# CLOSED-LOOP CONTROL FOR HYDRAULIC LABORATORY OPERATION

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## Abstract

The implementation of Closed-Loop Feedback Control in the Bureau of Reclamation's Hydraulic Laboratory flow delivery system has provided an important new modeling tool for the research engineer. The engineer now has the option of using closed-loop control, supervisory control, or traditional manual operation of physical models. The main laboratory flow delivery system provides automatic flow control using a programmable PID (proportional, integral, and derivative) algorithm.

## Introduction

The Bureau of Reclamation Hydraulics Laboratory flow control system was installed in 1947. The laboratory is nearly symmetric about each axis. The laboratory area has a large reservoir sump along the longitudinal axis which provides water to four 12-inch centrifugal pumps, two located at each end of the laboratory (figure 1). All pumps tee into a 12-inch diameter distribution pipe that forms a rectangular loop around the periphery of the laboratory. The peripheral pipe system can be sectioned off to isolate flow to individual models by closing in-line hydraulically actuated gate valves. Each quadrant of the laboratory contains a bank of venturi meters for flow measurement. The flow delivery system was designed to allow concurrent operation of up to four models in the laboratory using the fixed equipment. Additional models can be operated using portable pumps.

Operation prior to this time has been manual. The desired flow was set using a manometer and venturi meter to measure the flow and a hydraulically (water) actuated valve to adjust the flow. A need to rehabilitate the laboratory's flow control system was coupled with current technology to improve testing efficiency. Rehabilitating the flow control system was divided into two stages to allow half of the laboratory to operate during construction of the other half. Installation of the first stage of the new control system was completed in 1987.

During the design, members of the Hydraulics Branch were asked what features they desired in a new control system. These features were

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then compiled and reviewed by a team comprised of several members of the branch. The following areas were identified as the weak points of the existing manual control system:

1. With the laboratory's common sump design, the discharge delivered to a model was effected by other models operating concurrently. Filling or emptying a large model changes the sump reservoir level, i.e., the pump suction head, thus altering the discharge for all other models operating.

2. Model discharge could only be read from manometers located on the main control panels at each end of the laboratory.

3. Operation of the hydraulic valve actuators were subject to secondary effects such as feed line water quality, feed line water pressure, and the operation of feed line regulating valves.

4. Establishing a set discharge or pressure head in a model required the operator to estimate the control valve movement needed to adjust the discharge. The resulting iterative process of manually positioning the control valve was time intensive.

The last point identified is inherent in manual control systems. To minimize manual adjustments to the system, automated process control was needed.

## System Specifications

The specifications for the new flow control system were designed to meet the following objectives:

1. Replace hydraulically actuated venturi select gate valves with electric motor actuated valves.

2. Provide a resident closed loop control system to allow manual or automatic operation of the flow delivery system. The control system must be programmable and capable of delivering constant or time variant flows to models.

3. Provide a control board for the closed loop control system with valve controls, motor controls and a complete system schematic with status indication of all valves and motors.

4. Provide independent control and monitoring of flow for each quadrant of the laboratory via portable remote control terminals. The remote terminals must enable flow control from a model site.

## Control Algorithm

A proportional, integral, derivative (PID) algorithm was selected for the automatic control loops. The PID algorithm is common in off-the-self type controllers used for industrial process control applications. Astrom and Wittenmark define the standard PID algorithm in Laplace form as:

$$U(s) = K\,(1 + 1\,/T_I s + T_d s/(1 + T_d s))E(s)$$

where;

$U(s)$ = Laplace transform of the output signal
$E(s)$ = Laplace transform of the error signal
$K$ = proportional gain
$T_I$ = integral (or reset) time
$T_d$ = derivative time

The proportional term, $K*E(s)$, varies directly with the error. It results in an immediate correction to the valve. The integral term $K*E(s)/T_I s$ accumulates error over time causing further gate correction to restore the desired flow and null the proportional term. An anti-windup limit can be added to prevent integral accumulation beyond full open. The derivative term, $K(T_d s/(1+T_d s)E(s)$, responds to the rate of change in error. The derivative term can provide faster response to changes in flow. However, in control applications where flow patterns may change this term can lead to instability if not adjusted properly. The PID was initially programmed in a PI mode. The derivative term was deleted. The derivative control term may be incorporated into the algorithm in the future if required.

## Flow Control System

The final system configuration selected used individual off-the-shelf PID controllers for each valve and venturi pair. The controllers were programmed with an initial PI control algorithm designed for the laboratory system. Status controllers were used to monitor the status of pumps and isolation valves in the flow delivery loop. IBM compatible computers were chosen to be used as intelligent remote control terminals. Onspec process control software was used to provide a user-friendly interface between the remote terminals and the PID controllers. At the remote terminals the user has a full laboratory schematic with system status and flow control capability.

Each controller has an EPROM (erasable programmable read only memory) containing the control logic, settings for control parameters, and scaling of analog inputs and outputs. Each controller has the following external inputs and outputs:

4 analog inputs
2 analog outputs
3 contact inputs
3 digital outputs
1 pair valve open/close outputs

Two analog signal inputs and the valve open/close outputs are required for the control loop. The remainder are available for other analog and logic functions such as alarms, valve indication, or recorders. Switches for logic inputs are also provided. These can be used to select alternate control configurations or select different input signals.

## Flow Control Logic

The logic was designed to permit flow control based on constant discharge, constant pressure, or a time dependent set-point (figure 2). The control system was designed to deliver a constant discharge to any model as the routine function. Using discharge control, the feedback signal into the PI algorithm comes from the venturi meters which are fixed equipment. Differential pressure transducers were teed into the existing mercury manometers located in the control board. Plumbing a mercury manometer in parallel with each transducer has proven to provide good mechanical damping for the system. The manometer reduces high frequency pressure fluctuations fed from the venturi meters. Limiting the feedback control loop to fixed laboratory equipment allowed discharge control to be independent of the models. To implement constant pressure control in a model, such as maintaining a constant water elevation, requires direct feedback from the model. A remote transducer must be installed in the model to provide a pressure input signal to the controller. Flow or pressure control can also be implemented as a time dependent control scheme. For example, to model a flow hydrograph in a physical model, the reservoir stage would vary as a function of scaled time. This can be done by programming the controller to control the discharge to the model as a function of the time dependent reservoir level in the model. A table containing discharge or pressure set-points versus time must be entered into the controller as the data base for the variable set-point control.

## Conclusions

Incorporating Closed-Loop Feedback Control as a standard feature in the laboratory for flow control has improved standard modeling practices and opened up new avenues for physical modeling. The researcher can now utilize the automated flow control to regulate discharge or pressure as needed while obtaining model data over a range of other model parameters. Automated flow control of the laboratory has reduced the time required for testing of physical models and in some cases has improved the quality of the model data through a reduction in the level of data interpolation needed.

## References

1. Astrom, K.J., and Wittenmark B., "Computer-Controlled Systems, Theory and Design," Prentice-Hall, 1984, pp. 180-189.

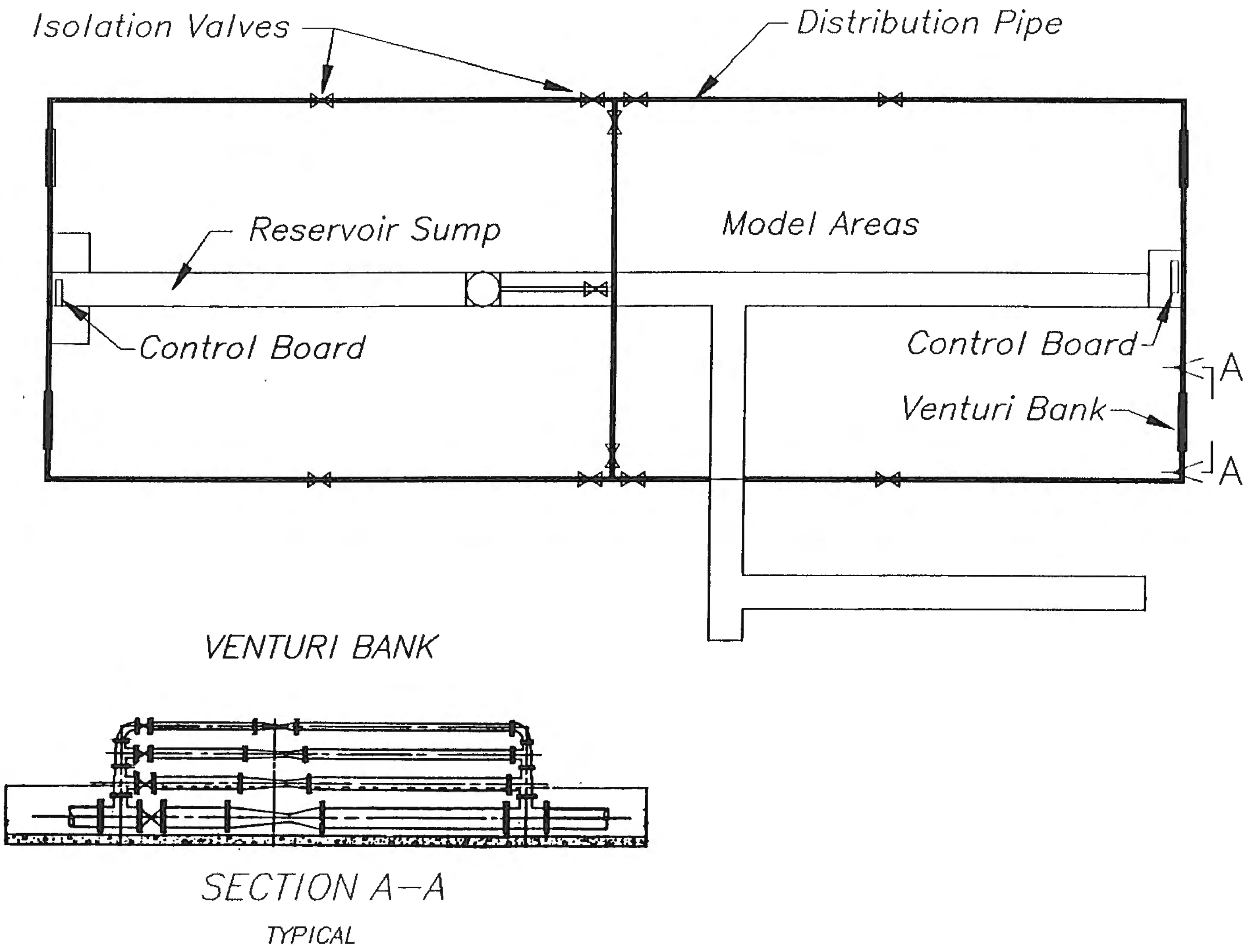

Figure 1. Hydraulics Laboratory

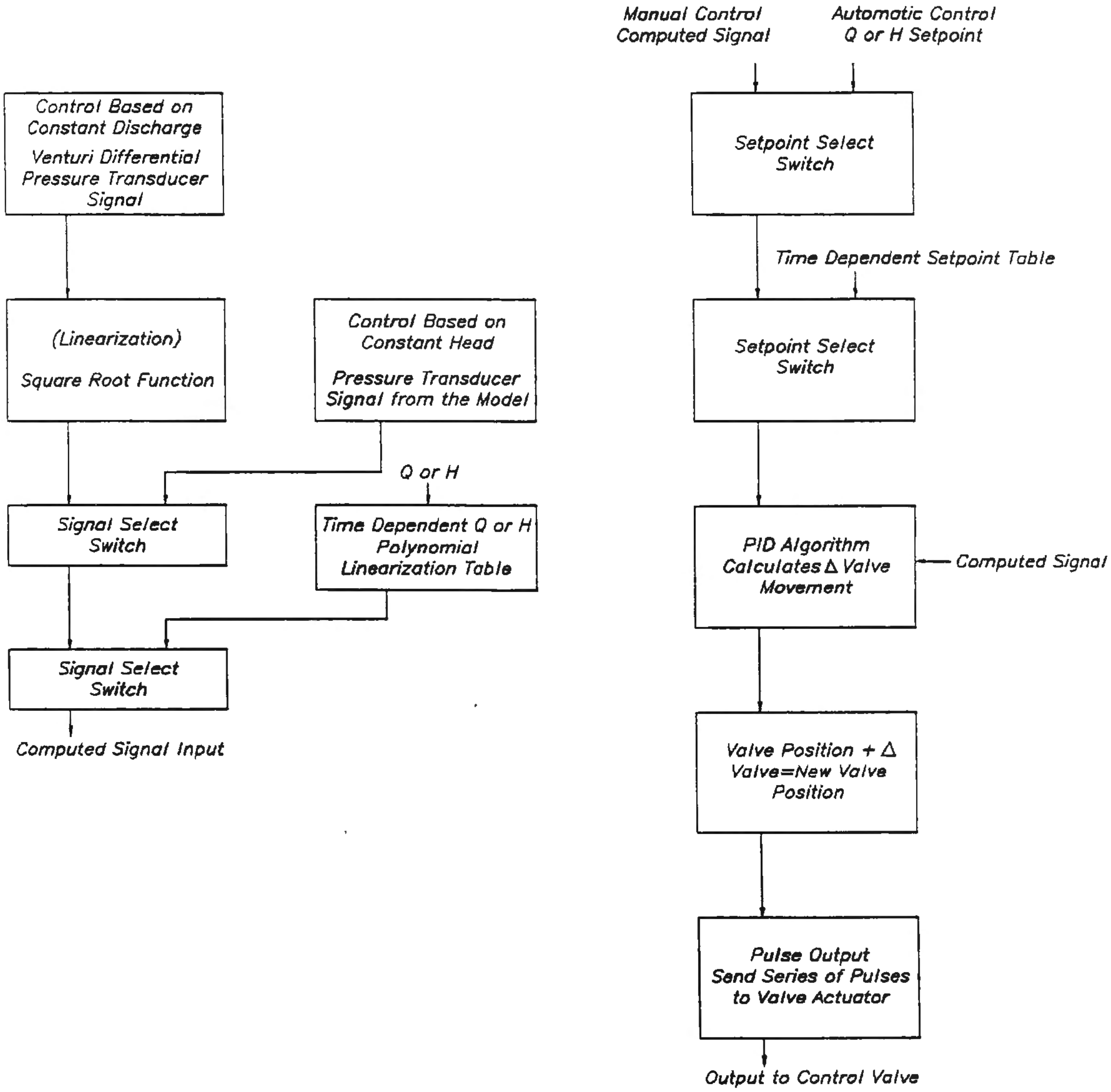

Figure 2. Flow Control Logic