Automated shower/faucet control system

Adam Wirtz

Follow this and additional works at: https://huskiecommons.lib.niu.edu/studentengagement-honorscapstones

Recommended Citation

This Dissertation/Thesis is brought to you for free and open access by the Undergraduate Research & Artistry at Huskie Commons. It has been accepted for inclusion in Honors Capstones by an authorized administrator of Huskie Commons. For more information, please contact jschumacher@niu.edu.
Automated Shower/Faucet Control System

A Thesis Submitted to the
University Honors Program
In Partial Fulfillment of the
Requirements of the Baccalaureate Degree
With Upper Division Honors
Department of
Mechanical Engineering

By
Adam Wirtz
DeKalb, Illinois
Capstone Title: Automated Shower/Faucet Control System

Student Name: Adam Wirtz

Faculty Supervisor: Shin Min Song

Faculty Approval Signature: [Signature]

Department of Mechanical Engineering

Date: 5/7/06
May 13th 2006

Honors Thesis Abstract
Thesis Submission Form

Author: Adam Wirtz

Thesis Title: Automated Shower/Faucet Control System

Advisor: Shin Min Song Advisor’s Dept: Mechanical Engineering

Discipline: Mechanical Engineering Year: 2006

Page Length: 63

Bibliography: Page 47

Illustrated: yes

Published: no

Copies Available: Hard Copy

Abstract:

The purpose of this project is to develop an automatically temperature and flow controlled faucet/shower system. The system should allow a user to pre-select a temperature for their comfort. The system should automatically maintain the desired temperature without further input. The system should also correct for any sudden drops in temperature or pressure in the piping system. The system should also be able to be integrated into any household piping system.

Some added benefits that are to be obtained are energy saving benefits. The device will be able to be put on a timer in order to conserve water usage. The conserved hot water will also save energy that would be used to heat more water. Also the device can have a safety feature to prevent children from accidentally being burned by hot water.

There are several key components of the product. There is the computer for inputting and logic calculation. The servo valves are actually what controls the flow of water. The thermocouple must be used to monitor the temperature of the water. The flow rate of the water must also be monitored to meet the desired objective of total temperature and some flow control.

This device should in the end be affordable and reliable. The luxury of an automatically controlled shower should be readily accessible by the average household.
# Table of Contents

Acknowledgements  Pg. 4

Abstract  Pg. 5

Chapter 1. Introduction  Pg. 6-9

Chapter 2. Design Specifications  Pg. 10-18

Chapter 3. Thermocouple Testing  Pg. 19-23

Chapter 4: Valve Selection  Pg. 24-25

Chapter 5: Flow Measurement Design  Pg. 26-29

Chapter 6: Cover Panel Design  Pg. 30-38

Chapter 7: Electronics  Pg. 39-41

Chapter 8: Prototype Design and Assembly  Pg. 42-44

Chapter 9: Discussion and Conclusion  Pg. 45-46

References  Pg. 47

Appendix A

Appendix B

Appendix C
List of Figures

Figure 2 - 1 Decomposition of Control System  Pg. 13
Figure 2 - 2 Decision Matrix  Pg. 17
Figure 3 - 1 Thermocouple Voltage vs. Temperature  Pg. 18
Figure 3 - 2 Thermocouple Locations  Pg. 21
Figure 3 - 3 Cold to Hot Temperature Transitions  Pg. 21
Figure 3 - 4 Hot to Cold Temperature Transitions  Pg. 22
Figure 5 - 1 Photo of the Pressure Couplers in Place  Pg. 26
Figure 6 - 1 Three Dimensional Model of System Components  Pg. 30
Figure 6 - 2 Representation of the inference fit for panel/box  Pg. 31
Figure 6 - 3 Free Body Diagram of cantilever side  Pg. 32
Figure 6 - 4 Stress Panel before stiffening insert  Pg. 34
Figure 6 - 5 Final Panel Design  Pg. 35
Figure 6 - 6 Final Design to hold panel  Pg. 36
Figure 7 - 1 Digilent D2SB FPGA Development Board  Pg. 38
Figure 7 - 2 Analog to Digital Converter Circuit  Pg. 40
Figure 8 - 1 Complete prototype assembly  Pg. 42
Acknowledgements

Dr. Simon Song- Advisor for design process and product development

Dr. Pradip Majumdar- Lab View test cell and equipment assistance

Adam Dye - ANSYS assistance and troubleshooting

NIU Honors Program - Financial assistance
Abstract:

The purpose of this project is to develop an automatically temperature and flow controlled faucet/shower system. The system should allow a user to pre-select a temperature for their comfort. The system should automatically maintain the desired temperature without further input. The system should also correct for any sudden drops in temperature or pressure in the piping system. The system should also be able to be integrated into any household piping system.

Some added benefits that are to be obtained are energy saving benefits. The device will be able to be put on a timer in order to conserve water usage. The conserved hot water will also save energy that would be used to heat more water. Also the device can have a safety feature to prevent children from accidentally being burned by hot water.

There are several key components of the product. There is the computer for inputting and logic calculation. The servo valves are actually what controls the flow of water. The thermocouple must be used to monitor the temperature of the water. The flow rate of the water must also be monitored to meet the desired objective of total temperature and some flow control.

This device should in the end be affordable and reliable. The luxury of an automatically controlled shower should be readily accessible by the average household.
Chapter 1: Introduction

I. Background

Since the ancient Greeks invented the shower in the early second century B.C. there have not been any groundbreaking changes to the shower, with the exception of using pre-heated water. The project at hand is one that will further the luxury and safety of indoor plumbing with new innovations. There is a great demand in the world for better more luxurious things. This project will make taking a shower more comfortable. Sudden temperature and pressure shocks while showering are very undesirable. An automated shower/faucet system will eliminate these unwanted and dangerous shocks, and make for a more enjoyable showering experience.

Some of the problems with current showers are quite dangerous. The first serious issue is the temperature control. If someone flushes a toilet, or some other device that uses water like dishwashers or washing machines are turned on, the water will suddenly switch from warm to cold or go from warm to hot, in the middle of someone’s shower. This is something that the automated shower will be able to prevent. Not only that, but the control system will have a built in maximum temperature employed as a safety feature to prevent users from accidentally being scalded. Pressure control is the second problem that normal showers face. The pressure is dependent on the source of the water and sometimes the showerhead in use. This project does not involve water pumps or similar devices and thus relies on the household water source for pressure.

More important than luxury, safety is a chief motive for this project. According to an 8 year review of the patients admitted to the Stoke Mandeville Hospital, Aylesbury,
UK because of hot bath and shower water there has been a surprising amount of trauma and fatalities. A total of 57 patients admitted in the eight year review were injured, nine of these patients received fatal injuries. The most predominant characteristics of the reported burns were analyzed for several groups. Children were mostly under three years of age, who mostly sustained superficial burns. Eighty three percent of the adult group was over the age of sixty. In comparison to the children, the adult group received much more extensive burns that resulted in a mortality of 44% of the group. This study supports a need for the development and implementation of safer water temperature controls in people’s homes, in order to prevent these types of accidents [1].

II. Professional Components

Economics

The dynamic controlled shower would definitely sustain a high demand level in the future. As technology advances people want to have more convenience and automation. Also, the technology is already here to produce a reliable control system. The demand for water conservation and convenience will only get larger and the cost of the technology to produce the system will only get smaller creating an increasingly more appealing and cheaper product to produce.

Environmental

There are large environmental advantages to the dynamic control of the faucet or shower in the household. The water saved from having timers to regulate water flow not
only saves money but also saves clean water which will lessen the demand for clean water. This will also lessen the amount of pollutants created in filtering the water.

**Manufacturability**

The manufacturability of this product isn’t even an issue. The control system will be made of several components that already exist and are in production. The main task of the group is to create the control system and get it to function properly. The manufacturability of the system as a whole is not a problem. There will be a few parts that will have to be designed specific to this project but manufacturing should not be a problem.

**Ethics & Safety**

The ethical responsibility of this project is no too much of a burden. The only ethical responsibility of the group also relates to safety. The control system is electronically controlled so it will be the group’s responsibility to ensure that no one is injured by electrocution or by a surge of water causing burning. These are the main concerns of the group relating to this project.

**Social & Political**

The social ramification of this proposal is minimal. The product will be a convenience that people will use in the privacy of their homes. It could become an interesting comparison of lifestyles based on if a person has or does not have an automatic shower or faucet. The political impact of this invention can only be a positive. The water conservation possible with eliminating half of the waste water needed for
every household can only have a positive political impact. This is a bipartisan issue that everyone can appreciate.

**III. Team Member Contributions**

There were several engineers involved in designing this device. There were two mechanical engineers working with 3 electrical engineers. Using concurrent engineering techniques the engineers were able to handle any problems in developing the system.

**Mechanical Engineers**

The mechanical engineers contributed by designing the prototype model. They will also be in charge of selecting electrical servo valves that will be controlled by a C.P.U. The mechanical engineers were also in charge of selecting the proper temperature and pressure input devices.

**Electrical Engineers**

The electrical engineers were in charge of most of the electrical aspects of the device. They were the members that selected the F.P.G.A and other control devices. The electrical engineers also chose an adequate power source for the system. Lastly they were the members to put the F.P.G.A. programs into place.
Chapter 2: Design Specifications

Concept Generation

Introduction:

Concept generation is where the generation of the control system started. The function of existing products are defined and evaluated. Then the function and sub-functions of the new product are defined and the relationships between the functions are created. Finally, the brainstorming section created concepts of how to accomplish the functions of the product. The product is then ready for concept evaluation.

1. Understanding the Function of Existing Devices:

   Current showers function quite simply. The person or operator of the shower or faucet manually adjusts two valves controlling the hot and cold water supplies. The operator adjusts the setting until the desired temperature and or flow rate is achieved. Once the valves are set, they only change position if the user manually forces to rotate and open or close the valves. This is a simple process but it is also a highly manual process.

2. Defining Function:

   a. The first flow of energy considered is the flow of the water in the pipes.

      The cold water and hot water flow through the valve system and converge to mix and create a mass flow equal to the incoming flow but at a different temperature.
b. The second flow of energy is the thermal energy through the system. The water carries with it thermal energy that enters and is monitored and then leaves the system with the flow of water.

c. The third flow in the system is the flow of electrical currents. An AC current comes into the system and an altered voltage is outputted from the digital control.

   i. This flow of electricity also causes a flow of mechanical energy to the valves which in turn affect the mass flow and thermodynamic flow.

   ii. This flow of electricity also induces a flow of logic and information in the controller. The electrical feedback from the sensors and the valves causes a change in flow of electricity and mass flow.

d. There are also several mechanical forces in the system. There are static forces holding the controller, valves, and sensors in place. There are also forces that are dynamic and change according to the valve position and obstruction of the mass flow.

3. Using Decomposition of the Product to Understand the Function of Existing Devices:

   a. The existing shower or faucet has few components. The hot and cold water valves are two such components. Both function to transmit materials and energy. The valve needs a mechanical torque as an input and this energy or work is transmitted to the valve by the threads on the valve. The
energy flows from the users hand to the knob and then the valve threads transmit this energy to cause a change in the position of the valve. The energy ultimately reaches the material inside the piping and causes a change in pressure of the material.

b. The water input from the well or water heater is the material input and the energy from the hot water input is transmitted to the cold water. The material flow is then out of the faucet to whatever the system is supplying.

4. Determining the Overall Function of the Product:

There are several tasks that the product needs to accomplish in order to successfully function. First, the thermodynamic energy must be conserved. This means that the system should minimize any loss in heat energy from the material, water that enters the system. This is a necessary step to control the water temperature of the output with the given input. Also, the material conservation is a necessary part of the function. All of the water that enters through the valves must leave through the faucet. The combination of the two tasks are necessary to ensure that the product is functioning correctly. In addition, the product must use the electrical input into the system to alter the output characteristics of the material. There are also certain mechanical components that must hold the system in place so that only certain parts will actuate to change the output flow and energy of the material. Finally, the logic or information fed to the system from the user must be transferred through the
system and thus create the desired outcome for the material also transferring through the system. If this function is accomplished the user will know from the feel of the water leaving the system.

5. Define and Order Sub-functions:

a. The controller computer must take the information from the user and transmit that information to the controls. This sub-function is the first step toward the control of the water flow and energy. The user must input the desired settings and these settings must be relayed to the actual control of the material passing through the system.

b. A temperature sensor must also monitor and relay information back to the system. The product must monitor the temperature of the exiting water and change correctly to hold the temperature close to constant.

c. In addition to holding and monitoring the temperature of the water, the system must also monitor and attempt to control the flow rate of the water out of the system.

d. The computer and electrical circuitry is responsible for sending the commands to control the water. After the logic has been transmitted and the monitoring of the system is established, a signal must be sent to the valves to alter the position.

e. The final sub-function of the system is the valves function of actually putting a force on the water to alter the flow rate of the hot and cold water independently out of the system. This task is where the system actually interacts with the water flowing through
Functional Decomposition of the Control System

Figure 2 - 1 Decomposition of Control System

6. Brainstorming:
   a. How to input the information from the user.
      i. Analog electrical control with a variable resistance.
      ii. Computer controlled knob to set temperature and flow.
      iii. Digital display with keypad inputs.
   b. How to relay the information to the control valves.
      i. Computer output to relay boards with varying voltage outputs.
      ii. Computer output with varying current outputs
      iii. Analog circuitry system to be used with a basic control.
   c. How to monitor the temperature of the water.
i. Thermocouple placed on the output pipe after the thermodynamics
   and fluid entry lengths.

ii. Two thermocouples placed on the hot and cold water inputs of the
    system.

d. How to monitor the flow rate of the water through the system.

   i. Two pressure transducers, one on each water input to the system.

   ii. Two flow rate monitors, one on each of the water inputs of the
        system.

e. How to control the water flow through valves.

   i. Two servo valves with stepper motor controls.

   ii. Two servo valves, one on each input with continuous varying
        voltage control.

   iii. Two servo valves, one on each input with continuous varying
        current control.

   iv. Two servo bypass valves and piping system for output flow control.
Concept Evaluation

Introduction:

Concept evaluation is where the control system and its various components are evaluated. The feasibility of the overall design is evaluated. The technologies and parts required to complete the finished product are evaluated as well. A decision matrix is used to compare and evaluate concepts.

1. Evaluation based on Feasibility Judgment

In generating concepts, the team began with two initial ideas for creating the control system. One way is to have a fully analog system of amplifiers, rectifiers, resistors and other electrical components. This idea is not feasible due to complex mathematics and electric circuit theory. Nobody in our group is familiar enough with these topics to be able to develop a system in this manor. The other idea the team has is to use a digital control system. This system is based off a computer chip that will control the system. This method seems to be feasible. All of the members of our team are familiar with computer programming. Computer programming is the most essential piece of this method. Because most of this method is digital, there is very little circuitry knowledge required, which makes the idea more easily realizable.

2. Evaluating based on Go/No-Go screening

I. Critical parameters that control the function

The critical parameters of the system are mostly controlled by the CPU. The most important parameter is the ability for the system to maintain a given temperature, which is the accuracy of the system. Another important parameter is the reaction
time of the system. Other important parameters are size, cost, computer processing capability, and power consumed.

II. Safe operating latitude and sensitivity of the parameters

Important safety parameters are the temperature accuracy and the reaction time. The system should react in less than 0.5 seconds in case of a hot water shock to the system. Also the temperature should stay within ±1 degree Fahrenheit. Also there should be no way for electricity to contact the water stream.

III. Failure Modes

There are various failure modes that could occur in this system. The first failure mode would have to be the valves not being controlled properly and the incorrect temperature water being produced. Another failure mode is if the system does not maintain a high water pressure as well as temperature. It does not do much good if the system produces a very low flow of water at the correct temperature. Another failure mode is if the computer chip fails or is shorted out.

IV. Availability of Required Technologies

All the technologies required for this project are readily available. The servo-controlled valves are available in many sizes and styles from various outside companies. The computer processor is a simple F.P.G.A. board that is found many places on the internet. The other technologies like pressure transducers and thermocouples are also available and easily integrated into the system.

V. Is the Technology Controllable Throughout the Products Life.

All of the technology used for this project is replaceable. The system will be modular so that if a piece fails, it can easily be replaced. Also the components of this system
will all most likely be recyclable. The pieces can be scrapped and made into something new or fixed or modified to function in a newer model.

3. Decision Matrix

The following is the decision matrix between the 2 leading possibilities for our design. The analog and digital systems are compared. The digital system has many more capabilities than the analog system. From this matrix the digital system will be chosen for further research.

<table>
<thead>
<tr>
<th></th>
<th>Reaction Time</th>
<th>Accuracy</th>
<th>Power Consumption</th>
<th>Size</th>
<th>Easy Installation</th>
<th>Safety Capabilities</th>
<th>Cost</th>
<th>No Maintenance</th>
<th>Memory Features</th>
<th>Timing Features</th>
<th>Expansion Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total +</th>
<th>Total -</th>
<th>Overall Total</th>
<th>Weighted Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>56</td>
</tr>
</tbody>
</table>

Figure 2 - 2 – Decision Matrix
Chapter 3: Thermocouple Testing

In order for the computer to know what the temperature of the water is, a thermocouple must be used. A thermocouple is a device made of two metals that measures the difference in temperature between the tip and the base. A J-type thermocouple will be used for this project. A J-type thermocouple's positive conductor is made of iron and the negative conductor is made of constantan. J-type thermocouples are good for a temperature range of about 0-480 degrees Celsius, which is consistent with the temperatures found in typical household waterlines. When there is a temperature difference between the base and tip of the thermocouple, a small current of 500 milliamps is generated. When this current is present there is also a voltage created. The voltage is processed by the computer translated into a temperature. The following chart is graph of the voltage created by the temperature difference and the temperature that it represents for a standard J-type thermocouple.

![Temperature vs. Voltage on a J type thermocouple](image)

Figure 3-1 Thermocouple Voltage vs. Temperature
The data in this chart shows that the relationship between temperature and voltage is linear. This property allows us to interpolate the voltage that the thermocouple outputs into a temperature. We can then compare this temperature with the desired temperature input by the user.

In order to place the thermocouple effectively we decided to do several tests with the thermocouple in different locations along the pipeline. Location 1 was determined from the thermodynamic entry length of the mixing water. The Reynolds number is calculated from Eq. 3-1.

\[ \text{Re} := \frac{\rho \cdot V \cdot D}{\mu} \quad \text{Eq. 3-1} \]

Once the Reynolds number is obtained the entry length is a function of Reynolds number and the diameter of the pipe as shown in Eq. 3-2.

\[ L_e := 0.06 D \cdot \text{Re} \quad \text{Eq. 3-2} \]

From these equations, we determined the entry length to be less than one thousandth of an inch. This allowed us to put a thermocouple very close to the mixing point. To make sure it was mixed we allowed for a few inches of space. The hand calculations are located in Appendix C. The other location chosen was near the top of the shower system to get a sample of the temperature right before it leaves the system to account for heat losses and gains through the pipes. The following is a diagram that shows the two different locations that were tested.
To see which location would be better we tested different situations. For each location we tested steady hot streams and cold streams. We also did rapid transient situations. For these we ran the system from steady cold and shocked it to cold water, we also went from cold to hot.
The above chart shows the data comparison of going from a cold water constant temperature to a sudden shock of hot water. The next chart shows a similar comparison, except for when going from hot to a cold shock.

Both of these plots have one important thing in common. In both of these plots, the location of the thermocouple that was closer to the mixing point of the fluids had a quicker response time. Since response time is basically the most important factor in location selection, thermocouple location one was selected for the final location. Using this location should give the best response time for the overall system and will mean that the user will be subjected to unwanted temperatures for the least amount of time.

Another thing that we had to consider was the thermodynamic entry length of the mixing point. If the thermocouple is at a location where the water is not fully mixed, the thermocouple could be reading the wrong temperature or varying greatly. To see if the location was far enough away from the mixing point we ran tests to measure the
consistency of the temperature readings. We ran tests at full hot, cold and mixed water temperatures. The following is a plot comparing the two different locations tested.

![Time vs. Temperature Chart](image)

Figure 3 - 4 Thermocouple Consistency Chart

This data shows that at extreme hot or cold temperatures the location is irrelevant. At both locations the temperature reading remains almost perfectly constant. At mixing temperatures the reading do vary a little more. The variance for location one near the mixing point was, 0.064761 (degrees C^2) which is fairly small. The variance for location two near the faucet was 0.008943 (degrees C^2), which does happen to be smaller than location one. However, at either location the temperature remains close to constant, and because there is a gain in speed of the system if we go with location one, location one was chosen as the final location of the thermocouple.
Chapter 4: Valve Selection

Valve selection and implementation was a critical part of developing a successful control system. Many valves were considered from several different manufactures. The final selection was Burkert 6023 proportional solenoid control valves. The product technical data sheet is attached in Appendix A. The valves had several characteristics that made them desirable for use.

The primary design criteria was the pressure drop that would be required across the valve to assure proper linear functioning during operation. In order to achieve a highly linear system the manufacture’s recommendation was for a 30 percent drop of the total pressure change to be across the valve. Since the hot and cold water valves would be in parallel this was the pressure drop each valve needed to achieve at full open. The system was designed for a common household water pressure of 60 psi. This resulted in a required pressure drop of 18 psi across each valve. The other driving factor in the valve selection was the ASTM standard that showers and other household devices shouldn’t consume more than 2.5 GPM. With these two required characteristics the flow factor of the valve could be calculated using the flow factor formula equation.

$$K_f = \frac{Q \sqrt{S_g}}{\sqrt{\Delta p}}$$

(4-1)

Where $Q$ is the flow in gallons per minute, $S_g$ is one for water, and $\Delta p$ is differential pressure. The required flow factor was approximately .58. The Burkert 6023 proportional valve had a flow factor of .44 which was the closest match.
Also, the control and output of the valve was a concern. Proportional solenoid valves run on a pulse width modulated signal. The Burkert valves came with a control unit to create the signal. The control unit even had different frequencies to select from to vary the hysteresis and fluctuation in the control. During testing the higher frequency was used to keep the valve position from fluctuating. The higher frequency did have higher hysteresis but for the primary goal of temperature measurement with a proportional controller the exact position of the valve wasn’t vital. The control unit took a standard zero to ten volt signal to control the valve. This was an analogue signal and the electrical engineers on the project were responsible for creating two such signals, one for each valve. In addition to the stable performance characteristics of the valve, these valves also came with a map for the different flow factors at any voltage from zero to ten volts. This would be useful for the development of a flow measurement and control system.
Chapter 5: Flow Measurement Design

The ability to measure flow and adjust the valves accordingly to achieve a desire flow was one of the design objectives that made this system unique. The final prototype system and program didn’t include flow monitoring and control because of budget constraints. However, several preliminary design tasks were completed to make the system ready to accommodate flow measurement.

Of all of the possible ways to measure flow, the way this system would measure flow would be the use of a differential pressure transducer setup across each valve. This setup had many advantages over other methods of flow measurement. First, venturis or orifices would use the same method of measuring pressure drops along the obstruction to achieve a flow rate. The problem with these methods of measurement was that this would be another obstruction in the system which would cause greater pressure loss and sacrifice the available energy for when the water reaches the shower head. Also, rotameters could have been used to measure the flow rate directly with less of an obstruction. However, these components are more expensive than differential pressure transducers and would be another component with moving parts which would increase the potential failure of the system.

In order to use the differential pressure across the valve the flow factor for the valve at any position had to be known. Fortunately, the selected valve already came with a completed map of the valve flow factor for any voltage from zero to full open. This plot was part of the product technical data sheet and can be found in Appendix A. The plot is a ratio of the flow factor and the full open flow factor. Ideally, since the flow factor was dependent on position and not supplied voltage an LVDT would be used to measure the
actual position of the valve. However, the valves are sealed already and the addition of an LVDT would not be cost effective. Instead, the supplied flow factor versus voltage was used. This plot was broken up into individual data points and stored in the computer processor. As a result for any measured differential pressure across a valve the flow through the valve would be known. The flows through each individual valve would directly add and yield the total flow.

In order to measure the differential pressure across each valve, couplers with taps for a pressure transducer fitting had to be designed. The reason that couplers had to be designed instead of using standard T connectors was that the galvanized fittings were not smooth and the rough coating would create a false or fluctuating pressure measurement. Refering to *Fundamentals of Fluid Mechanics* slight localized imperfections of the surface can cause unreliable and wrong static pressure measurement [3]. The pressure coupler was designed so that the pressure tap would be on the side of the fitting and could be machined perfectly smooth. Four couplers were used in the system, one on the inlet and outlet of each valve. Figure5-1 shows the final setup.

![Figure 5-1 Photo of the pressure coupler placement](image)

The machined inner surface allowed for unobstructed flow and an accurate pressure measurement. The use of a Pitot tube was considered; this would yield a stagnation
pressure differential instead of a static pressure differential but again as with orifices or venturis this would create another obstruction to the flow. The couplers were designed to accept an eighth inch NPT fitting for the pressure tap. This size is a standard connection for many industrial pressure transducers. Also, the coupler was designed to have one half inch NPT connections on each, so that the coupler could be easily connected in line with the valve and pipe. Research was done to get the nominal diameters for the NPT threads and the required length to form a water tight seal. The thread table used is in appendix***. The significance of the required sealing length was that the coupler would have to be at least thick for the pressure tap to not interfere with the flow. These design characteristics could be seen in the final coupler design below. The technical drawing of the coupler was attached in Appendix A.

Figure 5-2 Pressure Coupler

The coupler was designed to be 1 1/8 inch diameter brass hexagonal stock. This allowed for the required thickness and could easily be installed with the use of a standard wrench. However, the prototype couplers were made from aluminium round stock and machined to mimic the hexagonal dimensions. The reason the prototype couplers were made from aluminium was so that the college had an abundant supply of the material. The overall length of the couplers was 6 inches. However, this length could be shortened
in the final product. This was merely a safe guess so that the pressure measurement wouldn’t be influenced by entry or exiting disturbances. The only way to check the affect of the length would be to make several identical prototypes of different lengths and test each one. This would have taken too much time and money in excess material and machine time. The couplers made produced steady accurate pressures when observed with an analogue pressure gauge attached.

One concern in the design and material selection of the pressure coupler was that the coupler or valve might corrode overtime due to dissimilar metal contact. However, there wouldn’t be any corroding between the brass couplers and brass valves. The Galvanic Series was used to assure the brass wouldn’t corrode. Since normal household piping would typically be galvanized pipe the Zinc would corrode before anything else.
Chapter 6: Cover Panel Design

One of the design requirements for the project was to design an innovative way to access the valves and equipment behind the wall while preserving the aesthetics of the shower. With an electronic control system, eventually a problem will occur that requires maintenance. In fact, the thermocouple would require recalibration just from being used extensively. One advantage of having the thermocouple and valves in close proximity with each other was that only one access panel would have to be designed and implemented. The panel would have to be self locking so that no bolts or screws would be visible from the outside. Also, the panel would need to have a water tight seal and be non-corrosive in highly damp conditions. All iterations of the paneling was drawn in Pro/E and imported into ANSYS using workbench. The force and stress analysis was done with a combination of ANSYS modeling and hand free body diagrams and calculations.

The first step to designing the panel was to find out the size and geometry of the components of the control system. The panel would need to large enough to sufficiently access the thermocouple, valves, and pressure transducers. The required geometry is evident in the model of the system components Figure 6-1. The required length of the panel for access was 30 inches. The required height was about 10 inches. The panel height was designed for a 12 inch high hole so that a repair technician would have ample room to move and fit tools for maintenance.
After the initial dimensions were established the panel seals had to be selected. Basically market research was done to find a weather stripping or rubber seal that would fit this application. A seal that would compress at least an eighth of an inch was desired to allow for slight variations in the framework and the gap height. A weather-stripping silicon seal was selected. The stripping begins to compress at 3/8 of an inch and has an adhesive backing that is meant to stick to flashing, or door jams. This product was designed for household use so it adheres to all ASTM standards regarding smoke and fire testing. This seal could also be compressed to fit in a 1/16 inch gap. The large range of possible gap values made this product very appealing. A gap of ¼ inch gap between the access panel and frame was selected for sufficient compression of the seal without risk of over stressing the seal. From this geometry the final panel dimensions were 11.5 inches high by 29.5 inches wide.
Once the final dimensions of the panel were found, and the characteristics of the seal were known, the design of the paneling was started. First, in order to make the panel self-locking, the sides of the panel were designed as thin cantilever plates. This would allow for the plates to have a large deflection without being over stressed. The preliminary schematic of the interlocking sides, Figure 6-2, showed how the interference would keep the panel in place.

![Figure 6-2 Representation of the inference fit for interlocking panel/box](image)

To design the actual plate, the required ridge height would have to be selected. A quarter inch ridge height was selected to provide ample room for small errors in manufacturing or installation. If the ridge was too small then the panel could potentially slip off.

Once the required deflection was known, the length and the thickness of the cantilever had to be designed and tested. First, it was necessary for the overall length of the panel to be less than approximately 5 inches because the framework for the hole was designed to be made of a 2x6 inch standard board, which is only about 5 ½ inches wide (refer to the model of the wall). For the preliminary design a flat plate was tested under static loading with a slight chamfer on the ends and a fixed end. The load was set at 10 lbs directly cantilever. This 10 lb force was selected so that the total required pushing force neglecting friction would be only 20, which was considered as an acceptable
pushing or pulling force. The free body diagram of the side, Figure 6-3, shows how the pushing force was found.

![Free Body Diagram of cantilever side](image)

For each simulation, the equivalent Von Mises stress was found. This stress was then checked against the stress for several stainless steels to see if it was reasonable. The required thickness selected after preliminary testing was gauge 18 stainless steel. This corresponded to a .0478 thickness. There was a noticeable problem with the simulation. The chamfer on the end of the plate was creating intense stress concentrations. For a 10 lb cantilever force the deflection of the plate was only .13 inches and the stress was around 40 ksi. The results from the initial testing are in Appendix B. For this reason when the simulation was expanded the chamfers were changed to radii for a more gradual geometry change. Another potential problem that was revealed during the initial testing was that the default element sizing wasn’t giving accurate enough results. The sizing was changed and this produced a slightly higher Von Mises stress. As a result of these findings the sizing was changed and compared during later testing. The mesh alterations and corresponding results are in Appendix B.
After the initial tests, a side of the panel was tested under loading. For these simulations the farthest edge where the panel would have to be “cut” for testing was considered fixed. This constraint was used for several reasons. One, the stress and deflection of the cantilever would obviously be much higher than that of the panel face. This assumption was supported by the ANSYS results. Also, this face would be reinforced with Durrock, which would be the base for tile to be laid. This Durrock would stiffen the section. Finally, the design required that the front panel be rigid because bending of the panel would cause stress in the aesthetic tile and tiles could chip or fall off.

Using this fixed support as a constraint the side was tested under the extreme position, referring to the 10 lb horizontal force, and under the locked condition. The locked condition was considered to be the position where a five pound preload force was achieved. Both conditions were tested without the quarter-inch radius included. This radius shouldn’t and didn’t change the results significantly because it is a very small change.

In the extreme condition the results showed that significant stress was actually flowing to the front panel. This stress was large enough to cause a deflection and damage the Durrock and tiles. The ANSYS results are below in Figure 6-4. To fix this problem a one inch stiffener was placed in the center of the one inch flange on the side. This caused the maximum deflection to be slightly less but also greatly reduced the stress on the front side of the panel. The results after the inclusion of the stiffener are in Appendix B.
After this test, a half panel was tested. Since the panel was designed symmetrically, the center line was considered as fixed. The other rationalizations for this fixed support at the "cut" also still applied.

The half panel simulation didn't show much deviation from the smaller side simulation. The half panel results are in Appendix B. After checking the half panel the last stress analysis to be completed was for the panel hanger. The hanger would be used to support the weight of the panel so that the panel would be centered and the weight wouldn't crush the rubber seal. A flat plat would be welded on the end of the hanger to serve as a stop so that the panel could be preloaded. In order to design the panel hanger research was done to find the weights of the panel itself and the applied weight of the Durrock, tiles, and Thinset cement adhesive. For the properties of the materials see Appendix A. The final design weight was 25 lbs. The hanger would have to hold up a 25 lb force. A simple square thin wall tube was selected as the hanger on the panel. The final panel design is in Figure 6-5 on the following page.
The tube for the hanger would be welded at the end. A mating rectangular tube would serve as the hanger on the framework of the hole. The concentrated stress was extremely small. There was also almost no deflection at all due to the weight. The results are in Appendix B. However, the weight of the panel wasn't the only issue. The moment created by the weight also had to be considered. A basic diagram was used, the weight was centered at the farthest practical position from the hanger, and the moments were summed about the hanger edge. This schematic and the static equilibrium equations are located in Appendix C.

From this basic static problem the required holding force to prevent rotation was found to be 6.25 lbs. This was the total balancing force considering the weight and the preload force. Now with the completed panel the mating box had to designed. No stress analysis was done on the frame because the entire frame would be screwed into the wood frame and be essentially a rigid structure when compared to the deflections in the sides of the panel. The frame would be the same gauge sheet metal as the panel. The final design was dictated by the geometry of the panel and specified deflections for the interference fit.
There was also a tab designed at the base of the box to supply the reaction force needed to avoid rotation. The final box design can be seen in the Figure 6-6.

Figure 6-6 Final Box Design to Hold Panel

Once the final stress analysis was completed the exact material was selected. From market research, the required material for the panel using 18 gauge steel was S303 annealed stainless steel. This material provided a minimum of a 1.2 factor of safety. Also, this material had excellent ductility and workability. The annealed condition of this material was selected because of the forming that needs to be done. This information was from the ASKZM steel supplied website [4]. The manufacturer’s recommendation for annealed steel was to avoid potential cracking during forming. The hanger was selected to be made of standard S304 stainless steel tube [5]. This is a very readily available and cheap stainless steel. The box material was also selected to be S304 stainless steel since the stresses were small and the material didn’t have to be worked much.
The design and testing of the panel was now completed. No fatigue analysis was done because the number of cycles for the life of the panel would be extremely small. Also, the panel or cover wouldn’t be subjected to any dangerous vibrations. The final design accomplished all of the outlined criteria. The consumer would be able to add whatever handles they would want to the panel and tile and decorate the panel to match the aesthetic décor of the shower.
Chapter 7: Electronics

In order to control the valves and analyze the information coming from the thermocouple, and electronic circuit must be created. A field programmable gate array is a very crucial electronic component that can do both of these objectives. The F.P.G.A. for this project was chosen because it has many input and output ports as well read only memory that can be changed later if needed, as well as a four digit, seven LED display.

Figure 7-1 Digilent D2SB FPGA Development Board
Using a digital processor such as the one selected allows us many benefits. With this F.P.G.A. we can write a Verilog Hardware Description Language computer program for it and wipe the memory and change the program at a later date for updating purposes. Also this F.P.G.A allows us to make a user interface that enables the user to store presets for several different users, so that they can have one touch access when they use the shower system. This program that is written is the controller for everything in the system.

It takes input signals from the valves and thermocouple as well as from push button signals from the user, and proceeds to control the valves and displays.

There are several signals that will go to and from the F.P.G.A. There are thermocouple readings that are sent to the F.P.G.A. that are in the -1 to 1 volt range. Then signals are sent to and from the proportional valves telling the system how much they are currently open and how much too open or close. The valves will be operated on a 24v source, but controlled by a 0-10 volt signal from the F.P.G.A.

The F.P.G.A is digital and therefore sends and receives 8 bit digital signals. The valves however operate on an analog signal. In order for the F.P.G.A. to understand the different information, an analog to digital signal converter is required. The following is a circuit that was designed to convert the analog and digital signals.
Figure 7-2 Analog to Digital Converter Circuit
Chapter 8: Prototype Design and Assembly

The goal of the prototype design was to affectively simulate a standard shower. This includes both the dimensions of the shower wall for mounting and the pipe dimensions. The prototype wall allowed for a proper estimation of how the system would fit. In addition, the test shower made it possible to test the control system under realistic conditions with regards to any frictional losses along the pipe, heat loss, and any other irregularities that are difficult to model.

The wall of the prototype was basically the same dimensions of a standard wall in a house. The frame of the prototype was constructed with two by six boards on 16 inch centers, which is standard. The frame was held together by half inch plywood which basically made the prototype frame a standard wall.

All of the piping for the prototype was galvanized pipe and were the same as the dimensions established in the initial system design. There were several valves and fittings that had to be included in the prototype design that would not be included in the final product. The extra fittings and valves required were due to the prototype being a temporary assembly. In addition, several valves were required to make the system testable.

The water supply used was a standard water sink tap. However, the main problem with making the test stand usable was getting the stand hooked up to the building supply. To connect to the water supply’s and make the test system portable or movable vinyl tubing was used with barbed fittings. The fittings converted back to a standard half inch npt fitting on one side and a half inch compression fitting to hook up to the water supply. This setup can be easily seen in the figure.
The vinyl tubing used for this was reinforced and very strong. The tubing had a rating of 145 psi, which was much more than the pressure from the building which was only between 45 and 60 psi. In addition to having the tubing, the tube supplies had half inch ball valves on the ends. This was so the test stand could be disconnected allowing for changes in thermocouple position and installation or alteration of the proportional valves. This was the master shut-off for the system. In addition, there was T-junction with another half inch ball valve on the cold and hot water supplies. The valves are clearly apparent in the figure.

![Figure 8-1 Complete prototype assembly](image)

These valves just opened to the atmosphere and served two purposes. The primary purpose was that by open and closing these valves during testing, water pressure losses could be simulated on either water supply. The second purpose of these valves was to
drain the system. This was necessary for the prototype since the system would have to be
dismantled and disconnected several times. Draining the system kept the water from
spilling on the floor. Even though these potential problems had to be addressed and
corrected for the prototype, the actual system didn’t require any of these extra valves or
fittings. The hardware for the system would be installed at the time the shower was
installed.
Chapter 9: Discussion and Conclusion

Overall, the design project was a success. There was a lot of coordination between the mechanical and electrical teams. Many different tasks were completed to design a system that when implemented could be an added convenience in everyday life and protect users from accidental injuries. The tasks completed included the selection and implementation of the valves and thermocouple for the temperature feedback. Also, the system had to be customized slightly to allow for static differential pressure measurement for flow control. The access paneling was designed to be minimally obtrusive and easily removable. The prototype design and assembly was completed. The only disappointment of the project was that the electrical engineers were unable to incorporate the program into the hardware.

The proportional valves were incredibly difficult to select and to use. A lot of market research had to be done to find and select the best valve for the application. During preliminary tests with an analogue power supply the steadiness and usefulness of the valves surpassed expectations. The valves were wired and installed in the system. The pressure couplers were also developed to fit the selected valves. These couplers would provide steady pressure differential readings allowing for flow measurement and control by the valves.

The thermocouple selection and testing went as expected. By testing the response to step inputs the time constant was achieved. This was important because the thermocouple time constant dictated the loop time and the response of the system since all the other components had nearly instantaneous reaction to input. The proper
positioning of the thermocouple was established through testing to allow for the quickest response and an adequately steady reading.

The only disappointment of the project was that the entire control system could not be tested and evaluated. The electrical engineers had the program written but couldn’t successfully transfer the program to the hardware for the control. As a result the components and prototype system couldn’t actually be evaluated as an entire unit. However, there was no reason evident that would suggest the system wouldn’t work properly given the proper software to control it.

Even though the entire system couldn’t be tested together, the development of the access paneling was still done using ANSYS. This modern engineering tool proved to be extremely powerful and useful to design the interlocking cover. Stress, and deflection analysis was done. In addition, market research was done to find the proper material for the panel. This panel wasn’t actually built as there was no need for it in the prototype system.
References


Appendix A – Component Data Sheets and Technical Drawings
**Flow Solenoid Control Valve - General Purpose**

**Type 6022**

**Type 6023**

2/2-way; direct-acting; G 1/4" - G 3/4"; PN 0-8 bar

Design / Function

Type 6022 and Type 6023 are direct-acting solenoid control valves for $K_v$ flow rates from 0.1 to 0.7 m$^3$/h. The proportional characteristic curve is practically linear. Regulation deviations (hysteresis, repeatability) keep in between small tolerance limits. The responsibility is particularly high.

The solenoid control valve system consists of the basic components armature, push-over coil and the electronic plug-on control unit. It can be mounted in any position. The electronic control unit is integrated into the DIN 43 650 A plug, but can also be supplied as a standard DIN-rail mounting version.

- Adjustable ramp function from 0-10s cushions set-point jumps
- Standard input signals 4-20 mA, 0-10V
- Monitor signal to assist set-up and indication of coil current
- Tight shut-off due to zero-point suppression
- Compensation of the coil heating
- Start of opening and max. opening adjustable
- Simple ordering procedure with one order number for valve and control electronics

Advantages / Benefits

- Optimization of process and product quality through continuous regulation
- Increase of efficiency
- Extremely high control accuracy:
  - low hysteresis
  - high repeatability
  - high responsibility
- Fail safe (self-closing in case of power failure)
- A complete control system "all from one" with Burkert sensors and controllers
- Brass or Stainless Steel body

Applications

- Fluids:
  - Neutral gases and liquids
  - Slightly aggressive liquids

- Applications:
  - Water treatment
  - Printing and paper machines
  - Bottling plants
  - Analytical appliances
  - Combustion of natural gas
  - Decontamination facilities
  - Mechanical engineering
  - Autoclave producers
  - Chemical process engineering
  - Control of temperature, vacuum, humidity and combustion

bürkert Easy Fluid Control Systems
Flow Solenoid Control Valve - General Purpose

### Valve function

A 2/2-way flow valve, normally closed, direct-acting

### Technical data

#### Operational data (Armature)
- **Pressure range**: 0 - 8 bar, techn. vacuum
- **Port connection**: G 1/4", G 3/8" (see characteristics)
- **Body material**: Brass or Stainless Steel
- **Sealing material**: FKM
- **Medium**: Brass body - Neutral gases and liquids, SS body - Slightly aggressive liquids
- **Temperat. range of medium**: -10 ... +90°C
- **Max. ambient temperature**: +55°C
- **Max. Viscosity**: 21 cSt
- **Installation position**: Any, no limitation on function

#### Operational data (Solenoid)
- **Operational voltage**: DC 24 V=-, (max. 28V=)
- **Ripple**: ±10% (We recommend our power supply type 1610)
- **Input signal**: 4-20 mA, 0-10V (0 - 20mA on request)
- **Control signal for valve**: PWM (Pulse Width Modul.)
- **Max. current consumption**: 1.1A
- **Monitoring signal**: Directly proportional to coil current 1 mV = 1 mA as set-up aid, or for external display.
- **Ramp time**: 0 - 10 s (adjustable)
- **Protection class**: IP65 (when mounted on valve, version M)

#### Operational data for Control Electronics
- **Design version M**: DIN-rail mounting version
- **Design version H**: (on request)
- **Operational voltage**: DC 24 V=,
- **Ripple**: ±10% (We recommend our power supply type 1610)
- **Input signal**: 4-20 mA, 0-10V (0 - 20mA on request)
- **Control signal for valve**: PWM (Pulse Width Modul.)
- **Max. current consumption**: 1.1A
- **Monitoring signal**: Directly proportional to coil current 1 mV = 1 mA as set-up aid, or for external display.
- **Ramp time**: 0 - 10 s (adjustable)
- **Protection class**: IP65 (when mounted on valve, version M)
- **Electrical connection**: Screw terminals for ø7 mm cable

### Materials

1. Valve body: Brass or Stainless Steel
2. Plunger seal: FKM
3. O-rings: FKM
4. Armature guide tube: 1.4303
5. Plunger: 1.4105
6. Slip-rings: PTFE-Compound
7. Spring: 1.4310
8. Stopper: 1.4105
9. Coil: PA (Polyamid)
10. Locknut: 95MnPb28K (Surface-finish Zn5glcA)

**Flow direction**
**Characteristics Values with ordering information (other versions on request)**

### Brass body; Sealing FKM

<table>
<thead>
<tr>
<th>Port-connection</th>
<th>Orifice (mm)</th>
<th>( K_{\text{V}} \text{Value} ) (Water) (m³/h)</th>
<th>( K_{\text{M}} \text{Value} ) (Air) (l/min)</th>
<th>Pressure range(^\ast) (bar)</th>
<th>Power consumption (W)</th>
<th>max. Cont.-current ( \text{input} ) ( \text{signal} ) (mA)</th>
<th>Weight ( \text{Order-No.} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1/4</td>
<td>2.0</td>
<td>0.10</td>
<td>110</td>
<td>0 - 8</td>
<td>8</td>
<td>300</td>
<td>4 - 20 mA</td>
</tr>
<tr>
<td>G 1/4</td>
<td>2.0</td>
<td>0.10</td>
<td>110</td>
<td>0 - 8</td>
<td>8</td>
<td>300</td>
<td>0 - 10 V</td>
</tr>
<tr>
<td>G 1/4</td>
<td>4.0</td>
<td>0.40</td>
<td>400</td>
<td>0 - 4</td>
<td>16</td>
<td>330</td>
<td>0 - 10 V</td>
</tr>
<tr>
<td>G 3/8</td>
<td>4.0</td>
<td>0.40</td>
<td>400</td>
<td>0 - 4</td>
<td>16</td>
<td>330</td>
<td>4 - 20 mA</td>
</tr>
<tr>
<td>G 3/8</td>
<td>5.0</td>
<td>0.70</td>
<td>250</td>
<td>0 - 5</td>
<td>10</td>
<td>330</td>
<td>4 - 20 mA</td>
</tr>
</tbody>
</table>

### Stainless Steel body; Sealing FKM

<table>
<thead>
<tr>
<th>Port-connection</th>
<th>Orifice (mm)</th>
<th>( K_{\text{V}} \text{Value} ) (Water) (m³/h)</th>
<th>( K_{\text{M}} \text{Value} ) (Air) (l/min)</th>
<th>Pressure range(^\ast) (bar)</th>
<th>Power consumption (W)</th>
<th>max. Cont.-current ( \text{input} ) ( \text{signal} ) (mA)</th>
<th>Weight ( \text{Order-No.} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1/4</td>
<td>2.0</td>
<td>0.10</td>
<td>110</td>
<td>0 - 8</td>
<td>8</td>
<td>300</td>
<td>4 - 20 mA</td>
</tr>
<tr>
<td>G 1/4</td>
<td>2.0</td>
<td>0.10</td>
<td>110</td>
<td>0 - 8</td>
<td>8</td>
<td>300</td>
<td>0 - 10 V</td>
</tr>
<tr>
<td>G 1/4</td>
<td>4.0</td>
<td>0.40</td>
<td>400</td>
<td>0 - 4</td>
<td>16</td>
<td>330</td>
<td>0 - 10 V</td>
</tr>
</tbody>
</table>

---

1) All pressures quoted are gauge pressures with respect to the prevailing atmospheric pressure.
2) Input signal 0-20 mA on request.

### Regulation data - characteristics

**Characteristic**
- see diagram

- Hysteresis: < 5%
- Repeatability: < 0.5% F.S.
- Responsivity: < 0.5% F.S.
- Setting time (90%) < 50 ms
- Turn down ratio: 1 : 10

### Advice for selection of valve sizing

In fluid plants including continuous valves, the choice of the appropriate valve size is much more important than with on/off valves. The optimum orifice should be selected such that, on the one hand, the resulting flow in the fluid system is not unnecessarily reduced by the valve, and, on the other hand, a sufficient part of the pressure drop takes place over the valve even if it is fully opened:

**recommended value:** \( \Delta p_{\text{valve}} > 30\% \) of total \( \Delta p \) within the system

Otherwise, even a perfectly linear valve characteristic will be deformed to a heavily convex shape. For that reason, Burkert offers a competent guide service from the early planning phases of a fluid plant.
Flow Solenoid Control Valve - General Purpose

**Type 6022**

**Type 6023**

**Dimensions (in mm)**

**Type 6022; G1/4"**

Plug-on electronic control module included in delivery

**Type 6023; G3/8"**

Plug-on electronic control module included in delivery

**Variable Dimensions**

<table>
<thead>
<tr>
<th>Port connection</th>
<th>Orifice [mm]</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>G3/4&quot;</td>
<td>4.9</td>
<td>4.4</td>
<td>14.7</td>
<td>32.0</td>
<td>46.0</td>
<td>46.0</td>
<td>88.4</td>
</tr>
</tbody>
</table>

DIN-rail mounting version of control electronics on request (design version H).
1/2 inch npt thread

1/8 INCH NPT THREAD

45.0°
FRONT

3.00
6.0
DTM2

0.75

SYS_DEF

/PRT_CSYS_DEF

COUPLER FOR PRESSURE MEASUREMENT

PAUL BERWANGER  GROUP 8

3/20/06
MATERIAL: 18 GAUGE ASTM 304 STAINLESS

2.00

3.83

PRT_CSYS_DEF

FRONT

DTM2

45 DEGREE INCLINE/DECLINE

12.00

15.00

30.00

4.80

4.00

PAUL BERWANGER

PANEL BOX

5/5/06   GROUP 8
Appendix B– ANSYS Results of Panel Development
Initial Side Stress with default mesh sizing

Initial Side Stress with .15 in mesh sizing
Initial Side Stress with .05 in mesh sizing

Refinement of mesh from default, to .15 in to .1 in to .05 in
Side stress state before stiffening insert

Side stress state at maximum after stiffening insert
Final cover panel half simulation stress in locked position

Final cover panel half simulation deflection
Appendix C – Hand Calculations
Calculation of Required Reaction Force to Balance Preload and Weight Moments

SUM THE MOMENTS AND
SOLVE FOR REACTION FORCE.
\[ R = 6.25 \text{ LB} \]
Fluid entry length for the system at maximum flow. This is important to find where to place the thermocouple for the temperature feedback.

\[ \Delta Av_2 \]
\[ 2 \frac{1}{2} \text{ gal/min} \]

\[ \Delta Av_1 \rightarrow \]
\[ 1 \frac{1}{4} \text{ gal/min} \]

\[ \Delta Av_1 \leftarrow \]
\[ 1 \frac{1}{4} \text{ gal/min} \]

Neglecting minor losses in the pipe and fittings, Bernoulli Eq. should still be satisfied. We are planning for an approximate 15 psi pressure drop across the valve to result in 2 gal/min. So with an average stagnation pressure of 60 psi

For water: \( P = 1.94 \text{ slugs} \frac{\text{ft}}{\text{s}^2} \)

\[ M = 23.4 \frac{\text{ft} \cdot \text{lb}}{\text{s}^2} \]

\[ P_{	ext{stag}} = P_i + \frac{1}{2} \rho V_i^2 \]

\[ P_i = (60 \frac{\text{ft} \cdot \text{lb}}{\text{s}^2})(144 \frac{\text{in}^2}{\text{ft}^2}) = (51.94 \frac{\text{lb} \cdot \text{in}}{\text{ft} \cdot \text{s}^2})(2.043 \text{ in}^2) \]

\[ P_i \approx 8,035.9 \text{ lb/ft}^2 \]

\( \rho \approx 59.97 \text{ psi} \) into the valve

\( P_0 \approx 45 \text{ psi} \) out of the valve

Continuity Formula

\[ A_2 V_2 = A_1 V_1 \]

\[ \frac{4}{3} (0.5)^2 V_i = (1.25)(2.31) \text{ in}^3 \]

\[ \frac{60}{\text{sec}} \]

\[ V_i = 24.5 \text{ in/sec} \]

\[ V_i = 2.043 \text{ ft/sec} \]
Now, after mixing the pipe size is 3/4".

Using the continuity equations
the flow through this pipe is 2.5 \, gpm/min
which is what the shower head is designed for.

\[
\frac{2.5 \, \text{gpm}}{\text{min}} = A_2 V_2 \\
V_2 = \frac{(2.5 \, \text{gpm})(231 \, \text{in}^3)}{60} \\
\quad \quad \frac{\pi}{4} (0.75)^2 \\
V_2 = 21.786 \, \text{in/s} \\
V_2 = 1.815 \, \text{ft/s}
\]

Now, with this velocity the Reynolds number for the mixing pipe can be found.

\[
Re = \frac{\rho V D}{\mu}
\]

where \( \rho = 1.94 \, \text{slug/ft}^3 \)
\( V = 1.815 \, \text{ft/s} \)
\( D = \frac{0.75}{12} \, \text{ft} \)

\[
Re = \frac{(1.94 \times 1.815 \times 0.75)}{23.4} \\
\quad \quad \quad \quad \quad \quad \quad \quad \mu = 23.4 \, \text{slugs/ft} - \text{s}
\]

\[
Re = 0.009404 \, \text{This is a small Reynolds number and is clearly laminar.}
\]

So, the entrance length is governed by the equation

\[
\frac{le}{D} = (0.06 \times Re)
\]

\[
le = (0.06 \times 0.009404)(0.75 \, \text{in})
\]

\[
le = 4.23 \times 10^{-4} \, \text{in} \, \text{. This is almost an instantaneous mix into laminar flow, this also suggest that the thermodynamic entry length might be dominant.}
\]