DEVELOPMENT OF TEST RIG FOR CONTROL VALVE FAULT MONITORING SYSTEM USING ACOUSTIC EMISSION

By

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Dissertation submitted in partial fulfillment
of the requirements for the
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(Electrical and Electronics Engineering)

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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

December 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.

Jenny Ngu Yen Ping

ABSTRACT

Control valve is an important instrument in process industry. It has been used to control fluid flow rate in a process control system. The significance of this project is to maintain the quality of a process besides saving maintenance cost by developing a fault detection monitoring system using Acoustic Emission (AE) technique. The concept of AE technique is to attach a sensor at the body of the valve to detect fault and as a monitoring system. Since faults on control valve often happens in the plant, there is a need to carry out background study in order to investigate the problems occurring. This leads to the project objectives that are to design and build test rig for experimentation purposes followed by further analysis on the collected data. Based on the studies that have been done, it is believed that the project is feasible and realizable.

ACKNOWLEDGEMENTS

Firstly, I would like to praise God the Almighty for giving me strength to complete the challenging task. Not forgetting, I would like to take this chance to express my deepest gratitude for those who have assisted and guided me for my Final Year Project (FYP).

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Control valve acts as a final control element in a process control loop to regulate flow of process fluid. On the other hands, it means that a control valve is not used for shut off purposes. The actuator plays an important role which is to move the valve plug, stem to the required position, hold the position against the forces of the flow stream, close off the valve by applying sufficient force and operate the movement at the required speed.

Control valve's life span greatly depends on correct control valve selection for the application, proper storage and protection, proper installation technique and effective predictive maintenance program. Looking into control valve selection, it must offer minimum capital cost, minimum operating cost and efficient control characteristics to the plant. Therefore criteria such as pressure rating, flow range, leakage rate, corrosion and others are to be taken note to ensure longer life span of a control valve.

On the other hand, in this study of project, monitoring system for early detection of fault in control valve is greatly highlighted. By knowing the abnormal operating conditions, it can reduce the negative effect on the control valve which might lead to unplanned shutdown which will cause unnecessary losses. Through monitoring system, the fault can be detected and resolved at the early stage.

There are many techniques to encounter control valve fault detection at the beginning stage. Comparison had been done within each method which shows that Acoustic Emission (AE) technique is the better method to measure the sound wave originate from the leakage flow.

1.2 Problem Statement

Control valve life cycle starts from Installation, Commissioning, Preventive Maintenance, Corrective Maintenance and Replace New Valve. Replacement of control valve requires high expenses and same goes to corrective maintenance where shutdown of the plant has to be done if the discovery of the fault is only done after some error occurs. For that reason, if a fault can be detected at early stage before the control valve has reached its maximum tolerable limit and broke down, the plant can be guaranteed to have smooth production besides spending a large sum of money to replace the whole valve. In this project, Acoustic Emission (AE) technique is used as a monitoring system to detect fault at early stage to extend the life span of a control valve.

1.3 Objectives

The objectives of this project are as follow:

a) To be able to design and build test rig for experimentation purposes.
b) To be able to collect experiment data for analysis and comparison.
c) To verify the experiments result of test rig.

1.4 Scope of Study

The scope of study is to utilize Acoustic Emission technique to capture the data of healthy and unhealthy valve. The construction of test rig has to be done after detailed research on different aspects such as type of control valve, transmitters, pumps, sensor and others. By doing so, error on data generated from test rig can be minimized as much as possible. The data generated is used for analysis and comparison in order to predict possible cause of fault detected before any downtime of the control valve. The data generated must be processed and analyzed in order to get the final result.

CHAPTER 2: LITERATURE REVIEW

2.1 Literature Review

2.1.1 Past

Control valves have been used extensively in process control loop. The valve is selected based on factors such as cost, minimum maintenance, use the least of energy and compatibility which will keep the plant cost to the lowest.

In fact, control valves are considered the most important component which need much attention for the well-being of the process. Failure of any control valves during process is fatal to the process and might cause unnecessary losses. Therefore, proper and timely maintenance is vital. Manufacturers should take notice on the maintenance part which is gradually becoming priority of consideration for control valve by users.

However, in the past, maintenance part is not highly emphasized when a control valve encountered a defect. On the other hand, replacement concept is being carried out where the whole valve is being replaced by a new one. The reason is to save time from finding the cause of the failure. This method had increased the cost of production whenever a control valve broke down due to spare parts problem which can be solved instantly besides replacing the valve.

2.1.2 Present

Nowadays, preventive maintenance programs are conducted based on schedule. It is carried out by shutting down the plant (offline) where control valves were dismantled and overhaul. During overhaul, the valve components that are functioning normally are needlessly replaced, thereby increasing operating costs. All these are conducted by trained personnel who are mostly the technicians. They should be aware of the materials and design as well as the requirements of the service.

Moreover, the vendors companies which provide control valves are concerning more on the maintenance rather than the defect prevention stage. Maintenance is divided into four (4) categories which are warranty, planning, safety, and instruction. Warranties are issued to ensure functionality of the valve. If there is any defect, the company has to provide maintenance for free. Maintenance is planned during installation so that control valves are operating without fail. Thirdly, safety is greatly emphasized especially before any attempts are made to service a valve. Lastly, instructions are provided along with purchase of every control valve.

2.1.3 Future

A study reported that the cost of performing predictive maintenance on valves can be up to five times less expensive than preventive maintenance and 10 times less expensive than corrective maintenance. This statement shows the importance of a monitoring system to detect faults that happens in early stage before it deteriorates the condition of a control valve.

And here comes predictive maintenance. In future, fault diagnostic technology enables fault detection and analysis while the valve is in normal condition (online). In addition, the diagnostic not only collect data, but also analyze the cause of the fault and suggest how best to remedy it. It is used to monitor valve health. By utilizing it, when there is fault, it will send an early predictive warning to avoid unplanned shutdown. The diagnostic technology is configured not only collect data, but to establish the cause of the problem and recommend specific corrective action.

Therefore, looking into benefits of the technology, every critical control valve in the plant should be equipped to evaluate current valve operation and get precise information for forecasting performance. This would definitely control valve life span besides controlling operational cost.

2.2 Comparison between Acoustic Emission technique and Vibration technique

2.2.1 Acoustic Emission Technique

Figure 1: Acoustic Emission sensors

Acoustic Emission (AE) is an energy emitted in the form of transient elastic wave or sound wave within material. The AE signal is obtained using AE equipment after the sound wave has been detected and processed electrically. This technique is mainly used to monitor bearings, especially for slow speeds. Generally, the AE signal has a wide frequency range of 25kHz to 3MHz. However, it is normally analyzed and processed in the frequency range between 100 kHz to 1MHz due to high sensitivity. There are many types of AE sensor and one of the commonly used one is differential sensor. Its features are high common mode noise rejection for use in electrically noisy environments, lower noise overall resulting in the ability to set lower AE thresholds and good for detecting very low AE signals.

2.2.2 Vibration Technique

Figure 2: One of the Vibration sensor

Vibration technique is the most common and universally acceptable technique chosen over the years. It is usually used on rotating machines. When using this technique, it is important to select correct point to monitor from and fitting the most compatible vibration sensing device. The sensor used for the collection of data is an accelerometer which collects a signal in changing volts proportional to the acceleration signal seen. Vibration monitoring is effective in detecting faults in machines, however it is only in specific part of the motor. Besides, it needs more sensors to detect faults in one machine.

2.2.3 Comparison between Acoustic Emission technique and Vibration technique

Acoustic Emission (AE) is non-directional and hence is more sensitive to variation in defect size and no further analysis of the AE response was required in relating the defect source to the AE response, which was not the case for vibration signatures. Therefore, the sensor can be located anywhere on the test object to detect any emissions.

AE technique is widely used in non-destructive testing for the detection of failure in machinery. AE parameters can detect defects before the defects appear in the vibration acceleration range and can also detect the possible sources of AE generation during a fatigue test.

AE technique is able to give dynamic characteristics of active defects. Unlike vibration technique, it is able to detect the defection even in the initial stage. The spectrum frequency of vibration readings failed in the majority of cases to identify the defect frequency or source.

By referring to the comparison above, it clearly shows that AE technique has more advantages over vibration technique.

2.3 Control Valve

2.3.1 Definition and Working Principle

In simple illustration, control valve acts like a water tap which is to control the flow of water flowing out accordingly. Being related to industrial applications, it is a final controlling element used to control conditions such as pressure, flow, temperature and level by responding to the signals or the set point provided. The figure below shows the explode view of a typical control valve. Control valve has two (2) major components that are Body and Actuator. Generally, Body is used to let fluid to pass through while Actuator functions to control the movement of stem.

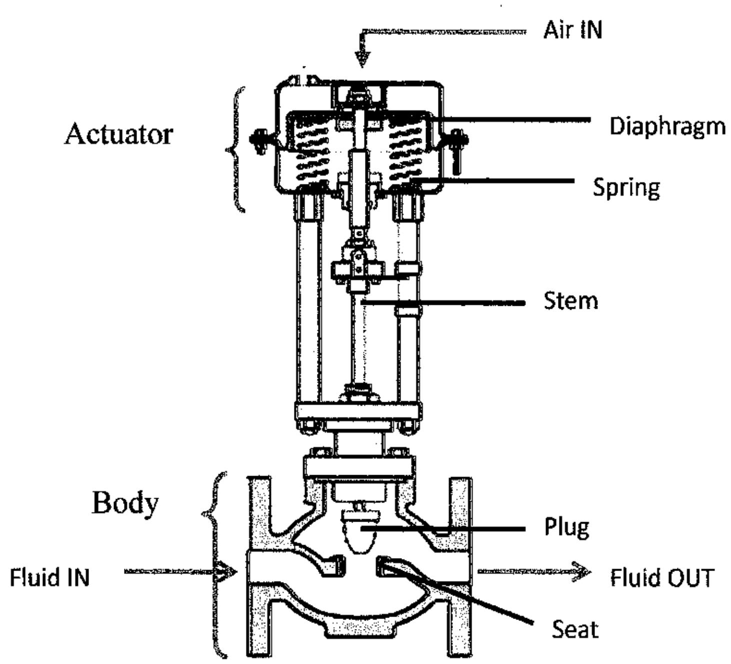

Figure 3: Explode View of Control Valve

For valve closing, the air is injected onto Diaphragm in Actuator which creates force to push the Stem downwards. That will cause the Plug to approach the Seat slowly. Throughout the process, the flow is regulated by the moving of Plug towards the Seat. When the Plug and Seat are fully touched, then the valve is considered fully close.

On the other hand, in order to open the valve, remove or reduce the air from Actuator and the Stem with Plug will moves upwards slowly, leading to valve opening. This is because the Spring below Diaphragm is returning back to its original position, since there is zero pressure exerted on the Diaphragm.

2.4 Type of Faults in Control Valve

In a long run, control valve tends to breakdown easily and require maintenance. Understanding the reason of fault is important in order to troubleshoot the problem easily. Common types of faults will be explained in detail as follow.

2.4.1 Cavitation

Cavitation (A. Masjedian Jazi, H. Rahimzadeh, 2009) happens when vapor bubbles formed in flowing liquid region where the pressure of the liquid falls below its vapor pressure. The formation and collapse of cavitation bubbles leads to erosion of valve components. Cavitation produces high level of noise and vibration which can loosen flange bolting, damage piping support structures and damage process instrument.

2.4.2 Flashing

Flashing is similar to cavitation. The difference is the vapor phrase persists and continues downstream because the pressure at downstream has not changed or below the vapor pressure of the liquid. High velocities are generated by the expansion of the liquid into vapor which can cause erosion to the wall of the valve body.

2.4.3 Packing Leakage

Packing is situated along the valve stem to seal the valve's pressure retaining section. There are different choices to be chosen from according to the usage of the valve. During installation, it is important to not damage the edges of rings which might eventually cause leakage because of the damage sealing surface.

2.4.4 Gasket Leakage

Leakage happens when torque applied on bonnet nuts is unbalanced. Thus, most manufacturers now use spirally wound gaskets as bonnet seals which provides better results. The gaskets are filled with different fillings and are made to accommodate different densities according to the nature of application.

2.5 Statistical Analysis

Statistical analysis is one of the commonly used methods to analyze data. Kurtosis, standard deviation, maximum amplitude and root mean square (RMS) are the examples of statistical analysis. The randomness in the generation of Acoustic Emission (AE) signal requires a statistical analysis of AE signals.

Kurtosis is any measure of the peaks of the probability distribution of a real-valued random variable. It is among the sensitive parameters for machines diagnosis.

Standard deviation is a measurement of variability or diversity used in statistics and probability theory. It basically shows how much variation or dispersion there is from the mean value. A high standard deviation indicates that the data is spread out over a large range of values while a low standard deviation indicates that the data is closer to the mean.

Maximum amplitude can be found by referring to maximum peak of graph in time domain. It can be easily observed during receiving the data from AE sensor.

Root mean square (RMS) is a statistical measure of the magnitude of a varying quantity. The RMS value of a set of values is the square root of the arithmetic mean of the squares of the original vales.

Based on past study (Y.M. Goh and Najiha Intan, 2010), a healthy control valve should possess values as in Table 1. Any values that are not within the range will be considered as unhealthy control valve.

Table 1: Statistical Analysis Values of Healthy Control Valve

	Healthy Control Valve
Kurtosis	< 3
Standard Deviation	< 0.5
Maximum Amplitude	< 2
Root Mean Square (RMS)	< 2

2.6 Review of Selected Papers

This section mainly summarized several selected papers that were used as review for current project. These selected papers provide general information about previous research work done by other researchers related to the topic of the project.

Mohamed A. Sharif and Roger I. Grosvenor have conducted experimental study to determine the lowest detectable compressed air leakage rate through an industrial control valve that can be reliably detected using an Acoustic Emission (AE) technique. At the beginning of this paper, it was presented that AE technique gives more accurate result compared to vibration analysis method. Therefore, AE technique will be continued to be used in this project. This paper also shows that AE is reliable when a very low leakage rate needs to be detected.

In their following research (Sharif and Grosvernor 2000), they improved the project by developing a graphical user interface diagnostic program to determine condition, estimate condition and perform step response analysis. Before the program was developed, test rig was built to conduct experiments to determine 12 conditions that will be the baseline for the program development. The diagnostic program was established using Visual Basic. It could be used to diagnose faults in typical industrial control valve and actuator without requiring any specialist knowledge. The faults considered and diagnosed include the gradual blockage of the actuator's vent hole, damaged valve packing rings and damaged valve stem. This paper is quite similar to the project since the project that is on-going is planning to create a diagnostic software. The difference is on the fault detected and the graphical programming language used.

Cavitation is one of the faults that this project is going to concentrate on, for this case, Masjedian Jazi and H. Rahimzadeh presented a related paper on the topic. According to the paper, there are two methods to detect cavitation in globe valves which are characteristic diagrams and acoustic analysis. Since cavitation is a potential hazard especially for valves, a proper solution is needed before matter got worse. Therefore, monitoring of cavitation is vital to prevent further losses. In this research, the team had constructed a cavitation test setup for experiment purposes. Both methods are being used to analyze the result from the experiment. The comparison of the results indicates a good agreement of between two.

In one of the recent paper, Y.M. Goh and Intan Najiha had managed to utilized Acoustic Emission (AE) technique to perform experiments on healthy and unhealthy valve using proper experimental setup, the result shows comparison between the two kinds of valves and statistical analysis values possess by both valves. This will be a good reference for the control valve used in this project.

In summary, the papers that have been elaborated above and read personally are helpful to provide plentiful information for this project. It is found that Acoustic Emission (AE) technique is suitable to detect leakage rate or to obtain various parameters for analysis. In addition, the papers also provide an idea how to create diagnostic software starting from scratch.

CHAPTER 3: METHODOLOGY

3.1 Analysis Technique

3.1.1 Literature Review

Undeniably, literature review had to be done to deepen the understanding towards the topic of the project. Resources comprises of journals, articles, reference books and others which generally can be obtained from different websites. As for this project, making full use of the resources is essential in order to select proper tools or equipment that is appropriate.

3.1.2 Experimental Setup

In this project, a test rig will be designed and built to perform experiments on control valves. The test rig includes main components such as control valve, pressure transmitter, level transmitter, pump, water tank and others. When the test rig is done, experiments will be conducted on the control valve to collect data for healthy and unhealthy valve.

During the experiments, then Acoustic Emission (AE) sensor is attached to valve body supported by adhesive tapes and the other end is connected to preamplifier. Next, it is connected to filter followed by amplifier. The setup is used to collect data for analysis and comparison. In short, a schematic diagram of the connection is shown in Figure 4. The functions of each component are explained in the next section. The actual experimental setup can be found in Appendix A.

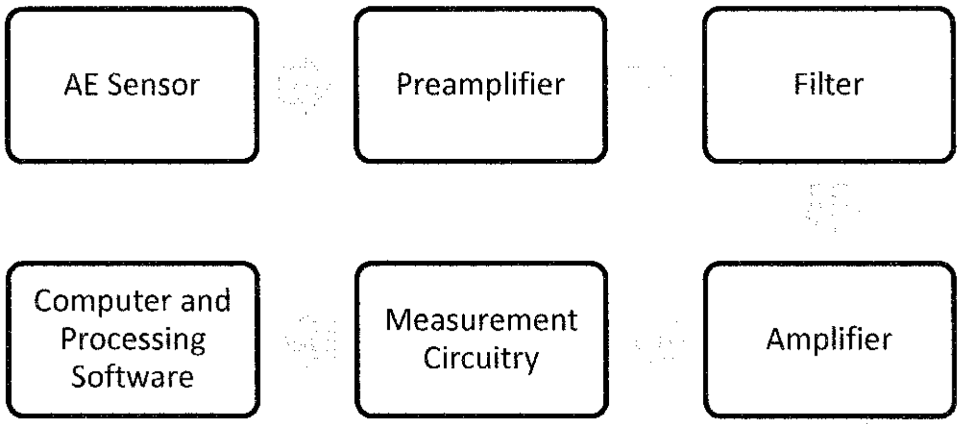

Figure 4: Schematic Diagram during experimentation

3.2 Materials, Equipment and Software

Equipments required to conduct this project is divided in two types which are hardware and software.

3.2.1 Hardware

a) Experimentation equipments include

i. Acoustic Emission Sensor (AE Sensor)

The function of the sensor is to convert the acoustic wave energy emitted by the source into usable electrical signal typically voltage time signal. The source in this case refers to the Body of Control Valve.

ii. Pre-Amplifier

Since the output from AE Sensor is small and noisy, the pre-amplifier is used to enhance the signal level against noise.

iii. Amplifier,

The output of filter is fed to an amplifier where the signal is further amplified.

iv. Data Acquisition System(DAQ) card (USB-1208FS)

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Its purpose in this project is equally simple. The output of AE Sensor is connected into one of the input channels of DAQ card as well as an analog ground (AGND) to provide a common ground for all input channels (Appendix E).

v. Computer

As the final destination of the experimental setup, it is used to process signal in order display and analyze the data.

b) Test Rig includes Control Valve, Level Transmitter, Pressure Transmitters Pump and Water Tanks.

3.2.2 Software

a) MATLAB

The software is used to generate graphical result from the output of AE Sensor.

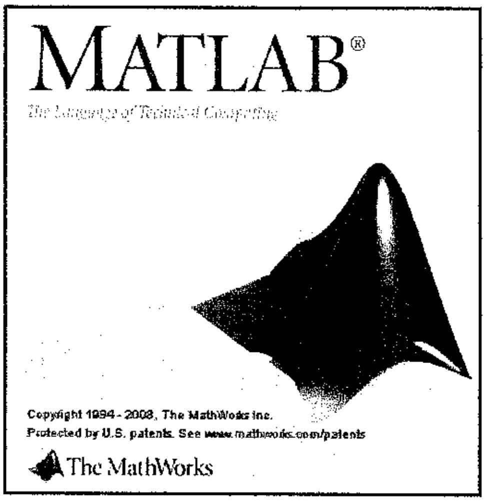

Figure 5: MATLAB Software Applications

b) INSTACAL (MCC DAQ)

This software is a platform for the computer to detect and add DAQ Card.

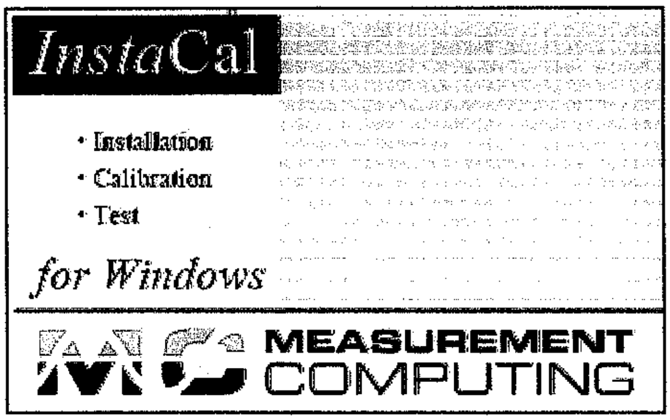

Figure 6: Data Acquisition Card (DAQ) Software Applications

3.3 Execution Flow Chart

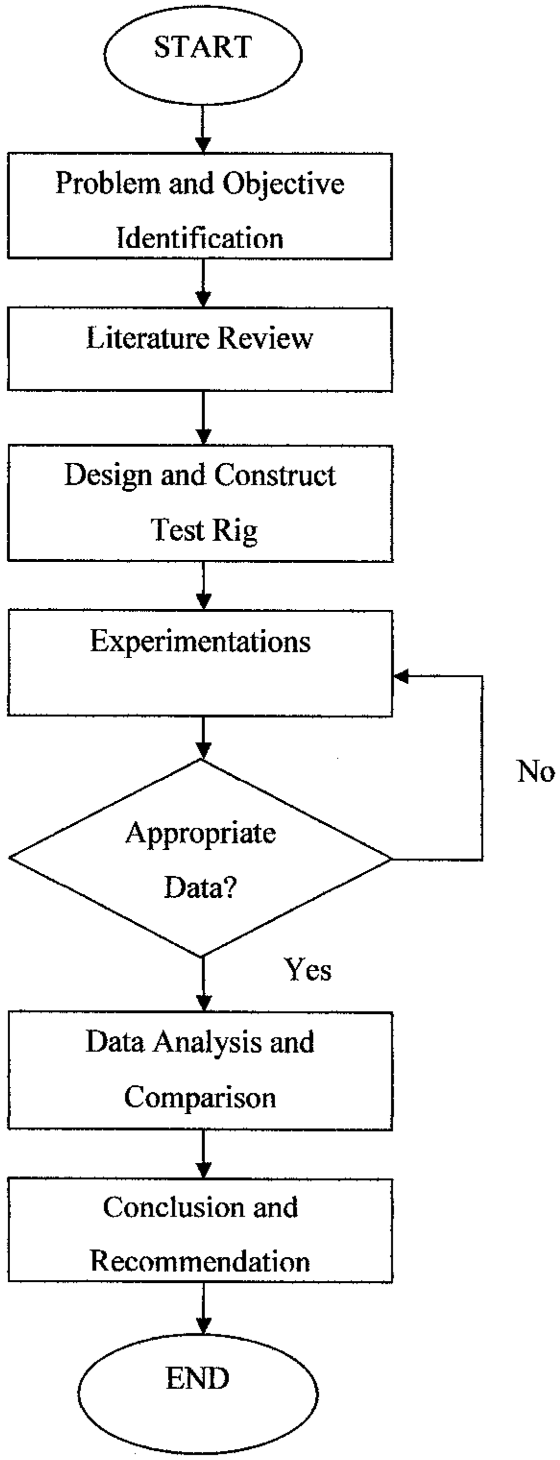

Figure 7: Execution Flow Chart

3.3.1 Activities and Milestone

This project started off with Problem and Objective Identification. The problems of control valve are identified in order to find out the objectives of the project. The objectives are the aims of the project which are intended to be achieved to solve the problems that were encountered.

In Literature Review, detailed preparations are important to ensure clear understanding on the subject. Reading related journals, articles and reference books are one of the few ways to assist in this project.

Next, the project proceeds technically to Design and Construct Test Rig. The purpose of the test rig is to perform experiments on control valve. However, before building up the test rig, an appropriate design is needed and checked to avoid error upon completion. All equipments used to construct Test Rig have to be cleaned or calibrated.

When the test rig is done, experiments will be performed on the control valve using Acoustic Emission (AE) technique. Proper experimental setup is prepared to collect signal from AE sensor appropriately.

After that, the data that is collected will be analyzed using Statistical Analysis. The result will also be compared to decide the condition of the control valve as well as the Test Rig.

Lastly, conclusions will be made based on the result and further implementation will be recommended for future work.

3.4 Gantt Chart

Gantt Chart is constructed to keep track of the progress for this project from time to time. This project is divided into two (2) terms that are Final Year Project I (FYP I) and Final Year Project II (FYP II). The charts can be found in Appendix B.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Test Rig

The construction of test rig was carried out to collect data had achieved one of the objectives in this project. The construction was undertaken in Universiti Teknologi PETRONAS' (UTP) Instrument and Control Laboratory at Block 23. This site has been chosen since it is fully equipped with utilities such as air, power and water supply as well as hardware tools. The final product of construction is presented in Appendix C.

4.1.1 Construction and Commissioning

Work began by designing the layout and general arrangements of each component. After consulting lecturers and technicians, the design was finally approved and moved on to construction. Figure 8 shows the main section of the Piping and Instrumentation Diagram (P&ID) of the test rig.

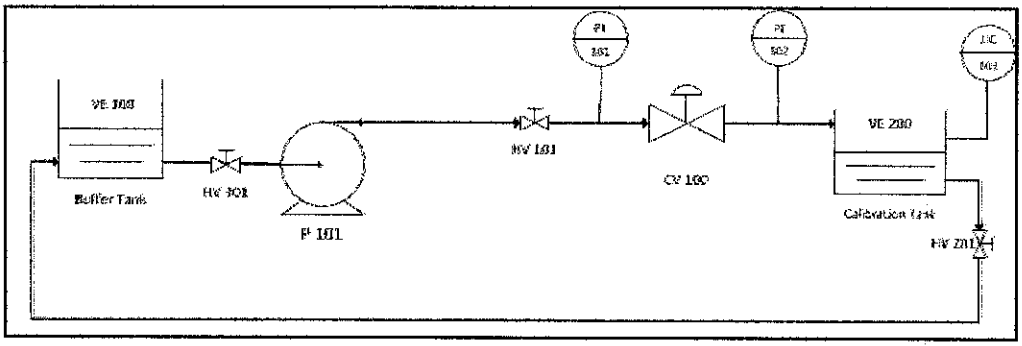

Figure 8: P&ID of Test Rig

The detailed specifications for each instrumentation can be found in Appendix D. As shown in the figure, the test rig consists of a control valve (CV-100) which is the main subject to be studied on. A pump (P-101) to exert force for the water to flow through the pipelines. Two tanks which are Buffer Tank (VE-100) and Calibration Tank (VE-200) to hold water alternatively. Two pressure transmitters (PT-101 and PT-102) to measure pressure drop at Orifice plates. And also pressure transmitter which acts as a level transmitter (LIC-103) to monitor and control the level of water in Calibration Tank (VE-200). There are three Hand-valves (HV-101, HV-201, HV-301) to determine the presence of water by turning it on or off.

The process kicked start when water is pumped from Buffer Tank (VE-100) into the pipe to flow through Control Valve (CV-100). The Orifice plates are installed at the inlet and outlet of the body of Control Valve to measure the differential pressure of the flow. Then, the water is fed back to Calibration Tank where level of tank not only can be monitored but controlled by the controller. Water from Calibration Tank will flow into Buffer Tank where the process will be repeating until the pump is stopped manually.

4.1.2 Testing on Controller

Controller is important in this test rig since it is used to control the water level of Calibration Tank. In other word, the level can be set at the point that the user wanted it to be when it is in Auto Mode. This test focused on collecting data from level transmitter (LIC-103) which is connected to Data Acquisition System (DAQ) card. The test was done by adjusting the Set Point (SP) of the level of tank at 0, 25, 50, 75 and 100% at the controller. The range of water level in the tank is 0-800 mmH20 while the range in voltage is 1-5V. The graphical result is observed in MATLAB software in computer. The expected result of the testing is shown in the Table 1 while the actual result is shown in Table 2.

Table 2: Expected Result from Controller Testing

Controller Set Point (%)	Voltage (V)
0	1
25	2
50	3
75	4
100	5
75	4
50	3
25	2
0	1

The result from the experiment that is as follow:

SP at 0%

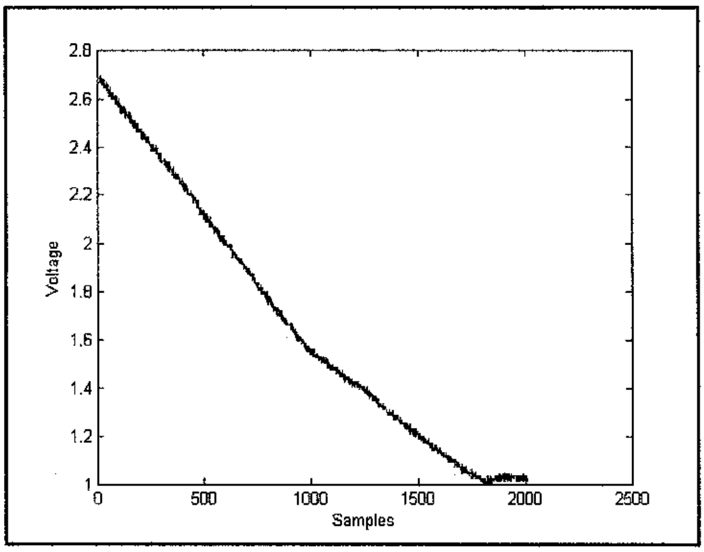

Figure 9: Controller Set Point (SP) at 0%

SP at 25%

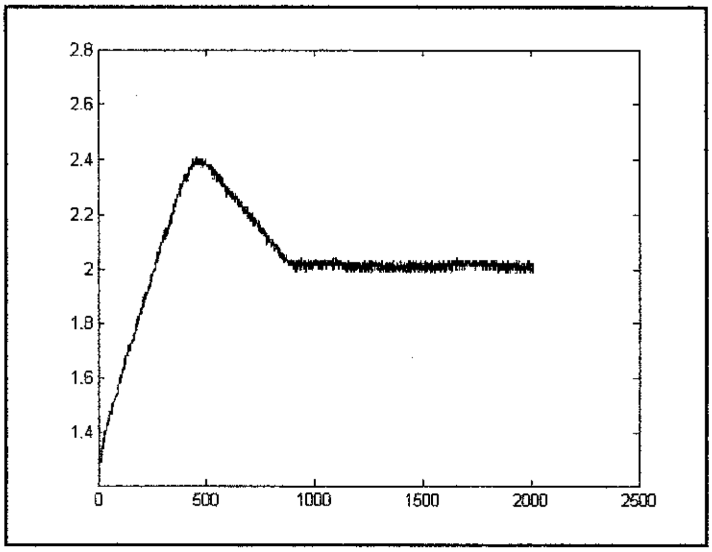

Figure 10: SP increased to 25%

SP at 50%

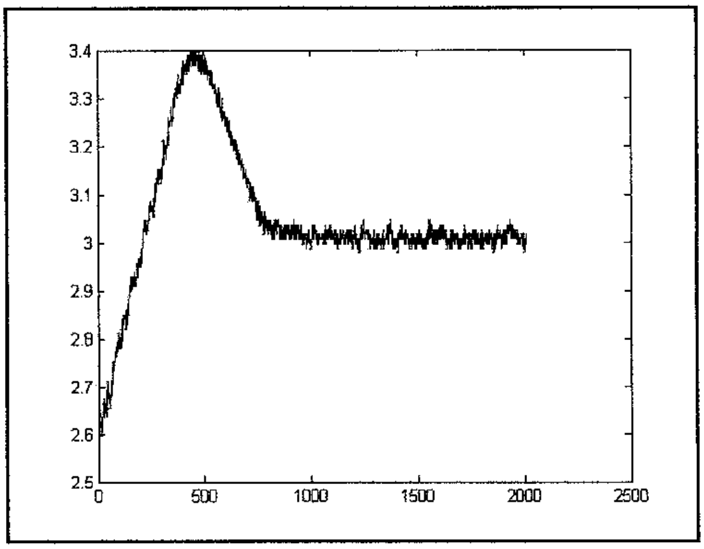

Figure 11: SP increased to 50%

SP at 75%

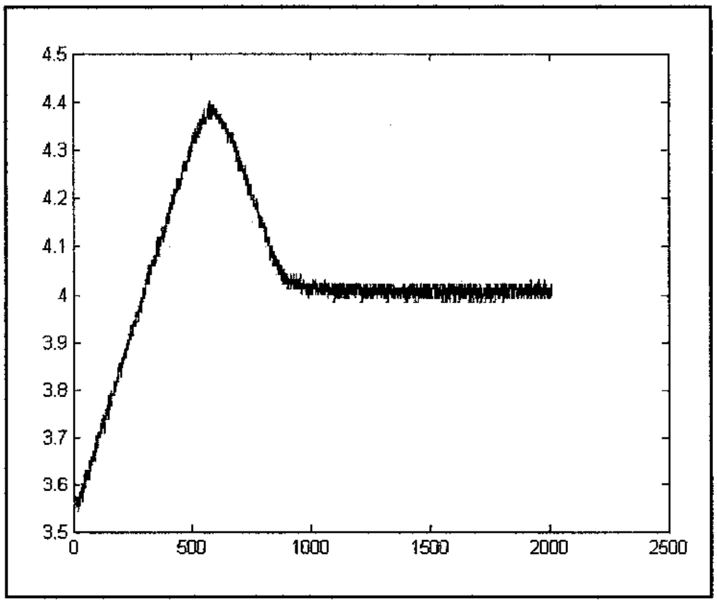

Figure 12: SP increased 75%

SP at 100%

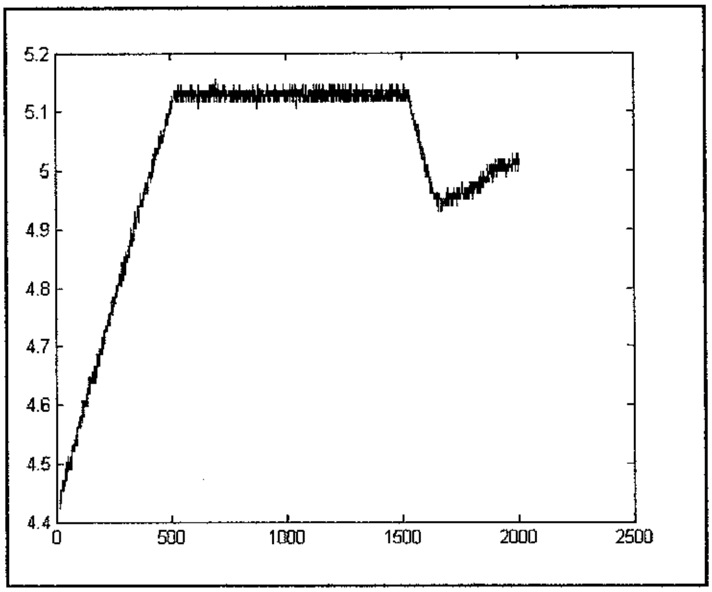

Figure 13: SP increased to 100%

SP at 75%

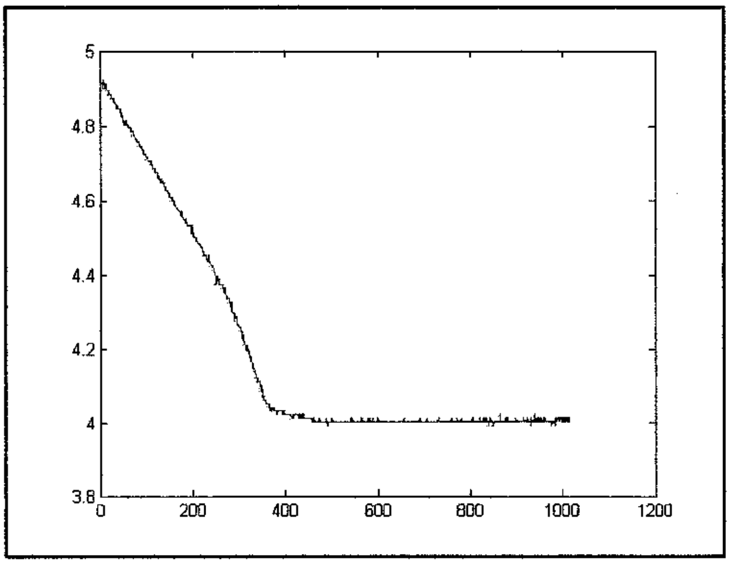

Figure 14: SP reduced to 75%

SP reduced to 50%

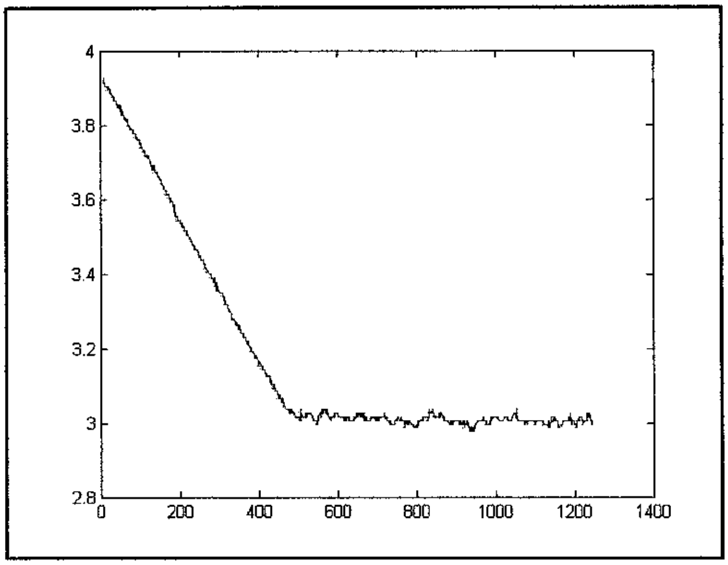

Figure 15: SP reduced to 50%

SP reduced to 25%

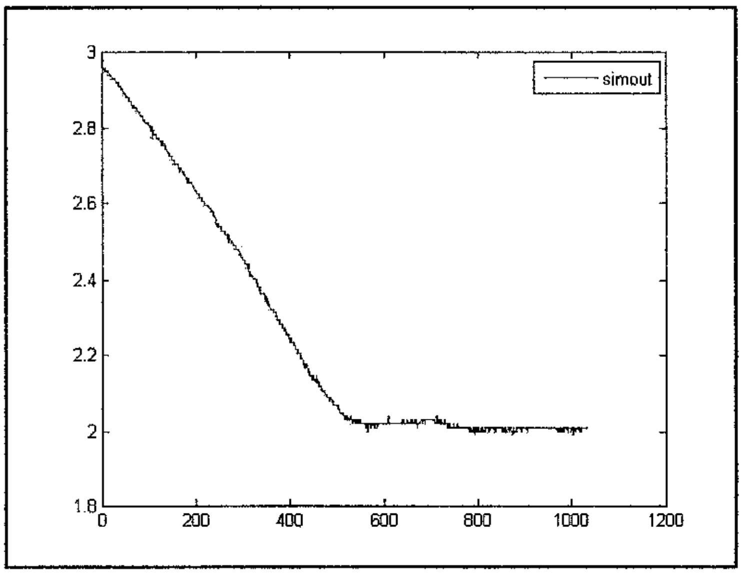

Figure 16: SP reduced to 25%

SP reduced to 0%

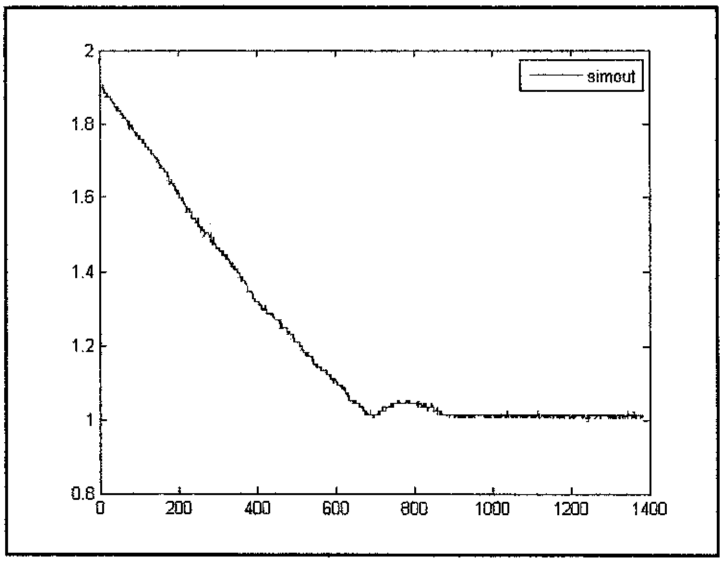

Figure 17: SP reduced to 0%

The actual result of the testing is as follow:

Table 3: Actual result from Controller Testing

Controller Set Point (%)	Voltage (V)
0	1
25	2
50	3
75	4
100	5.1
75	4
50	3
25	2
0	1

Based on Figure 9, when SP is at 0%, the graph does not show any complication and the voltage sent from transmitter to DAQ card is 1V which is same as the exact result that is wanted. By looking at Figure 12, 13 and 14, there is a similarity where there is a slight overshoot. It is because the Manipulated Variable (MV) of the control valve had increased more than enough when it wanted to arrive at the Set Point given. Although it increased more than the value set, it managed to return to its original value. As for SP at 100%, the voltage had an overshoot of 0.1V at the beginning and it decreases around 0.2V. Finally, the voltage shows 5V. This is because when the water level had passed the SP, the controller will play its role by decreasing the MV so that the voltage generated will be 5V.

Testing by increasing the SP is insufficient, thus this experiment is continued by reducing the SP from 100% to 0%. Referring to Figure 16, 17, 18 and 19, the water level has minimum overshoot when SP is being set.

As a conclusion for testing of controller, it can be concluded that the controller performed excellently for the test rig in controlling the water level in the tank when it is in Auto mode.

4.2 Experimentations Result

Experiments were conducted on healthy control valve using the test rig that has been successfully constructed. Analysis on result is focused mostly on Acoustic Emission signal which is in time domain. The signal will be analyzed using Statistical Analysis. The experiments were repeated for many times, however only a few will be discussed and compared.

The experiments were conducted on healthy control valve to obtain original Acoustic Emission (AE) signal. It is conducted by setting test rig's controller in manual mode and being performed at each valve opening specifically 0%, 25%, 50%, 75% and 100%. The same procedure had been repeated for 10 trials to ensure data are reliable and consistent. The result is shown in sections below.

4.2.1 Results: Trial 1

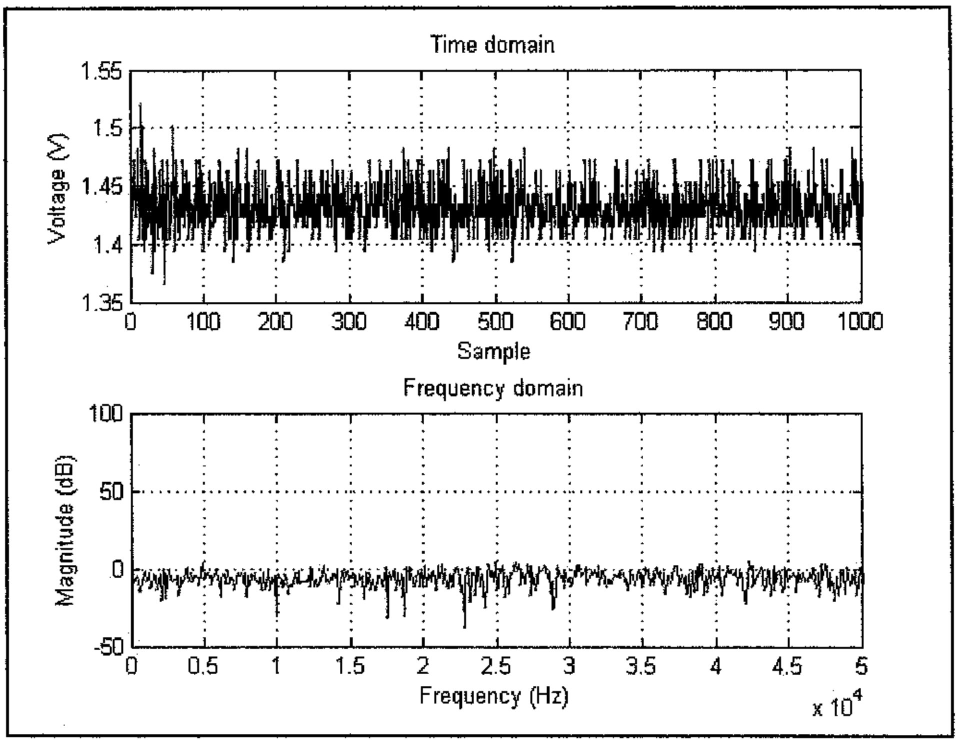

Figure 18: 0% Valve Opening (Trial 1)

Table 4: Data Statistic for 0% Valve Opening (Trial 1)

Min (Time domain)	1.365
Max (Time domain)	1.521
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.02049
Range	0.1563
Min(Frequency Domain), dB	-32.5
Max (Frequency Domain), dB	63.13

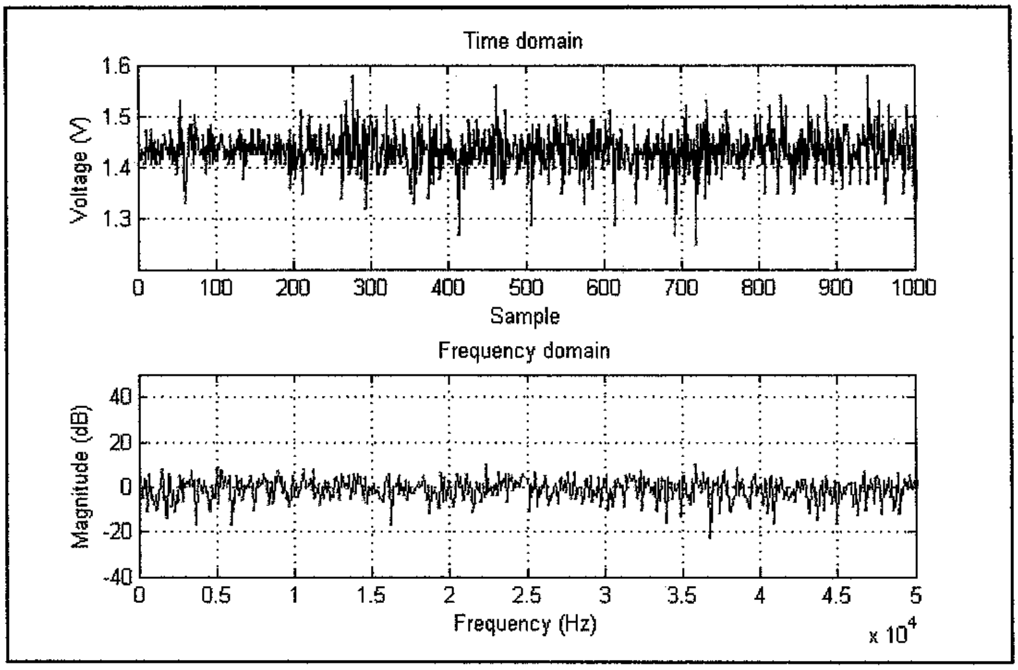

Figure 19: 25% Valve Opening (Trial 1)

Table 5: Data Statistic for 25% Valve Opening (Trial 1)

Min (Time domain)	1.209
Max (Time domain)	1.58
Mean	1.431
Median	1.433
Mode	1.443
Standard Deviation	0.03898
Range	0.3712
Min(Frequency Domain), dB	-25.79
Max (Frequency Domain), dB	66.01

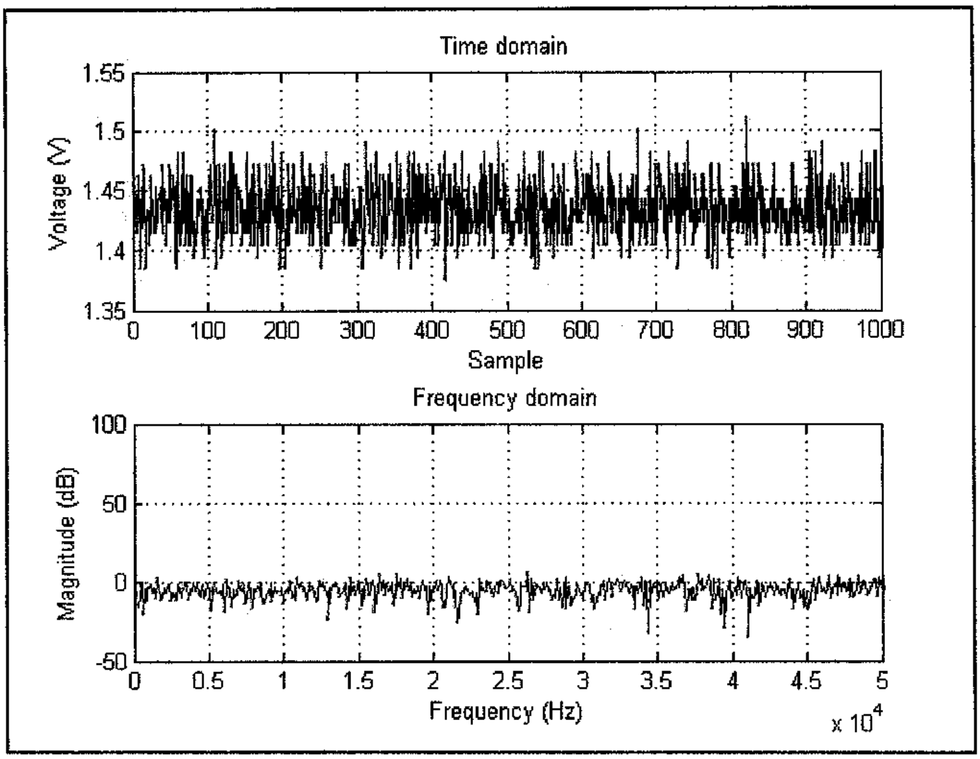

Figure 20: 50% Valve Opening (Trial 1)

Table 6: Data Statistic for 50% Valve Opening (Trial 1)

Min (Time domain)	1.370
Max (Time domain)	1.512
Mean	1.434
Median	1.433
Mode	1.424
Standard Deviation	0.02237
Range	0.1758
Min(Frequency Domain), dB	-33.28
Max (Frequency Domain), dB	65.81

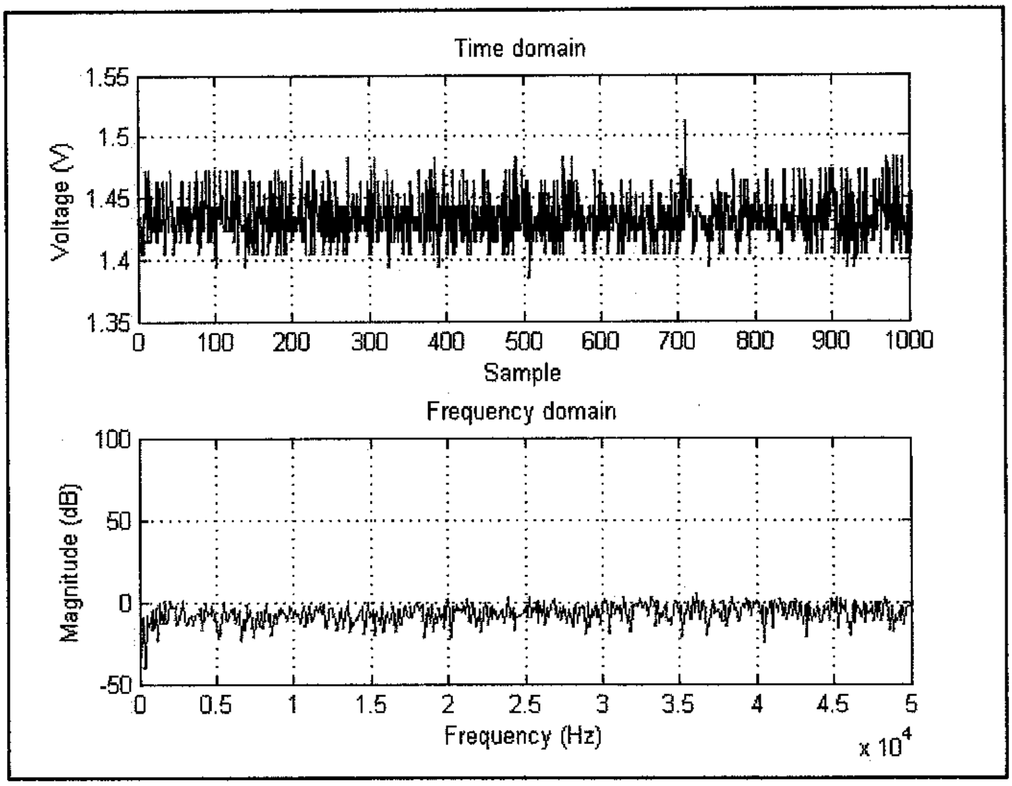

Figure 21: 75% Valve Opening (Trial 1)

Table 7: Data Statistic for 75% Valve Opening (Trial 1)

Min (Time domain)	1.385
Max (Time domain)	1.512
Mean	1.433
Median	1.433
Mode	1.424
Standard Deviation	0.01955
Range	0.127
Min(Frequency Domain), dB	-34.75
Max (Frequency Domain), dB	64.71

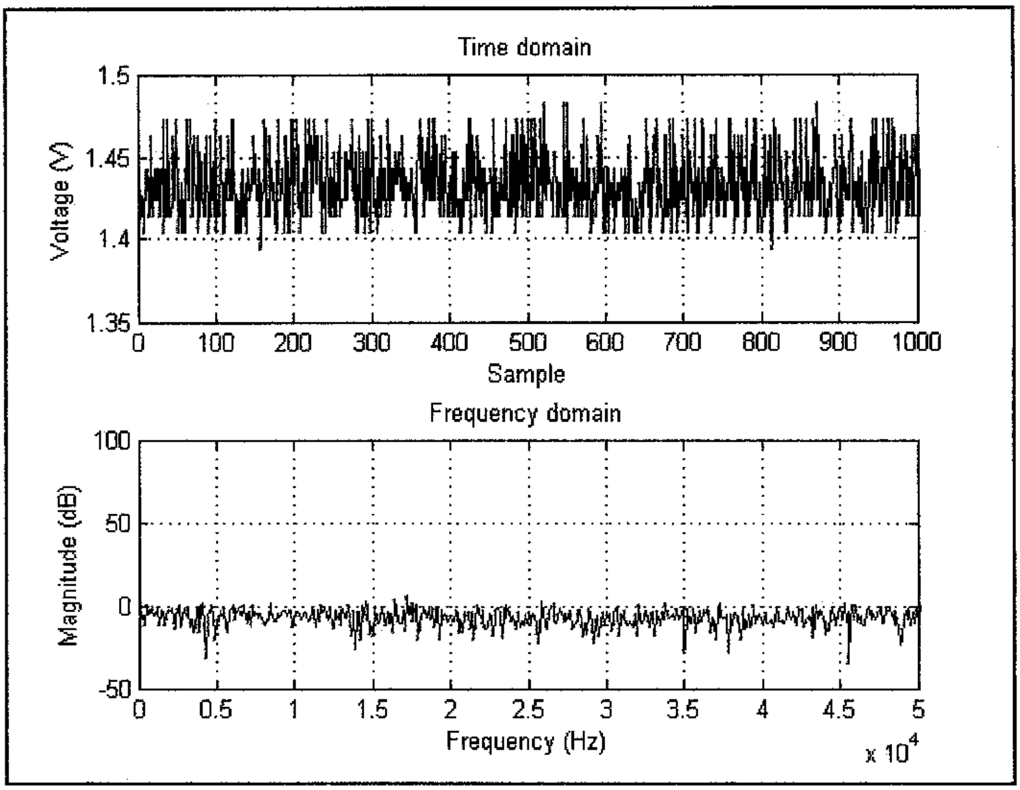

Figure 22: 100% Valve Opening (Trial 1)

Table 8: Data Statistic for 100% Valve Opening (Trial 1)

Min (Time domain)	1.394
Max (Time domain)	1.482
Mean	1.433
Median	1.433
Mode	1.424
Standard Deviation	0.0187
Range	0.08791
Min(Frequency Domain), dB	-31.61
Max (Frequency Domain), dB	64.14

4.2.2 Results: Trial 2

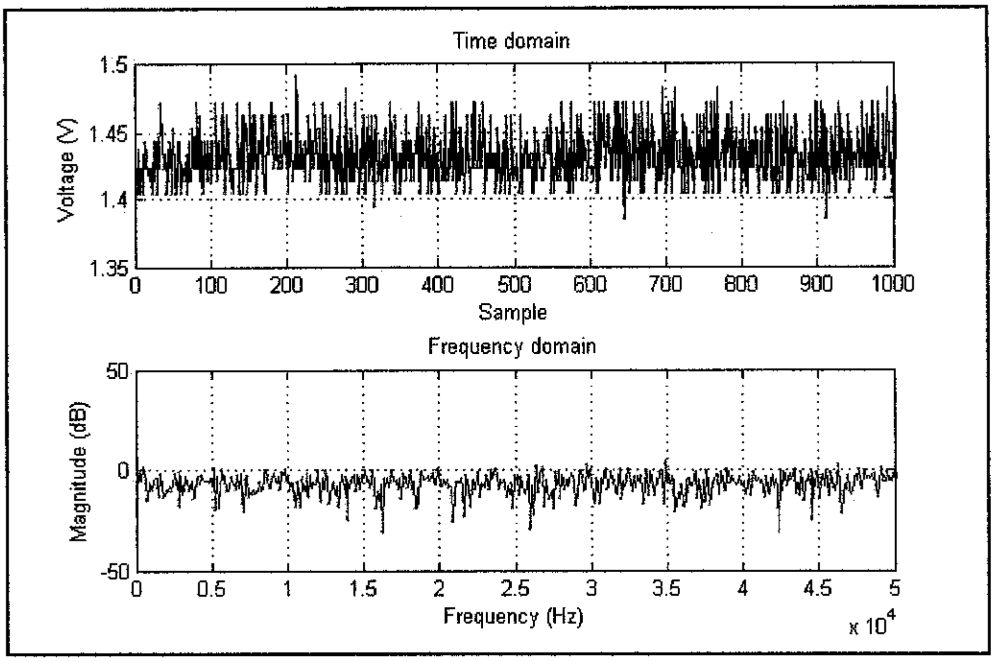

Figure 23: 0% Valve Opening (Trial 2)

Table 9: Data Statistic for 0% Valve Opening (Trial 2)

Min (Time domain)	1.385
Max (Time domain)	1.492
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.01861
Range	0.1074
Min(Frequency Domain), dB	-30.89
Max (Frequency Domain), dB	63.12

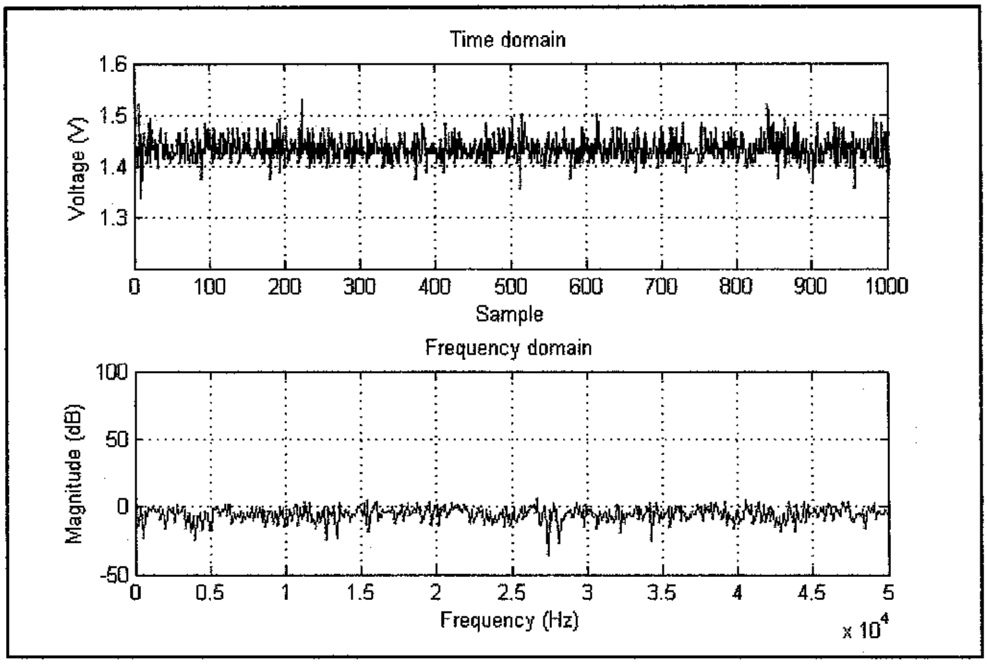

Figure 24: 25% Valve Opening (Trial 2)

Table 10: Data Statistic for 25% Valve Opening (Trial 2)

Min (Time domain)	1.336
Max (Time domain)	1.531
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.02269
Range	0.1954
Min(Frequency Domain), dB	-35.99
Max (Frequency Domain), dB	63.12

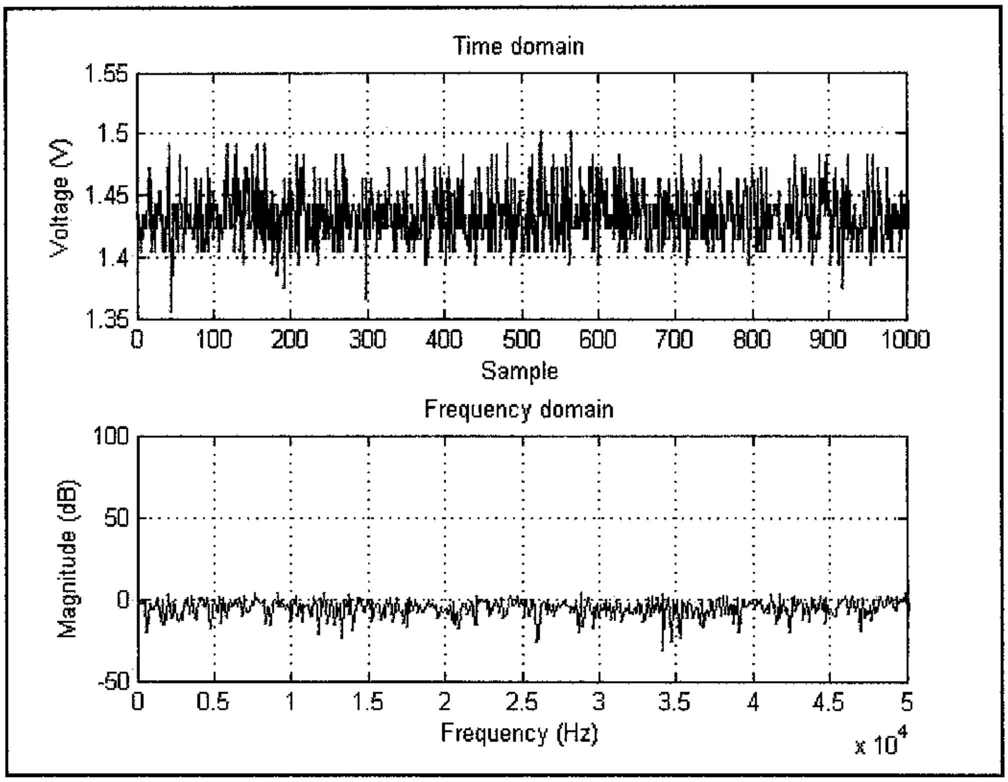

Figure 25: 50% Valve Opening (Trial 2)

Table 11: Data Statistic for 50% Valve Opening (Trial 2)

Min (Time domain)	1.355
Max (Time domain)	1.502
Mean	1.433
Median	1.433
Mode	1.424
Standard Deviation	0.02182
Range	0.1465
Min(Frequency Domain), dB	-31.74
Max (Frequency Domain), dB	63.12

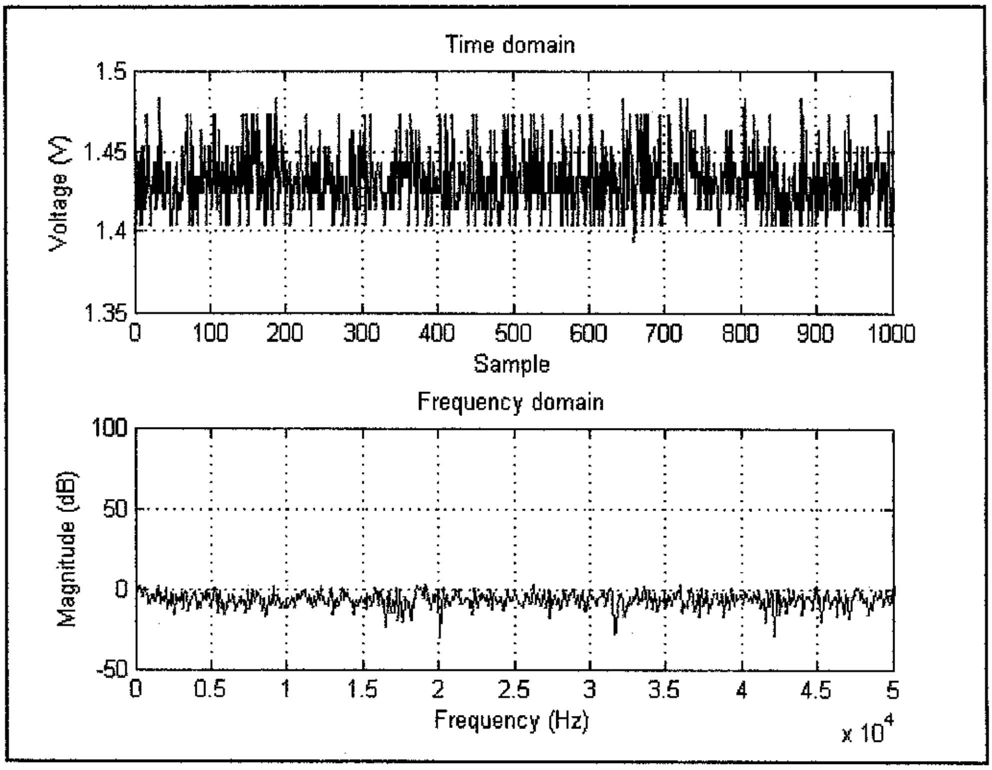

Figure 26: 75% Valve Opening (Trial 2)

Table 12: Data Statistic for 75% Valve Opening (Trial 2)

Min (Time domain)	1.394
Max (Time domain)	1.482
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.01855
Range	0.08791
Min(Frequency Domain), dB	-30.11
Max (Frequency Domain), dB	63.12

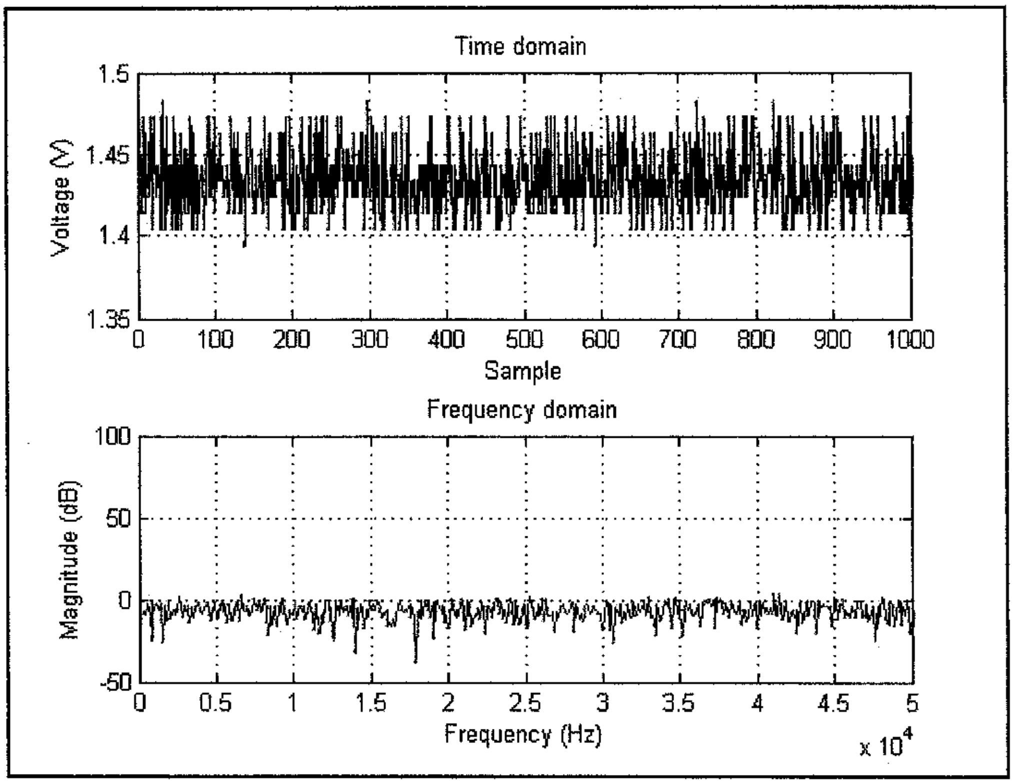

Figure 27: 100% Valve Opening (Trial 2)

Table 13: Data Statistic for 100% Valve Opening (Trial 2)

Min (Time domain)	1.394
Max (Time domain)	1.482
Mean	1.434
Median	1.433
Mode	1.424
Standard Deviation	0.01901
Range	0.08791
Min(Frequency Domain), dB	-38.65
Max (Frequency Domain), dB	63.13

4.2.3 Results: Trial 3

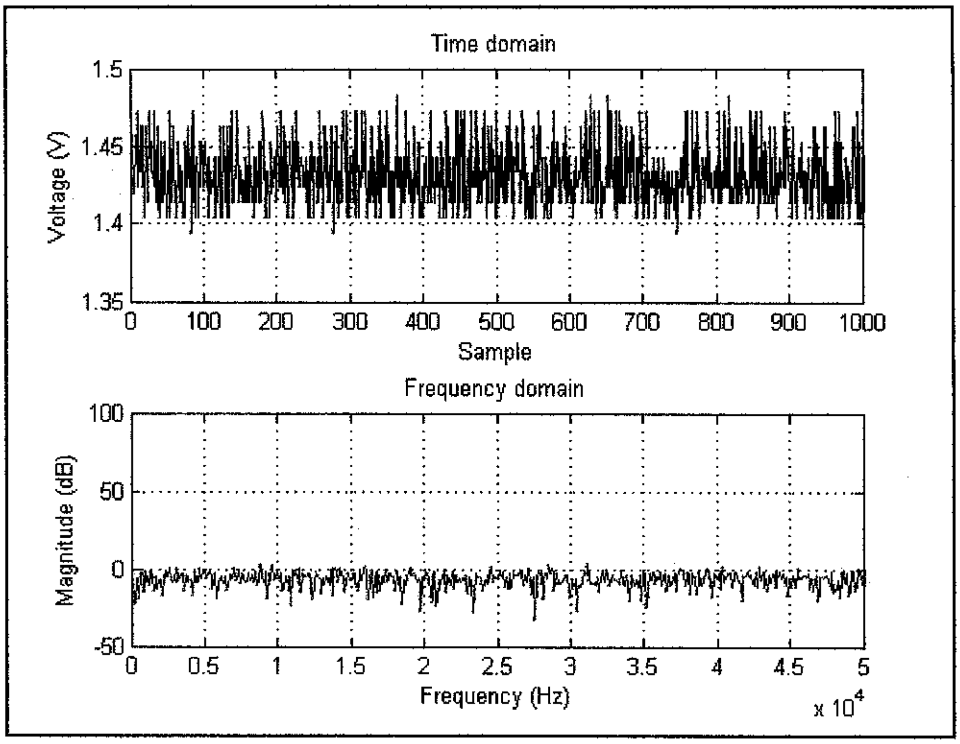

Figure 28: 0% Valve Opening (Trial 3)

Table 14: Data Statistic for 0% Valve Opening (Trial 3)

Min (Time domain)	1.394
Max (Time domain)	1.482
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.01873
Range	0.08791
Min(Frequency Domain), dB	-32.33
Max (Frequency Domain), dB	63.12

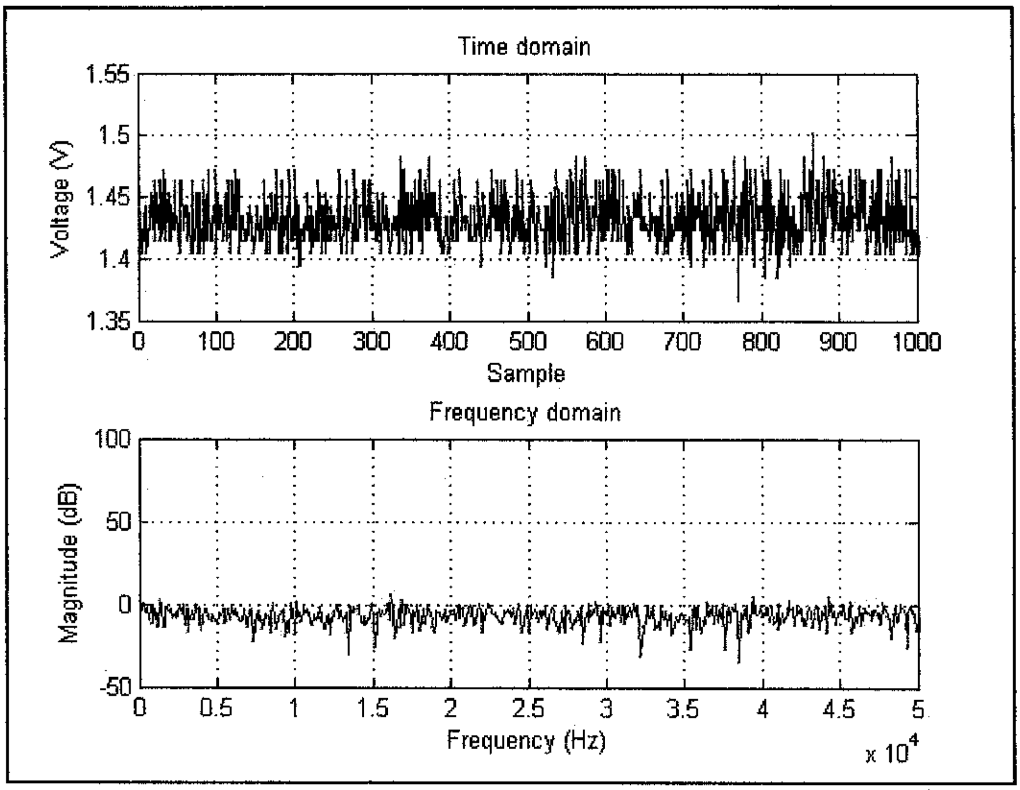

Figure 29: 25% Valve Opening (Trial 3)

Table 15: Data Statistic for 25% Valve Opening (Trial 3)

Min (Time domain)	1.365
Max (Time domain)	1.502
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.01938
Range	0.1368
Min(Frequency Domain), dB	-35.2
Max (Frequency Domain), dB	63.12

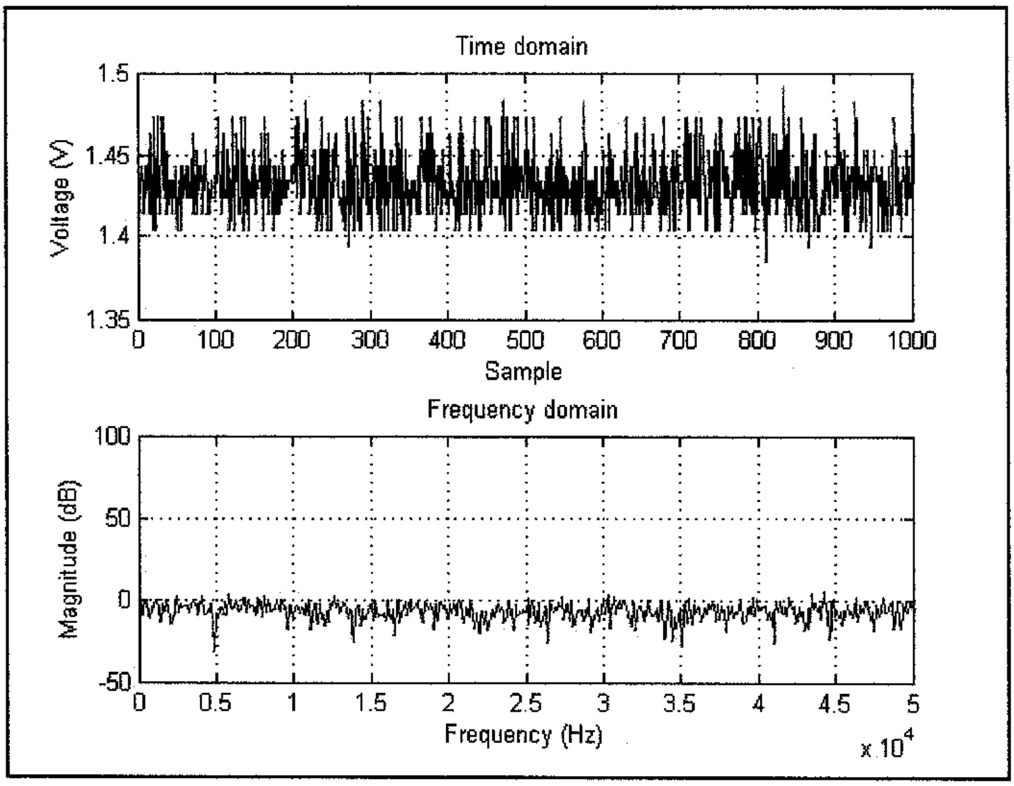

Figure 30: 50% Valve Opening (Trial 3)

Table 16: Data Statistic for 50% Valve Opening (Trial 3)

Min (Time domain)	1.385
Max (Time domain)	1.492
Mean	1.433
Median	1.433
Mode	1.424
Standard Deviation	0.01879
Range	0.1074
Min(Frequency Domain), dB	-31.83
Max (Frequency Domain), dB	63.12

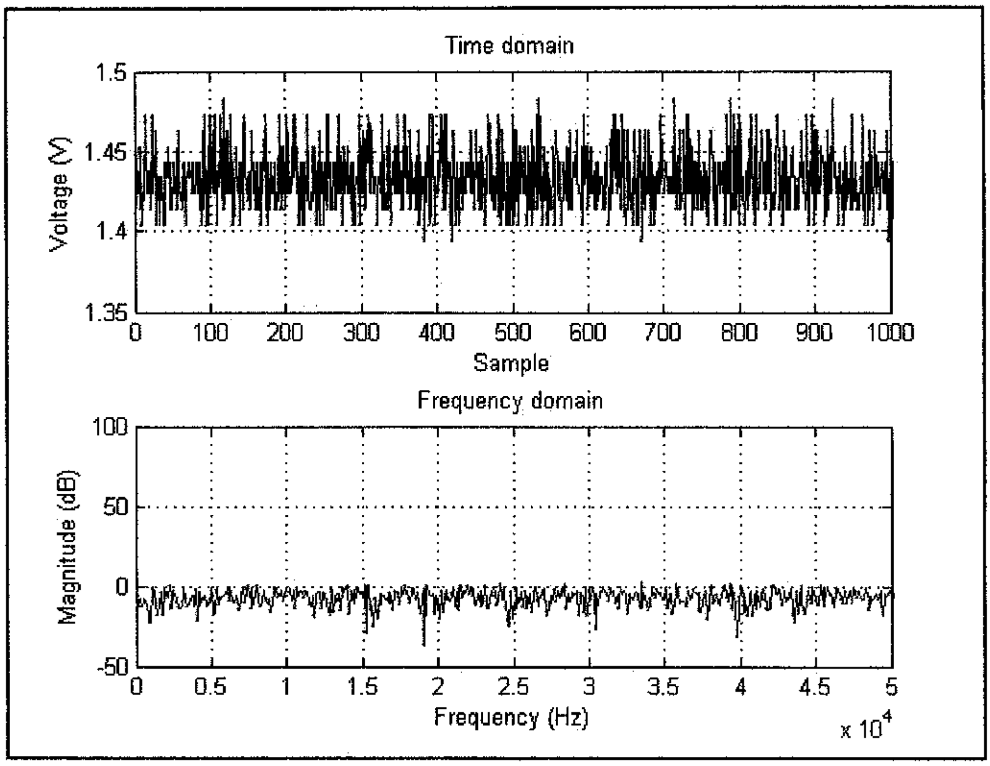

Figure 31: 75% Valve Opening (Trial 3)

Table 17: Data Statistic for 75% Valve Opening (Trial 3)

Min (Time domain)	1.394
Max (Time domain)	1.482
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.01807
Range	0.08791
Min(Frequency Domain), dB	-37.13
Max (Frequency Domain), dB	63.12

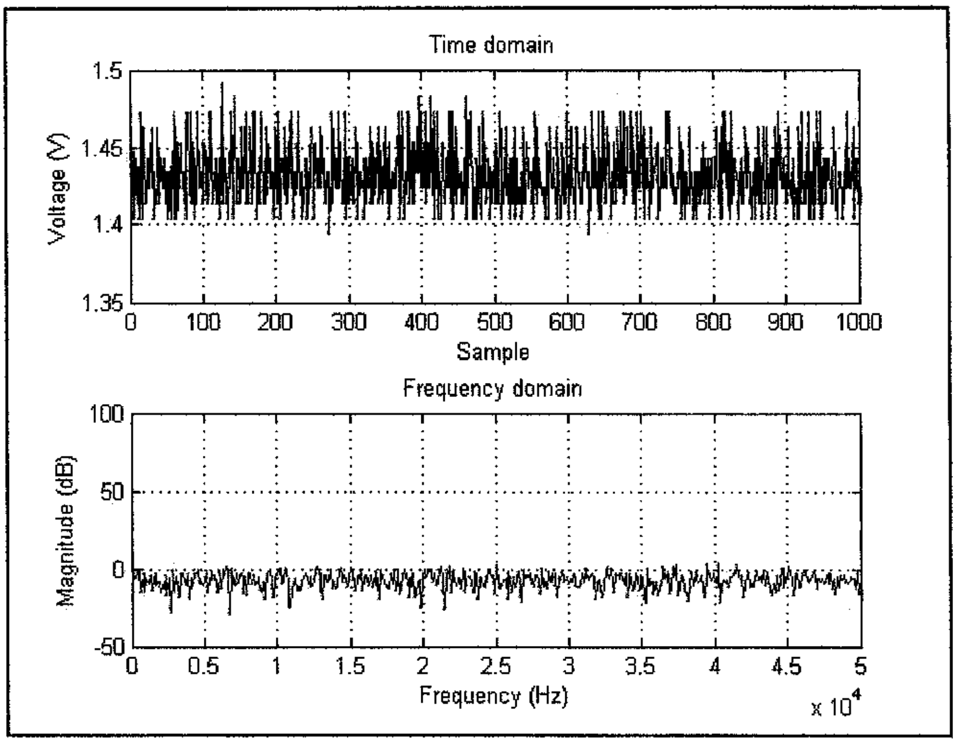

Figure 32: 100% Valve Opening (Trial 3)

Table 18: Data Statistic for 100% Valve Opening (Trial 3)

Min (Time domain)	1.394
Max (Time domain)	1.492
Mean	1.432
Median	1.433
Mode	1.424
Standard Deviation	0.01828
Range	0.09768
Min(Frequency Domain), dB	-29.77
Max (Frequency Domain), dB	63.12

4.3 Discussion: Time Domain Analysis and Frequency Domain Analysis using Fast Fourier Transform

The time domain analysis provides much information such as maximum and minimum amplitude, mean, mode, median, standard deviation and range. For maximum and minimum amplitude, it shows that the samples have minimum and maximum peak of 1.3 to 1.5 which is very stable and consistent in every result analyzed. It also gives consistent result of mean, median and mode which is acceptable.

Fast Fourier Transform (FFT) technique transforms a set of data from time domain to the frequency domain. It displays the frequency components within a time series of data. Based on the analysis from the trials, most of the peak magnitudes of control valves are between 60 to 65 dB while lower peak magnitudes are between -30 to -35 dB.

Therefore, both time and frequency domain analysis shows satisfactory result and analysis since the data are consistent Statistical Analysis will be used to further analyze the data.

4.4 Discussion: Statistical Analysis

Kurtosis analysis, standard deviation, maximum amplitude and root mean square (RMS) are the methods of statistical analysis. It was proven that a healthy control valve possess quality as follow [12].

Table 19: Statistical Analysis Values of Healthy Control Valve

	Healthy Control Valve
Kurtosis	< 3
Standard Deviation	< 0.5
Maximum Amplitude	< 2
Root Mean Square (RMS)	< 2

4.4.1 Kurtosis

Table 20: Kurtosis Values of Test Rig Valve at Different Percentage of Valve Opening

Trial	Percentage of Valve Opening (%)				
	0	25	50	75	100
1	2.9887	2.7967	3.1823	2.8098	2.7432
2	2.9088	2.7656	3.0281	2.8540	2.5378
3	2.7933	2.9757	2.7842	2.8320	2.9075
4	2.7508	2.8723	2.7594	2.7072	2.6691
5	2.4366	2.8283	2.9983	2.7201	2.7188
6	2.8990	2.5934	2.8061	2.6666	2.5475
7	2.7391	3.0846	2.8059	2.8585	2.6921
8	2.7076	2.7038	2.7812	2.7228	2.6835
9	2.6025	2.6439	2.5813	2.5588	2.5859
10	2.7928	2.5256	2.6178	2.7335	2.688

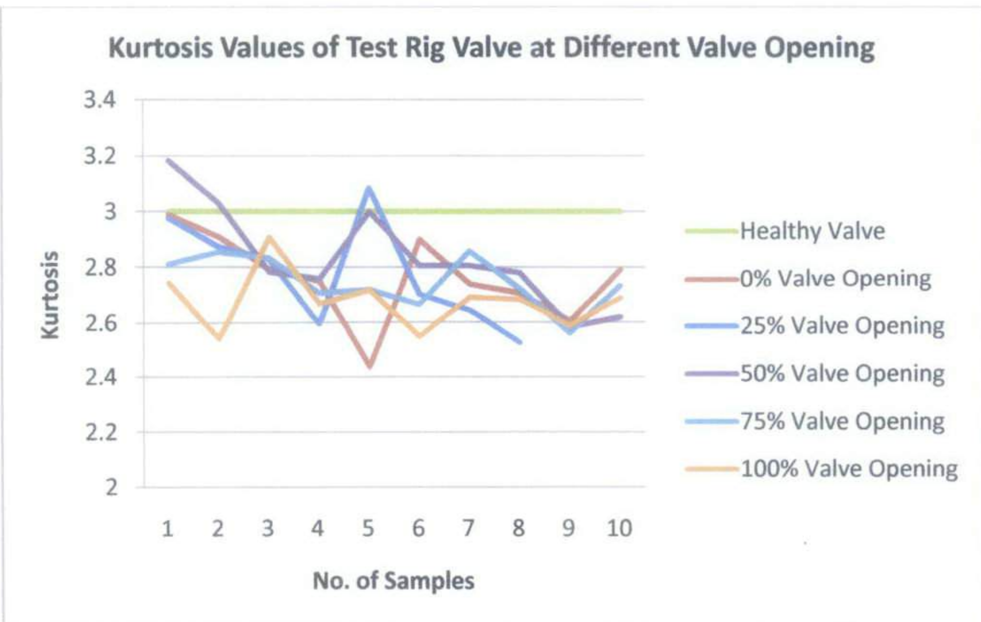

Figure 33: Graph for Kurtosis Values of Test Rig Valve

According to the table above, the kurtosis values are less than 3 for the test rig valve. The result meets one of the requirements of statistical analysis that is to have kurtosis values that are less than 3. This proves that the control valve used on test rig is healthy. On the other hand, if the kurtosis shows values more than 3, it means that the machine is not functioning up to standard. The kurtosis value increases with the machine defect severity.

4.4.2 Standard Deviation

Table 21: Standard Deviation Values of Test Rig Valve at Different Percentage of Valve Opening

Trial	Percentage of Valve Opening (%)				
	0	25	50	75	100
1	0.20950	0.03898	0.02237	0.01955	0.01870
2	0.01861	0.02269	0.02182	0.01855	0.01901
3	0.01873	0.01938	0.01879	0.01807	0.01828
4	0.01856	0.01952	0.01848	0.01867	0.01820
5	0.01925	0.01881	0.01808	0.01834	0.01837
6	0.01831	0.01933	0.01859	0.01861	0.01892
7	0.01827	0.01979	0.01829	0.01856	0.01813
8	0.01840	0.01869	0.01816	0.01853	0.01779
9	0.01831	0.01863	0.01886	0.01789	0.01857
10	0.01766	0.01854	0.01832	0.01765	0.01780

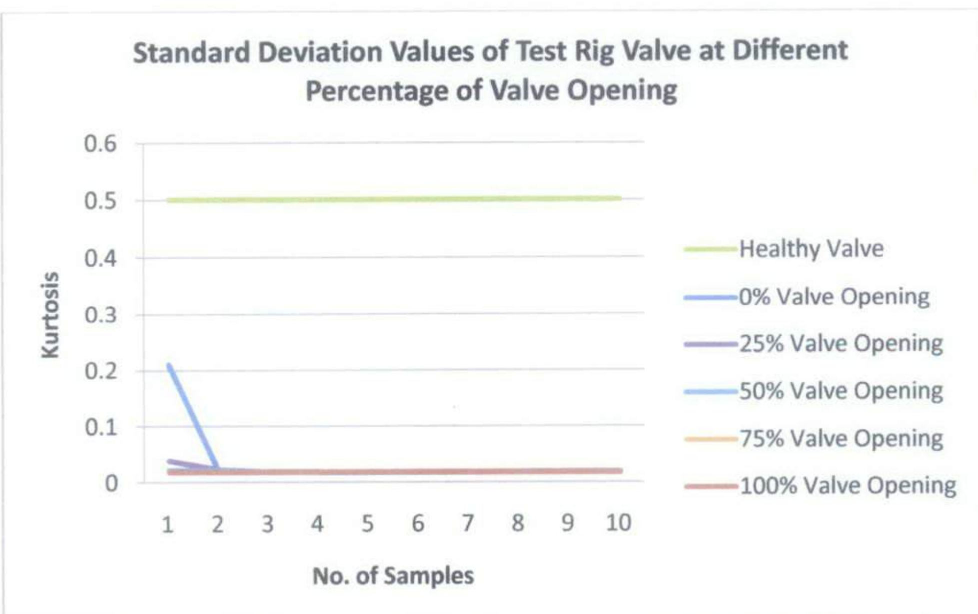

Figure 34: Graph for Standard Deviation Vales for Test Rig Valve

According to the table above, the standard deviation values are less than 0.5 for the test rig valve. The result meets one of the requirements of statistical analysis that is to have standard deviation values that are less than 0.5. This proves that the control valve used on test rig is healthy. Standard deviation shows how much variation or dispersion there is from the mean value. A low standard deviation signifies that the data points are closer to the mean while high standard deviation signifies the data points are spread out over a large value from the mean.

4.4.3 Maximum Amplitude

Table 22: Maximum Amplitude Values of Test Rig Valve at Different Percentage of Valve Opening

Trial	Percentage of Valve Opening (%)				
	0	25	50	75	100
1	1.521	1.58	1.512	1.512	1.482
2	1.492	1.531	1.502	1.482	1.482
3	1.482	1.502	1.492	1.482	1.492
4	1.482	1.482	1.482	1.482	1.482
5	1.482	1.492	1.502	1.482	1.482
6	1.482	1.482	1.482	1.482	1.482
7	1.482	1.502	1.482	1.482	1.482
8	1.492	1.492	1.482	1.482	1.482
9	1.482	1.502	1.482	1.482	1.482
10	1.482	1.482	1.482	1.482	1.482

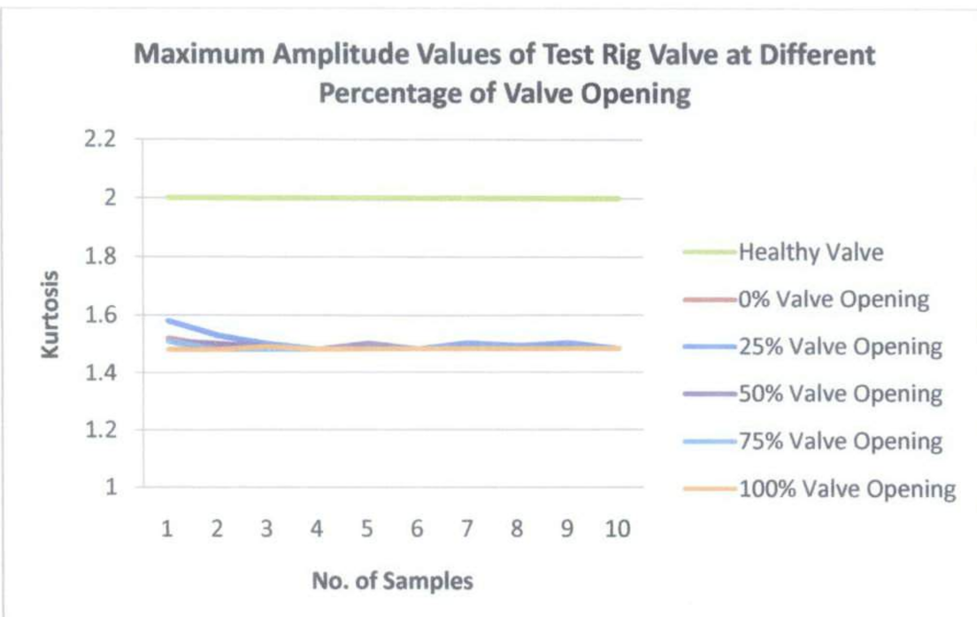

Figure 35: Graph for Maximum Amplitude Values for Test Rig Valve

According to the table above, the maximum amplitude values are less than 2 for the test rig valve. The result meets one of the requirements of statistical analysis that is to have maximum amplitude values that are less than 2. The data in Table 22 also show consistent trend which is well accepted. This proves that the control valve used on test rig is healthy. Amplitude is the measurement of the degree of change in atmospheric pressure caused by sound waves. It is the most obvious measurement that can be seen anytime. During abnormal condition, the maximum amplitude will show values more than 2, it indicates that the control valve is faulty and needs instant maintenance.

4.4.4 Vrms

Table 23: Vrms Values of Test Rig Valve at Different Percentage of Valve Opening

Trial	Percentage of Valve Opening (%)				
	0	25	50	75	100
1	1.4318	1.4319	1.4343	1.4330	1.4328
2	1.4322	1.4324	1.4330	1.4321	1.4345
3	1.4319	1.4321	1.4327	1.4325	1.4325
4	1.4332	1.4328	1.4320	1.4328	1.4324
5	1.4340	1.4329	1.4337	1.4329	1.4335
6	1.4317	1.4342	1.4321	1.4336	1.4332
7	1.4326	1.4329	1.4333	1.4325	1.4335
8	1.4331	1.4334	1.4330	1.4331	1.4331
9	1.4334	1.4337	1.4336	1.4340	1.4329
10	1.4339	1.4338	1.4334	1.4340	1.4329

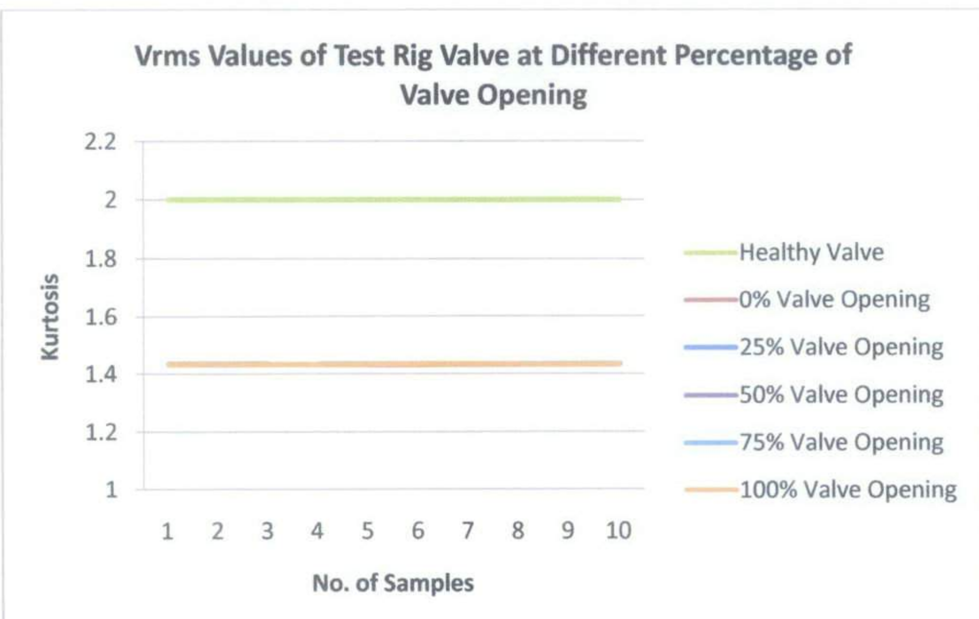

Figure 36: Graph for Vrms Values of Test Rig Valve

According to the table above, the root mean square (RMS) values are less than 2 for the test rig valve. The result meets one of the requirements of statistical analysis that is to have maximum amplitude values that are less than 2. The generation of signal shows that the data are precise in which each value are close to each other. This proves that the control valve used on test rig is healthy. RMS amplitude is the square root of the mean over time of the square of the vertical distance of the graph. The RMS value will be more than 2 if the control valve is damaging. Similar to kurtosis, the RMS value will increase according to the severity of deterioration.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The project has achieved the objectives that is to design and build test rig for experimentation purposes. The test rig was constructed to perform experiments on control valve using Acoustic Emission (AE) technique. It consists of control valve, pump, tanks, pressure and level transmitter as well as controller. Testing had been done on controller to ensure the water level in Calibration Tank can be controlled accurately. AE sensor is used by attaching it to the body of valve using adhesive tapes. An appropriate experimental setup is being designed to enable transmission of AE signals from sensor to MATLAB in computer. The data received from AE sensor will be analyzed using Statistical Analysis which consists of Kurtosis, Standard Deviation, Maximum Amplitude and Root Mean Square (RMS). The outcome of analysis will be compared with the result obtained from experiments performed on healthy valve by another party beforehand. The analysis of the result from test rig shows that test rig valve is in good condition besides the test rig is able to produce result that is meeting requirements.

5.2 Recommendation

For future work, experimentations on unhealthy control need to be done in order to analyze and compare both results from healthy and unhealthy valve. It is advisable to obtain the unhealthy control valve from any PETRONAS manufacturing plant which is willing to contribute their unwanted or redundant control valve. This reason is it is difficult to create the fault manually on control valve.

The outcome of the comparison will be utilized to develop diagnostic software for fault detection of control valve. The diagnostic software will be able to detect faulty control valve during earlier stage.

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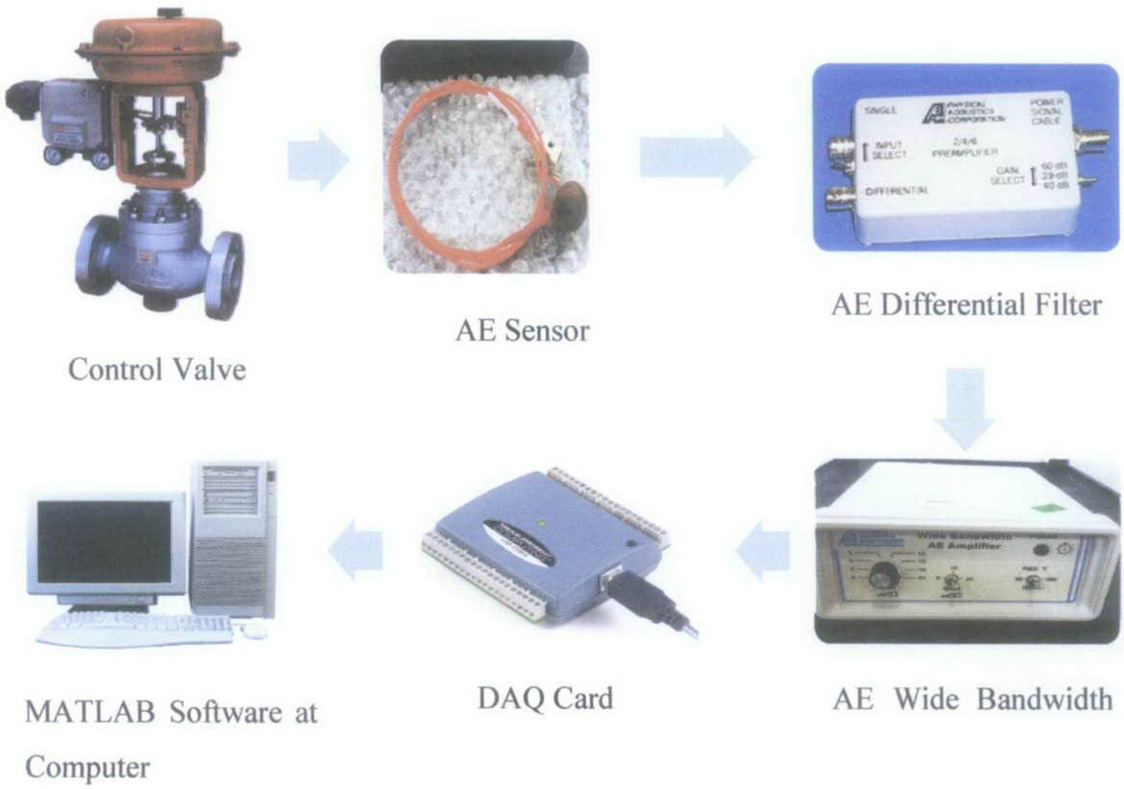
APPENDICES

APPENDIX A: Actual Experimental Setup



APPENDIX B: Gantt Chart for FYP I and FYP II

Gantt Chart for FYP I:

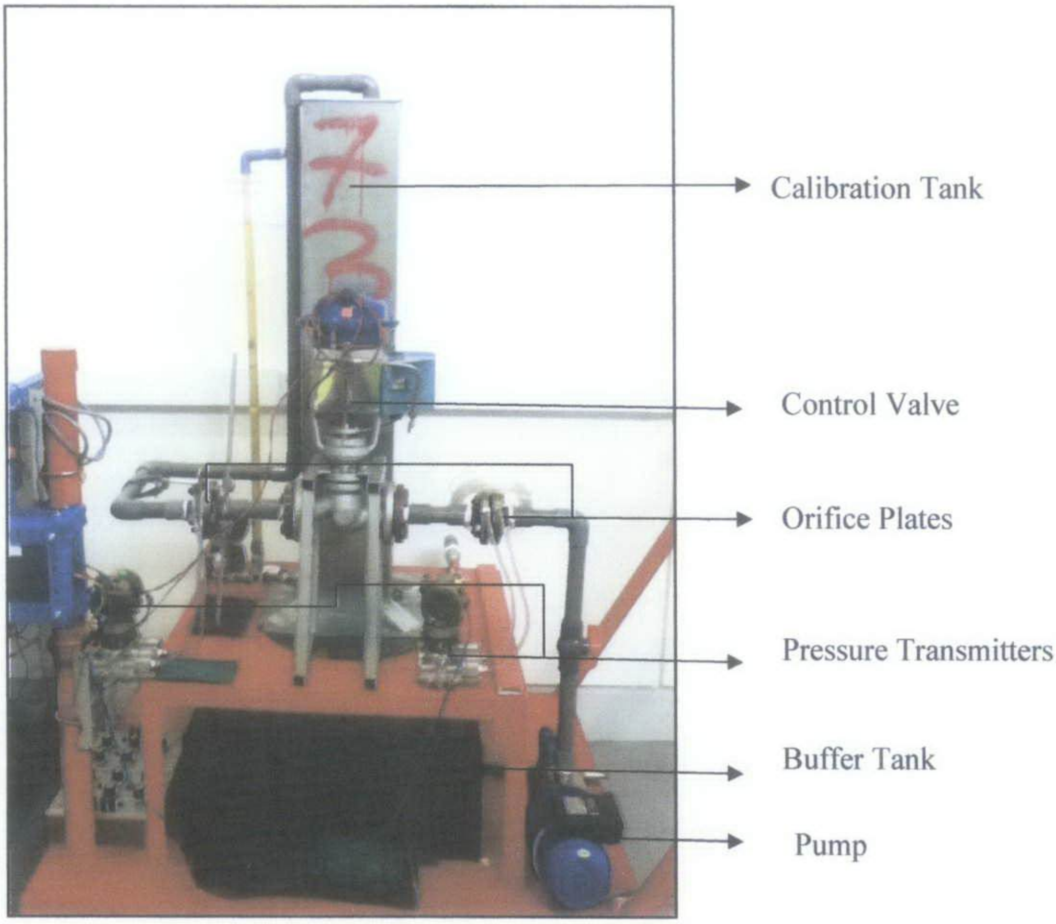
Week Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Activities														
Selection of Project Title														
Literature Review & Research Work														
Submission of Extended Proposal														
Design and Construct Test Rig														
Submission of Interim Report														

Gantt Chart for FYP II:

Week Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Activities														
Testing of Test Rig														
Experimentations on Healthy Control Valve														
Analysis of Data														
Progress Report														
Electrex														
Submission of Draft Report														
Submission of Final Report and Technical Report														
Project Viva														

APPENDIX C: Photograph of Test Rig

Front View:



Side View:

Level Sight Glass

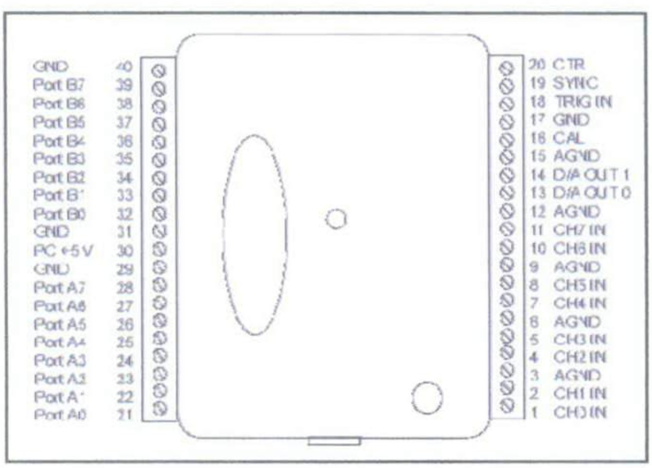
Level Transmitter

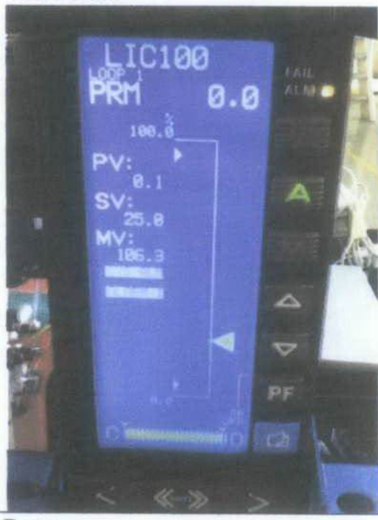
Controller

APPENDIX E: Specifications of DAQ Card

Model: USB-1208FS

Main connector and pin out for 8-channel single-ended mode



3	Pressure (Level) Transmitter 	To measure level of water in the tank Brand: Smar	Calibrated Range:0-800mmH20
4	Controller 	To control water level in the tank To control opening of control valve Brand: Yokogawa	Calibrated
5	Pump 	To pump water into test rig Brand: Ebara Flow rate: 5-45 l/min HP: 0.5	Inspected

8-channel single-ended mode

Pin	Signal Name	Pin	Signal Name
1	CH0 IN	21	Port A0
2	CH1 IN	22	Port A1
3	AGND	23	Port A2
4	CH2 IN	24	Port A3
5	CH3 IN	25	Port A4
6	AGND	26	Port A5
7	CH4 IN	27	Port A6
8	CH5 IN	28	Port A7
9	AGND	29	GND
10	CH6 IN	30	PC+5V
11	CH7 IN	31	GND
12	AGND	32	Port B0
13	D/A OUT 0	33	Port B1
14	D/A OUT 1	34	Port B2
15	AGND	35	Port B3
16	CAL	36	Port B4
17	GND	37	Port B5
18	TRIG IN	38	Port B6
19	SYNC	39	Port B7
20	CTR	40	GND

APPENDIX D: Equipments Specifications

No.	Equipment & Purpose	Specifications	Actions
1	Control Valve 	To control flow of water Brand : Foxboro	Overhauled
2	Pressure Transmitter 	To obtain differential pressure by measuring from both sides of control valve Brand : Yokogawa	Calibrated