Stiction Analysis of Emergency Shutdown Valve Based on Partial Stroke Test

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

MAY 2011

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CERTIFICATION OF APPROVAL

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May 2011

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.

Faten Adawiyah Bt Radin Mohd Fuad

ABSTRACT

This paper presents an analysis on the stiction of emergency shutdown valve based on data gathered from partial stroke test software. It is meant to complement the existing software used to perform partial stroke test. Currently, most of the partial stroke software does not provide extensive offline analysis. Therefore, this project is intended to do extensive offline analysis based on available operational data. The stiction analysis is done based on test rig at Universiti Teknologi PETRONAS which used ball and butterfly valves. The analysis comprises Baseline Analysis, Present Analysis, and Comparison of Baseline Analysis and Present Analysis. First step of the analysis is to determine the baseline whereby first partial stroke test's data on a specific valve are gathered. Next step is to do analysis on present data which will be compared with the baseline analysis in order to detect any unconformity of the valve. Apart from the analysis, Graphical User Interface is developed for user-friendly interface for offline analysis of emergency shutdown valve.

ACKNOWLEDGEMENTS

First and foremost, the author would like to express gratitude to Allah the Almighty for making the project flow smoothly and successfully. The author's deepest gratitude goes to Ir Dr Idris for giving her the opportunity to do this project under his supervision and for his valuable ideas and guidance throughout the course of this project.

The author would also like to express gratitude to Electrical and Electronics Engineering Department of Universiti Teknologi PETRONAS (UTP) for providing this chance to undertake this final year project. Next, the author would like to thank the Final Year Project (FYP) committee for arranging various seminars to assist the students. Thanks to all lecturers and technicians from UTP especially Mr. Azhar Zainal Abidin who had provided untiring guidance and help throughout the period of the project.

Also, special thanks to Ms. Haryattie Azizi and Ms. Nur Alina Jelani, Instrumentation & Control Engineer from GTS for their help and guidance in completion of this project. Finally, I would like to thank all parties that were involved directly or indirectly in making this project a success. Thank you.

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LIST OF ABBREVIATIONS AND NOMENCLATURES

ESDV	Emergency Shut Down Valve
ESD	Emergency Shut Down
FST	Full Stroke Valve Testing
GTS	Global Technology Solution
GUI	Graphical User Interface
OREDA	Offshore Reliability Data
PFD	Probability to Fail on Demand
PLC	Programmable Logic Controller
PST	Partial Stroke Valve Testing

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Emergency Shutdown (ESD) system is required to protect plant facilities by performing safe shutdown when there is an emergency. ESD system composed of elements including primary element, logic solver and final element. ESD system can fail in two ways which are dangerous failure which the ESD system fail to perform safety action when it is urgently needed and safe failure which the ESD system fail without any equipment failure. As a result, testing of the Emergency Shutdown Valve (ESDV) is important to maintain its integrity. Basically, there are two ways of doing stroke test. They are Full Stroke Test (FST) and Partial Stroke Test (PST).

FST is a method of stroking the ESDV hundred percent in order to detect current and potential failure mode of the valve. PST is an option to FST; it is a method to check periodically that the ESDV is operated securely without any non-conformity by closing the ESDV typically to range of 20 to 30 percent and back to normal condition in a short period of time as not to interfere the process during plant operation. From the PST, diagnostic information is retrieved to determine the condition of ESDV for further safety action and to analyse the stiction of the ESDV.

1.2 Problem Statements

ESD system comprises primary element, logic solver and final element. Based on experience, final element specifically ESDV is by far the largest source of failure in ESD system. Turn-around being planned further apart, ranging from three to five years. The incapability to conduct FST within the required period, causing safety issues to arise due to ESDV being stuck in position due to the very long period in one fixed position. Therefore, testing the reliability of the ESDV is important. As mentioned earlier, ESDV can be tested by FST and PST.

These tests are to be conducted in order to detect any possible faulty that may lead to malfunction of ESDV. The ESDV is dormant and it is prone to stiction due to any deposit build up and corrosion. PST will detect the current and possible problem of the ESDV as well as when the valve moves to perform PST, it removes any deposit build-up and the valve is free again.

1.2.1 Problem Identification

Before any testing and designing can be made using PST software and Matrix Laboratory (MATLAB), understanding the basic principle of PST is needed. Only then can the analysis of ESDV as well as the developing of the Graphical User Interface (GUI) for ESDV's offline analysis can be continued.

1.2.2 Significant of Project

The idea of the project is to analyze the stiction of ESDV as well as to come up with a Graphical User Interface (GUI) called Valve Stiction Analysis User Interface. The GUI is to be developed in order to perform offline analysis of the ESDV.

1.3 Objectives

The objectives of this project are:

i. To do baseline analysis on the performance of ESDV based on PST. This analysis is based on the data that are gathered on the first time the PST is carried out. The data will be used as a baseline to be compared with present PST data.
ii. To analyze and compare the set of data gained from the performance of the PST with baseline analysis. The values of potential attributes from Baseline Analysis are compared with the values of potential attributes that are obtained from the Present Analysis.
iii. To develop a fuzzy logic in order to determine the operational condition of the valve. This fuzzy logic is developed based on the membership function established for friction band as well as deadband.
iv. To develop a Valve Stiction Analysis User Interface as a means to do offline analysis on the data gained from the PST. This user interface is meant to provide offline analysis interface of ESDVs. It can be used to calculate potential attributes, plot graphs, and view valve status as well as to generate report.

1.4 Scope of Study

The scope of study will evolve around the MATLAB programming for the Valve Stiction Analysis User Interface development. Learning on the PST is also needed as the analysis is done on the data gathered from PST on the ESDV. Overall, the project scope can be divided into two stages whereby the first stage is the study of the theories behind PST. The second stage is to analyse the performance of ESDV based on data gathered from PST software, to develop a fuzzy logic and Valve Stiction Analysis User Interface for ESDV's offline analysis based on actuator pressure, valve travel, deadband, friction band, actuator pressure needed per percentage of valve travel and stroke rate.

CHAPTER 2

LITERATURE REVIEW ON ESDV STICTION ANALYSIS

2.1 Emergency Shutdown System

ESD system is intended to protect the plant of oil and gas company from hazard as well as to protect plant personnel, equipment and the surroundings [1]. This system comprises sensor, logic solver and final element.

2.1.1 Hardware

2.1.1.1 Primary Element

It collects information necessary to identify emergency event. It detects unusual operating conditions such as high flow, low flow, low level, high level or incorrect valve positioning.

2.1.1.2 Final Element

It implements the safety action depending on the output sent by logic solver. This element which is an ESDV is important as it bring the process to safe condition when emergency happens. Failure of doing safety action will lead to fatalities, loss of production and catastrophe. As a result, the reliability of this element is essential.

2.1.2 Software

2.1.2.1 Logic Solver

A logic solver receives the sensor input signal, make appropriate decisions based on the character of the signal and provide suitable output. Basically, it determines the action to be taken based on the information obtained from the primary element.

2.2 Current Practices and Problem in Industries

2.2.1 PST

PST is an option to FST, it is a method to check at regular intervals that the final element or specifically the ESDV is operated without any non-conformity by closing the valve typically to range of 20 to 30 percent and back to normal condition in a short period of time as not to interfere the process during plant operation [2].

From this test, diagnostic information is retrieved to determine the condition of the ESDV for further safety action. The main objective of PST is to supplement the full stroke test as to reduce the valve Probability to Fail on Demand (PFD). This allows annual test which is FST intervals to be extended and the costs to be reduced due to reduction in maintenance work and downtime. This method does prove that the valve can move and any deposit build-up is removed and the valve is free again [3]. The detectable failure by performing PST is tabulated in Table 1.

Table 1: Valve failure modes and associated effect

Valve Failure Modes	
Mode	**Effect**
Stem packing seized	Valve stuck
Air line blocked	Fail to close
Valve stem build up	Valve stuck
Air line to actuator crimped	Sluggish response

PST detects a percentage of potentially dangerous failures in the actuator, the valve and within it. Diagnostic are achieved because the valve status and its response to mechanical movement can be monitored during the test. Valve performance are monitored and analysed after each PST so that a potentially failing valves can be identified before it is fully unavailable to do safety action. The results of a signature test as in Figure 1 can be used to determine packing problems due to friction, leakage in the pressurized pneumatic path to the actuator, valve sticking, actuator spring rate and deadband [4].

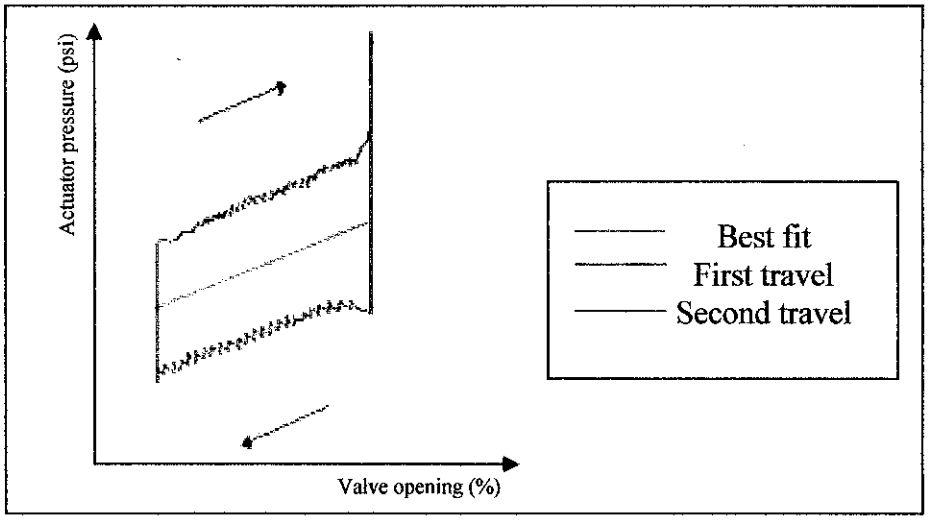


Figure 1: Valve signature from diagnostics.

Offshore Reliability Data (OREDA) differentiates between critical, degraded and developing failures. A critical failure is defined as a failure that results in direct and complete loss of a systems capability of providing its output. A degrade failure is a failure that do not allow the system from providing its output within specifications, while a developing failure is a failure that is not critical but may become one if it is not repaired [5]. The critical and degraded failure modes that may be considered as dangerous are delayed operation, external leakage of process medium, failure to close on demand and leakage in closed position. The leakage in closed position can only be detected by performing FST.

2.2.2 Valve Stiction

Based on experience, if valves are not exercised, they tend to stick in one position. Stiction is the resistance to begin a movement which is usually measured as the difference between the driving values required to overcome static friction upscale and down scale [6]. In fact, the common awareness is that sticking is the main failure mode of safety valves. Valve sticking or stuck at preset position could be cause by dirt accumulation and corrosion debris.

Valves that continue to move from one position to another position (e.g. full close to full open and vice versa) will reduce the probability of dirt and corrosion debris accumulation. Movement of the valves can lessen dirt build-up and can give an indication if corrosion is present for example because the stroking time is longer than specified [3].

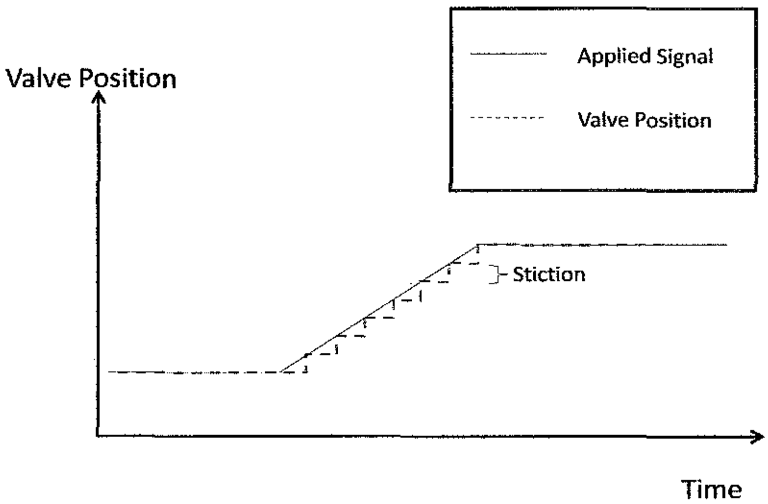


Figure 2 : Stiction Signature

According to Michael Ruel, stiction is much more harmful than the other valve problems. A moving object has less stiction compared to the one in stationary. The effect of stiction is that it will not allow the stem to move and it can only be moved when there is enough force. The result of stiction is that the force required in moving the stem is more than the force required to travel to the desired stem position. The movement is jumpy as in Figure 2 if stiction present.

2.3 Potential Attributes to Stiction Analysis

2.3.1 Deadband

Deadband is the range through which an input can be varied without initiating observable response. There are separate and distinct input-output relationships for increasing and decreasing signals [7]. In a diaphragm actuated control valve, deadband is the amount that the instrument air signal can be changed without initiating valve stem movement. The amount of deadband is determined by measuring the changeover pressure for a given stem position [8]. Dead band can increase due to the increase in the frictional force as a result of blocking the actuator vent hole [9].

2.3.2 Friction Band

Based on Figure 1, the separation of the red and blue lines is the friction band. The relationship of friction band with the amount of friction is that the higher the friction the wider the separation. Since friction always apposes movement, the net spread of these lines is actually double the friction. The main source of friction on a good valve is the valve packing. Packing materials that have a high coefficient of friction, such as graphite, will produce a greater amount of friction and thus a wider friction band then the low coefficient materials, such as PTFE [10].

2.3.3 Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel

The stroking time of a valve is the time taken for the valve to stroke over its entire travel. The duration is measured from signal increase or decrease to full travel. Actuator pressure needed is the amount of pressure changed to move the stem of a valve a percentage of its full travel. This may be from the partially open position to the fully closed position, or vice versa. The followings are the influencing factors listed in order of priority; actuator size, actuator stroke, air supply, pressure, size of pipe work connections, spring rate, air to open/close and type of positioner [8].

2.4 Statistical Analysis

2.4.1 Median

In probability theory and statistics, a median is described as the numeric value separating the higher half of a sample, a population, or a probability distribution, from the lower half. The median of a finite list of numbers can be found by arranging all the observations from lowest value to highest value and picking the middle value. If there is an even number of sample, then there is no single middle value. Therefore, the median is then defined to be the mean of the two middle values [11] [12].

In an even sample size of data there may be no member of the sample whose value is identical to the median. Half the population have values less than the median and half have values greater than the median. If both groups contain less than half the population, then some of the population is exactly equal to the median. For example, if $a < b < c$, then the median of the list {a, b, c} is b, and, if $a < b < c < d$, then the median of the list {a, b, c, d} is the mean of b and c. It is $(b + c)/2$ [13].

2.5 Fuzzy logic

Fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. It is a super set of conventional (boolean) logic that has been extended to handle the concept of partial truth and the truth values between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions [14].

2.5.1 Definition (Universe of discourse)

The universe of discourse is a set X, discrete ({x1; : : : ; xn}), or continuous (union of intervals on the real line) [15].

2.5.2 Definition (Membership Function)

A membership function is a function $\mu_A : X \rightarrow [0, 1]$ [15].

2.5.3 Definition (Fuzzy Set)

A fuzzy set is defined by a membership function, it consists of some elements x of a universe of discourse X together with their membership values (or degrees) $\mu_A(x)$ [15].

2.5.4 Basic Logic Operations [15]:

1) Definition (AND)

$$\mu_{A\cap B}(x) = \min(\mu_A(x), \mu_B(x)) \quad (1)$$

2) Definition (OR)

$$\mu_{A\cup B}(x) = \max(\mu_A(x), \mu_B(x)) \quad (2)$$

3) Definition (NOT, optional)

$$\mu_{-A}(x) = 1 - \mu_A(x) \quad (3)$$

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

In order to achieve the aim of the project, researches had been done on several resources from seminar materials, journals, reports and internet related to ESD System, PST, valve stiction, fuzzy logic, GUI, potential attributes to ESDV stiction analysis such as deadband, friction band, stroke rate and actuator pressure needed per percentage of valve travel. For the first step, gathering information with regards to PST need to be done in order to learn and enhance knowledge on PST. After all the researches and studies are done, the next stage is the data acquisition stage whereby the parameters (actuator pressure versus time and valve travel (valve opening) versus time) are retrieved from the PST software in laboratory. The data taken are from the previous PST done from year 2008 to year 2009. In this stage, the author needs to be familiar with the PST software by referring and discussing with previous student and GTS representatives. After the data acquisition, analysis on stiction of ESDV can be done based on relationship of actuator pressure and valve opening, valve opening and time, stroke rate, deadband, actuator pressure needed per percentage of valve travel and friction band. The analysis is done by plotting graph, mathematical calculation as well as using fuzzy logic. Apart from the analysis, Valve Stiction Analysis User Interface is developed from time to time in order to produce suitable interface for offline analysis of ESDV. The overall project work flow is elaborated in Figure 3.

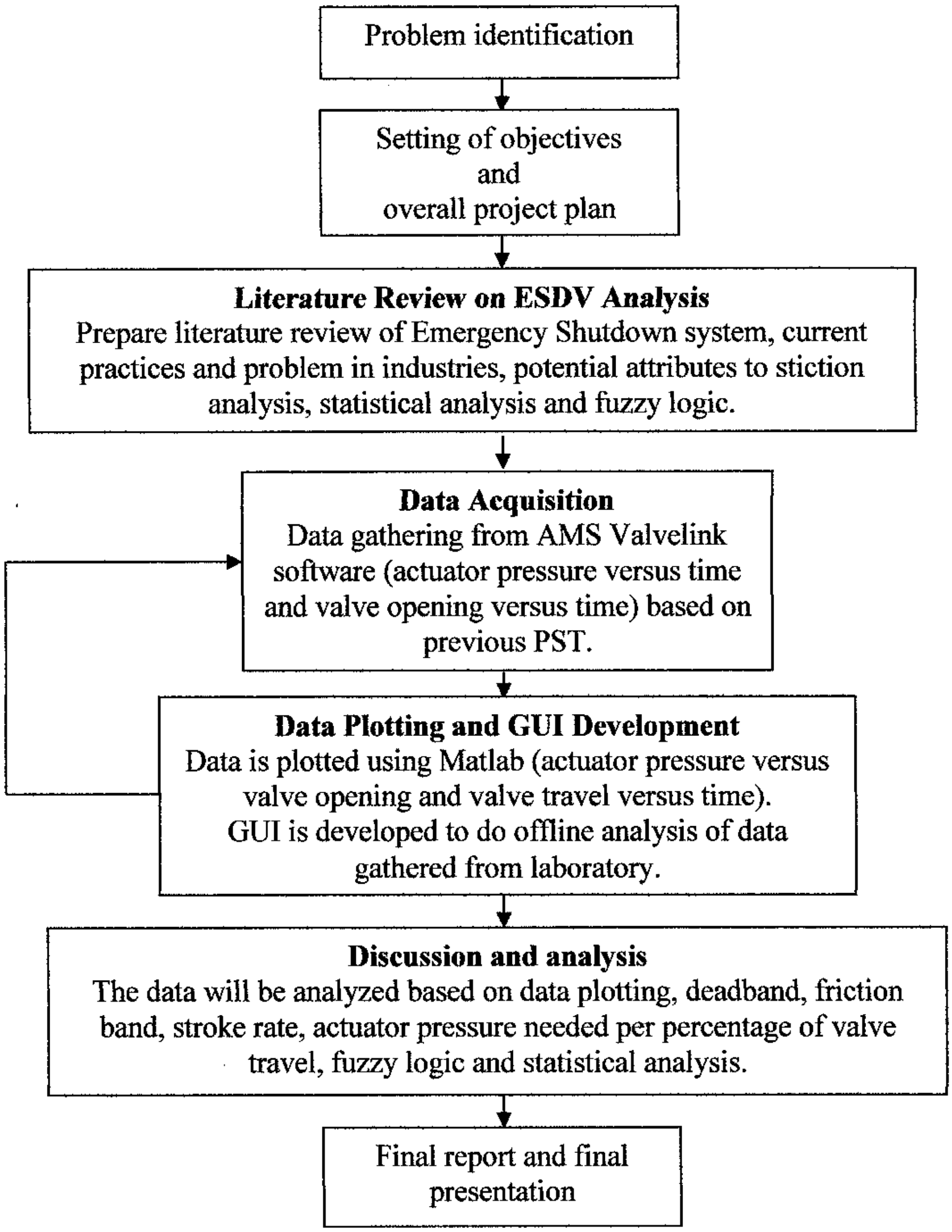


Figure 3: Project activities flow chart

3.2 Gantt Chart

The Gantt chart is attached in the *Appendix I.* The Gantt chart is a guideline for the project timeline. It can be changed from time to time depending on certain circumstances.

3.3 Tools Required

3.3.1 Hardware

For the accomplishment of the project, there are needs for hardware such as ESDV, Yokogawa FA-M3 controller and computer. ESDV is a valve that is use to do safe shutdown in case of emergency by implementing the action determined by the logic solver. This final control element is typically a pneumatically actuated On-Off valve operated by solenoid valves. It will stop the flow or isolate units when hazardous situation is detected to prevent loss, fatalities, equipment damage, plant explosion, etc. There are two types of valve used in this project which are ball valve and butterfly valve. The Programmable Logic Controller (PLC) that been used for this project is FA-M3 Controller which is manufactured by Yokogawa.

3.3.2 Software

There are three software that are been used for this project which are PLC, Asset Management Software by vendor and Matlab 7.1. Basically, the PLC provide signal for a Full Stroke Testing execution, while the Asset Management Software is programmed to perform PST. The software provides the diagnostics of the emergency shutdown valve performance for each test that are implemented. This software is used to analyse data gathered from the PST experiment done in laboratory by doing data plotting and data analysis in determining the potential attributes (stroke rate, deadband, friction band and actuator pressure needed per percentage of valve travel).

3.4 Analysis Methodology

In this project, the stiction analysis is done on two different ESDV which are ball and butterfly valve. The analysis consists of 3 parts:

1) Baseline Analysis
- This analysis is based on the data that are gathered on the first time the PST is carried out on both ball and butterfly type of ESDV. The data that are gathered from this analysis will be used as a baseline to be compared with present PST data.

2) Present Analysis
- This analysis is based on the data that are gathered after removing the solenoid valve that connects the digital valve controller output to the actuator of ball valve. While for butterfly valve, the analysis is done based on the data of PST carried out after the valve packing is tightened to observe the effect on the stiction of the valve.

3) Comparison of Baseline Analysis and Present Analysis
- The values of potential attributes (deadband, friction band, actuator pressure needed per percentage of valve travel and stroke rate) from Baseline Analysis are compared with the values of potential attributes that are obtained from the Present Analysis.

3.5 Methodology of Determining the Value of Potential Attributes for Stiction Analysis

3.5.1 Stroke Rate

One of the potential attributes for ESDV stiction is the stroke rate of the valves. It is proportional to the valve travel (valve opening) and inversely proportional to time taken for it to move the stem of the valve (stroke time). Stroke rate can be determined by manipulating the value of valve travel and time taken for it to travel. Equation (4), (5), (6) and (7) will give the result of stroke rate for the respective valve. The stroke rate for baseline analysis is compared with the present analysis.

$$t_1 = t_2 = t_{max} - t_{min} \quad (4)$$

$$s_1 = s_2 = s_{max} - s_{min} \quad (5)$$

$$\text{Stroke Rate 1} = \text{Stroke Rate2} = \frac{s}{t} \quad (6)$$

$$\text{Average Stroke Rate (\%/s)} = \frac{\text{Stroke Rate 1} + \text{Stroke Rate2}}{2} \quad (7)$$

where;

t_1 = total time taken for the first travel to complete in seconds

t_2 = total time taken for the second travel to complete in seconds

t_{max} = maximum time

t_{min} = minimum time

s_1 = total valve travel for the first travel in percentage

s_2 = total valve travel for the second travel in percentage

s_{max} = maximum travel

s_{min} = minimum travel

3.5.2 Friction Band

Friction band can also be used to analyze the stiction of ESDV. If the band is wider, the friction in the valve packing is higher and vice versa. The friction band can be determined directly from the valve signature (refer Figure 1) by observing separation of the red and blue lines. Friction band unit is in pounds per square inch (psi).

3.5.3 Deadband

Another potential attribute use to analyze the stiction of ESDV is deadband. Deadband of the valves can be determined by referring to the valve signature as in Figure 4. Deadband is the amount of actuator pressure in psi needed to be exhausted to move the valve stem from its initial position. Dead band can increase due to the increase in the frictional force as a result of blocking the actuator vent hole.

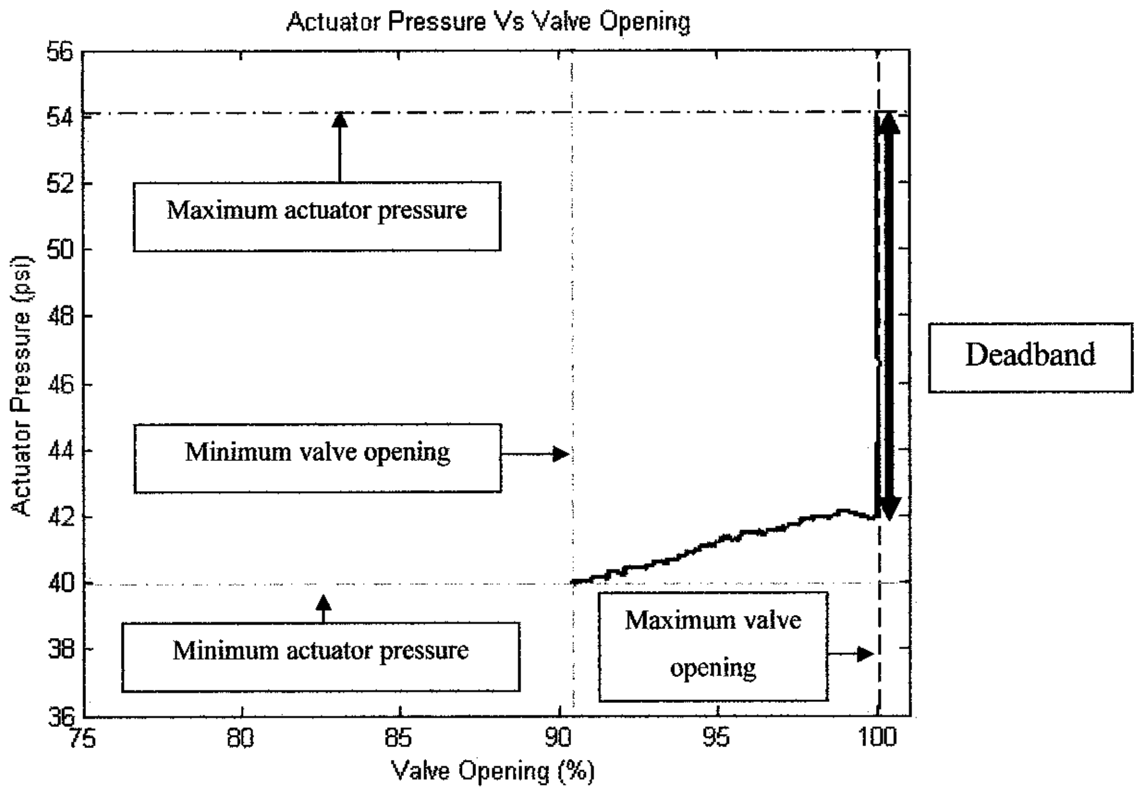


Figure 4: Valve signature for first travel

3.5.4 Actuator Pressure Needed Per Percentage of Valve Travel

Another potential attributes for ESDV stiction is the actuator pressure needed per percentage of valve travel. It can be determined by manipulating the value of actuator pressure and percentage of valve travel. Equation (8), (9), (10) and (11) will give the result of actuator pressure needed per percentage of valve travel for the respective valve. The actuator pressure needed per percentage of valve travel for baseline analysis is compared with the present analysis.

$$p_1 = p_2 = p_{max} - p_{min} \quad (8)$$

$$s_1 = s_2 = s_{max} - s_{min} \quad (9)$$

$$A1 = A2 = \frac{p}{s} \quad (10)$$

$$\text{Average actuator pressure needed per percentage of valve travel (psi/\%)} = \frac{A1 + A2}{2} \quad (11)$$

where;

p_1 = total pressure needed to move the valve for the first travel in psi

p_2 = total pressure needed to move the valve for the second travel in psi

p_{max} = maximum pressure

p_{min} = minimum pressure

s_1 = total valve travel for the first travel in percentage

s_2 = total valve travel for the second travel in percentage

s_{max} = maximum travel

s_{min} = minimum travel

A1 = Actuator pressure needed per percentage of valve travel for first travel

A2 = Actuator pressure needed per percentage of valve travel for second travel

3.6 Statistical Analysis

Statistical Analysis is used to find the value of friction band. The median of a group of data can be found by arranging all the data from lowest value to highest value and picking the middle value. If there is an even number of sample, the median is then defined to be the mean of the two middle values. The median of actuator pressure for first travel is subtracted by the median of actuator pressure for second travel in order to obtain friction band.

3.7 Fuzzy Logic

Fuzzy logic is one of the methods to identify operational condition of an ESDV by determining the degree of unhealthy friction band and deadband. Membership functions for unhealthy friction band as well as deadband are established. From the graph plotted based on the membership function, we can identify the stiction status for each ESDV.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Partial Stroke Test

4.1.1 Ball Valve

4.1.1.1 Baseline Analysis of PST based on Deadband and Friction Band

This analysis is based on the operational data that are gathered on the first time the PST is carried out on the ESDV. The data that are gathered from this analysis will be used as a baseline to be compared with future data of PST.

Figure 7 shows the ball valve signature of a successful PST executed. The y-axis represents actuator pressure in pounds per square inch and x-axis represents valve travel (opening) in percentage. The valve is initially 100% (90 degree) open which is a normal opening for the emergency valve for normal operation and the valve is set to partially stroke until 90% (81 degree).

Figure 5 shows the first travel valve signature of ESDV. The y-axis represents actuator pressure in pounds per square inch while x-axis represents valve opening in percentage. The maximum actuator pressure used for first travel of valve in performing PST is 54 psi and it is denoted by dark blue line while the minimum actuator pressure used is 39.92 psi and it is denoted by blue line.

Based on Figure 6, the maximum actuator pressure used for second travel of valve in performing PST is 54.01 psi and it is denoted by dark blue line while the minimum actuator pressure used is 39.92 psi and it is denoted by blue line.

The valve travels from 90 degrees to 81 degree when the valve is partially stroked. From Figure 5, the actuator pressure drops from about 54 psi to 42 psi at 90 degree travel in order to move the stem. The actuator need to bleed out about 12 psi before the stem started to move. Therefore, the deadband is 12 psi. The maximum valve opening (Test End Point) is set from the AMS Valvelink software and can be seen as in Table 2.

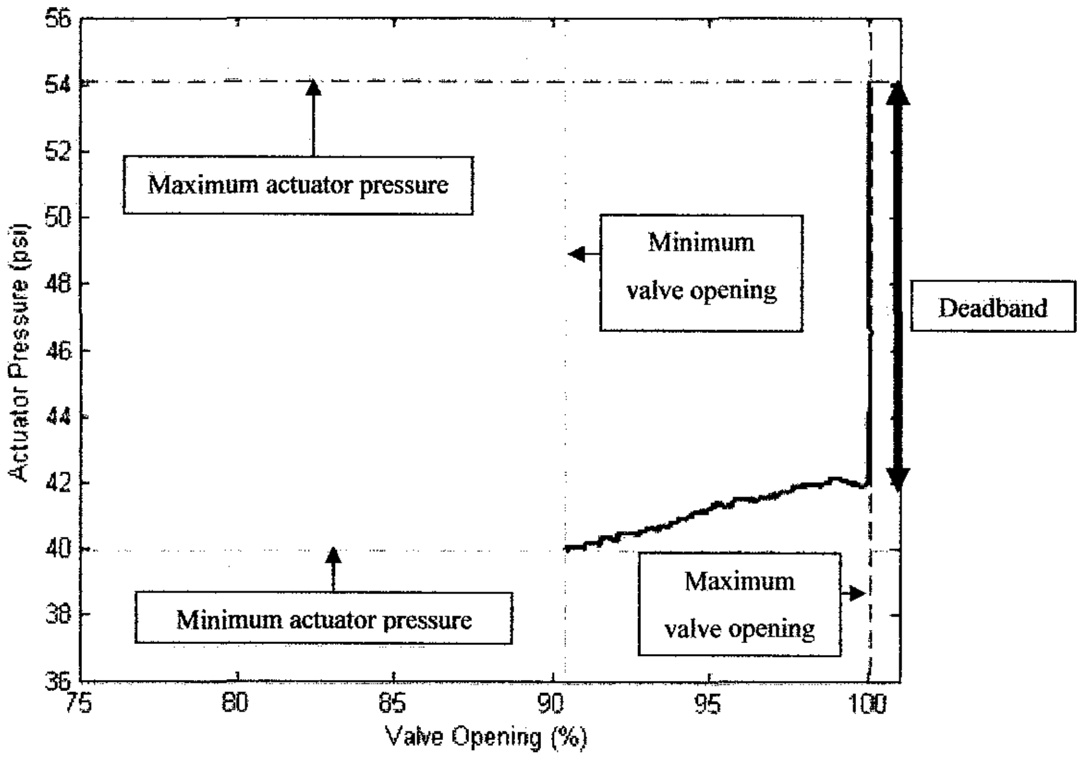


Figure 5: Baseline valve signature for ball valve (first travel)

Table 2: PST information for ball valve

Test Start Point	100%
Test End Point	90%

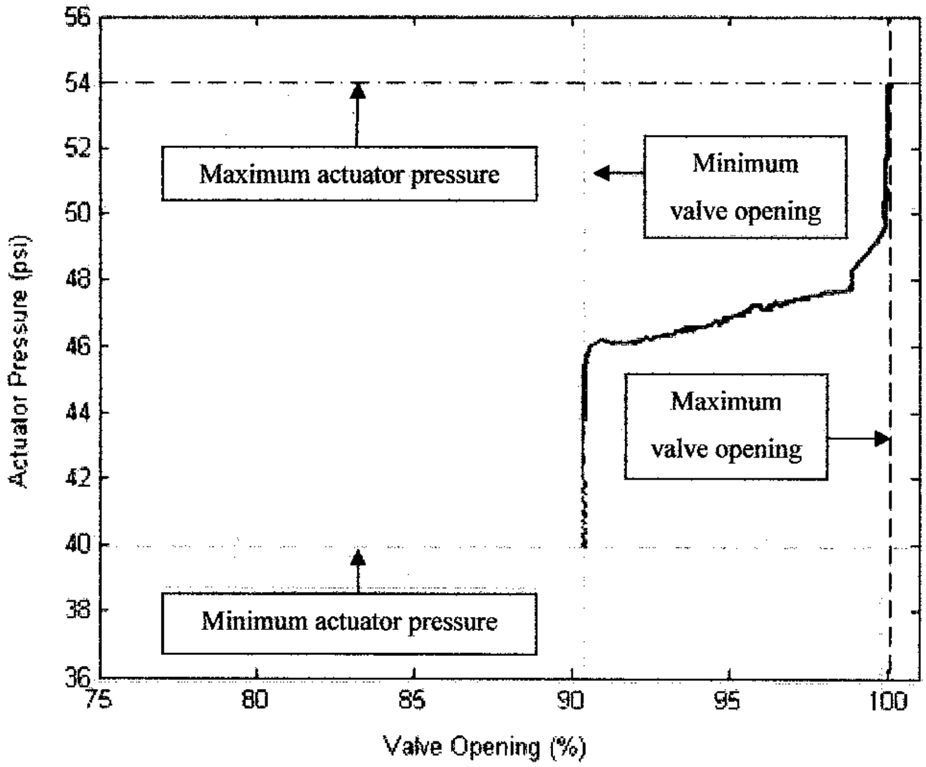


Figure 6: Baseline valve signature for ball valve (second travel)

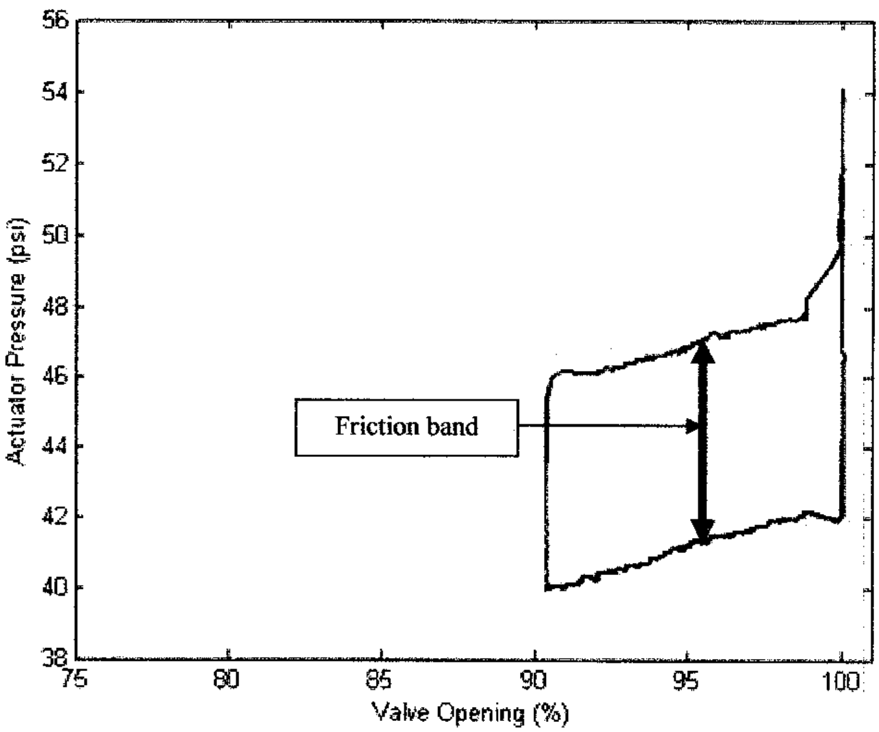


Figure 7: Baseline ball valve signature for ball valve

Based on figure 6, for second travel which means the opening of the valve back to normal position, the pressure increased from 39.92 psi to 54.01 psi at 81 degree. This is due to the friction which needs more pressure to move the valve. Then the pressure is increased up until the valve travel reaches 90 degree (Test Start Point). The Test Start Point can be set from the AMS Valvelink software.

There is difference between actuator pressure for first travel and second travel although both travel the same distance. The difference between the red line (closing curve) and the blue line (opening curve) is the friction band. The friction band for baseline data is 5.66 psi. This value will be compared with the present data in analysing the stiction of the ESDV.

4.1.1.2 Baseline Analysis of PST based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel

Figure 8 shows the graph of ball valve first travel versus time. From the graph, the time taken for the first travel to complete can be determined by using equation (4) and the total valve travel is calculated as in equation (5). The stroke rate and average stroke rate of the valve can be determined by using equation (6) and (7) respectively. The results are tabulated in Table 3.

Table 3: Stroke rate of baseline analysis (ball valve first travel)

Time taken for the first travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)
50.5	9.69	0.192

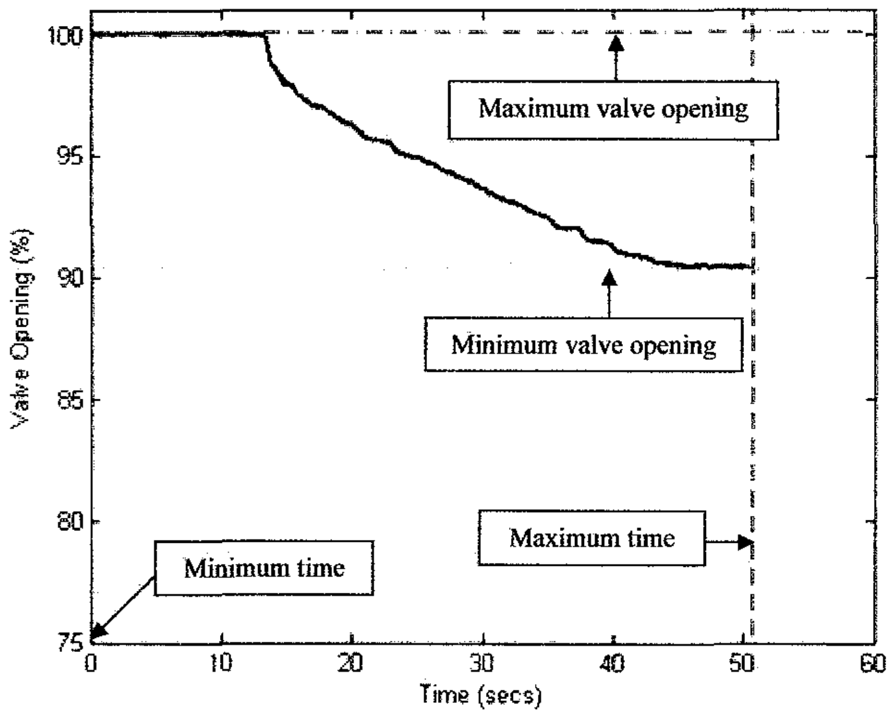


Figure 8: Graph of first travel versus time for ball valve.

Figure 9 shows the graph of ball valve second travel versus time. From the graph, the time taken for the second travel to complete, the total valve travel and stroke rate of the valve can be determined. The results are tabulated in Table 4.

Table 4: Average stroke rate of baseline analysis (ball valve)

Time taken for the second travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)	Average Stroke Rate (%/s)
50.55	9.7	0.192	0.192

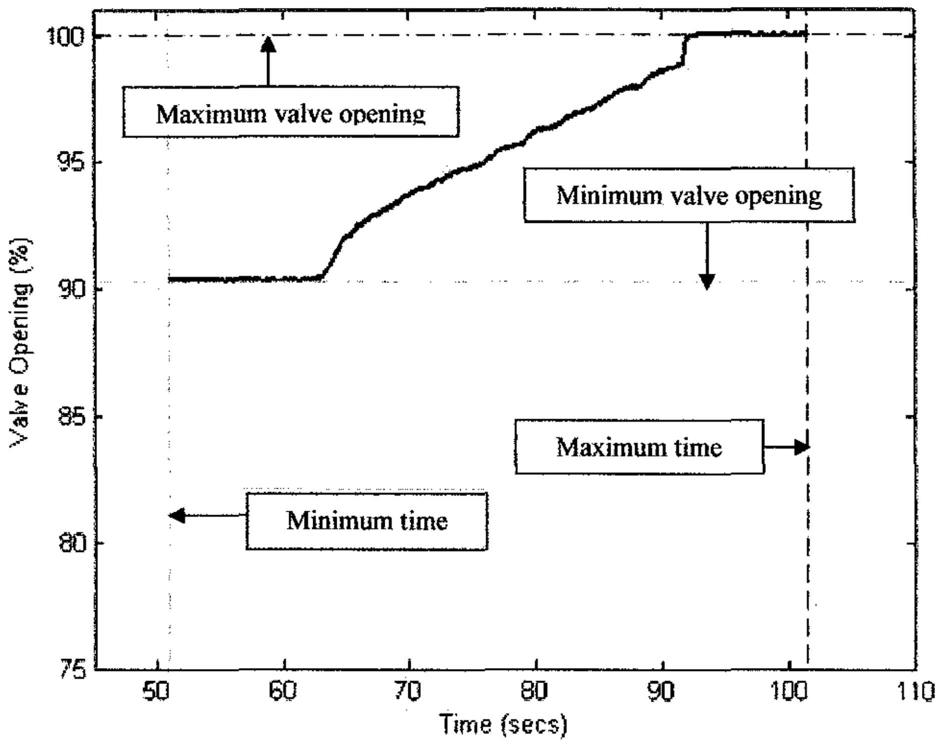


Figure 9: Graph of second travel versus time for ball valve.

Figure 10 shows the graph of ball valve actuator pressure versus valve opening for first travel. From the graph, the actuator pressure needed to close the valve for the first travel can be determined by using equation (8) and the total valve travel is calculated as in equation (9). The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated in Table 5.

Table 5: Actuator pressure needed per percentage of valve travel for baseline analysis (ball valve first travel)

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)
14.19	9.69	1.46

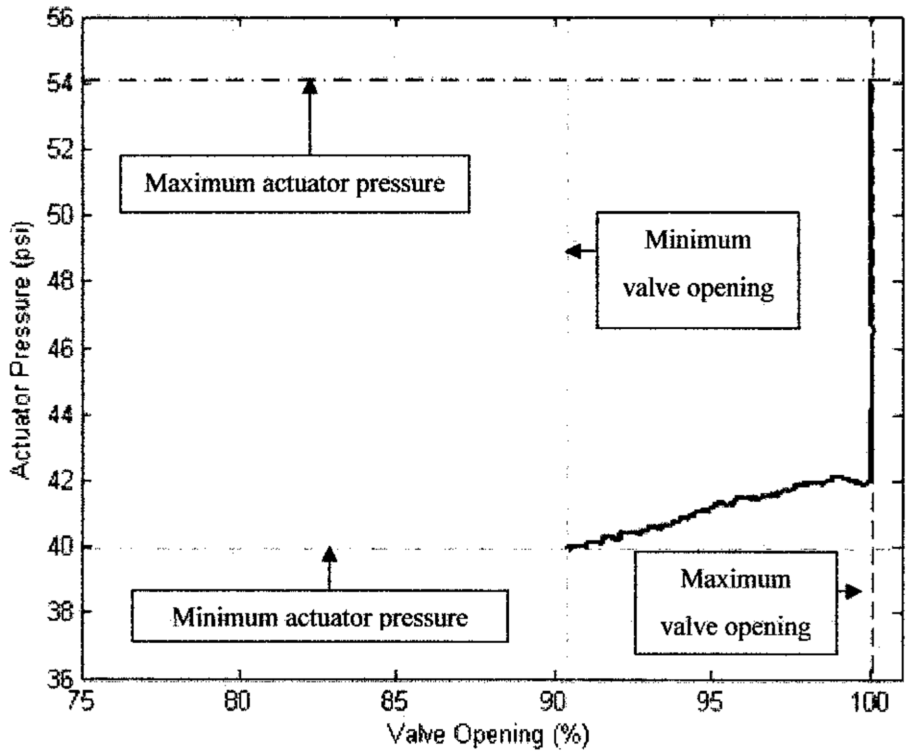


Figure 10: Graph of actuator pressure versus valve opening for first travel (ball valve).

Figure 11 shows the graph of actuator pressure versus valve opening for second travel. From the graph, actuator pressure needed to open the valve for the second travel can be determined by using equation (8) and the total valve travel is calculated as in equation (9). The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated in Table 6.

Table 6: Average actuator pressure needed per percentage of valve travel for baseline analysis (ball valve second travel)

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)	Average actuator pressure needed per percentage of valve travel (psi/%)
14.09	9.7	1.45	1.46

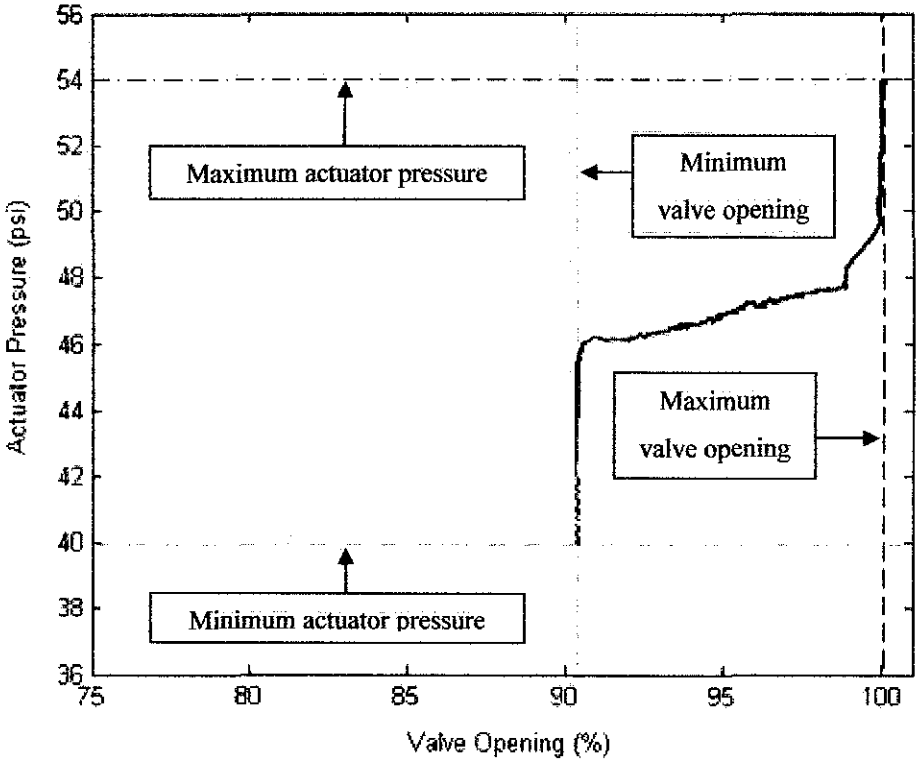


Figure 11: Graph of actuator pressure versus valve opening for second travel (ball valve).

4.1.2 Butterfly Valve

4.1.2.1 Baseline Analysis of PST based on Deadband and Friction Band

Figure 12 shows the butterfly valve signature of a successful PST executed. The y-axis represents actuator pressure in pounds per square inch and x-axis represents valve travel in degree. The valve is initially 100% open which is a normal opening for the emergency valve for normal operation and it is equivalent to 90 degrees. The valve is set to partially stroke until 88% which is about 79 degrees.

Table 7: PST information for butterfly valve

Test Start Point	100%
Test End Point	88%

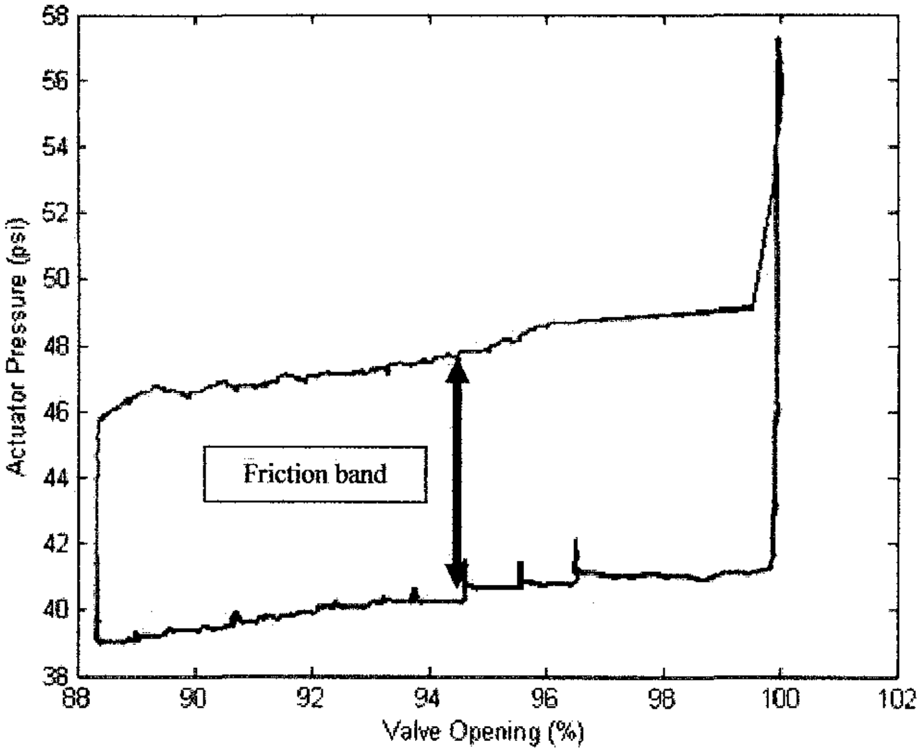


Figure 12: Baseline valve signature for butterfly valve.

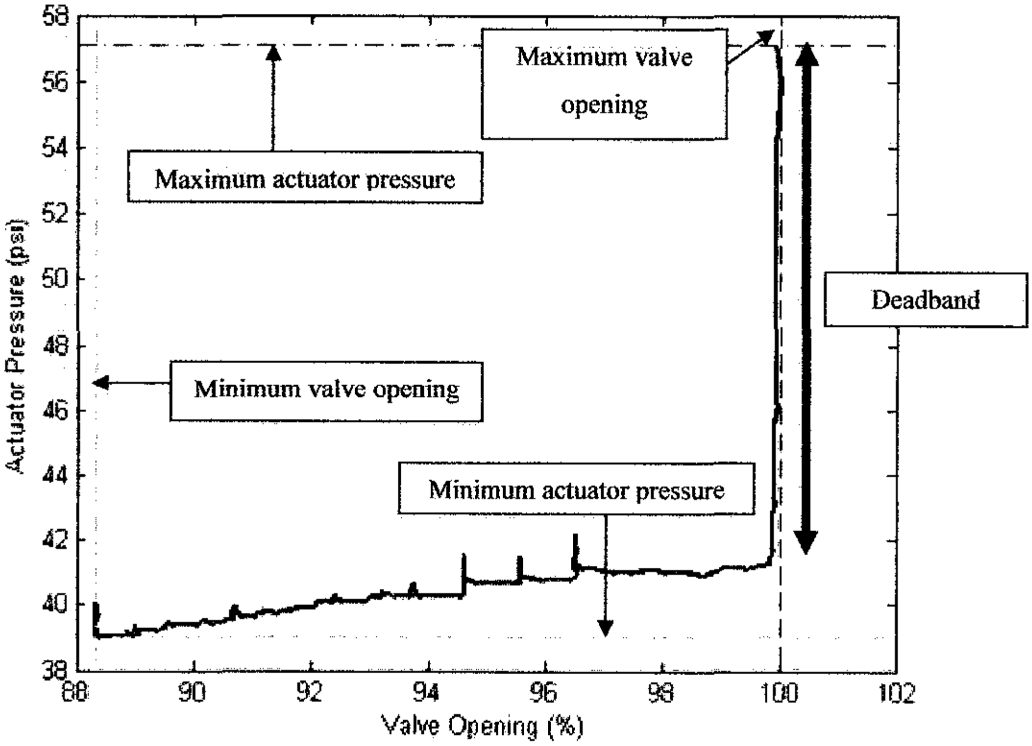


Figure 13: Baseline valve signature for butterfly valve (first travel)

Based on the Figure 13, the valve travels from 90 degrees to 79 degree when the valve is partially stroked. The actuator pressure drops from about 57.08 psi to 41.08 psi at 90 degree travel in order to move the valve. Therefore, the deadband is equals to 16 psi. The maximum travel (Test End Point) is set from the AMS Valvelink software and can be seen as in Table 7.

Based on Figure 14, the y-axis represents actuator pressure in pounds per square inch while x-axis represents travel in percentage. The maximum actuator pressure used for second travel of valve in performing PST is 57.26 psi and it is denoted by dark blue line while the minimum actuator pressure used is 39.35 psi and it is denoted by blue line.

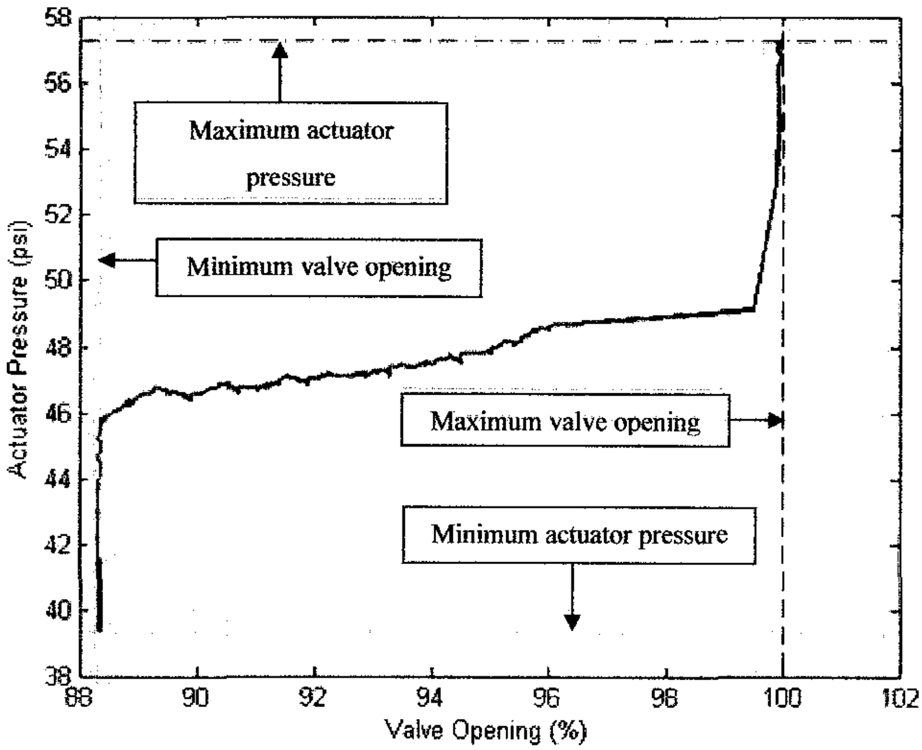


Figure 14: Baseline valve signature for butterfly valve (second travel)

For second travel which means the opening of the valve back to normal position, the pressure increased from 39.35 psi to 45.71 psi at 79 degree. Then the pressure is increased up until the valve travel reaches 90 degree. There are difference between actuator pressure for first travel and second travel although both travel the same distance. The difference between the red line (closing curve) and the blue line (opening curve) is the friction band. The friction band in this case is 7.13 psi. The wider the band, the higher the friction is.

4.1.2.2 Baseline Analysis of PST based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel

Figure 15 shows the graph of butterfly valve for first travel versus time. The y-axis represents valve opening in percentage while the x-axis represents time taken for the valve to travel at certain percentage. From the graph, the time taken for the first travel to complete, the total valve travel and stroke rate of the valve can be determined. The results are tabulated in Table 8.

Table 8: Stroke rate of baseline analysis (butterfly valve first travel)

Time taken for the first travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)
51.9	12	0.23

Figure 16 shows the graph of ball valve second travel versus time. The y-axis represents valve travel in percentage while the x-axis represents time taken for the valve to travel at certain percentage. From the graph, the time taken for the first travel to complete, the total valve travel and stroke rate of the valve can be determined. The results are tabulated in Table 9.

Table 9: Average stroke rate of baseline analysis (butterfly valve)

Time taken for the first travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)	Average Stroke Rate (%/s)
51.75	12	0.23	0.23

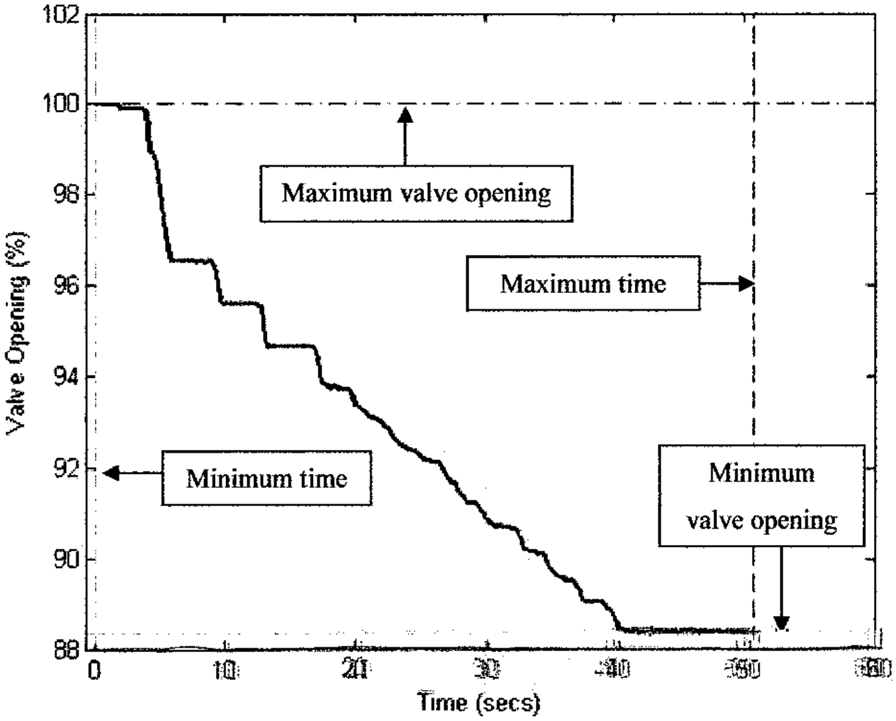


Figure 15: Graph of first travel versus time for butterfly valve.

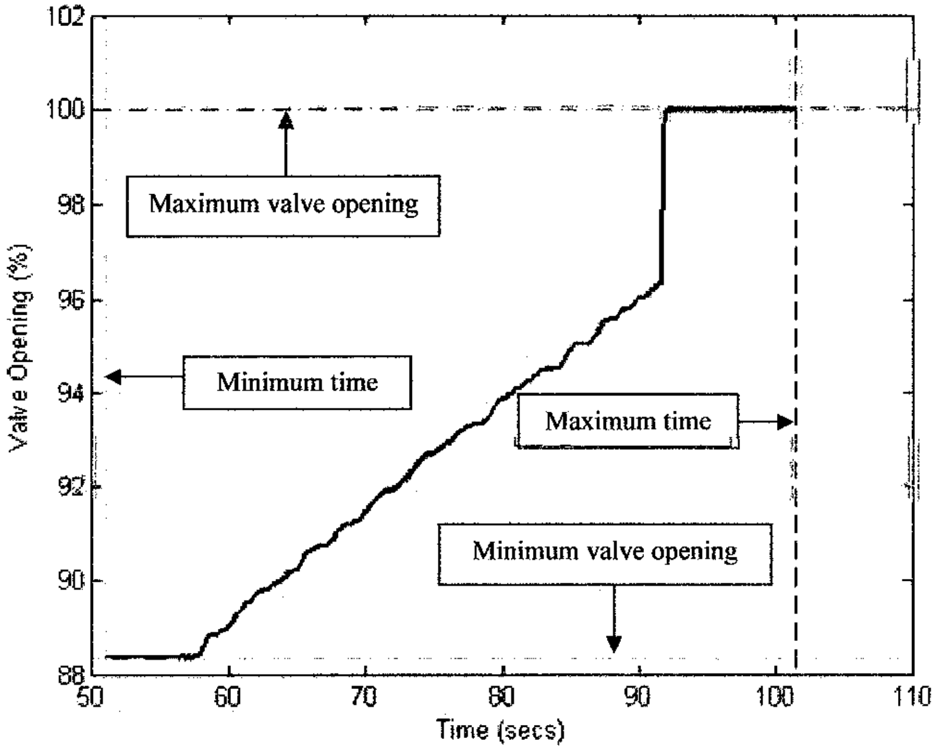


Figure 16: Graph of second valve travel versus time for butterfly valve.

Figure 17 shows the graph of butterfly valve actuator pressure versus valve opening for first travel. From the graph, the actuator pressure needed to close the valve for the first travel can be determined by using equation (8) and the total valve travel is calculated as in equation (9). The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated in Table 10.

Table 10: Actuator pressure needed per percentage of valve travel for baseline analysis (butterfly valve first travel)

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)
18.5	12	1.54

Figure 18 shows the graph of actuator pressure versus valve opening for second travel. From the graph, actuator pressure needed to open the valve for the second travel can be determined by using equation (8) and the total valve travel is calculated as in equation (9). The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated in Table 11.

Table 11: Average actuator pressure needed per percentage of valve travel for baseline analysis (butterfly valve second travel)

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)	Average actuator pressure needed per percentage of valve travel (psi/%)
18.4	12	1.53	1.54

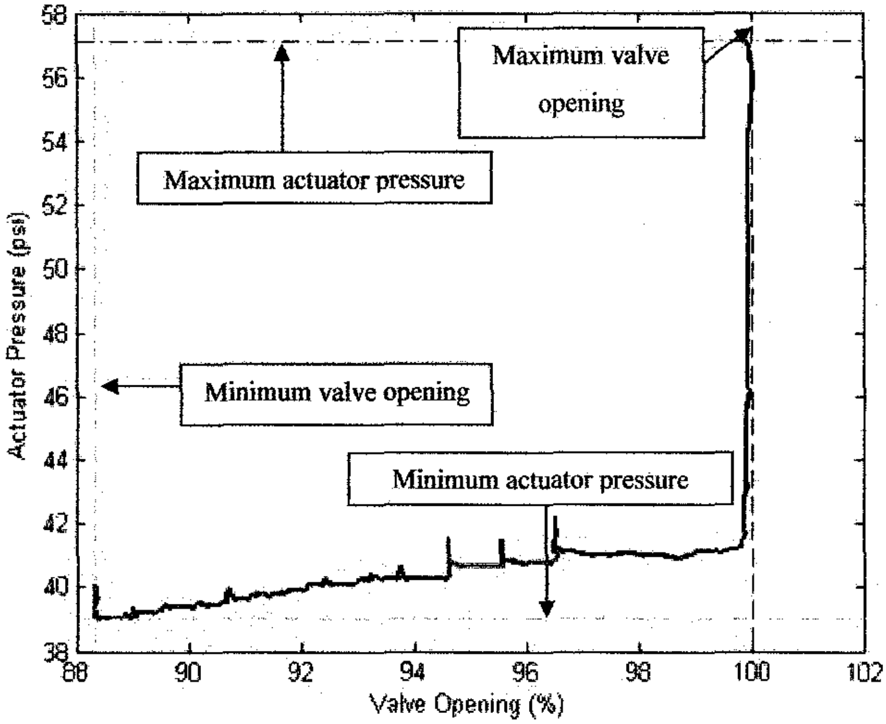


Figure 17: Graph of actuator pressure versus valve opening for first travel (butterfly valve).

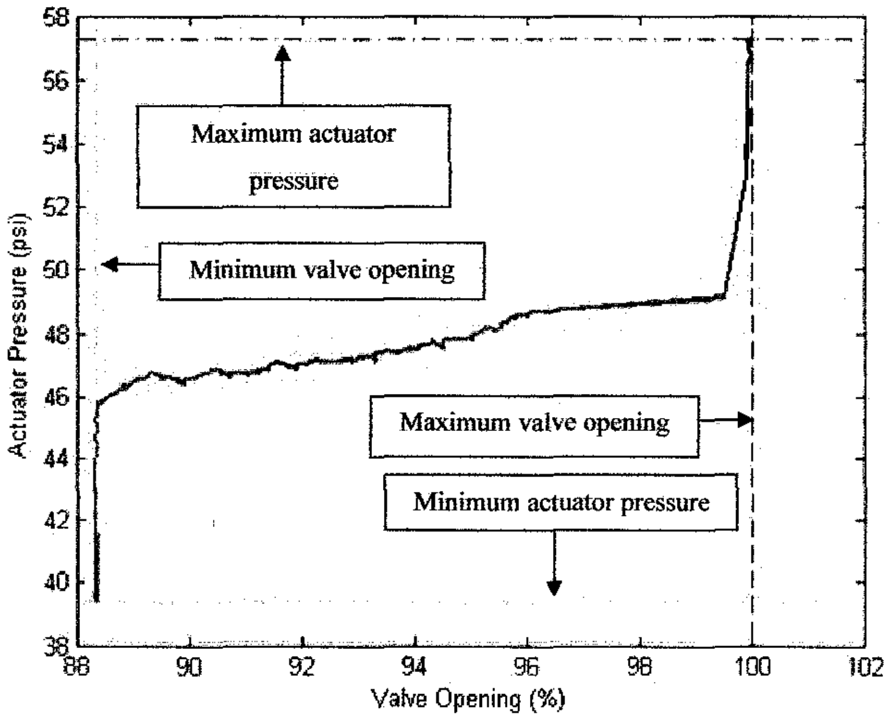


Figure 18: Graph of actuator pressure versus valve opening for second travel (butterfly valve).

4.1.3 Comparison between baseline and present PST data of ESDV.

4.1.3.1 Ball Valve Analysis based on Deadband and Friction Band

Figure 19 shows the ball valve signature of a successful PST executed. The y-axis represents actuator pressure in pounds per square inch and x-axis represents valve travel in degree. The valve is initially 100% open which is a normal opening for the emergency valve for normal operation and it is equivalent to 90 degrees. The valve is set to partially stroke until 80% which is about 72 degrees.

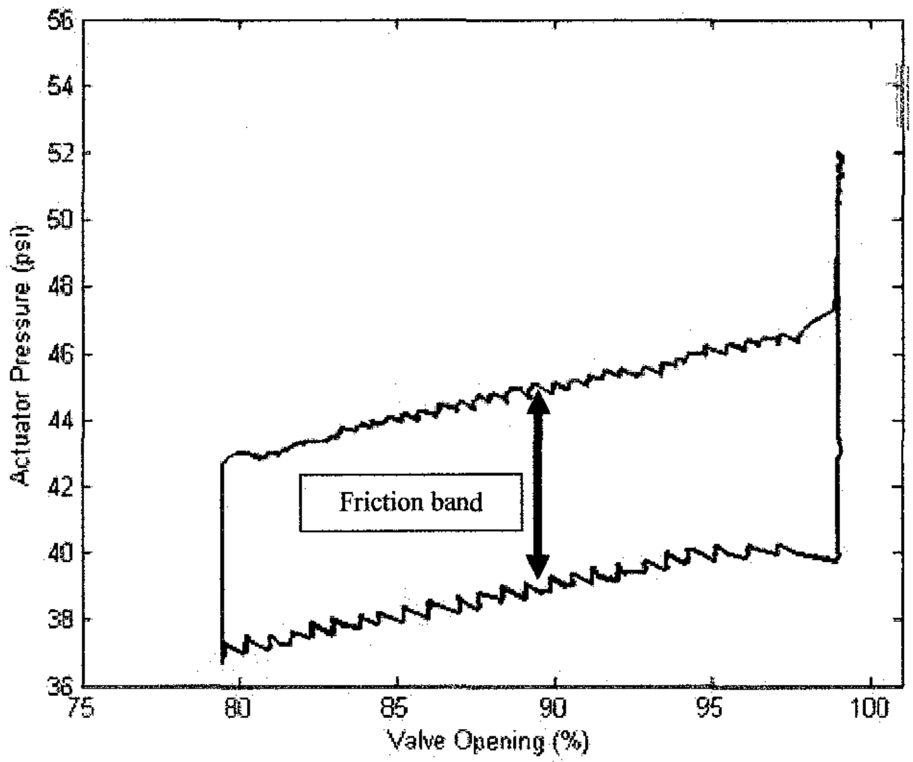


Figure 19: Valve signature for ball valve

The valve travels from 90 degrees to 72 degree when the valve is partially stroked. The actuator pressure drops from about 51.76 psi to 40 psi at 90 degree travel in order to move the stem. The actuator need to bleed out about 11.76 psi before the stem started to move. Therefore, the deadband is equals to 11.76 psi which is lesser than the baseline analysis, 12 psi. The percentage difference compared to baseline analysis is 2%. This is because the SOV had been removed causing less of actuator pressure needed to be released in order to make the valve move. The maximum travel (Test End Point) is set from the AMS Valvelink software and can be seen as in Table 12.

Table 12: PST information for ball valves

Test Start Point	100%
Test End Point	80%

For second travel which means the opening of the valve back to normal position, the pressure increased from 36.79 psi to 42.29 psi at 72 degree. Then the pressure is increased up until the valve travel reaches 90 degree. Based on Figure 20, the y-axis represents actuator pressure in pounds per square inch while x-axis represents travel in percentage. The maximum actuator pressure used for first travel of valve in performing PST is 52.05 psi and it is denoted by dark blue line while the minimum actuator pressure used is 36.79 psi and it is denoted by blue line.

Based on Figure 21, the y-axis represents actuator pressure in pounds per square inch while x-axis represents travel in percentage. The maximum actuator pressure used for second travel of valve in performing PST is 51.87 psi and it is denoted by dark blue line in Figure 21 while the minimum actuator pressure used is 36.7 psi and it is denoted by blue line.

Based on Figure 19, there is difference between actuator pressure for first travel and second travel although both travel the same distance. The difference between the red line (closing curve) and the blue line (opening curve) is the friction band. The friction band for baseline data is 5.90 psi. The percentage difference compared to the ball baseline friction band is 4.24%.

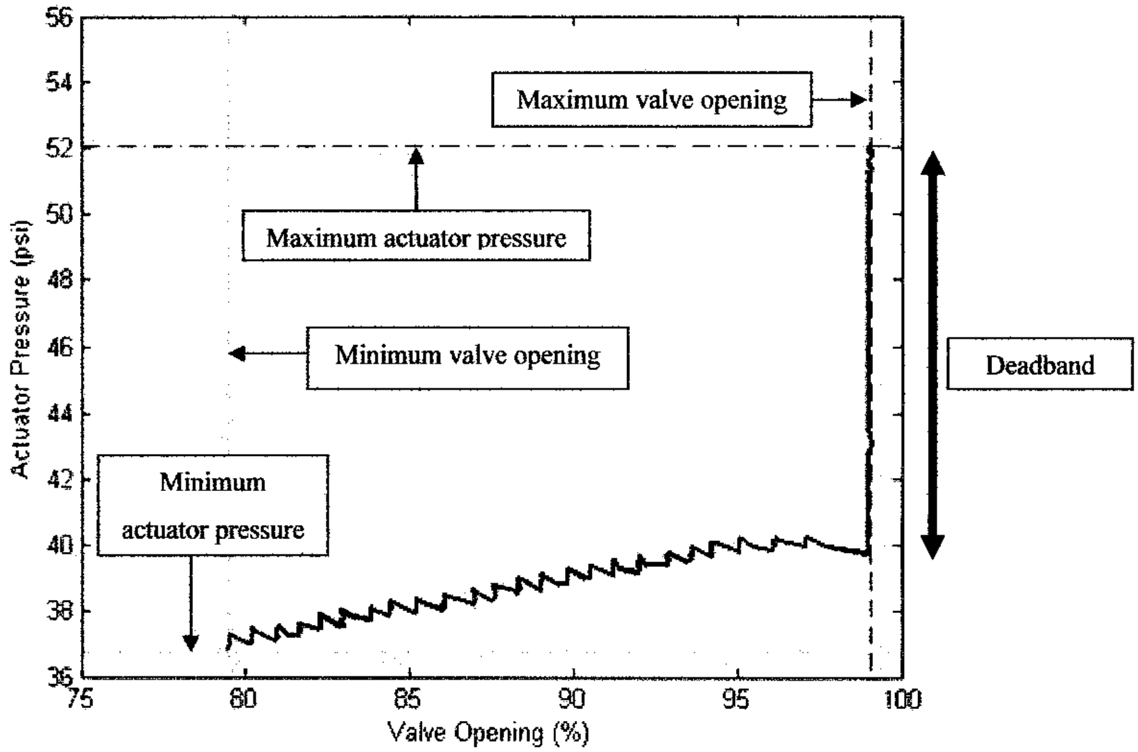


Figure 20: Valve signature for ball valve (first travel)

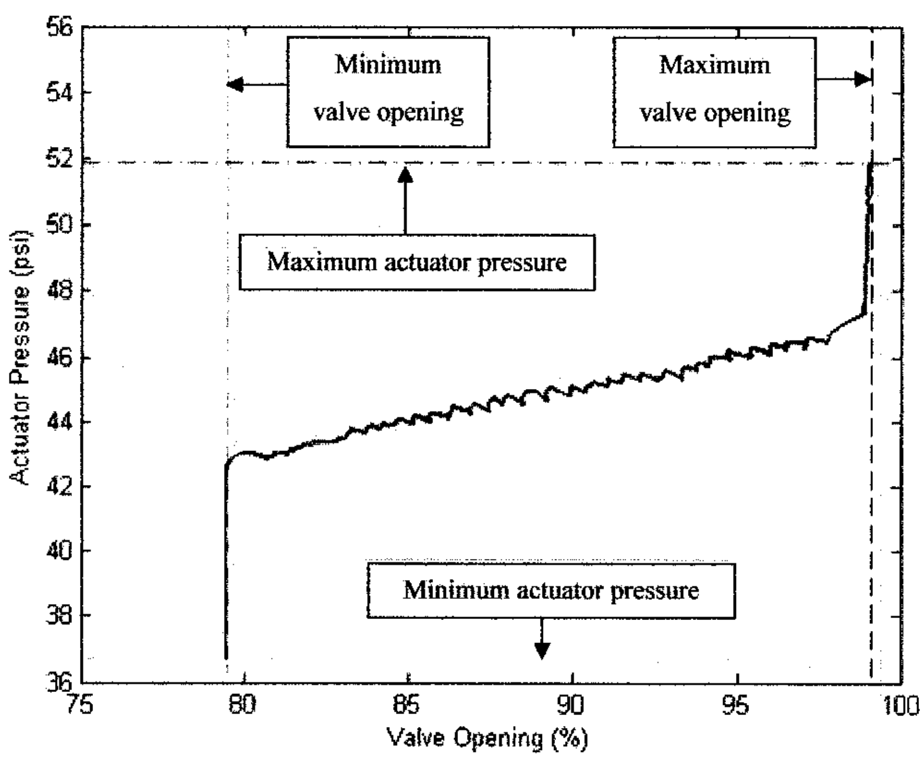


Figure 21: Valve signature for ball valve (second travel)

4.1.3.2 Ball Valve Analysis based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel

Figure 22 shows the graph of ball valve first travel versus time. The y-axis represents valve travel in percentage while the x-axis represents time taken for the valve to travel at certain percentage. From the graph, the time taken for the first travel to complete, the total valve travel and stroke rate of the valve can be determined. The results are tabulated in Table 13.

Table 13: Stroke rate of ball valve analysis (first travel)

Time taken for the first travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)
46	20	0.43

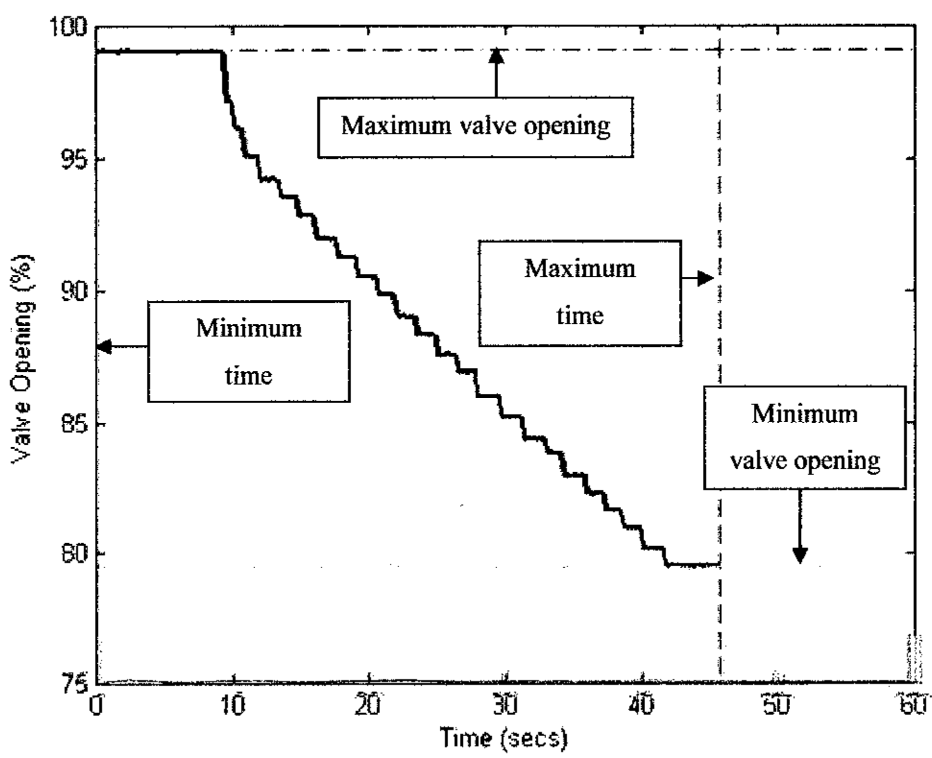


Figure 22: Graph of ball valve travel versus time for first travel of PST

Table 14: Average stroke rate of ball valve analysis

Time taken for the first travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)	Average Stroke Rate (%/s)
45.9	20	0.435	0.43

Figure 23 shows the graph of ball valve second travel versus time. From the graph, the time taken for the first travel to complete, the total valve travel and stroke rate of the valve can be determined and tabulated in Table 14. The overall stroke rate for present analysis is 0.43 %/s while the overall stroke rate for baseline analysis is 0.192 %/s. This shows that without SOV, the stroke rate is faster as there is less restriction.

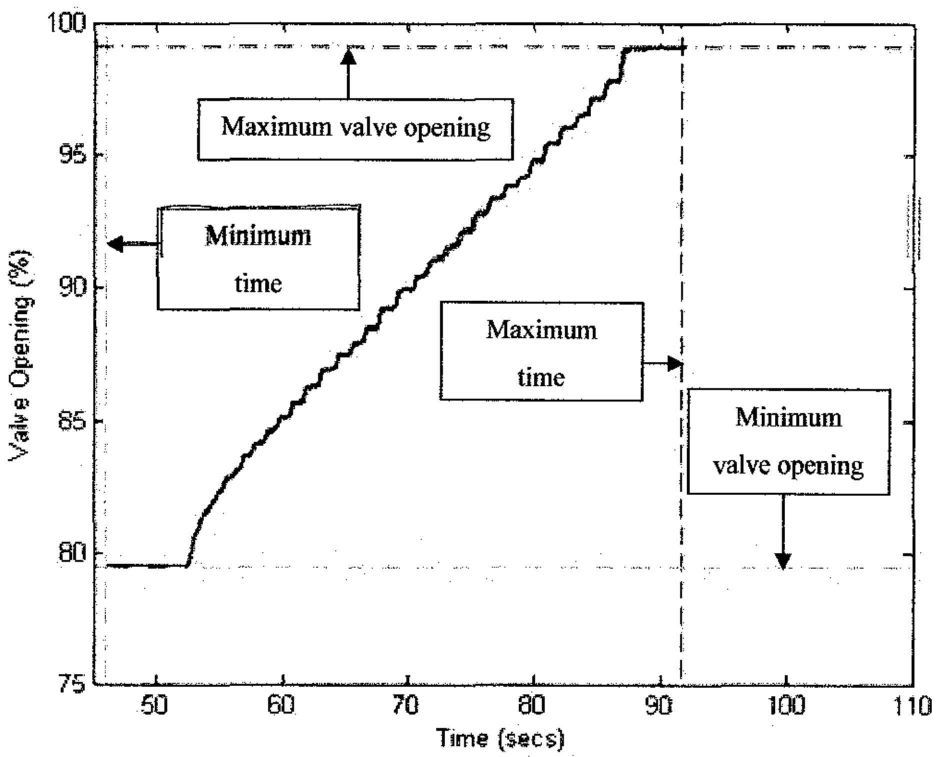


Figure 23: Graph of ball valve travel versus time for second travel of PST

Figure 24 shows the graph of ball valve actuator pressure versus valve opening for first travel. The x-axis represents valve opening in percentage while the y-axis represents actuator pressure needed to move a valve to certain percentage. From the graph, the actuator pressure needed to close the valve for the first travel and total valve travel can be determined. The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated in Table 15.

Table 15: Actuator pressure needed per percentage of valve travel for ball valve analysis (first travel)

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)
15.3	20	0.77

Figure 25 shows the graph of actuator pressure versus valve opening for second travel. From the graph, actuator pressure needed to open the valve for the second travel and the total valve travel can be determined. The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated as in Table 16. The overall actuator pressure needed per percentage of valve travel for present analysis is 0.77 psi/% while the overall actuator pressure needed per percentage of valve travel for baseline analysis is 1.46 psi/%. This shows that without SOV, the actuator pressure needed per percentage of valve travel is less as there is less restriction.

Table 16: Average actuator pressure needed per percentage of valve travel for ball valve analysis.

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)	Average actuator pressure needed per percentage of valve travel (psi/%)
15.2	20	0.76	0.77

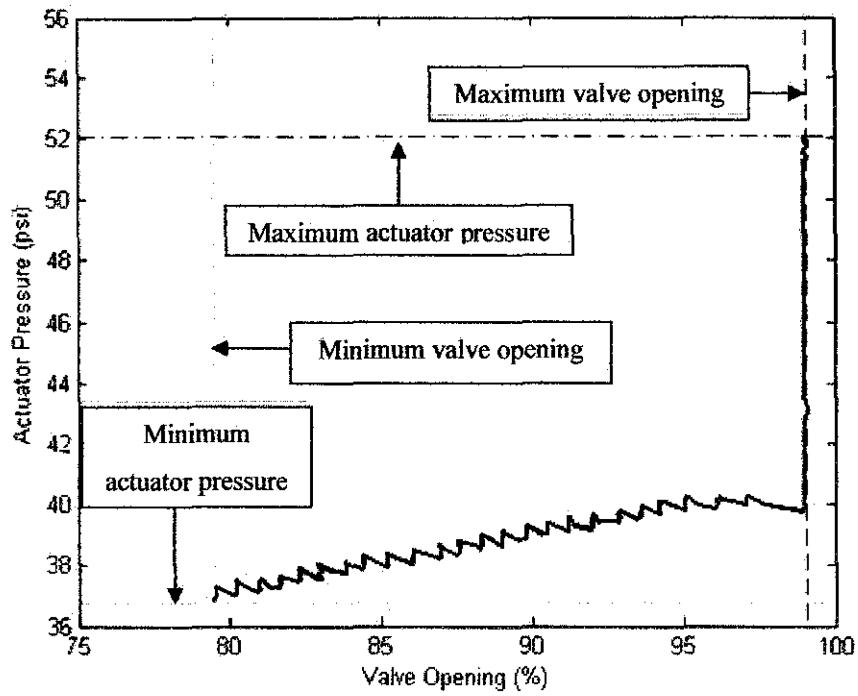


Figure 24: Graph of actuator pressure versus valve opening for first travel (ball valve)

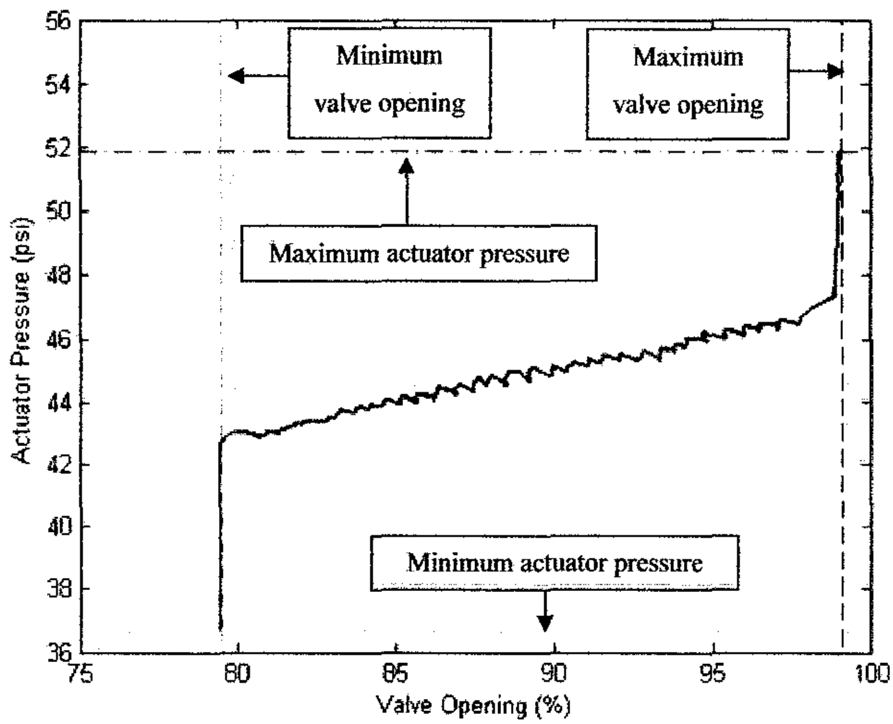


Figure 25: Graph of actuator pressure versus valve opening for second travel (ball valve)

4.1.3.3 Ball Valve Analysis based on Fuzzy Logic

Figure 26 (a) shows the graph of membership function based on friction band. From the graph, the degree of unhealthy friction band can be identified in order to determine the operational condition of the valve. The value zero of y-axis represents non-membership and the value one represents membership. The membership function is as the following:

Unhealthy friction band (x) =
{0.00, if friction band (x) < 6psi,
(friction band (x) – 6psi)/2, if 6psi < friction band (x) < 8psi,
1.00, if friction band (x) > 8psi}

Figure 26 (b) shows the graph of membership function based on deadband. From the graph, the degree of unhealthy deadband can be identified in order to determine the operational condition of the valve. The membership function is as the following:

Unhealthy deadband (x) =
{0.00, if deadband (x) < 12.5psi,
(deadband (x) – 12.5psi)/3, if 12.5psi < deadband (x) < 15.5psi,
1.00, if deadband (x) > 15.5psi}

Figure 26 (c) shows the combination of fuzzy subset friction band and deadband. The blue line indicates the graph of fuzzy subset for friction band while red region indicates the graph of fuzzy subset of deadband.

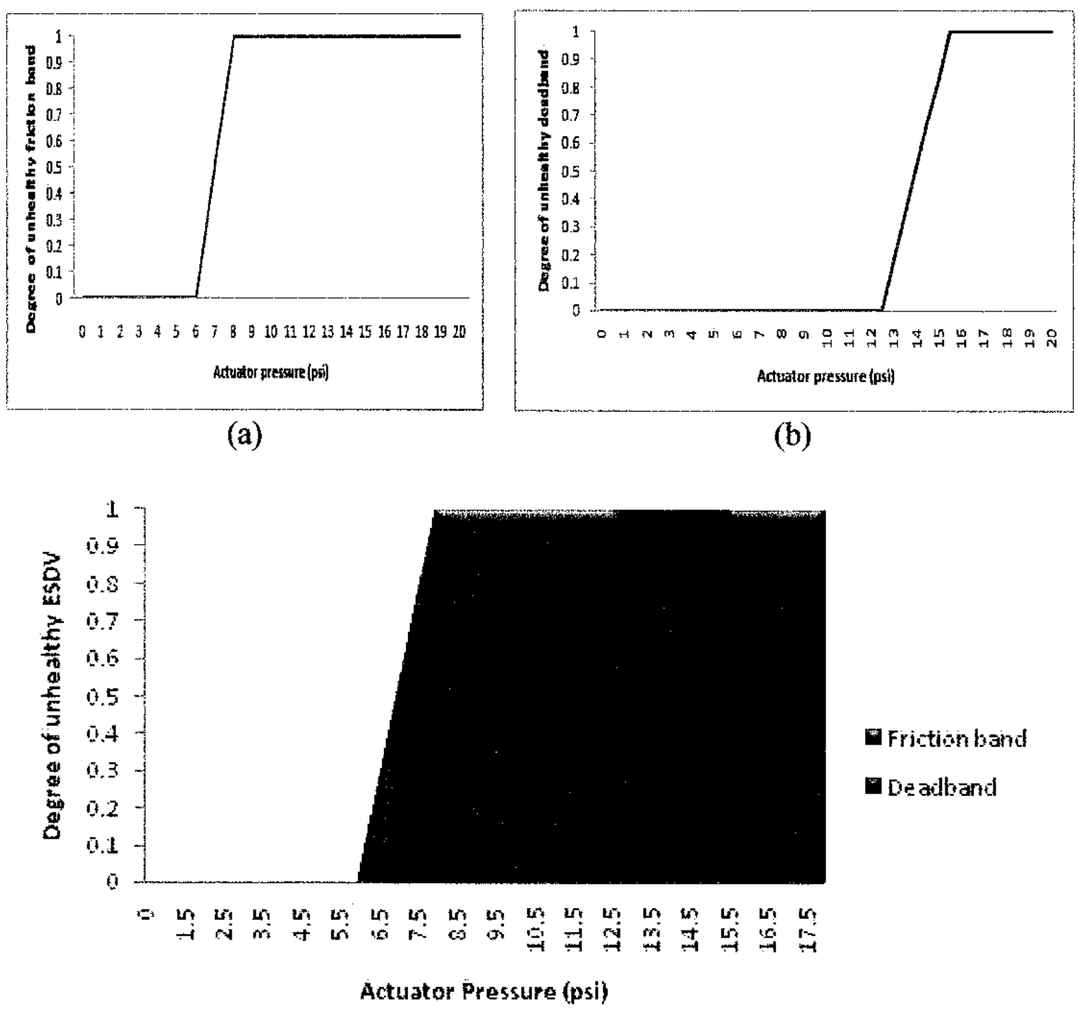
Let,
A= ESDV has unhealthy friction band and unhealthy deadband
B= ESDV has unhealthy friction band or unhealthy deadband.
C= not (ESDV has unhealthy friction band)
D= not (ESDV has unhealthy deadband)

If ESDV=A, it falls above 15.5 psi;

if ESDV=B, it falls above 15.5 psi or 8psi;

if ESDV=C, it falls below 8 psi;

And if ESDV=D, it falls below 15.5 psi.



(a) (b)

(c)

Figure 26: (a) Graph of membership function based on friction band, (b) Graph of membership function based on deadband, (c) Graph of combination of membership function based on deadband and friction band.

4.1.3.4 Butterfly Valve Analysis based on Deadband and Friction Band

Figure 27 shows the butterfly valve signature of a successful PST executed. The y-axis represents actuator pressure in pounds per square inch and x-axis represents valve travel in degree. The valve is initially 100% open which is equivalent to 90 degrees. The valve is set to partially stroke until 90% which is about 81 degrees. The maximum travel (Test End Point) is set from the AMS Valvelink software and can be seen as in Table 17.

Table 17: PST information for butterfly valve

Test Start Point	100%
Test End Point	90%

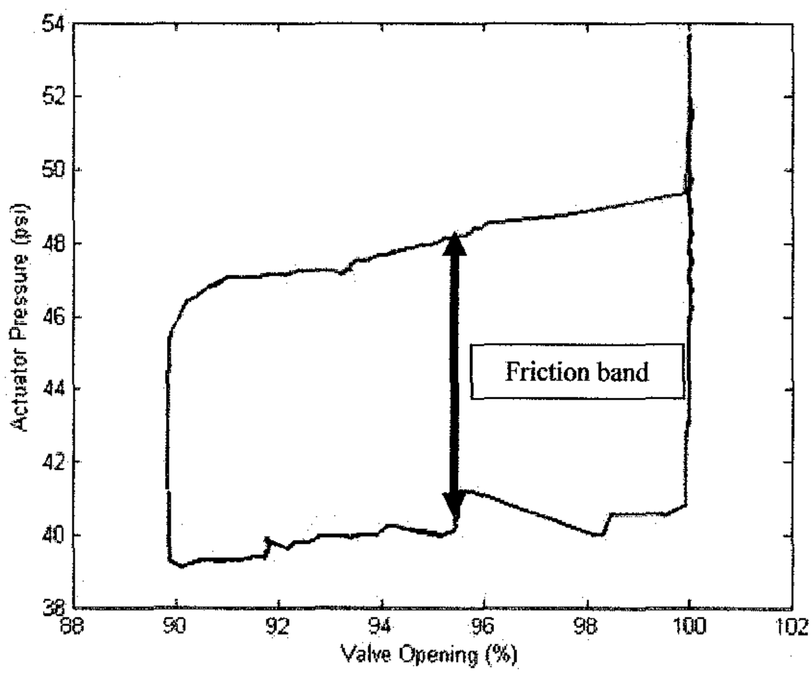


Figure 27: Valve signature for butterfly valve

The valve travels from 90 degrees to 81 degree when the valve is partially stroked. Based on Figure 28, the actuator pressure drops from 53.27 psi to 40 psi at 90 degree travel in order to move the stem. The actuator need to bleed out about 13.27 psi before the stem started to move. Therefore, the deadband is equals to 13.27 psi which is lesser than the baseline analysis, 16 psi. The percentage difference is equals to 17%.

For second travel which means the opening of the valve back to normal position, the pressure increased from 50.85 psi to 53.85 psi at 81 degree. Then the pressure is increased up until the valve travel reaches 90 degree. There are difference between actuator pressure for first travel and second travel although both travel the same distance. The difference between the red line (closing curve) and the blue line (opening curve) is the friction band which is equals to 7.35 psi. The friction band for baseline data is 7.13 psi. The percentage difference is equals to 3%. This is due to tightening the valve packing which cause more friction. Therefore, more actuator pressure needed to be released in order to make the valve move.

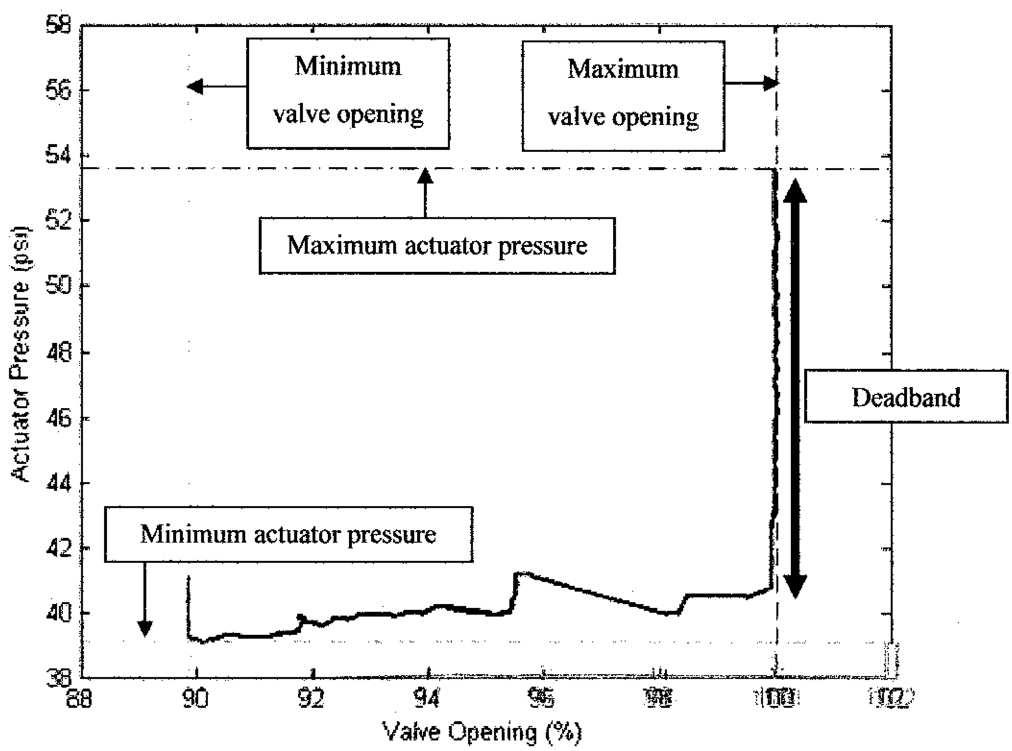


Figure 28: Valve signature for butterfly valve (first travel)

Based on Figure 28, the maximum actuator pressure used for first travel of valve in performing PST is 53.27 psi and it is denoted by dark blue line while the minimum actuator pressure used is 39.12 psi and it is denoted by blue line.

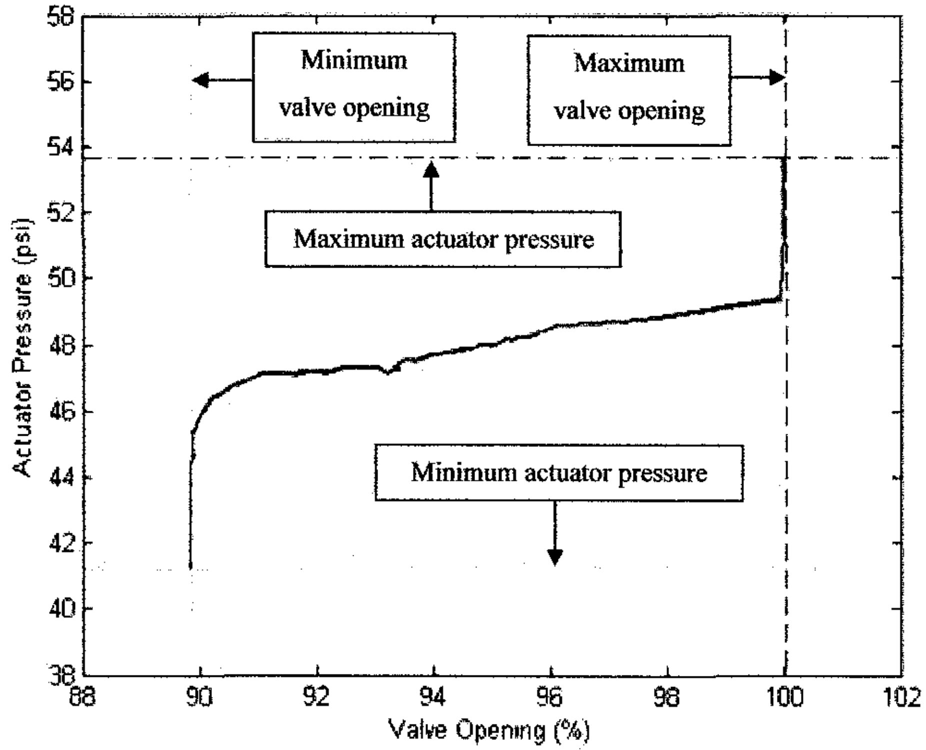


Figure 29: Valve signature for butterfly valve (second travel)

Based on Figure 29, the maximum actuator pressure used for second travel of valve in performing PST is 53.67 psi and it is denoted by dark blue line while the minimum actuator pressure used is 41.23 psi and it is denoted by blue line.

4.1.3.5 Butterfly Valve Analysis based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel

Figure 30 shows the graph of butterfly valve first travel versus time. The y-axis represents valve travel in percentage while the x-axis represents time taken for the valve to travel at certain percentage. From the graph, the time taken for the first travel to complete, the total valve travel and stroke rate of the valve can be determined. The results are tabulated in Table 18.

Table 18: Stroke rate of butterfly valve analysis (first travel)

Time taken for the first travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)
15	10.12	0.675

Table 19: Average stroke rate of butterfly valve analysis

Time taken for the first travel to complete (s)	Total valve travel (%)	Stroke rate (%/s)	Average Stroke Rate (%/s)
15	10.15	0.675	0.675

Figure 31 shows the graph of butterfly valve second travel versus time. From the graph, the time taken for the first travel to complete, the total valve travel and stroke rate of the valve can be determined. The results are tabulated in Table 19. The overall stroke rate for present data is 0.675%/s while the overall stroke rate for baseline data is 0.23%/s. The present stroke rate is faster than the baseline.

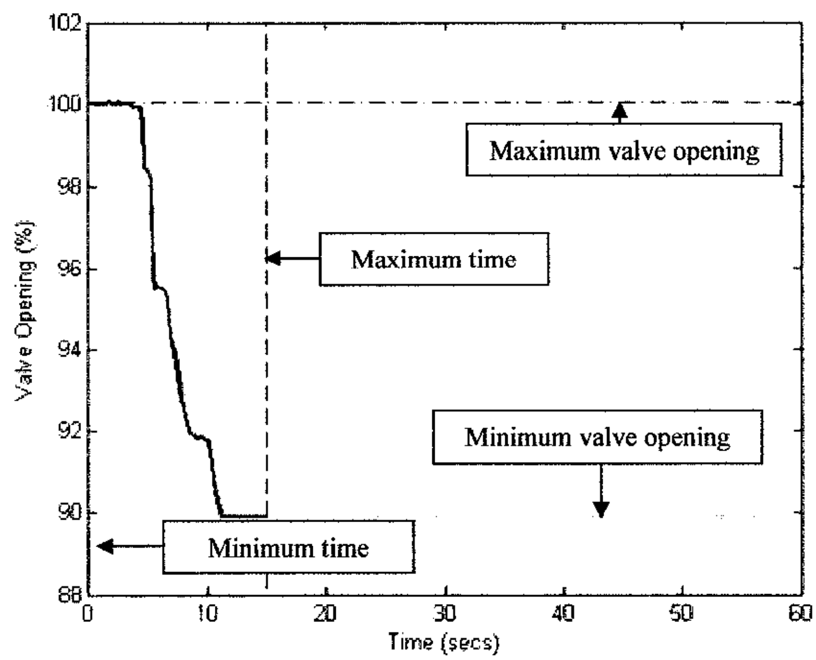


Figure 30: Graph of butterfly valve travel versus time for first travel of PST

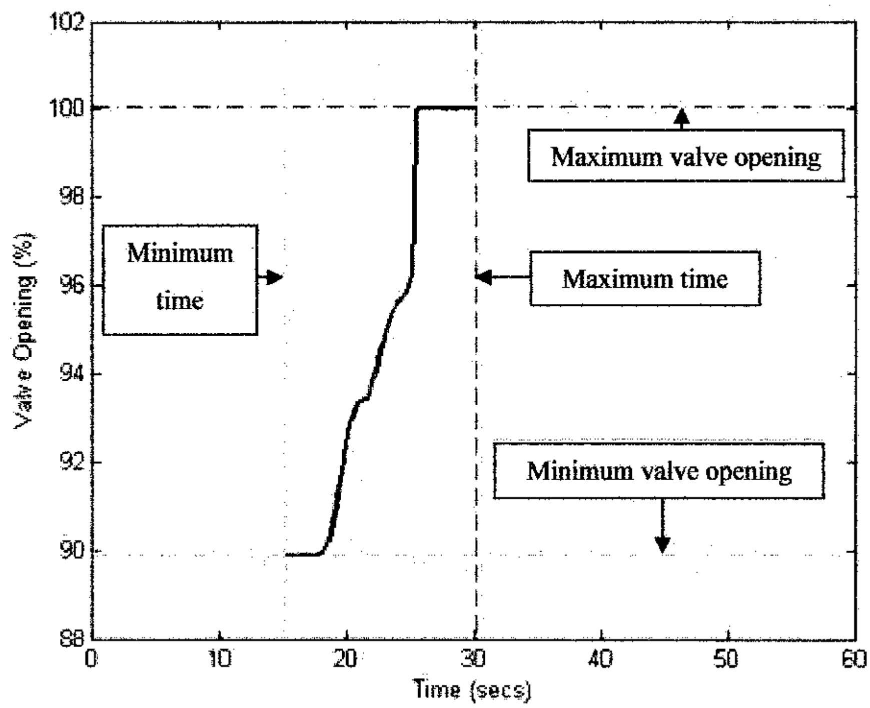


Figure 31: Graph of butterfly valve travel versus time for second travel of PST

Figure 32 shows the graph of butterfly valve actuator pressure versus valve opening for first travel. The x-axis represents valve opening in percentage while the y-axis represents actuator pressure needed to move a valve to certain percentage. From the graph, the actuator pressure needed to close the valve for the first travel and total valve travel can be determined. The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated in Table 20.

Table 20: Actuator pressure needed per percentage of valve travel for butterfly valve analysis (first travel)

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)
14.45	10.15	1.4

Figure 33 shows the graph of actuator pressure versus valve opening for second travel. From the graph, actuator pressure needed to open the valve for the second travel and the total valve travel can be determined. The actuator pressure needed per percentage of valve travel and average actuator pressure needed per percentage of valve travel can be determined by using equation (10) and (11) respectively. The results are tabulated as in Table 21. The overall actuator pressure needed per percentage of valve travel for present analysis is 1.32 psi/% while the overall actuator pressure needed per percentage of valve travel for baseline analysis is 1.54 psi/%.

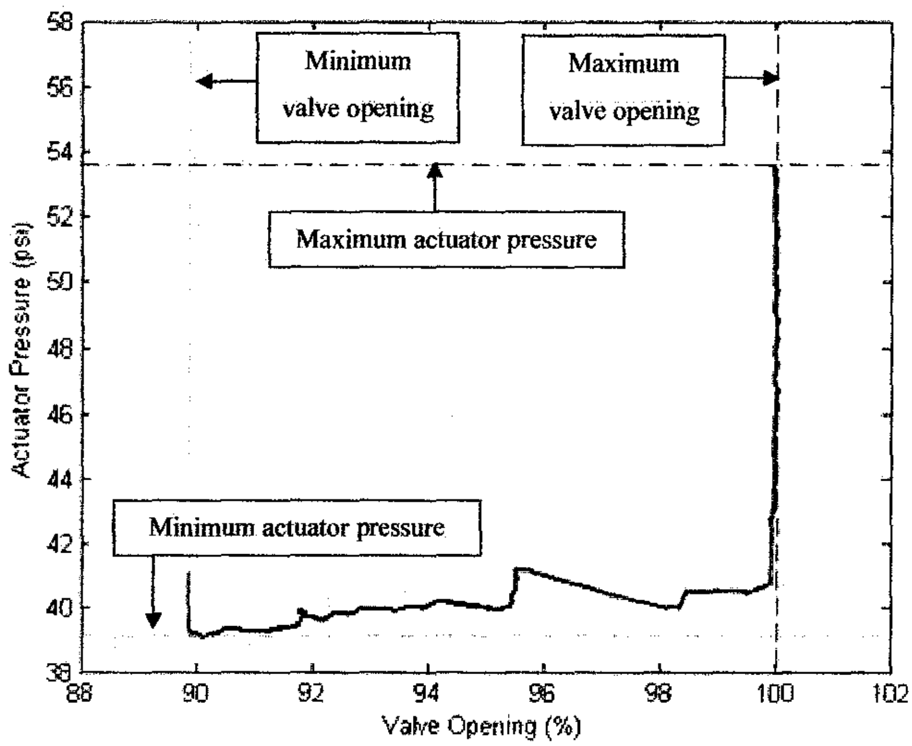


Figure 32: Graph of actuator pressure versus valve opening for first travel (butterfly valve)

Table 21: Average actuator pressure needed per percentage of valve travel for butterfly valve analysis.

Actuator pressure needed (psi)	Total valve travel (%)	Actuator pressure needed per percentage of valve travel (psi/%)	Average actuator pressure needed per percentage of valve travel (psi/%)
12.44	10.15	1.23	1.32

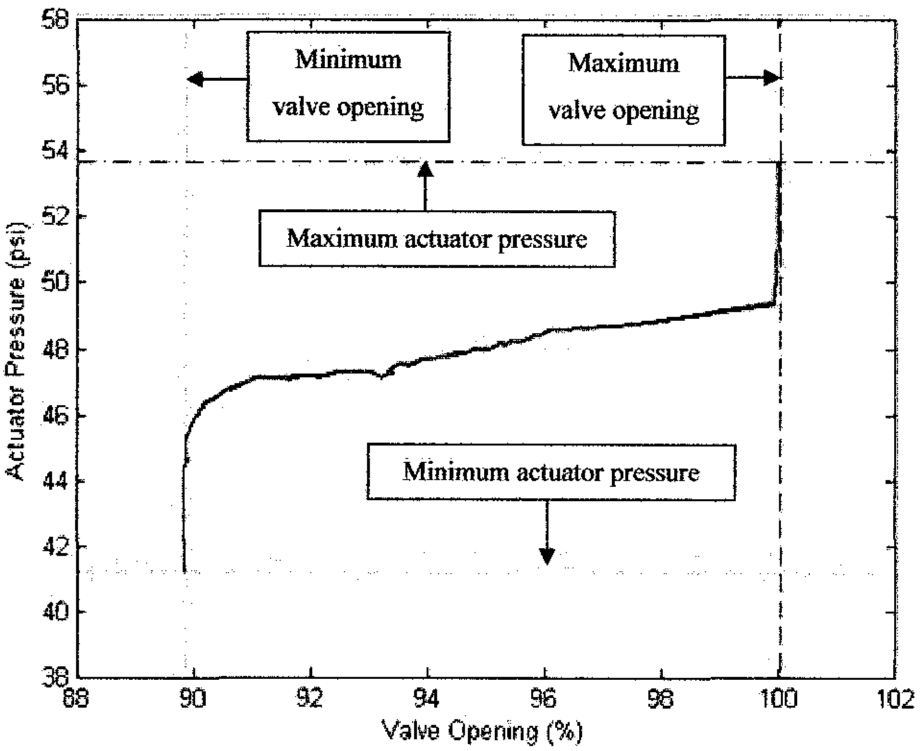


Figure 33: Graph of actuator pressure versus valve opening for second travel (butterfly valve)

4.1.3.6 Butterfly Valve Analysis Based on Fuzzy Logic

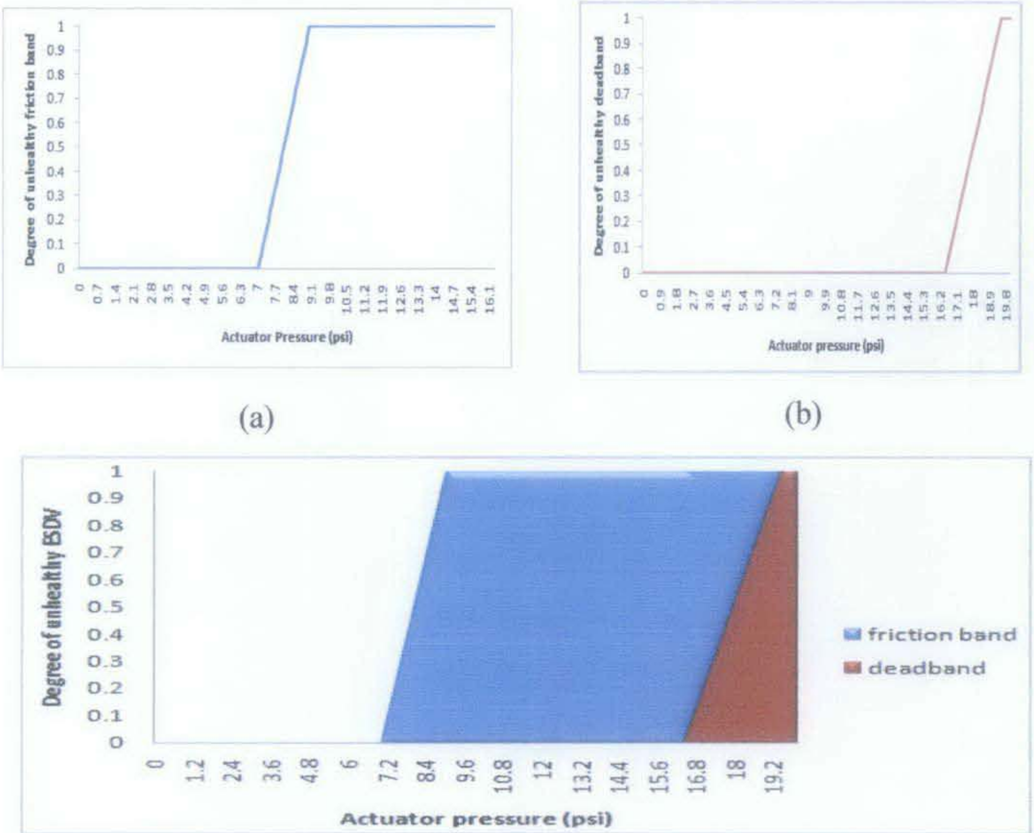
Figure 34 (a) shows the graph of membership function based on friction band. From the graph, the degree of unhealthy friction band can be identified in order to determine the operational condition of the valve. The value zero of y-axis represents non-membership and the value one represents membership. The membership function is as the following:

Unhealthy friction band (x) =
{0.00, if friction band (x) < 7.1psi,
(friction band (x) – 7.1psi)/2, if 7.1psi < friction band (x) < 9.1psi,
1.00, if friction band (x) > 9.1psi}

Figure 34 (b) shows the graph of membership function based on deadband. From the graph, the degree of unhealthy deadband can be identified in order to determine the operational condition of the valve. The membership function is as the following:

Unhealthy deadband (x) =
{0.00, if deadband (x) < 16.5 psi,
(deadband (x) – 16.5 psi)/3, if 16.5 psi < deadband (x) < 19.5 psi,
1.00, if deadband (x) > 19.5 psi}

Figure 34 (c) shows the combination of fuzzy subset friction band and deadband. The blue line indicates the graph of fuzzy subset for friction band while red region indicates the graph of fuzzy subset of deadband.



(c)

Figure 34: (a) Graph of membership function based on friction band, (b) Graph of membership function based on deadband, (c) Graph of combination of membership function based on deadband and friction band.

Let,

A= ESDV has unhealthy friction band and unhealthy deadband

B= ESDV has unhealthy friction band or unhealthy deadband.

C= not (ESDV has unhealthy friction band)

D= not (ESDV has unhealthy deadband)

If ESDV=A, it falls above 19.5 psi;

if ESDV=B, it falls above 19.5 psi or 9.1 psi;

if ESDV=C, it falls below 9.1 psi;

And if ESDV=D, it falls below 19.5 psi.

4.2 Valve Stiction Analysis User Interface

Figure 36 shows the GUI for offline analysis of ESDV stiction. The source code of developing this GUI is attached in Appendix II, III and IV. The function of this GUI is to do offline analysis of ESDV based on PST data. The GUI is started via Matlab. The steps to use the GUI are illustrated in Figure 35.

4.2.1 Data Export and Plotting

The procedure of data export and data plotting is elaborated in the following:

1) Enter date of analysis
2) Enter the tag number of respective ESDV.
3) Select baseline file and present file that to be analyzed.

- The buttons 'Select File' in Figure 36 are used to select excel file which contains data for baseline analysis and present analysis. Baseline analysis data is the data of healthy ESDV based on PST while present analysis data contain data of ESDV that to be analyzed the performance by comparing with baseline analysis data. By clicking the buttons, pop up window will appear where the user can select file name of excel file that will be used for baseline analysis and present analysis respectively. The filenames will appear in the text box next to the buttons 'Select File' in Figure 36.

4) Plot graph

- On the list menu in Figure 36, the user can select what graph to be plotted in order to compare the performances. There are five options of graph plotting which are Valve Signature, Valve Opening Vs Time (1^{st} Travel), Actuator Pressure Vs Valve Opening (1^{st} Travel), Valve Opening Vs Time (2^{nd} Travel) and Actuator Pressure Vs Valve Opening (2^{nd} Travel). In order to plot the graph, the user has to click 'Plot' buttons. By clicking the buttons, the graphs for baseline and present analysis will appear at axis 1 and axis 2 in the GUI. On axes 2, there will be two graphs plotted which are the baseline graph as well as the present graph. This is to do comparison between the two data.

4.2.2 Data Analysis

The procedure of data analysis is elaborated in the following:

1) Start analysis
- Start analysis by clicking button 'Analysis' as in Figure 36. A pop up window for analysis will appear.
2) Calculate deadband, friction band and stroke rate
- Click button 'Calculate' to display the deadband, friction band and stroke rate for baseline analysis and present analysis. The values will be displayed on the text boxes in Figure 37.
3) Click button 'Valve Stiction Setting' to set the upper and lower range value of deadband and friction band.
4) Click button 'Valve Stiction Status' to display the stiction status of the valve.

4.2.3 Valve Stiction Setting

- The user is able to set the lower and upper range of deadband and friction band. These values will be used to determine the tolerable range of the attributes.
- Procedure:

1) Enter lower range value and upper range value of deadband.
2) Enter lower range value and upper range value of friction band.
3) Click button "Enter".

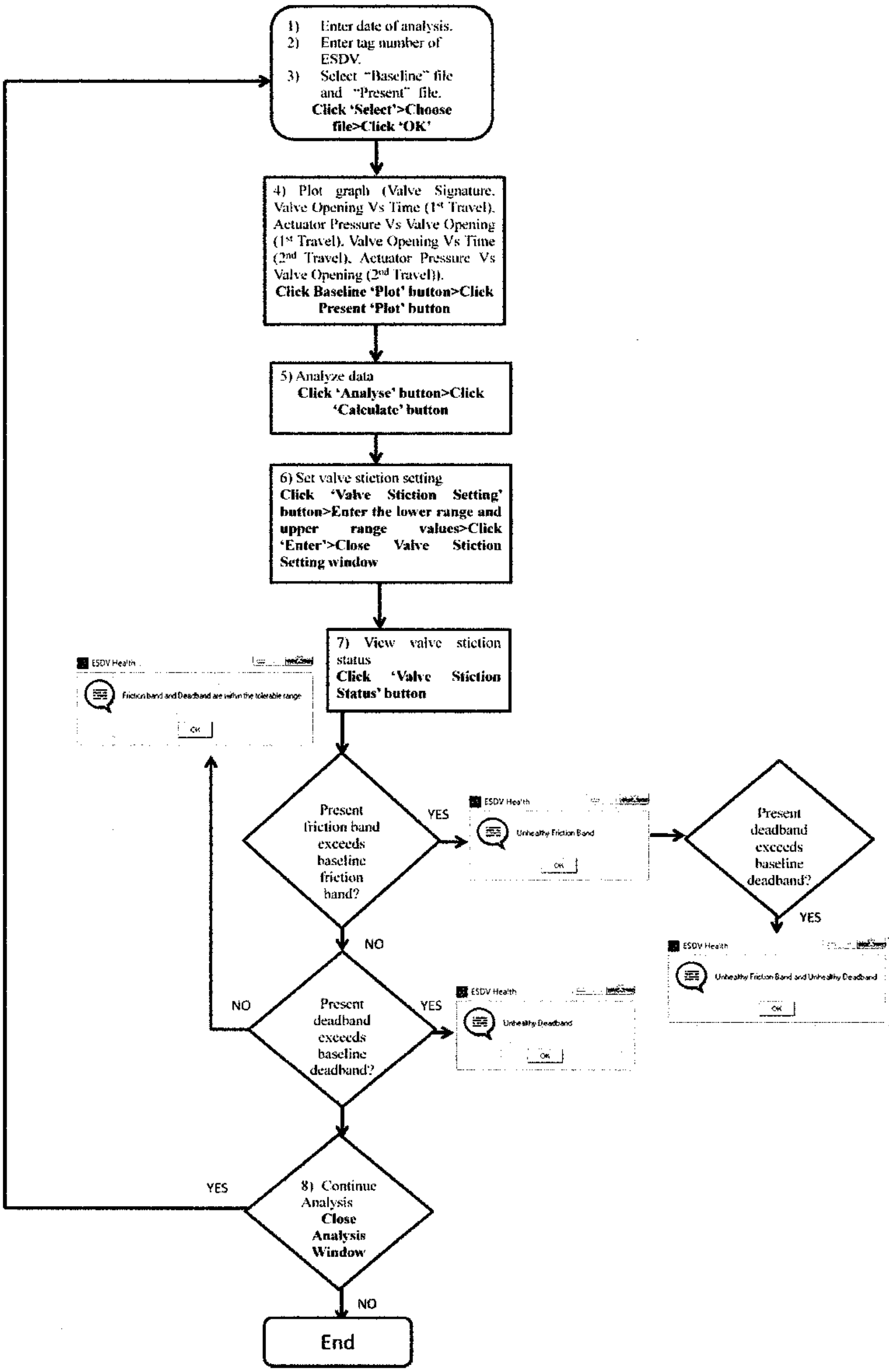


Figure 35: GUI flowchart

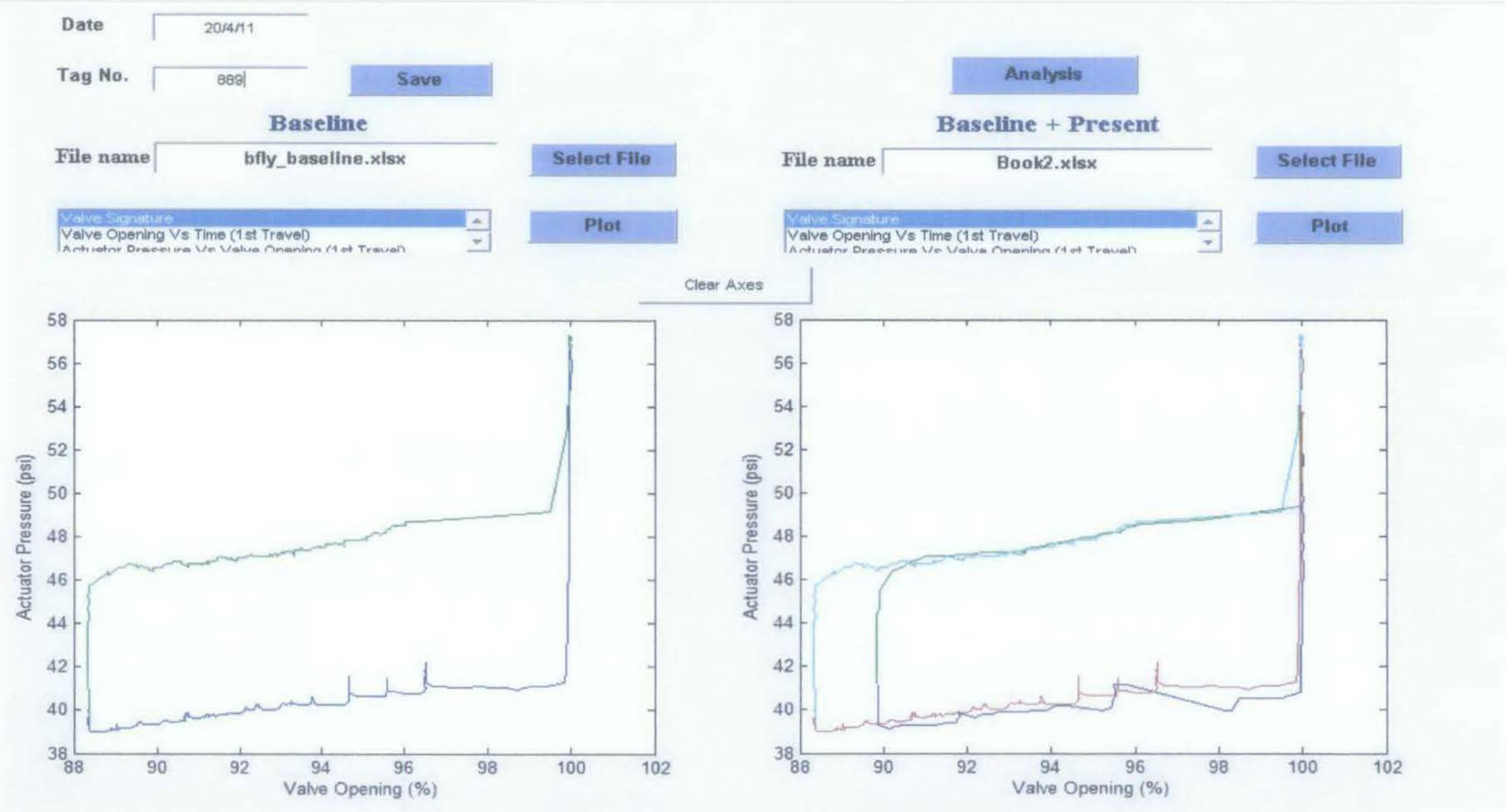


Figure 36: GUI for offline analysis

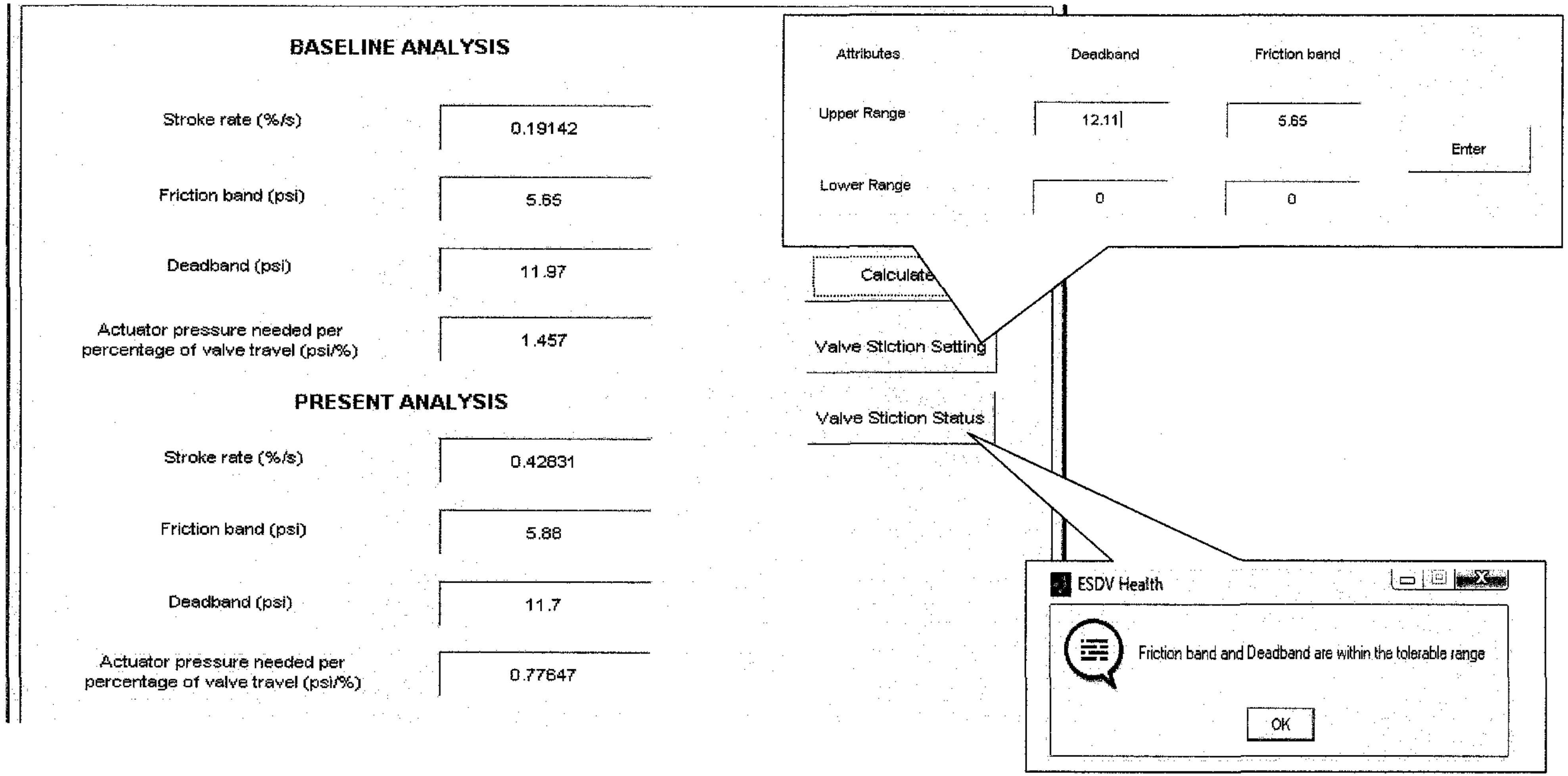


Figure 37: Analysis window

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The first objective of this project has been achieved as the baseline analysis of PST data has been done based on the data that are gathered on the first time PST is carried out on two types of valves which are ball valve and butterfly valve. The data that have been obtained are actuator pressure versus time and valve travel versus time. From all the data, the author has done calculations, data plotting and analyzed graph that have been plotted. The calculations and data plotting are done to carry out present analysis as well as to compare the set of data gained from the performance of PST with baseline analysis as elaborated in chapter 4. A fuzzy logic based on deadband as well as friction band has been developed. The fuzzy logic is developed in order to determine the operational condition of the valve. Apart from analysis, a GUI that can plot graphs, calculate potential attributes for both Baseline Analysis and Present Analysis and view the ESDV stiction status has been developed. Besides, the author is intended to submit a conference paper (attached in Appendix V) to IEEE Control and System Graduate Research Colloquium (ICSGRC 2011).

1.2 RECOMMENDATION

The following recommendations are made to improve the problems faced while working on this project. First is to solve the problem regarding the test rig available in UTP in order to allow more testing on both ESDVs. Second is to improve the GUI features by adding significant application such as alarm and generate report and last but not least is to compare several data from PST by using statistical analysis such as box plot, median, mean and standard deviation.

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APPENDIX I

GANTT CHART FOR FYPII

			JAN	FEB				MAR				APR				MAY	
No.	Task Name	Duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	PST analysis using AMS Valvelink Software and Matlab 7.1	1 week	■														
2	Developing GUI for PST offline analysis.	12 weeks	■	■	■	■	■	■	■	■	■	■	■	■			
3	Prepare Technical report and abstract	3 weeks				■	■	■									
4	PST analysis using fuzzy logic	12 weeks	■	■	■	■	■	■	■	■	■	■	■	■			
5	Progress Report Submission	1 day								●							
6	Draft Report Submission	1 day													●		
7	Final Report & Technical Report Submission	1 day													●		
8	Viva	1 day														●	
9	Final Report Submission	1 day															●

APPENDIX II

MATLAB SOURCE CODE FOR MAIN GUI

```
function varargout = select_axes1(varargin)

gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @select_axes_OpeningFcn, ...
                   'gui_OutputFcn',  @select_axes_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% --- Executes just before select_axes is made visible.
function select_axes_OpeningFcn(hObject, eventdata, handles, varargin)

% Choose default command line output for select_axes
handles.output = hObject;
set(hObject,'toolbar','figure');
% Update handles structure
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = select_axes_OutputFcn(hObject, eventdata, handles)

% Get default command line output from handles structure
varargout{1} = handles.output;

function edit1_Callback(hObject, eventdata, handles)
filename=get(handles.edit1,'string');

function edit2_Callback(hObject, eventdata, handles)
filename1=get(handles.edit2,'string');

% --- Executes on button press in pbSelect.
function pbSelect_Callback(hObject, eventdata, handles)
[filename,pathname]=uigetfile('*.xlsx');
set(handles.edit1,'string',filename)
edit1_Callback(hObject,eventdata,handles)
save mydata.mat filename

% --- Executes on button press in pbSelect1.
function pbSelect1_Callback(hObject, eventdata, handles)
[filename1,pathname1]=uigetfile('*.xlsx');
set(handles.edit2,'string',filename1)
edit2_Callback(hObject,eventdata,handles)
save mydata1.mat filename1

% --- Executes during object creation, after setting all properties.
function popupmenu_CreateFcn(hObject, eventdata, handles)
if ispc
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

set(hObject, 'String', {'Valve Signature', 'Valve Opening Vs Time (1st Travel)', 'Actuator Pressure Vs Valve Opening (1st
Travel)', 'Valve Opening Vs Time (2nd Travel)', 'Actuator Pressure Vs Valve Opening (2nd Travel)'});

function popupmenu1_Callback(hObject, eventdata, handles)
```

```
% --- Executes during object creation, after setting all properties.
function popupmenu1_CreateFcn(hObject, eventdata, handles)
if ispc
   set(hObject,'BackgroundColor','white');
else
   set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

set(hObject, 'String', {'Valve Signature', 'Valve Opening Vs Time (1st Travel)', 'Actuator Pressure Vs Valve Opening (1st
Travel)', 'Valve Opening Vs Time (2nd Travel)', 'Actuator Pressure Vs Valve Opening (2nd Travel)'});

% --- Executes on button press in pushbutton.
function pushbutton_Callback(hObject, eventdata, handles)

axes(handles.axes1);
cla reset;


load mydata.mat
popup_sel_index = get(handles.popupmenu, 'Value');
switch popup_sel_index
   case 1

 BV = xlsread (filename);
p1=BV(:,4);
p2=BV(:,9);
first=BV(:,2);
second=BV(:,7);
t1=BV(:,5);
t2=BV(:,10);
      plot(first,p1,second,p2);
      xlabel({'Valve Opening (%)'});
      ylabel({'Actuator Pressure (psi)'});
     save mydata2.mat BV
   case 2
     BV = xlsread (filename);
p1=BV(:,4);
p2=BV(:,9);
first=BV(:,2);
second=BV(:,7);
t1=BV(:,5);
t2=BV(:,10);
      plot(t1,first);
       xlabel({'Time (secs)'});
      ylabel({'Valve Opening (%)'})
      save mydata2.mat BV
   case 3
     BV = xlsread (filename);
p1=BV(:,4);
p2=BV(:,9);
first=BV(:,2);
second=BV(:,7);
t1=BV(:,5);
t2=BV(:,10);
      plot(first,p1);
      xlabel({'Valve Opening (%)'});
      ylabel({'Actuator Pressure (psi)'});

      save mydata2.mat BV
   case 4
      BV = xlsread (filename);
p1=BV(:,4);
p2=BV(:,9);
first=BV(:,2);
second=BV(:,7);
t1=BV(:,5);
t2=BV(:,10);
      plot(t2,second);
      xlabel({'Time (secs)'});
      ylabel({'Valve Opening (%)'})
      save mydata2.mat BV
```

```
     case 5
      BV = xlsread (filename);
p1=BV(:,4);
p2=BV(:,9);
first=BV(:,2);
second=BV(:,7);
t1=BV(:,5);
t2=BV(:,10);
      plot(second,p2);
      xlabel({'Valve Opening (%)'});
      ylabel({'Actuator Pressure (psi)'});
      save mydata2.mat BV
   end

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)

axes(handles.axes2);
cla reset;
load mydata.mat
load mydata1.mat
popup_sel_index = get(handles.popupmenu1, 'Value');
switch popup_sel_index
   case 1
      B=xlsread(filename);
       BV1 = xlsread (filename1);
      p_1=B(:,4);
p_2=B(:,9);
first_=B(:,2);
second_=B(:,7);
t1_=B(:,5);
t2_=B(:,10);
p1=BV1(:,4);
p2=BV1(:,9);
first=BV1(:,2);
second=BV1(:,7);
t1=BV1(:,5);
t2=BV1(:,10);
      plot(first,p1,second,p2,first_,p_1,second_,p_2);
       xlabel({'Valve Opening (%)'});
      ylabel({'Actuator Pressure (psi)'})
 save mydata3.mat BV1
   case 2
      B=xlsread(filename);
        BV1 = xlsread (filename1);
        p_1=B(:,4);
p_2=B(:,9);
first_=B(:,2);
second_=B(:,7);
t1_=B(:,5);
t2_=B(:,10);
p1=BV1(:,4);
p2=BV1(:,9);
first=BV1(:,2);
second=BV1(:,7);
t1=BV1(:,5);
t2=BV1(:,10);
       plot(t1,first,t1_,first_);
         xlabel({'Time (secs)'});
      ylabel({'Valve Opening (%)'})
        save mydata3.mat BV1

   case 3
           B=xlsread(filename);
      BV1 = xlsread (filename1);
      p_1=B(:,4);
p_2=B(:,9);
first_=B(:,2);
second_=B(:,7);
t1_=B(:,5);
t2_=B(:,10);
p1=BV1(:,4);
```

```
p2=BV1(:,9);
first=BV1(:,2);
second=BV1(:,7);
t1=BV1(:,5);
t2=BV1(:,10);
      plot(first,p1,first_,p_1);
      xlabel({'Valve Opening (%)'});
      ylabel({'Actuator Pressure (psi)'});
       save mydata3.mat BV1

   case 4
      B=xlsread(filename);
      BV1 = xlsread (filename1);
      p_1=B(:,4);
p_2=B(:,9);
first_=B(:,2);
second_=B(:,7);
t1_=B(:,5);
t2_=B(:,10);
p1=BV1(:,4);
p2=BV1(:,9);
first=BV1(:,2);
second=BV1(:,7);
t1=BV1(:,5);
t2=BV1(:,10);
      plot(t2,second,t2_,second_);
       xlabel({'Time (secs)'});
      ylabel({'Valve Opening (%)'})
       save mydata3.mat BV1
            case 5
               B=xlsread(filename);
       BV1 = xlsread (filename1);
       p_1=B(:,4);
p_2=B(:,9);
first_=B(:,2);
second_=B(:,7);
t1_=B(:,5);
t2_=B(:,10);
p1=BV1(:,4);
p2=BV1(:,9);
first=BV1(:,2);
second=BV1(:,7);
t1=BV1(:,5);
t2=BV1(:,10);
      plot(second,p2,second_,p_2);
      xlabel({'Valve Opening (%)'});
      ylabel({'Actuator Pressure (psi)'});
       save mydata3.mat BV1
end

% --- Executes on button press in pushbutton20.
function pushbutton20_Callback(hObject, eventdata, handles)
Analysis

function edit14_Callback(hObject, eventdata, handles)
user_string = str2double(get(hObject,'string'))
save mydata21.mat user_string

% --- Executes during object creation, after setting all properties.
function edit14_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in pushbutton21.
function pushbutton21_Callback(hObject, eventdata, handles)
load mydata31.mat
load mydata32.mat
load mydata33.mat
load mydata34.mat
load mydata21.mat
```

```
load mydatadate.mat
 a=parameter2_2;
 b=parameter;
 c=BAvgequation;
 d=Avgequation;
 e=user_string;
 f=date;
 g={'date','Tag No.','Baseline friciton band','Present friciton band', 'Baseline stroke rate', 'Present stroke rate';f,e,a,b,c,d};
xlswrite('Test22data.xlsx',g,1,'E5')

function edit15_Callback(hObject, eventdata, handles)
date = str2double(get(hObject,'string'))
save mydatadate.mat date

% --- Executes during object creation, after setting all properties.
function edit15_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in pushbutton24.
function pushbutton24_Callback(hObject, eventdata, handles)
cla reset
```

APPENDIX III

MATLAB SOURCE CODE FOR ANALYSIS WINDOW

```
function varargout = analysis(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
               'gui_Singleton',  gui_Singleton, ...
               'gui_OpeningFcn', @analysis_OpeningFcn, ...
               'gui_OutputFcn',  @analysis_OutputFcn, ...
               'gui_LayoutFcn',  [] , ...
               'gui_Callback',   []);
if nargin && ischar(varargin{1})
   gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
   [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
   gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before analysis is made visible.
function analysis_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = analysis_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;


% --- Executes on button press in pushbutton2.
function pushbutton2_Callback(hObject, eventdata, handles)
load mydatahighdeadband.mat
load mydatahighfrictionband.mat
load mydatalowdeadband.mat
load mydatalowfrictionband.mat

load mydatadeadbandpresent.mat
load mydataparameter2_2.mat
lfricband=low_frictionband
ldeband=low_deadband
hfricband=high_frictionband
hdeband=high_deadband
fricband=parameter2_2
deband=deadbandpresent

if ((fricband>hfricband)&& (deband>hdeband))
        helpdlg('Unhealthy Friction Band and Unhealthy Deadband','Valve Health')

else if (fricband>hfricband)
   helpdlg('Unhealthy Friction Band','Valve Health')

else if (deband>hdeband)
 helpdlg('Unhealthy Deadband','Valve Health')

else if ((lfricband<fricband<hfricband) && (ldeband<deband<hdeband))
   helpdlg('Friction band and deadband are within the tolerable range','ESDV Health')
        end
end
end
end


% --- Executes on button press in pushbutton3.
```

```
function pushbutton3_Callback(hObject, eventdata, handles)

% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
tolerable_range

% --- Executes on button press in pushbutton5.
function pushbutton5_Callback(hObject, eventdata, handles)
load mydata2.mat
load mydata3.mat
p1=BV(:,4);
p2=BV(:,9);
p_1=BV1(:,4);
p_2=BV1(:,9);
x=[p1,p2];
y=[p_1,p_2];
param=median (x)
param2=median(y)
parameter1=param(:,1)
parameter2=param(:,2)
parameter_1=param2(:,1)
parameter_2=param2(:,2)
parameter=parameter2-parameter1
parameter2_2=parameter_2-parameter_1
parameter_in_string=num2str (parameter);
parameter2_2_in_string=num2str (parameter2_2);

set(handles.edit1,'string',parameter_in_string)
set(handles.edit2,'string',parameter2_2_in_string)
save mydataparameter2_2.mat parameter2_2
edit1_Callback(hObject,eventdata,handles)
edit2_Callback(hObject,eventdata,handles)

load mydata1.mat
load mydata3.mat

Bp1=BV1(:,4);
Bp2=BV1(:,9);
Bfirst=BV1(:,2);
Bsecond=BV1(:,7);
Bt1=BV1(:,5);
Bt2=BV1(:,10);
Bmaximum=max(Bfirst);
Bminimum=min(Bfirst);
Btime_max=max(Bt1);
Btime_min=min(Bt1);
Btime=Btime_max-Btime_min;
Bequation=(Bmaximum-Bminimum)/Btime;

B2maximum=max(Bsecond);
B2minimum=min(Bsecond);
B2time_max=max(Bt2);
B2time_min=min(Bt2);
B2time=B2time_max-B2time_min;
B2equation=(B2maximum-B2minimum)/B2time;

BAvgequation=(Bequation+B2equation)/2;
eq_in_string1=num2str (BAvgequation);
save mydata33.mat  BAvgequation

set(handles.edit5,'string',eq_in_string1)
edit3_Callback(hObject,eventdata,handles)

load mydata.mat
load mydata2.mat

p1=BV(:,4);
p2=BV(:,9);
first=BV(:,2);
second=BV(:,7);
t1=BV(:,5);
t2=BV(:,10);
```

```
maximum=max(first);
minimum=min(first);
time_max=max(t1);
time_min=min(t1);
time=time_max-time_min;
equation=(maximum-minimum)/time;

maximum2=max(second);
minimum2=min(second);
time_max2=max(t2);
time_min2=min(t2);
time2=time_max2-time_min2;
equation2=(maximum2-minimum2)/time2;

Avgequation=(equation+equation2)/2;
 save mydata34.mat  Avgequation
 eq_in_string=num2str (Avgequation);
 set(handles.edit3,'string',eq_in_string)

 i=10;
while (BV(i+1,2)>max (BV(:,2))-1)
i=i+1;
end
i=i+1
B1=BV(i+1,4)
deadbandbaseline = BV(1,4)-BV(i+1,4)
save mydatadeadbandbaseline.mat deadbandbaseline
deadband_in_string=num2str(deadbandbaseline);

set (handles.edit4,'string',deadband_in_string)
 j=10;
while (BV1(j+1,2)>max (BV1(:,2))-1)
j=j+1;
end
j=j+1
B=BV1(j+1,4)
deadbandpresent = BV1(1,4)-BV1(j+1,4)
save mydatadeadbandpresent.mat deadbandpresent
deadbandpresent_in_string=num2str(deadbandpresent);
 set (handles.edit6,'string',deadbandpresent_in_string)
 edit5_Callback(hObject,eventdata,handles)

function edit1_Callback(hObject, eventdata, handles)
w=get(handles.edit1,'string');

% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit2_Callback(hObject, eventdata, handles)
w_1=get(handles.edit2,'string');

% --- Executes during object creation, after setting all properties.
function edit2_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit3_Callback(hObject, eventdata, handles)
strokerate1=get(handles.edit3,'string');

% --- Executes during object creation, after setting all properties.
function edit3_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
 function edit4_Callback(hObject, eventdata, handles)
deadbandbaseline=get (handles.edit4,'string');

% --- Executes during object creation, after setting all properties.
```

```
function edit4_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end



function edit5_Callback(hObject, eventdata, handles)
strokerate2=get(handles.edit5,'string');


% --- Executes during object creation, after setting all properties.
function edit5_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end



function edit6_Callback(hObject, eventdata, handles)
deadbandpresent=get (handles.edit6,'string');

% --- Executes during object creation, after setting all properties.
function edit6_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
```

APPENDIX IV

MATLAB SOURCE CODE FOR VALVE STICTION SETTING WINDOW

```
function varargout = tolerable_range(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
               'gui_Singleton',  gui_Singleton, ...
               'gui_OpeningFcn', @tolerable_range_OpeningFcn, ...
               'gui_OutputFcn',  @tolerable_range_OutputFcn, ...
               'gui_LayoutFcn',  [] , ...
               'gui_Callback',   []);
if nargin && ischar(varargin{1})
   gui_State.gui_Callback = str2func(varargin{1});
end
 if nargout
   [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
   gui_mainfcn(gui_State, varargin{:});
end

% --- Executes just before tolerable_range is made visible.
function tolerable_range_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
guidata(hObject, handles);

function varargout = tolerable_range_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;

function edit1_Callback(hObject, eventdata, handles)
load mydatahighdeadband.mat
high_deadband = str2double(get(hObject,'string'))
save mydatahighdeadband.mat high_deadband

% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit5_Callback(hObject, eventdata, handles)
high_frictionband = str2double(get(hObject,'string'))
save mydatahighfrictionband.mat high_frictionband

% --- Executes during object creation, after setting all properties.
function edit5_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

 function edit7_Callback(hObject, eventdata, handles)
low_deadband = str2double(get(hObject,'string'))
save mydatalowdeadband.mat low_deadband

 % --- Executes during object creation, after setting all properties.
function edit7_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

 function edit8_Callback(hObject, eventdata, handles)
low_frictionband = str2double(get(hObject,'string'))
save mydatalowfrictionband.mat low_frictionband
 % --- Executes during object creation, after setting all properties.
function edit8_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
```

Stiction Analysis of Emergency Shutdown Valve Based on Partial Stroke Test (PST)

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***act—* This paper presents an analysis on the stiction of rgency Shutdown Valve (ESDV) based on data gathered Partial Stroke Test (PST) software. It is meant to ›lement the existing software used to perform PST. ently, most of the PST software does not provide offline /sis. Therefore, this project is intended to do extensive ıe analysis based on available operational data. The on analysis is done based on test rig at Universiti ıologi PETRONAS which used ball and butterfly valves. analysis comprises Baseline Analysis, Present Analysis, Comparison of Baseline Analysis and Present Analysis. step of the analysis is to determine the baseline whereby PST's data on both valves are gathered. Next step is to do /sis on present data which will be compared with the ine analysis in order to detect any unconformity of the :.**

'ords-emergency shutdown valve; valve stiction; deadband; on band

1. INTRODUCTION

PST is a very useful method of detecting possible s of ESDV. If certain ESDV are used infrequently h it will open or close only during emergency tions of the plant, this will result in increase of friction it may become stuck. Long experience has shown that lves are not exercised, they can stick in one position The friction which is caused of corrosion or increasing ıstation of the plug stem is one of the failure modes of V. If the friction increases, usually the safety valve will vorks if emergency event happens and when the ability alve operating is urgently needed. To disallow this ınction, a PST in defined time intervals is required. objective of this project is to analyze the stiction of V based on data gathered from PST software. The /sis comprises Baseline Analysis, Present Analysis, Comparison of Baseline Analysis and Present Analysis. analysis on PST data can be done based on relationship ctuator pressure versus valve travel and actuator ıure versus time. There are four attributes that are ı into consideration; deadband, friction band, stroke and actuator pressure needed per percentage of valve l. Apart from analysis, Graphical User Interface (GUI) ›veloped in order to produce suitable interface for ıe analysis of ESDVs. By doing calculations and ing graphs, the valve stiction status of ESDVs can be mined.

2. APPROACHES AND METHODS

2.1 *Analysis Methodology*

In this project, the stiction analysis is done on two different ESDVs which are ball and butterfly valve. The analysis consists of three parts which are baseline analysis, present analysis and comparison of baseline analysis and present analysis.

2.1.1 *Baseline Analysis*

This analysis is based on the data that are gathered on the first time the PST is carried out on both ball and butterfly type of ESDVs. The data that are gathered from this analysis will be used as a baseline to be compared with present data of PST.

2.1.2 *Present Analysis*

This analysis is based on the data that are gathered after removing the solenoid valve (SOV) that connects the digital valve controller output to the actuator of ball valve. While for butterfly valve, the analysis is done based on the data of PST carried out after the valve packing is tightened in order to observe the effect on the stiction of the valve.

2.1.3 *Comparison of Baseline Analysis and Present Analysis*

The values of potential attributes (deadband, friction band, actuator pressure needed per percentage of valve travel and stroke rate) from Baseline Analysis are compared with the values of potential attributes that are obtained from the Present Analysis.

2.2 *Methodology of Determining The Value of Potential Attributes*

2.2.1 *Stroke Rate*

One of the potential attributes to analyze ESDV's stiction is the stroke rate of the valves. It is proportional to the valve travel and inversely proportional to the time taken for valve stem to move (stroke time). Stroke rate can be determined by manipulating the percentage of valve travel and time taken for it to travel. Equation (1), (2), (3) and (4) will give the result of stroke rate for the respective valve.

$$t_1 = t_2 = t_{max} - t_{min} \quad (1)$$

$$s_1 = s_2 = s_{max} - s_{min} \quad (2)$$

$$\text{Stroke Rate 1} = \text{Stroke Rate 2} = \frac{s}{t} \quad (3)$$

$$\text{erage Stroke Rate (\%/s)} = \frac{\text{Stroke Rate 1} + \text{Stroke Rate2}}{2} \quad (4)$$

:e;

= total time taken for the first travel to complete in seconds
= total time taken for the second travel to complete in seconds
= maximum time
= minimum time
= total valve travel for the first travel in percentage
= total valve travel for the second travel in percentage
= maximum travel
= minimum travel

: *Friction Band*

Friction band is used to analyze the stiction of ESDV. relationship of friction band with the amount of friction at the higher the friction the wider the separation. Since ion always apposes movement, the net spread of these is actually double the friction. The main source of ion on a good valve is the valve packing. Valve packing :rials that have a high coefficient of friction, such as hite, will produce a greater amount of friction and thus ider friction band then the low coefficient materials, as PTFE [4]. The friction band can be determined :tly from the valve signature (refer Fig. III) by rving separation of the first travel and second travel. :ion band is measured in pounds per square inch (psi).

Deadband

Another potential attribute that is manipulated to yze the stiction of ESDV is deadband. Deadband is the e through which an input can be varied without iting observable response. There are separate and nct input-output relationships for increasing and easing signals [5]. Deadband of the valves can be rmined by referring to the valve signature as in Fig. III. lband is the amount of actuator pressure in psi needed e exhausted to move the valve stem from its initial tion. Deadband can increase due to the increase in the ional force as a result of blocking the actuator vent .

Actuator Pressure Needed per Percentage of valve Travel

Another potential attributes for ESDV stiction is the ator pressure needed per percentage of valve travel. It be determined by manipulating the value of actuator sure and percentage of valve travel. Equation (5), (6), nd (8) will give the result of actuator pressure needed percentage of valve travel for the respective valve. The ator pressure needed per percentage of valve travel for line analysis is then compared with the present analysis.

$$p_1 = p_2 = p_{max} - p_{min} \quad (5)$$

$$s_1 = s_2 = s_{max} - s_{min} \quad (6)$$

$$A1 = A2 = \frac{p}{s} \quad (7)$$

$$\text{Average actuator pressure needed per percentage of valve travel (psi/\%)} = \frac{A1 + A2}{2} \quad (8)$$

where;

p_1 = total pressure needed to move the valve for the first travel in psi
p_2 = total pressure needed to move the valve for the second travel in psi
p_{max} = maximum pressure
p_{min} = minimum pressure
s_1 = total valve travel for the first travel in percentage
s_2 = total valve travel for the second travel in percentage
s_{max} = maximum travel
s_{min} = minimum travel
A1 = Actuator pressure needed per percentage of valve travel for first travel
A2 = Actuator pressure needed per percentage of valve travel for second travel

3. Results and Discussions

3.1 *Valve Stiction Analysis User Interface*

A GUI has been developed to assist user in determining the ESDV stiction status. Fig. I and Fig. II shows the GUI for offline analysis of ESDV stiction. The function of this GUI is to do offline analysis of ESDV based on PST data. This GUI is able to plot graphs, calculate friction band, deadband and stroke rate for both baseline and present data as well as to display the stiction status of ESDV.

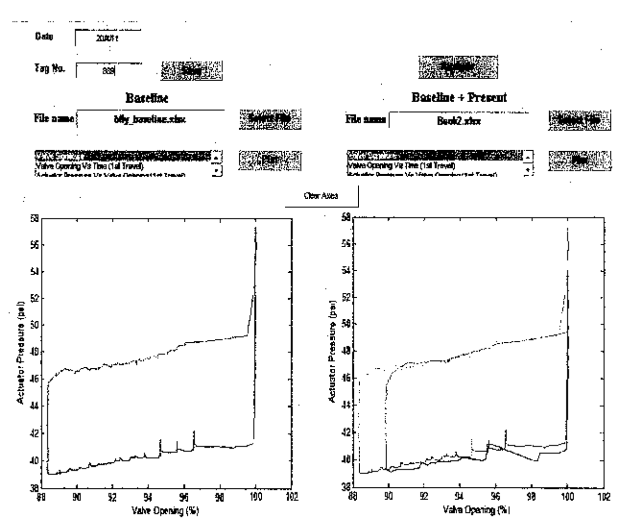


Figure I: GUI for offline analysis.

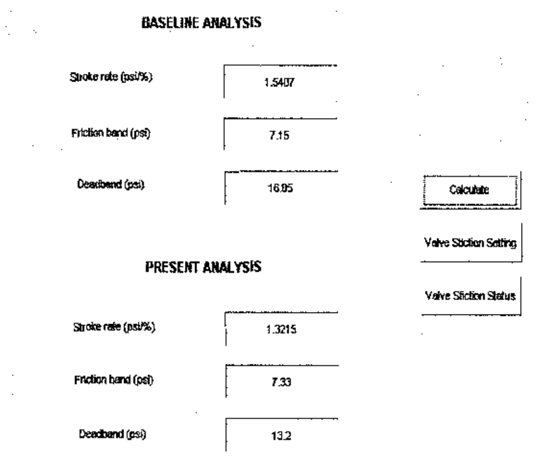


Figure II: Analysis window.

Ball Valve

Baseline Analysis of PST Based on Deadband and Friction Band

This analysis is based on the data that are gathered on irst time the PST is carried out on the ESDV. The data are gathered from this analysis will be used as a line to be compared with future data of PST. Fig. III /s the ball valve signature of a successful PST uted. The y-axis represents actuator pressure in pounds square inch and x-axis represents valve travel in entage. The valve is initially 100% (90 degree) open h is a normal opening for the emergency valve for ial operation and the valve is set to partially stroke 90% (81 degree). The results for deadband and friction of ball valve baseline analysis are tabulated in Table I.

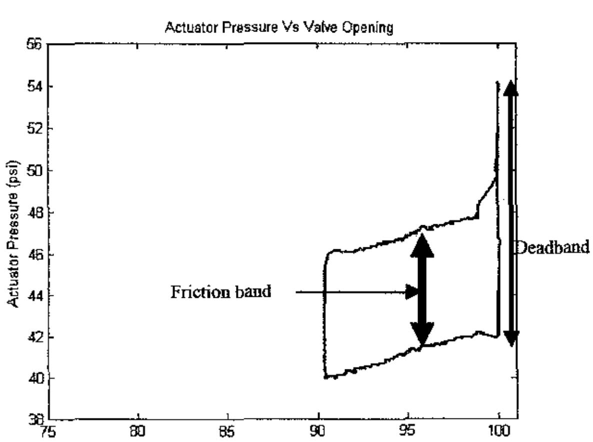


Figure III: Baseline valve signature for ball valve.

Baseline Analysis of PST Based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel

Based on the graph valve opening versus time as in IV and Fig. V, the average stroke rate can be mined by equations (1), (2), (3) and (4). Based on Fig. he average actuator pressure needed per percentage of valve travel can be obtained using equations (5), (6), (7) and (8). The results on stroke rate and actuator pressure needed per percentage of valve travel are tabulated in Table I.

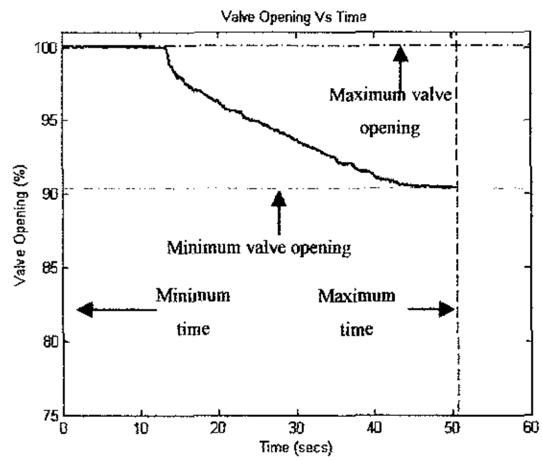


Figure IV: Graph of ball valve opening versus time for first travel of PST.

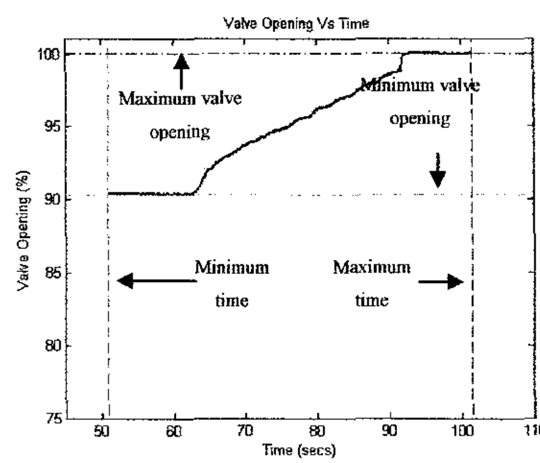


Figure V: Graph of ball valve opening versus time for second travel of PST.

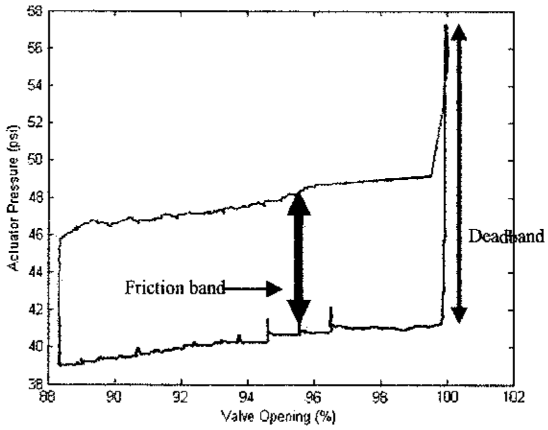
Table I: Baseline analysis result.

Attributes	Ball Valve	Butterfly Valve
Deadband (psi)	12	16
Friction band (psi)	5.66	7.13
Average stroke rate (%/s)	0.192	0.23
Average actuator pressure needed per percentage of valve travel (psi/%)	1.46	1.54

3.3 *Butterfly Valve*

3.3.1 *Baseline Analysis of PST Based on Deadband and Friction Band*

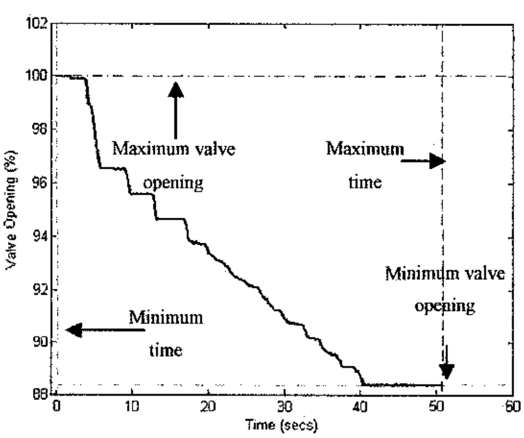
Fig. VI shows the butterfly valve signature of a successful PST executed. The valve is initially 100% open which is a normal opening for the emergency valve for ıal operation and it is equivalent to 90 degrees. The e is set to partially stroke until 88% which is about 79 ees. The results for deadband and friction band of ›rfly valve baseline analysis are tabulated in Table I.



gure VI: Baseline valve signature for butterfly valve.

: Baseline Analysis of PST Based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel

Based on the graph valve opening versus time for ›rfly valve (as illustrated in Fig. VII and Fig. VIII), the age stroke rate can be determined using equations (1), (3) and (4). While, based on graph actuator pressure us valve opening, the average actuator pressure needed ›ercentage of valve travel can be obtained by equations (6), (7) and (8). The results on stroke rate and actuator sure needed per percentage of valve travel are tabulated ıble I.



ŗure VII: Graph of butterfly valve opening versus time for first travel of PST.

Comparison Between Baseline and Present PST Data of ESDV

Ball Valve Analysis Based on Deadband and Friction Band

The deadband is equals to 11.76 psi which is lesser the baseline analysis, 12 psi. This is because the SOV been removed causing less of actuator pressure needed e exhausted in order to make the valve move. The friction band for present data is 5.90 psi. The percentage difference compared to the ball baseline friction band is 4.24%.

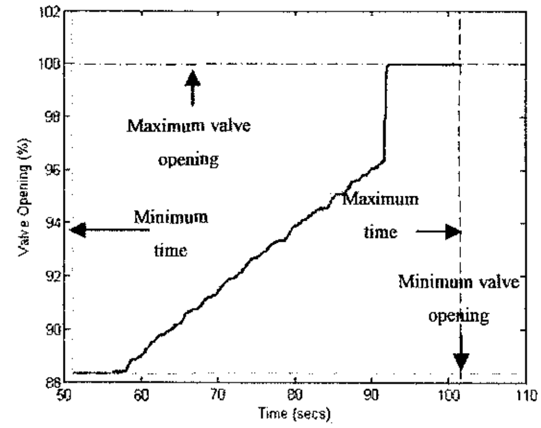


Figure VIII: Graph of butterfly valve opening versus time for second travel of PST.

3.3.5 *Ball Valve Analysis Based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel*

The average stroke rate for present analysis is 0.43%/s while the average stroke rate for baseline analysis is 0.192%/s. This shows that without SOV, the stroke rate is faster as there is less restriction. While the average actuator pressure needed per percentage of valve travel is 0.77psi/% compared to the baseline analysis which is equals to 1.46psi/%. This shows that without SOV, the actuator pressure needed per percentage of valve travel is lesser.

3.3.6 *Ball Valve Analysis Based on Fuzzy Logic*

Fig. IX shows the combination of fuzzy subset friction band and deadband. The membership function for friction band is as the following: Unhealthy friction band (x) = {0.00, if friction band (x) < 6psi, (friction band (x) – 6psi)/2, if 6psi < friction band (x) < 8psi, 1.00, if friction band (x) > 8psi}

The membership function for deadband is as the following:Unhealthy deadband (x) = {0.00, if deadband (x) < 12.5psi, (deadband (x) – 12.5psi)/3, if 12.5psi < deadband (x) < 15.5psi, 1.00, if deadband (x) > 15.5psi}

Let,

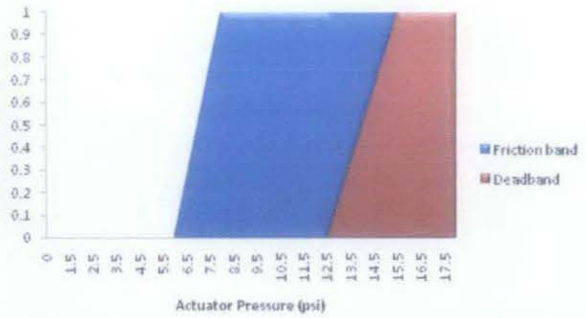
A= ESDV has unhealthy friction band and unhealthy deadband

B= ESDV has unhealthy friction band or unhealthy deadband.

C= not (ESDV has unhealthy friction band)

D= not (ESDV has unhealthy deadband)

If ESDV=A, it falls above 15.5 psi;
if ESDV=B, it falls above 15.5 psi or 8psi;
if ESDV=C, it falls below 8 psi;
And if ESDV=D, it falls below 15.5 psi.



ure IX: Graph of combination of membership function based on deadband and friction band.

' *Butterfly Valve Analysis Based on Deadband and Friction Band*

The deadband is 13.27 psi which is lesser than line analysis, 16 psi. While, the friction band for ent analysis is equals to 7.35 psi. There is 3% of rence between friction band's baseline and present ysis. The difference is becasue of tightening the valve ing which causes more friction. Therefore, more ator pressure needs to be exhausted in order to make alve move.

: *Butterfly Valve Analysis Based on Stroke Rate and Actuator Pressure Needed per Percentage of Valve Travel*

The average stroke rate is 0.675%/s while the overall ce rate for baseline data is 0.23%/s. The average ator pressure needed per percentage of valve travel is psi/% compared to the baseline analysis which is ls to 1.54psi/%.

) *Butterfly Valve Analysis Based on Fuzzy Logic*

Fig. X shows the combination of fuzzy subset friction l and deadband. The membership function for friction l is as the following: Unhealthy friction band (x) = 0, if friction band (x) < 7.1psi, (friction band (x) – si)/2, if 7.1psi < friction band (x) < 9.1psi, 1.00, if ion band (x) > 9.1psi}

The membership function for deadband is as the wing: Unhealthy deadband (x) = {0.00, if deadband (x) 5.5 psi, (deadband (x) – 16.5 psi)/3, if 16.5 psi < band (x) < 19.5 psi, 1.00, if deadband (x) > 19.5 psi}

ESDV has unhealthy friction band and unhealthy deadband
ESDV has unhealthy friction band or unhealthy deadband.
not (ESDV has unhealthy friction band)
not (ESDV has unhealthy deadband)

SDV=A, it falls above 19.5 psi;
SDV=B, it falls above 19.5 psi or 9.1 psi;
SDV=C, it falls below 9.1 psi;
if ESDV=D, it falls below 19.5 psi.

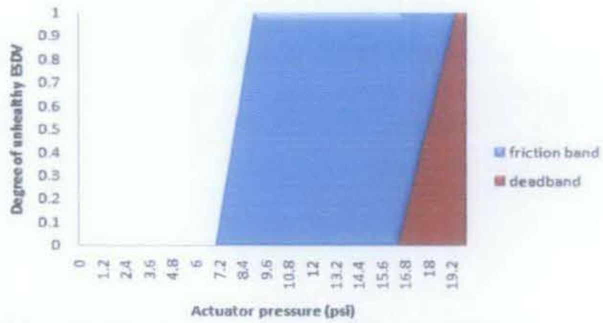


Figure X: Graph of combination of membership function based on deadband and friction band.

ACKNOWLEDGEMENT

The author would like to express gratitude to Allah the Almighty for making the project flow smoothly and successfully. The author's deepest gratitude goes to Ir Dr Idris for giving her the opportunity to do this project under his supervision. Last but not least, the author would like to thank the author's family members who have been very supportive and cooperative.

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