Operability and Performance Analysis of Various Control Valves

Final Report

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Abstract
In 2015 an assortment of control valves were implemented in the Murdoch University Instrumentation and Control Laboratory and in the Pilot Plant. This project is a result of this proposed implementation and is important to gain a proper understanding of the valves’ usage; behaviour; and to confirm the new valves are an improvement on any valves they may be replacing.

This project aimed to compare and analyse the operability and performance of the Baumann 24000S with Fisher 3660 Positioner and the existing Badger Meter Research Control Valves within the Instrumentation and Control Laboratory. The operability and performance was analysed by investigating the valves’ usage; functionality; hysteresis; valve type and sizing; dead band; and dead time.

The first test checked if one valve opening resulted in two flow rates for different directions of the stem movement (otherwise known as hysteresis). Eliminating hysteresis is important as it signifies that the valve is less susceptible to variations caused by friction and other forces, resulting in a single flow rate for each valve opening.

The valve type, sizing and usage was analysed with the flow coefficient and characteristic curves. The flow coefficient indicates a valve’s maximum flow capacity, whereas the characteristic curve shows the flow behaviour with change in valve opening; this should be as linear as possible. The type and size of a valve is important in order to optimise a process. A valve that is too small will not allow sufficient fluid to pass; whereas a valve that is too big will cause most of the process gain to come from the valve and not the controller [1].

Dead band is the range the valve opening can change in both directions without change in the flow being observed; this is a result of backlash and friction. The smaller the dead band the better the valve’s ability is to respond to minor changes.

Dead time allows the evaluation of the valve’s response time, in order to compare the speed of the valves.

In comparing the Research Valve results to the Baumann 24000S results, the Baumann 24000S had no visible hysteresis; it had the strongest linear relationship; it had a small dead band of 0.5% and a quicker dead time. Based on these findings it is determined that the Baumann 24000S surpasses the performance of the Research Valve; therefore it is advised that the Baumann 24000S with Fisher 3660 positioner is a suitable replacement for the Badger Meter Research Valve.
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1. Introduction
Control valves are one of the most commonly used final control elements within a control loop and often one of the most expensive so it is vital that a proper understanding of control valves is developed [1]. The optimization of production in a process can be improved by selecting appropriate valves. In 2015 a variety of control valves will be implemented into the Murdoch University Instrumentation and Control Laboratory in the Physical Sciences Building and in the Engineering Building Pilot Plant. These valves include the Baumann 24000S [6] with Fisher 3660 Positioner [5]; the Baumann 51000 [3] high pressure low flow valve; the Fisher 24000S [6] with Baumann Electric Actuator [17] and the existing Badger Meter Research Control Valves [9]. This project came as a result of the implementation of these new valves in which knowledge was required in order to know their functionality. To also find out which system to implement the valves into, to ensure that they were used correctly. This project is important to gain a proper understanding of the valves, their usage; behaviour; and to confirm the new valves are better than any valves they may be replacing.

1.1 Objectives
This project aims to compare and analyse the operability and performance of a variety of valves within the Instrumentation and Control Laboratory.

The operability was analysed by investigating the valves’:

- Usage – Specifically whether the valve is suited for the water system or the air system.
- Functionality – A detailed research executed on features of the valve assembly that may have impact the performance.

A comparison was made between existing and new valves to ensure the replacement of any of the valves was warranted by carrying out a series of performance based tests, which also provided insight into their behaviour and functionality. Prior to this the valves were calibrated to ensure they functioned as specified by their manufacturers. The parameters that were investigated in order to compare the performance of the valves include:

- Hysteresis [20]
- Valve type and sizing [1]
- Dead band [2]
- Dead Time [18]

A brief background and calibration on all the new valves is provided in order to give some knowledge of the valves prior to installation. However, due to the limitations of this project the main focus will be on the Baumann 24000S with Fisher 3660 Positioner and the existing Badger Meter Research
Control Valves. These valves were of particular interest because the Baumann 24000S with Fisher 3660 is the proposed replacement for the Badger Meter Research Valve. Testing of these valves was required to ensure that the replacement is warranted and to compare the effects that the positioner had on a valve.

1.2 Report Structure
Section 2 of this report will introduce some background information on valves including the importance of valves to a process; components of a valve and information on how valves work. Section 2.1 will introduce the valves that will be implemented along with a description and their usage. Section 3 will go into detail about the tests performed on the valves. Section 4 contains the results of the tests performed and difficulties that were faced and ways to troubleshoot them. Section 4.7 will summarise the results and provide a suggested outcome from them. Section 6 will provide a conclusion to this thesis report with potential future work that could be done and recommendations.
2. Literature Review/ Background

In order to gain an accurate understanding of the operability and performance of a control valve, background is needed on what a control valve are, the components that make up a control valve, their functionality, the way in which these components work together to change the flow in a process and the importance of control valves to a process.

Control valves are instruments that change the flow of fluid through a system by completely or partly opening or closing in order to compensate for disturbances and keep the process variable as close as possible to a set point [1]. The existing valves in Instrumentation and Control Laboratory work by receiving a current signal from the controller where the I/P (current to pressure) converter translates this signal into instrument air pressure that passes through the pressure connection into the diaphragm casing. Pressure builds up on the diaphragm plate that pushes on the actuator spring and moves the stem up or down depending on the type of valve. The stem is connected to the closure member that partially or fully opens or closes the valve thus manipulating the flow of fluid.

Control valves come in various types such as Rotary Ball, Rotary Butterfly and Sliding Stem. This report will focus on the Sliding Stem Valve. The Sliding Stem Valve has two main parts, the actuator and valve body assembly. The actuator is made up of the pressure connection; the diaphragm and diaphragm plate; the actuator spring; the spring adjuster; the actuator stem; the yoke; and stem connector. The main components in the valve body are the packing; the bonnet; the gaskets; the cage; the seat ring; the seat ring gasket; and the closure member [1].

Control valves are important as they are often used as the final control element within a control loop. The control loop consists of a process variable that is required to reach a desired set point within a certain allowable tolerance. Sensors and transmitters test the process variable and information is then sent to a controller that will evaluate the appropriate action required to get the process variable to the set point. The final control element then implements this action [1]. All elements in a control loop are important; if anything fails the loop breaks. Control valves play a significant role in a control loop because it is the only component that moves to react to set point changes and disturbances [2].

There are two main systems in the Instrumentation and Control Laboratory including the air system and the water system. The setup of these systems is shown in Section 3.3 Figure 5. The valves are either suited for use with water or with air, further details on the difference between these valves are provided later in this report.
2.1 Valves to be tested
The valves to be installed in the laboratory along with the current Badger Meter Research Control Valves, include the Baumann 51000 High-Pressure Low-Flow Control Valve, Baumann 24000S with Fisher 3660 Positioner and the Baumann 24000S with Electric Actuator. This section will give a brief overview of each type in order to gain insight into their functionality.

2.1.1 Baumann 51000 High-Pressure Low-Flow Control Valve

The Baumann 51000 is ideal for situations such as laboratories that often require low flow and high pressure [3]. The valve as shown in Figure 1 is also very compact which is often required in laboratories where space is limited. The corrosion resistant design of the valve means it is appropriate for a variety of gases and highly viscous fluids such as caustic solutions. The compact actuator is multi-spring with low friction and can easily be switched between air-to-open and air-to-close without extra parts or special tools [3]. Murdoch University currently have two types of the Baumann 51000 one with a Cv (flow coefficient) of 0.45 and one with a Cv of 1.5 as described by the identification plates located on the valves’. Where the flow coefficient is the gallons of water that passes through the valve over a period of one minute with the difference in pressure through the valve set as 1 psi at a temperature of 60°F, this quantifies the valve’s flow capacity.
2.1.2 Baumann 24000S with Fisher 3660 Positioner

The Baumann 24000S is the body type and the Fisher 3660 is the Positioner type. The Baumann 24000S with Fisher 3660 Positioner shown in Figure 2 is different from the other valves used in this project because of the single acting pneumatic valve positioner. This positioner acts as an on-board controller where the process variable is the position of the valve actuator. The actuator has an arm mechanically connected to it and the positioner automatically adjusts its output to the actuator to maintain a desired position in relation to the input signal [1]. The positioner will provide any output pressure to the actuator to satisfy this relationship between the input signal and the valve position [4]. A positioner improves the performance of a control valve because it continuously inspects to see if the stem has reached the set point; if the stem has not reached the set point the valve pressure adjusts. A valve without a positioner sends a signal to the current to pressure (I/P) converter which outputs an air pressure and the stem moves, no further measurement is necessary to ensure the stem is in the correct location. Some other advantages of the Baumann 24000S is that it is designed to provide an accurate fast response and is able to withstand the vibrations of most plant environments. Efficient operation is achieved through low steady-state air consumption and the easily adjustable gain and damping enable fine tuning of the positioner stability making it adaptable to specific application requirements [5]. There are two different types of Baumann 24000S with Fisher 3660 to be tested, one for the air system and the other for the water system. The air valve has a Cv of 0.2 and the water valve has a Cv of 1.
2.1.3 Baumann 24000S with Baumann Electric Actuator

The Baumann 24000S as seen in Figure 3 is ideal for the control of pressure, temperature, level and flow [6]. The stainless steel body and epoxy powder-coated actuator is built to withstand mildly corrosive fluids, yet compact and light enough for laboratory use. The actuator is multi-spring with reduced dead band and can easily be switched between air-to-open and air-to-close. Where dead band is the band through which the manipulated variable can be changed in both directions without a change in the process variable being observed [1]. A useful feature of the actuator is the ability to perform auto calibrations [6]. The difference between this valve’s actuator and the others is that it contains an electric actuator module instead of the diaphragm; consequently it no longer requires instrument air, however a power supply is needed. The Baumann 24000S has a high Cv of 9.5 and is slow opening with a maximum travel time of 150 seconds. Typically slow opening valves are used for applications such as boilers that have an ignition system where gas is required to ignite it. If a fast opening valve were used it could cause excessive gas build up or make a loud noise during ignition; whereas a slow opening valve would ignite at a lower pressure and would be a lot quieter [7]. Slow opening valves also prevent sudden thermal shock and stress to a system and the pressure is more controlled [8]. Given this information the best application for this valve at Murdoch University would be in the Pilot Plant on the steam system.
2.1.4 Existing Badger Meter Research Control Valve

The Badger Meter Research Control Valves displayed in Figure 4 are categorised by their serial numbers; there are two different model numbers written on the valves in the Instrumentation and Control Laboratory these are 1002GCN36VOSCLN36 and 1002GCN36VOSGLN36. The only difference in the model numbers is the trim size & characteristic where the trim is the internal components of the valve that change the flow of fluid [1]. “C” linear trim has a Cv of 1.25; this valve is used for water. “G” linear trim has a Cv of 0.2; this valve is used for air [9].
3. Methodology

3.1 Assumptions
The Instrumentation and Control Laboratory had no separate water flow meters, as they were all connected to the existing valves. Initially the method used to get the flow rate was to pass water into the new valve, then into the existing completely open Badger Meter Research Valves and subsequently the flow meter. Due to differences in flow coefficient this could impact the results for the performance tests. In order to get the most accurate results a bypass was made, effectively splitting up the water flow meter and the water Research Valve.

The air valves all have the same flow coefficient, so it was assumed that the Research Valve would not alter the Baumann 24000S results when air passed through it in order to go through the flow meter.

It is assumed that the existing Badger Meter Research valves cannot be calibrated as there are no pressure gauges on the valves and they are already installed in the laboratory.
3.2 Valve Calibration

The valve calibration test is an experiment to ensure the valve current to pressure converter is functioning as designed. In most cases this means a current signal of 4-20mA is converted to 3-15psi. If the current is not producing the correct pressure range the valve’s span and zero can be adjusted to correct any errors. Current to pressure converter calibration is important in order for the valve to operate correctly or else a current signal will be sent and an incorrect pressure will cause the valve stem to move to the wrong position, creating unexpected results and variability. Valve calibration is generally done prior to performance testing in order to adjust the valve if the stem is not moving to the correct position.

In each of the control valve manuals it is outlined the input current signal for the current to pressure (I/P) converter and what the corresponding pressure reading for this current signal should be. In order to test that these were the correct values the valves were bench tested using the following equipment:

- Fluke 744 Documenting Process Calibrator;
- Instrument air and pressure regulator;
- All the valves have pressure gauges attached.

Some of the valves had additional equipment requirements that are outlined in their individual results and discussion sections. The overall steps to calibrating the I/P converters of the valves included:

- Connecting the instrument air;
- Removal of the face plate of the I/P converter;
- Connect the terminals from the Fluke 744 to the terminals in the I/P converter;
  1. Press Meas/Source button
  2. Press mA button
  3. Select “Source mA”
  4. Press Enter
  5. Type in the mA source to be used, press enter
  6. Read from gauge on valve and record the pressure reading.
3.3 Hysteresis

Hysteresis of a valve is the greatest difference in the flow for any single per cent valve opening; this difference is caused by friction and other forces acting on the valve [1]. Eliminating hysteresis is important as it signifies that the valve is less susceptible to these variations resulting in a single flow rate for each valve opening as seen in the ideal scenario (series 1) in Figure 6. Hence the controller can be tuned for one operating point as opposed to two, where the controller would require more complex tuning in order to adjust to the different directions of stem travel. Usually it is tuned for the average of the two or just one of the scenarios, giving rise to decreased process optimisation, increased variability and more inconsistencies.

The setup of equipment is shown in Figure 5. The equipment used to test the hysteresis, valve type and sizing, dead band and dead time is as follows:

- Various valves to be tested;
- Instrument air;
- Flow meter;
- Computer with Labview using a basic experimental template;
- Water supply tank with pump and power supply (When using the water system);
- Water tank (When using the water system);
- Air tank (When using the air system);
- Pipes;
- Analogue input and output leads.

![Figure 5 Laboratory Equipment Setup](image)

To test the hysteresis of the valves, the valve opening was gradually stepped up in increments of 10% from 0% to 100% capacity and the steady state flow for each increment was recorded. Then the valve was gradually stepped down and the flow rates recorded like Figure 6, where the centre linear line represents an ideal valve. This was repeated three times to ensure consistent results, only one of the three sets of results is in the results section, the other results are in Appendix 1. All results were logged in Labview to a comma separated file and analysed using Microsoft Excel.
3.4 Valve type and sizing

The flow coefficient (Cv) and the flow characteristic curves directly quantify and represent the effect a valve’s type and sizing has on the flow. The flow coefficient quantifies the valve’s flow capacity, as it is the gallons of water that passes through the valve over a period of one minute with the difference in pressure through the valve set as 1 psi at a temperature of 60°F. The type and size of a valve determines the value of the flow coefficient, specifically the trim and body style and size [10]. Knowing the flow coefficient allows an easy comparison of different valve’s fluid flow ability because it is measured and obtained with specified standard experimental conditions. It can also be obtained mathematically using Equation (3.1) given the following is known [1]:

\[ C_V = Q \frac{\sqrt{SG}}{\Delta P} \]  

(3.1)

Throughout this project the flow coefficient was obtained from data sheets or written on the valve itself. The flow coefficient only represents the maximum flow capacity and does not give an indication of how the flow changes with valve opening in the build up to the maximum; this is where the inherent characteristic curve is superior. The inherent characteristic is the relationship between the flow coefficient as a percent of the maximum and the percent valve opening [10]. The style of this curve and its movement depends on the type of closure member. The flow characteristic is generally categorised as linear, equal percentage or quick opening as seen in Figure 7.
• Linear: Useful for systems that have a constant gain [11]. A linear valve is one in which the percent of maximum flow increases linearly with the percent stem opening. These valves perform well when used for water systems [12].
• Equal Percentage: As the valve opening increases, the flow rate increases by a percentage of the preceding flow [13].
• Quick Opening: Commonly used for on/off applications; quick opening valves give a large increase in flow rate for small changes in the valve opening from the closed position [13].

The inherent characteristic is obtained under standardised temperature and pressure testing conditions, while the installed characteristic curve is acquired as the valve operates in the process it is intended for, with actual pressure and temperature conditions. Under installed process conditions different components of the system may have nonlinearities or interact and affect each other causing nonlinearities [14]. Ideally the installed characteristic curve will be linear. Nonlinear characteristics result in controllers that are not tuned for all operating points and only produce prime results for one operating point. The process speed could become quite slow as the valve position moves away from this point [15]. In order to obtain a linear installed characteristic curve and a constant process gain an inherent characteristic other than linear, such as equal percentage or fast opening, may be selected to compensate for any the nonlinearities or for any system gain changes.

Valve type and sizing through the selection of flow coefficient and characteristic curves can either optimize process production or impair it. A valve that is too small or has a small flow coefficient will not allow sufficient fluid to pass, starving the process. The valve needs to be small enough so that

![Figure 7 Inherent Valve Characteristics](image)
most of the gain is still coming from the controller and not the valve, otherwise it can result in the
decrease in adjustability of the controller [1]. A reduction in controller gain will often be required in
order to maintain stability.

The installed flow characteristic was measured by recording the flow as the valve opening was
manually stepped up from 0% to 100% in increments of 10%. The flow was recorded for each step
once it had reached a steady state.

There are two main types of existing valves in the Instrumentation and Control Laboratory and two
main systems, the water system and the air system. From flow coefficient and characteristic curves it
can be determined which valve is suited for air or for water. The existing Research valves either have
a Cv of 0.2 or a Cv of 1.25. An air valve in the Instrumentation and Control Laboratory would be
identified as having a flow coefficient smaller than a water valve because air is less dense than water
so it flows through the valve a lot quicker. A valve with Cv of 0.2 would be suited for use on the air
system whereas a valve with Cv of 1.25 would be suited for use on the water system; this is how
they are currently utilised. This is currently one existing Badger Meter Research Valve that is fitted
incorrectly which is identified as M17/c; it has a “C” trim type with a corresponding Cv of 1.25 so it is
better suited to the water system but it is fitted in the air system.

If the flow coefficient is not known a good indication of whether the valve is suited for air or for
water can be obtained experimentally from the installed characteristic curve. An oversized valve or a
water valve used on the air system will rapidly increase the flow rate at small changes in stem
position until the flow saturates. An undersized valve or air valve used on the water system would
only let a small amount of fluid through with large changes in stem position when compared to a
water valve used on the water system [13].
3.5 Dead Band

Dead band is the band through which the manipulated variable can be changed in both directions without a change in the process variable being observed. Dead band is triggered by backlash and friction where backlash is the outcome of loose mechanical connections within a device when the direction of the device input changes [1]. Having a small dead band improves a control valve’s performance and is an important characteristic; it means the valve has a higher level of accuracy due to its ability to respond to minor changes, therefore decreasing process variability [1].

The dead band was tested by changing the system controller output in Labview in various steps of 0.25% up to 5%. In most cases the initial valve opening was set to 55% and step changes were made above and below 55%. The per cent valve openings to test the dead band was: 55; 54.75; 54.5; 54.75; 55.5; 55; 54.5; 54; 54.5; 56; 55; 54; 55; 57; 55; 53; 55; 60; 55; 50; and 55.

The flow rate, valve opening and time were logged to a comma separated value file. The data was then analysed in Microsoft Excel with the flow rate and valve opening being plotted against time. The dead band was then evaluated by observing whether the flow rate was changing with per cent step changes as seen in Figure 8 [2] where the dead band is 5%. This was repeated three times to ensure consistent results, only one of the three sets of results is in the results section, the other results are in Appendix 2.

![Figure 8 Dead Band Test](image)

Figure 8 Dead Band Test [2]
3.6  Dead Time

Dead time is generally the time taken from when the input signal is sent, to the time when the actuator first moves in response, or the time from when the input signal is sent to when the process variable reacts. The first scenario requires a way to measure the time the signal changes to the time the stem first moves. A way to accurately measure the time the stem first moved was not identified without the use of additional equipment. Therefore in this case the second dead time has been used. This dead time would be slightly longer than the time the stem first moved. Dead time allows the evaluation of the valve response time, in order to compare the speed of the valve. Some of the causes of dead time include the holding time of measurements within the control loop; the time it takes for fluid to travel from the valve to the flow meter; the time for sensors to produce results; and the time it takes for the valve to process a signal change, convert it into pressure initiating stem movement [16]. Dead time can be improved by using shorter pipes, using a fast responding valve, having sensors close to the manipulated variable and using fast responding sensors [16].

To test the dead time, the valve was initially set to 50% instead of zero because between 0% and 20% valve opening there was not enough flow for the flow meter to register any changes. In order to get a more accurate representation of the dead time for the entire range of the stem span, the valve was initially set to 50%. The valve opening was then stepped up 2% in Labview to 52% then to 54% and 56%, then an average of the 3 dead times was calculated to gain an accurate result. The results were logged and exported to Microsoft Excel for analysis.
4. Results

4.1 Valve Calibration Results

**Baumann 24000S with Fisher 3660 Positioner Calibration**

The Baumann 24000S with Positioner has an input current signal of 4 to 20mA and a resulting pressure of 3 to 15psi [5]. The setup for the calibration of the Baumann 24000S is shown in Figure 9.

Between 4mA and 5mA the pressure increased significantly from 0psi to 5.5psi. A significant jump was observed between 19mA- 20mA from approximately 14.5psi to 20psi. The range of pressure change stayed within the bounds of 0-100% at a current range of 4-20mA. Between 5-19mA the pressure increased linearly as seen in Figure 10. These jumps in pressure indicate that the valve requires more pressure to get the stem to the correct position for the lower and higher signals.

![Figure 9 Calibration Setup for Baumann 24000S with Fisher 3660 Positioner](image)

![Figure 10 Baumann 24000S with Fisher 3660 Positioner I/P Converter Calibration Results](image)
Recommendations: Reading the pressure from the pressure gauge is subject to errors, purchasing the Fluke 744 pressure module [22] would give a more accurate reading of the pressure due to the digital interface.

**Baumann 24000S with Electric Actuator**

The Baumann 24000S with Electric Actuator was tested using a slightly different method to the other valves due to the addition of the electric actuator. Instead of feeding a current input signal, an equivalent input voltage of 2-10V was implemented. Instead of recording pressure, output voltage was noted. This valve does not have an I/P converter, instead it has an input current or voltage and an output current or voltage. A 24 VAC transformer to power the electric actuator was required and no instrument air was needed. Instrument air was not required for this valve as the actuator electronically shifts the valve stem. The results of this calibration are displayed in Figure 11 where output voltage increases linearly with input voltage until it rapidly increases at 6V. The Baumann 24000S with Electric Actuator exhibited interesting behaviour, unlike the other valves it was extremely slow and once the input voltage reached 7V the stem would not move any further than halfway to fully open as seen in Figure 11. The Baumann Actuator instruction manual [17] outlines the travel time at a maximum of 150 second for 0.5 and 0.75 inch travel and spring fall time of 30 seconds for full travel. This shows it is actually designed to be sluggish; the reasoning for this was discussed in the valve type section of this report. In investigating why the valve would only open half way, the actuator casing was opened and there were switches for auto calibration. An auto calibration was performed. The stem only reached half way on the travel indicator. The data sheet states the full range is approximately 20mm which is half way on the travel indicator; it is again designed to perform this way, the travel indicator is larger than what it should be.

![Baumann 24000S with Electric Actuator Calibration](Image)

Figure 11 Baumann 24000S with Electric Actuator Calibration Results
Baumann 51000 Calibration

The Baumann 51000 manual states that the input current signal ranging from 4 to 20mA should result in a pressure of 3 to 15psi, however in Figure 12 this was not the case. The Baumann 51000 has a 582 module which is not adjustable, meaning there is no zero or span screws, providing no means to change the calibration settings. When the Baumann 51000 valves were manufactured they would have a positioner on the outlet that would adjust the valve mechanically to give the correct output despite the valves calibration settings. The manager from Western Process Controls has suggested in order to compensate for the un-adjustable valve calibration errors, the valve should be fitted with an adjustable module or positioner; however this is not possible as compatible fittings are no longer manufactured. Another suggestion is to calibrate the process controller to compensate for the un-adjustable valve. This is not ideal, as the process variable would need to be affected before the controller would respond. Due to calibration errors, it is advised that these valves only be used for teaching and learning purposes and not in industrial applications.

![Figure 12 Baumann 51000 Calibration Setup](image)

Another observation made from Figure 13 is that, unlike the Baumann 24000S with Fisher 3660 Positioner that has a pressure of zero at 4mA, the Baumann 51000 has an elevated zero. This is useful to technicians when there is a problem as it is easier to fault find. If the power goes out the
valve pressure will be at 0. If the fault is with the instrument air the pressure will be fine at its elevated zero.

4.2 Troubleshooting

This section will provide insight into some of the challenges faced while conducting and setting up for experimental testing within the Instrumentation and Control Laboratory. It gives an explanation why further testing was not conducted on some of the valves. This section has also been provided to help future students when encountered with the similar problems.

Troubleshooting 1

Several concerns were revealed while testing the Badger Meter Research valve fitted for the air system. These include:

- The M19/a Research valve was producing results expected for a water valve used on the air system. The flow coefficient of 0.2 was obtained for the data sheet, which is correct for an air valve consequently it is not a water valve; it is indeed an air valve.
- The M19/b Research valve has the same specifications as the M19/a, however it has different results that are neither suited for the air or water systems.

Based on this information predictions of the cause of these errors include:

- If the error is caused by a malfunction of the flow meters then swapping the flow meters would not produce the same results for the corresponding valve.
- If the error is caused by a malfunction in the valves, then swapping the flow meters would produce the same results for the corresponding valve.

Each flow meter was labelled “g” and “d” in order to keep track of them.

M19/a with “g” flow meter in Figure 14 gives different results than with “d” in Figure 15, with the “d” flow meter it gives results expected for an air valve. The flow is stepping in proportion to the valve opening. With the “g” flow meter the valve is acting similar to what would be expected from a water valve fitted for the air system in which the valve is oversized for the system. The flow rate rapidly increases with each step until it saturates. Referring back to the proposed causes of the test differences tests there must be a malfunction in the flow meters because it is the same valve with different flow meters and the results are not the same.
Further testing was conducted with each flow meter with the Badger Meter Research valve M19/b. Figure 16 and Figure 17 show that the flow rate does not change between 0-40% valve openings, and then it rapidly increases. This is consistent between both flow meters, which suggest there is a fault with the M19/b valve that should be looked into further in the future.
With the M19/a the results are different for each flow meter but with the M19/b the results are the same, suggesting that the errors are due to both the flow meters and the valves. Further testing was conducted with the Baumann 24000S with Fisher 3660 positioner to make a final conclusion about the cause of the discrepancies.
The Baumann 24000S was tested with each flow meter and each Research Valve as seen in Figures 18 and 19 in which different results were obtained. The flow rate in Figure 18 increases with each step increase of the valve opening, this is as expected. In Figure 19 the flowrate increases rapidly then saturates once the valve is open 50 percent, this is not what is expected from the valve.
In Table 1 the results for all tests are summarised with the results categorised as either expected or unexpected.

### Table 1 Badger Meter Research Air Valve and Air Flow Meter Troubleshooting

<table>
<thead>
<tr>
<th>Valve</th>
<th>Flow Meter</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>M19/a</td>
<td>g</td>
<td>unexpected</td>
</tr>
<tr>
<td>M19/a</td>
<td>d</td>
<td>expected</td>
</tr>
<tr>
<td>M19/b</td>
<td>g</td>
<td>unexpected</td>
</tr>
<tr>
<td>M19/b</td>
<td>d</td>
<td>unexpected</td>
</tr>
<tr>
<td>M19/a + Baumann</td>
<td>g</td>
<td>expected</td>
</tr>
<tr>
<td>M19/b + Baumann</td>
<td>d</td>
<td>unexpected</td>
</tr>
</tbody>
</table>

From Table 1 we see that M19/b is consistently providing unexpected results. This strongly suggests this valve has discrepancies requiring maintenance and calibrating. M19/a results are generally as expected however one set is still unexpected as it behaves like a water valve used on the air system. It is also suggested that the flow meters be mounted to their own panels so the Baumann 24000S does not have to flow through the Research valve. This would make troubleshooting in future easier as the flow meters would not constantly have to be taken to the workshop to be removed. Due to the obvious inconsistencies with M19/b no further performance tests were conducted on this valve. As M19/a and M19/b are the only air valves only one air valve, the M19/a, will be compared with the Baumann 24000S for the remainder of this project.

### Troubleshooting 2

While setting up to test the M17/c water valve fitted for air in which the air would have to pass through the M19/a with a flow meter, an error occurred where the M19/a was not opening. The possible causes of this included:

- The control systems analogue output was not working.
- The valve was damaged.
- The lead was damaged.

The analogue output was changed to one that had just been previously working for the M17/c, but the M19/a was still not responding. So either the valve or the lead was the problem. The leads were then changed and the M19/a responded.
Troubleshooting 3

A step test was performed to get the characteristic curve of the Badger Meter Research M17/c water valve fitted for air connected to the M19/a air valve and flow meter. The flow rate for a water valve fitted for the air system increases rapidly with small changes in valve openings, then saturates above 100%. The results in Figure 20 showed the flow did not change between 0%-30% valve openings. The M17/c was disconnected from the system in order to check if the M19/a was causing the errors. This was not the case as the M19/a generated results like prior tests. The M17/c was reconnected, no stem movement was observed between 0%-30% valve openings resulting in no fluid flow. A scale attached to the stem to measure its position had 10 increments. The stem position in relation to these increments for each valve opening was observed and recorded in Table 2. At 100% the stem position is only 7 increments out of 10, the valve is not going to its maximum position. This valve should be recalibrated and requires a span and zero adjustment.

![Badger Meter Research Valve M17/c (water valve fitted for air) Step Test](image)

Figure 20 Badger Meter Research Valve M17/c (water valve fitted for air) Step Test
### Table 2 Badger Meter Research Valve M17/c Stem Movement with Valve Opening

<table>
<thead>
<tr>
<th>Valve Opening</th>
<th>Increments (Stepping Up)</th>
<th>Increments (Stepping Down)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40%</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>50%</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>60%</td>
<td>3.5</td>
<td>3</td>
</tr>
<tr>
<td>70%</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>80%</td>
<td>5.5</td>
<td>5</td>
</tr>
<tr>
<td>90%</td>
<td>6.5</td>
<td>6</td>
</tr>
<tr>
<td>100%</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

#### 4.3 Hysteresis Results

The Baumann 24000S with Fisher 3660 Positioner water valves in both Figures 23 and 24 have no visible hysteresis. The Badger Meter Research water valves in both Figures 21 and 22 have obvious hysteresis. The data was analysed to see what the maximum difference between the stepping up and the stepping down. The Research valve had a maximum difference of 7.4% at a valve opening of 30%. The Baumann 24000S with Fisher 3660 Positioner had a maximum difference of approximately 0.193%. The Baumann 24000S has significantly less hysteresis than the Research valve. This is due to the Baumann 24000S addition of the Fisher 3660 Positioner. Positioners eliminate hysteresis due to the adjustable air pressure that can be adjusted to overcome friction [4]. The positioner continuously checks that the stem has reached the set point. If not the air pressure adjusts so the measured stem position is the same as the desired, resulting in one value for each signal eliminating hysteresis.

Another observation made from the Research valve M08/a and the Baumann 24000S valve 1 in Figures 21 and 23 is that a significant range from 0% to 20% of the valve opening resulted in no measured flow. This could either be a consequence of the valves not letting fluid through, in which case no stem movement would be observed or the flow meter not working properly. Stem movement of the Baumann 24000S was observed for all signal changes both during the calibration and conducting these tests. This confirms that from 0% to 20% the valve stem was not stuck at zero and was allowing fluid to move through. The Research M08/a valve and Baumann 24000S valve 1 were tested with the flow meter attached to the M08/a panel; whereas the valves used in Figures 2 and 24 were tested with the flow meter on the M08/d panel, where a change in flow is observed between 0-20%. From these observations it is concluded that the flow meter is the cause of these
discrepancies and not the valves. It is suggested that further testing including calibration and maintenance be performed on the flow meter on the M08/a panel in the future works.

The Badger Meter Research valve M19/a used on the air system produced inconsistent results when compared with the results in Figure 25 with the additional results in Appendix 1 showing that repeatability of the results is an issue. This was discussed in the troubleshooting section which concluded that the valve should be calibrated and the air system flow meters need to be checked.

The results in Figures 26 and 27 show that the Baumann 24000S used on the air system produce different results when partnered with different flow meters. This gives an indication that the valves are likely to be the cause of these discrepancies. Despite the errors exhibited, the Baumann 24000S is still consistently providing less hysteresis than the Research valves.

**Water System**

![M08/a Badger Meter Research (Water) Valve Hysteresis Test 1](image)

*Figure 21 Badger Meter Research (Water) Valve M08/a Hysteresis Test 1 Results*
Figure 22 Badger Meter Research (Water) Valve M08/d Test 1 Hysteresis Results

Figure 23 Baumann 24000S (Water) Valve 1 with Fisher 3660 Positioner Test 1 Hysteresis Results (The two curves are almost superimposed.)
Figure 24 Baumann 24000S (Water) Valve 2 with Fisher 3660 Positioner Test 2 Hysteresis Results (The two curves are almost superimposed.)

Air System

Figure 25 Badger Meter Research Valve M19/a Hysteresis Test 1 Results
Figure 26  Baumann 24000S with Fisher 3660 Positioner (Air) Valve 1 with M19/b Hysteresis Test 1 Results

Figure 27  Baumann 24000S with Fisher 3660 Positioner (Air) Valve 2 with M19/a Hysteresis Test 1 Results
4.4 Valve Type and Sizing Results

Flow Coefficient

In the Instrumentation and Control Laboratory there is an air system and a water system. Section 3.4 provided information that showed the flow coefficient would be larger for a valve used on the water system than a valve used for air. The existing Badger Meter Research with a flow coefficient of 0.2 would be used for the air system. The valves with a flow coefficient of 1.25 would be used for the water system. The new Baumann 24000S with Fisher 3660 Positioner valves have a flow coefficient of 0.2 making it well matched for air or a coefficient of 1 for use with water. The flow coefficient valve size or style changes with. Both of these valves are 1/2” in size but the trim style is different; both where the trim is in the plug and the seat arrangement. The orifice (the flow area or diameter between the plug and seat) will change with different trims. In this case as shown in Table 3 the larger orifice results in a larger Cv.

Table 3 Badger Meter Research Valve Flow Coefficient

<table>
<thead>
<tr>
<th>Trim designation</th>
<th>Max Cv</th>
<th>Orifice diameter (inch)</th>
<th>Orifice area (square inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1.25</td>
<td>0.2810</td>
<td>0.0620</td>
</tr>
<tr>
<td>G</td>
<td>0.2</td>
<td>0.1560</td>
<td>0.0191</td>
</tr>
</tbody>
</table>

The Baumann 24000S valves in Table 4 are both ½” and have the same orifice and plug travel. However the trim styles are different. The valve with flow coefficient of 0.2 has a linear low flow style trim whereas the valve with the flow coefficient of 1 has a linear trim.

Table 4 Baumann 24000S Flow Coefficient

<table>
<thead>
<tr>
<th>Trim designation</th>
<th>Max Cv</th>
<th>Orifice diameter (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>102 Linear Low Flow</td>
<td>0.2</td>
<td>0.25</td>
</tr>
<tr>
<td>688 Linear</td>
<td>1</td>
<td>0.25</td>
</tr>
</tbody>
</table>

In contrast to the Baumann 24000S the flow coefficient of the Research water valve is 1.25. The flow coefficient of the Baumann is 1; this indicates that the Research valve has a larger flow capacity. The flow coefficient of the Research air valve is 0.2 which is the same as the Baumann 24000S. This indicates that both valves have the same flow capacities.

Water System Characteristic Curves

The inherent characteristic curves for the Baumann 24000S and the Research valves are specified as linear. The installed characteristic curves in Figures 30 and 31 show the Baumann valves continue to have strong linear relationships with r squared (measure of closeness in proximity of data is to linear curve) values of 0.9857 and 0.993. The Research valves with r squared values of 0.9283 and 0.8584 in Figures 28 and 29 do not maintain a linear relationship as strong as the Baumann 24000S.
The Baumann 24000S installed characteristic curves in Figures 30 and 31 seem to change from slightly equal percentage towards linear, and then to quick opening. This is as anticipated as the pressure drop increases when the flow rate decreases [10]. The installed characteristic curves of the Research valves in Figures 28 and 29 do not behave like this as they appear to have more of a quick opening curve since the flow rate is changing quickly with small changes in the valve opening. The pressure drop across the Research valve could be a cause of this difference in behaviour of the installed characteristic curves. The pressure across the valve has caused the flow to choke as it changes valve opening. Both valves have different types of linear trims; the differences in trim react differently with the nonlinearities within the system.

The difference in installed characteristic curves is also be affected by the Baumann 24000S addition of the controller which ensures that for each current signal, the correct stem position is obtained. The Research valve change in signal is not proportional to the valve opening because the signal is sent and the valve moves in response. However there is no controller to ensure that the stem is in the right position.

**Air System Characteristic Curves**

From Figure 32 it can be observed that the Badger Meter M19/a air valve responds similar to the water valve used on the air system, as small changes in valve opening cause significant changes in flow until it saturates. This was discussed previously the troubleshooting section of the report, which found that this valve has a Cv of 0.2 implying it is an air valve. These results suggest that this valve is not functioning as specified and need to be replaced.

Figures 33 and 34 shows that the Baumann 24000S used on the air system has a stronger linear relationship compared to the Research valve. This is as expected given the errors produced by the Research valve.
Water System

**Figure 28** The Installed Characteristic Curve for Badger Meter Research (Water) Valve M08/a

**Figure 29** The Installed Characteristic Curve for Badger Meter Research (Water) Valve M08/d
**Baumann 24000S (Water) Valve 1 with Fisher 3660 Positioner**

**Installed Characteristic Curve**

![Graph showing the Installed Characteristic Curve for Baumann 24000S (Water) Valve 1 with Fisher 3660 Positioner. The graph includes a line with an R² value of 0.9857.]

**Figure 30** The Installed Characteristic Curve for Baumann 24000S (Water) Valve 1 with Fisher 3660 Positioner

---

**Baumann 24000S (Water) Valve 2 with Fisher 3660 Positioner**

**Installed Characteristic Curve**

![Graph showing the Installed Characteristic Curve for Baumann 24000S (Water) Valve 2 with Fisher 3660 Positioner. The graph includes a line with an R² value of 0.993.]

**Figure 31** The Installed Characteristic Curve for Baumann 24000S (Water) Valve 2 with Fisher 3660 Positioner
Figure 32 The Installed Characteristic Curve for Badger Meter Research (Air) Valve M19/a

Figure 33 The Installed Characteristic Curve for Baumann 24000S (Air) Valve 1 with Fisher 3660 Positioner and M19/b
Figure 34 The Installed Characteristic Curve for Baumann 24000S with Fisher 3660 Positioner (Air) Valve 2 with M19/a
4.5 Dead Band Results

Dead band is the band through which the manipulated variable can be changed in both directions without a change in the process variable being observed. The Baumann 24000S with Fisher 3660 Positioner water valve dead band was 0.5% as seen in Figures 37 and 38. The Badger Meter Research water valves in Figures 35 and 36 have a dead band of 5%. The Research valve in comparison with the Baumann 24000S demonstrates the positioner’s ability to significantly improve the dead band of a valve. These results were exactly as expected as the Instrument Engineers’ Handbook [11] states “the dead band of a valve/actuator combination can be as much as 5%; when a positioner is added, it can be reduced to less than 0.5%”. The positioner decreases the dead band because it continuously checks for errors between the desired stem position and the measured stem position. If there is a difference, corrective action takes place, with the adjustment of the instrument air. Without a positioner no corrective action occurs, as the signal is being sent but there is nothing checking to see if the stem is in the right location.

Dead band can be overcome by the overall process controller. This is not ideal as a large error between the desired flow rate and the measured flow rate is required for the controller to cause an adjustment in the valve. The positioner does not require a difference in the desired flow and the measured flow to be affected for corrective action to occur. The positioner will adjust if there is an error between the desired stem position and the measured stem position before the flow is affected.

Dead band and hysteresis could also be decreased by regular valve maintenance, because the main causes of dead band are backlash and friction and the main cause of hysteresis is friction. Backlash occurs when the input of a device changes direction and slack occurs between the input and output due to loose mechanical connections [1]. Friction can be reduced by regularly lubricating the valve; backlash can be reduced by ensuring mechanical connections are tightened regularly. The Baumann 24000S is a brand new valve whereas the Research valve is old with an unknown service and maintenance history, so it experiences more friction and backlash.

When changing direction of the Research valve opening in Figure 35, the final steady state flow rates are different for the same valve opening, whereas in Figure 37 the Baumann 24000S consistently settles to the same flow rate despite the direction of valve opening. This indicates the Baumann 24000S lack of hysteresis and the Research valves obvious hysteresis that is visible from the dead band test results.

Figure 40 displays a larger dead band for the Baumann 24000S when fluid is also passed through the Research valve M19/b when compared to Figure 41, in which fluid is passed through the M19/a. This
suggested that the flow meters in the air system should be permanently disconnected from the valves in order to get the Baumann 24000S dead band without errors from the Research valves impacting the flow. Even with the addition of the errors from the Research valves, the Baumann 24000S still provides a significantly smaller dead band.

**Water System**

![Diagram of Badger Meter Research Valve M08/a (Water Valve) Deadband- Test 1](image)

*Figure 35 Badger Meter Research (Water) Valve M08/a Dead Band Results*
Figure 36 Badger Meter Research (Water) Valve M08/d Dead Band Results

Figure 37 Baumann 24000S (Water) Valve 1 with Fisher 3660 Positioner Dead Band Results
Figure 38 Baumann 24000S (Water) Valve 2 with Fisher 3660 Positioner Dead Band Results

Air System

Figure 39 Badger Meter Research (Air) Valve M19/a Dead Band Results
Figure 40 Baumann 24000S (Air) Valve 1 with Fisher 3660 Positioner and M19/b Dead Band Results

Figure 41 Baumann 24000S (Air) Valve 2 with Fisher 3660 Positioner and M19/a Dead Band Results
4.6  Dead Time Results

The Badger Meter Research valves consistently have a longer dead time than the Baumann 24000S with Fisher 3660 Positioner valves as shown in Tables 5 and 6. Some of the causes of dead time include the holding time of measurements within the control loop; the time it takes for fluid to travel from the valve to the flow meter; the time for sensors to produce results and the time it takes for the valve to respond to process signal changes by converting it into pressure, initiating stem movement [16]. The length pipes, sensors and other system components were kept constant except for the valve itself; this indicates the Baumann 24000S responds to process signal changes quicker and initiates stem movement faster than the Research Valves.

Water System

Table 5 Water System Dead Time Results

<table>
<thead>
<tr>
<th>Valve</th>
<th>Dead Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badger Meter Research Valve M08/a</td>
<td>3.85</td>
</tr>
<tr>
<td>Badger Meter Research Valve M08/d</td>
<td>3.44</td>
</tr>
<tr>
<td>Baumann 24000S Valve 1 with Fisher 3660 Positioner</td>
<td>2.89</td>
</tr>
<tr>
<td>Baumann 24000S Valve 2 with Fisher 3660 Positioner separate flow meter</td>
<td>2.56</td>
</tr>
</tbody>
</table>

Air System

Table 6 Air System Dead Time Results

<table>
<thead>
<tr>
<th>Valve</th>
<th>Dead Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badger Meter Research Valve M19/a</td>
<td>3.44</td>
</tr>
<tr>
<td>Baumann 24000S Valve 1 with Fisher 3660 Positioner and M19/b</td>
<td>2.67</td>
</tr>
<tr>
<td>Baumann 24000S Valve 2 with Fisher 3660 Positioner and M19/a</td>
<td>2.67</td>
</tr>
</tbody>
</table>
4.7 Results Summary
The findings of this project are summarised in Tables 7 and 8. In Table 7 the Badger Meter Research valve had

- observable hysteresis;
- the installed characteristic curve did not have the strongest linear relationship;
- significantly larger dead band;
- a slower dead time.

The Baumann 24000S with Fisher 3660 Positioner had

- no visible hysteresis;
- it had the strongest linear relationship;
- a small dead band of 0.5%;
- a quicker dead time.

Based on these findings it is determined that the Baumann 24000S with Fisher 3660 Positioner surpasses the performance of the Badger Meter Research valve, therefore it is advised that the Baumann 24000S with Fisher 3660 positioner is a suitable replacement for the Badger Meter Research valve.

Table 8 summarises the findings of the valves used on the air system. Most results provided the same conclusions as Table 7, that the Baumann 24000S had stronger linearity, less dead band and a faster dead time. Unlike Table 7 the hysteresis for the Baumann 24000S used on the air system was observable although still less than the Research valve. The Baumann 24000S also did not produce constant results for the dead band. These errors are a result of the Research valve being permanently connected to the air valve flow meters. The Research valves cause inconsistencies with the Baumann 24000S results because the fluid has to flow through both valves. The Research air valves should be replaced or serviced as they do not perform as specified by their manufacturer.
### Water System

**Table 7 Summary of Water System Test Results**

<table>
<thead>
<tr>
<th>Test</th>
<th>Badger Meter Research Valve M08/a</th>
<th>Badger Meter Research Valve M08/d</th>
<th>Fisher 3660 with Positioner Valve- 1</th>
<th>Fisher 3660 with Positioner Valve- 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.9283</td>
<td>0.8584</td>
<td>0.9857</td>
<td>0.993</td>
</tr>
<tr>
<td>Flow Characteristic Linearity ($r^2$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Coefficient</td>
<td>1.25</td>
<td>1.25</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dead Band</td>
<td>5%</td>
<td>5%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Dead Time (s)</td>
<td>3.85</td>
<td>3.44</td>
<td>2.89</td>
<td>2.56</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>Yes</td>
<td>Yes</td>
<td>Not Observable</td>
<td>Not Observable</td>
</tr>
</tbody>
</table>

### Air System

**Table 8 Summary of Air System Test Results**

<table>
<thead>
<tr>
<th>Test</th>
<th>Badger Meter Research Valve M19/a</th>
<th>Fisher 3660 with Positioner Valve- 1 with M19/b</th>
<th>Fisher 3660 with Positioner Valve- 2 with M19/a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.872</td>
<td>0.9812</td>
<td>0.9778</td>
</tr>
<tr>
<td>Flow Characteristic Linearity ($r^2$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Coefficient</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Dead Band</td>
<td>7%</td>
<td>1%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Dead Time (s)</td>
<td>3.44</td>
<td>2.67</td>
<td>2.67</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>Significant</td>
<td>Significantly less than M19/a</td>
<td>Significantly less than M19/a</td>
</tr>
</tbody>
</table>
5. Conclusion

This project sets out to analyse the operability and performance of the Baumann 24000S with Fisher 3660 Positioner in comparison with the Badger Meter Research Valve by investigating the usage and functionality, valve type and sizing, dead band, dead time, and hysteresis.

The valve usage was identified with the flow coefficient and either specified as an air valve or water valve. The Baumann 24000S water valve has a Cv of 1 and Research Water Valve has a Cv of 1.25; both air valves are smaller with a Cv of 0.2. Air is less dense than water so it flows through the valve a lot quicker consequently only a small orifice valve is required for air.

The first test exploring the hysteresis found that, when tested on the water system, the Baumann 24000S valve had no visible hysteresis and the Research water valve did demonstrate hysteresis. This is a result of the addition of the positioner which reduces hysteresis by ensuring the valve stem consistently moves to the same position, despite the direction of movement of the stem.

The valve type and sizing was analysed by examining the flow coefficient and characteristic curves. It was found that the Baumann 24000S had a more linear characteristics compared to the Research valve. This is due to a combination of the trim styles, the pressure drop through the valve, and the addition of the positioner.

Testing the dead band showed the Baumann 24000S has significantly less dead band than the Research Valve. Positioners have the ability to check the stem is in the right position, so it can easily adjust to overcome dead band before the flow is affected. Maintenance of a valve also has an effect on the amount of dead band and hysteresis. The Baumann 24000S is a new valve so it would not need maintenance like the Research Valve.

The dead time results indicated the response time of the Baumann 24000S was quicker than the Research valve.

The hysteresis for the Baumann 24000S used on the air system was observable although still less than the Research valve. The Baumann 24000S also did not produce consistent dead band results. The Research valves are permanently connected to the air valve flow meters resulting in inconsistencies with the Baumann 24000S results.

Based on these findings it is advised that the Research air valves be replaced or serviced as they do not perform as specified by their manufacturer. It was also found that the positioner significantly improves the performance of a valve. Under all performance tests the Baumann 24000S with Fisher
3660 Positioner surpasses the Badger Meter Research Valve and is a suitable replacement for the Badger Meter Research Valve.

5.1 Future Work
As this is the first project focusing primarily on the control valves in the Instrumentation and Control laboratory, there is a lot of work that can be undertaken in future projects which include:

- Analysing and comparing the performance of the Baumann 51000 high pressure low flow valve; the Fisher 24000S with electric actuator and the existing control valves in the Pilot Plant. These valves could also be compared with the Baumann 24000S with Fisher 3660 Positioner or the Badger Meter Research valves.
- Further analysis of the dead time by testing the time from when the valve opening signal change is sent to when the stem first moves in response.
- Additional performance tests could include how the maintenance of the valve affects the valve performance; further research into valve type and sizing; analysing the resolution; investigating valve and valve positioner overshoot; modelling the valves and tuning controllers to compensate for these nonlinearities.
- The I/P converter of the Badger Meter Research valves used for the air system should be calibrated, in which case a pressure gauge needs to be fitted.
- The Fluke 744 pressure module should be purchased in order to accurately measure the pressure while calibrating the I/P converter; in this case a pressure gauge attached the Badger Meter Research Valve is not required.
- The Badger Meter Research valves could also be calibrated in terms of current signal to stem position.
- The flow meters all need testing as some of them seem to give inconsistent results. It is also advised that all the flow meters should be mounted on separate panels or permanently disconnected from the existing valves. This will allow the valves to be tested with different flow meters and to ensure that there is no interference from the existing valves.
References


Appendices

Appendix 1- Hysteresis Test Results

Badger Meter Research Water Valve Results

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**M08/a Badger Meter Research (Water) Valve Hysteresis Test 2**

- **Flow Rate (%)** vs. **Valve Opening (%)**
- **Stepping Up** vs. **Stepping Down**

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**M08/a Badger Meter Research (Water) Valve Hysteresis Test 3**

- **Flow Rate (%)** vs. **Valve Opening (%)**
- **Stepping Up** vs. **Stepping Down**
M08/d Badger Meter Research Valve
Hysteresis Test 2

Flow Rate (%)

Valve Opening (%)

Stepping Up
Stepping Down

M08/d Badger Meter Research Valve
Hysteresis Test 3

Flow Rate (%)

Valve Opening (%)

Stepping Up
Stepping Down
Baumann 24000s with Fisher 3660 Positioner (Water 1)
Hysteresis Test 2

% Flow Rate
% Valve Opening

Stepping Up
Stepping Down

Baumann 24000s with Fisher 3660 Positioner (Water 1)
Hysteresis Test 3

Flow Rate (%)
Valve Opening (%)

Stepping Up
Stepping Down
Baumann 24000S with Fisher 3660 Positioner  
(Water 2)  
Hysteresis Test 1

Baumann 24000S with Fisher 3660 Positioner  
(Water 2)  
Hysteresis Test 3
Hysteresis Test 2 Badger Meter Research Valve M19/a

Hysteresis Test 3 Badger Meter Research Valve M19/a
Baumann 24000S with Fisher 3660 Positioner Air Valve Results

Baumann 24000S with Fisher 3660 Positioner (Air) Valve 1 with M19/b
Hysteresis Test 2

Stepping Up
Stepping Down

Baumann 24000S with Fisher 3660 Positioner (Air) Valve 1 with M19/b
Hysteresis Test 3

Stepping Up
Stepping Down
Baumann 24000S with Fisher 3660 Positioner
(Air) Valve 2 with M19/a
Hysteresis Test 2

![Graph showing valve opening vs. flow rate for stepping up and down.]

Baumann 24000S with Fisher 3660 Positioner
(Air) Valve 2 with M19/a
Hysteresis Test 3

![Graph showing valve opening vs. flow rate for stepping up and down.]

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Appendix 2- Dead Band Test Results

Badger Meter Research Water Valve Results

Badger Meter Research Valve M08/a (Water Valve) Deadband - Test 2

Badger Meter Research Valve M08/a (Water Valve) Deadband - Test 3
Baumann 24000S with Fisher 3660 Positioner Water Valve Results

Baumann 24000S with Fisher 3660 Positioner (Water) Valve 1 Dead Band - Test 2

Baumann 24000S with Fisher 3660 Positioner (Water) Valve 1 Dead Band - Test 3
Deadband M19/a Badger Meter Research (Air) Valve - Test 1

Flow Rate (%)
Valve Opening (%)

Time (s)

Deadband M19/a Badger Meter Research (Air) Valve - Test 3

Flow Rate (%)
Valve Opening (%)

Time (s)
Baumann 24000S with Fisher 3660 Positioner
(Air) Valve 2 with M19/a
Dead Band Test 2

Baumann 24000S with Fisher 3660 Positioner
(Air) Valve 2 with M19/a Dead Band Test 3