ANALYSIS OF PARTIAL STROKE TESTING FOR MASONEILAN EMERGENCY SHUTDOWN VALVE

By

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Hafiz Azizi Bin Azaldin

ABSTRACT

This study is about the Analysis of Partial Stroke Testing for Masoneilan Emergency Shutdown Valve. This project is a collaboration between PETRONAS Skill Group 14 (SKG14) through PETRONAS Group Technical Services (GTS) and Universiti Teknologi PETRONAS (UTP). The objectives for this project are to analyze the results obtained from Partial Stroke Test (PST) using Masoneilan ESD valves, analyze the effect of swapping the PST controller during PST experimental period and predict the breakaway pressure of ESD valves using Artificial Neural Network. In analyzing the PST for Masoneilan's ESD valve, PST data which is available in the historian were obtained. These data were based on the PST which had been done earlier for a specific time period. Later on, the data obtained will be analyzed using Microsoft Excel and MATLAB to see the PST performance. Besides, a neural network modeling also being used to predict the performance of the valve based on the data obtained from PST. The findings from PST shows that the parameter's data patterns such as friction, breakaway pressure and droop suddenly chanced starting day 54 onwards since the PST smart positioners had been swapped between ball and butterfly valves. This PST smart positioner swapping caused the analysis become inaccurate and the neural network model used to predict the breakaway pressure of the valve is unable to predict it accurately. To eliminate the influence of smart positioners swapping, the data had been divided into groups of data before the smart positioners had been swapped and the data after the smart positioners had been swapped. By doing this, the analysis become more accurate and the prediction of valve's breakaway pressure can be done by neural network modeling more accurate. As a conclusion, performing PST can help us in predicting how long the ESD valve can be used which can be as a guideline when to do the maintenance to ESD valve or replacing it.

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LIST OF ABBREVATIONS

PST	Partial Stroke Test
ESD	Emergency Shutdown
SKG14	Skill Group 14
GTS	Group Technical Services
UTP	Universiti Teknologi PETRONAS
PLC	Programmable Logic Controller
FST	Full Stroke Test
SIS	Safety Integrity System
SIL	Safety Integrity Level
PFD	Probability Failure on Demand
psi	pound per square inch
P&ID	Piping and Instrumentation Diagram
ANN	Artificial Neural Network
MSE	Mean Square Error
RMSE	Root Mean Square Error

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In process plant, Emergency Shutdown System (ESD) plays a major role in protecting people, instruments and also environments when plant trip occur. This unpredictable event may lead to major disaster to the plant as well as giving major impact to production profit. As a last line of plant protection system, ESD system will simultaneously react to the plant trip so that it can ensure the situation in a safe condition [15]. Generally, ESD system consists of sensors, logic solvers and final element [5]. Upon three elements mentioned 50% of the failure caused by final element [10]. The final element in ESD system is Emergency Shutdown (ESD) valve. In a real operation, ESD system is rarely used since it only operated when emergency occur. This can decrease the reliability of the ESD valve to work accordingly for safety function purpose [7].

To overcome the issue, partial stroke testing (PST) had been introduced to ensure system reliability and safety when process plant condition is in danger. This PST is a good solution to maintain the probability of failure on demand (PFD) for safe plant operation where it can save both plant initial and running cost compared to other methods in order to achieve plant safety integrity level (SIL) [1].

Before PST was introduced, industry depends on Full Stroke Test (FST) to test ESD valve. However, it is only possible during unit turnaround in order to demonstrate the performance [11]. As the mechanical reliability and preventive maintenance programs were done successfully, many operating companies have been able to extend the unit turnarounds interval from two or three years to five or six years. This turnaround interval extension gives great economic impact by increasing production but it means that the ESD valve is expected to be in good condition between the function tests, yet still achieve the same performance [3].

1.2 Problem Statement

There is no guarantee that ESD valve is in good condition when emergency occurs once it is in full open position for a long time [1]. The ESD valve maybe stuck in one position due to several factors such as dirt clogging and corrosion build up in ESD valve. By exercising the valve, the dirt build up can be reduced and the presents of corrosion can be indicated [8, 11]. The only possible way to fully test the valves are during schedule shutdowns and turnarounds.

Ensuring ESD valve in good condition is very critical since it will results in massive destruction to the plant if it cannot be operated properly when the situation require it to do so. Besides, the number of failure in PST around the world has given rise to concerns on the reliability of it. As different fluid pass through ESD valve has different characteristics, the result of PST will be different for different fluid being used.

Besides, the conventional testing method to test the reliability of ESD valve is too costly. This happen because well rained manpower will be hired just to do testing. Other than that, traditionally this test requires the process unit to shutdown. Shutdown the unit process will decrease the production rate which is a major concern to the company. In order to start up the unit, it takes some times to do so. For example, to start up the boiler it may takes a few days before the process unit is ready to be operated.

Table 1: Cost break down to test one valve [17]

Description	Rate	Cost
Manual Testing	2 pers. x 2 h x $60	$240
Reporting	1 pers. x 1 h x $60	$60
Management	1 pers. x 1 h x $80	$80
Data Handling	1 pers. x 1 h x $60	$60
Testing equipment & safety permits etc.	-	$60
Total to carry out testing for one valve		$500

Based on the Table 1 above, the cost need to be cover to test one valve only using conventional method is $500 [17]. If the plants have hundreds of ESD valve, we can estimate how much it cost just for testing. This figure does not include the loss of the plant if shutdown need to be done which may reach roughly around $60 000 just for a few hours unit shutdown.

Partial stroke test is very unique because the reliability of ESD valve can be tested without disturbing the process as compared to full stroke test which will definitely disturb the process since ESD valve will fully close. The only way to do full stroke test is during shutdown and turnaround [9]. If we only depend on full stroke test just to test the reliability of the ESD valve, the plant needs to face the issue of production loss due to certain need to be shutdown. However, implementing partial stroke test and full stroke test can reduce the production loss where the reliability of ESD valve still high even though the time interval for scheduled unit shutdown is extended to five or six years [7].

1.3 Objectives of the Project

The objectives of this project are listed as below:

a. To analyze the results obtained from Partial Stroke Test (PST) using Masoneilan ESD valves.

b. To analyze the effect of swapping the PST controller during PST experimental period.

c. To predict the breakaway pressure of ESD valves using Artificial Neural Network.

1.4 Scope of Study

The scope of work for this project is to analyze the data obtained from performing partial stroke test and full stroke test using dry test skid. The test was done by using vendor's database software. Safety, performance, efficiency and reliability are the aspects to be monitor. The data obtained will be used to measure the reliability of ESD valve. The data will be analyzed using two methods which are statistical analysis and modeling using MATLAB Artificial Neural Network (ANN) in order to predict the breakaway pressure of the valve based on sets of parameters obtained from the tests. In the project, two types of ESD valve will be used which are ball valve and butterfly valve.

Therefore, knowledge on the process control is essential in order to understand the background of the project. A basic understanding of Safety Integrity System (SIS) will help students to understand the purpose of the project and analyze the results from the project. Besides, the ability to analyze the data using both statistical analysis and Artificial Neural Network (ANN) is a must since these two methods will be used in analyzing the data given. Understanding on how the software run the PST and FST is an advantage so that we can understand on the relationships between the parameters obtained from the test.

1.5 The Relevancy of the Project

This project is very important in most of industries in the world because safety is the main concern especially in oil and gas industry. If safety is not ranked at high priority, it may give bad impact to other issues such as productivity, environment and health. At the design stage of the plant, safety issue is very crucial and every personnel always looked at the safety issue first before concerning to other issues. One of the safety systems in the plant is Emergency Shutdown System (ESD) which is related to the project. The system must always able to operate smoothly during the situation need it to do so. However, people always have doubt with the reliability of the system since there are many factors may decrease the reliability of the system. In order to test the reliability of the system, periodical tests need to be done. This is one of the best ways to ensure the whole system can work properly at any time required.

1.6 Feasibility of the Project within the Scope and the Time Frame

This Partial Stroke Testing for Masoneilan Emergency Shutdown Valve is about to test the reliability of ESD valves for both ball and butterfly valves. The testing was completed and what is left is analyzing the data.

In analyzing the data, the data obtained will be analyzed using statistical analysis and Artificial Neural Network (ANN). In statistical analysis, the data will be analyzed based on the data tabulation to see whether the data is consistent or not. Having a consistent data is essential in order to ensure the data obtained is accurate. In the development of Artificial Neural Network (ANN), the relationship among the parameters obtained from the PST data can be identified. These relationship are then can be used to predict the most significant parameter based on the other parameters obtained. This prediction is important because we can predict when the valve will stuck during the operation based on the relationship among the parameters obtained from Artificial Neural Network (ANN) modeling.

As a conclusion, it is possible to complete the project within the time given since statistical analysis and Artificial Neural Network (ANN) works independently.

CHAPTER 2
LITERATURE REVIEW

2.1 Emergency Shutdown (ESD) System

Emergency Shutdown (ESD) System is one of Safety Integrity System (SIS) required in the plant. As a last protection layer in a process plant, it must be function when the plant is pushed in a critical situation by fully close the emergency shutdown (ESD) valve. For ESD system, it generally consists of sensors, logic solvers and final elements. Among three of elements mentioned above, 50% of the failure rate comes from final elements which make people questioning the availability and the reliability of ESD system when the situation require it to take into action [14].

In industry, IEC61511 and IEC61508 use Safety Integrity Level (SIL) as a measure of SIS reliability. The SIL is a numerical benchmark, related to the probability of failure of demand (PFD). It is determined by some methodology such as risk graph, considering Personnel, Production & Equipment Loss and Environment. PFD is defined as the probability that the safety system does not work properly when the safety action is required [1]. As stated by the industry, the SIL is determined according to the Table 2 below:

Table 2: SIL Determination

SIL	Low Demand Mode of Operation
0	$\geq 10^{-1}$
1	$\geq 10^{-2}$ to $<10^{-1}$
2	$\geq 10^{-3}$ to $<10^{-2}$
3	$\geq 10^{-4}$ to $<10^{-3}$
4	$<10^{-4}$

2.2 Emergency Shutdown (ESD) Valve

Emergency Shutdown (ESD) valve is the final element used in ESD system. In the system, it will fully close when operated with the intention to protect the process, personnel, equipment and environment from process disruption. In the pipeline, it is used to isolate the process media at the upstream side from reaching the downstream side as the ESD system is activated [15].

For the project, two types of valve will be used which are Ball valve and Butterfly Valve.

2.2.1 Ball Valve

Ball valve is a quarter-turn valve. It has a shaft that attaches to the ball of the valve located inside the valve body in order to open or close the valve by turning the shaft within 90 degree angle. In the middle of the ball, it has a hole or port where the process media can flow through when the port is in line with the both end of the valve. If the port is perpendicular to both end of valve, the valve is in close position. This valve can be used as ESD valve because it has tight shut-off characteristics [14, 15].

Figure 1: Ball Valve

2.2.2 *Butterfly Valve*

This valve is also a quarter-turn valve. A metal disk is turned by turning a stem that mounted to it on order to open or close the valve. The valve is fully open when the metal disk surface is in parallel to the process media flow and fully close when it is perpendicular to the process media flow. Among the advantage of using butterfly valve is because it is low cost and suitable for low-pressure applications [14, 15].

Figure 2: Butterfly Valve

2.3 Full Stroke Test (FST) and Partial Stroke Test (PST)

Full Stroke Test (FST) is a method to test the reliability of ESD valve to operate in critical condition. This test is performed by fully close the ESD valve in order to ensure the valve is not stick in open position after remain in that position for a long period [13]. The sticking valve issue may due to several factors such as corrosion at valve's stem or dirt clogging around it. By fully exercise the valve, the dirt clogging can be reduced and the present of corrosion can be detected by looking at the valve time travel which is longer than specified [11]. However, this past technology to test the reliability of ESD valve only can be performed during scheduled shutdowns and turnarounds [6]. This happen because it will definitely disturb the process if the test is done online as the valve need to 100% close [9]. Besides, the extending of time interval for turnaround from two or three years to five or six years for mechanical reliability improvement and also preventive maintenance had extended the time interval for full stroke test to be performed which will reduce the reliability of the ESD valve.

To overcome this issue, partial stroke test (PST) had been introduced. It is done by partially move the valve to a certain closing percentage and move it back to initial position [4, 13]. In order to perform this test, it must be ensured the movement of ESD valve does not affect the process as disturbance to the process may cause process upset and the worst case may lead to plant trip. The advantages of PST are listed as follows:

- May provide an improvement to the Safety Integrity Level (SIL) of the Safety Integrity Function (SIF).
- Provides predictive maintenance data.
- May allow extension of the full stroke test (FST).
- May overcome IEC61511 architectural constraints.
- May reduce the need for valve bypasses.

- Valve is always available to respond to a process demand during the test period [12].

Having PST does not mean FST is not required. Implementation of FST with monthly PST will increase the reliability of ESD valve as shown in table 3 below [1]:

Table 3: PFD of FST and PST

FST Interval (Year)	FST only	FST with monthly PST
1	1.257E-02	4.548E-03
2	2.507E-02	8.298E-03
3	3.757E-02	1.205E-02
4	5.007E-02	1.580E-02
5	6.257E-02	1.955E-02

As shown in the Table 3 above, we can see that implementation of FST with monthly PST can slowdown the increment of probability failure on demand (PFD) compared to the implementation of FST only. The smaller value of PFD indicates the reliability of ESD valve is high.

2.4 Probability Failure on Demand (PFD)

Probability failure on demand (PFD) can be defined as the probability that the safety system does not work properly when the safety action is required. In order to calculate PFD for the system, PFD for every element in the loop must be taken into account [1]. The formula is as follows:

$$PFD_{SIS} = PFD_{SE} + PFD_{LS} + PFD_{FE} \qquad (1)$$

where SIS : Safety Instrumented System (Total System)

SE : Safety sensor

LS : Logic Solver

FE : Final Element

PFD for every element is calculated using the following equation:

$$PFD = \frac{1}{2}\lambda * Ti \qquad (2)$$

where λ = Dangerous failure rate (defined by current operation)

Ti = Test interval

Based on the equation, PFD can be reduced either by reducing failure rate or shorten the test interval [1]. Introducing PST is one way to shorten the test interval.

2.5 Methods of Partial Stroke Testing (PST)

There are three methods of PST being implemented which are mechanical limiting, solenoid and smart positioner [3].

2.5.1 Mechanical Limiting

This is the previous technology of PST. This method involved in installation of mechanical device such as collars, valve jacks and jammers to limit the degree of valve travel. A limit switch is used to confirm the valve movement. This method is inexpensive but there are several disadvantages such as:

- Lack of assurance the valve is in or has been returned back to initial position.
- Unauthorized use of the valve jack or jammer cannot be determined by casual inspection.
- Potential of spurious trip during PST.
- Procedural mistakes can result in the valve closing completely rather than just partially [3].

2.5.2 Solenoid

This is the current technology of PST. It is done by pulsing a solenoid valve which is controlled by the operator by turning a field-mounted switch. This will de-energize the solenoid coil for as long as the field operator holds the switch. The movement of the valve can be traced by monitoring the valve movement by the field operator or using limit switch. After reaching the required position, the field operator will release the button so that the valve will move back to the initial position. The disadvantages of this method are:

- The operator may hold the switch too long, allowing the valve to close sufficiently to disrupt the process, resulting in unit shutdown.
- Failure of solenoid valve may result in excessive valve travel.
- If the solenoid valve does not reset after PST, the test become a trip [13].

2.5.3 Smart Positioner

This a latest technology which will widely used in the future. It is a digital valve controllers-microprocessor-based, current-to-pneumatic instrument with internal logic capabilities. When using it as part of final element, it allows PST online testing of the valve and eliminates the need for special mechanical-limiting devices. This ensures the valve will not disturb the process during PST. This happen because smart positioners hold the programming of the test procedures. So, PST happens automatically and no operator attention required. During PST, it will continually check the valve travel to monitor the valve responds properly. If it is not, the smart positioner will abort the test and alert the operator that the valve is stuck. This will avoid the valve from slamming shut if the valve does suddenly break loose [16].

2.6 Introduction to Artificial Neural Network

Artificial Neural Network (ANN) is a mathematical model or computational model that is inspired by the structure and functional aspects of biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. Modern neural networks are non-linear statistical data modeling tools. They are usually used to model complex relationships between inputs and outputs or to find patterns in data [24].

These networks are also similar to the biological neural networks in the sense that functions are performed collectively and in parallel by the units, rather than there being a clear delineation of sub subtasks to which various units are assigned. Currently, the term Artificial Neural Network (ANN) tends to refer mostly to neural network models employed in statistics, cognitive psychology and artificial intelligence [26].

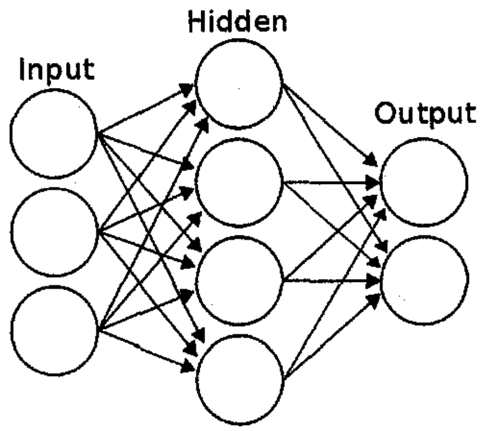


Figure 3: Neural Network architecture

2.7 Neural Network Basic Components

There are a number of ways in which neural network may be categorized based on characteristics such as [24]:

- The method of training adopted, directed or non-directed
- Whether after training feedback or non feedback operation is involved
- The type of training algorithm employed

The terms normally used in neural networks are as follows:

- Neurons

  The neuron forms the node at which connections with other neurons in the networks occur. Depending on the type of neural network being considered, connections may or may not exist between neurons within the layer in which they are located [26].

- Weights

  In the trained artificial neural network, the intelligence of the network is stored in the values of the connections existing between the neurons. In artificial neural network terminology, the values of the connections between the neurons are generally referred to as weights [26].

2.8 Training the Neural Network

In contrast to expert system which incorporates a knowledge base, neural networks do not have such a collection of information. They need to be trained for a given problem or situation so that the weights will then contain the required information. Training procedure can be classified into two categories which are supervised training, unsupervised training and reinforcement training [24].

- Supervise training

  The network is trained by providing it with input and matching output patterns. These input-output pairs can be provided by an external teacher, or by the system which contains the neural network (self-supervised).

- Unsupervised training

  Also called self-organization in which an (output) unit is trained to respond to clusters of pattern within the input. In this paradigm the system is supposed to discover statistically salient features of the input population. Unlike the supervised learning paradigm, there is no a priori set of categories into which the patterns are to be classified; rather the system must develop its own representation of the input stimuli.

- Reinforcement Learning

  This type of learning may be considered as an intermediate form of the above two types of learning. Here the learning machine does some action on the environment and gets a feedback response from the environment. The learning system grades its action good (rewarding) or bad (punishable) based on the environmental response and accordingly adjusts its parameters. Generally, parameter adjustment is continued until an equilibrium state occurs, following which there will be no more changes in its parameters. The self organizing neural learning may be categorized under this type of learning.

2.9 Neural Network Topology

Neural network topology can be divided into two which are [26]:

- Feed-forward neural networks

  The data from input to output units is strictly feedforward. The data processing can extend over multiple (layers of) units, but no feedback connections are present, that is, connections extending from outputs of units to inputs of units in the same layer or previous layers.

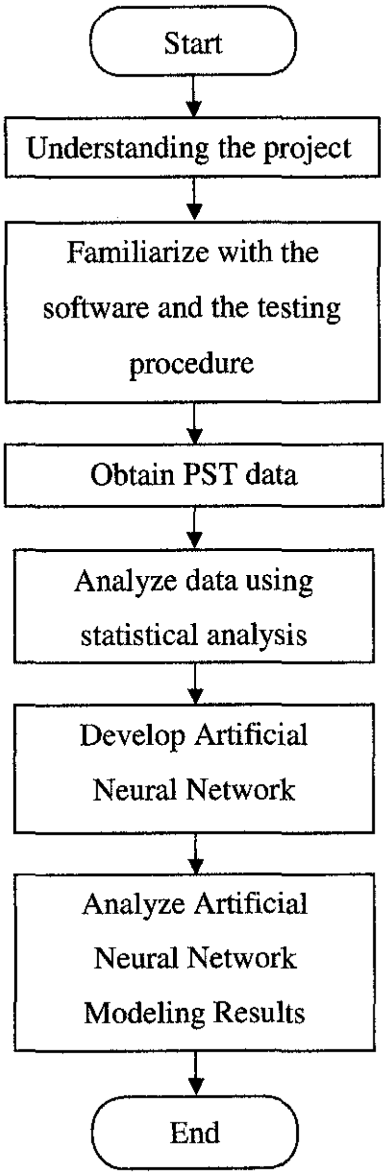
- Recurrent neural networks

  It contains feedback connections. Contrary to feed-forward networks, the dynamical properties of the network are important. In some cases, the activation values of the units undergo a relaxation process such that the neural network will evolve to a stable state in which these activations do not change anymore. In other applications, the changes of the activation values of the output neurons are significant, such that the dynamical behavior constitutes the output of the neural network

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

3.1.1 Analysis of Partial Stroke Test



- Understand the project by do some research through internet, journals and books.
- Familiarize with the testing skid, WideField2 and ValVue ESD software and testing procedure
- Obtain the data from ValVue ESD software historian.
- Analyze the data using statistical analysis method.
- Develop Artificial Neural Network modeling to analyze PST data.
- Analyze the results obtained from Artificial Neural Network modeling.

Figure 4: Methodology for Analyzing Partial Stroke Test

3.2 Key Milestones

As the key milestone of the project, all PST data for a testing period of 88 days were managed to be plotted in a graph using Microsoft Excel and MATLAB. The data that managed to be plotted were:

- Valve signatures.
- Average friction.
- Average breakaway pressure.
- Average droop.
- Average response time to exhaust.
- Average response time to fill.
- Average upper and lower spring range.

From the graph plotted, a statistics of the data for both ball and butterfly valve had been obtained. This includes:

- Mean.
- Median.
- Mode.
- Minimum value.
- Maximum value.
- Standard deviation.

In analyzing the data using Artificial Neural Network (ANN) Model, the relationship between parameters are managed to be obtained by using 8 neurons for layer 1 and 5 neurons for layer 2 for ball valve and using 6 neuron for layer 1 and 3 neurons for layer 2 for butterfly valve. The combination of neuron for each layer was obtained by try and error method where the combination of neurons is tested starting from 1 neuron at layer and 1 neuron at layer 2 up until 10 neuron of layer 1 and 10 neuron for layer 2. The best neuron combination was selected by looking at the root mean square error (RMSE) for each neuron combination. The least RMSE indicated by the model means the combination of neurons for layer 1 and layer 2 is the best for the model.

From Artificial Neural Network (ANN) modeling, the performance of training, validation and testing data can be analyzed. Besides, the regression of the data also can be seen where the relationship between the outputs and targets are strong when regression value is close to 1. If the regression value is 0, it means there Is no relationship between outputs and targets. Other than that, this model also manages to train the data so that the predicted breakaway pressure is close to the actual breakaway pressure for both ball and butterfly valve data. The details on the Artificial Neural Network (ANN) analysis will be discuss further in Chapter 4.

3.3 Tools and Equipments Used

There are several tools, equipments and software required in this project have been identified as listed below:

A. For PST statistical data analysis:
   - ValVue ESD.
   - Microsoft Excel.

B. For predicting breakaway pressure using Artificial Neural Network (ANN)
   - Microsoft Excel.
   - MATLAB.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Data Gathering and Analysis

The data for Partial Stroke Testing on both ball and butterfly valves were managed to be obtained from the previous tests which had been conducted for duration of 88 days. The criteria required by PETRONAS have been fulfilled and the data obtained will be used for analysis. For each day, 5 partial stroking test was done and followed by a partial stroke test performed with full stroke test in order to test the full stroke test is able to override partial stroke test. This was done to ensure ESD system can be operated instantaneously if the emergency occurs during partial stroke test is performed.

4.1.1 PST Performance Parameters

Before performing Partial Stroke Test (PST), a few parameter need to be set in the computer. All the parameters must be fixed and used throughout 88 days. The parameters are as in the Table 4 [15]:

Table 4: Parameter settings for Partial Stroke Test

PARAMETER	SPECIFIED VALUE	
Type of valve	**Ball Valve**	**Butterfly Valve**
PST Travel (%)	20	20
Maximum Pressure (psi)	10	5
Maximum Time (s)	30	75
PST Speed (%/s)	0.5	0.5
Dwell Time (s)	4	4
Friction Low Limit (psi)	0	0
Friction High Limit (psi)	5	28
Breakaway Limit (psi)	15	28
Droop Limit (psi)	10	15

a. PST travel

It indicates the allowed valve movement from full open position condition measured in percentage level. A typical value is 20% closing and the maximum allowed is 30% closing. More accurate results can be obtained if more travel range is allowed.

b. Minimum Pressure

It indicates the minimum pressure which will allow the reduction in the pressure inside the valve's actuator so that the desired PST travel position can be achieved. The value typically would be depending on the spring range and the valve hysteresis.

c. Maximum Time

It is referred to the allowable amount of time taken before the PST aborts. This value can be determined by using the equation:

$$Max. Time = (Travel\ range \times 2 \times PST\ Speed) + Dwell\ Time + 5\ Sec \qquad (3)$$

d. PST Speed

It is defined in percentage travel per second. The speed travel particularly vary depends on the setting parameter that has been setup by the user. 0.5% per second is the fixed speed used for this PST testing.

e. Dwell Time

It indicates the amount of time between the down ramp and the up ramp of valve stroke. It is a time in which a developer is in contact with the surface of the part. Sometimes, it also described as an international time delay during which an intender is held against a material under load during a hardness test. Dwell time is used to ensure the accuracy hardness ratings.

f. Breakaway Limit

It indicates the alarm threshold for the valve breakaway force (force to initiate valve movement). This alarm is set if the analyzed friction from the PST is more than this value.

g. Droop Limit

It indicates the alarm threshold for air supply inlet droop. The alarm is set if the analyzed air supply droop from PST test is more that this value. In other words, it means the allowable amount of valve droop during PST.

4.1.2 PST Summary

ValVue ESD software, software to perform Partial Stroke Testing for Masoneilan Emergency Shutdown Valve was used to obtain the data for every partial stroke conducted. After every stroke, a summary of PST can be obtained which consist of:

- PST Passed flag
- Friction
- Breakaway Pressure

- Droop
- Spring Range (Lower and upper)
- Response Time (Exhaust and Fill)

Each of the value must not exceed the value which had been set in the parameter setting. If the data obtained from the stroking exceed the parameter setting value, the PST is consider fail.

4.1.3 Data Analysis

4.1.3.1 Valve Signature

For every valve stroking, the ValVue ESD software will display a diagnostic graph which can be used for analysis. This graph will display a valve signature curve for the respective PST stroking. It is a graph plotting position (%) versus pressure (psi). During the first travel, the actuator would vent the instrument air to close at the pre-determined stroking speed. Decreasing the instrument air pressure inside the actuator will cause the valve to close from fully open to 20% close position. During the second travel, the instrument air will be filling in the valve actuator to force the valve to open at pre-determined speed. The increasing instrument air pressure inside the valve actuator will force the valve to move from 20% close position to fully open position.

The opening and closing slopes in the valve signature are parallel. The separations of these lines are the results of the friction band. The higher the friction, the wider the separation slope lines. That is why the separation slope lines for ball valve is wider compared to the separation slope lines for butterfly valve. These reflected to the friction due to valve packing. By assuming both valve use the same material, the only factors that determine the friction is the valve packing area. Valve packing area for ball valve is higher compared to butterfly valve. So, the friction for ball valve will be higher than butterfly valve.

Besides, the slope in the closing and opening lines indicates that the actuator contains a spring. If there is no spring, the opening and closing lines will be flat (vertical).

When the sixth stroke was done, it is just to ensure the full stroke test can overwrite PST function. This is because the ESD system must capable to fully close the valve in case the emergency happen during the PST is done. If the ESD system unable to do so, a massive destruction may occur in the plant.

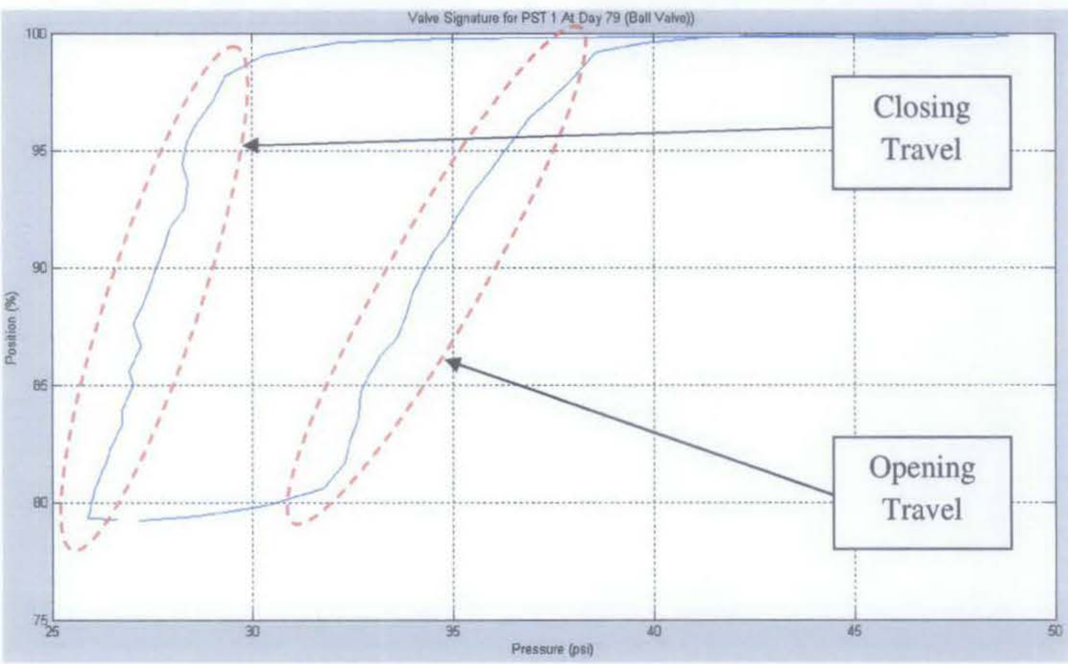


Figure 5: Example of valve signature for ball valve.

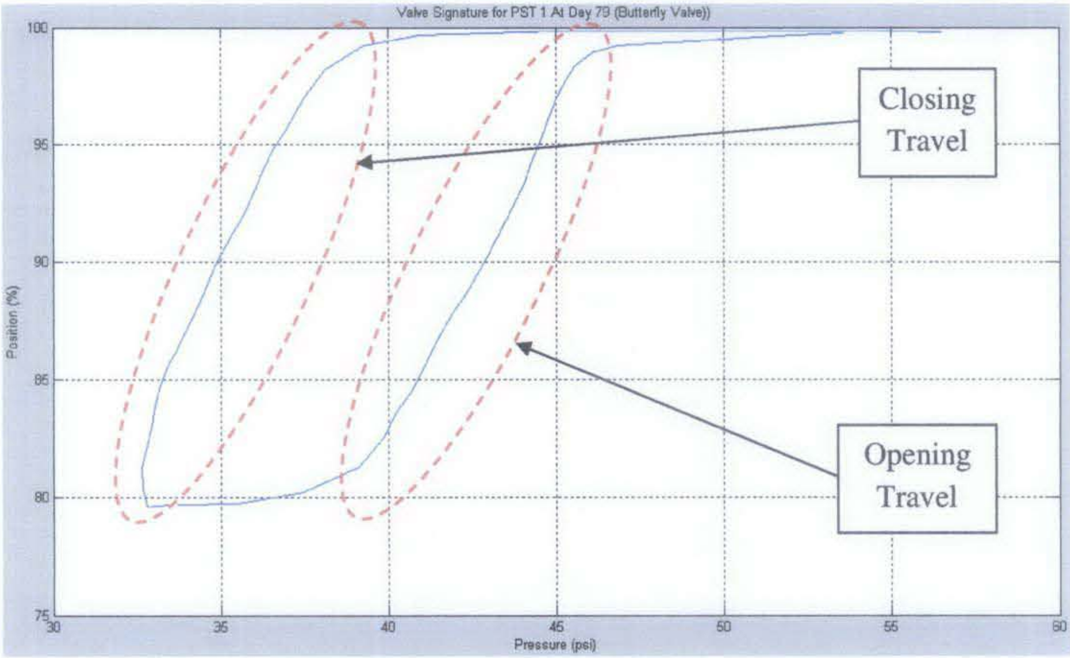


Figure 6: Example of valve signature for butterfly valve.

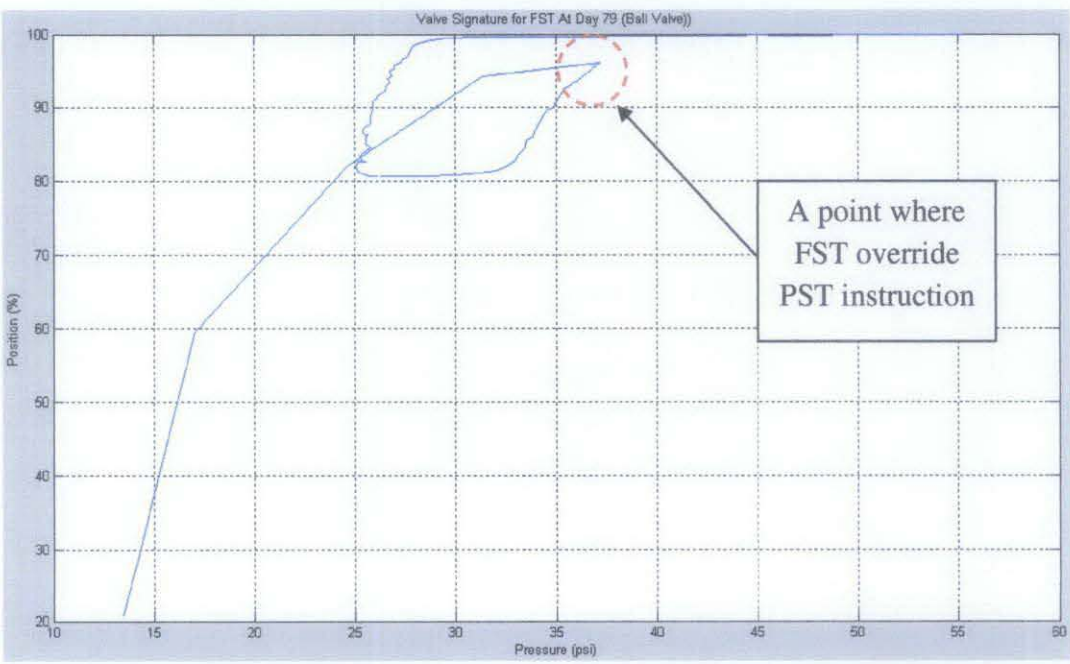


Figure 7: Example of valve signature when full stroke test override the partial stroke test instruction.

4.1.3.2 Average Friction

Figure below showing the average friction obtained from PST which had been done for 88 days for ball and butterfly valve respectively. The set of data used to plot the graph can be referred to Appendix III. Based on Figure 8 and 9, the average friction for ball valve is slightly higher compared to the average friction for butterfly valve. This can be seen clearly seen by looking at the mean, minimum and maximum value of the data obtained. This happen because ball valve has larger area of contact between the ball and the valve body while for butterfly valve, the area of contact between the valve plate and valve body is smaller. Every moving part will must have a friction and the amount of friction is depend on the amount of area of contact. The larger the area of contact, the greater the friction occur. Besides, data for butterfly valve is more consistent compared to ball valve. This can clearly be seen by looking at the standard deviation where the standard deviation for butterfly valve is lower compared to standard deviation for ball valve. However, these data cannot directly be used to analyze the PST. This is because there are sudden changes of data patterns starting from day 54 onwards. After further investigations, the sudden changes of data patterns were caused by the swapping of the smart positioners used for PST. At day 54, the smart positioner for ball valve had been swapped with smart positioner for butterfly valve and vice versa. After the swapping was done, both smart positioners were not being retuned according the respective valve. This means staring from day 54 onwards, the smart positioner used for ball valve was operated based on the setting parameter for butterfly valve and vice versa. As a result, the slopes obtained from the data were not because of the valve current condition but it is reflected by the swapping smart positioners.

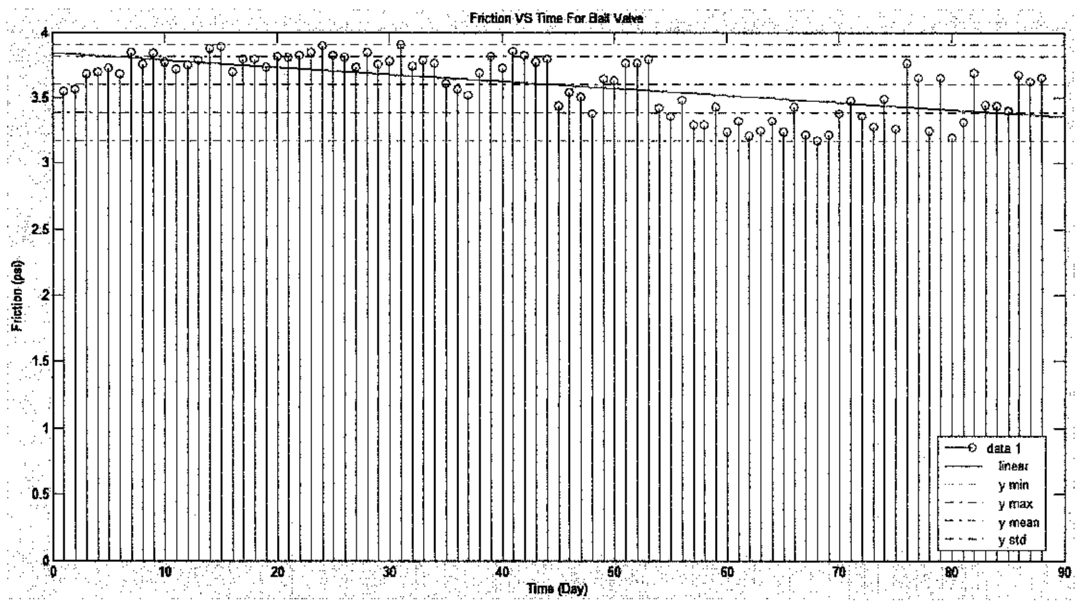


Figure 8: Graph of average friction versus day for ball valve

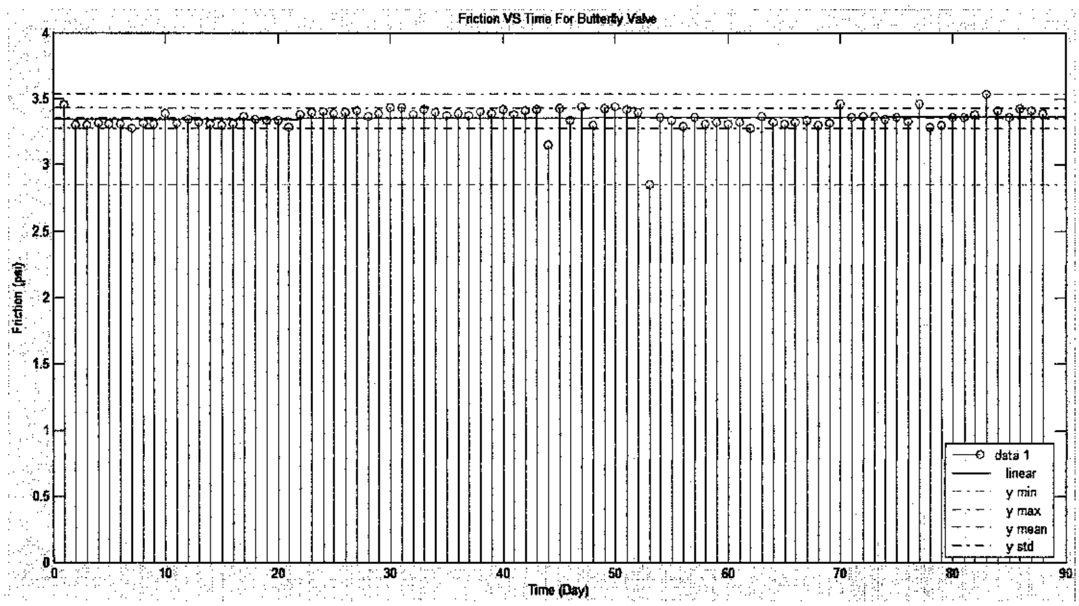


Figure 9: Graph of average friction versus day for butterfly valves

Table 5: Statistics from average friction for ball and butterfly valves

TYPE	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	3.171	9.907	3.602	0.2169	-0.00542
BUTTERFLY	2.855	3.535	3.353	0.07767	0.0002845

In order to overcome these problem, the data for both valves had been divided into two groups which were system 1 which represented the data taken before the smart positioners had been swapped and system 2 which represents the data taken after the smart positioners had been swapped. Data for system 1 were from day 1 until day 54 while data for system 2 were from day 55 until the day 88. The data for both systems based on respective valve are shown as follows:

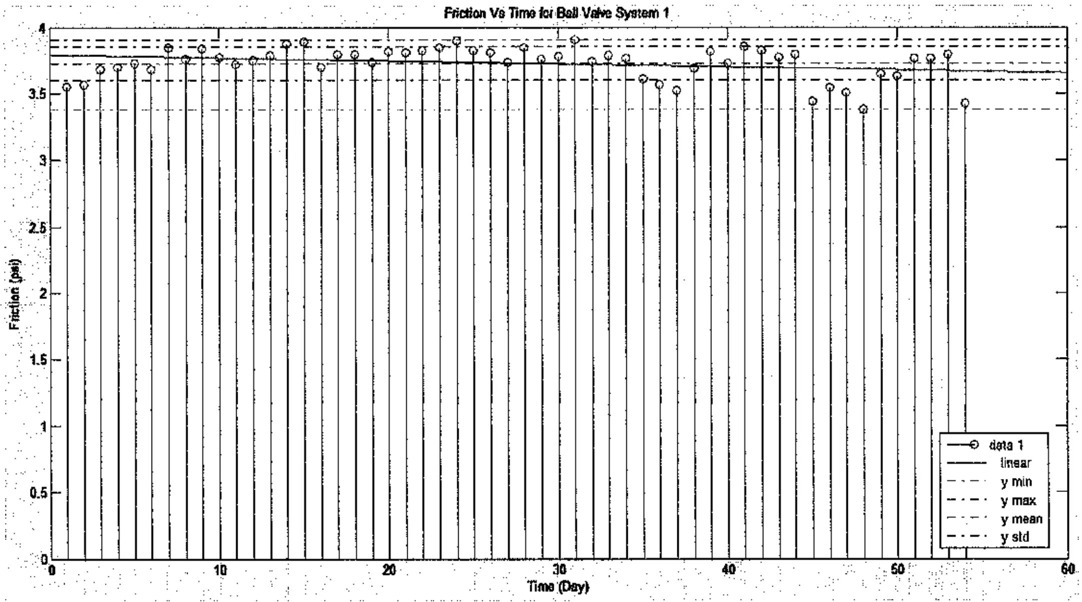


Figure 10: Graph of average friction versus day for ball valve system 1

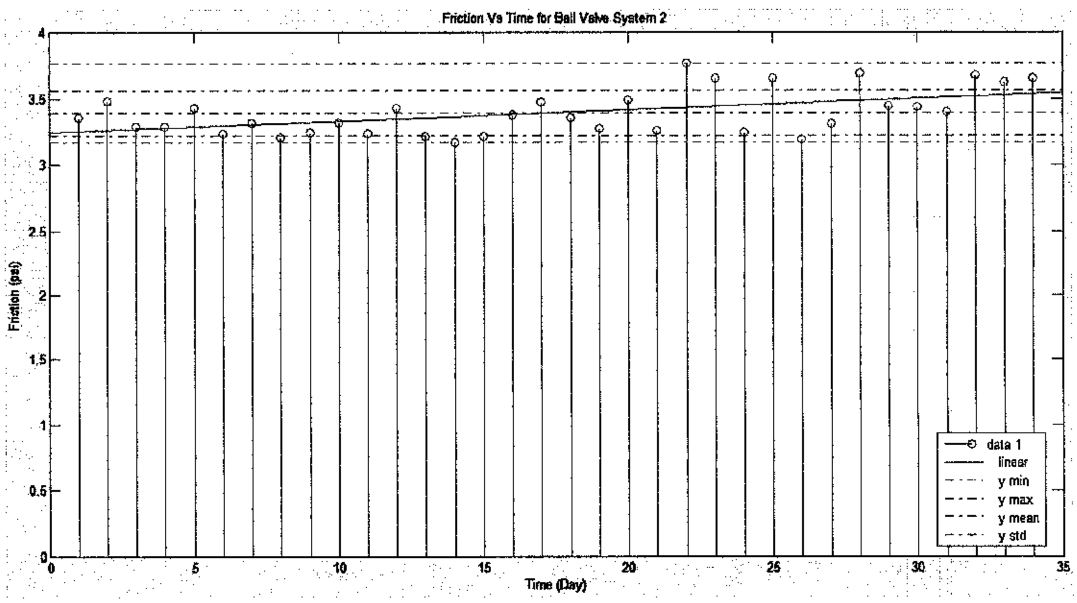


Figure 11: Graph of average friction versus day for ball valve system 2

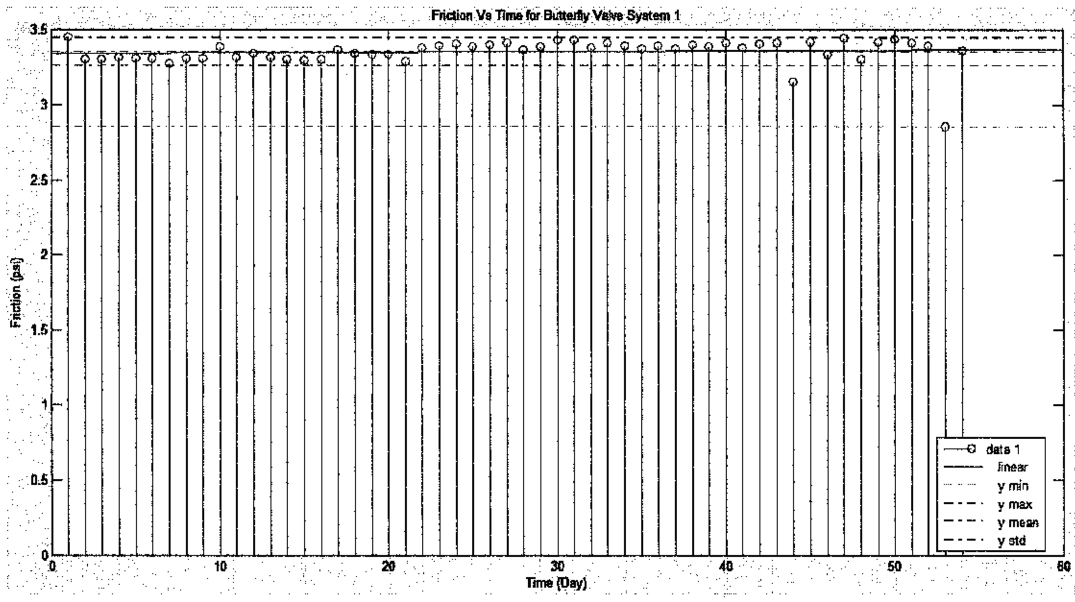


Figure 12: Graph of average friction versus day for butterfly valve system 1

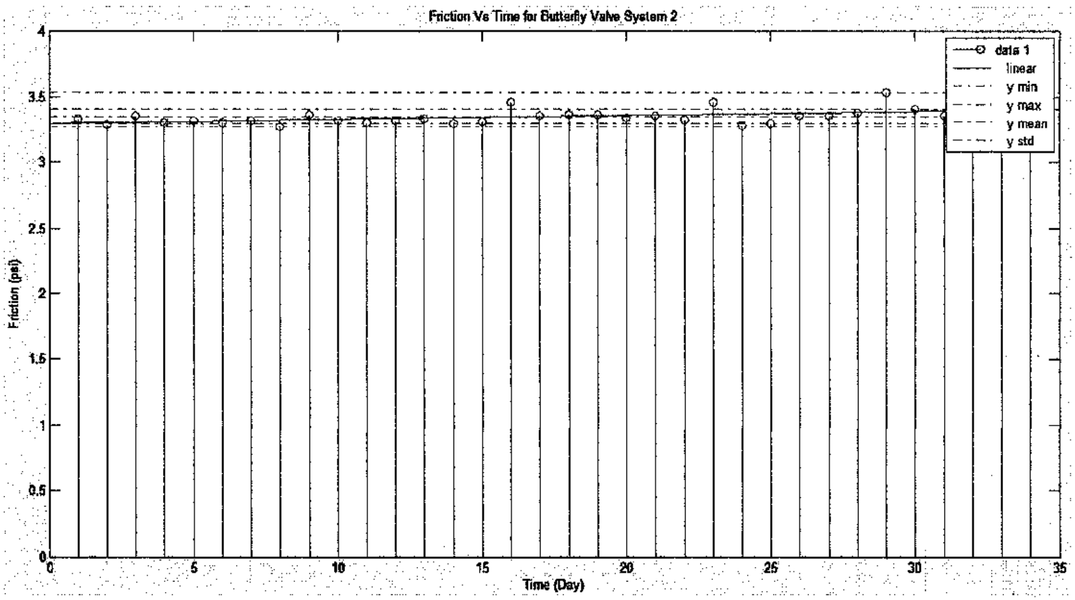


Figure 13: Graph of average friction versus day for butterfly valve system 2

Table 6: Statistics from average friction for ball and butterfly valves system 1 and system 2

TYPE	SYSTEM	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	1	3.3775	3.907	3.7308	0.1248	-0.00224
	2	3.171	3.764	3.3970	0.1689	0.008577
BUTTERFLY	1	2.855	3.443	3.3689	0.1054	0.0004418
	2	3.276	3.535	3.3536	0.0567	0.003056

Based on Figure 10, 11, 12, 13 and Table 6, we can see that the PST results for both valve is more consistent since both system for the respective valve have small and almost the same standard deviation. However, the standard deviation for ball valve system 1 is higher compared to the standard deviation for ball valve system 2 but the standard deviation for butterfly valve system 1 is smaller compared to standard deviation for butterfly valve system 2. This is due to the swapping the smart positioned without retune it according to the respective valve. Besides, the slopes for the ball valve system 1 and ball valve system 2 have different sign. The sign for the slopes should be negative since the valve was being exercise daily and the valve friction should be decreasing. However for ball valve system 2, the slope is positive which is totally different from what is supposed to be. For butterfly valve, even though both systems have positive slopes, the slope for system 2 is higher than system 1 due to the smart positioned swapping. If we refer to the graphs, butterfly valve did not give clear difference between system 1 and system 2 because valve friction is depend on the area of contact between internal valve body and the valve plate for butterfly which is smaller as compared to the ball valve where the area of contact between the ball and the internal valve body is larger.

4.1.3.3 Average Breakaway Pressure

Figure 14 and 15 below showing the average breakaway pressure obtained from PST which had been done for 88 days for ball valve and butterfly valve respectively. The set of data used to plot the graph can be referred to Appendix IV. Based on both figures, ball valve has higher breakaway pressure compared to butterfly valve. It is clearly shown by looking at the mean and maximum value of the data obtained. This can be related to the area of contact between ball and valve body for ball valve and between valve plate and valve body for butterfly valve. The more are of contact, the more friction will be faced by the valve. To make a valve start moving, more pressure required. This is what it means by breakaway pressure. However, the breakaway pressure for ball is smaller towards the end of testing period. This can be observed by looking at the graph pattern for ball valve and the minimum data value for ball valve is slightly smaller as compared to the minimum data value for butterfly valve. This is due to the area of contact between the ball and body for ball valve getting wear as more frequent the valve is moving. Due to the area of contact also, the standard deviation for butterfly valve is smaller compared to the standard deviation for ball valve. Smaller standard deviation means the data is more consistent. All data value did not exceed the parameter setting value which indicates PST is passed.

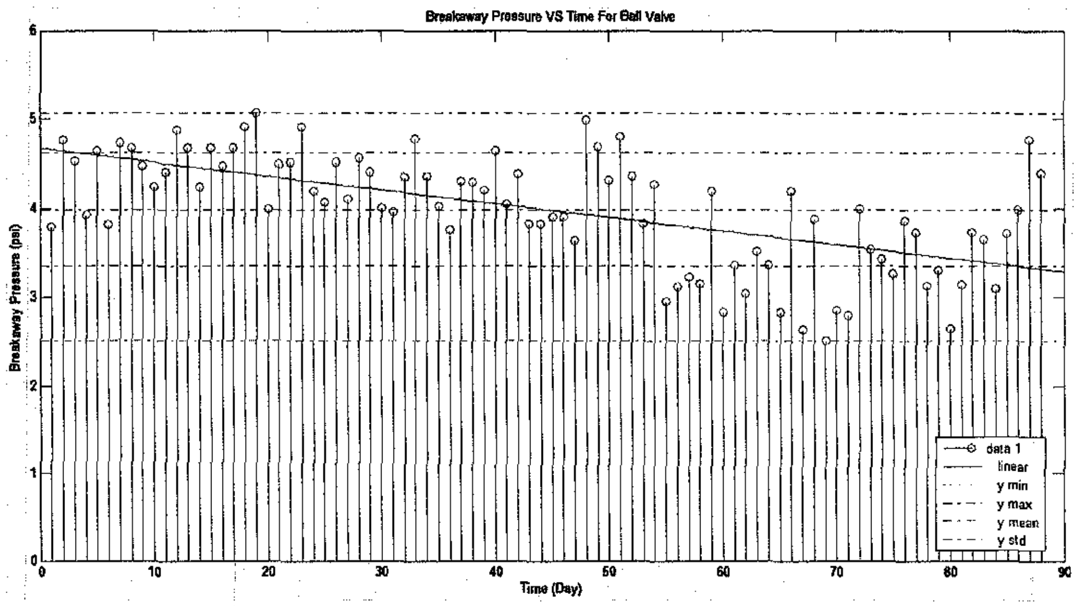


Figure 14: Graph of average breakaway pressure versus day for ball valve

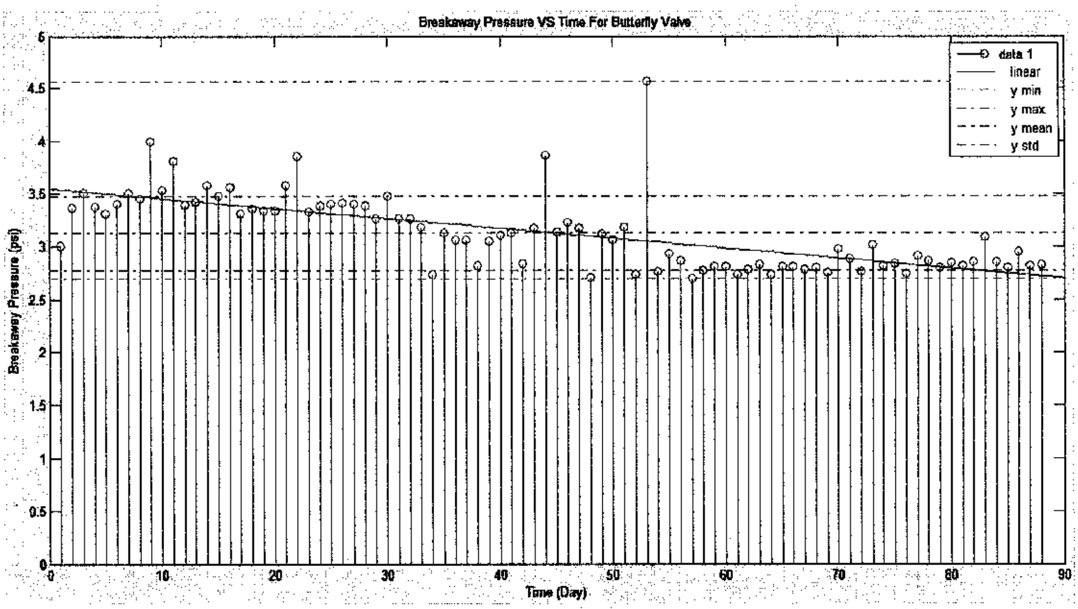


Figure 15: Graph of average breakaway pressure versus day for butterfly valve

Table 7: Statistics from average breakaway pressure for ball and butterfly valves

TYPE	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	2.525	5.065	3.991	0.6374	-0.01537
BUTTERFLY	2.703	4.571	3.134	0.3515	-0.009382

However, due to smart positioned swapping, there are sudden changes of breakaway pressure pattern starting from day 54. This pattern obviously can be seen at data for ball valve. To analyze the breakaway pressure of the valve more accurate, the data had been divided into two groups which are system 1 represents the data before swapping the smart positioner and system 2 represents data after swapping the smart positioner. After dividing the data into system 1 and system 2, the graphs and table for PST breakaway pressure are as follows:

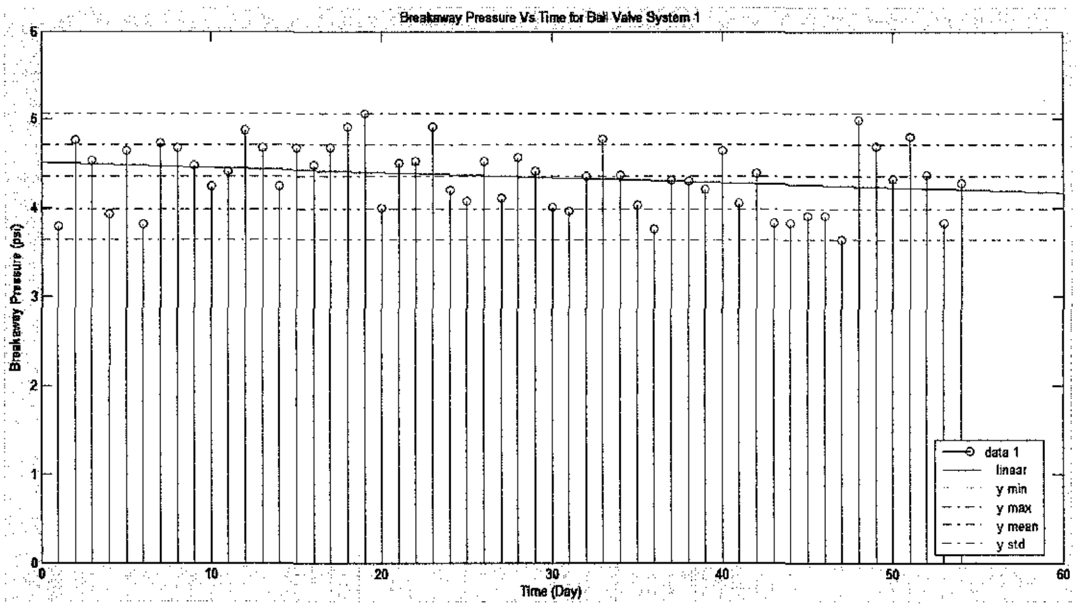


Figure 16: Graph of average breakaway pressure versus day for ball valve system 1

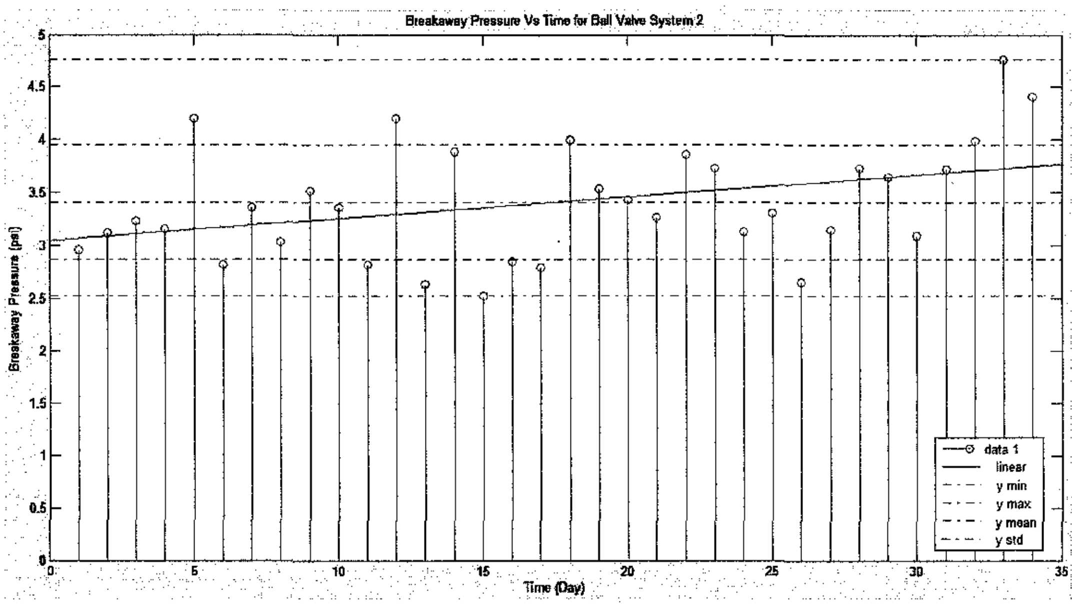


Figure 17: Graph of average breakaway pressure versus day for ball valve system 2

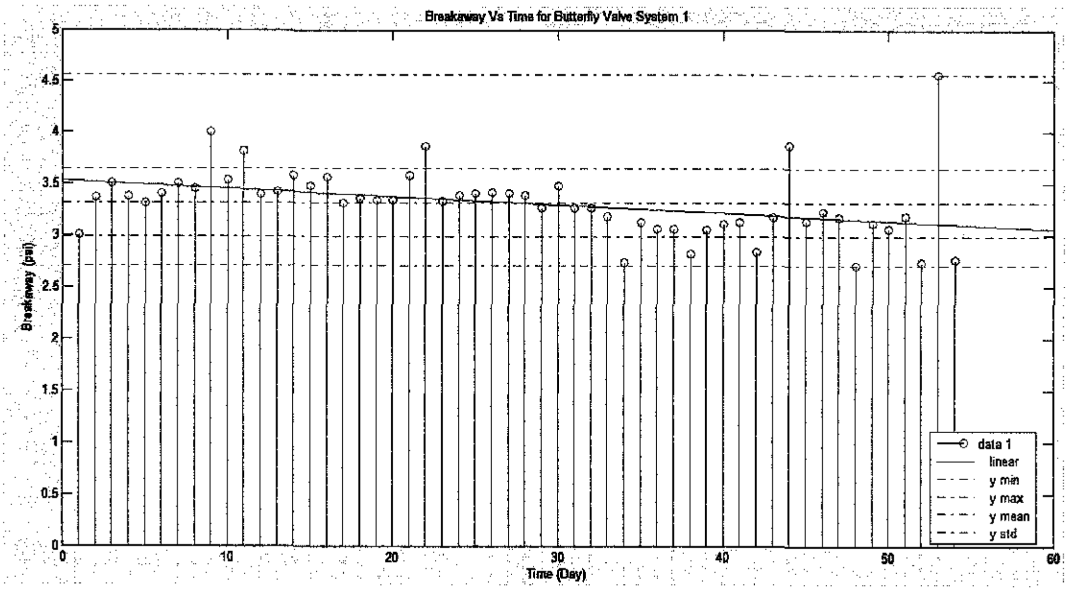


Figure 18: Graph of average breakaway pressure versus day for butterfly valve system 1

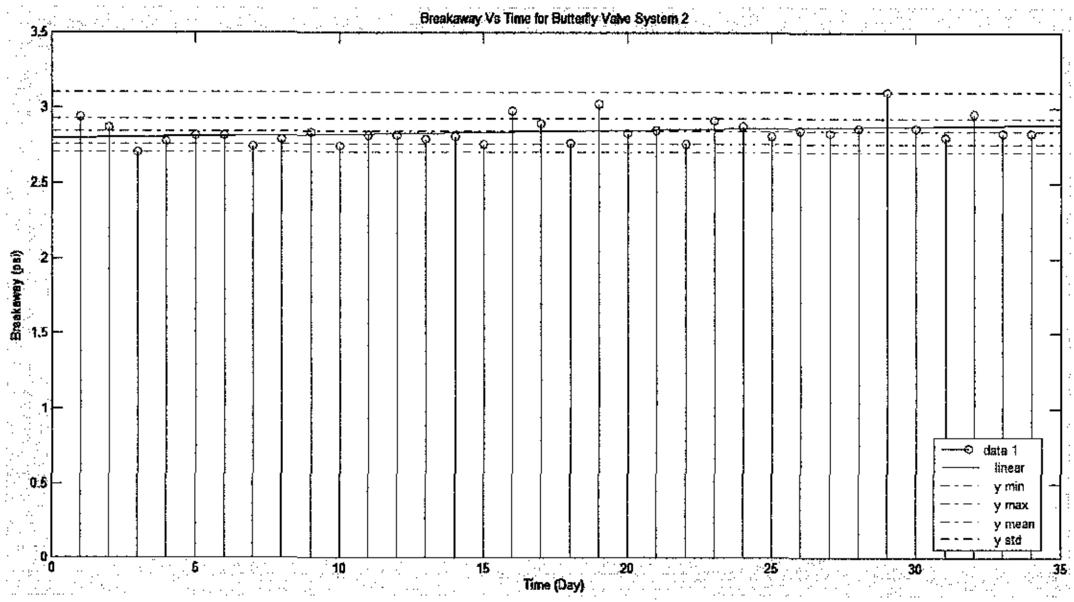


Figure 19: Graph of average breakaway pressure versus day for butterfly valve system 2

Table 8: Statistics from average breakaway pressure for ball and butterfly valves for system 1 and system 2

TYPE	SYSTEM	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	1	3.65	5.065	4.3553	0.3645	-0.005635
	2	2.525	4.765	3.4118	0.5431	0.020629
BUTTERFLY	1	2.715	4.571	3.2358	0.3652	-0.007921
	2	2.703	3.098	2.8415	0.08262	0.002678

Based on Figure 16, 17, 18, 19 and Table 8, the standard deviation for ball valve and butterfly valve for system 1 are almost similar which are around 0.3650. However, the standard deviation for ball valve system 2 is higher compared to ball valve system 1 while the standard deviation for butterfly valve system 2 is smaller compared to butterfly valve system 1. The difference of standard deviation from system 1 and system 2 indicates the effect of swapping the smart positioned during PST experiment period. Because of the smart positioner swapping, the PST results are not really accurate since the smart positioner swapping gave major influence to the results. The effect of swapping controller swapping also can be seen by comparing the slope for breakaway pressure system 1 and breakaway pressure system 2. As the valves were being exercise day by day, the breakaway pressure should be decrease which is correct for system 1 where the slopes are negative. However, the slope is positive for system 2 for both valves. These indicate the breakaway pressure for both valves are increasing after the smart positioner had been swapped. This should not be happen because by right, exercising the valve will decrease the breakaway pressure.

4.1.3.4 Average Droop

Figure 20 and 21 below showing the average droop obtained from PST which had been done for 88 days for ball valve and butterfly valve respectively. The set of data used to plot the graph can be referred to Appendix V. Both graphs display quite similar pattern where at the beginning of the testing period both valve's average droop were recorded below the parameter settings. This indicates PST is passed. However, after day 57, there is a sudden increment of average droop for both ball and butterfly valve. Some of the sudden increments exceed parameter setting which cause PST to be considered failed. By comparing the two data, butterfly valve experienced more droop effect as compared to ball valve. This can be seen by looking at the mean, minimum, maximum and standard deviation value of the data. Droop is the difference of pressure between upstream and downstream side as the valve travels from full open position to full close position. In PST, the valve only close by 20% and it goes back to full open position immediately. The droop effect is then recorded by the ValVue ESD software. If the droop effect is too high, PST exercise may effects the process flow and as a result may cause the plant to trip. This is critical as the droop value suddenly goes high for PST starting day 57 onwards. From the statistics, we can see that the effect of droop effect is smaller for ball valve compared to butterfly valve. This indicates that butterfly valve having more droop effect compared to ball valve.

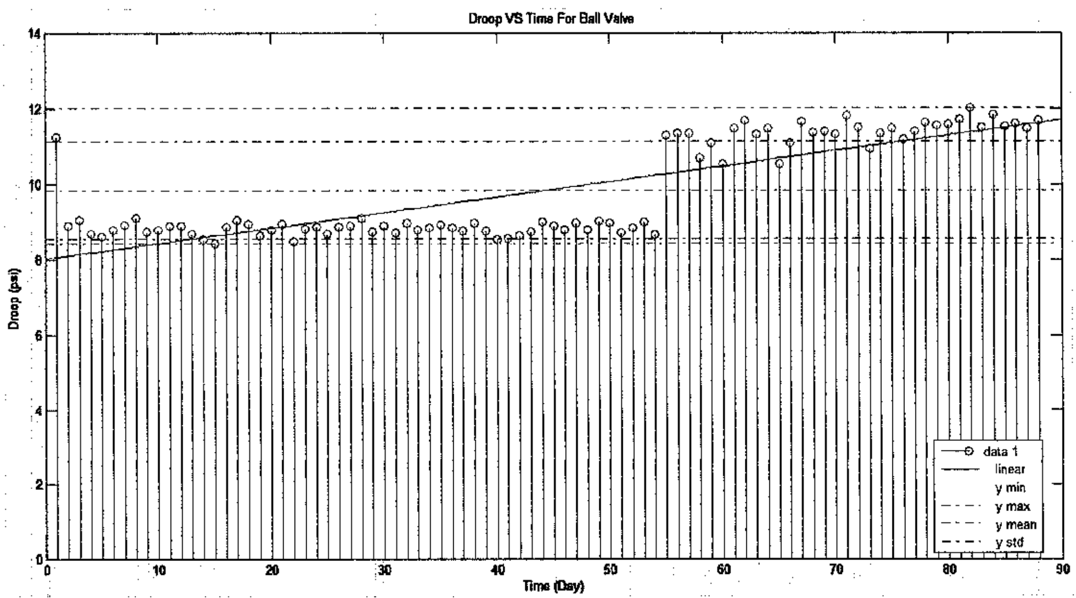


Figure 20: Graph of average droop versus day for ball valve

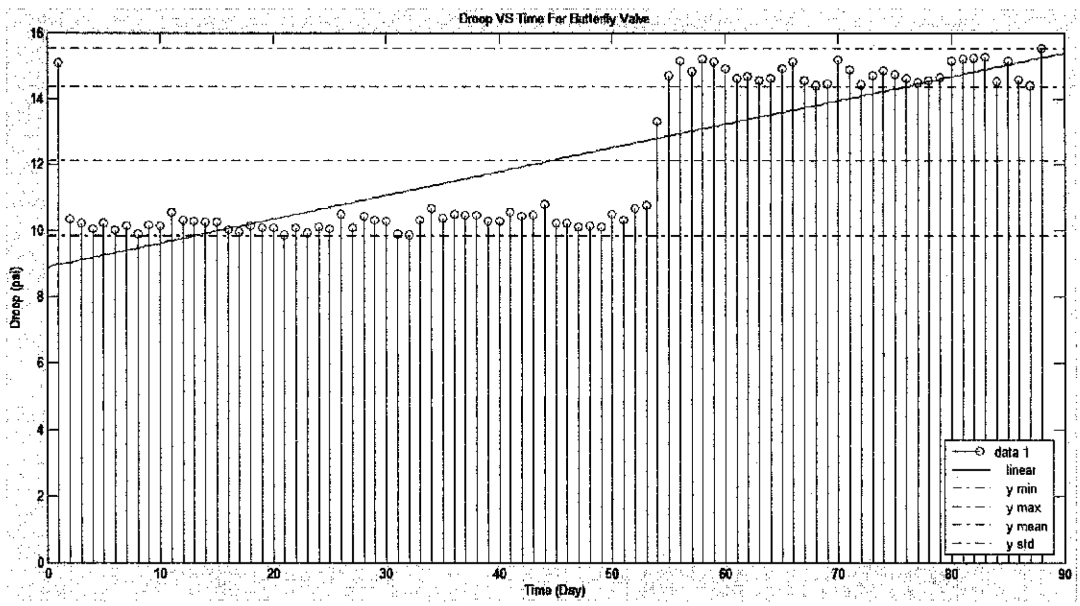


Figure 21: Graph of average droop versus day for butterfly valve

Table 9: Statistics from average droop for ball and butterfly valves

TYPE	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	8.427	12.02	9.8393	1.2855	0.040815
BUTTERFLY	9.857	15.55	12.1117	2.2636	0.072172

However, since there is a sudden change of pattern during the experiment period, the data is not really accurate to be used for analysis. After further investigation, it indicates that the smart positioner had been swapped during experimentation period which is on day 54. To make the analysis more accurate, the sets of data had been divided into system 1 and system 2 which represents the data before swapping the smart positioner and the data after swapping the smart positioner respectively. After dividing the data, the graphs and the table for PST droop are as follows:

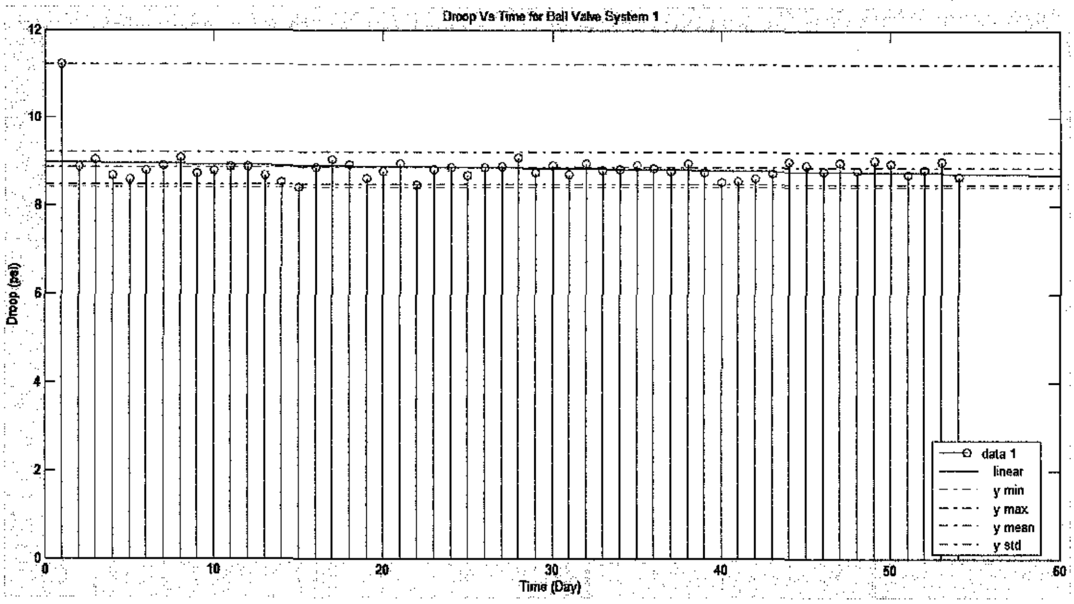


Figure 22: Graph of average droop versus day for ball valve system 1

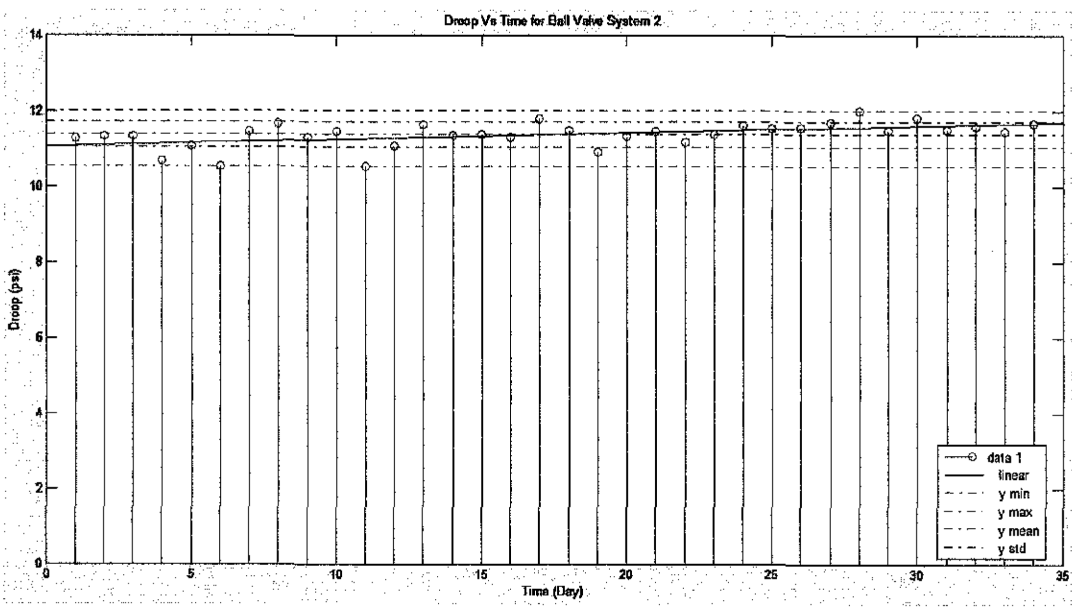


Figure 23: Graph of average droop versus day for ball valve system 2

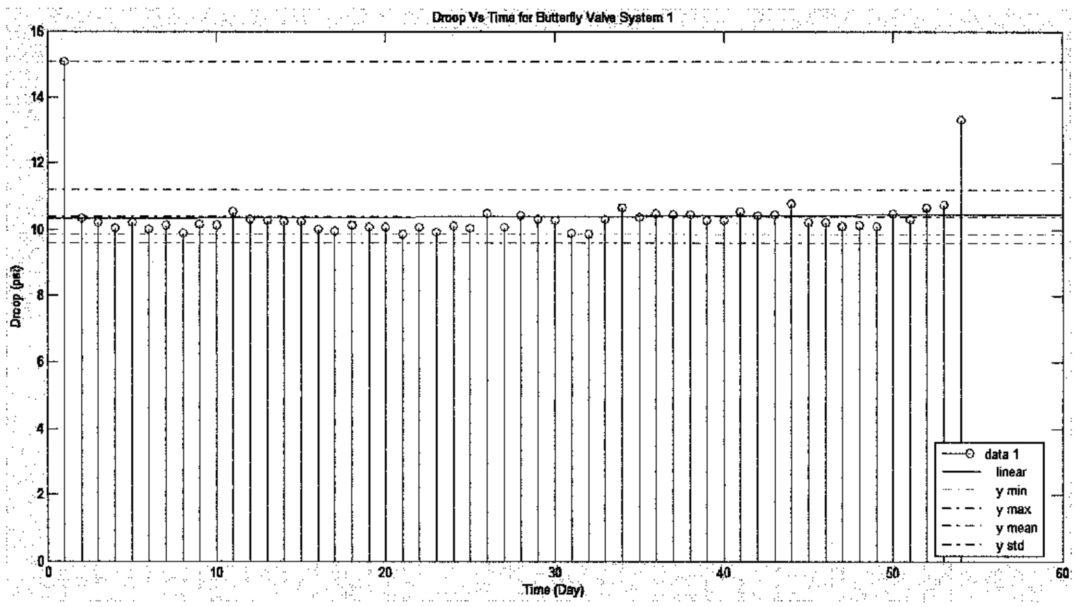


Figure 24: Graph of average droop versus day for butterfly valve system 1

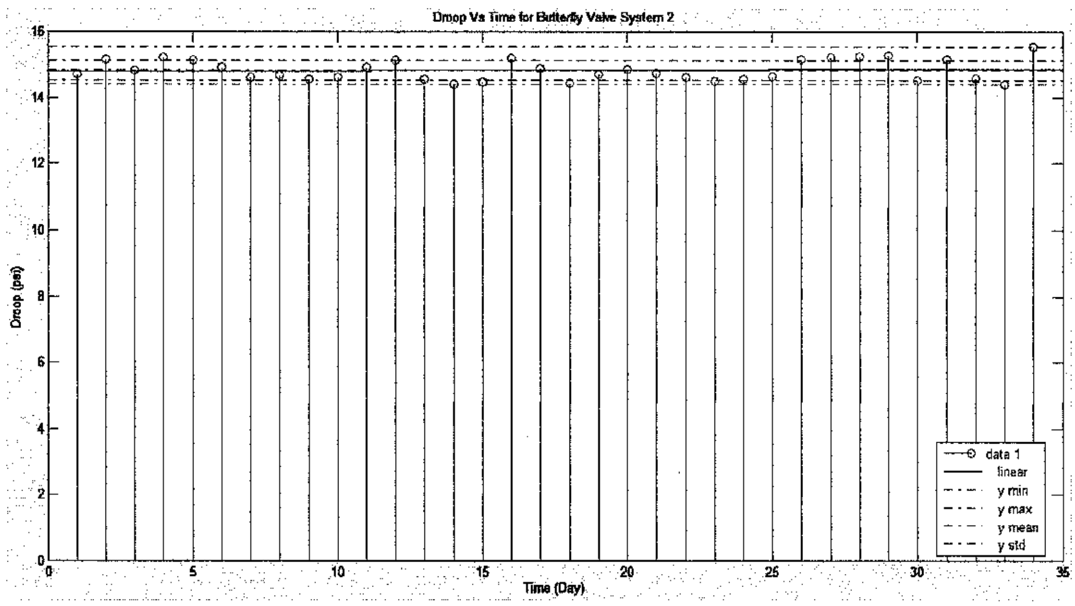


Figure 25: Graph of average droop versus day for ball valve system 2

Table 10: Statistics from average droop for ball and butterfly valves system 1 and system 2

TYPE	SYSTEM	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	1	8.427	11.24	8.8639	0.3644	-0.004477
	2	10.53	12.02	11.3883	0.3388	0.018003
BUTTERFLY	1	9.857	13.31	10.3944	0.5715	0.002288
	2	14.40	15.55	14.8263	0.3098	0.002169

Based no Figure 22, 23, 24, 25 and Table 10, we can see that the data recorded are more consistent where the standard deviation for each system is smaller compared to the standard deviation when the data are not divided based on before and after the smart positioners swapping. Besides, the slopes for each system is much smaller compared to the slope before diving the data based on before and after the smart positioners swapping. These obviously shown that swapping the smart positioners can influence the results of PST. The sign of the slope can be negligible because the value of the slope is too small. These small values of the slope can be obtained by dividing the data into system 1 and system 2 in order to eliminate the effect of the controller swapping during analyzing the PST data.

4.1.3.5 Average Response Time to Exhaust

Figure 26 and 27 shown below showing the average response time to exhaust obtained from PST which had been done for 88 days for ball valve and butterfly valve respectively. The set of data used to plot the graph can be referred to Appendix VI. This response time to exhaust means the time required for the instrument air to exhaust from actuator in order to close the valve within the specified time. The unit used to measure the response time is in pound per square inch (psi) per second. From the graph pattern and the statistics, we can see that the average response time to exhaust for butterfly valve is higher than ball valve. The time required to close is very critical. Too slow response time to exhaust will caused the valve too slow to isolate the process media from flowing through downstream. On the other hand, too fast response time to exhaust may results in too fast valve travel and slam shut may occur which will damage the valve.

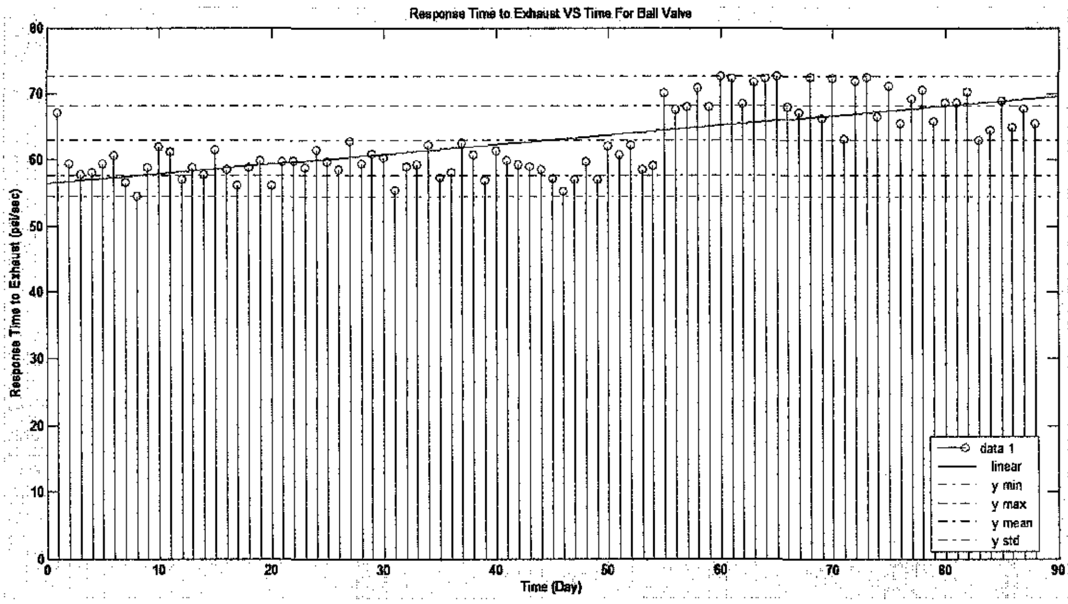


Figure 26: Graph of average response time to exhaust versus day for ball valve

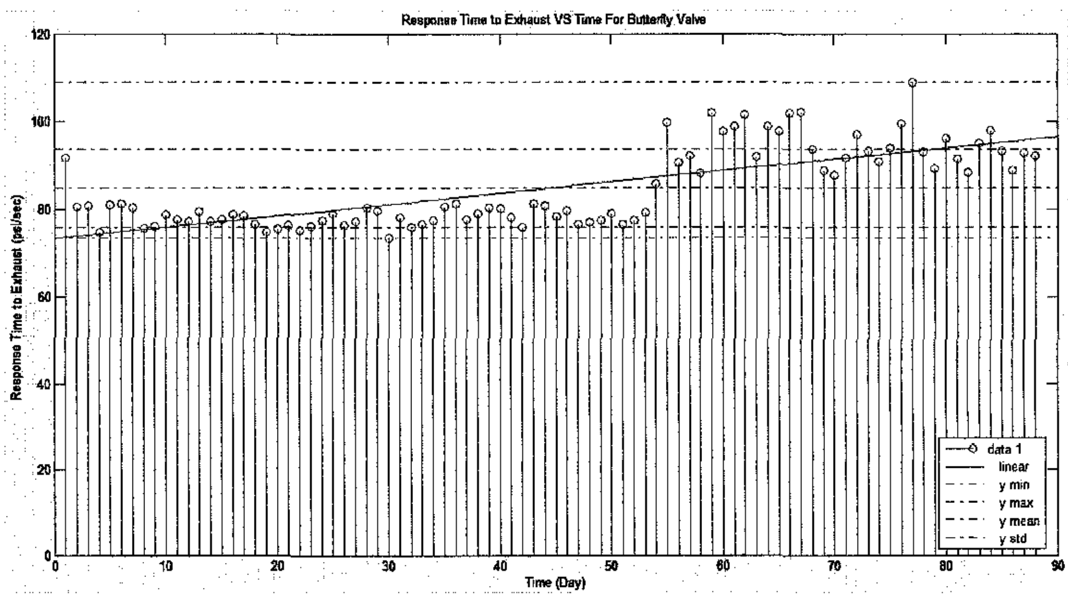


Figure 27: Graph of average response time to exhaust versus day for butterfly valve

Table 11: Statistics from average response time to exhaust for ball and butterfly valves

TYPE	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	54.56	72.71	62.9716	5.2945	0.1460
BUTTERFLY	73.5	109	84.9411	8.9318	0.2575

During the experiment, the pattern of data suddenly change where the response time to exhaust instrument air from the actuator suddenly increase. These patterns occur on for both ball and butterfly valve. After further investigation, the cause of these sudden changes of response time for instrument air to exhaust from the actuator is swapping the smart postitoner of the valve. After dividing the data into before the smart positioner was being swapped and after smart positioner was being swapped, the graphs and the table are as follows:

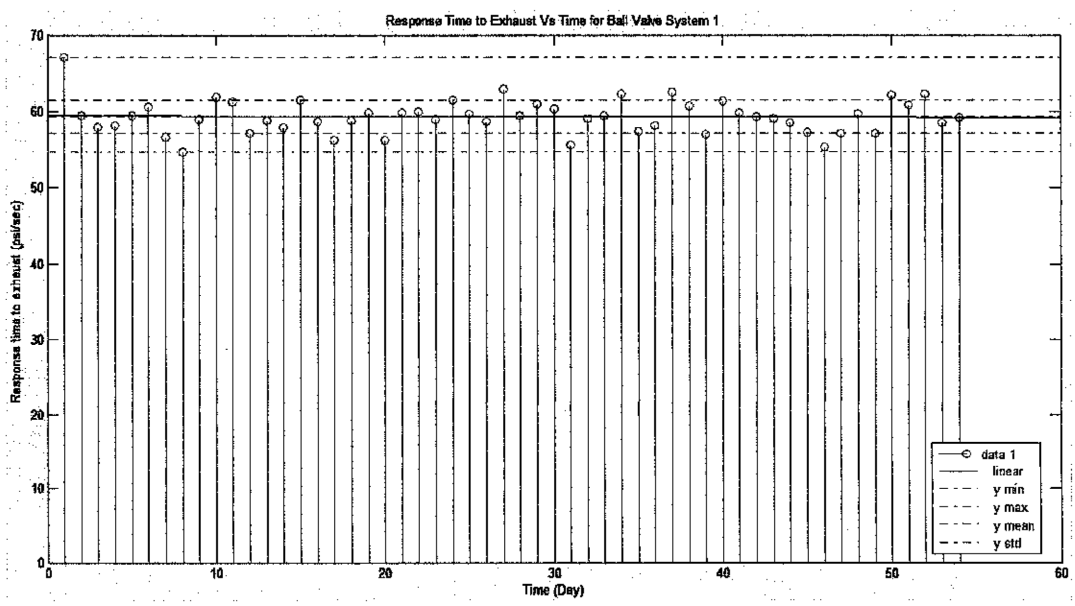


Figure 28: Graph of average response time to exhaust versus day for ball valve system 1

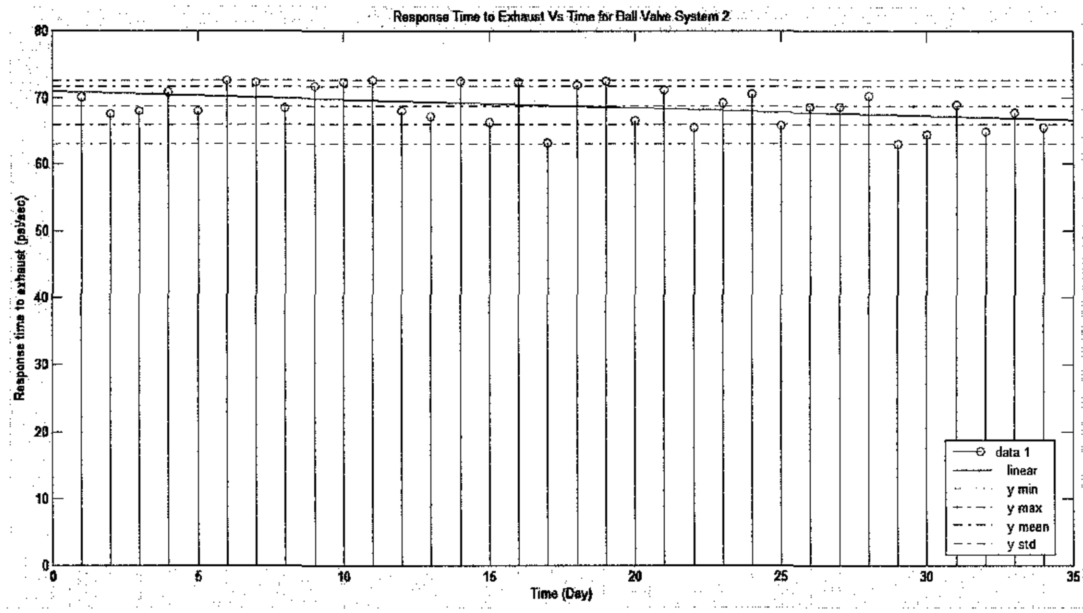


Figure 29: Graph of average response time to exhaust versus day for ball valve system 2

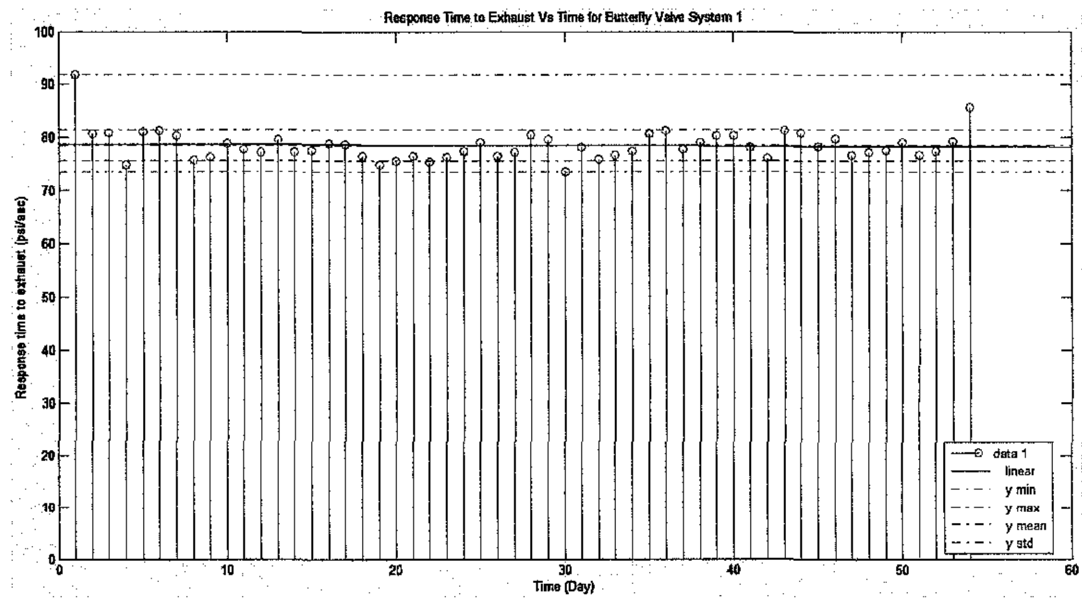


Figure 30: Graph of average response time to exhaust versus day for butterfly valve system 1

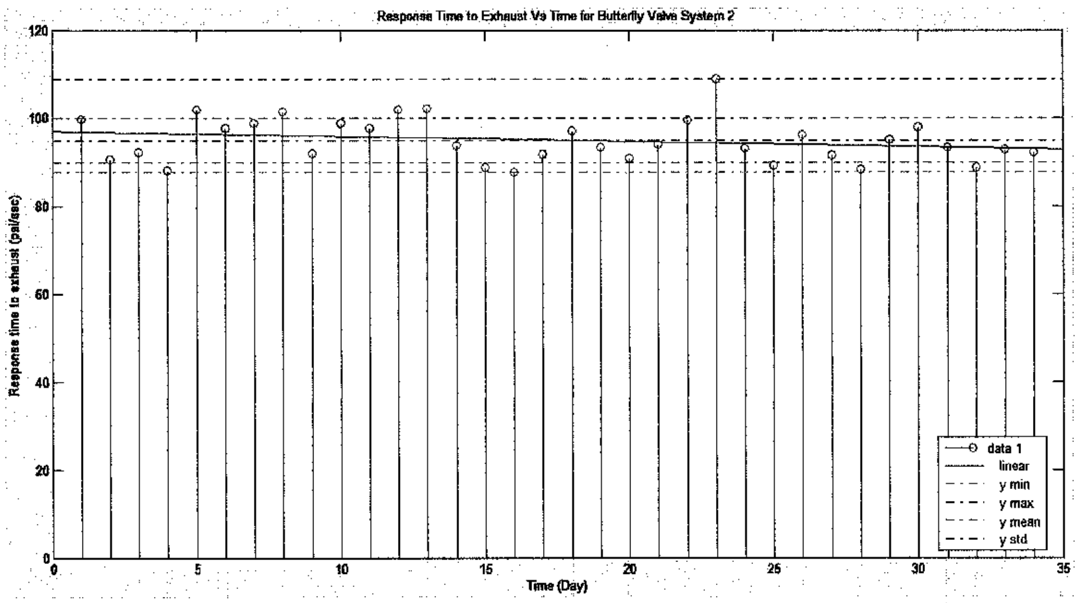


Figure 31: Graph of average response time to exhaust versus day for butterfly valve system 2

Table 12: Statistics from average response time to exhaust for ball and butterfly valves system 1 and system 2

TYPE	SYSTEM	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	1	54.56	67.12	59.2923	2.2455	-0.002992
	2	63	72.71	68.8151	2.9101	-0.125244
BUTTERFLY	1	73.5	85.84	78.4015	2.3060	-0.009111
	2	87.85	109	95.0493	5.0361	-0.117090

Based on Figure 28, 29, 30, 31 and Table 12, the data obtained after dividing the data into the data obtained before swapping the smart positioners and the data obtained after swapping the smart positioners are more consistent compared to the sets of data which have not been divided into before and after swapping the smart positioners. This can be seen by comparing the standard deviation where the standard deviation of data before being divided is higher compared to the data after being divided. Higher standard deviation indicates that the sets of data are being influenced by the smart positioners which had been swapped. By dividing the data into system 1 and system 2, the influence of smart positioners can be eliminated since we are only concern about the valve condition. Besides, the slopes of data after being divided into system1 and system 2 have negative signs which indicate the response time to exhaust instrument air from the actuator is decreasing from day to day. This is relevant because as the valve is being exercise, the valve friction and breakaway pressure are getting decrease. So, the response time to exhaust instrument air from the actuator should be decreased since the restrictions for the valve to move become less.

4.1.3.6 Average Response Time to Fill

Figure 32 and 33 shown below showing the average response time to fill obtained from PST which had been done for 88 days for ball valve and butterfly valve respectively. The set of data used to plot the graph can be referred to Appendix VII. Response time to fill means the time required for instrument air to be filled in the actuator to open the valve. Both graphs display the same pattern where at the beginning, the response time is small at certain value. The unit to measure the response time is pound per square inch (psi) per second. The data obtained is far smaller compared to response time to exhaust because the instrument air needs to be filled into the actuator until it is high enough to open the valve is flowing through small instrument air tubing.

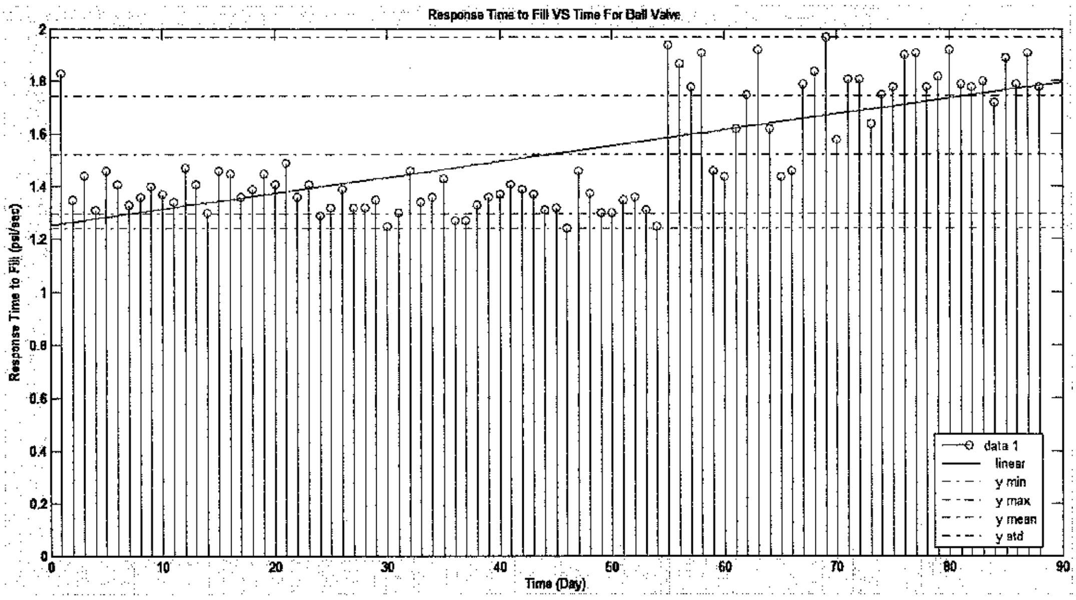


Figure 32: Graph of average response time to fill versus day for ball valve

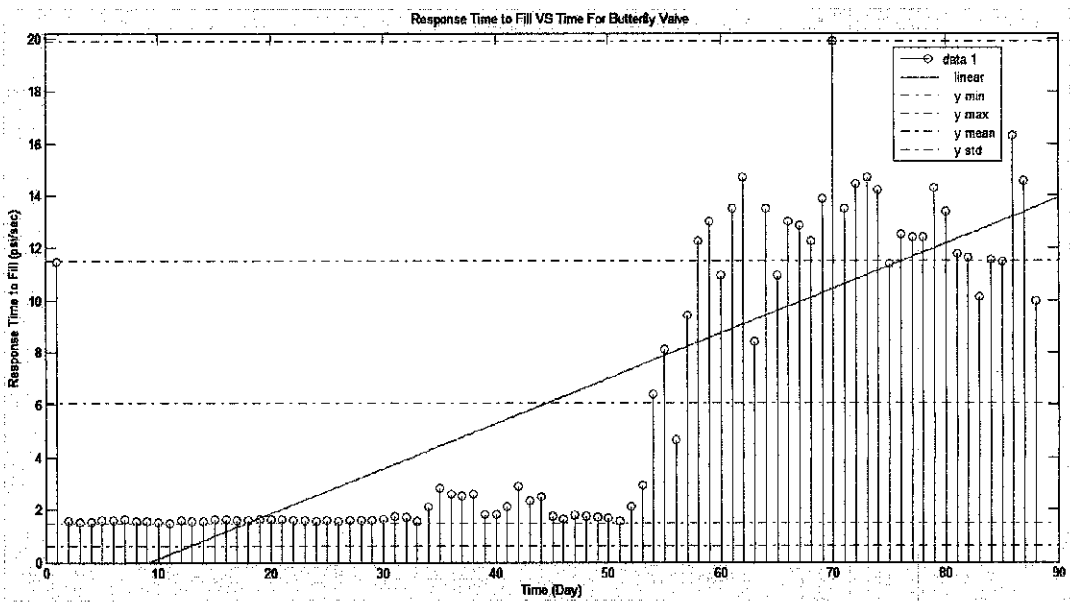


Figure 33: Graph of average response time to fill versus day for butterfly valve

Table 13: Statistics from average response time to fill for ball and butterfly valves

TYPE	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	1.24	1.97	1.5228	0.2242	0.006036
BUTTERFLY	1.48	19.93	6.0733	5.4487	0.172234

However, there is a sudden increment for response time starting from day 54. It is far obvious happen to the butterfly valve as we can see from the mean, maximum and standard deviation value of the data obtained for butterfly valve compared to ball valve. After further investigation, the cause of sudden increment in the data is due to the swapping of smart positioners during the experiment period. Since the smart positioners were changed on day 54, there are huge difference between the data before day 54 and the data after day 54. In order to obtain more accurate data, the influence of swapping the smart positioners must be eliminated. This can be done by dividing the data into two parts, system 1 which represents data before the smart positioners being swapped and system 2 which represents the data after the smart positioners being swapped. By dividing the data, the graphs and the datble will be as follows:

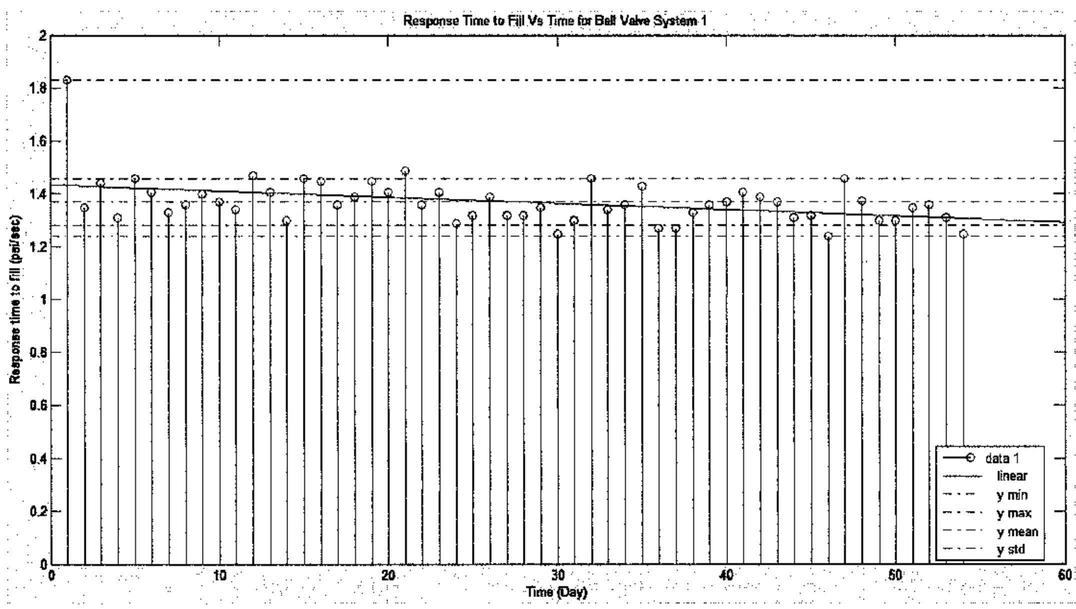


Figure 34: Graph of average response time to fill versus day for ball valve system 1

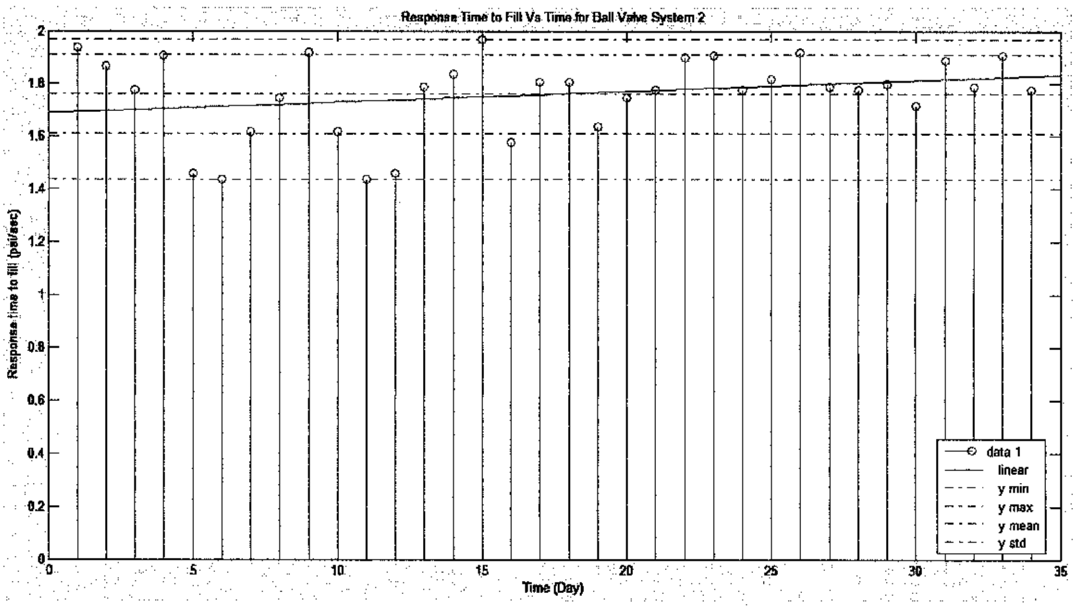


Figure 35: Graph of average response time to fill versus day for ball valve system 2

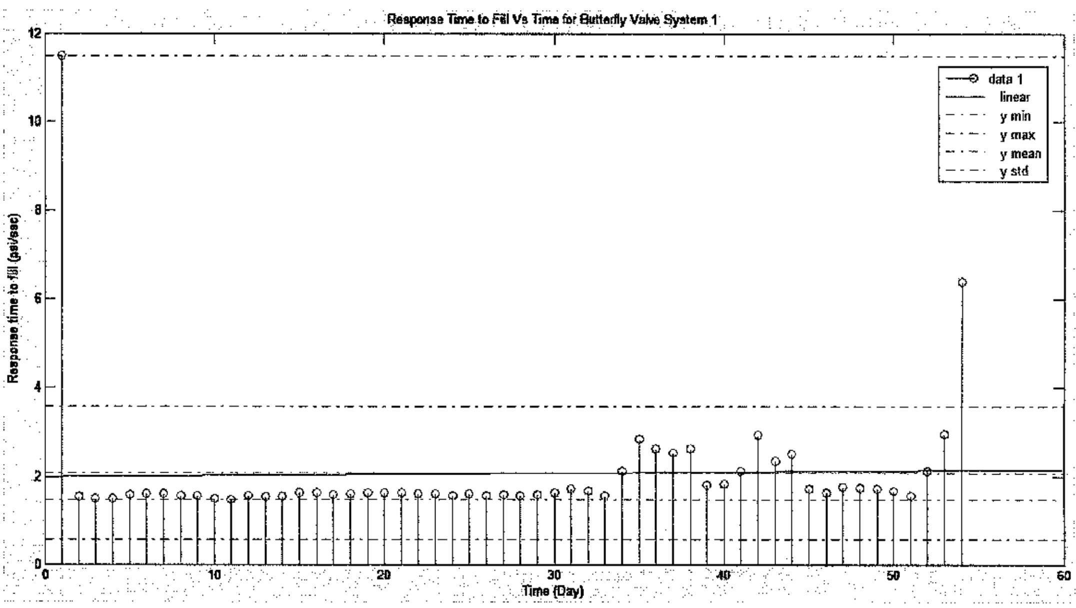


Figure 36: Graph of average response time to fill versus day for butterfly valve system 1

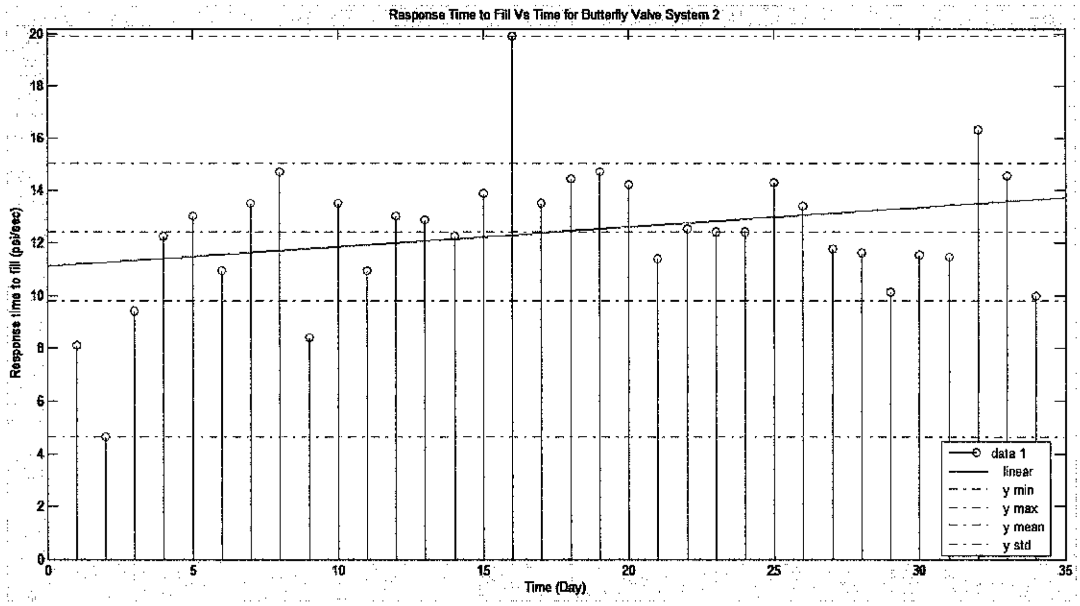


Figure 37: Graph of average response time to fill versus day for butterfly valve system 2

Table 14: Statistics from average response time to fill for ball and butterfly valves system 1 and system 2

TYPE	SYSTEM	MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
BALL	1	1.24	1.83	1.3711	0.088858	-0.002364
	2	1.438	1.97	1.7637	0.149793	-0.004083
BUTTERFLY	1	1.56	6.41	2.0753	0.885014	0.002652
	2	4.66	19.928	12.4254	2.628759	0.074060

Based no Figure 34, 35, 36, 37 and Table 14, the data become more consistent as the influence of swapping the smart positioned had been removed. This can be seen by comparing the standard deviation of the data before and after being divided. Data which had been removed the influence of swapping smart positioners have smaller standard deviation compared to the data which the influence of swapping the smart positioned had not been removed. Besides, the slope of the data also decreased after the influence of swapping the smart positioners. For ball valve, the slopes are negative which indicates the response time to fill is decreased as times goes by. This is what it supposes to be since by exercising the valve, the friction and breakaway pressure getting decrease and as a result the response time to fill the instrument air inside the actuator to move the valve to full open position within the time limit also decrease. However, for the butterfly valve, the slopes for both systems are positive. Even though the butterfly valve had been exercised, the response time to fill instrument air inside the actuator dose not determine by the friction between the valve plate and the valve body since the area of contact between the valve plate and valve body is small. Other small factors may lead to the increase the response time to fill the instrument air into the actuator such as the air filter which might not be clean, size and length of the instrument air tubing.

4.1.3.7 Average Spring Range

Figure 38, 39, 40 and 41 showing the average spring range obtained from PST which had been done for 88 days for ball valve and butterfly valve respectively. The set of data used to plot the graph can be referred to Appendix VIII and Appendix IX. In spring range, we are concerned on upper spring range and lower spring range. Upper spring range is the minimum pressure of instrument air used to counter the force applied by the spring inside the actuator in order to make the valve full open. On the other hand, lower spring range is the maximum pressure of instrument air used to counter the force applied by the spring inside the actuator in order to make the valve remain full close. Based on the graphs below, the upper spring range for both ball and butterfly valves are almost consistent. But as times goes by, the upper spring range is getting decreased. For the lower spring range, the data are not consistent. This can be seen by looking at the graphs of lower spring range for both ball and butterfly valves.

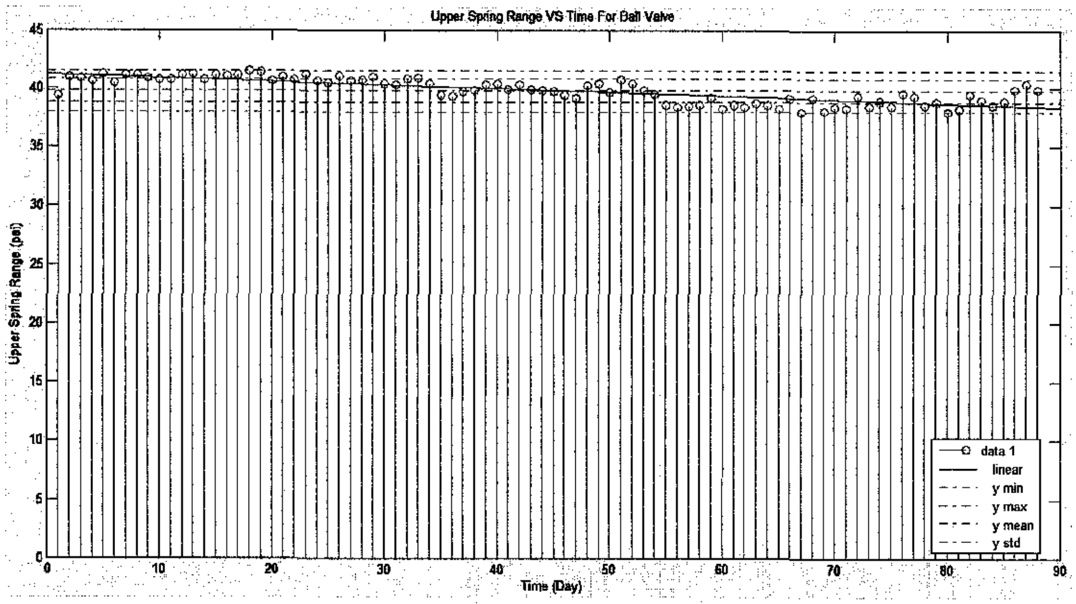


Figure 38: Graph of average upper spring range versus day for ball valve

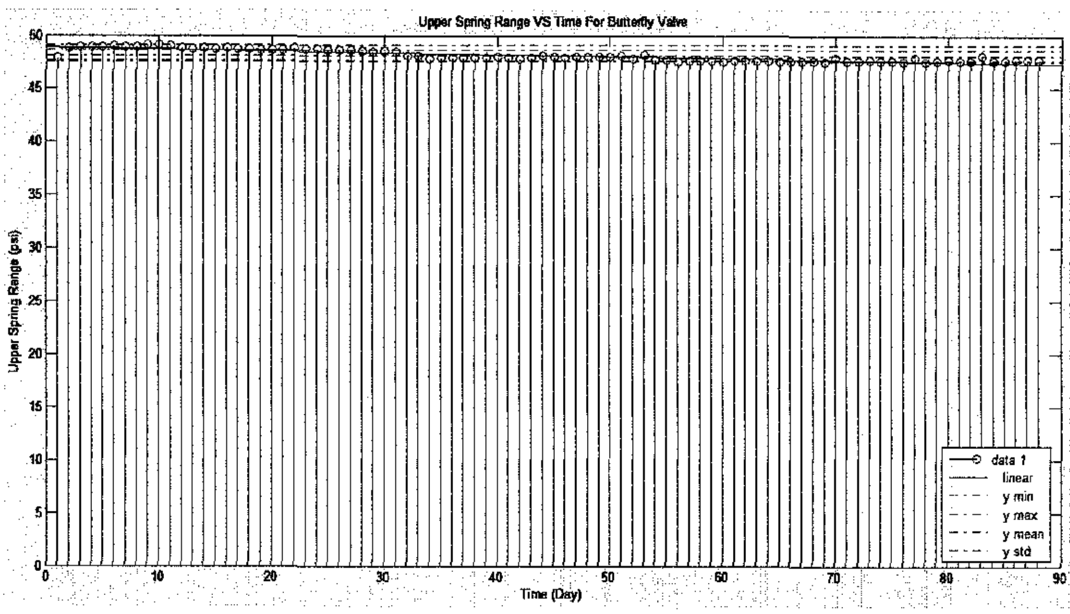


Figure 39: Graph of average upper spring range versus day for butterfly valve

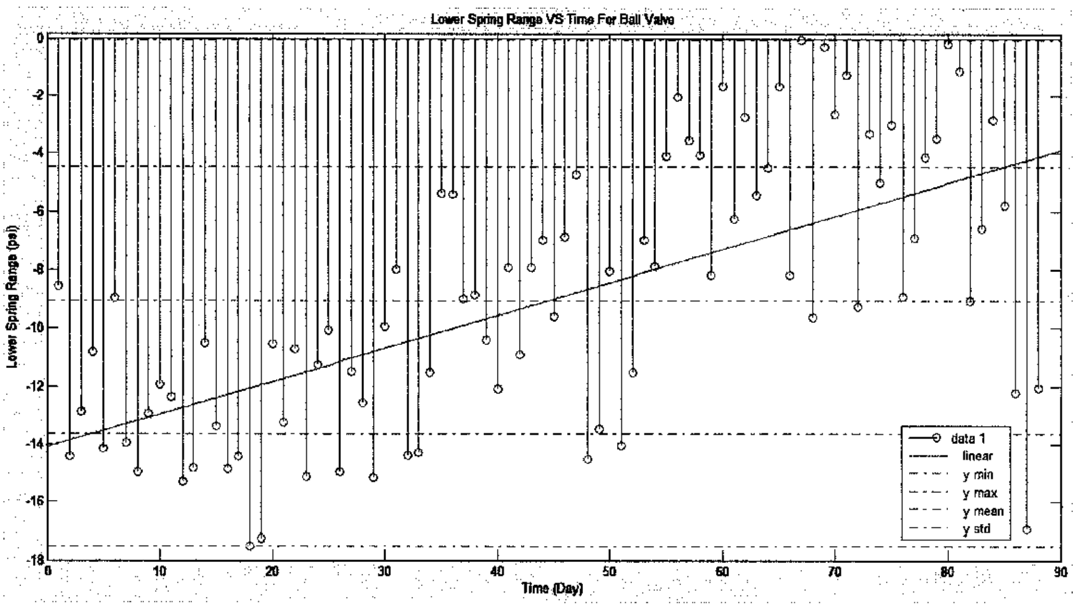


Figure 40: Graph of average lower spring range versus day for ball valve

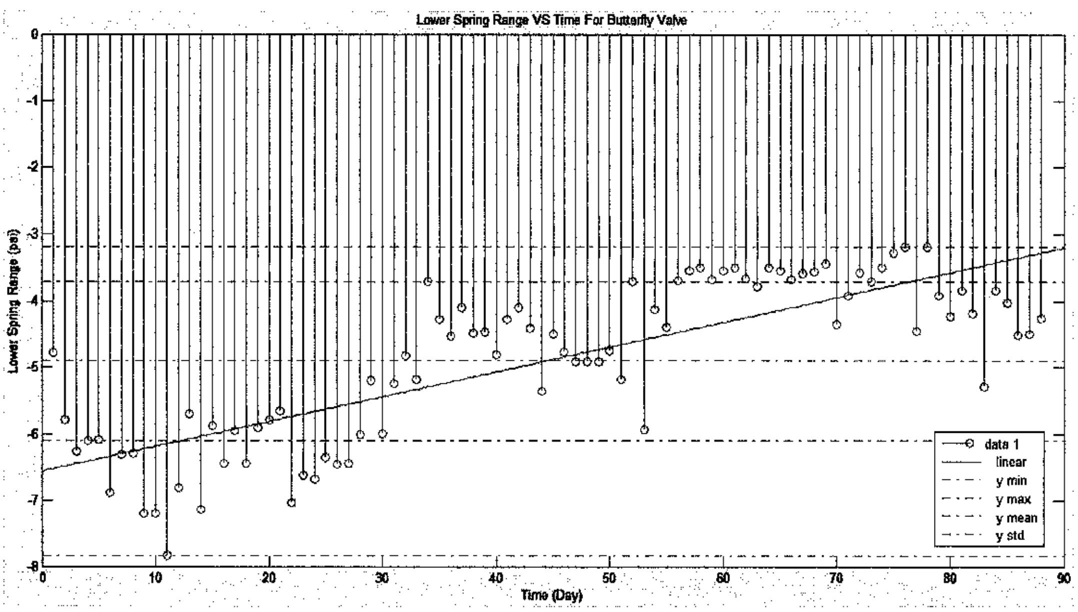


Figure 41: Graph of average lower spring range versus day for butterfly valve

Table 15: Statistics from average upper and lower spring range for ball and butterfly valves

TYPE		MIN	MAX	MEAN	STANDARD DEVIATION	SLOPE
UPPER	BALL	38.04	41.54	39.8819	1.024	-0.031561
	BUTTERFLY	47.54	49.15	48.1305	0.5110	-0.017411
LOWER	BALL	-17.52	-0.039	-9.0437	4.6024	0.113305
	BUTTERFLY	-7.835	-3.178	-4.8921	1.1956	0.037282

Towards the end of the experiment period, there are sudden changes of data pattern where a group of data starting from day 54 suddenly increase. After further investigation, the cause of sudden changes of data pattern is caused by the swapping of the smart positioners on day 54. Swapping the smart positioners influence the analysis of the data. In order to nalayze the data more accurate, the influence of smart positioners swapping need to be removed. This can be done by divide the data into two groups, system1 represents the data before the smart positioners were swapped and system 2 represents the data after the smart positioners were swapped. After the data were divided, the graphs and table are as follows:

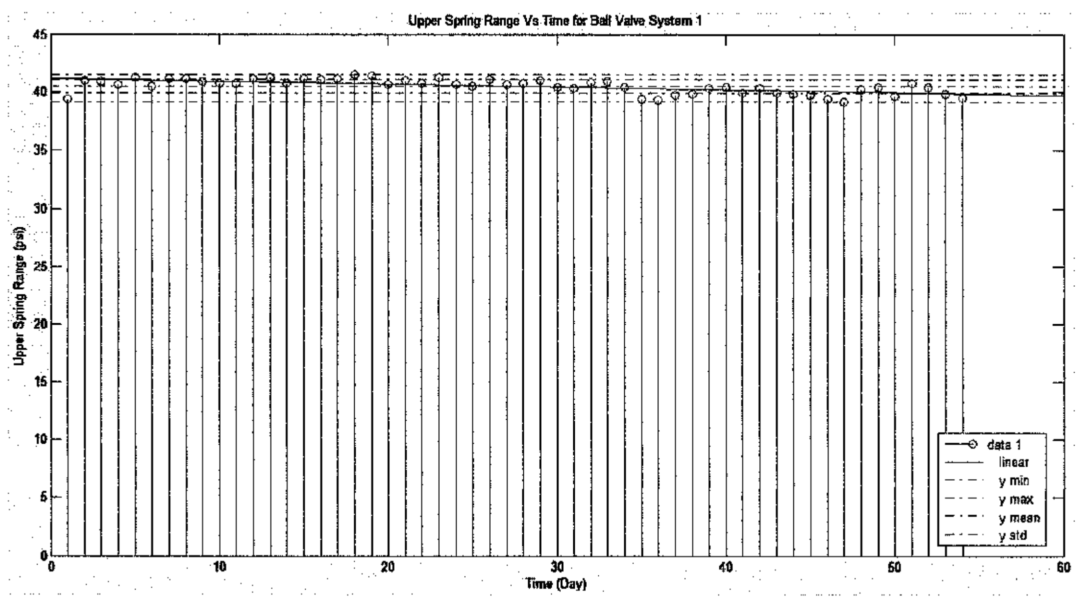


Figure 42: Graph of average upper spring range versus day for ball valve system 1

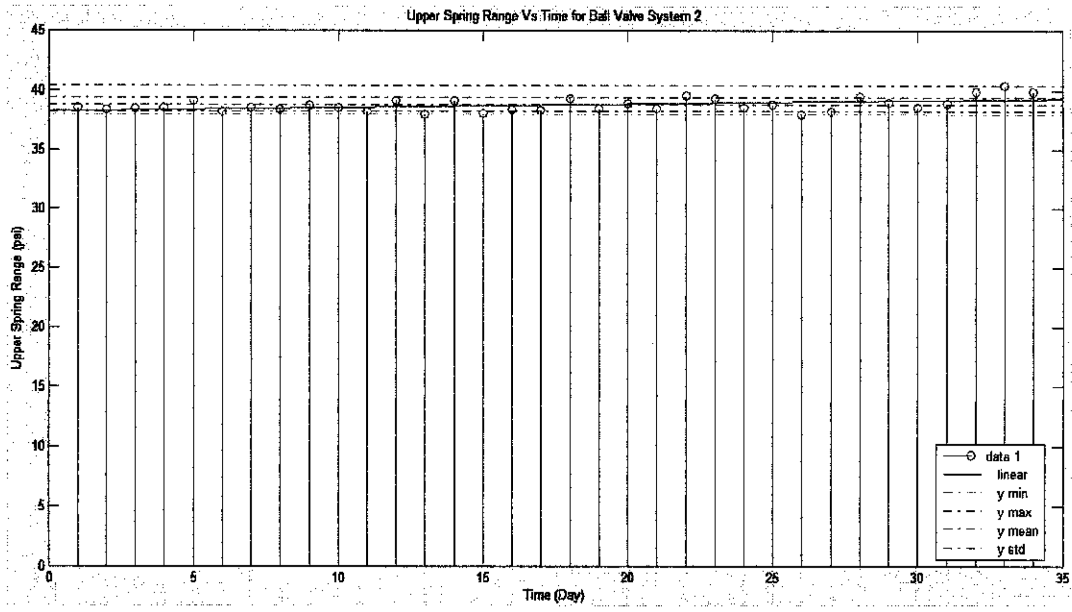


Figure 43: Graph of average upper spring range versus day for ball valve system 2

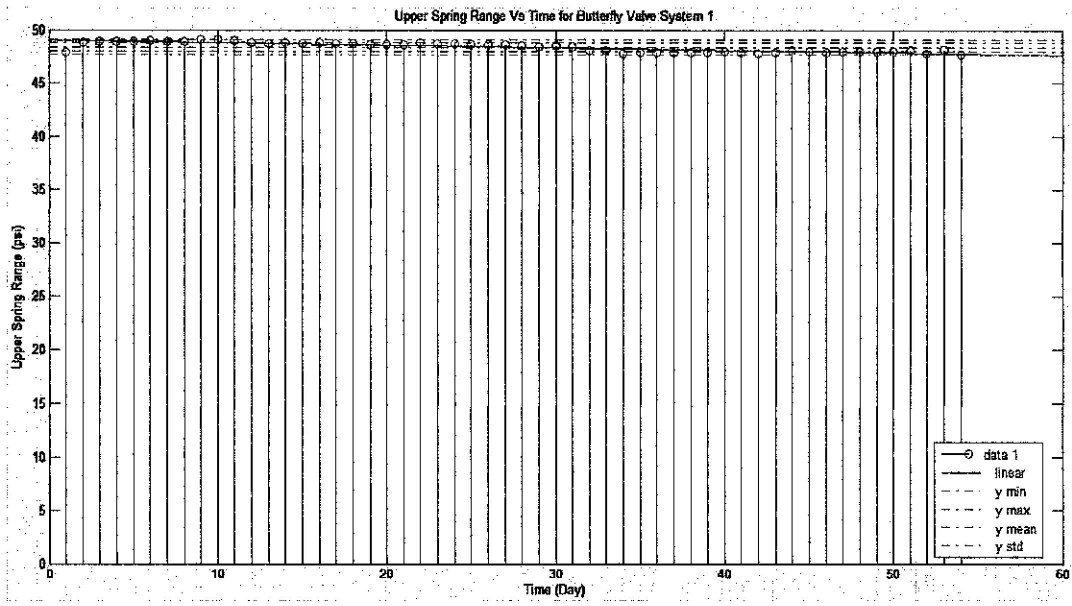


Figure 44: Graph of average upper spring range versus day for butterfly valve system 1

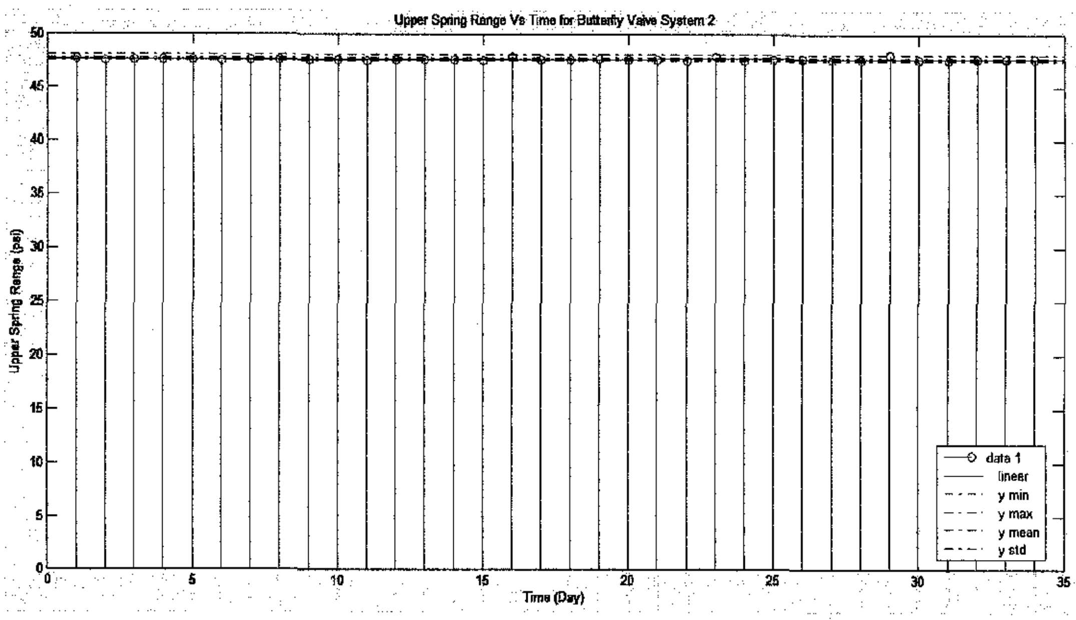


Figure 45: Graph of average upper spring range versus day for butterfly valve system 2

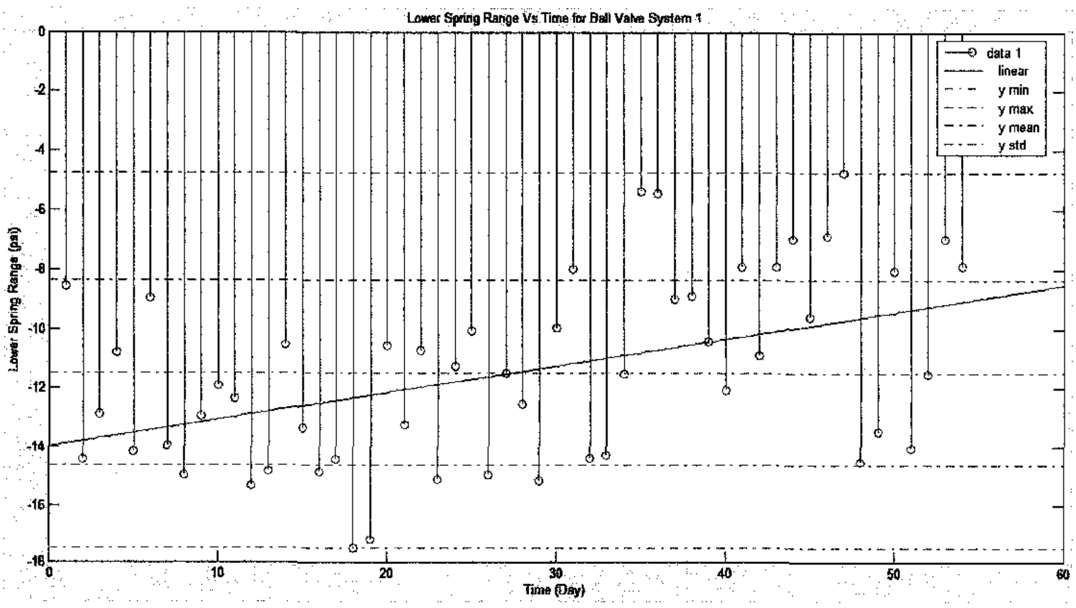


Figure 46: Graph of average lower spring range versus day for ball valve system 1

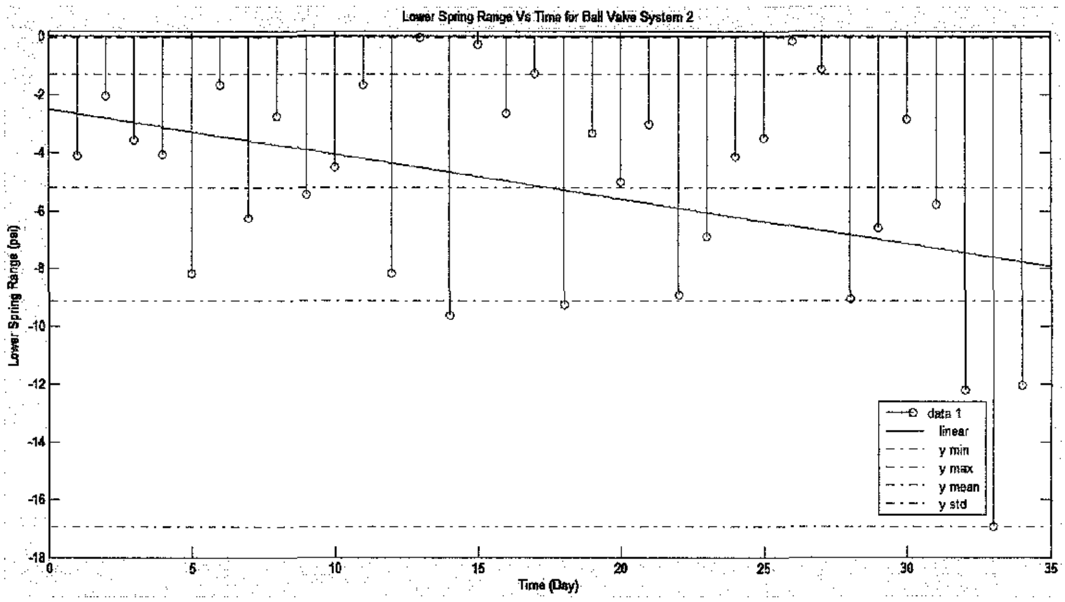


Figure 47: Graph of average lower spring range versus day for ball valve system 2

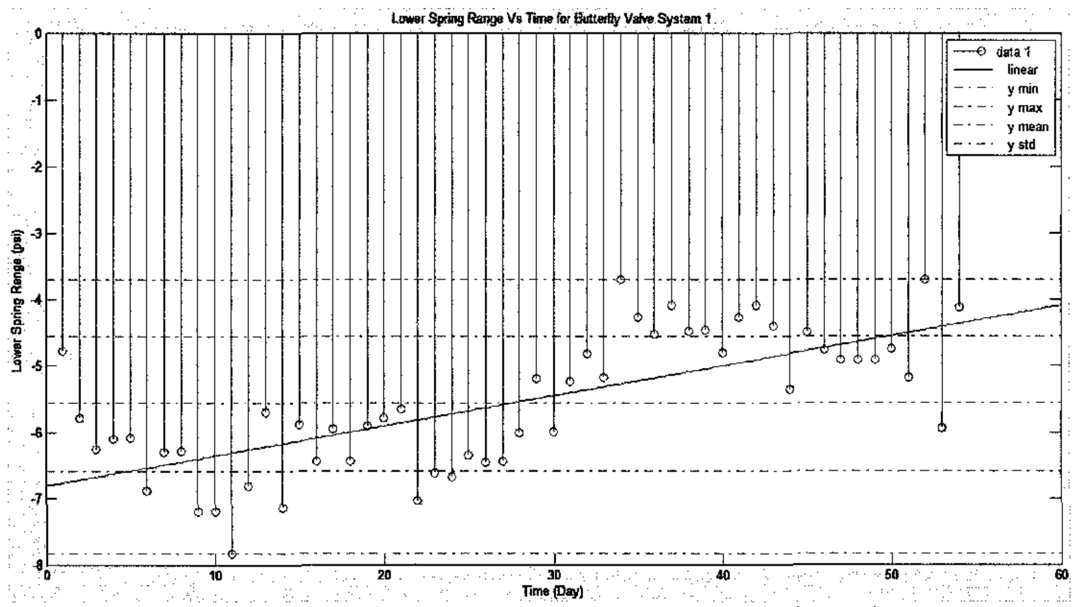


Figure 48: Graph of average lower spring range versus day for butterfly valve system 1

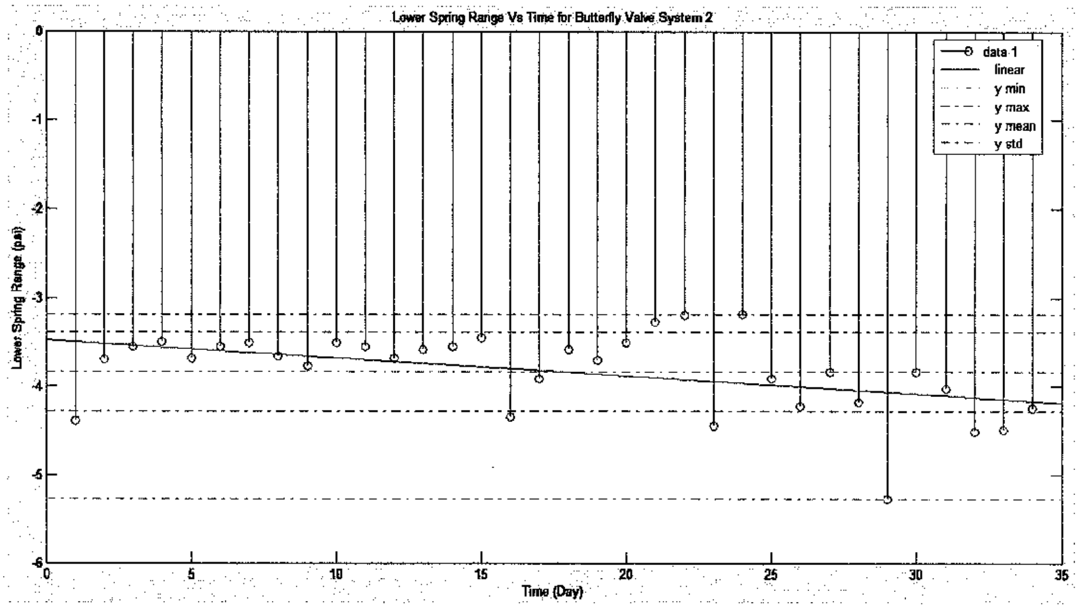


Figure 49: Graph of average lower spring range versus day for butterfly valve system 2

Table 16: Statistics from average upper and lower spring range for ball and butterfly valves system 1 and system 2

TYPE		SYSTEM	MIN	MAX	MEAN	STD. DEV.	SLOPE
UPPER	BALL	1	39.183	41.543	40.5411	0.6067	-0.024416
		2	38.042	40.442	38.8351	0.5784	0.028820
	BUTTERFLY	1	47.748	48.802	48.1824	0.3368	-0.023478
		2	47.542	48.076	47.6663	0.1130	0.004176
LOWER	BALL	1	-17.52	-4.714	-11.4626	3.1396	0.090947
		2	-16.94	-0.039	-5.2018	3.9028	-0.154846
	BUTTERFLY	1	-7.032	-3.709	-5.1070	0.9052	0.045291
		2	-5.275	-3.178	-3.8293	0.4526	-0.020515

Based on Figure 42, 43, 44, 45, 46, 47, 48, 49 and Table 16, the data become more consistent after the influence of smart positioners swapping had been removed. This had been proven by comparing the standard deviation and slope between the data before and after eliminating the influence of smart positioner swapping.

However, the standard deviation for lower spring of ball valve is still far higher compared to the rest parameters. This is due to the maximum pressure of instrument air supplied into the actuator during the valve is full close is depends on the mechanical parts of the valve such as the contact between the ball and the internal body of the valve, spring inside the actuator and stem. When the valve is full close, the instrument air is vent out from the actuator and the main pars that make the valve moving to the full close position is the spring inside the actuator. Since the spring is stretching and squeezing every time the valve is moving, the elasticity of the spring may change when the spring is in squeezing or stretching position for a long time. When looking to the slope of the upper and lower spring range for both valves for both systems, we can see that system 1 gives relevant results where the spring range is approaching to 0 psi as time goes by. These had been proven by looking at the negative slope for upper spring range and positive slope for lower spring range. However, it is the other way around for system 2 where the upper and lower spring range become further from 0 psi as time goes by. This is due to the setting of the smart positioner which is supposed to be for ball valve but being applied to the butterfly valve and vice versa.

4.2 Experimentation/Modeling

4.2.1 Analysis Using Artificial Neural Network (ANN)

Based on the data obtained from partial stroke testing using dry test skid which had been completed by previous final year students, the data was then being analyzed using Artificial Neural Network (ANN). From all 90 days data collected, only first 54 days data being used to be analyze. This due to the controller swapping between ball valve and butterfly valve which was done on day 55 during testing period. This data selection was done in order to eliminate the effect of the controller which may results inaccurate data analysis.

From the partial stroke test, there are seven parameters which had been recorder for every valve stroking which are:

- Friction
- Breakaway Pressure
- Droop
- Response time to exhaust
- Response time to fill
- Lower Spring Range
- Upper Spring Range

In Artificial Neural Network (ANN), we need to determine which parameters need to be used as inputs and targets. Based on the parameters listed, breakaway pressure had been selected as targets while the rest parameters had been used as inputs. This kind of selection had been done because breakaway pressure can be used as indication that the valve is sticking since more pressure required when the valve just want to move from static position compared to the pressure required when the valve already moves with constant speed.

In analyzing the data using Artificial Neural Network (ANN), two layers of neurons had been used. There is no rule of thumb on how many neurons required to be used. The only way to determine the number of neuron to be used of each layer is by try and error method. In try and error method, the number of neutron for each layer is increased until we got the combination of neuron in layer one and layer two which results in the least root mean square error (RMSE) for both training and validation data. For the time being, the number of neuron for each layer is increased up until 10 neurons. The best results for try and error in determining number of neurons need to be used are as follows:

Table 17: Number of neuron for each layer selected based on the root mean square error for each model

VALVE TYPE	SYSTEM	NUMBER OF NEURONS IN LAYER 1	NUMBER OF NEURONS IN LAYER 2	RMSE FOR TRAINING DATA	RMSE FOR VALIDATION DATA
Ball	1	8	5	0.1706	0.1675
	2	7	8	0.1962	0.1928
Butterfly	1	6	3	0.1224	0.2320
	2	5	3	0.0569	0.0627

4.2.1.1 Artificial Neural Network Data Analysis for Ball Valve System 1

For ball valve, eight and five neurons had been used for each layer one and layer two when analyzing data for ball valve using Artificial Neural Network (ANN). The results are as follows:

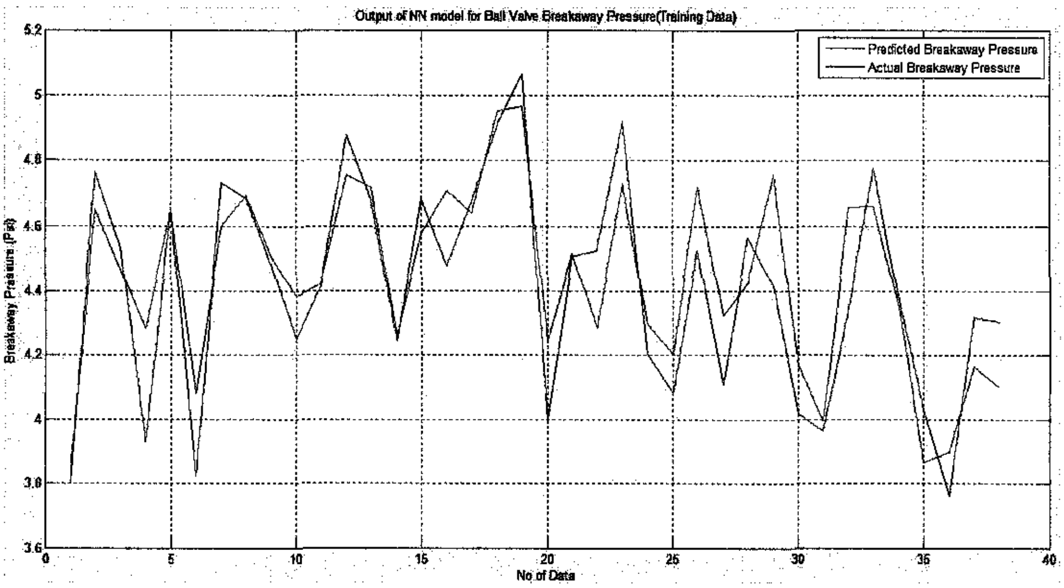


Figure 50: Output of Neural Network model for breakaway pressure of ball valve system 1(Training Data)

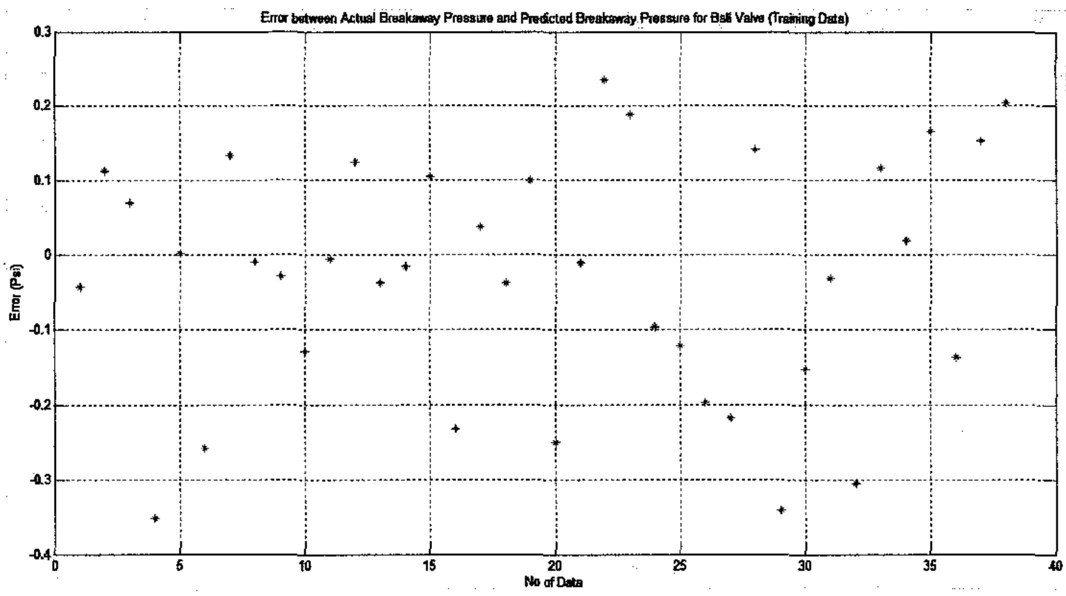


Figure 51: Error between actual breakaway pressure and predicted breakaway pressure for ball valve system 1(Training Data)

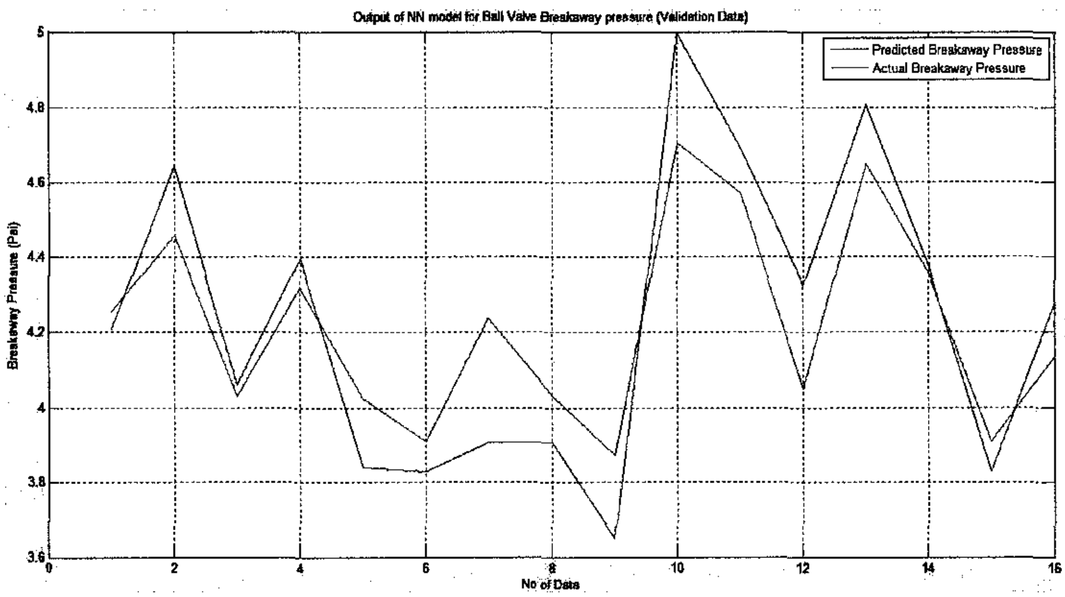


Figure 52: Output of Neural Network model for breakaway pressure of ball valve system 1 (Validation Data)

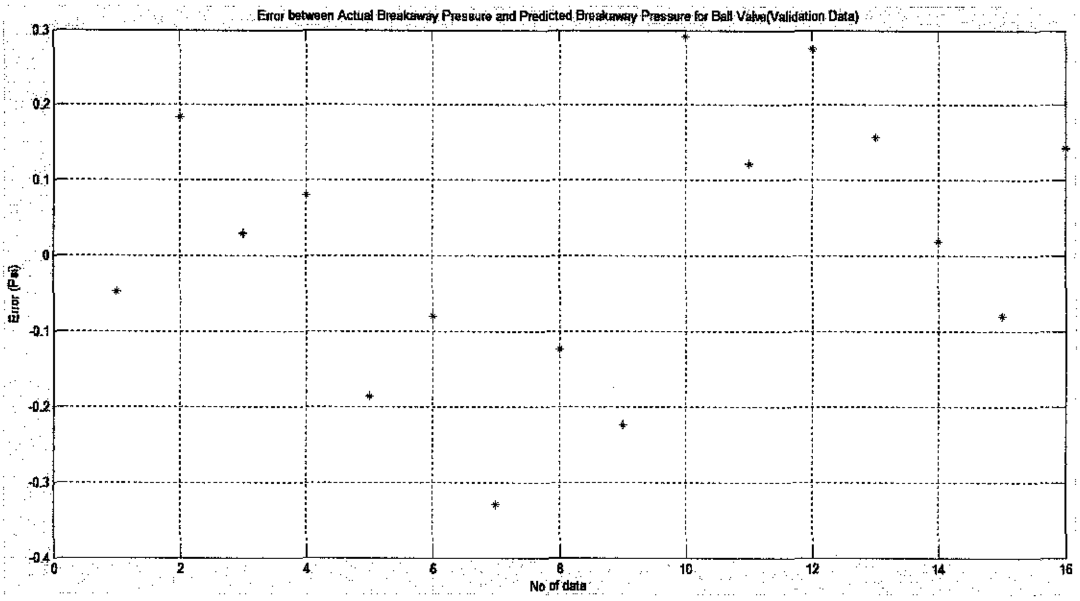


Figure 53: Error between actual breakaway pressure and predicted breakaway pressure for ball valve system 1(Validation Data)

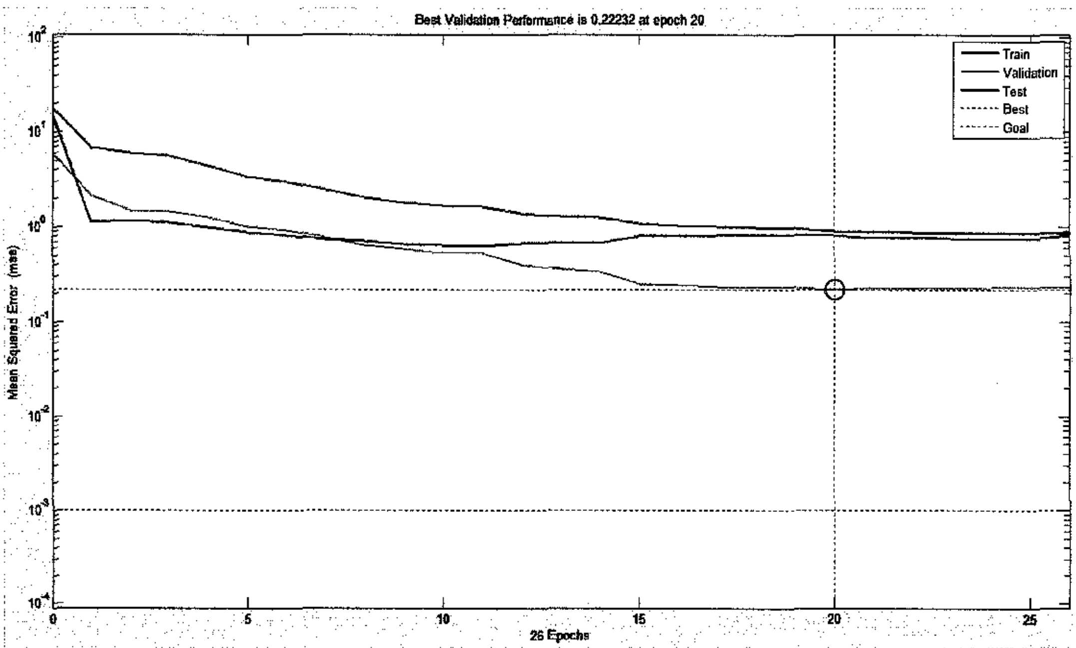


Figure 54: Network Performance for breakaway pressure of ball valve system 1.

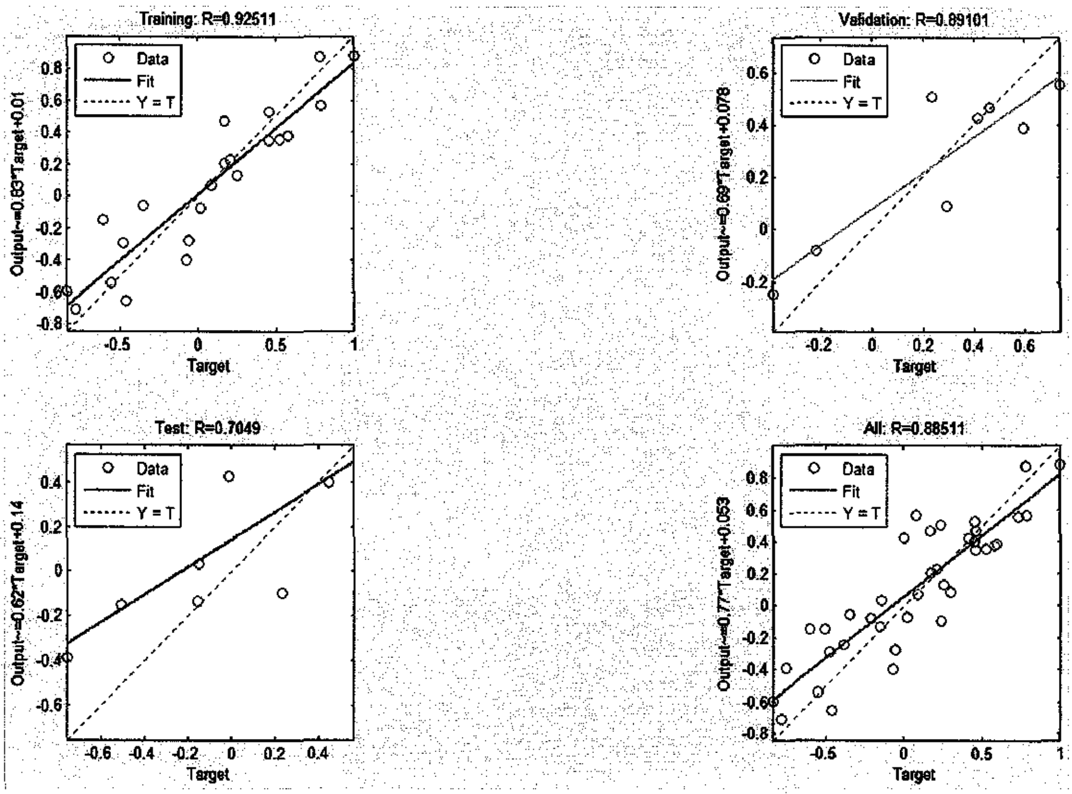


Figure 55: Linear regression for breakaway pressure of ball valve system 1

Table 18: Summary of breakaway pressure for ball valve system 1 data analysis using Artificial Neural Network (ANN)

Correlation	0.8831	
Number of neuron in layer 1	8	
Number of neuron in layer 2	5	
	Training Data	Validation Data
Number of data	38	16
Fit Value	52.2187	55.1554
Index Value	22.8305	20.1104
Percentage Error	2.8720%	3.4890%
Mean Square Error (MSE)	0.0258	0.0303
Root Mean Square Error (RMSE)	0.1607	0.1740

Based on Figure 50, it displays the actual and predicted breakaway pressure for ball valve based on training data which represented by blue and red lines respectively. We can see that the predicted breakaway pressure for each number of data is close to the actual breakaway pressure. This indicates that the neural network had been trained according to the data provided very well. This can be proven by looking at the pattern of the predicted breakaway pressure which is almost similar to the actual breakaway pressure.

When looking at the training data error as in Figure 51 which is the difference between the actual and predicted breakaway pressure for ball valve, the error tabulated are closed to 0 psi which indicates the neural network model was train very well. Even though there are some errors which are ±0.4 psi, the errors are acceptable because it rarely happen. Besides, this error tolerance still gives high accuracy to the ball valve's predicted breakaway pressure. Other than that, the root mean square error (RMSE) for ball valve's training data is only 0.1607 with is close to 0 as shown in Table 18. The closer RMSE value to 0 means the results is more accurate. This also supported by referring to the percentage error which is only 2.8720% which already prove that the neural network model is very accurate.

The validation data results as shown in Figure 52 also gives the same results where the pattern of ball valve's breakaway pressure is almost similar to actual ball valve's breakaway pressure as shown in Figure 50. Besides, the error between actual breakaway pressure and predicted breakaway pressure for ball valve for validation data as in Figure 53 gives same tolerance value as training data which is ±0.4 psi. The RMSE and percentage error for validation data are 0.1740 and 3.4850% which indicates the neural network model is very accurate.

After the training was completed, we can check the network performance and determine if any changes need to be made to the training process, the network architecture or the data sets. This can be done by referring to the network performance graph as shown in Figure 54. From the graph, the iteration at which the validation performance reach a minimum was 20 with mean square error (MSE) is 0.22232. The training continued for 6 more iteration before the training stop. This figure seems like indicates major problems with the training since the validation and test curve are not similar. Since the test curve had increased slightly before validation increased, then it is possible that some overfitting might have occurred [23].

The next step in validating the network is through regression plot. This plot shows the relationship between the outputs of the network and the targets. If the training were perfect, the network output and the targets would be exactly equal. However, the relationship is rarely in practice. As shown in Figure 55, the four axes represent the training, validation, testing and overall data. The dashed line in each axis represents the perfect result where outputs are equal to targets. The solid line in each axis represents linear regression line between outputs and targets. The R value is an indication of the relationship between the outputs and targets. If R is equal to 1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets. Based on figure 31, there are strong relationship between the targets and the outputs since the R values for training, validation, testing and overall data indicates 0.92511, 0.89101, 0.7049 and 0.88511 respectively. All these values are close to 1. Even though R value for testing data is the lowest, it still indicates strong relationship since it close to 1. These values also shows that training data indicates the best fit followed while testing data has the worst fit. However, the overall data still indicates a good fit [25].

4.2.1.2 Artificial Neural Network Data Analysis for Ball Valve System 2

For system 2, seven and eight neurons had been used for each layer one and layer two respectively when analyzing data for ball valve using Artificial Neural Network (ANN). The results are as follows:

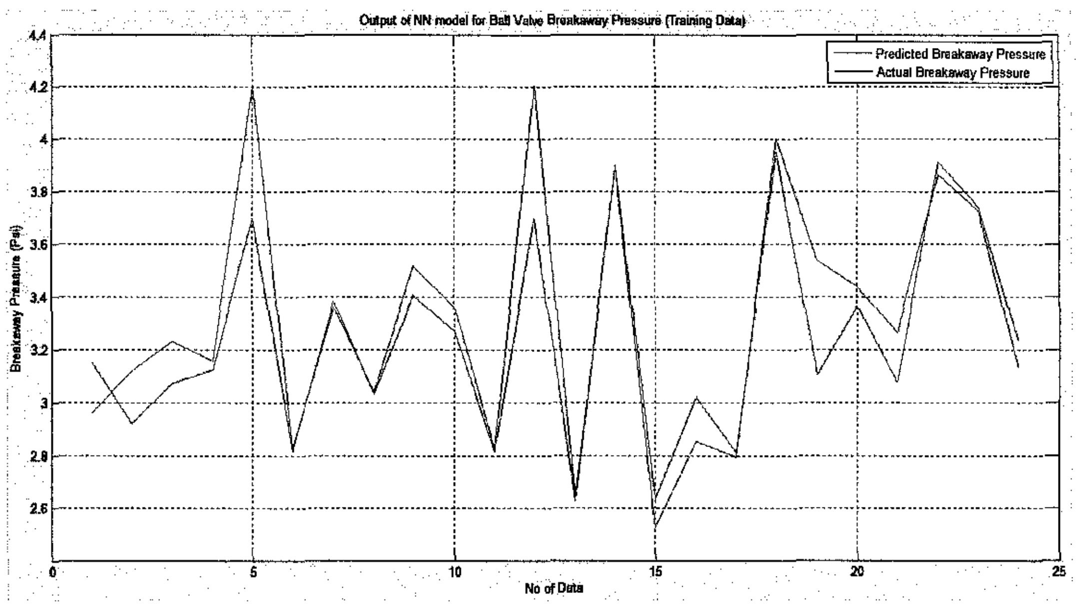


Figure 56: Output of Neural Network model for ball valve breakaway pressure system 2 (Training Data)

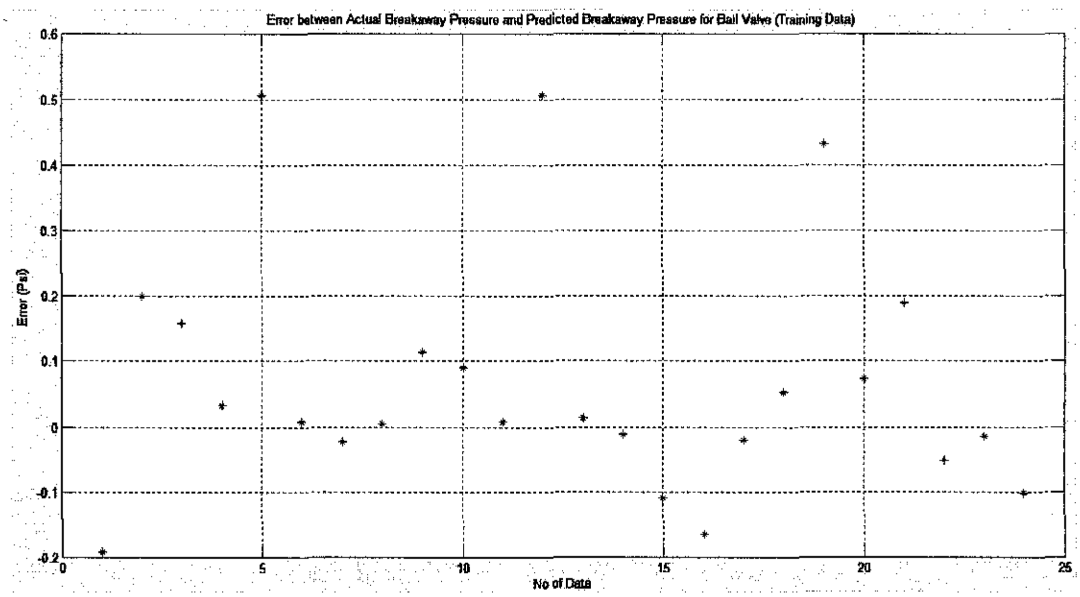


Figure 57: Error between actual breakaway pressure and predicted breakaway pressure for ball valve system 2 (Training Data)

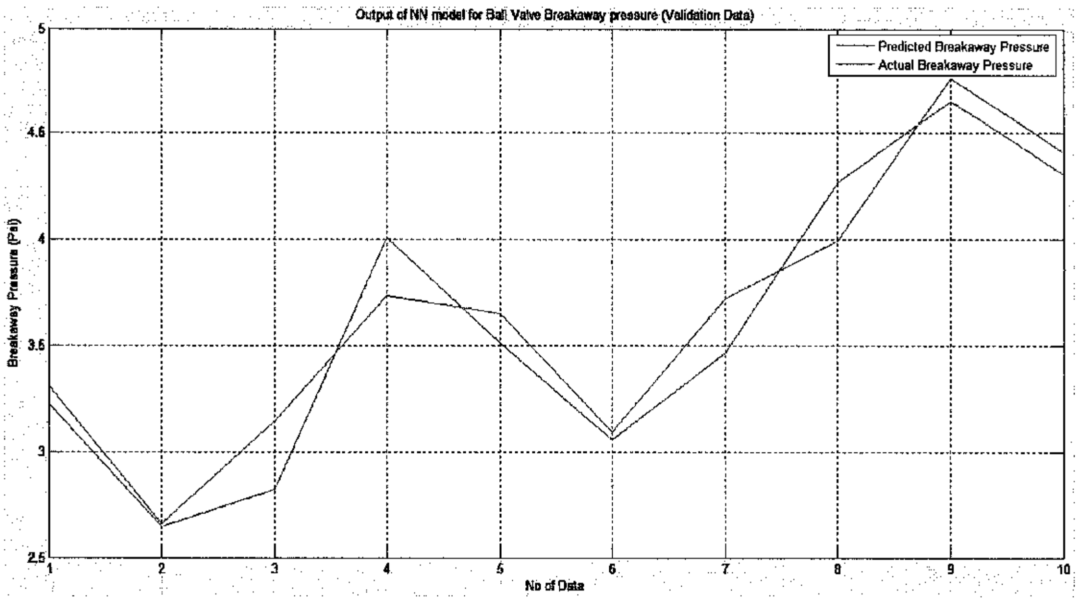


Figure 58: Output of Neural Network model for breakaway pressure of ball valve system 2 (Validation Data)

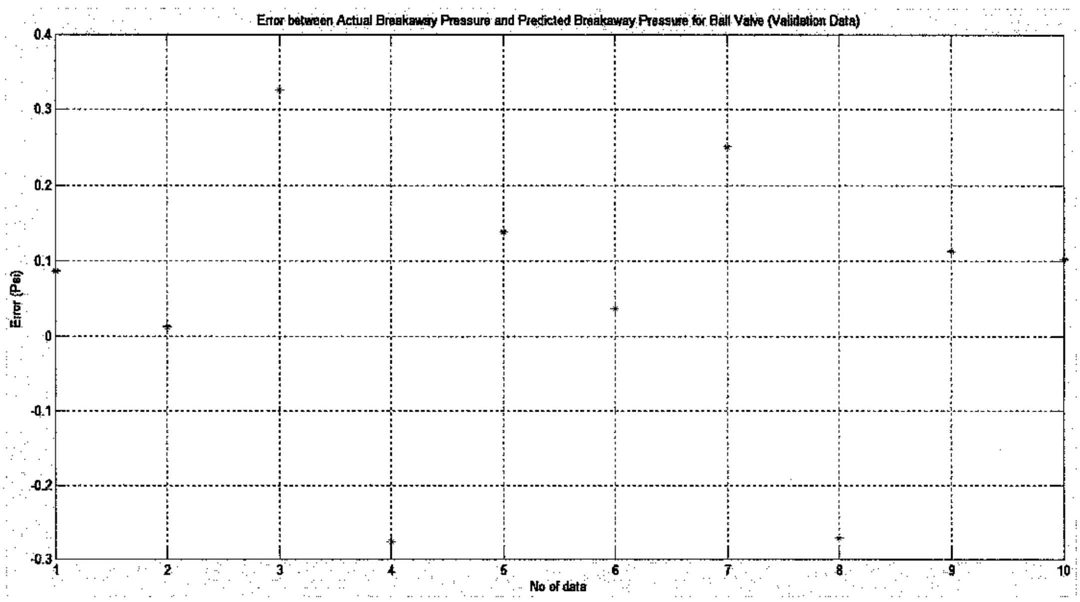


Figure 59: Error between actual breakaway pressure and predicted breakaway pressure for ball valve system 2 (Validation Data)

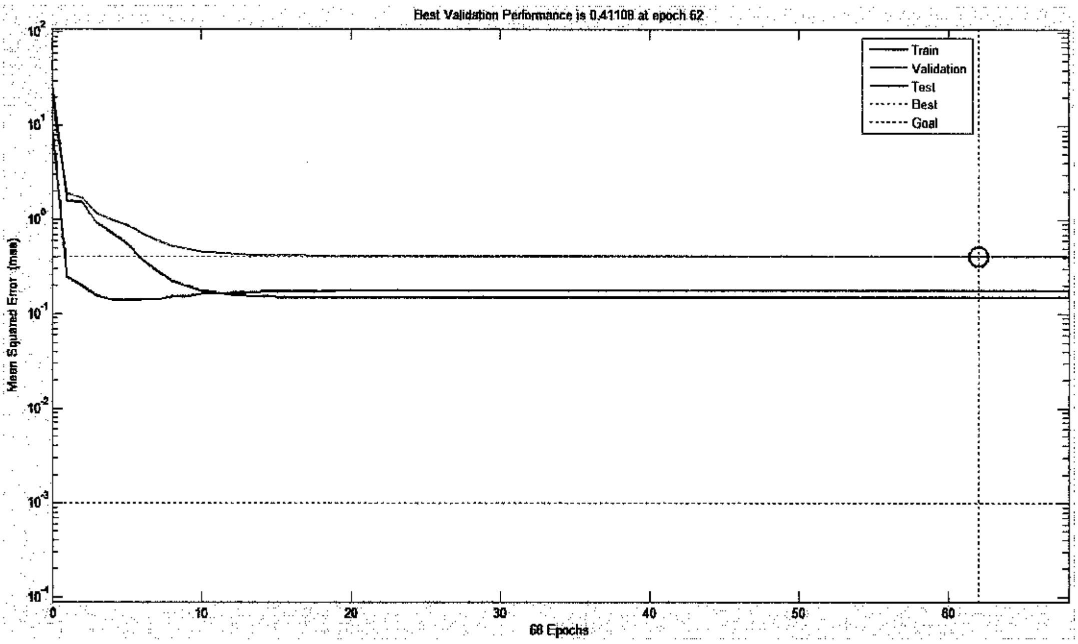


Figure 60: Network Performance for breakaway pressure of ball valve system 2.

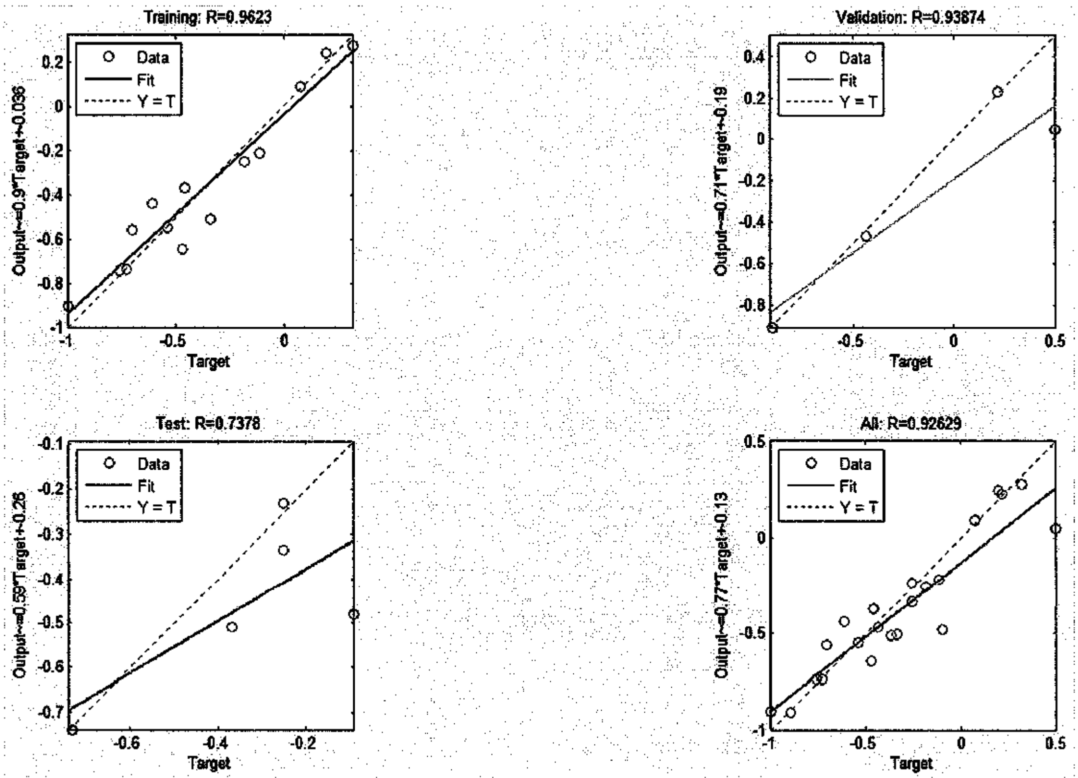


Figure 61: Linear regression for breakaway pressure of ball valve system 2

Table 19: Summary of breakaway pressure for ball valve system 2 data analysis using Artificial Neural Network (ANN)

Correlation	0.9263	
Number of neuron in layer 1	7	
Number of neuron in layer 2	8	
	Training Data	Validation Data
Number of data	24	10
Fit Value	58.3629	67.8884
Index Value	17.3365	10.3115
Percentage Error	4.0888%	4.3905%
Mean Square Error (MSE)	0.0385	0.0372
Root Mean Square Error (RMSE)	0.1962	0.1928

Based on Figure 56, it displays the actual and predicted breakaway pressure for ball valve system 2 based on training data which represented by blue and red lines respectively. We can see that the predicted breakaway pressure for each number of data is closer to the actual breakaway pressure compared to the ANN for system 1. This indicates that the neural network had been trained according to the data provided very well. This can be proven by looking at the pattern of the predicted breakaway pressure which is almost similar to the actual breakaway pressure.

When looking at the training data error as in Figure 57 which is the difference between the actual and predicted breakaway pressure for ball valve, the error tabulated for system 2 are closed to 0 psi which indicates the neural network model was train very well However, the error is higher compared to system 1. Even though the errors recorded are ±0.5 psi, the errors are acceptable because it rarely happen. Besides, this error tolerance still gives high accuracy to the ball valve's predicted breakaway pressure which is similar to system 1. Other than that, the root mean square error (RMSE) for ball valve's training data is higher compared to system 1 which is 0.1962 as shown in Table 19. The closer RMSE value to 0 means the results is more accurate. When comparing the percentage error, the percentage error for system 2 is higher compared to system 1 which is 4.0888%. This shows that swapping the smart positioners had because the data obtained were in accurate and it leads to inaccurate breakaway pressure prediction by Artificial Neural Network (ANN).

The validation data results for ball valve system 2 as in Figure 58 also gives the same results where the pattern of breakaway pressure for ball valve is almost similar to actual ball valve's breakaway pressure as shown in Figure 56. However, the error between actual breakaway pressure and predicted breakaway pressure for ball valve for validation data was reduced to ±0.3 psi. The RMSE and percentage error for validation data are higher compared to system 1 which are 0.1928 and 4.3905% respectively. These are another indication that swapping the smart positioner leads to inaccurate data prediction since the percentage error and RMSE value for system 2 are higher compared to system 1.

After the training was completed, we can check the network performance and determine if any changes need to be made to the training process, the network architecture or the data sets. This can be done by referring to the network performance graph as shown in Figure 59. From the graph, the iteration for system 2 at which the validation performance reach a minimum was 62 with mean square error (MSE) is 0.41108. The training continued for 6 more iteration before the training stop. This figure does not indicate major problems with the training since the validation and test curve are similar [23]. However swapping the smart positioners had caused the MSE for system 2 is higher compared to system 1.

The next step in validating the network is through regression plot. Based on Figure 60, the relationship between the targets and the outputs for system 2 are stronger compared to system1 since the R values for training, validation, testing and overall data indicates 0.9623, 0.93874, 0.7378 and 0.92629 respectively. All these values are close to 1. Even though R value for testing data is the lowest, it still indicates strong relationship since it close to 1. These values also shows that training data indicates the best fit followed by validation data while testing data has the worst fit. These sequences are still similar to results from system 1. The only effect of swapping the smart positioners is the relationship between the targets and the outputs are getting stronger. Even though the relationships between the targets and the outputs are stronger, the data obtained for system 2 are not good to be used to predict breakaway pressure of ball valve since the percentage error and RMSE value are higher compared to system 1.

4.2.1.3 Artificial Neural Network Data Analysis for Butterfly Valve System 1

For butterfly valve, six and three neurons had been used for each layer one and layer two respectively when analyzing the data using Artificial Neural Network (ANN). The results are as follows:

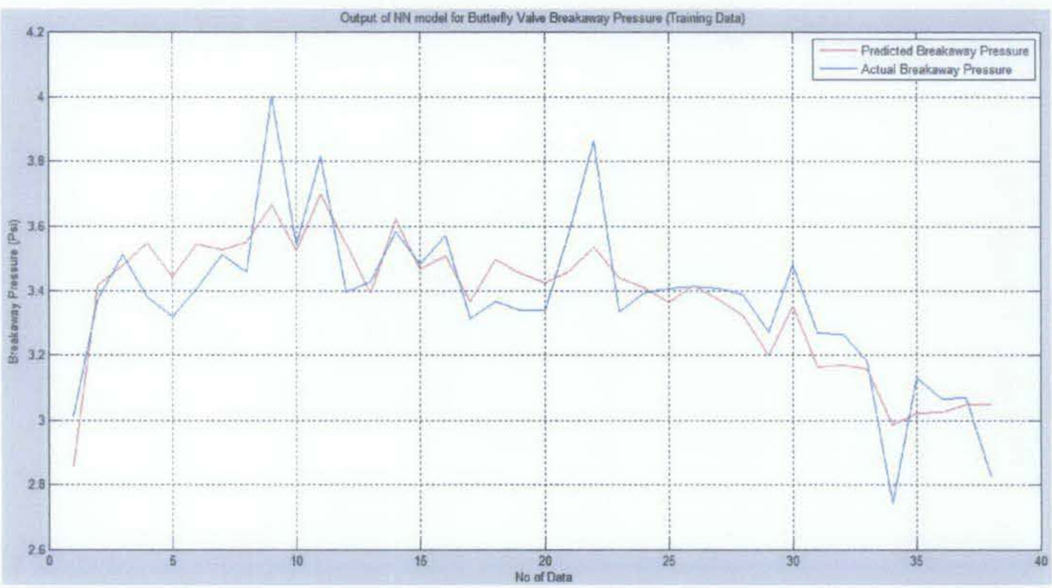


Figure 62: Output of Neural Network model for breakaway pressure of butterfly valve system 1 (Training Data)

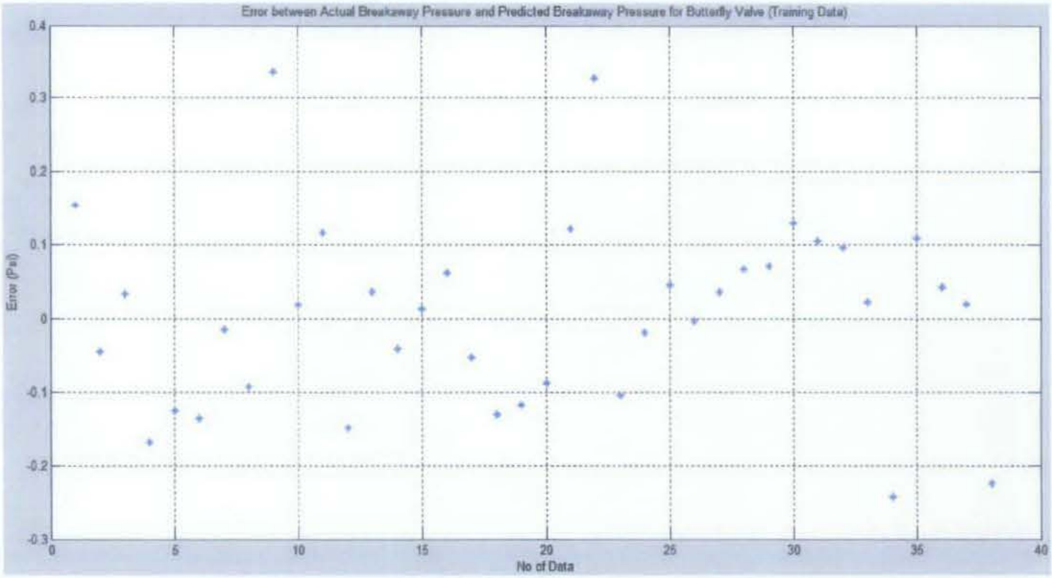


Figure 63: Error between actual breakaway pressure and predicted breakaway pressure for butterfly valve system 1 (Training Data)

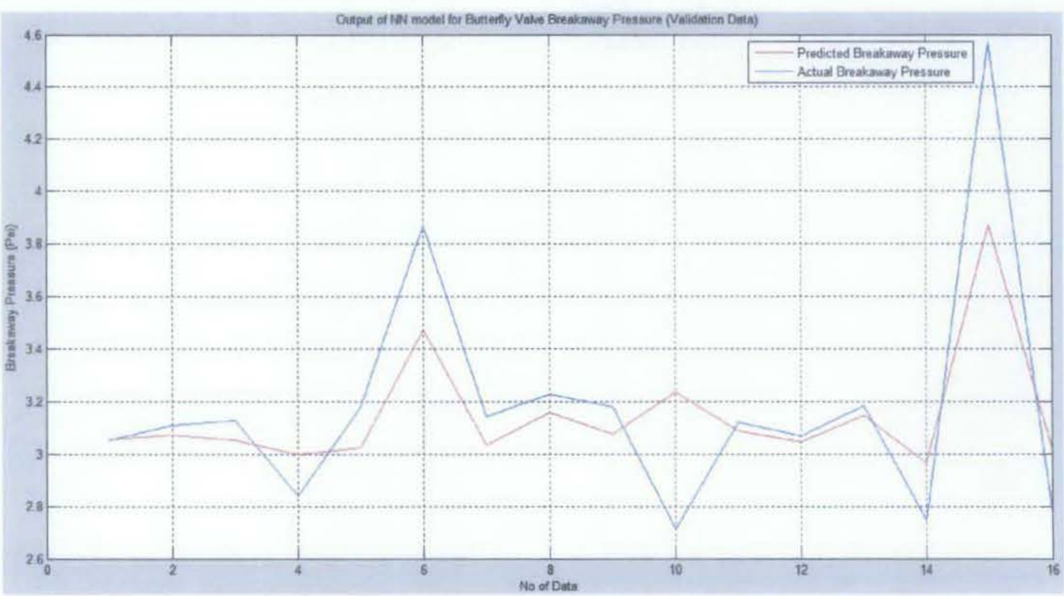


Figure 64: Output of Neural Network model for breakaway pressure of butterfly valve system 1 (Validation Data)

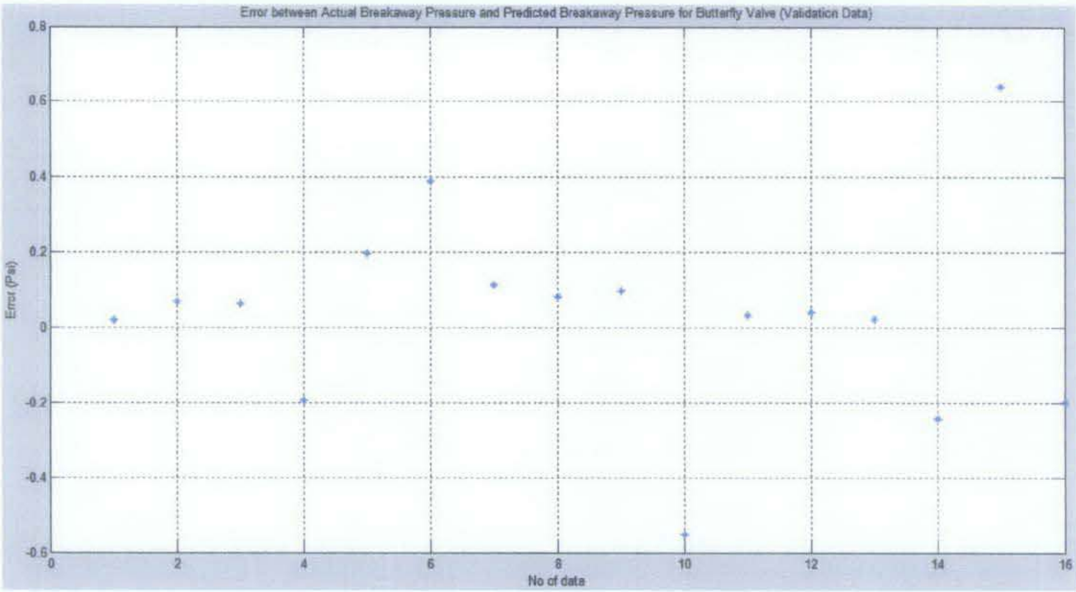


Figure 65: Error between actual breakaway pressure and predicted breakaway pressure for butterfly valve system 1 (Validation Data)

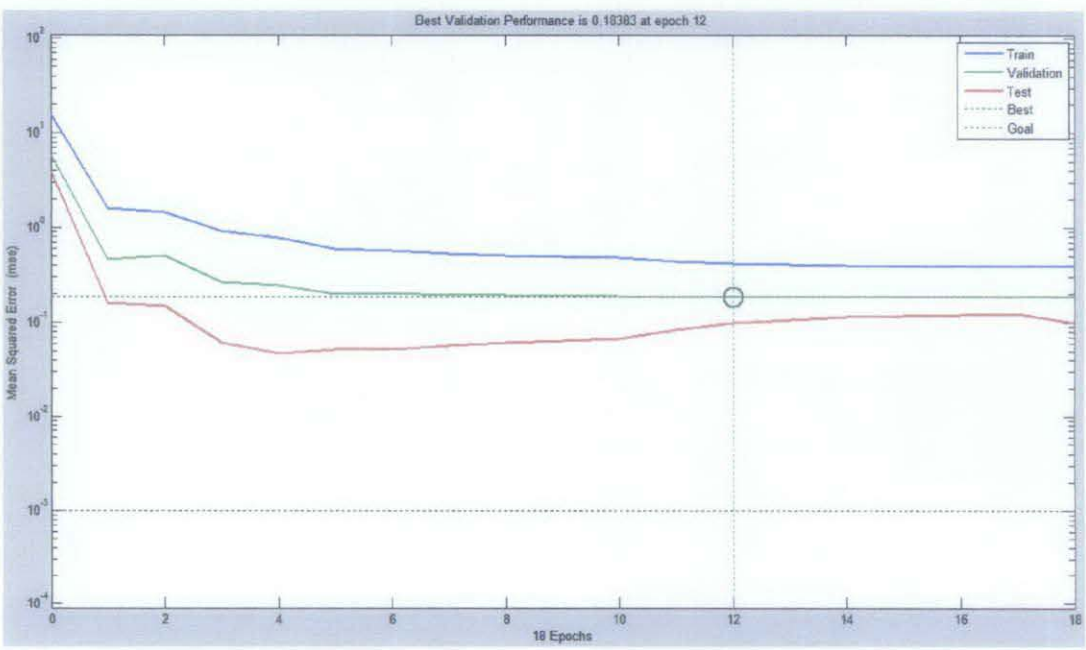


Figure 66: Network Performance for breakaway pressure butterfly valve system 1

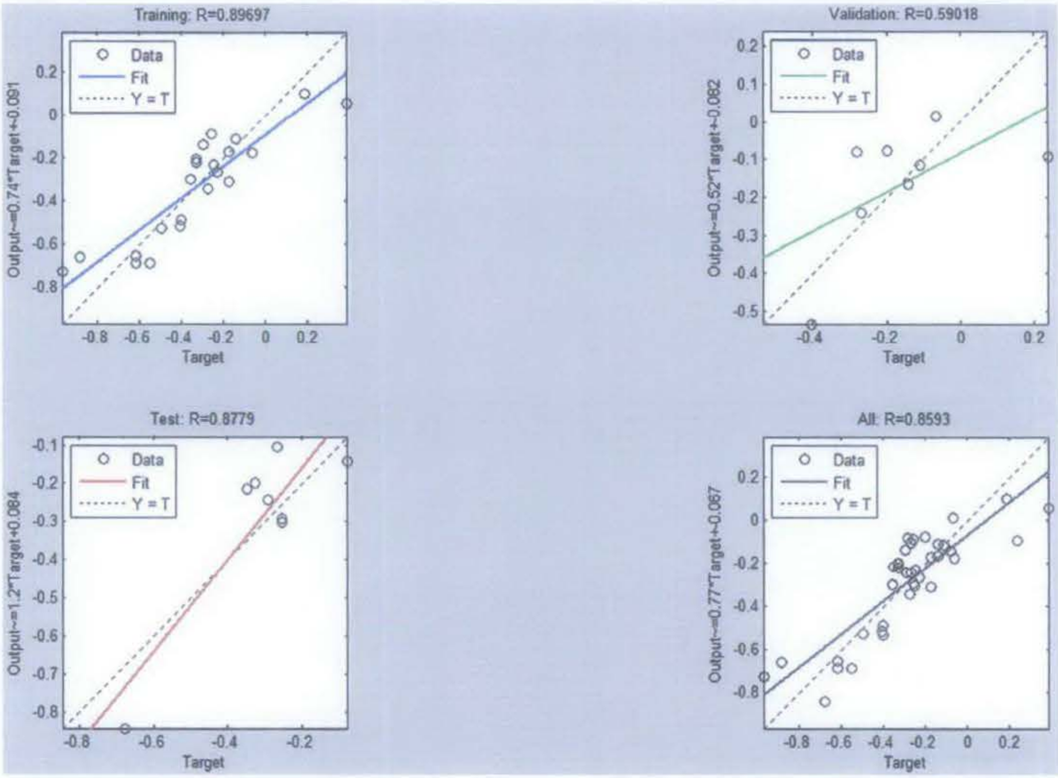


Figure 67: Linear regression for breakaway pressure of butterfly valve system 1

Table 20: Summary of breakaway pressure for butterfly valve system 1 data analysis using Artificial Neural Network (ANN)

Correlation	0.8537	
Number of neuron in layer 1	6	
Number of neuron in layer 2	3	
	Training Data	Validation Data
Number of data	38	16
Fit Value	47.8569	41.3934
Index Value	27.1890	34.3473
Percentage Error	2.8981%	6.096%
Mean Square Error (MSE)	0.0159	0.0675
Root Mean Square Error (RMSE)	0.1259	0.2599

Based on Figure 62, it displays the actual and predicted breakaway pressure for butterfly valve based on training data which represented by blue and red lines respectively. We can see that the predicted breakaway pressure for each number of data is close to the actual breakaway pressure. This indicates that the neural network had been trained according to the data provided very well. This can be proven by looking at the pattern of the predicted breakaway pressure which is almost similar to the actual breakaway pressure. However, the predicted butterfly valve's breakaway pressure is not able to reach the peak of the actual butterfly valve's breakaway pressure.

When looking at the training data error as in Figure 63 which is the difference between the actual and predicted breakaway pressure for butterfly valve, the error tabulated are closed to 0 psi which indicates the neural network model was train very well. Even though there are some errors which are ±0.4 psi, the errors are acceptable because it rarely happen. Besides, this error tolerance still gives high accuracy to the butterfly valve's predicted breakaway pressure. Other than that, the root mean square error (RMSE) for butterfly valve's training data is only 0.1259 with is close to 0 as shown in Table 20. The closer RMSE value to 0 means the results is more accurate. This also supported by referring to the percentage error which is only 2.8981% which already prove that the neural network model is very accurate.

The validation data results as shown in Figure 64 also gives the same results where the pattern of butterfly valve's breakaway pressure is almost similar to actual butterfly valve's breakaway pressure as shown in Figure 62. However, the error between actual breakaway pressure and predicted breakaway pressure for butterfly valve for validation data is slightly higher compared to the training data which is ±0.6 psi. The RMSE and percentage error for validation data are 0.2599 and 6.0960% which indicates the neural network model is slightly less accurate.

After the training was completed, we can check the network performance and determine if any changes need to be made to the training process, the network architecture or the data sets. This can be done by referring to the network performance graph as shown in Figure 65. From the graph, the iteration at which the validation performance reach a minimum was 12 with mean square error (MSE) is 0.18383. The training continued for 6 more iteration before the training stop. This figure seems like does not indicates major problems with the training since the validation and test curve are similar [23].

The next step in validating the network is through regression plot. This plot shows the relationship between the outputs of the network and the targets. If the training were perfect, the network output and the targets would be exactly equal. However, the relationship is rarely in practice. As shown in Figure 66, the four axes represent the training, validation, testing and overall data. The dashed line in each axis represents the perfect result where outputs are equal to targets. The solid line in each axis represents linear regression line between outputs and targets. The R value is an indication of the relationship between the outputs and targets. If R is equal to 1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets. Based on figure 37, there are strong relationship between the targets and the outputs since the R values for training, testing and overall data indicates 0.89697, 0.8779 and 0.8593 respectively. All these values are close to 1. However, validation data has less relationship where the R value indicates is 0.59018. Even though R value for validation data is the lowest, it still indicates strong relationship since it closer to 1 compared to 0. These values also show that training data indicates the best fit followed while validation data has the worst fit. However, the overall data still indicates a good fit [25].

4.2.1.4 Artificial Neural Network Data Analysis for Butterfly Valve System 2

For system 2, five and three neurons had been used for each layer one and layer two respectively when analyzing the data using Artificial Neural Network (ANN). The results are as follows:

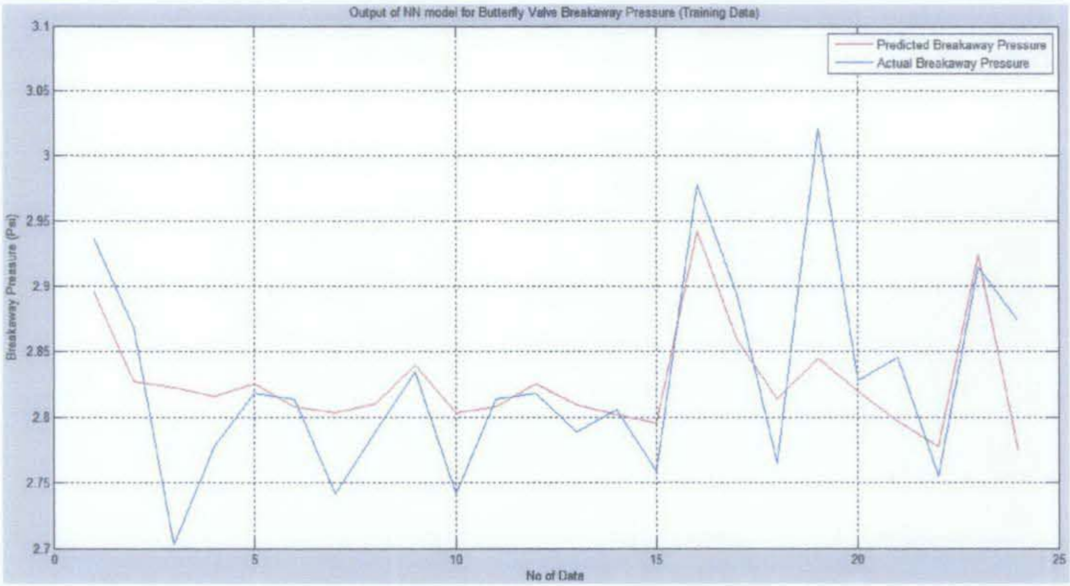


Figure 68: Output of Neural Network model for breakaway pressure of butterfly valve system 2 (Training Data)

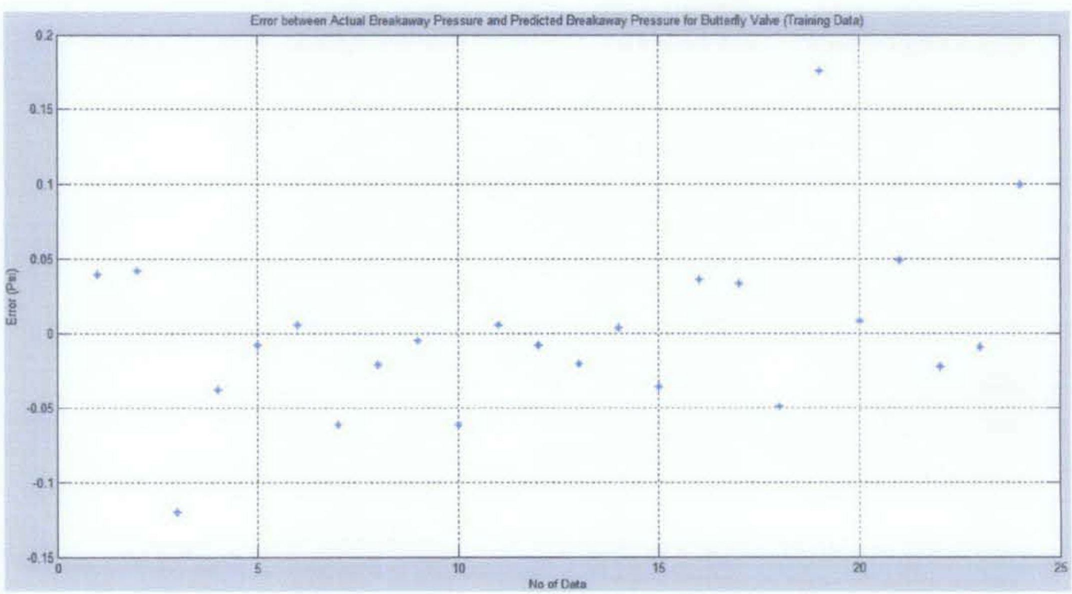


Figure 69: Error between actual breakaway pressure and predicted breakaway pressure for butterfly valve system 2 (Training Data)

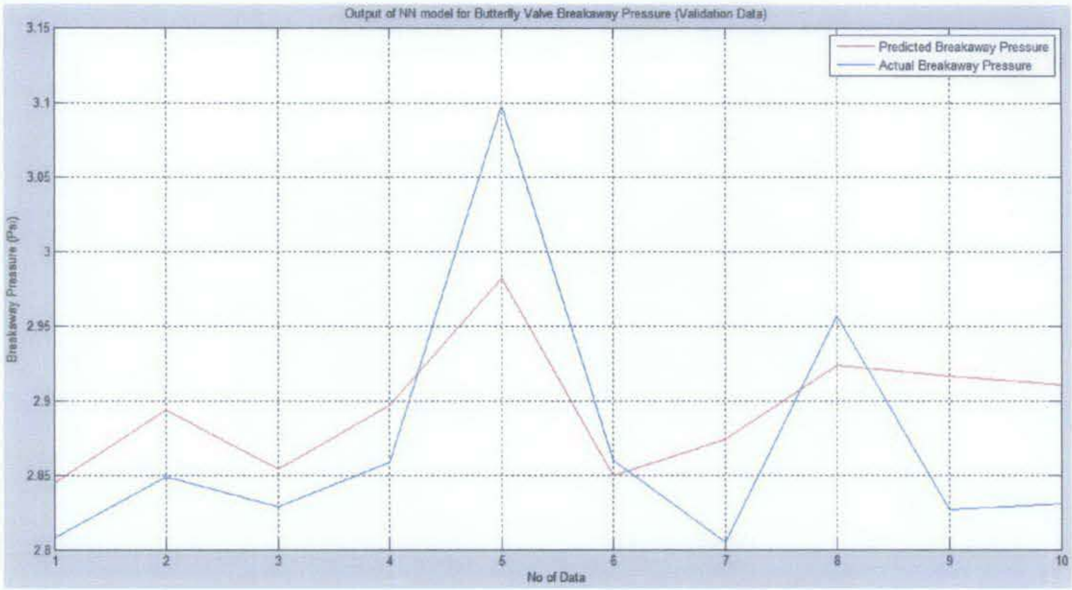


Figure 70: Output of Neural Network model for breakaway pressure of butterfly valve system 2(Validation Data)

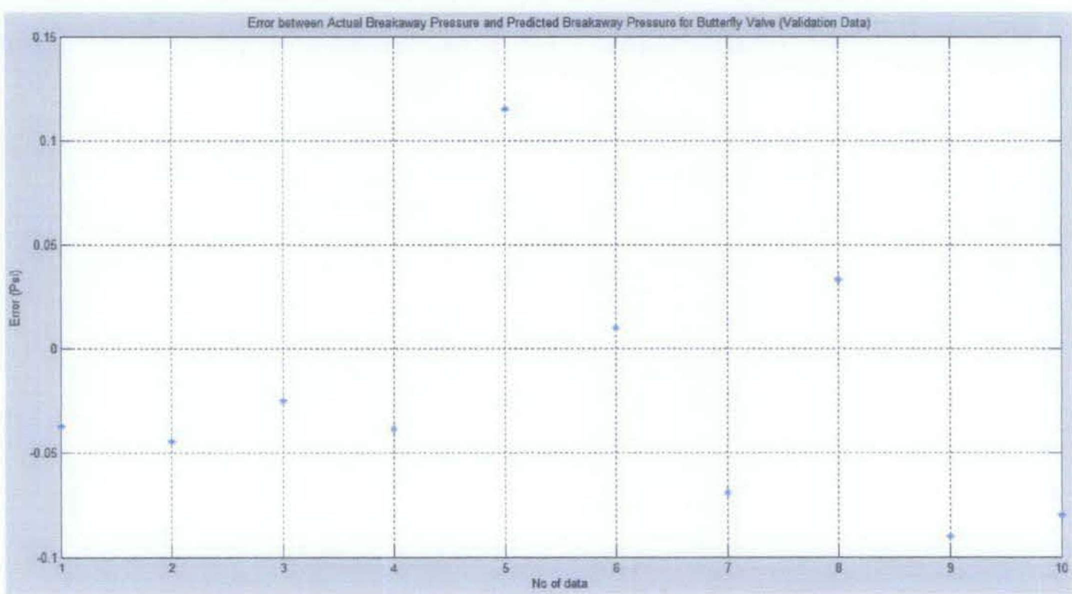


Figure 71: Error between actual breakaway pressure and predicted breakaway pressure for butterfly valve system 2 (Validation Data)

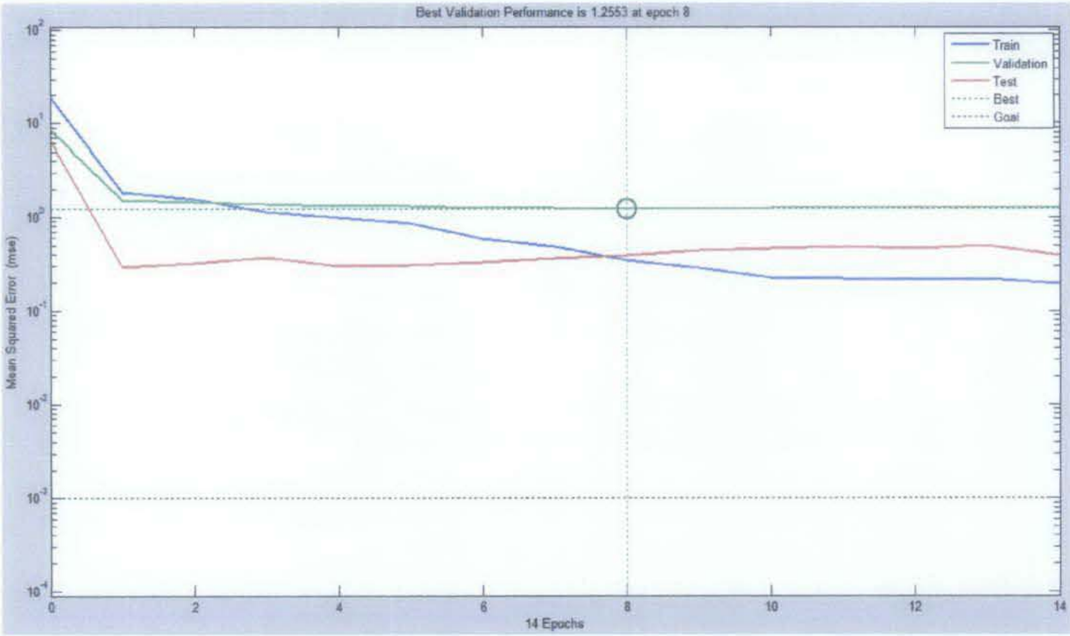


Figure 72: Network Performance for breakaway pressure of butterfly valve system 2.

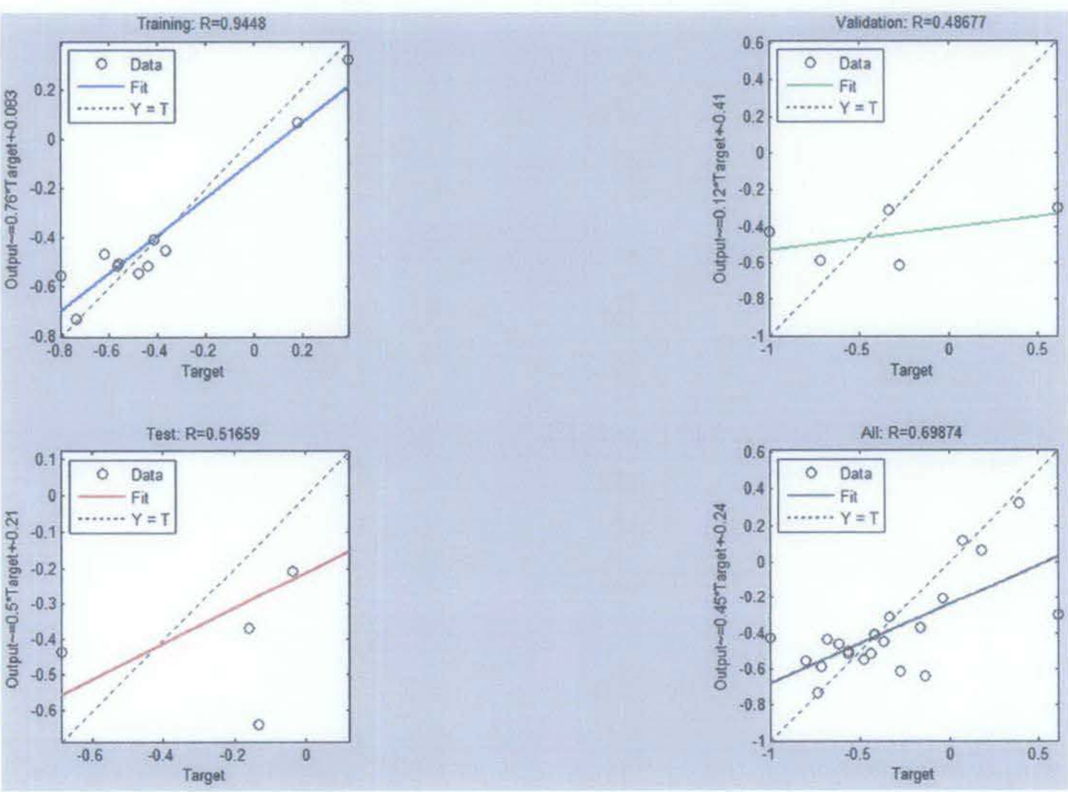


Figure 73: Linear regression for breakaway pressure of butterfly valve system 2.

Table 21: Summary of butterfly valve's breakaway pressure data analysis using Artificial Neural Network (ANN)

Correlation	0.6781	
Number of neuron in layer 1	5	
Number of neuron in layer 2	3	
	Training Data	Validation Data
Number of data	24	10
Fit Value	25.0896	26.7671
Index Value	56.1156	53.6306
Percentage Error	1.4199%	1.9046%
Mean Square Error (MSE)	0.0032	0.0039
Root Mean Square Error (RMSE)	0.0569	0.0627

Based on Figure 68, it displays the actual and predicted breakaway pressure for butterfly valve system 2 based on training data which represented by blue and red lines respectively. We can see that the predicted breakaway pressure for each number of data is not close enough to the actual breakaway pressure. This indicates that the neural network unable to train the data provided very well. This can be proven by looking at the pattern of the predicted breakaway pressure where the direction of the predicted breakaway pressure line is opposite to the direction of actual breakaway pressure line. Besides, the predicted butterfly valve's breakaway pressure is not able to reach the peak of the actual butterfly valve's breakaway pressure. These kind of pattern is caused by using the data after the smart positioners had been swapped which result the prediction of breakaway pressure for butterfly valve system 2 is worst than system 1.

When looking at the training data error as in Figure 69 which is the difference between the actual and predicted breakaway pressure for butterfly valve system 2, the error tabulated are less that 0.2 psi. Other than that, the root mean square error (RMSE) for butterfly valve's training data is only 0.0569 which is close to 0 as shown in Table 21. The closer RMSE value to 0 means the results is more accurate. Besides, the percentage error is only 1.4199. Even though the RMSE value and percentage error for system 2 are smaller compared to system 1, these value cannot be used to conclude that the Artificial Neural Network (ANN) model managed to train the data very well because some of the direction of predicted breakaway pressure lines are at the opposite direction of the actual breakaway pressure lines. The ANN is considered managed to train the data if the pattern of predicted breakaway pressure is close enough to the actual breakaway pressure.

The validation data results for system 2 as shown in Figure 70 also gives the same results as system 1 where the pattern of butterfly valve's breakaway pressure is far from the actual butterfly valve's breakaway pressure as shown in Figure 68. However, the error between actual breakaway pressure and predicted breakaway pressure for butterfly valve for validation data is slightly smaller compared to the training data which is less than 0.15 psi. The RMSE and percentage error for validation data are 0.0627 and 1.9046% respectively. These validation results shows that swapping the smart positioners does not help to improve the prediction of butterfly valve's breakaway pressure but it leads the prediction of breakaway pressure of butterfly valve off the target.

After the training was completed, we can check the network performance and determine if any changes need to be made to the training process, the network architecture or the data sets. This can be done by referring to the network performance graph as shown in Figure 71. From the graph, the iteration at which the validation performance reach a minimum was 8 with mean square error (MSE) is 1.2553. The training continued for 6 more iteration before the training stop. This figure seems does not indicate major problems with the training since the validation and test curve are similar [23].

The next step in validating the network is through regression plot. Based on Figure 72, there are less relationship between the targets and the outputs for system 2 compared to system 1 since the R values for training, validation, testing and overall data indicates 0.9448, 0.48677, 0.51659 and 0.69874 respectively. Most of the values are far from 1. Besides, validation data has less relationship where the R value indicates is 0.0.48677. These values show that training data indicates the best fit followed by test data while validation data has the worst fit [25]. As a conclusion, Artificial Neural Network (ANN) is unable to train the data in order to predict the breakaway pressure of butterfly valve due to the influence of swapping the smart positioners during the experimental period.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As a conclusion, implementing PST to complement with FST can increase the reliability of ESD valve in order to ensure ESD system can work properly during emergency shutdown. Besides, it can reduce production loss that need to be faced by the company due to frequent shutdown need to be done just to test ESD valve [17]. As PST is done without disturbing the process, it can be perform online and more frequent for example every six month [12]. This can be used as a proof that ESD valve is not stuck after be in an open position for a long time. Besides, this test help ESD valve reduced the corrosion and dirt clogging in the valve which is among the cause of ESD valve sticking [11]. This test ensures one of SIS element in good condition so that ESD system can be operated accordingly when the situation requires it to do so. The evolution of the technology had introduced the industry methods of performing PST. It starts with using mechanical limiting and then followed by using solenoid which attach to ESD valve. The latest technology which is still new is by using smart positioner. The evolution of PST methods reduced the use of manpower and improves the safety when performing PST [3].

This project which is in collaboration between PETRONAS Group Technology Solutions (GTS) and Universiti Teknologi PETRONAS (UTP) is able to meet its objectives to analyze the reliability of Masoneilan's ESD valves and predicting the breakaway pressure based on ESD data obtained. This project can achieve the objectives mentioned within two semesters given by following the methodology as proposed. In order to complete the project, it is divided in two parts. First part will involve in analyzing Masoneilan ESD valves using statistical analysis.

For second part, the breakaway pressure of ESD valves can be predicted by using Artificial Neural Network (ANN) modeling. Based on the breakaway pressure prediction, we can predict the valve's condition in the future. During the analysis and modeling, the effect of swapping the smart positioners can be analyzed. This analysis can be used to improve the experiment procedure in order to obtain more accurate results.

During the project, a few data had been obtained from the previous tests including friction, spring range, breakaway pressure, droop limit and response time to fill and exhaust the instrument air. These data had been analyzed using two methods which are statistical analysis and Artificial Neural Network (ANN) modeling.

5.2 Suggested Future Work for Expansion and Continuation

For future work expansion and continuation, the experiment needs to be extend much longer time. This will allow more data to be collected during the experiment. Having more data will lead to more accurate results and Artificial Neural Network (ANN) modeling can be train more in order to achieve better results where the predicted breakaway pressure will be as close as possible to the actual breakaway pressure. Besides, the smart positioners must be not being swap during the experiment to avoid inaccurate data collected. Having inaccurate data will lead to inaccurate analysis and as a result the reliability of ESD valves cannot be ensured

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APPENDICES

APPENDIX I

GANTT CHART FOR FINAL YEAR PROJECT 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Selection and Confirmation of Project Title	▒							MID SEMESTER BREAK								STUDY WEEK	EXAM WEEK			
2	Literature review of Partial Stroke Testing	▒	▒	▒	▒																
3	Submission of Preliminary Report				●																
4	Familiarization with testing skid & Software				▒	▒															
5	Submission of Progress Report									●											
6	Data gathering from historian					▒	▒	▒													
7	PST Statistical Analysis							▒		▒	▒	▒									
8	Seminar											●									
9	Developing Artificial Neural Network Model												▒	▒	▒	▒					
10	Submission of Interim Draft Report												●								
11	Submission of Interim Final Report														●						
12	Oral Presentation															●					

APPENDIX II

GANTT CHART FOR FINAL YEAR PROJECT 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Neural Network Modeling	■	■	■	■	■	■	■	■	■	■	■	■					
2	Submission of Progress Report 2								●									
3	Artificial Neural Network Data Analysis					■	■	■	■	■	■	■	■					
4	Poster Exhibition											●				STUDY WEEK		
5	Submission Draft Report													●				
6	Submission of Dissertation (soft bound)														●			
7	Submission of Technical Paper														●			
8	Oral Presentation															●		
9	Submission of Project Dissertation (hard bound)																	●

APPENDIX III

AVERAGE FRICTION FOR BALL AND BUTTERFLY VALVES

Day	Ball Valve	Butterfly Valve
3	3.55	3.454
4	3.563	3.301
5	3.683	3.302
6	3.703	3.312
7	3.729	3.309
8	3.682	3.307
9	3.845	3.277
10	3.758	3.311
11	3.837	3.308
12	3.776	3.389
13	3.724	3.315
14	3.754	3.34
15	3.791	3.318
16	3.88	3.305
17	3.896	3.297
18	3.699	3.304
19	3.798	3.364
20	3.797	3.343
21	3.736	3.337
22	3.817	3.337
23	3.81	3.287
24	3.825	3.379
25	3.85	3.395
26	3.897	3.405
27	3.828	3.389
28	3.81	3.397
29	3.737	3.413
30	3.851	3.366
31	3.757	3.386
32	3.781	3.429
33	3.907	3.43
34	3.743	3.381
35	3.786	3.415
36	3.769	3.393
37	3.613	3.376
38	3.568	3.391
39	3.525	3.374
40	3.689	3.399
41	3.82	3.387
42	3.731	3.415
43	3.857	3.382
44	3.826	3.409
45	3.771	3.414
46	3.79375	3.15
47	3.441	3.422
48	3.541	3.337
49	3.504	3.443
50	3.3775	3.299
51	3.645	3.422
52	3.633	3.436
53	3.768	3.415
54	3.769	3.393
55	3.79375	2.855
56	3.428	3.359
57	3.361	3.334
58	3.483	3.289
59	3.288	3.358
60	3.293	3.305
61	3.431	3.323
62	3.2425	3.307
63	3.322	3.322
64	3.213	3.276
65	3.248	3.365
66	3.322	3.322
67	3.2425	3.307
68	3.431	3.323
69	3.218	3.335
70	3.171	3.297
71	3.214	3.312
72	3.381	3.465
73	3.479	3.36
74	3.36	3.362
75	3.275	3.369
76	3.491	3.344
77	3.263	3.355
78	3.764	3.328
79	3.654	3.462
80	3.248	3.286
81	3.652	3.296
82	3.195	3.359
83	3.311	3.355
84	3.692	3.379
85	3.45	3.535
86	3.438	3.41
87	3.404	3.357
88	3.68	3.428
89	3.622	3.409
90	3.658	3.387

APPENDIX IV

AVERAGE BREAKAWAY PRESSURE FOR BALL AND BUTTERFLY VALVES

Day	Ball Valve	Butterfly Valve
3	3.802	3.014
4	4.765	3.372
5	4.535	3.513
6	3.931	3.382
7	4.651	3.319
8	3.824	3.408
9	4.731	3.512
10	4.684	3.458
11	4.479	4.004
12	4.252	3.542
13	4.417	3.816
14	4.879	3.396
15	4.679	3.43
16	4.247	3.583
17	4.683	3.482
18	4.477	3.571
19	4.676	3.314
20	4.912	3.367
21	5.065	3.34
22	4	3.34
23	4.506	3.585
24	4.524	3.863
25	4.918	3.336
26	4.204	3.393
27	4.083	3.409
28	4.525	3.414
29	4.109	3.408
30	4.567	3.389
31	4.415	3.273

Day	Ball Valve	Butterfly Valve
32	4.017	3.482
33	3.964	3.269
34	4.353	3.266
35	4.778	3.183
36	4.372	2.745
37	4.032	3.132
38	3.763	3.069
39	4.319	3.07
40	4.306	2.824
41	4.209	3.056
42	4.642	3.112
43	4.06	3.127
44	4.397	2.84
45	3.839	3.181
46	3.83	3.87
47	3.908	3.142
48	3.909	3.229
49	3.65	3.181
50	4.99625	2.715
51	4.693	3.12
52	4.325	3.069
53	4.806	3.183
54	4.372	2.745
55	3.83	4.571
56	4.278	2.766
57	2.961	2.936
58	3.12	2.869
59	3.233	2.703
60	3.158	2.778

Day	Ball Valve	Butterfly Valve
61	4.206	2.818
62	2.8275	2.814
63	3.362	2.742
64	3.039	2.789
65	3.519	2.835
66	3.362	2.742
67	2.8275	2.814
68	4.206	2.818
69	2.641	2.78875
70	3.892	2.806
71	2.525	2.759
72	2.856	2.978
73	2.795	2.893
74	4.006	2.765
75	3.541	3.021
76	3.439	2.828
77	3.266	2.846
78	3.866	2.755
79	3.732	2.915
80	3.131	2.874
81	3.311	2.808
82	2.659	2.849
83	3.148	2.829
84	3.734	2.859
85	3.653	3.098
86	3.097	2.86
87	3.72	2.805
88	3.996	2.957
89	4.765	2.827
90	4.408	2.831

APPENDIX V

AVERAGE DROOP FOR BALL AND BUTTERFLY VALVES

Day	Ball Valve	Butterfly Valve	Day	Ball Valve	Butterfly Valve	Day	Ball Valve	Butterfly Valve
3	11.241	15.104	32	8.909	10.3	61	11.084	15.137
4	8.885	10.337	33	8.724	9.912	62	10.5325	14.902
5	9.043	10.241	34	8.964	9.881	63	11.462	14.628
6	8.699	10.053	35	8.8	10.301	64	11.685	14.67
7	8.612	10.227	36	8.837	10.674	65	11.318	14.549
8	8.804	10.031	37	8.919	10.372	66	11.462	14.628
9	8.923	10.143	38	8.839	10.489	67	10.5325	14.902
10	9.104	9.91	39	8.777	10.472	68	11.084	15.137
11	8.746	10.173	40	8.971	10.478	69	11.638	14.55875
12	8.801	10.147	41	8.763	10.282	70	11.372	14.402
13	8.891	10.567	42	8.532	10.297	71	11.389	14.461
14	8.884	10.317	43	8.564	10.56	72	11.323	15.186
15	8.688	10.277	44	8.638	10.428	73	11.815	14.892
16	8.534	10.245	45	8.741	10.464	74	11.485	14.427
17	8.427	10.266	46	8.995	10.792	75	10.915	14.709
18	8.877	10.023	47	8.909	10.238	76	11.334	14.857
19	9.041	9.971	48	8.783	10.224	77	11.475	14.745
20	8.946	10.135	49	8.98	10.119	78	11.172	14.628
21	8.632	10.081	50	8.79875	10.15	79	11.393	14.512
22	8.789	10.08	51	9.02	10.1	80	11.614	14.549
23	8.95	9.857	52	8.964	10.487	81	11.544	14.638
24	8.482	10.07	53	8.721	10.301	82	11.581	15.142
25	8.821	9.943	54	8.837	10.674	83	11.712	15.204
26	8.878	10.107	55	8.995	10.761	84	12.021	15.257
27	8.687	10.034	56	8.662	13.312	85	11.491	15.268
28	8.877	10.502	57	11.281	14.712	86	11.839	14.533
29	8.894	10.076	58	11.349	15.146	87	11.521	15.148
30	9.103	10.446	59	11.345	14.834	88	11.601	14.578
31	8.751	10.307	60	10.686	15.203	89	11.465	14.402
						90	11.682	15.549

APPENDIX VI

AVEARGE RESPONSE TIME TO EXHAUST FOR BALL AND BUTTERFLY VALVES

Day	Ball Valve	Butterfly Valve
3	67.12	91.93
4	59.38	80.76
5	57.84	81.03
6	58.06	74.86
7	59.4	81.17
8	60.64	81.35
9	56.62	80.4
10	54.56	75.88
11	58.85	76.3
12	61.92	79.03
13	61.27	77.84
14	57.13	77.31
15	58.83	79.69
16	57.88	77.31
17	61.52	77.73
18	58.58	79.03
19	56.15	78.8
20	58.83	76.6
21	59.87	74.82
22	56.11	75.65
23	59.81	76.48
24	59.91	75.39
25	58.9	76.26
26	61.53	77.51
27	59.73	79.1
28	58.61	76.56
29	62.88	77.31
30	59.42	80.57
31	60.95	79.71
32	60.31	73.5
33	55.46	78.25
34	59	75.94
35	59.36	76.66
36	62.29	77.48
37	57.38	80.77
38	58.08	81.42
39	62.58	77.89
40	60.73	79.07
41	56.89	80.44
42	61.42	80.37
43	59.86	78.17
44	59.31	76.07
45	58.97	81.35
46	58.4875	80.92
47	57.25	78.38
48	55.26	79.88
49	57.13	76.71
50	59.6875	77.2
51	57.02	77.69
52	62.18	79.22
53	60.83	76.66
54	62.29	77.48
55	58.4875	79.4
56	59.22	85.84
57	70.18	99.78
58	67.57	90.82
59	67.98	92.29
60	70.82	88.37
61	68.01	102.11
62	72.7125	97.95
63	72.35	98.99
64	68.44	101.59
65	71.7	92.09
66	72.35	98.99
67	72.7125	97.95
68	68.01	102.11
69	67.22	102.225
70	72.52	93.91
71	66.29	88.89
72	72.3	87.85
73	63.09	91.93
74	71.95	97.14
75	72.47	93.31
76	66.63	90.86
77	71.2	94.05
78	65.55	99.67
79	69.19	109
80	70.53	93.23
81	65.82	89.34
82	68.67	96.22
83	68.7	91.69
84	70.25	88.55
85	63	95.15
86	64.45	98.05
87	68.91	93.3
88	64.93	89.02
89	67.71	92.9
90	65.5	92.35

APPENDIX VII

AVERAGE RESPONSE TIME TO FILL FOR BALL AND BUTTERFLY VALVES

Day	Ball Valve	Butterfly Valve
3	1.83	11.49
4	1.35	1.55
5	1.44	1.5
6	1.31	1.51
7	1.46	1.6
8	1.41	1.61
9	1.33	1.62
10	1.36	1.56
11	1.4	1.57
12	1.37	1.51
13	1.34	1.48
14	1.47	1.58
15	1.41	1.55
16	1.3	1.55
17	1.46	1.63
18	1.45	1.64
19	1.36	1.59
20	1.39	1.61
21	1.45	1.64
22	1.41	1.64
23	1.49	1.64
24	1.36	1.61
25	1.41	1.61
26	1.29	1.56
27	1.32	1.61
28	1.39	1.56
29	1.32	1.6
30	1.32	1.58
31	1.35	1.6
32	1.25	1.63
33	1.3	1.73
34	1.46	1.69
35	1.34	1.57
36	1.36	2.12
37	1.43	2.83
38	1.27	2.62
39	1.27	2.53
40	1.33	2.62
41	1.36	1.82
42	1.37	1.83
43	1.41	2.12
44	1.39	2.92
45	1.37	2.34
46	1.3125	2.5
47	1.32	1.73
48	1.24	1.63
49	1.46	1.78
50	1.375	1.75
51	1.3	1.72
52	1.3	1.67
53	1.35	1.57
54	1.36	2.12
55	1.3125	2.94
56	1.25	6.41
57	1.94	8.11
58	1.87	4.66
59	1.78	9.41
60	1.91	12.27
61	1.46	13.04
62	1.4375	10.95
63	1.62	13.5
64	1.75	14.72
65	1.92	8.43
66	1.62	13.5
67	1.4375	10.95
68	1.46	13.04
69	1.79	12.875
70	1.84	12.27
71	1.97	13.89
72	1.58	19.928
73	1.81	13.52
74	1.81	14.45
75	1.64	14.7
76	1.75	14.24
77	1.78	11.42
78	1.9	12.54
79	1.91	12.44
80	1.78	12.44
81	1.82	14.31
82	1.92	13.38
83	1.79	11.78
84	1.78	11.63
85	1.8	10.15
86	1.72	11.58
87	1.89	11.49
88	1.79	16.31
89	1.91	14.56
90	1.78	9.98

APPENDIX VIII

AVERAGE UPPER SPRING RANGE FOR BALL AND BUTTERFLY VALVES

Day	Ball Valve	Butterfly Valve	Day	Ball Valve	Butterfly Valve	Day	Ball Valve	Butterfly Valve
3	39.452	47.869	32	40.462	48.568	61	39.161	47.615
4	41.06	48.83	33	40.386	48.461	62	38.28125	47.584
5	40.961	48.952	34	40.845	48.064	63	38.653	47.612
6	40.708	48.952	35	40.91	48.08	64	38.458	47.614
7	41.247	48.927	36	40.414	47.822	65	38.795	47.652
8	40.515	49.024	37	39.489	47.911	66	38.653	47.612
9	41.172	48.944	38	39.402	47.956	67	38.28125	47.584
10	41.213	48.935	39	39.808	47.873	68	39.161	47.615
11	40.991	49.084	40	39.906	47.944	69	38.046	47.62125
12	40.811	49.146	41	40.326	47.931	70	39.176	47.592
13	40.82	49.038	42	40.446	47.98	71	38.087	47.542
14	41.201	48.884	43	39.981	47.943	72	38.461	47.946
15	41.251	48.772	44	40.374	47.862	73	38.393	47.654
16	40.8	48.873	45	39.969	47.956	74	39.357	47.632
17	41.178	48.719	46	39.885	48.106	75	38.566	47.729
18	41.077	48.815	47	39.77	47.962	76	38.936	47.651
19	41.164	48.752	48	39.426	47.957	77	38.489	47.64
20	41.543	48.793	49	39.183	48.028	78	39.604	47.566
21	41.466	48.663	50	40.2925	48.005	79	39.37	47.912
22	40.673	48.651	51	40.41	47.982	80	38.625	47.55
23	40.993	48.638	52	39.689	47.966	81	38.89	47.627
24	40.788	48.802	53	40.747	48.08	82	38.042	47.685
25	41.31	48.734	54	40.414	47.822	83	38.274	47.616
26	40.714	48.717	55	39.885	48.183	84	39.533	47.667
27	40.551	48.684	56	39.568	47.748	85	39.064	48.076
28	41.087	48.701	57	38.578	47.71	86	38.608	47.677
29	40.666	48.682	58	38.472	47.582	87	38.93	47.661
30	40.821	48.57	59	38.52	47.643	88	39.909	47.733
31	40.998	48.484	60	38.587	47.589	89	40.442	47.753
						90	39.99	47.713

APPENDIX IX

AVERAGE LOWER SPRING RANGE FOR BALL AND BUTTERFLY VALVES

Day	Ball Valve	Butterfly Valve
3	-8.54	-4.777
4	-14.407	-5.783
5	-12.865	-6.261
6	-10.783	-6.094
7	-14.154	-6.081
8	-8.947	-6.883
9	-13.932	-6.306
10	-14.934	-6.279
11	-12.93	-7.186
12	-11.898	-7.187
13	-12.348	-7.835
14	-15.298	-6.811
15	-14.817	-5.698
16	-10.497	-7.134
17	-13.356	-5.869
18	-14.847	-6.433
19	-14.397	-5.939
20	-17.517	-6.437
21	-17.228	-5.903
22	-10.54	-5.778
23	-13.242	-5.652
24	-10.699	-7.032
25	-15.114	-6.606
26	-11.222	-6.666
27	-10.048	-6.338
28	-14.961	-6.443
29	-11.474	-6.433
30	-12.538	-6.002
31	-15.149	-5.18
32	-9.92	-5.982
33	-7.979	-5.239
34	-14.387	-4.822
35	-14.279	-5.179
36	-11.497	-3.709
37	-5.368	-4.265
38	-5.416	-4.521
39	-8.966	-4.09
40	-8.854	-4.472
41	-10.388	-4.456
42	-12.088	-4.799
43	-7.885	-4.271
44	-10.886	-4.094
45	-7.904	-4.401
46	-6.96	-5.345
47	-9.575	-4.483
48	-6.861	-4.763
49	-4.714	-4.907
50	-14.4988	-4.903
51	-13.466	-4.898
52	-8.041	-4.745
53	-14.048	-5.179
54	-11.497	-3.709
55	-6.96	-5.934
56	-7.86	-4.119
57	-4.071	-4.389
58	-2.023	-3.685
59	-3.537	-3.542
60	-4.047	-3.491
61	-8.175	-3.679
62	-1.6625	-3.546
63	-6.2478	-3.498
64	-2.743	-3.653
65	-5.429	-3.77
66	-4.4838	-3.498
67	-1.6625	-3.546
68	-8.175	-3.679
69	-0.039	-3.58375
70	-9.621	-3.549
71	-0.284	-3.442
72	-2.645	-4.347
73	-1.238	-3.908
74	-9.251	-3.576
75	-3.324	-3.705
76	-5.003	-3.5
77	-3.005	-3.268
78	-8.918	-3.188
79	-6.898	-4.442
80	-4.11	-3.178
81	-3.482	-3.909
82	-0.18	-4.23
83	-1.131	-3.838
84	-9.058	-4.178
85	-6.57	-5.275
86	-2.845	-3.836
87	-5.786	-4.02
88	-12.224	-4.511
89	-16.942	-4.491
90	-12.051	-4.247

APPENDIX X

MATLAB M-FILE NEURAL NETWORK CODING FOR BALL VALVE

```
%Clear workspace and command window
clear all;
close all;
clc;

load PST_NN;  %load matlab file (eg: datajanuarymay4.mat) with data

%load data from workspace
x = data(:,1:5)';  %separate input and output, x=input
y = data(:,6)';    %separate input and output  y=output

%-----------------------------------------------------------------------
----%
%prepocess the input and output [-1,1]
%-----------------------------------------------------------------------
----%
[x_i,x_s1] = mapminmax(x);    %INPUT training data
[y_i,y_s1] = mapminmax(y);    %OUTPUT training data
% [x_v1,x_s2] = mapminmax(x_v);    %INPUT validation data
% [y_v1,y_s2] = mapminmax(y_v);    %OUTPUT validation data
%maximum and minimum value of TRAINING data
t = minmax(x_i);

%-----------------------------------------------------------------------
----%
%divide data into TRAINING and VALIDATION
%-----------------------------------------------------------------------
----%
%get the number of input and number of data
train_data = 38; %number of TRAINING data
validation_data =16; %number of VALIDATION data
numofvar = size(x,1); %number of input
numofout = size(y,1); %number of input

for m=1:numofvar
    for n=1:train_data
    x_t(m,n)=x_i(m,n);
    end
end

for m=1:numofvar
    for n=1:validation_data
    x_v(m,n)=x_i(m,n+train_data);
    end
```

```
end

for m=1:numofout
    for n=1:train_data
    y_t(m,n)=y_i(m,n);
    end
end

for m=1:numofout
    for n=1:validation_data
    y_v(m,n)=y_i(m,n+train_data);
    end
end

%----------------------------------------------------------------
----%
%set network properties
%----------------------------------------------------------------
----%
%number of neurons for layer 1 and layer 2
neuron_1 = 8; %number of neurons for layer 1
neuron_2 = 5; %number of neurons for layer 2

%network and parameters
net=newff(x_t,y_t,neuron_1,{'tansig','purelin'},'trainbr');
net.trainParam.show = 50;   %Epochs between displays
net.trainParam.lr = 0.1;    %Learning Rate
net.trainParam.epochs = 1000;   %Maximum number of epoch to train
net.trainParam.goal = 0.001;    %Performance goal
net=init(net);

%checking the weights and biases (make sure all are 0)
net.IW{1,1}; %weights of 1st layer
net.LW{2,1}; %weights of 2nd layer
net.b{1}; %bias of 1st layer
net.b{2}; %bias of 2nd layer
%----------------------------------------------------------------
----%
%train the network
%----------------------------------------------------------------
----%
[net,tr]=train(net,x_t,y_t);
%----------------------------------------------------------------
----%
%simulate the network
%----------------------------------------------------------------
----%
%simulate the network with TRAINING data
% xtest_t = mapminmax('apply',x_t,x_s1);  %prepare input data for
training
ytrain = sim(net,x_t);  %simulate the network
ytrain1 = mapminmax('reverse',ytrain,y_s1); %descale the output
yactualt = mapminmax('reverse',y_t,y_s1); %descale the output
%calculate the different between the actual and predicted breakaway
pressure
etrain=yactualt-ytrain1;    %Training error

%simulate the network with VALIDATION data
```

```
% xtest_v = mapminmax('apply', x_v, x_s1);    %prepare input data for
training
yvalid=sim(net,x_v); %simulate the network
yvalid1 = mapminmax('reverse',yvalid,y_s1);%descale the output
yactualv = mapminmax('reverse',y_v,y_s1);%descale the output
%calculate the different between the actual and predicted breakaway
pressure
evalid=yactualv-yvalid1;    %Validation error
%-------------------------------------------------------------------
-----%
%plot graph
%-------------------------------------------------------------------
-----%
%plot the actual and predicted Breakaway Pressure from TRAINING data
%figure(1);
subplot(2,2,1);
plot (ytrain1,'r');
hold on;
plot (yactualt,'b');
xlabel('No of Data');
ylabel('Breakaway Pressure (Psi)');
title('Output of NN model for Ball Valve Breakaway Pressure (Training
Data)');
legend('Predicted Breakaway Pressure','Actual Breakaway Pressure');
grid on;

%plot the different between the actual and predicted Breakaway
Pressure from TRAINING data
%figure(2);
subplot(2,2,2);
plot(etrain,'*');
xlabel('No of Data');
ylabel('Error (Psi)');
title('Error between Actual Breakaway Pressure and Predicted
Breakaway Pressure for Ball Valve (Training Data)');
grid on;

%plot the actual and predicted Breakaway Pressure from VALIDATION
data
%figure(3);
subplot(2,2,3);
plot (yvalid1,'r');
hold on;
plot (yactualv,'b');
xlabel('No of Data');
ylabel('Breakaway Pressure (Psi)');
title('Output of NN model for Ball Valve Breakaway pressure
(Validation Data)');
legend('Predicted Breakaway Pressure','Actual Breakaway Pressure');
grid on;

%plot the different between the actual and predicted Breakaway
Pressure from VALIDATION data
%figure(4);
subplot(2,2,4);
plot(evalid,'*');
xlabel('No of data');
ylabel('Error (Psi)');
```

```
title('Error between Actual Breakaway Pressure and Predicted
Breakaway Pressure for Ball Valve (Validation Data)');
grid on;
%-------------------------------------------------------------------
-----%
%error analysis
%-------------------------------------------------------------------
-----%
%error analysis for the TRAINING data
fit_train = (1-norm(etrain)/norm(yactualt-mean(yactualt)))*100 %fit
value
mse_train = mse(etrain);     %mean square error
rmse_train = sqrt(mse(etrain)) %root mean square error
index_train = (sum((etrain).^2)/sum((yactualt-
mean(yactualt)).^2))*100 %index value
correlation_train = corrcoef (yactualt,ytrain1)
percenterror_train = ((abs(yactualt-ytrain1)/yactualt)*100);
%actualTrain_predictedTrain = [y_t' ytrain1']

%error analysis for the VALIDATION data
fit_valid = (1-norm(evalid)/norm(yactualv-mean(yactualv)))*100; %fit
value
mse_valid = mse(evalid);     %mean square error
rmse_valid = sqrt(mse(evalid)) %root mean square error
index_valid = (sum((evalid).^2)/sum((yactualv-
mean(yactualv)).^2))*100 %index value
correlation_valid = corrcoef (yactualv,yvalid1)
percenterror_valid = ((abs(yactualv-yvalid1)/yactualv)*100);
%actualValid_predictedValid = [y_v' yvalid1']
```

APPENDIX XI

MATLAB M-FILE NEURAL NETWORK CODING FOR BUTTERFLY VALVE

```
%Clear workspace and command window
clear all;
close all;
clc;

load PST_NN_BUTTERFLY;  %load matlab file (eg: datajanuarymay4.mat)
with data

%load data from workspace
x = data_butterfly(:,1:5)';  %separate input and output, x=input
y = data_butterfly(:,6)';    %separate input and output  y=output

%-----------------------------------------------------------------------
----%
%prepocess the input and output [-1,1]
%-----------------------------------------------------------------------
----%
[x_i,x_s1] = mapminmax(x);   %INPUT training data
[y_i,y_s1] = mapminmax(y);   %OUTPUT training data
% [x_v1,x_s2] = mapminmax(x_v);   %INPUT validation data
% [y_v1,y_s2] = mapminmax(y_v);   %OUTPUT validation data
%maximum and minimum value of TRAINING data
t = minmax(x_i);

%-----------------------------------------------------------------------
----%
%divide data into TRAINING and VALIDATION
%-----------------------------------------------------------------------
----%
%get the number of input and number of data
train_data = 38; %number of TRAINING data
validation_data =16; %number of VALIDATION data
numofvar = size(x,1); %number of input
numofout = size(y,1); %number of input

for m=1:numofvar
    for n=1:train_data
    x_t(m,n)=x_i(m,n);
    end
end

for m=1:numofvar
    for n=1:validation_data
    x_v(m,n)=x_i(m,n+train_data);
```

```
    end
end

for m=1:numofout
    for n=1:train_data
    y_t(m,n)=y_i(m,n);
    end
end

for m=1:numofout
    for n=1:validation_data
    y_v(m,n)=y_i(m,n+train_data);
    end
end

%----------------------------------------------------------------------
----%
%set network properties
%----------------------------------------------------------------------
----%
%number of neurons for layer 1 and layer 2
neuron_1 = 10; %number of neurons for layer 1
neuron_2 = 10; %number of neurons for layer 2

%network and parameters
net=newff(x_t,y_t,neuron_1,{'tansig','purelin'},'trainbr');
net.trainParam.show = 50;   %Epochs between displays
net.trainParam.lr = 0.1;    %Learning Rate
net.trainParam.epochs = 1000;   %Maximum number of epoch to train
net.trainParam.goal = 0.001;    %Performance goal
net=init(net);

%checking the weights and biases (make sure all are 0)
net.IW{1,1}; %weights of 1st layer
net.LW{2,1}; %weights of 2nd layer
net.b{1}; %bias of 1st layer
net.b{2}; %bias of 2nd layer
%----------------------------------------------------------------------
----%
%train the network
%----------------------------------------------------------------------
----%
[net,tr]=train(net,x_t,y_t);
%----------------------------------------------------------------------
----%
%simulate the network
%----------------------------------------------------------------------
----%
%simulate the network with TRAINING data
% xtest_t = mapminmax('apply',x_t,x_s1);  %prepare input data for
training
ytrain = sim(net,x_t);  %simulate the network
ytrain1 = mapminmax('reverse',ytrain,y_s1); %descale the output
yactualt = mapminmax('reverse',y_t,y_s1); %descale the output
%calculate the different between the actual and predicted breakaway
pressure
etrain=yactualt-ytrain1;

%simulate the network with VALIDATION data
```

```
% xtest_v = mapminmax('apply', x_v, x_s1);     %prepare input data for
training
yvalid=sim(net,x_v);    %simulate the network
yvalid1 = mapminmax('reverse',yvalid,y_s1);      %descale the output
yactualv = mapminmax('reverse',y_v,y_s1);        %descale the output
%calculate the different between the actual and predicted breakaway
pressure
evalid=yactualv-yvalid1;
%---------------------------------------------------------------------
-----%
%plot graph
%---------------------------------------------------------------------
-----%
%plot the actual and predicted Breakaway Pressure from TRAINING data
%figure(1);
subplot(2,2,1);
plot (ytrain1,'r');
hold on;
plot (yactualt,'b');
xlabel('No of Data');
ylabel('Breakaway Pressure (Psi)');
title('Output of NN model for Butterfly Valve Breakaway Pressure
(Training Data)');
legend('Predicted Breakaway Pressure','Actual Breakaway Pressure');
grid on;

%plot the different between the actual and predicted Breakaway
Pressure from TRAINING data
%figure(2);
subplot(2,2,2);
plot(etrain,'*');
xlabel('No of Data');
ylabel('Error (Psi)');
title('Error between Actual Breakaway Pressure and Predicted
Breakaway Pressure for Butterfly Valve (Training Data)');
grid on;

%plot the actual and predicted Breakaway Pressure from VALIDATION
data
%figure(3);
subplot(2,2,3);
plot (yvalid1,'r');
hold on;
plot (yactualv,'b');
xlabel('No of Data');
ylabel('Breakaway Pressure (Psi)');
title('Output of NN model for Butterfly Valve Breakaway Pressure
(Validation Data)');
legend('Predicted Breakaway Pressure','Actual Breakaway Pressure');
grid on;

%plot the different between the actual and predicted Breakaway
Pressure from VALIDATION data
%figure(4);
subplot(2,2,4);
plot(evalid,'*');
xlabel('No of data');
ylabel('Error (Psi)');
```

```
title('Error between Actual Breakaway Pressure and Predicted
Breakaway Pressure for Butterfly Valve (Validation Data)');
grid on;
%-----------------------------------------------------------------
-----%
%error analysis
%-----------------------------------------------------------------
-----%
%error analysis for the TRAINING data
fit_train = (1-norm(etrain)/norm(yactualt-mean(yactualt)))*100 %fit
value
mse_train = mse(etrain);    %mean square error
rmse_train = sqrt(mse(etrain)) %root mean square error
index_train = (sum((etrain).^2)/sum((yactualt-
mean(yactualt)).^2))*100 %index value
correlation_train = corrcoef (yactualt,ytrain1)
percenterror_train = ((abs(yactualt-ytrain1)/yactualt)*100);
%actualTrain_predictedTrain = [y_t' ytrain1']

%error analysis for the VALIDATION data
fit_valid = (1-norm(evalid)/norm(yactualv-mean(yactualv)))*100; %fit
value
mse_valid = mse(evalid);    %mean square error
rmse_valid = sqrt(mse(evalid)) %root mean square error
index_valid = (sum((evalid).^2)/sum((yactualv-
mean(yactualv)).^2))*100 %index value
correlation_valid = corrcoef (yactualv,yvalid1)
percenterror_valid = ((abs(yactualv-yvalid1)/yactualv)*100);
%actualValid_predictedValid = [y_v' yvalid1']
```

APPENDIX XII

NEURAL NETWORK PERFORMANCE FOR BALL VALVE

NEURON 1	NEURON 2	Percentage Error Train	Percentage Error Valid	MSE Train	MSE Valid	RMSE Train	RMSE Valid	Correlation
1	1	3.3158	5.5259	0.0314	0.081	0.1772	0.2847	0.8668
2	1	3.1887	5.1187	0.0296	0.0597	0.1719	0.2443	0.8744
3	1	4.7058	6.1057	0.0587	0.0852	0.2422	0.2919	0.8565
4	1	0.545	5.7762	0.0325	0.0865	0.1803	0.2941	0.8707
5	1	2.8088	6.1363	0.0242	0.0875	0.1556	0.2958	0.8746
6	1	3.5418	6.0349	0.0363	0.0892	0.1905	0.2987	0.8292
7	1	3.6859	5.107	0.0356	0.062	0.1887	0.249	0.8516
8	1	3.3838	4.8097	0.0365	0.0573	0.191	0.2394	0.8507
9	1	3.971	6.0197	0.0443	0.0802	0.2104	0.2831	0.8261
10	1	3.7415	5.1993	0.0349	0.0703	0.1868	0.2652	0.8566
1	2	3.5207	4.8046	0.0327	0.0543	0.1809	0.233	0.8668
2	2	3.097	4.1409	0.0278	0.0391	0.1667	0.1997	0.8744
3	2	3.5019	4.9317	0.0339	0.0608	0.184	0.2466	0.8565
4	2	3.2256	5.4591	0.0284	0.0748	0.1684	0.2735	0.8707
5	2	3.183	5.7827	0.0281	0.0874	0.1677	0.2956	0.8746
6	2	2.8963	5.7558	0.026	0.0759	0.1613	0.2755	0.8787
7	2	3.1672	4.9398	0.0315	0.0546	0.1776	0.2338	0.8508
8	2	3.3608	3.8129	0.0332	0.0366	0.1821	0.1913	0.8522
9	2	3.5495	5.3433	0.0345	0.0778	0.1858	0.2789	0.854
10	2	5.1546	6.4879	0.0687	0.0985	0.2621	0.3138	0.8342
1	3	3.6002	5.1481	0.0373	0.0596	0.1932	0.2442	0.8424
2	3	6.5477	7.8529	0.1163	0.1622	0.3411	0.4027	0.7074
3	3	3.4321	5.0277	0.0313	0.0597	0.1769	0.2443	0.8633
4	3	3.0221	3.5907	0.0294	0.0338	0.1714	0.1839	0.8729
5	3	3.019	5.6494	0.0263	0.0784	0.1621	0.28	0.88
6	3	3.3583	4.584	0.0306	0.0476	0.1749	0.2183	0.8683
7	3	3.3421	4.0504	0.0309	0.0386	0.1757	0.1964	0.8595
8	3	2.7802	5.6851	0.0245	0.0759	0.1565	0.2755	0.8865
9	3	3.9826	5.6661	0.0409	0.0758	0.2022	0.2753	0.8546
10	3	4.1375	6.0011	0.0439	0.0892	0.2096	0.2986	0.8559
1	4	3.6499	6.6642	0.0357	0.1296	0.1889	0.36	0.8397

2	4	3.2329	5.1645	0.028	0.0634	0.1673	0.2517	0.8741
3	4	4.1325	5.9545	0.0539	0.0866	0.2323	0.2943	0.7697
4	4	3.6931	5.3643	0.0353	0.0722	0.1878	0.2687	0.8531
5	4	3.4621	5.2878	0.0316	0.064	0.1779	0.253	0.8658
6	4	3.4177	5.9801	0.0305	0.0938	0.1746	0.3063	0.8715
7	4	6.0308	7.8855	0.105	0.166	0.324	0.4074	0.8424
8	4	3.9558	5.1781	0.0419	0.0612	0.2047	0.2475	0.8547
9	4	2.9754	3.6822	0.0285	0.0359	0.1687	0.1895	0.8667
10	4	3.2145	5.2528	0.0305	0.0756	0.1747	0.2749	0.8645
1	5	3.5456	4.7313	0.0313	0.0502	0.1768	0.224	0.8772
2	5	2.736	4.2465	0.0248	0.0495	0.1575	0.2225	0.8931
3	5	2.9925	5.3194	0.0274	0.0708	0.1657	0.2661	0.8715
4	5	3.6915	5.4424	0.0352	0.0727	0.1876	0.2696	0.8575
5	5	3.2985	4.9479	0.033	0.0538	0.1818	0.2319	0.8492
6	5	3.7239	5.6245	0.0369	0.073	0.1921	0.2702	0.8646
7	5	3.62	6.5022	0.0379	0.1148	0.1948	0.3388	0.8434
8	5	2.9875	3.2661	0.0291	0.0281	0.1706	0.1675	0.8668
9	5	3.4254	4.1038	0.0318	0.0389	0.1784	0.1973	0.8602
10	5	3.0559	3.4548	0.03	0.0305	0.1731	0.1745	0.8579
1	6	3.0081	5.3995	0.0283	0.0765	0.1682	0.2766	0.8693
2	6	3.1015	6.2551	0.0287	0.1105	0.1694	0.3323	0.8672
3	6	3.5827	5.1886	0.0341	0.0675	0.1847	0.2598	0.8533
4	6	3.5886	4.9478	0.0338	0.0558	0.1838	0.2362	0.8649
5	6	3.3769	6.5926	0.0316	0.1156	0.1778	0.34	0.8623
6	6	3.7196	4.6706	0.0371	0.0522	0.1925	0.2284	0.8526
7	6	3.1848	5.0349	0.0295	0.0779	0.1716	0.2791	0.8609
8	6	3.4235	7.7565	0.0392	0.1524	0.198	0.3904	0.8646
9	6	4.2125	6.0863	0.0453	0.1044	0.2129	0.3232	0.8215
10	6	5.2696	7.0179	0.0802	0.1284	0.2832	0.3584	0.7423
1	7	3.0137	7.362	0.0304	0.1503	0.1744	0.3877	0.8704
2	7	3.2956	6.2669	0.0325	0.1122	0.1802	0.335	0.8596
3	7	3.4158	5.4095	0.0332	0.0628	0.1823	0.2506	0.8553
4	7	3.2493	6.8854	0.0333	0.1305	0.1824	0.3612	0.8505
5	7	3.3728	5.7596	0.0299	0.0842	0.1729	0.2901	0.8711
6	7	3.3621	4.661	0.0323	0.0538	0.1797	0.2319	0.8506
7	7	3.7881	4.4455	0.0376	0.0475	0.1939	0.218	0.8516
8	7	3.3863	4.4461	0.0335	0.0455	0.183	0.2132	0.8607
9	7	2.8886	5.5591	0.0242	0.0743	0.1555	0.2725	0.8881
10	7	3.4349	4.4488	0.0312	0.0537	0.1767	0.2318	0.8546
1	8	3.0474	4.378	0.0267	0.0492	0.1633	0.2218	0.8753
2	8	3.2537	5.8859	0.0309	0.0882	0.1727	0.2969	0.8748
3	8	3.098	4.2344	0.0289	0.0425	0.1699	0.2061	0.8764
4	8	3.264	5.5294	0.0299	0.0847	0.1729	0.291	0.8609
5	8	3.1692	5.5279	0.0288	0.0717	0.1698	0.2679	0.8795

6	8	4.607	6.0705	0.0554	0.0849	0.2354	0.2913	0.8515
7	8	3.2314	3.9089	0.0307	0.0372	0.1752	0.1928	0.8548
8	8	3.2413	4.2015	0.031	0.042	0.1761	0.2049	0.8572
9	8	3.4936	5.4196	0.0327	0.0752	0.1809	0.2743	0.8617
10	8	3.6971	4.6475	0.0372	0.0501	0.1928	0.2238	0.8571
1	9	3.3681	4.7809	0.0304	0.058	0.1742	0.2409	0.8628
2	9	3.7475	5.2519	0.0346	0.0761	0.1861	0.2758	0.8582
3	9	3.1281	4.2588	0.0319	0.0426	0.1787	0.2063	0.8483
4	9	3.1821	3.7819	0.0317	0.0343	0.1782	0.1852	0.8523
5	9	3.045	4.8748	0.0277	0.0574	0.1664	0.2396	0.884
6	9	3.4173	5.9844	0.0333	0.1034	0.1824	0.3215	0.856
7	9	2.8757	4.8598	0.0255	0.0547	0.1596	0.2338	0.8811
8	9	2.9385	3.5075	0.0272	0.0307	0.1651	0.1752	0.8715
9	9	3.4079	4.4991	0.0315	0.0553	0.1776	0.2351	0.8544
10	9	3.7197	4.1033	0.0382	0.0398	0.1955	0.1995	0.841
1	10	3.2856	4.804	0.0295	0.052	0.1719	0.2279	0.8689
2	10	3.4436	4.7612	0.035	0.0514	0.1872	0.2266	0.8442
3	10	3.0217	4.9915	0.0263	0.0578	0.1622	0.2405	0.8801
4	10	3.4573	5.2468	0.0335	0.0674	0.1831	0.2596	0.8478
5	10	2.9342	6.1624	0.0318	0.0934	0.1783	0.3056	0.8487
6	10	3.0888	3.4407	0.0291	0.0357	0.1707	0.189	0.8653
7	10	2.9501	4.7162	0.0272	0.0572	0.165	0.2392	0.8735
8	10	4.2804	6.0593	0.047	0.0894	0.2168	0.2989	0.8575
9	10	3.2423	4.0313	0.0299	0.0414	0.173	0.2035	0.8637
10	10	3.4612	4.5336	0.0314	0.0508	0.1772	0.2254	0.8628

APPENDIX XIII

NEURAL NETWORK PERFORMANCE FOR BUTTERFLY VALVE

NEURON 1	NEURON 2	Percentage Error Train	Percentage Error Valid	MSE Train	MSE Valid	RMSE Train	RMSE Valid	Correlation
1	1	2.9356	7.0672	0.0198	0.102	0.1406	0.3194	0.8279
2	1	2.886	7.2635	0.0178	0.1143	0.1332	0.3382	0.8398
3	1	4.797	11.6885	0.0479	0.3773	0.2189	0.6143	0.6532
4	1	2.9661	6.8701	0.0196	0.0942	0.1401	0.3069	0.8347
5	1	2.757	7.0911	0.019	0.1105	0.1378	0.3324	0.8663
6	1	2.7081	5.3848	0.0143	0.0608	0.1197	0.2466	0.8729
7	1	2.9439	6.1332	0.0217	0.0827	0.1472	0.2876	0.8433
8	1	2.7976	7.2099	0.0186	0.1203	0.1363	0.3468	0.859
9	1	2.9518	5.8441	0.0152	0.0607	0.1235	0.2465	0.8657
10	1	2.796	6.3004	0.016	0.0701	0.1265	0.2648	0.8582
1	2	4.9131	12.8007	0.058	0.2313	0.2408	0.481	0.411
2	2	2.7703	6.3346	0.0171	0.0848	0.1306	0.2912	0.8487
3	2	3.2742	7.6643	0.0252	0.113	0.1588	0.3362	0.8251
4	2	2.8706	7.351	0.0189	0.1257	0.1374	0.3546	0.8483
5	2	2.8393	7.7347	0.0171	0.133	0.1309	0.3647	0.8581
6	2	2.7275	6.9391	0.0155	0.1061	0.1246	0.3258	0.8656
7	2	2.7506	5.8624	0.0169	0.0749	0.1299	0.2737	0.8598
8	2	3.1509	6.4339	0.021	0.0828	0.145	0.2877	0.8477
9	2	3.004	7.5868	0.02	0.1183	0.1415	0.344	0.8483
10	2	2.8307	7.7679	0.0179	0.145	0.1339	0.3808	0.8578
1	3	3.2988	8.3473	0.0278	0.1427	0.1667	0.3777	0.8406
2	3	2.7708	6.5502	0.0177	0.0944	0.133	0.3073	0.8567
3	3	3.1018	8.0181	0.0243	0.1388	0.156	0.3726	0.8597
4	3	2.6893	6.4987	0.0156	0.0937	0.1247	0.3061	0.8696
5	3	2.8648	6.962	0.0151	0.0932	0.1229	0.3052	0.8609
6	3	2.6331	4.8904	0.015	0.0538	0.1224	0.232	0.8638
7	3	2.6871	5.4872	0.0156	0.0649	0.1247	0.2547	0.8584
8	3	2.985	7.7066	0.0226	0.1293	0.1503	0.3596	0.8552
9	3	2.8784	6.8274	0.0187	0.0938	0.1368	0.3063	0.8701
10	3	2.8879	6.5027	0.0145	0.067	0.1205	0.2589	0.8681
1	4	2.837	6.9873	0.0169	0.1006	0.13	0.3172	0.8632

2	4	3.0724	6.7314	0.0231	0.0939	0.152	0.3065	0.842
3	4	2.7159	7.0145	0.0161	0.1126	0.127	0.3355	0.8638
4	4	4.5836	12.6799	0.0532	0.2193	0.2306	0.4683	0.7304
5	4	2.8809	6.9534	0.0146	0.1008	0.1209	0.3174	0.8672
6	4	3.1725	6.9408	0.0255	0.1063	0.1596	0.326	0.8189
7	4	3.029	7.0484	0.0198	0.1154	0.1408	0.3397	0.8452
8	4	3.1586	8.2406	0.0241	0.1367	0.1554	0.3697	0.8503
9	4	2.6825	6.4339	0.0156	0.0899	0.1251	0.2998	0.8633
10	4	2.9152	8.3614	0.0179	0.1674	0.1338	0.4091	0.8494
1	5	3.106	7.8853	0.0238	0.126	0.1543	0.3549	0.8455
2	5	3.0771	7.1942	0.017	0.0979	0.1304	0.3129	0.8492
3	5	3.0136	6.9258	0.0224	0.1102	0.1498	0.332	0.8199
4	5	2.8682	6.4827	0.0187	0.092	0.1366	0.3033	0.8675
5	5	2.7844	5.5738	0.0162	0.068	0.1274	0.2608	0.8634
6	5	2.7365	6.8468	0.0176	0.1023	0.1328	0.3198	0.8671
7	5	2.6897	5.6178	0.0151	0.068	0.1228	0.2612	0.8662
8	5	2.9067	7.7358	0.0205	0.1393	0.143	0.3732	0.8641
9	5	3.2328	8.342	0.025	0.1332	0.158	0.3649	0.8432
10	5	2.7648	6.3877	0.0141	0.0775	0.1186	0.2784	0.8721
1	6	2.9859	8.2539	0.0218	0.1652	0.1477	0.4065	0.8351
2	6	3.779	8.1009	0.0236	0.1224	0.1535	0.3498	0.7895
3	6	2.7746	5.8792	0.0174	0.0773	0.1319	0.2781	0.8555
4	6	3.1206	7.9201	0.0238	0.1497	0.1542	0.3869	0.8434
5	6	2.824	7.2112	0.0203	0.1204	0.1423	0.347	0.8428
6	6	3.199	8.3384	0.0249	0.1338	0.158	0.3658	0.8485
7	6	2.9304	6.9585	0.0194	0.1136	0.1394	0.3371	0.8328
8	6	3.0258	7.5573	0.0228	0.1318	0.151	0.363	0.8564
9	6	2.7226	6.1225	0.0173	0.0818	0.1316	0.286	0.8638
10	6	2.9663	7.5941	0.0223	0.1298	0.1494	0.3603	0.8562
1	7	2.8851	7.7019	0.0172	0.139	0.1312	0.3728	0.8463
2	7	2.8535	7.8932	0.0173	0.151	0.1314	0.3885	0.8564
3	7	2.8065	6.9576	0.0161	0.1107	0.127	0.3327	0.8558
4	7	4.1087	11.1004	0.0409	0.1775	0.2022	0.4213	0.814
5	7	2.8855	7.1597	0.0153	0.0967	0.1237	7.1597	0.859
6	7	2.7886	7.0958	0.0163	0.1151	0.1277	0.3393	0.8631
7	7	2.7392	6.5783	0.0171	0.0893	0.1306	0.2989	0.8486
8	7	2.8792	7.2087	0.0166	0.1176	0.1287	0.343	0.8599
9	7	2.7903	6.2992	0.0168	0.0837	0.1297	0.2893	0.8637
10	7	4.9466	11.92	0.0564	0.2122	0.2374	0.4607	0.8372
1	8	2.8918	6.2096	0.0182	0.0733	0.1349	0.2707	0.8514
2	8	2.788	5.8997	0.0156	0.0737	0.125	0.2714	0.8688
3	8	3.1737	8.5448	0.0248	0.1519	0.1575	0.3897	0.8447
4	8	2.8333	7.4113	0.0184	0.1282	0.1355	0.358	0.8564
5	8	2.7788	5.8977	0.0152	0.0618	0.1234	0.2485	0.8627

6	8	2.9179	7.5463	0.021	0.1314	0.145	0.3624	0.8574
7	8	2.6671	6.169	0.0171	0.0835	0.1306	0.289	0.8617
8	8	2.7964	6.7509	0.0176	0.1018	0.1326	0.3191	0.8625
9	8	2.9155	7.6937	0.0159	0.1378	0.1261	0.3712	0.8564
10	8	2.7249	6.1215	0.018	0.0828	0.1342	0.2878	0.85
1	9	2.7383	5.9949	0.0145	0.0729	0.1206	0.27	0.8677
2	9	2.9585	6.3164	0.0162	0.0796	0.1274	0.2822	0.8522
3	9	3.0743	7.2565	0.0222	0.1173	0.149	0.3425	0.8661
4	9	2.6632	5.981	0.0167	0.0753	0.1292	0.2743	0.8529
5	9	2.7694	6.0669	0.0155	0.0768	0.1245	0.2772	0.8609
6	9	2.7324	6.8233	0.0161	0.1025	0.127	0.3202	0.8684
7	9	2.6936	6.4184	0.0152	0.0859	0.1232	0.2932	0.8647
8	9	3.1429	7.3307	0.0242	0.1148	0.1557	0.3389	0.8478
9	9	2.677	6.0579	0.0151	0.078	0.1228	0.2793	0.8677
10	9	2.792	5.9726	0.0155	0.0764	0.1245	0.2764	0.8572
1	10	2.8931	7.5874	0.0212	0.1252	0.1456	0.3538	0.8567
2	10	2.8568	6.3475	0.0152	0.0697	0.1233	0.264	0.86
3	10	2.748	7.3132	0.0176	0.119	0.1326	0.345	0.8612
4	10	4.1555	9.4363	0.0394	0.1986	0.1985	0.4456	0.8276
5	10	2.7651	6.9448	0.016	0.0983	0.1266	0.3135	0.8618
6	10	2.7583	6.5306	0.0146	0.094	0.1207	0.3066	0.8696
7	10	3.2163	8.3047	0.0254	0.1293	0.1595	0.3596	0.8446
8	10	2.8431	7.2434	0.0203	0.1216	0.1423	0.3488	0.849
9	10	2.9699	8.3774	0.0214	0.1674	0.1464	0.4091	0.8514
10	10	2.5757	5.3428	0.0158	0.0614	0.1257	0.2478	0.8613