable between different computers with only a (possible) change in A/D interface board settings being required. The performance of any new or replacement A/D board should be similar to those of the current NI board. The programs are built with the expectation of certain analog and digital signals being provided on specific hardware channels. Changing these will result in failure of the program to control the flume properly.

B.2 Functions of the GUI and LabVIEW Program

The primary goal of the GUI in the LabVIEW program is to assist the operator in safely and repeatability achieving a desired flow state at the test section. The code is dedicated to flume operations and should not be altered for any other tasks. It is assumed that any electronic data acquisition will occur using a different system. It is possible for the user to do data acquisition on unused channels of the supplied data acquisition board, however it is recommend to use a different system altogether.

Proper operation of the program is dependent upon the underlying hardware, sensors, and connections. This is a complex system and there are no fool-proof protocols that can be invoked blindly. The operator is cautioned to carefully inspect the state of the system prior to operation and to be prepared for emergency shutdown if needed.

This program assumes the operator has verified that the system is in good order and functioning properly.

B.2.1 General

The main program GUI is shown in Figure B - 1. To start the program, press the "run" arrow at the upper left of the VI screen, high-lighted in yellow in Figure B - 2.

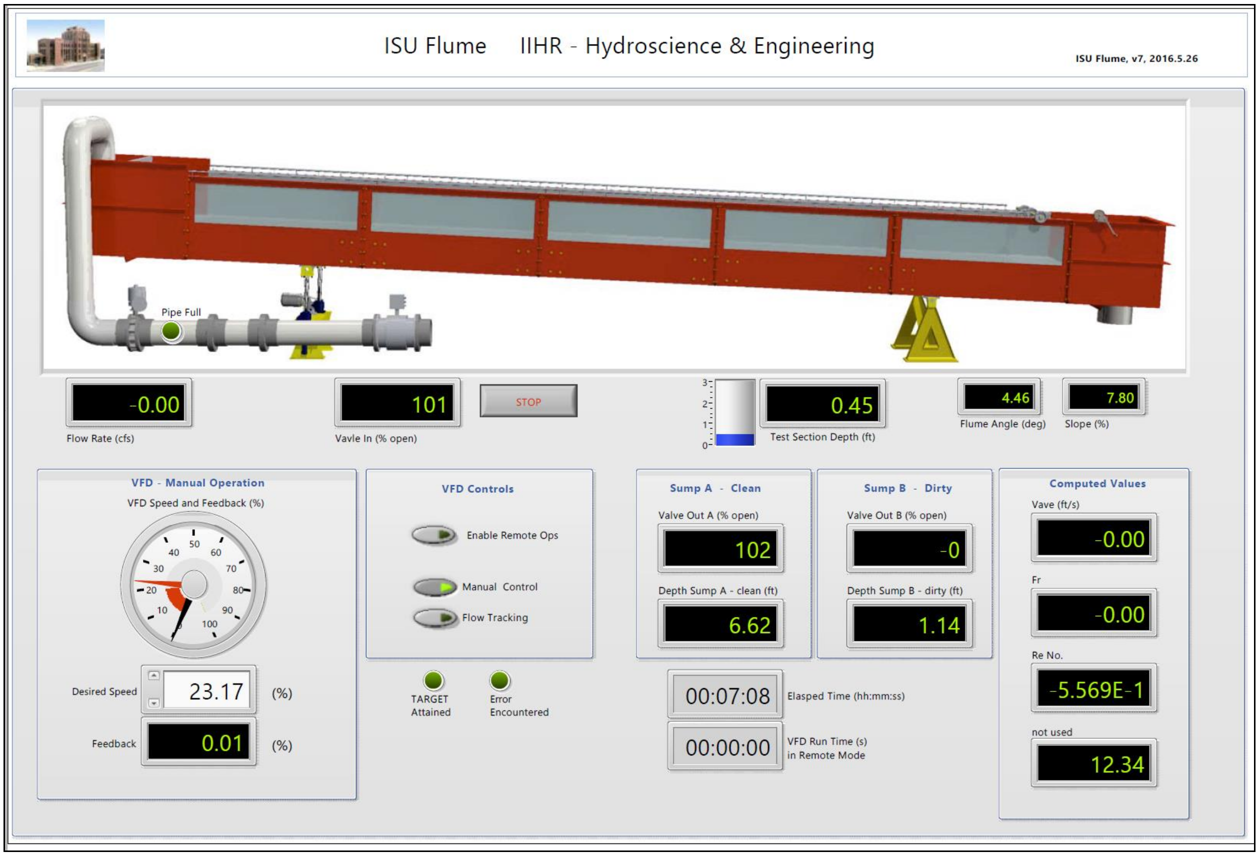


Figure B - 1. Main user interface

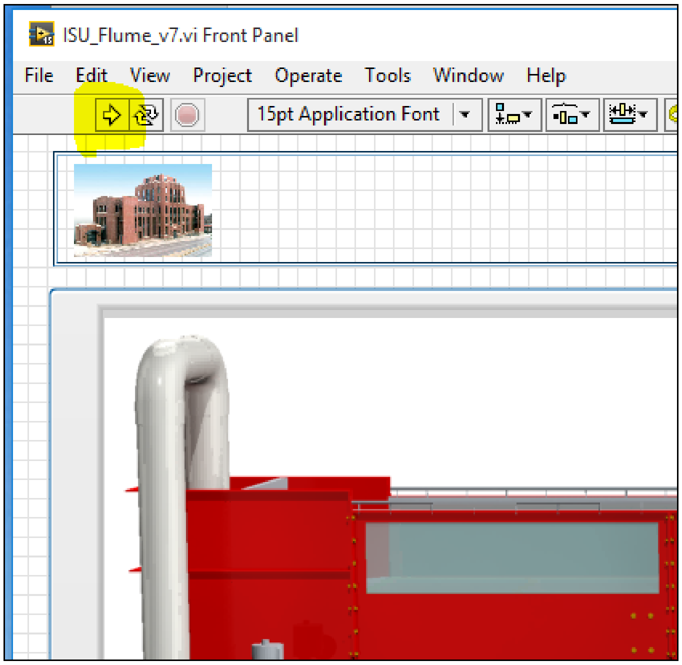


Figure B - 2. Starting the main VI

To stop the program, press the "STOP" button in the middle of the VI as seen in Figure B - 3.

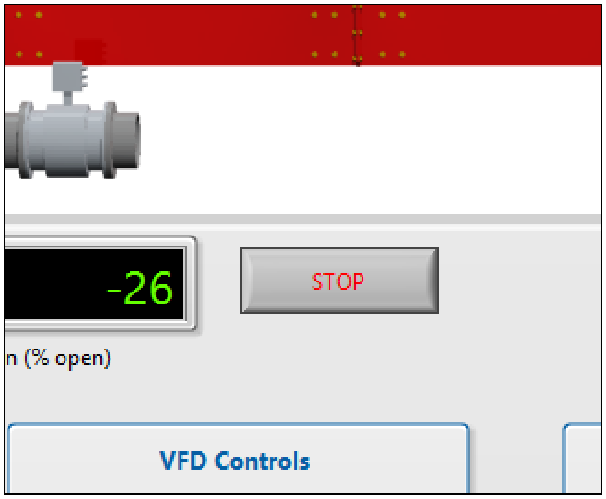


Figure B - 3. Stopping the main VI

B.2.2 VFD and Pump Control Features

The program starts up in a state that will not command the VFD until the “Enable Remote Ops” rocker switch is set. In Figure B - 4, the “Enable Remote Ops” rocker has been pressed and the VI is now sending commands to the VFD and reading the VFD feedback channel.

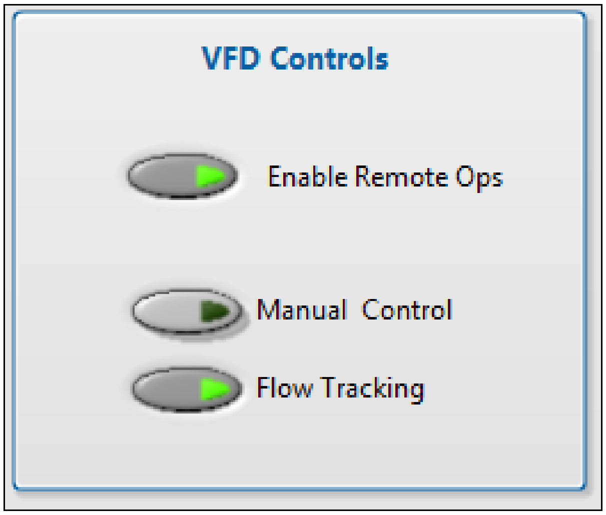


Figure B - 4. Remote ops and flow control options

There is also a pair of radio buttons called “Manual Control” and “Flow Tracking”. These select the desired mode of flow control. You may either set a VFD speed as given by percentage of full scale (%) or you may select the Flow Tracking mode that is designed to adjust the VFD speed to maintain a desired flow rate as reported by the magflow meter. In Figure B - 4, the Flow Tracking mode is enabled. To switch back to manual control of VFD speed, simply press the “Manual Control” radio button.

To halt operations of the flume, it is suggested that you lower the VFD speed manually to about 20% and then deselect the “Enable Remote Ops” control to break communication with the VFD. The VFD will then slow to a safe halt.

B.2.3 Magflow Meter

The magflow meter reports the flow rate through the supply pipe. Due the physics of how it operates, it will produce inconsistent results until the feed pipe is full. Ignore any flow rates presented until the "Pipe Full" indicator is illuminated. In Figure B - 5, the pipe is not yet full and the flow rate is not valid.

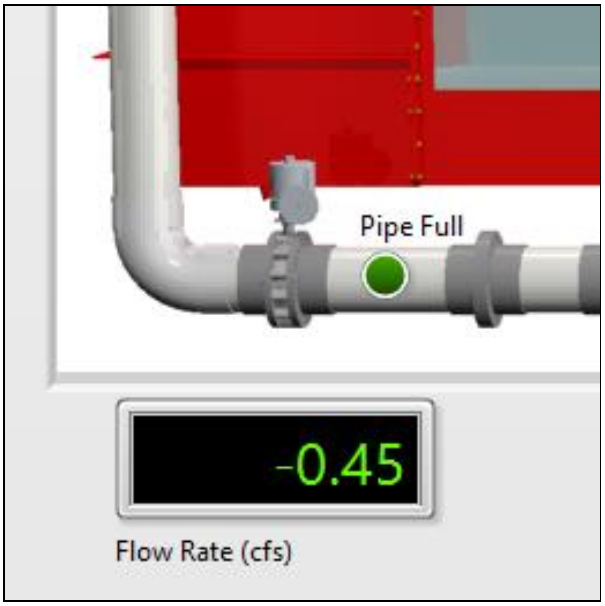


Figure B - 5. Flow rate display

B.2.4 Manual and Flow Tracking Control Modes

The desired mode of flow control may be either 1) Manual Control → set a VFD speed as given by percentage of full scale (%) and monitor the flow rate or 2) Flow Tracking → the desired flow rate is entered and the VI attempts to adjust the VFD speed to maintain the specified flow rate as reported by the magflow meter.

The program takes the current state of operation of the VFD, including values from pervious iterations, and computes a new set of operational parameters to provide a tracking feature for VFD operations. This is essentially a "Proportional" or "P" controller as the slow rate of change of the system did not require a full "Proportional-Integral-Derivative" or "PID" control system.

Manual VFD speed control is the start-up condition and is indicated by the high-lighted "Manual Control" radio button on the right of Figure B - 6.

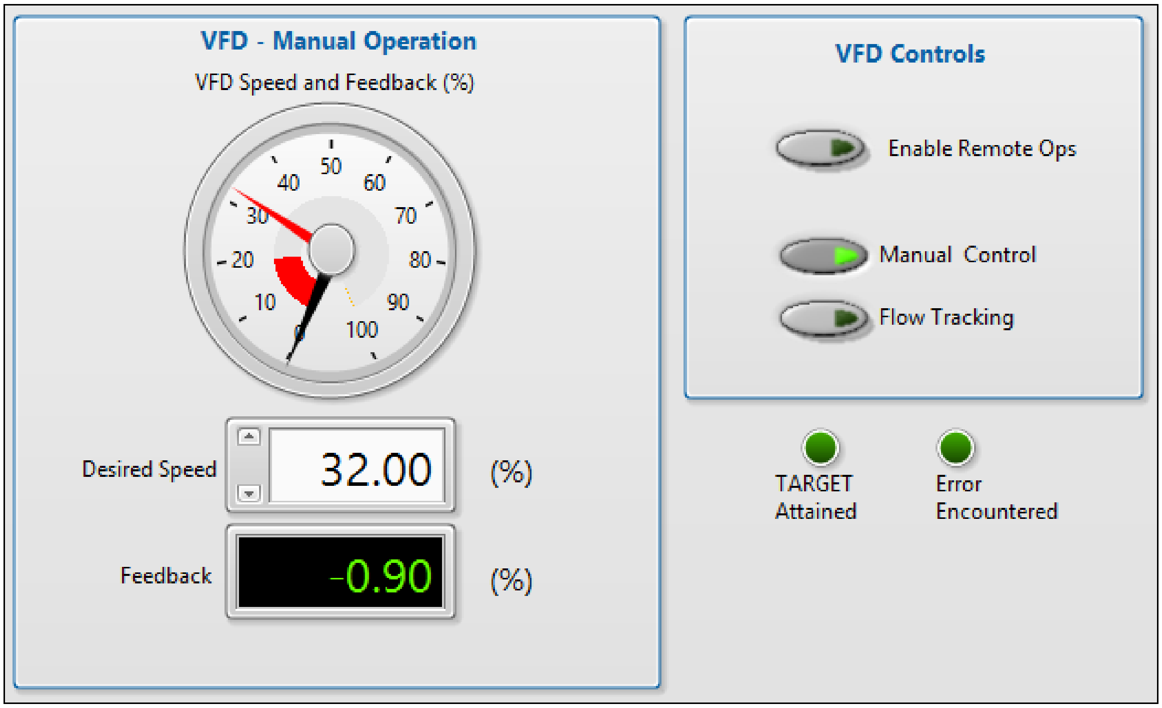


Figure B - 6. VFD manual flow control operations

Once the "Enable Remote Ops" button is selected you may set a VFD speed, in % of full scale, just under the "VFD Speed and Feedback (%)" dial. The above control is set to 32.0 % of full scale. The red needle indicates the desired VFD speed and the black needle shows what the VFD is reporting as its current speed. The black needle will approach the red needle according to the VFD ramp-up and ramp-down limiting rates in the VI. When the feedback reaches the desired setting the "TARGET Attained" indicator will illuminate. The flow rate observed is presented just above the dial indicator as seen in Figure B - 5.

The second mode of operation is to allow the VI to control the VFD to maintain a specified flow rate. You select this mode of operation by pressing the "Flow Tracking" radio button as in Figure B - 7.

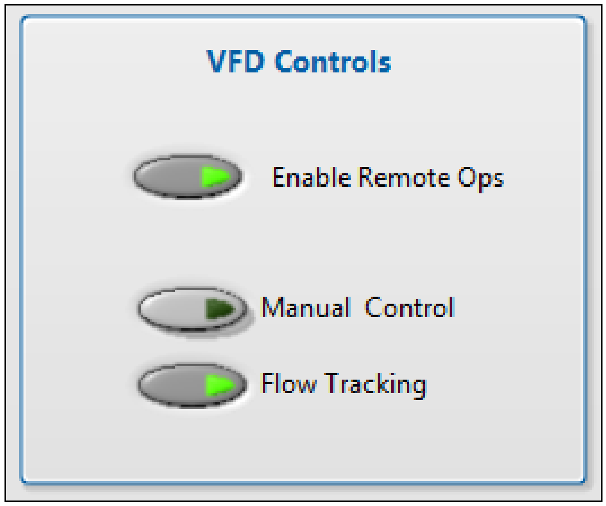


Figure B - 7. VFD operations set to Flow Tracking

The dial changes to reflect flow rates rather than VFD speed as in Figure B - 8.

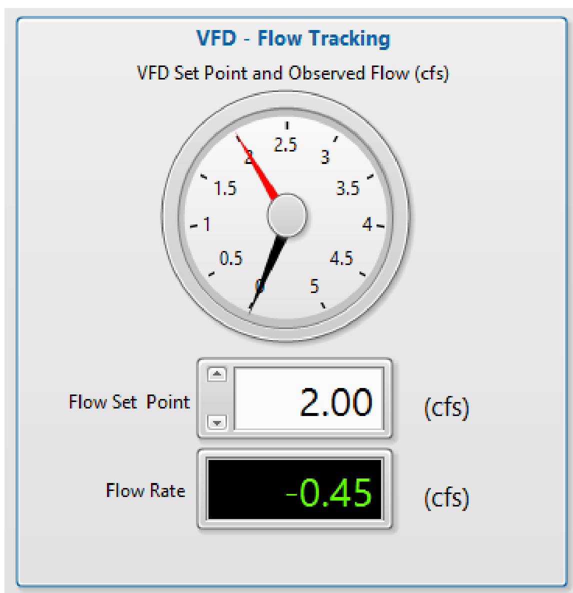


Figure B - 8. Flow Tracking mode of operation

In this case the VFD will be commanded to speed up or slow down to reach a given, desired flow rate set point, “Flow Set Point”. Again, the red needle indicates the desired setting and the black needle indicates the VFD feedback computed flow rate.

You may switch back and forth between the manual control and Flow Tracking control whenever you wish. The flow rate set point will be whatever flow rate the system was experiencing when the switch from manual to tracking was selected. Similarly, the VFD setting will be whatever it was when the switch back to manual was selected. This keeps the pump and flow at the same rate as we transition between modes of operation.

B.2.5 Ultrasonic Level Sensors

Three ultrasonic level sensors are utilized to calculate water levels in the test section (Figure B - 9) and sumps A and B (Figure B - 10). Each sensor is calibrated and mounted with calibration and offset values set in the calibration sub-VI. The current water levels are reported to the front panel.

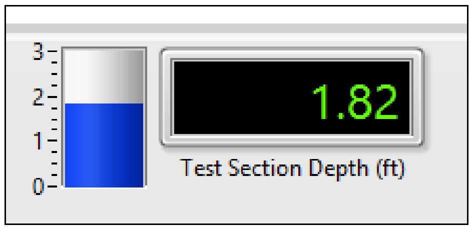


Figure B - 9. Test section depth indicator

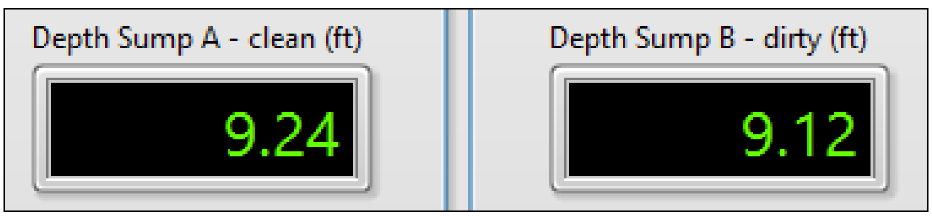


Figure B - 10. Sump depth indicators

B.2.6 Actuated Valves

The three actuated valves report the percentage open and are displayed on the front panel. The position of the 12-inch valve in the supply pipe is denoted as “Valve In (% open)” as seen in Figure B - 11. The sump A and sump B valve positions are reported as shown Figure B - 12.

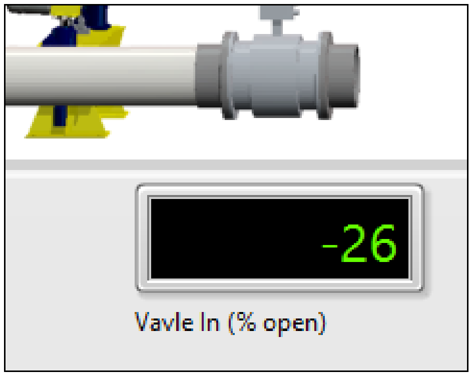


Figure B - 11. 12-inch supply pipe valve opening (%)

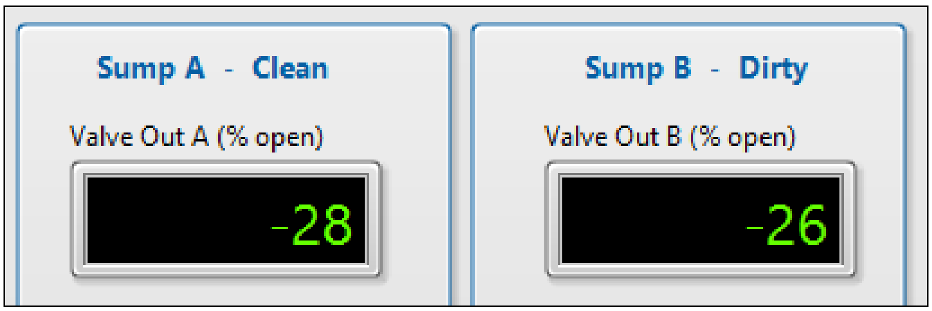


Figure B - 12. Sump A and B valve opening (%)

B.2.7 Jack Control - Tilting

There is an independent jack control program provided for moving the flume by extending or contracting the jack (Figure B - 13). Be sure to run this VI independently from the main control interface as it relies on the same hardware and connections, and therefore cannot run coincidentally with the main VI.

This routine takes the target flume slope (%) as user input and moves the jack accordingly to achieve the specified slope. The move time and move distance are displayed so the operator can observe the jack motion. The STOP button will halt the jack motion.

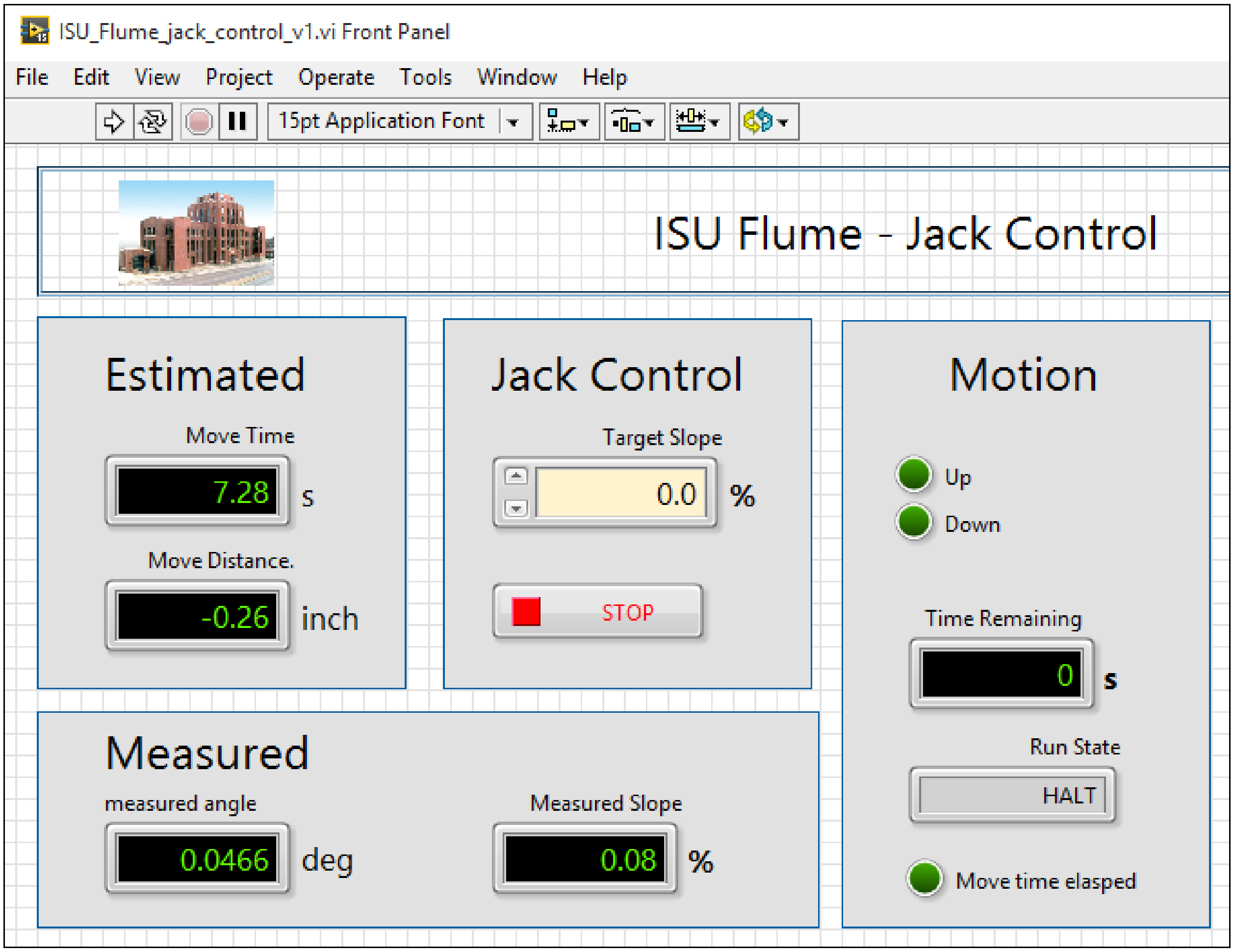


Figure B - 13. Jack Control main user interface

B.2.8 Inclinometer

The jack control VI as well as the main VI use a mounted digital inclinometer to continuously measure the flume slope. Vendor software is provided that will permit you to re-zero the inclinometer if readings appear questionable or remounting becomes necessary. This is done through an RS-232 interface and will not impact the VI's since they utilize the inclinometer's voltage output signal.

B.3 <u>Main Control Program Features and Details</u>

The main control program VI and its supporting VI's are described here in detail. The following sub-sections show the front panel for each routine. The data types and significant parameters may be seen from the block diagrams. Since LabVIEW is polymorphic, it is important to keep the specific data types in mind as you read the block diagrams.

Each section below shows the block diagram icon and the input and output variables for each routine. The front panel of each VI is also shown with sample data and results.

The main VI (ISU_Flume_v7.vi) opens with a main operator's view on the left of the screen and a configuration and monitoring view on the right (Figure B - 14). The right of the screen consists of a several tabbed pages. The contents of each page may be displayed by pressing the corresponding tab at the top.

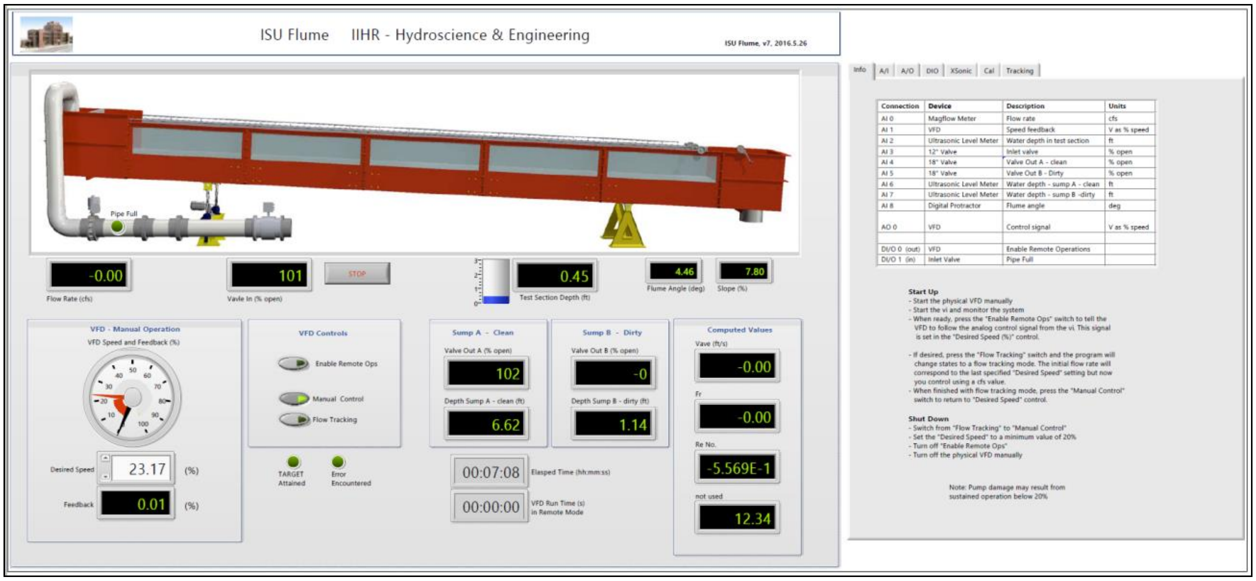


Figure B - 14. Main user interface

Key elements of the front panel interface include a visualization of the flume slope: the flume image tilts corresponding to the slope of the actual flume in 0.5 degree increments; a Boolean indicator when the feed pipe is full; a number of digital indicators – black with green lettering – showing the flume's state of operation (e.g., valve closures, sump depths, test section depth, average flow velocity, Froude Number, Reynolds Number; a dial showing VFD speed, both in the control and tracking modes; several Boolean rocker switches controlling remote operations, and manual or tracking control modes. A close-up view of the primary operator interface is shown in Figure B - 15.

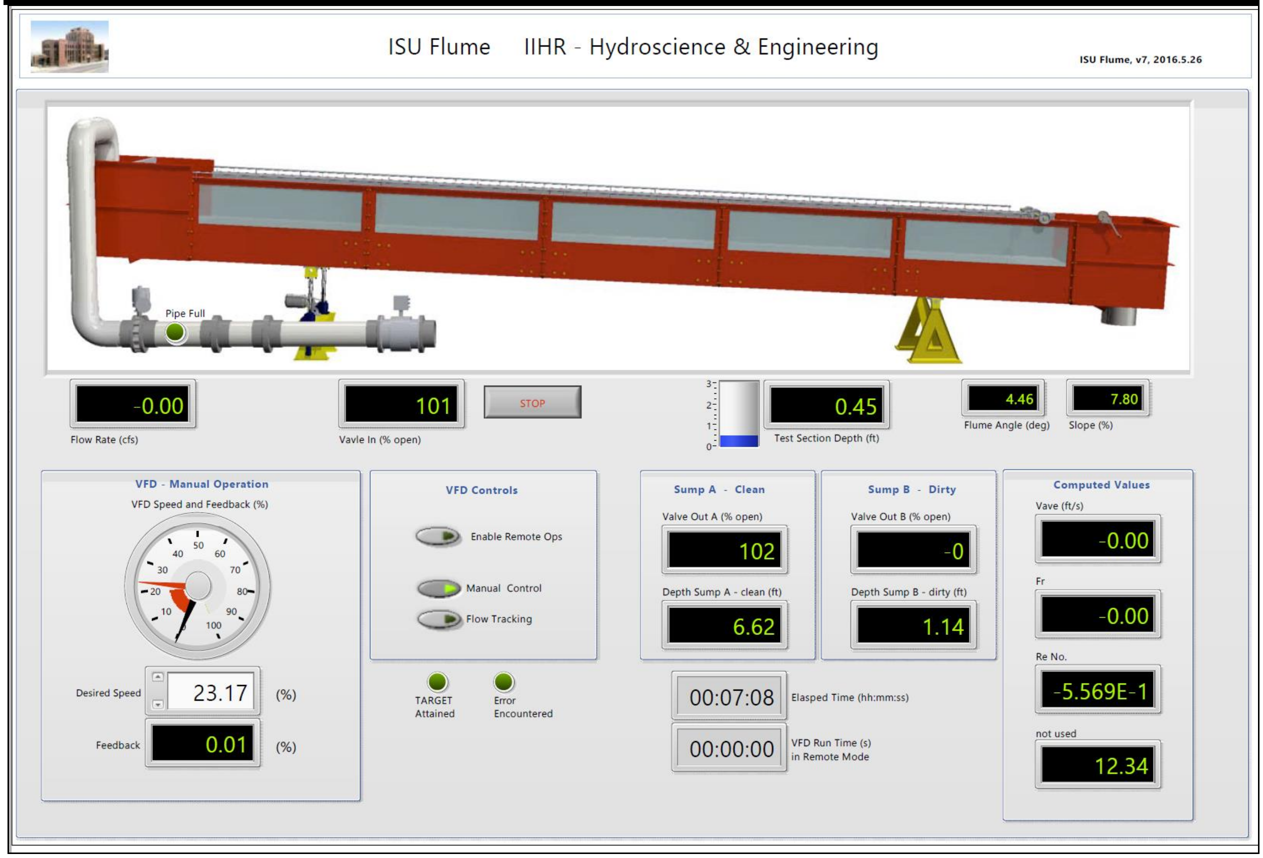
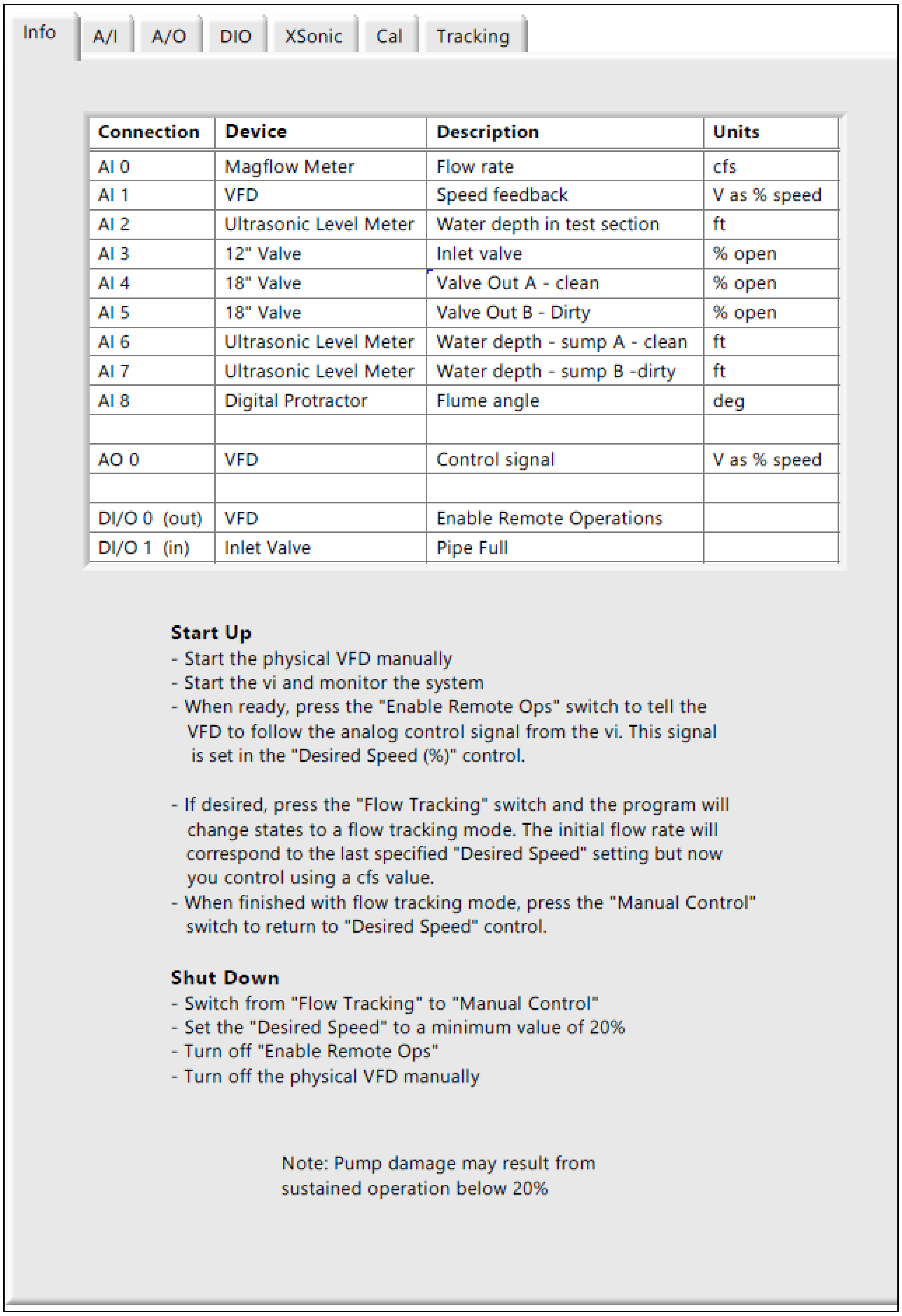


Figure B - 15. Primary operator interface

B.3.1 Info Tab

The "Info" page summarizes information relating to the operation of the flume and a quick statement of operational startup and shutdown procedures (Figure B - 16).



Connection	Device	Description	Units
AI 0	Magflow Meter	Flow rate	cfs
AI 1	VFD	Speed feedback	V as % speed
AI 2	Ultrasonic Level Meter	Water depth in test section	ft
AI 3	12" Valve	Inlet valve	% open
AI 4	18" Valve	Valve Out A - clean	% open
AI 5	18" Valve	Valve Out B - Dirty	% open
AI 6	Ultrasonic Level Meter	Water depth - sump A - clean	ft
AI 7	Ultrasonic Level Meter	Water depth - sump B -dirty	ft
AI 8	Digital Protractor	Flume angle	deg
AO 0	VFD	Control signal	V as % speed
DI/O 0 (out)	VFD	Enable Remote Operations	
DI/O 1 (in)	Inlet Valve	Pipe Full	

Start Up
- Start the physical VFD manually
- Start the vi and monitor the system
- When ready, press the "Enable Remote Ops" switch to tell the VFD to follow the analog control signal from the vi. This signal is set in the "Desired Speed (%)" control.

- If desired, press the "Flow Tracking" switch and the program will change states to a flow tracking mode. The initial flow rate will correspond to the last specified "Desired Speed" setting but now you control using a cfs value.
- When finished with flow tracking mode, press the "Manual Control" switch to return to "Desired Speed" control.

Shut Down
- Switch from "Flow Tracking" to "Manual Control"
- Set the "Desired Speed" to a minimum value of 20%
- Turn off "Enable Remote Ops"
- Turn off the physical VFD manually

Note: Pump damage may result from sustained operation below 20%

Figure B - 16. Information tab

B.3.2 A/I Tab

The analog input page shows the current settings for the National Instruments hardware for the differential channels, single-ended channels, and hardware timing. See Figure B - 17. These settings come from a configuration sub-VI described later.

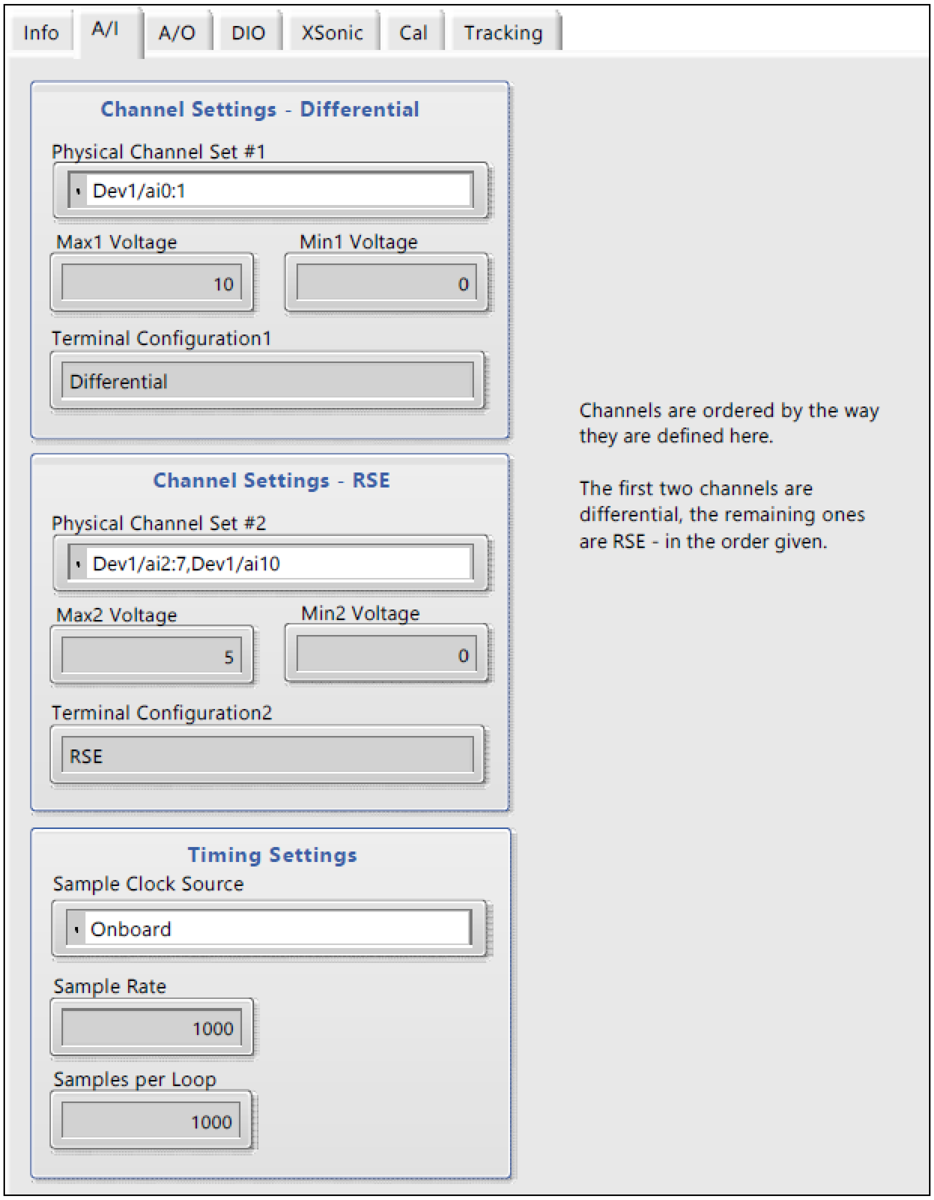


Figure B - 17. Analog input information tab

B.3.3 A/O Tab

The analog output page shows the current settings for the National Instruments hardware for the analog output channels related to VFD control. See Figure B - 18. These settings come from a configuration sub-VI described later.

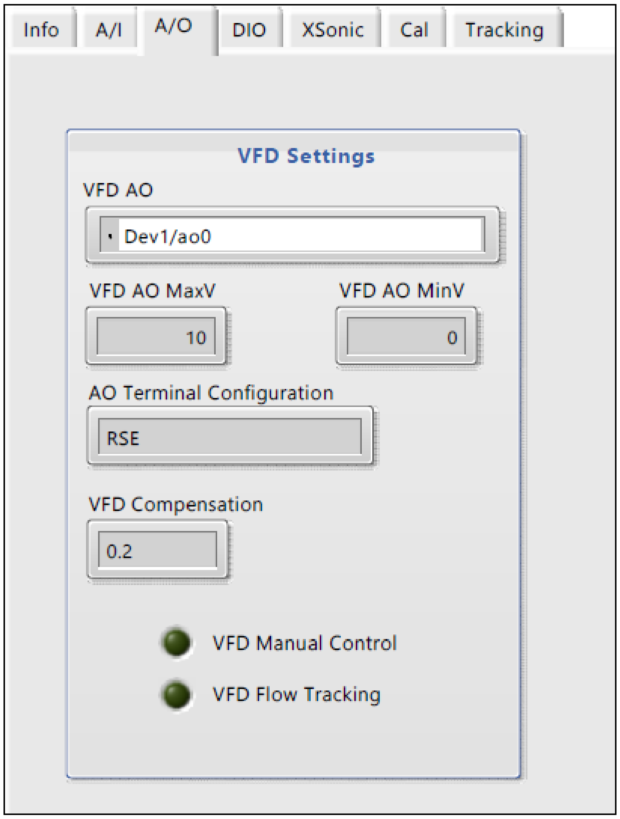


Figure B - 18. Analog output information tab

B.3.4 DIO Tab

The digital input/output page shows the current settings for the National Instruments hardware for the digital input and output channels related to VFD control and feedback. See Figure B - 19. These settings come from a configuration sub-VI described later.

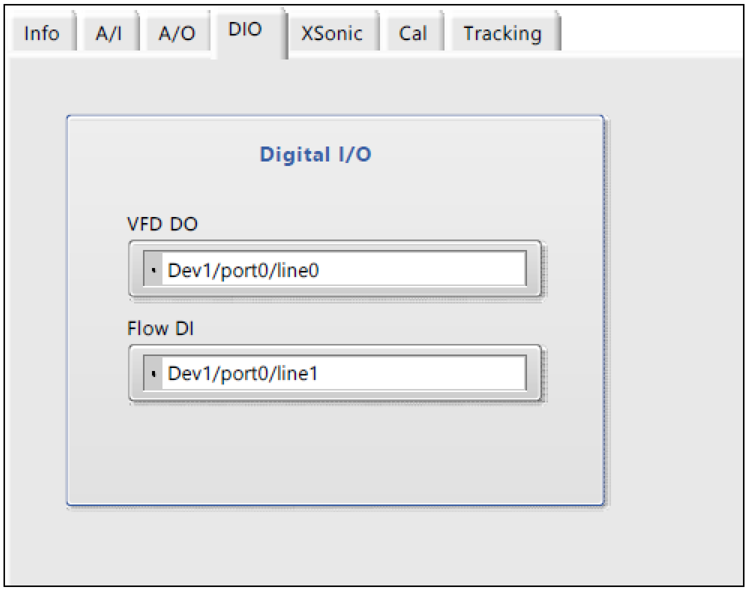


Figure B - 19. Digital input and output information tab

B.3.5 XSonic Tab

The XSonic page summarizes the geometric offsets used in the mounting of the sump ultrasonic water level sensors. A small diagram of the mounting geometry is provided in Figure B - 20. These settings come from a configuration sub-VI described later.

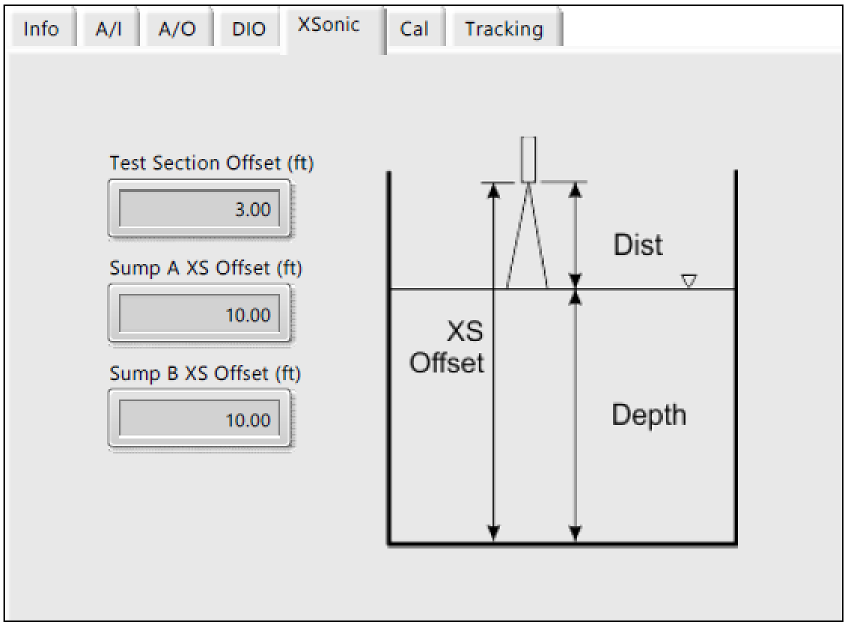


Figure B - 20. Ultrasonic probe information tab

B.3.6 Cal Tab

The calibration page summarizes the linear slopes and offsets used by each of the analog input channels. These calibrations covert sampled voltages to engineering units. A graph of the sampled voltages is provided so you may confirm proper sampling. See Figure B - 21. These settings come from a configuration sub-VI described later.

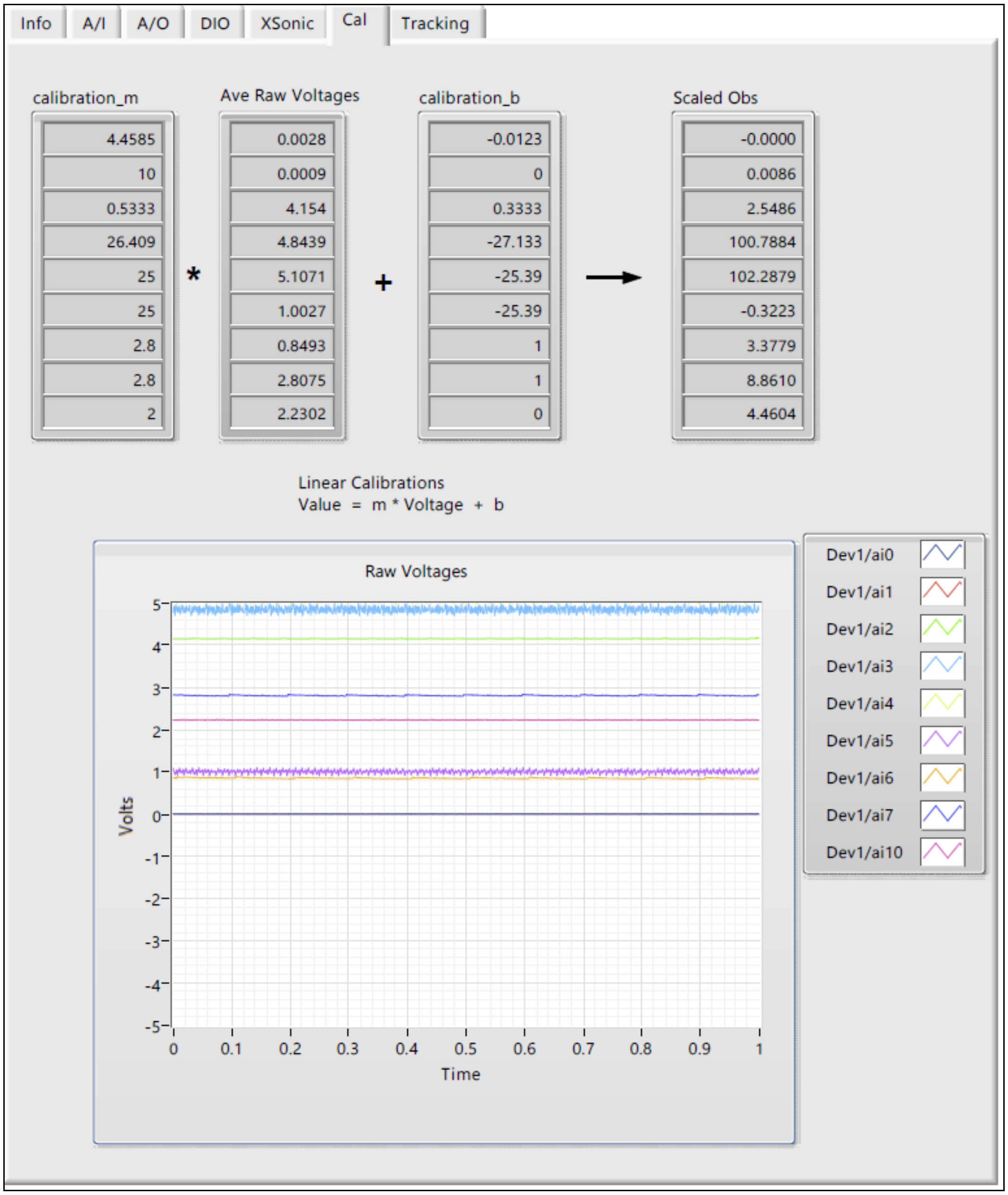


Figure B - 21. Calibration information tab

B.3.7 Tracking Tab

The tracking page summarizes the control settings and feedback used by the Flow Tracking mode of operation. A graph of the VFD speed and the state of the tracker is provided so you may confirm proper operation. See Figure B - 22. These settings come from a configuration sub-VI described later.

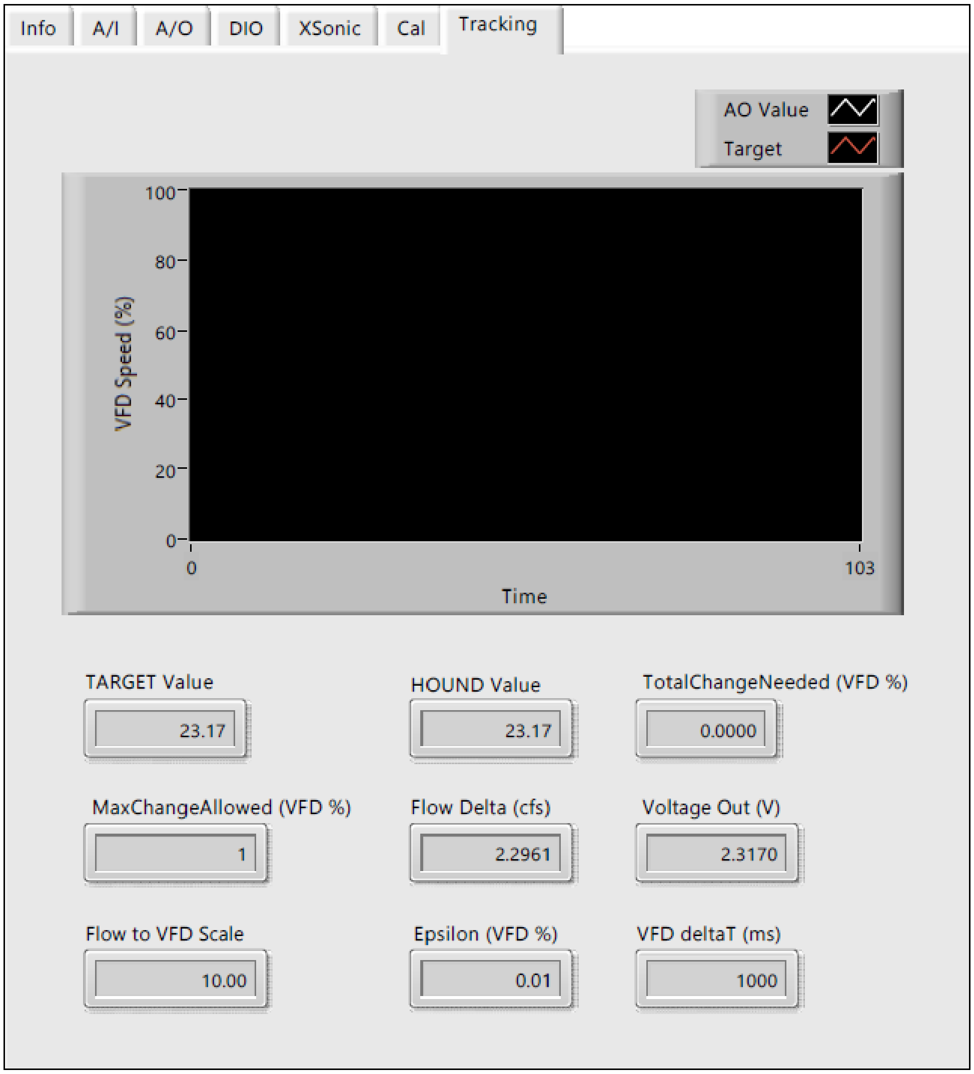


Figure B - 22. Tracking mode information tab

B.3.8 ISU_Flume_Scale.vi

This routine performs scaling on all sampled analog input channels. It converts from raw voltages to engineering units according the linear calibration data provided. The input and output variables are listed in Figure B - 23 and Figure B - 24 shows the primary user interface for this sub-VI.

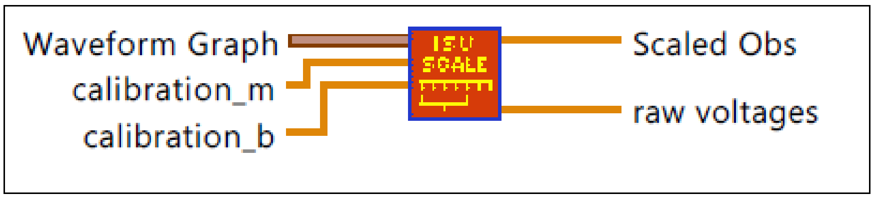


Figure B - 23. ISU_Flume_Scale.vi input and output variables

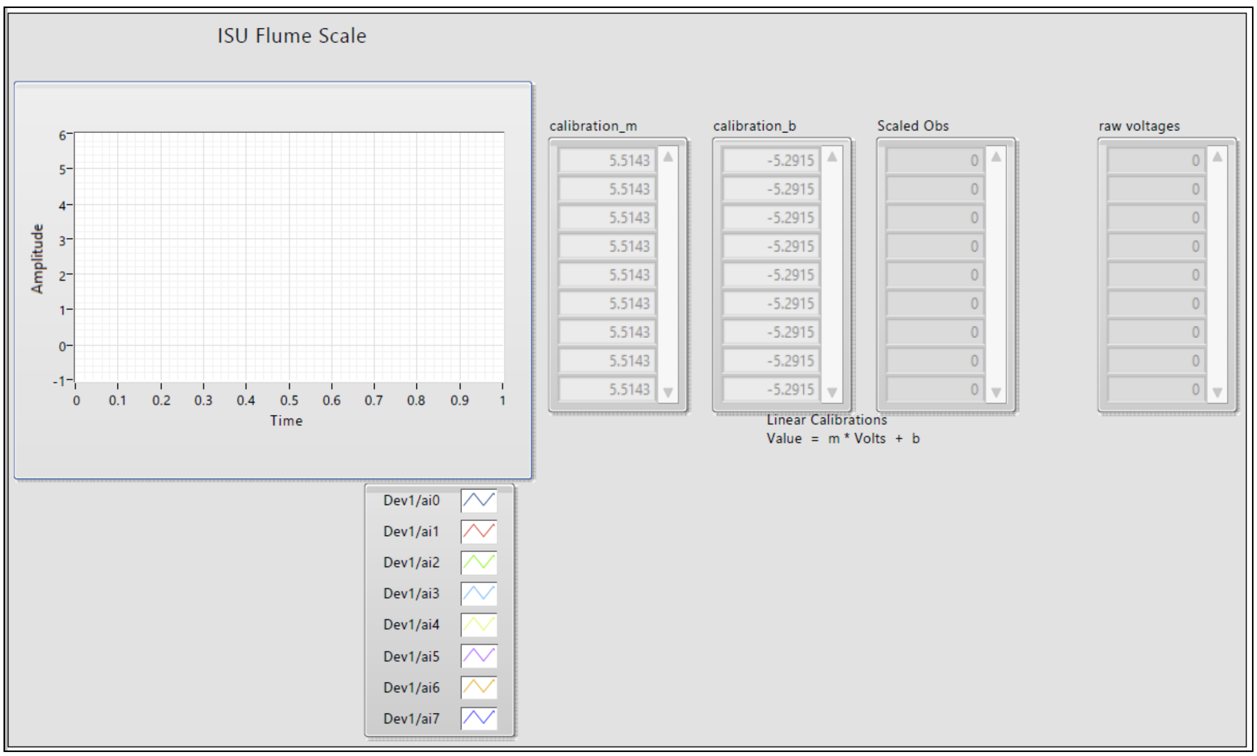


Figure B - 24. ISU_Flume_Scale.vi main interface

B.3.9 ISU_Flume_Set_Config.vi

This VI defines many of the operational parameters for the main program. This is the place where most configuration values are defined for other program units to use. Each value is defined on the left of the display screen and echoed on the right as they are passed back to the calling routine. The input and output variables are listed in Figure B - 25 and Figure B - 26 shows the primary user interface for this sub-VI.

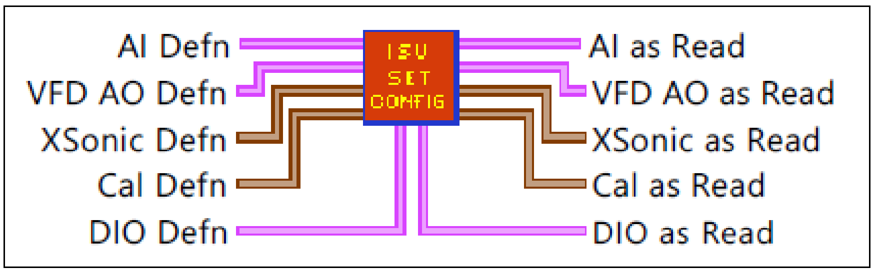


Figure B - 25. ISU_Flume_Set_Config.vi input and output variables

ISU_Flume_Set_Config

Calibration Definitions

The following are the linear calibration coefficients
associated with each channel.

Connection	Device	Description	Units	Notes
AI 0	Magflow Meter	Flow rate	cfs	slope 0 and intercept 0 are selected from the MagFlow Cal Defn cluster based on range value selected
AI 1	VFD	Speed feedback	V as % speed	slope 1 and intercept 1
AI 2	Ultrasonic Level Meter	Water depth in test section	ft	slope 2 and intercept 2
AI 3	12" Valve	Inlet valve	% open	slope 3 and intercept 3
AI 4	N/A			slope 4 and intercept 4
AI 5	N/A			slope 5 and intercept 5
AI 6	Ultrasonic Level Meter	Water depth - sump A - clean	ft	slope 6 and intercept 6
AI 7	Ultrasonic Level Meter	Water depth - sump B -dirty	ft	slope 7 and intercept 7
AI 8	Dig. Protractor	Flume angle	deg	slope 8 and intercept 8

Figure B - 26. Calibration definitions for display on the front panel

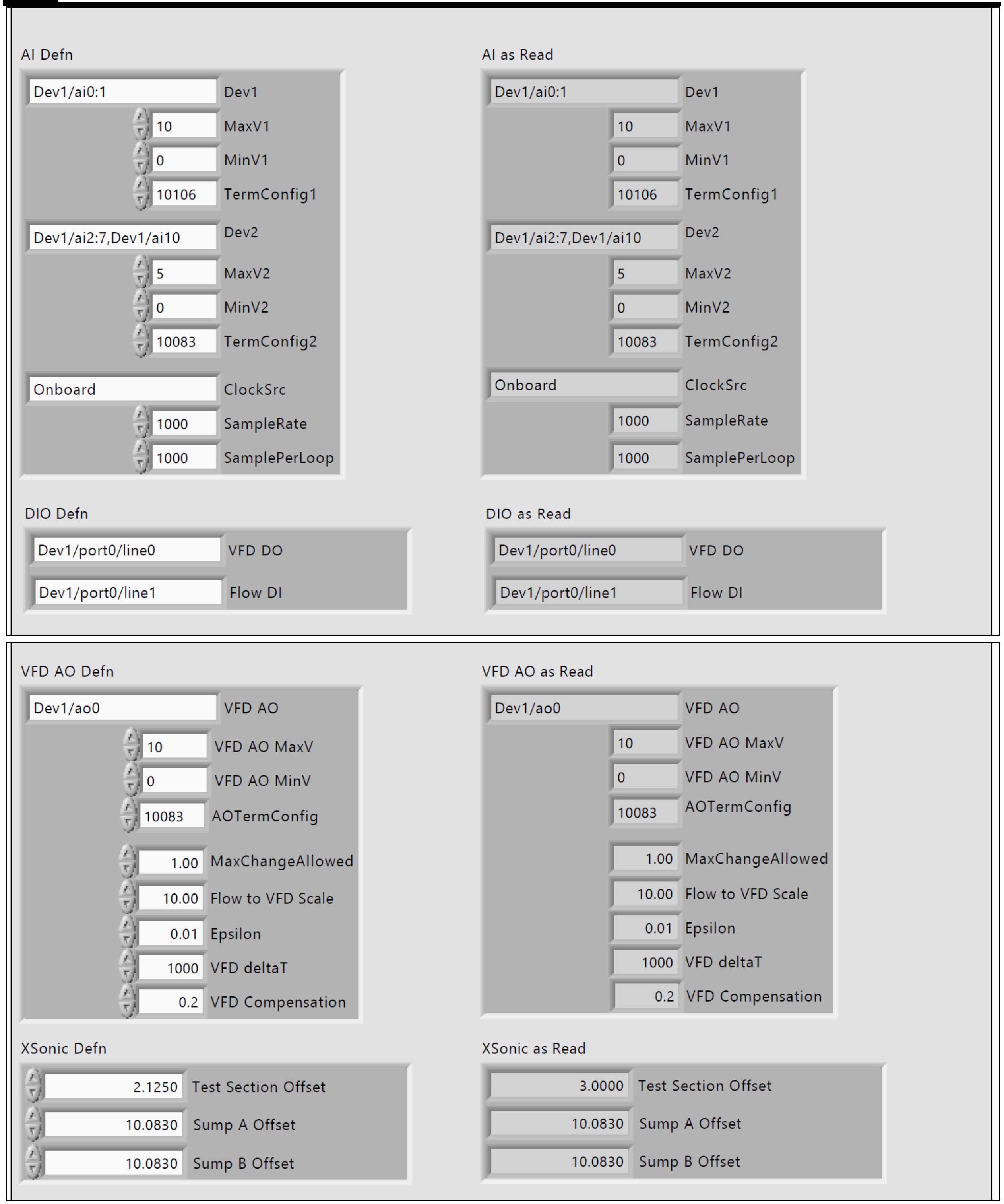


Figure B – 26 cont. Calibration definitions for display on the front panel

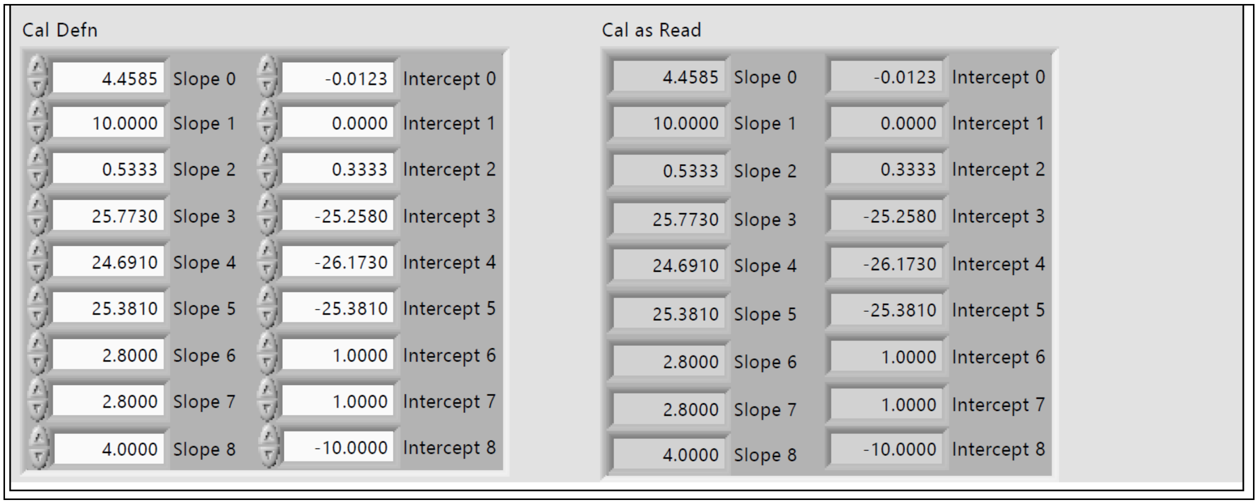


Figure B – 26 cont. Calibration definitions for display on the front panel

B.3.10 ISU_Flume_VFD_Tracker.vi

This routine takes the current state of operation of the VFD, including values from previous iterations, and computes a new set of operational parameters in order to provide a tracking feature for VFD operations. This is essentially a "P" controller as the slow rate of change of the system did not require a full "PID" control system. Note that the tuning values may be altered in this interface as opposed to most sub-VI's that use the configuration VI for data. The input and output variables are listed in Figure B - 27 and Figure B - 28 shows the primary user interface for this sub-VI.

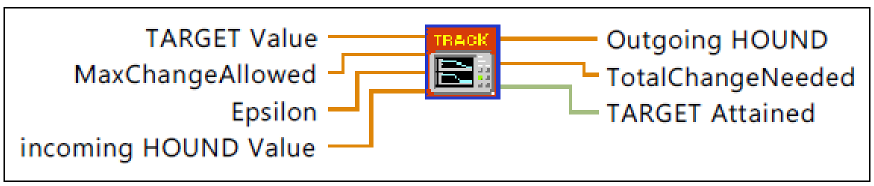


Figure B - 27. ISU_Flume_VFD_Tracker.vi input and output variables

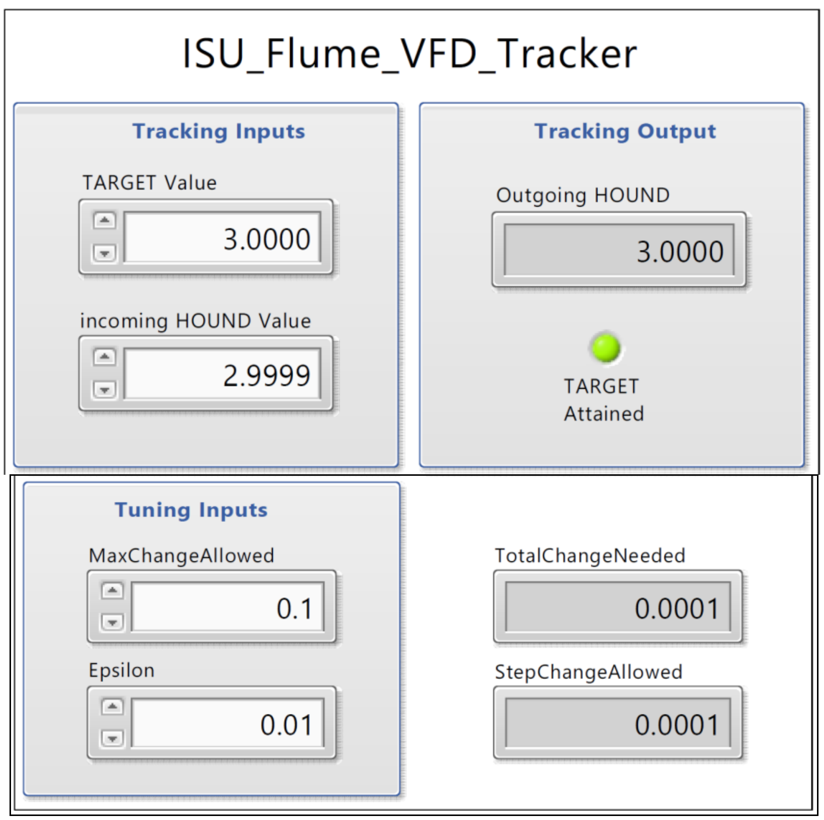


Figure B - 28. ISU_Flume_VFD_Tracker.vi main interface

B.3.11 ISU_Flume_Error_States.vi

Several significant error states are observed during flume operations. There are minimum values for each sump and the test section to ensure that an alarm is raised if the sumps get too low or water is draining from the test section due to a leak or other incident. In order to distinguish between low flow in the test section at start-up versus low flow later in a run there is a minimum run time before this alarm is raised. The input and output variables are listed in Figure B - 29 and Figure B - 30 shows the primary user interface for this sub-VI.

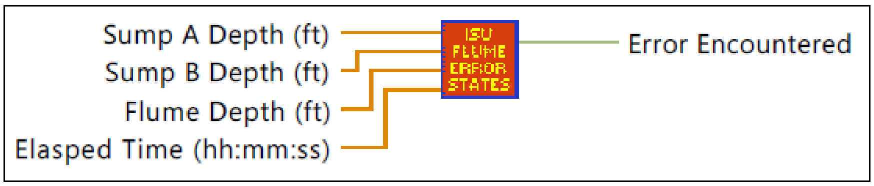


Figure B - 29. ISU_Flume_Error_States.vi input and out variables

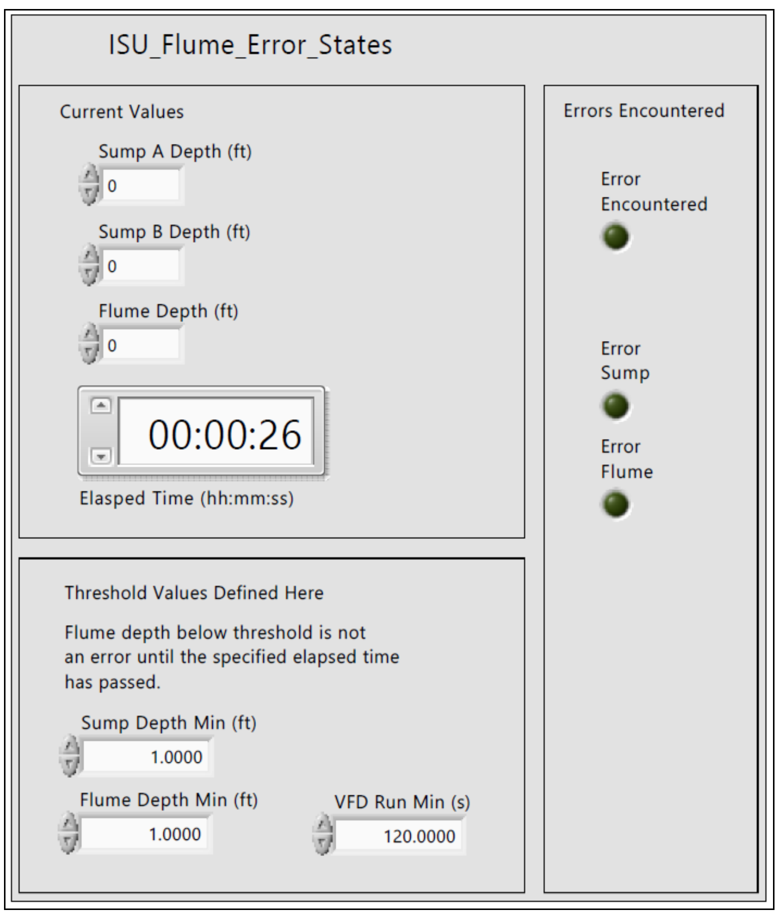


Figure B - 30. ISU_Flume_Error_States.vi main user interface

B.3.12 ISU_Flume_Flow_Stats.vi

This routine computes several flow statistics at each iteration for display on the main panel. The input and output variables are listed in Figure B - 31 and Figure B - 32 shows the primary user interface for this sub-VI.

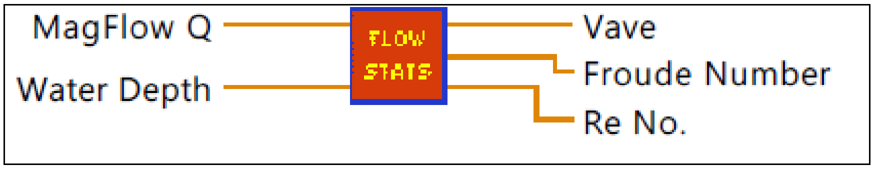


Figure B - 31. ISU_Flume_Flow_Stats.vi input and output variables

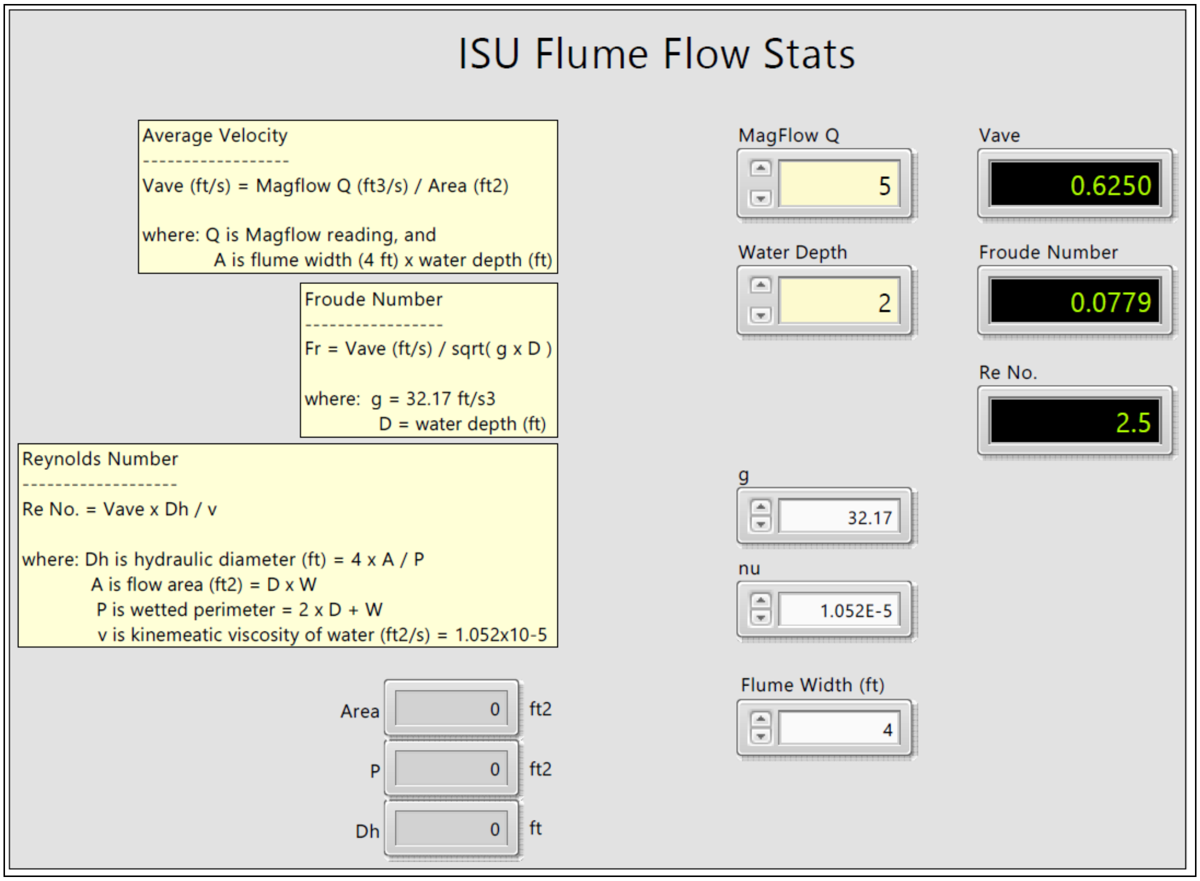


Figure B - 32. ISU_Flume_Flow_Stats.vi main user interface

B.4 Tilting/Slope Control Program Features and Details

B.4.1 ISU_Flume_jack_control_v1.vi

This is a top-level routine and runs independently of the main VI. This VI cannot be run while the main VI is running, as described previously. Figure B - 33 shows the primary user interface.

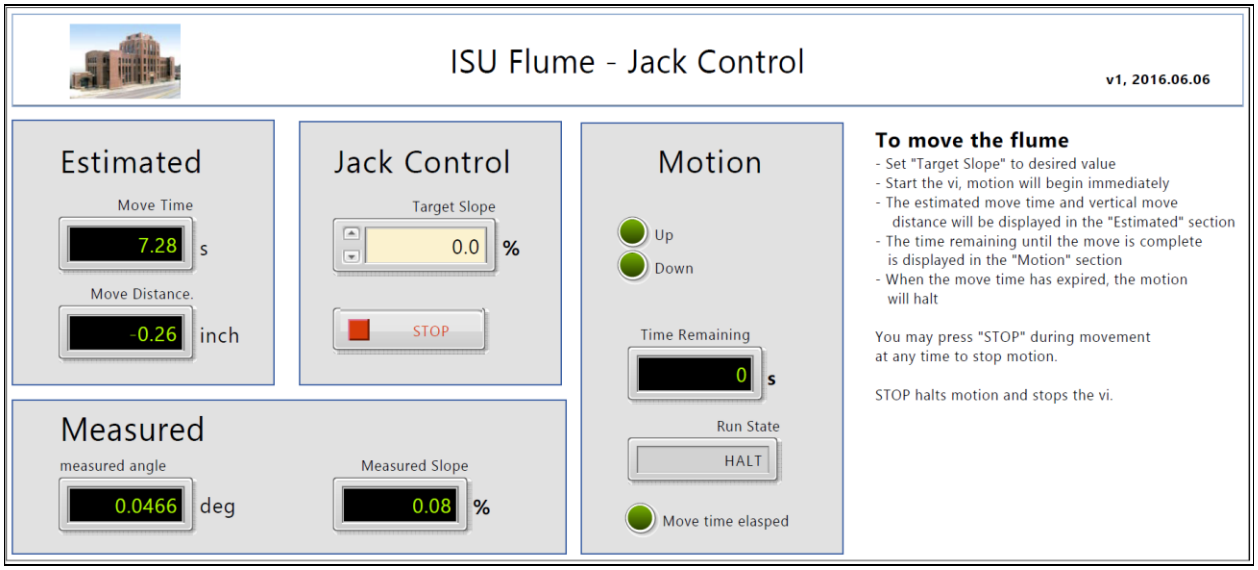


Figure B - 33. ISU_Flume_jack_control_v1.vi main user interface

B.4.2 ISU_Flume_write_DO.vi

This routine is used to implement the jack motion. The Boolean logic and resulting motion is explained on the front panel. The input and output variables are listed in Figure B - 34 and Figure B - 35 shows the primary user interface for this sub-VI.

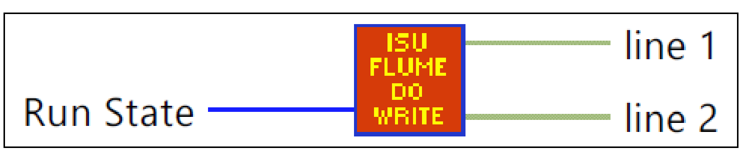


Figure B - 34. ISU_Flume_write_DO.vi input and output variables

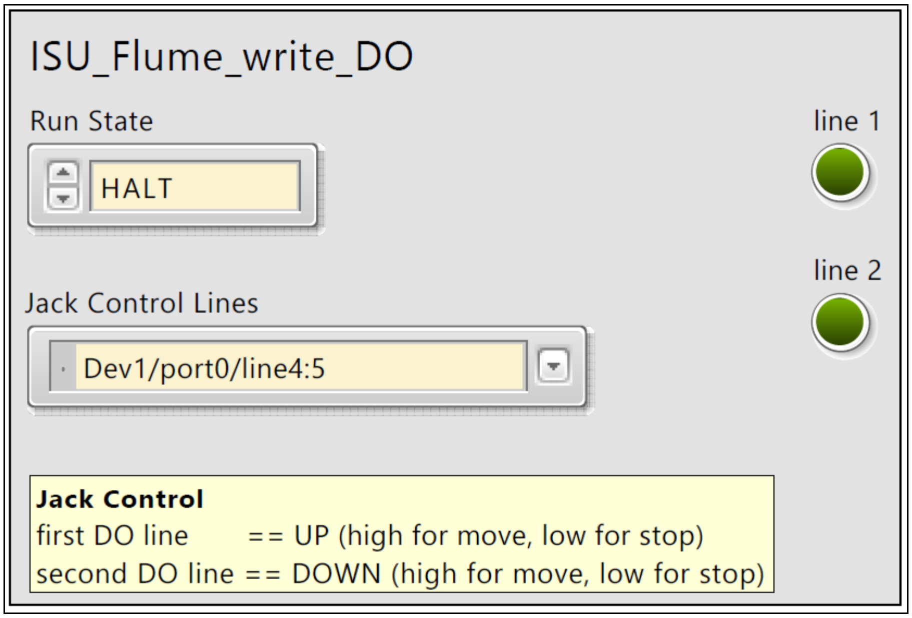


Figure B - 35. ISU_Flume_write_DO.vi main user interface

B.4.3 ISU_Flume_get_current_slope.vi

This routine reads the digital protractor are displays the measured angle and resulting slope. The input and output variables are listed in Figure B - 36 and Figure B - 37 shows the primary user interface for this sub-VI.

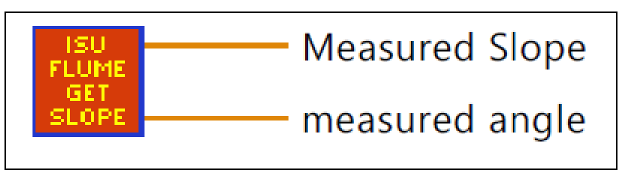


Figure B - 36. ISU_Flume_get_current_slope.vi input and output variables

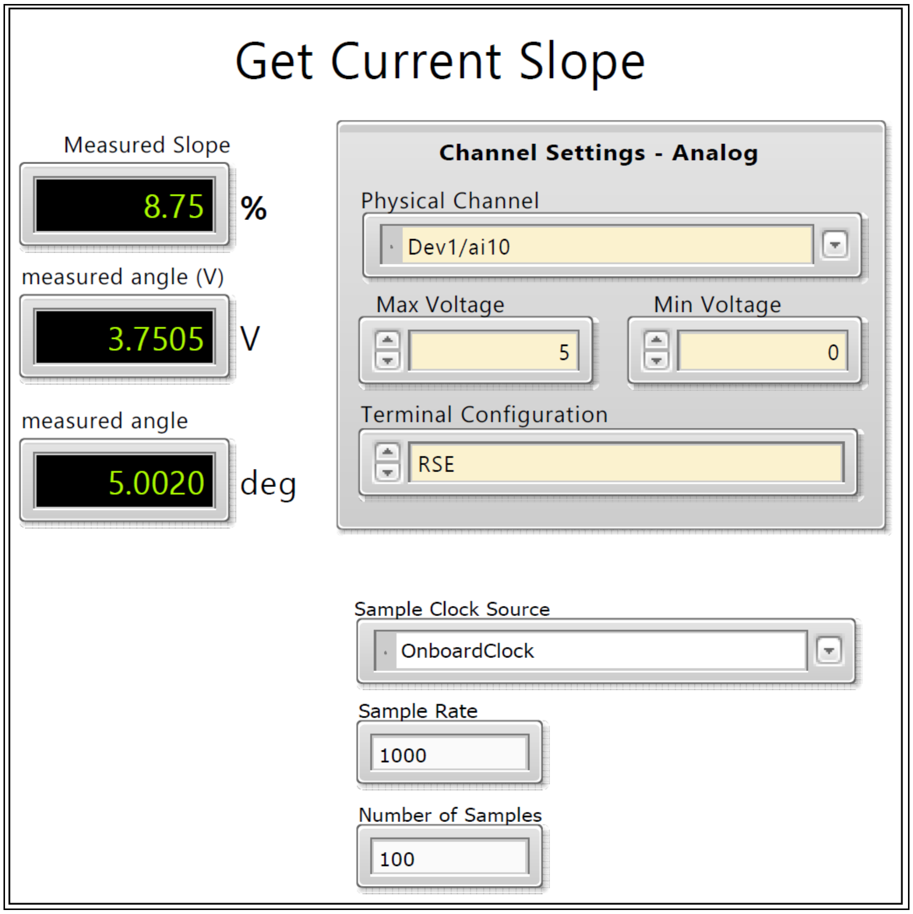


Figure B - 37. ISU_Flume_get_current_slope.vi main user interface

B.4.4 ISU_Flume_jack_parameters.vi

This sub-vi takes the desired state of the jack and references it to the current state to determine how long and how far to move the jack. The jack calibration is defined here in terms of % slope relative displacement of the jack. The input and output variables are listed in Figure B - 38 and Figure B - 39 shows the primary user interface for this sub-VI.

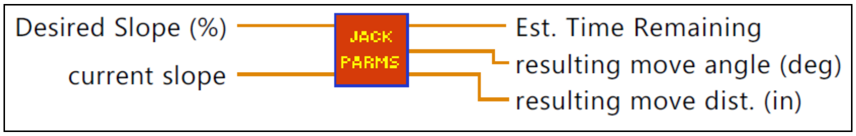


Figure B - 38. ISU_Flume_jack_parameters.vi input and output variables

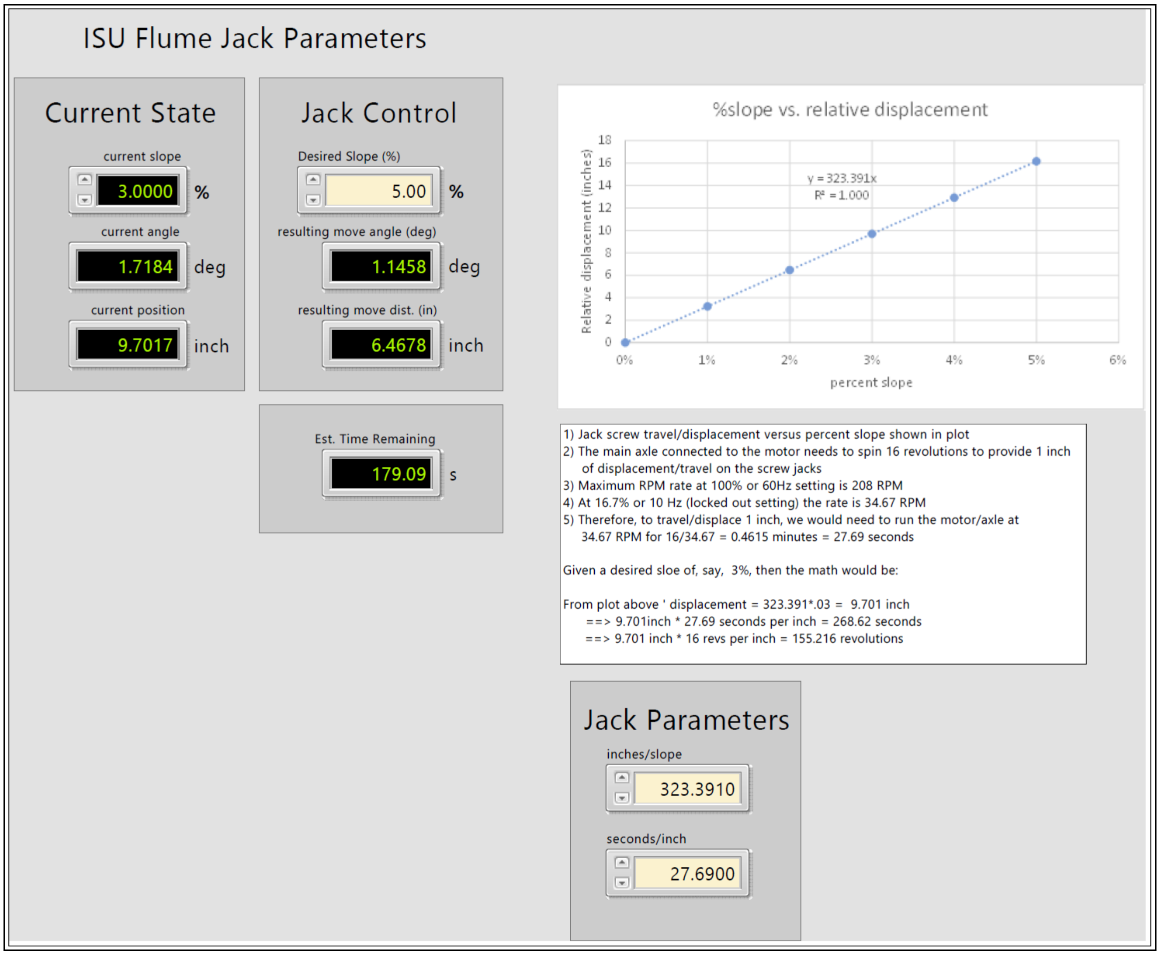


Figure B - 39. ISU_Flume_jack_parameters.vi main user interface

B.5 Operational and Safety Features

B.5.1 Manual and Flow Tracking Modes of Operation

In order to maintain a smooth transition between the manual and Flow Tracking control modes and hence eliminate large step changes in desired VFD speeds, the current state of operation in one mode is translated to the equivalent state in the target mode. That is to say, when moving from manual/speed control to Flow Tracking control the reported flow observed in the manual state is set as the first value in the tracking state. Similarly, when moving from tracking to manual control, the observed VFD value while in tracking is made to be the value for the beginning of the manual operation.

B.5.2 VFD/Pump Ramp-up and Ramp-down

There are two control systems covering the VFD start-up and shut-down. One is a pre-programmed set of ramps in the firmware of the VFD controller itself and the second is in the LabVIEW program. The VI limits the rate of change of any VFD state to 1% of full scale. This is to say that if the VFD is operating at 42% then the next commanded VFD state would either be to 41% or 43% in the next cycle. This keeps the VFD in a safe mode and prevents any large or sudden changes in speed. The firmware is pre-programmed to serve as a backup in case of computer failure or other incident. If a sudden change in VFD state is detected (e.g. loss of power to the computer) the VFD will ramp down following a safe curve. Similarly, if a sudden increase in VFD state is commanded (unforeseen failure of the computer code) the ramp up will be follow a safe curve.

APPENDIX C: INSTRUMENT CALIBRATIONS

C. INSTRUMENT CALIBRATIONS

C.1 General Calibration Procedure

Calibration of any electronic instrument included in this design requires the same basic concept. That is, provide a designated state/condition for the instrument (i.e. open/closed, high/low, etc.) and measure it's corresponding electrical response (i.e. voltage). All instruments included behave in a linear fashion and therefore require only two valid points to be calibrated. However, it is wise to cover the full range of response from the instrument when doing so, or at least above and below the range of expected operation (bracketing).

The provided LabVIEW routine "i_Aquire.vi" provides a simple means for instrument calibration. The program allows the user to interrogate the input channel of interest and provides raw output signals (i.e. voltages).

An Excel spreadsheet containing all calibrations "Instrument Calibrations 5-26-16.xls" has been provided.

C.1.1 Magflow meter calibration

As programmed upon installation, the magflow meter is able to measure flows up to 10,000 gpm. 0 – 5 volts corresponds with 0 – 10,000 gpm per factory calibration settings. In this case, however, the resident voltage while zero flow was occurring was slightly above zero. Therefore, the actual output voltage with no flow of 0.00276 volts was plotted. The calibration plot for the magflow meter is included below in Figure C - 1.

Q (gpm)	Q (cfs)	I (mA)	V
0.0	0.0	0.011	0.00276
10000.0	22.3	20.0	5.0

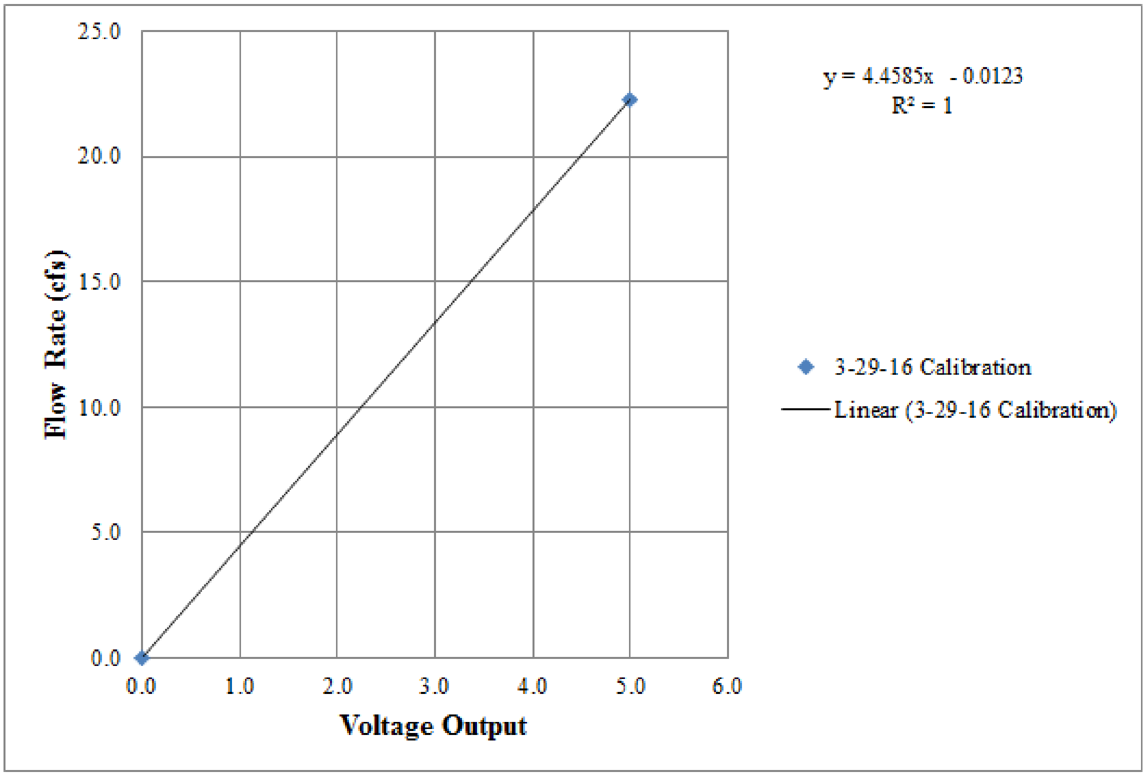


Figure C - 1. Magflow meter calibration data and plot

C.1.2 Ultrasonic level sensor calbirations

Ultrasonic level sensor calibrations are internal to the instrument. The sensors are set to output 0 to 5 volts over the desired range distance measurements. As installed, the ultrasonic sensor in the flume test section was set to output 0 – 5 volts over the range of 0.33 feet to 3.0 feet. The sensors in the sumps were set to output 0 – 5 volts over the range of 1 feet to 15 feet. Calibration plots are provided in Figure C - 2 through Figure C - 4.

volts	distance (ft)
0	0.333
5	3

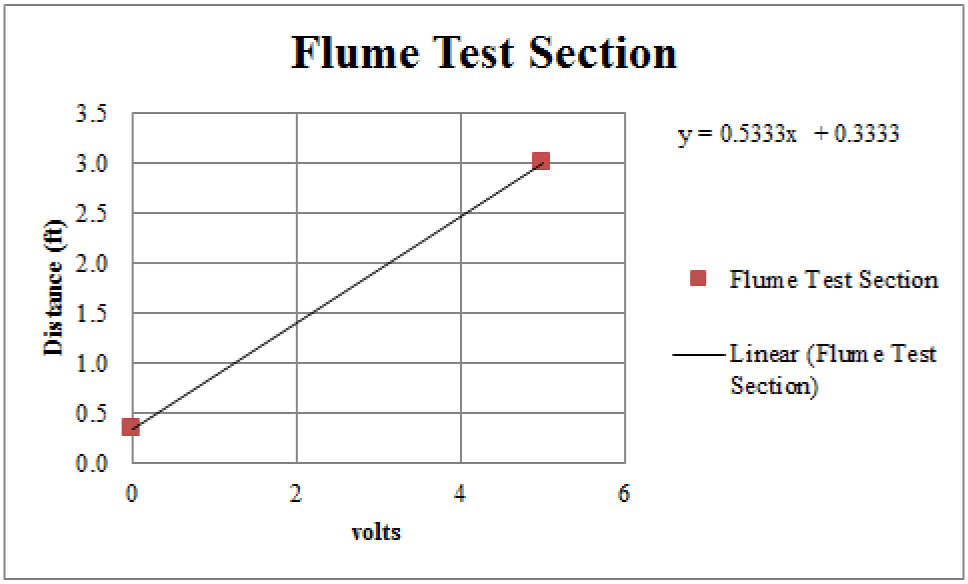


Figure C - 2. Flume test section ultrasonic level sensor calibration

volts	distance (ft)
0	1
5	15

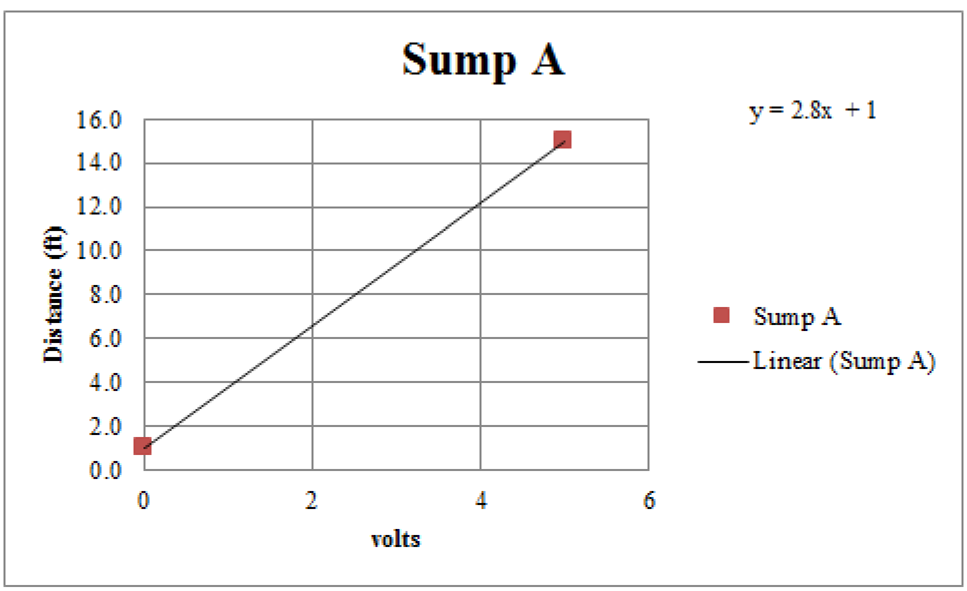


Figure C - 3. Sump A ultrasonic level sensor calibration

volts	distance (ft)
0	1
5	15

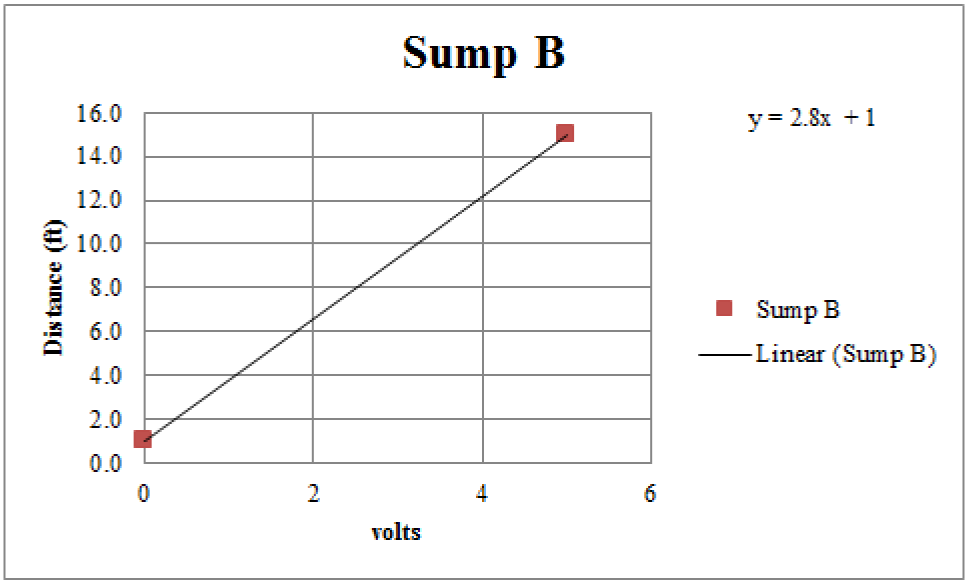


Figure C - 4. Sump B ultrasonic level sensor calibration

C.1.3 Actuated valve calibrations

The actuated valves were calibrated as installed at ISU by setting each valve to fully open and fully closed positions and recording their respective output voltages using i_Acquire.vi. Calibrations for the three actuated valves are provided in Figure C - 5 through Figure C - 7.

Volts	% Open
4.86	100
0.98	0

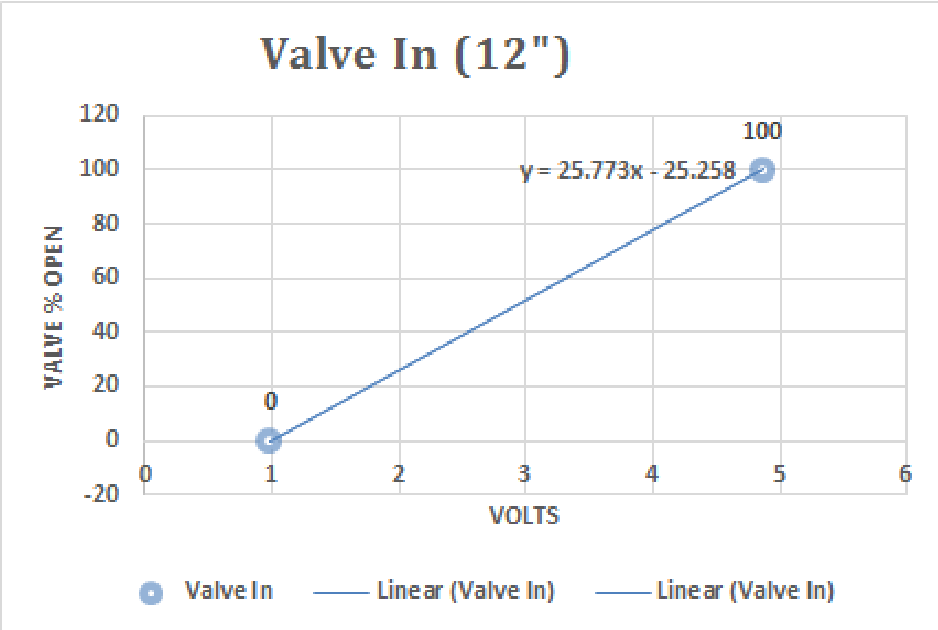


Figure C - 5. 12-inch valve calibration

Volts	% Open
5.11	100
1.06	0

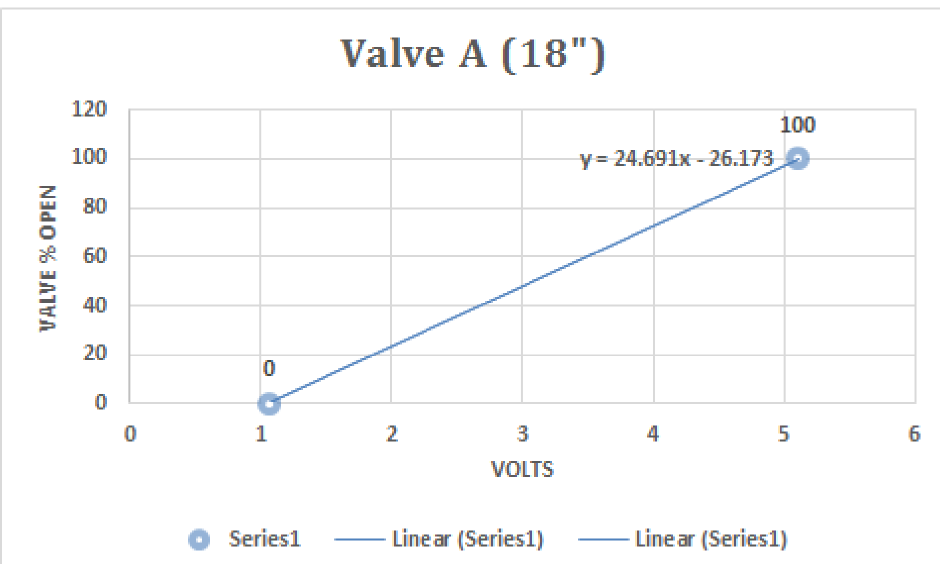


Figure C - 6. 18-inch (Sump A) valve calibration

Volts	% Open
4.94	100
1.00	0

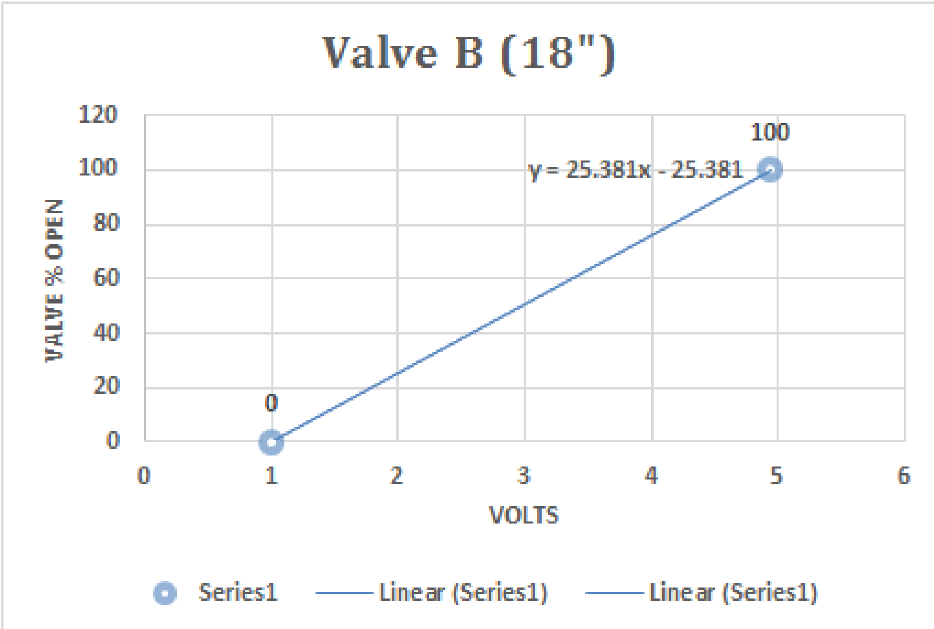


Figure C - 7. 18-inch (Sump B) valve calibration

C.1.4 Inclinometer calibration

The inclinometer was calibrated as installed at ISU by setting the flume at various slopes ranging from 0% to just above 5%. The angle as measured by the inclinometer was taken from the vendor-supplied software. The corresponding output voltages were measured and recorded using i_Acquire.vi. The resulting calibration plot is provided in Figure C - 8.

volts	angle (deg)
2.511	0.000
2.763	1.007
2.958	1.788
3.231	2.874

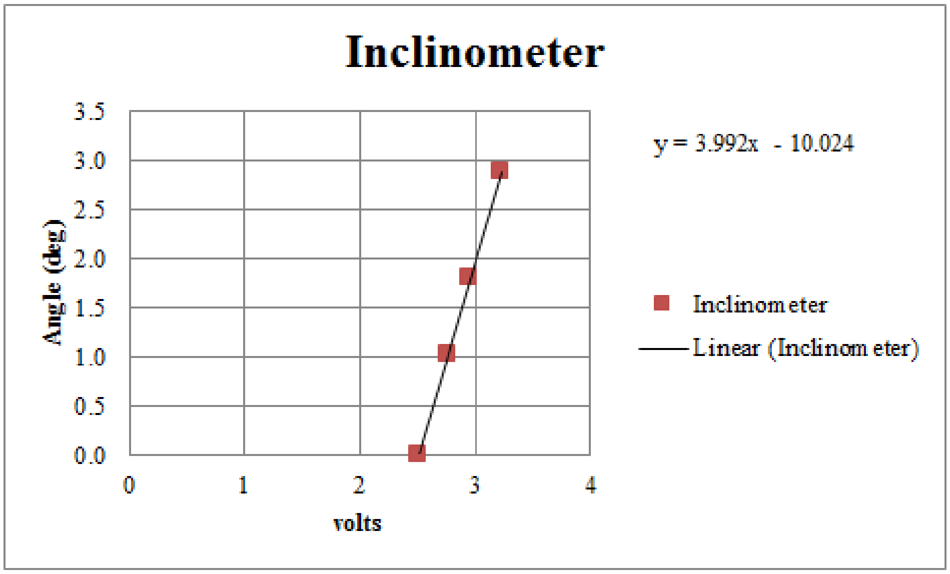


Figure C - 8. Inclinometer calibration

C.1.5 Orifice flow meter calibration

The 12-inch by 10.5-inch orifice flow meter was calibrated at Utah State University using by measuring differential pressures across the meter and plotting against weigh-tank measured volumetric flow rates. The resulting calibration data and plot are provided in Figure C - 9. The slope of the line in the calibration plot is the coefficient of discharge for the orifice meter. The flow rate in cubic feet per second (cfs) is calculated with the following equation:

$$\mathbf{Q = C_d \Delta H^{1/2}} \text{ --> Cd = slope of calibration plot (4.970)}$$

Where ΔH is measured in feet.

ΔH (inch)	Q (gpm)	$\Delta H^{1/2}$ ($ft^{1/2}$)	Q (cfs)
0	0	0	0
0.48	465.5	0.200	1.04
1.83	898.0	0.391	2.00
4.63	1407.1	0.621	3.14
4.65	1404.2	0.622	3.13
8.41	1875.9	0.837	4.18
13.05	2333.8	1.043	5.20
13.20	2346.8	1.049	5.23
19.09	2812.8	1.261	6.27
26.30	3300.1	1.480	7.35
33.60	3730.1	1.673	8.31
42.84	4203.9	1.889	9.37
43.22	4219.7	1.898	9.40
53.40	4703.6	2.110	10.48

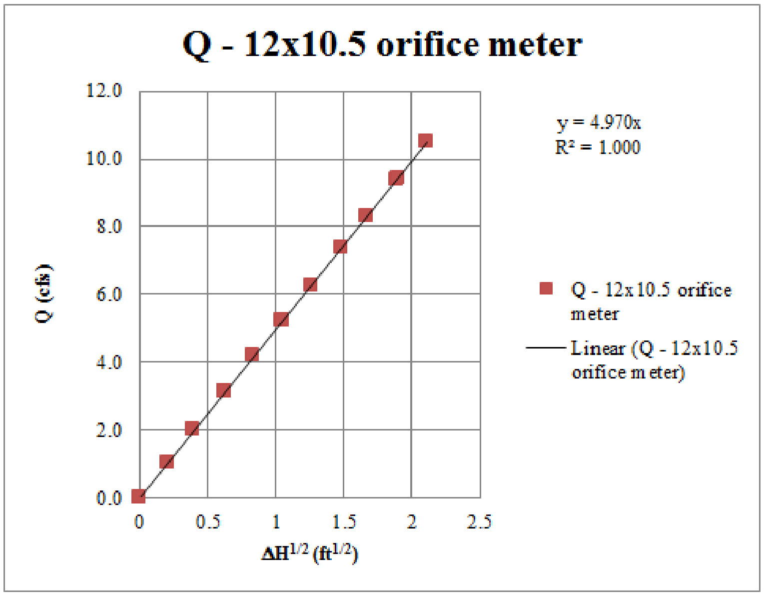


Figure C - 9. Orifice flow meter calibration

APPENDIX D: FLUME MAINTENANCE

D. ISU FLUME MAINTENANCE INSTRUCTIONS

Failure to follow the recommended maintenance guidelines provided in this document and referenced documents voids all IIHR responsibility. IIHR is providing these maintenance instructions as suggested guidelines and in no way implies any type of warranty on the materials, products, or performance of the flume and its components.

Any questions or concerns regarding maintenance or repair advisement can be directed to the IIHR Shop Manager Brandon Barquist – (319) 984-3273, brandon-barquist@uiowa.edu

D.1 <u>Lubrication for Mechanical Components</u>

D.1.1 Pump

- In general, the pump is a fairly maintenance free device in a lab situation, given that the pump is used infrequently compared to an industrial setting of constant operation. However, preventative maintenance should not be neglected.
- The pump consists of two components: an electric motor and pump assembly. These were provided by two different manufacturers.
- The pump has a stuffing box that receives packing glands. These glands should be replaced every 2000 hours of operation.
- The pump has a grease line near the visible portion of the shaft that should receive 2-3 shots of grease every 3-6 months, depending on use.
- The electric motor has an oil reservoir near the top of the motor. The type of fluid is specified on the motor along with the date of installation. Should that note somehow be removed, the required fluid is IS0 32 gear oil.
- The motor has a grease line and near the bottom of the motor frame that should also receive 2-3 shots of grease every 3-6 months, depending on use. See the manual listed below page 24 for a schematic.
- Service manuals:
  http://apps.motorboss.com/Manuals/in509-1d.pdf
  http://www.hydroflopumps.com/downloads/HydrofloFiles/OEMManual_VerticalTurbine_2012.pdf

D.1.2 Gearmotor

- NORD helical-worm reducers are shipped from the factory with a pre-determined oil fill level in accordance to the specified reducer size and mounting position. NORD helical worm gear reducers are filled with ISO VG 680 synthetic-hydrocarbon/polyalphaolefin (SHC/PAO) worm gear oil.

- Oil should be replaced every 20,000 hours or every 4 years of use.
- For important information regarding installation, operation and maintenance refer to Nord Drive Systems Publication U10770 referencing Part No. SK-92672-132S/4

D.1.3 Mechanical Screw Actuators

- Grease the assemblies using the recommended lubricant
- Lubricate annually or monthly depending on frequency of use. Pump grease until old grease emerges from the top of the housing. Then run the jacks up and down to insure the entire working area of the screw is lubricated.
- NOTE: Mechanical screws should never be run dry. Inspect frequently at regular intervals to be certain that a lubrication film is present.
    - Service manual:

http://www.nookindustries.com/Content/media/MSJ_Booklet_web.pdf

D.1.4 Tailgate Winch

- Grease the worm gear with lithium grease.
- Lubricate annually or monthly depending on frequency of use.
- Run tailgate up and down while flowing water to insure grease is applied to the spool gear as well.

D.2 Repairs, Parts, or Replacement

- Product: Pump: Hydroflo H14PMF and HF12
- Manufacturer: Hydroflo Pumps
- Manufacturer Contact: *www.hydroflopumps.com*; 308-398-0920
- Vendor: Pumping Solutions
- Vendor Contact: 708-272-1800

- Product: Gearmotor: SK 92672-132S/4
- Manufacturer: Nord Drive Systems
- Manufacturer Contact: *www.nord.com*; (888)314-6673
- Vendor: Van Meter Inc.
- Vendor Contact: 319-339-1816

- Product: Screw Actuators: 15-MSJ-U
- Manufacturer: Nook Industries
- Manufacturer Contact: *www.Nookindustries.com*; (800)321-7800
- Vendor: Nook Industries (direct purchase)

- Product: Tailgate Winch
- Vendor: McMaster Carr
- Item: *www.mcmaster.com/#3205t42/=14r76oc*

D.3 Cleaning

- **Interior**

1) When cleaning the interior, always start by rinsing with garden hose and soft bristled brush.
2) Remove as much sand and abrasive material as possible before scrubbing or rubbing the glass.
3) Any further scrubbing should be done with non-abrasive tools.
4) De-calcifying cleaners can be used for lime scale, but should be used with caution, as a spot treatment only, and under the use and concentration of manufacturer's recommendations only.

- **Glass**

1) Glass can be cleaned with a non-abrasive cloth and a solution intended specifically for glass.
2) Clean glass according to manufacturer’s recommendations.
3) Permanent marker or other stubborn marks can be removed with a generic denatured alcohol.
4) Sprayway Glass Cleaner is suggested for use

- **Exterior**

1) Dust and debris can be removed using water and mild detergent or Windex.
2) Avoid using solvents such as denatured alcohol and lacquer thinner that may remove or discolor the paint finish.
3) Start with mild cleaners and progress to more aggressive cleaners as needed.

D.4 Water Leakage

As a note, flumes will tend to leak when left dried out for periods of 6 months or longer. It is best to flow water through the flume on at least a monthly basis to prevent seals from drying and shrinking. Often times, small leaks will self-heal after 2-3 days of wet conditions.

- In the event that a leak occurs in the system, the leak should be located and the entire basin drained and dried. With an appropriate tool, thoroughly remove the silicone one foot in either direction of the leak. Use caution not to scratch the glass or injure oneself when using scrapers and knives.
- Once the silicone is completely removed, all dirt, grease, and/or additional moisture should be removed and the area wiped clean with denatured alcohol. Allow area to dry thoroughly.
- Apply painters tape along edges with a 3/4" allowance from where the silicone will be applied in order to maintain a neat and clean appearance.
- Apply silicone according to manufacturer's recommendations (use plenty). Wipe excess silicone away with a non-abrasive scraper or coving tool made of rubber or a soft plastic.
- Remove painter's tape.
- Let silicone set according to manufacturer's recommendations (usually 24 hours).
- Dow Corning 733 Black silicone adhesive is recommended for use

D.5 Paint

- In the event that the painted areas of the flume must be touched-up due to chips, rust marks, or other cause, a non-water soluble paint must be applied.
- Clean the area with denatured alcohol and allow area to dry thoroughly.
- Apply paint according to manufacturer's recommendations.
- The specific paints used on the flume and suggested for touch-ups are listed below:
  - Aquapon 35 two-component epoxy paint
    - Safety Red: 95-10 (A) Curing Agent: 95-98 (B)
    - Safety Yellow: 95-13 (A) Curing Agent: 95-98 (B)
      - Manufacturer: PPG Architectural Finishes, Inc.
        - Nearest Supplier: PPG Paint Store, 1220 8th St., West Des Moines, IA 50265, (515) 223-5237

- Supermarine – Marine Paint
  - SM-266 Ironside Urethane – Black MT
    - http://supermarinepaint.com/marinepaint/pc/SM-266-Ironside-Urethane-Gallon-p7.htm