EXPERIMENTAL STUDY ON PIPE FLUID INDUCED VIBRATION

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Mechanical Engineering
Universiti Teknologi PETRONAS
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CERTIFICATION OF ORIGINALITY

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

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Muhammad Haziem Bin Abdul Hamid

ABSTRACT

This report discusses the outcome of pipe flow induced vibration. The objective of this project is to have a study on pipe flow induced vibration and establish correlation between vibration signal on various fluid flow conditions with various diameter pipes and different types of fluids which simulates the present of scale in the pipe. This understanding enables to bring benefits to the industry problem in terms of downtime and low-cost. All the equipment, accelerometer, acquisition system has been determined to be used in this experiment. The different size of PVC pipe diameter ranging from 2.494 cm to 4.540 cm and the different types of fluids (water, diesel and palm oil) are used. The result show clearly the range of valve opening effects the acceleration signal on each accelerometer mounted. The vertical and horizontal axis of the accelerometer on the pipe and accelerometer located at different points has shown effect on the acceleration signal reading on the pipe walls. The acceleration signal noises are increasing as the pipe diameter pipe decreasing. The graph patterns are changing as the different types of fluids are used.

ACKNOWLEDGEMENTS

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CHAPTER 1
INTRODUCTION

This chapter discusses about the introduction to this project. It covers the background of study which discusses the background knowledge involved in this project. The problem statement and the reasons that lead to the implementation of this project are also discussed in this chapter.

1.1 Background Study

Flow measurements are used in many application purposes especially in Oil and Gas Industry. Several main purpose of the main purpose of flow meter is providing data for system control, process and analysis. Monitoring of the flow meter could give understanding of the pipe condition at plant. Therefore, the integrity of the pipe can be estimated for maintenance or replacement if necessary. Based on figure 1.1 calcium carbonate scale growth in production tubing obstructs more than 40% of the flowing area of the tubing and prevents access to lower section by well-remediation tools in the North Sea well in the Miller Field [1]. Besides, the same problem occurred at Iran Oil and Gas Industry where the hydrate formation in natural gas transmission pipeline based on figure 1.2. This type of crystals of any type of chemical bond between water molecules into the gas holes are being created and sustained is not dependent on the crystal hydrate hydrogen bonds between water molecules (host molecules) and van deer Waals forces between host molecules [2].

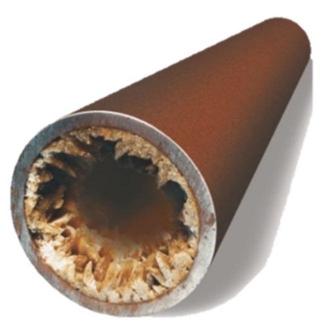


Figure 1.1: The effects of scale in the North Sea well in the Miller Field [1]

Figure 1.2: Hydrate formation in natural gas transmission pipeline [2]

Nowadays, in modern centuries, lot of methods to measure the flow rate, velocity of the fluid flow in pipes and the pressure changes in the pipe. The flow meter can be divided into two methods: intrusive sensing flow meter and non- intrusive sensing flow meter [3]. Intrusive sensing flow meter is where the sensor is required to interrupt the flow. For examples the intrusive sensing flow meter are orifice and venturi meter, flow nozzles, vortex shedding meter, turbine meter and Coriolis flow meter. Besides, there are a number of drawbacks of these types of sensor. Some of these types of sensors are not applicable for certain types of fluid. Besides, high maintenance cost by installing and maintaining the pipe's structural is one of the main drawbacks. In industry production, the maximization of the product and reduction of the cost is important in order to maintain the sustainability.

Another method of measuring the fluid flow can be introduced by non-intrusive sensing flow meter. Based on the studies, there is correlation of pipe vibration level between the flow rate in the pipes. The main advantage of this sensor type is to provide the necessary data without compromising the infrastructure of the pipe [3]. Thus, there is no leakage potential along the pipeline and no moving parts to wear out. In addition, this method can work well with dirty or corrosive fluid as it is measure at external pipe wall. Thus, further investigation of the non-intrusive method as has potential to bring broad application in industries [3].

The Doppler flow meter is one of the instruments uses widely in industry in order to measure the flow rate in pipes. The working principle is where high frequency or ultrasonic is transmitted and this signal is reflected off particulate matter or entrained gas bubbles in the fluid. The frequencies difference between transmitted and reflected signals is measured and correlated into flow rate. The transit- time flow meter has similar working principle as Doppler flow meter but has a slightly difference based on positioning the transmitter and receiver frequency. Even though, the flow meter is non-intrusive sensing flow meter, there is some drawback of this instrument device. The liquid stream must have particulates, bubbles, or other types of solids in order to reflect the ultrasonic signal. A part from that, accuracy is depends on particle-size distribution, concentration as well as any relative velocity between the particulates and the fluid. In this experiment, the correlation of the fluid flow induced vibration is the potential method to develop to overcome these drawbacks of the flow meter in the market.

1.2 Problem Statement

1.2.1 Problem Identification

Pipe carrying fluid often vibrate with changes of fluid flow condition such as flow rate, fluid velocity etc. Any changes deformation of scale inside tube wall would influence the flow rate. This problem can be determined by simply examine the flow rate changes of internal fluid flow rate. At present, there is no data relating the flow condition with the pipe vibration signature. If such data is available, it would provide plant operator to have a better understanding on the fluid flow condition especially if there is any blockage by simply measuring the pipe vibration. Thus, this project is proposed to perform experimental study to establish correlation between fluid flow condition and vibration signature.

1.2.2 Significant of the project

The variation of fluid flow in the pipes will simulate scale formation for this investigation. Beside varying diameter of the pipe, different types of fluids are also used in this project. The experiment is conducting by using a simple experimental test rig.

The correlation between all of the entire specified parameters these parameters will be determined. This understanding enables to bring benefits to the industry problem in terms of downtime and low-cost.

1.3 Objective

To perform comprehensive study on pipe fluid induced vibration and establish correlation between vibration signal and various fluid flow conditions, diameter pipes and different type of fluid used for the experimental analysis.

1.4 Scope of Study

This study will start with literature review related fluid flow induced vibration by varying the fluid flow condition. The design work and developing manual of the testing rig will be conducted next after the completion of the research work from the previous studies. This activity needs to be done before the experimental work of building the simple testing rig can get started. In this experiment, the accelerometers are used in order to provide a vibration signal data effect on the variation of diameter pipe and different type of fluid between the ranges of opening valve. The data will be analyzed and correlation of this parameter different can be established through this study. Due to time constraints, the analysis is done based only on experimental analysis. Future work of this project may consist on modeling and simulation.

1.5 The Relevancy of the Project

By carrying this study, it would provide a better understanding on the internal fluid flow condition especially in the situation where there is any blockage by simple measuring the pipe vibration. This study enables to bring benefits to the industry problem in terms of downtime and low-cost. The internal pipe condition will be determined by simply collecting the data of vibration outside surface of the pipe.

1.6 Feasibility of the Project

The entire project is expected to be completed in 8 months. This will include three main parts which are research, design and develop experimental test rig, and also conduct the experiment. This experiment will be built at Laboratory Block 18. The accelerometer and data acquisition system are available at UTP. Based on the description, the expectation of this project can be achieved within the given period.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses about the theories and paperwork reviews related to this project. Besides that, details on the experimental test rig would also be discussed in this chapter.

2.1 Fluid Structure Interaction

Fluid-structure interaction in piping systems consists of the transfer of momentum and forces between piping and the contained liquid during unsteady flow. Excitation mechanisms are caused by rapid changes in flow and pressure or may be initiated by mechanical action of the piping. The interaction is established in pipe vibration in velocity and pressure of the liquid. Three coupling mechanisms can be identified in FSI: Poisson coupling, friction coupling, and junction coupling [4].

Poisson coupling is related with the circumferential hoop stress perturbations produced by liquid pressure transients that translate to axial stress perturbations by virtue of the Poisson ratio coefficient [4]. The axial stress and accompanying axial strain perturbations travel as waves in the pipe wall at approximately the speed of sound in solid beams. Friction coupling is created by the transient liquid shear stresses acting on the pipe wall; usually it is insignificant when compared to the other two coupling mechanisms. Both Poisson and friction coupling are distributed along the axis of a pipe element.

The most significant coupling mechanism is junction coupling, which results from the reactions set up by unbalanced pressure forces and by changes in liquid momentum at discrete locations in the piping such as bends, tees, valves, and orifices. Thus, the vibration of the pipe is depends on the liquid in the internal pipe and vice versa [4]. The figure 2.1 shows that, the coupling mechanism is related to our experimental study.

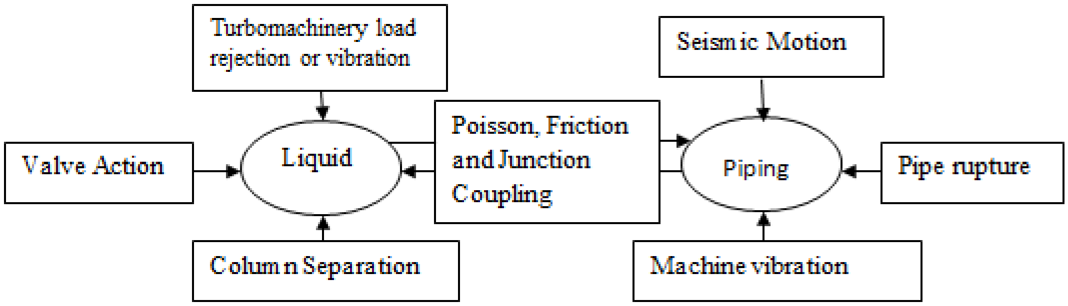


Figure 2.1: Sources of excitation and interaction between liquid and piping

2.1.1 Fluid Flow Region

In the turbulent flow regions eddies and vortices is consisting of various sizes [6]. Eddies kinetic energy will increase as the flow velocity increases and greater pressure instability is influenced. The turbulent kinetic energy in eddies has various amount of energy. The entire energy is loss or transfer as approach the pipe wall. This dissipated energy converted into heat, pressure and pressure fluctuation which is in a form of potential energy [8]. The flow region of the pipe flow is related on this study. Nevertheless, the turbulent flow is complex mechanism and the theory of turbulent flow remains undeveloped [5].

According to Osborne Reynolds, the flow regime was discovered depends mainly on the ratio of inertial forces to viscous forces in the fluid. The transition from laminar to turbulent flow depends on the geometry, surface roughness, flow velocity, surface temperature, and type of fluid, among other things [5].

$$Re = \frac{Inertial\ Forces}{Viscous\ Forces} = \frac{\rho V_{avg} D}{\mu} \qquad (1)$$

Where V_{avg} =Average flow velocity (m/s),

D = Characteristic length of the geometry (m)

$\nu = \frac{\mu}{\rho}$, Kinematic viscosity of the fluid (m^2/s).

It is desirable to have precise values of Reynolds numbers for laminar, transitional, and turbulent flows, but this is not the case in practice. It turns out that the transition from laminar to turbulent flow also depends on the degree of disturbance of the flow by surface roughness, pipe vibrations, and fluctuations in the flow as per described below [5].

$$Re \leq 2300 \quad \text{Laminar Flow}$$

$$2300 \leq Re \leq 4000 \ \text{Transitional Flow}$$

$$Re \geq 4000 \ \text{Turbulent Flow}$$

2.2 Review of Previous Experimental Set Up

2.2.1 Experiment Facility

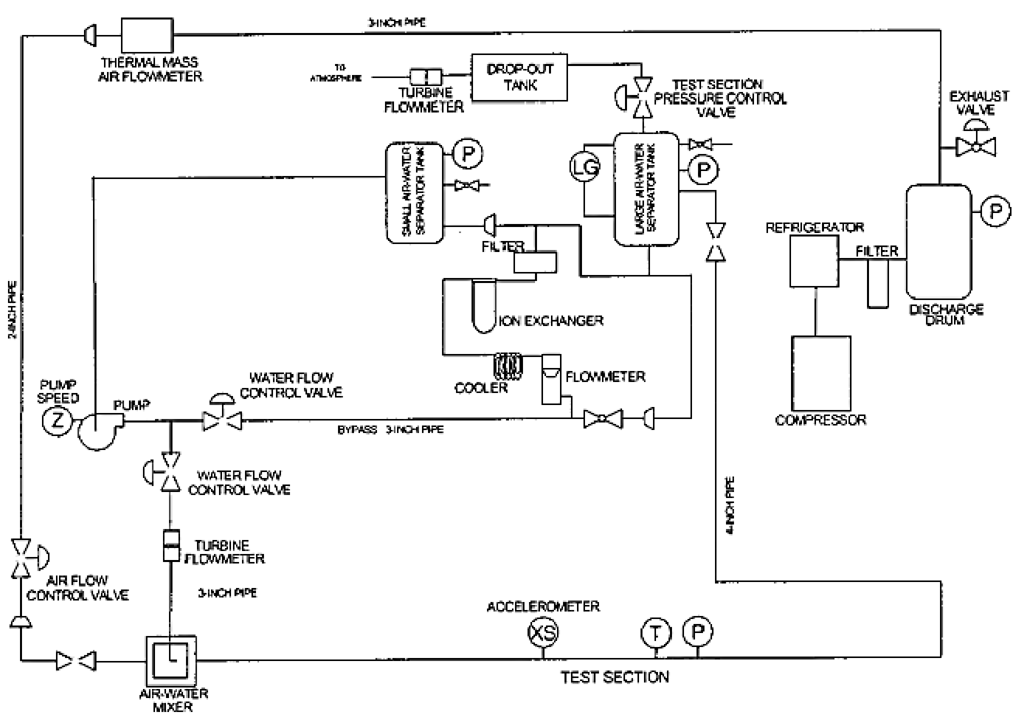


Figure 2.2: Flow Loop Schematic [6]

The figure 2.2 shows experimental set up at Idaho State University was focused on the single phase [6]. Water is circulated through the flow loop centrifugal pump. The flow path for the water is controlled by valves at the outlet of the pump, thus the flow can be controlled through the test section [6].The separator tanks function is to allow any entrained air to separate from the water by gravity. The pressure and water level in the tank are monitored by a pressure gage and level indicator. The bypass loop provides two functions which it provides an alternate path for the water so that the amount of water flowing through the test section can be controlled without changing the pump speed. Beside it is provides a system to cool and clean the loop water as fluid become heated as it passes through the pump. The heated passing the water through a heat exchanger [6]. The water also passes through an ion exchanger and filter to clean the water before reentering the flow path between the first and second air water separator tanks.

The structural support for the test section was designed to minimize any external vibration. The test section was connected to the flow loop through rubber isolators and the pump was mounted to isolate as much vibration as possible. Background noise tests indicated a quiet system and the data required minimal filtering for extraneous noise.

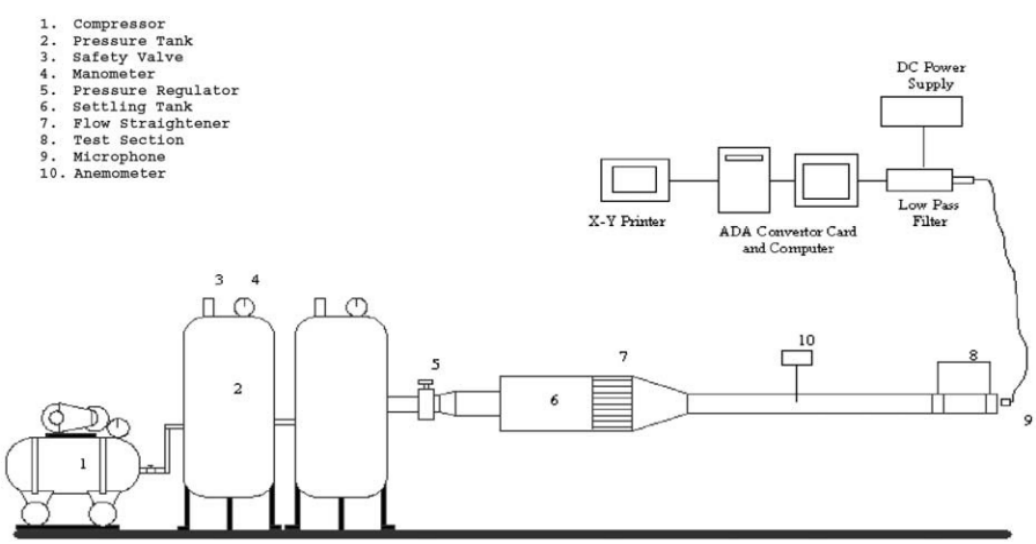


Figure 2.3:Set-up for flow-induced vibration experiments [7]

The experimental set-up in figure 2.3 was used to determine the structural characteristics of vortices produced by the conical-ring enhancement devices in the flow. This experiment used air as fluid flow inside the pipe [7]. The pressure air of the tanks was stopped when reached 950 kPa. In order to prevent any disturbance before the air entered the test section, a flow stabilizer in the settling tank was used to prevent any disturbance before the air entered the test section. For the fully developed flow condition, a pipe with a length of 6 m used in the heat transfer system (for L/D=30) was placed between the anemometer and the test section [7].

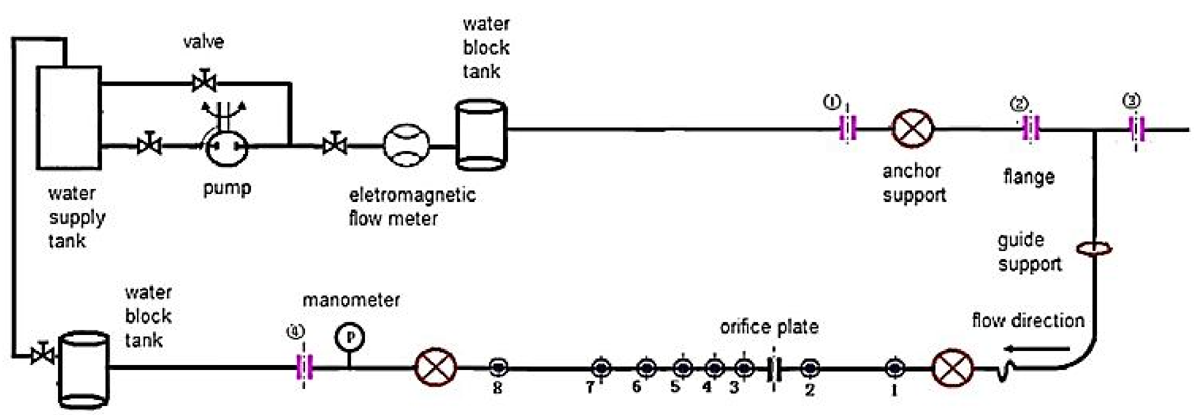


Figure 2.4: Hydraulic Test Loop **[8]**

The experiment set-up was prepared is based on a nuclear piping system that has encountered orifice-induced vibrations as figure 2.4. Driven by a centrifugal pump, this loop is capable of providing 50-t water flow per hour. Centrifugal pump was located separately from the test section to minimize the possible vibration influenced from the ground [8]. Check valves situated on the main loop and bypass loop to control the flow rate. The test section is situated at the fully developed flow area to avoid the influence of valves and pipe elbows. The straight pipe for test section is made of stainless steel with an orifice in the middle, 6-m long, 90-mm diameter, and 2.5-mm thickness, and anchored at both ends. The anchor supports of the test section were strengthened to block off the vibrations transmitted from the test loop [8].

A water block tank was installed at the pump outlet to absorb the pump induced pressure pulsation wave and other acoustic waves before they can enter the test section, and another water block tank has been put at the outlet of the test section to eliminate the backwards propagated acoustic wave. The mounted dynamic pressure transducers were positioned in axial and radial position. The effect of other causes such as support transmitting vibration or acoustic noise from the upstream section was existed in this experiment rig [8]. Initially, fluctuating pressure and acceleration data have been collected for the test section without an orifice plate was collected. Thus, the data was used as a reference point for the test section with an orifice plate.

2.2.2 Methodology of Data Collection

Based on previous experiment, Kim and Kim (1996) have utilized three accelerometers in order to measure the flow rate of the pipe along steel pipe and transporting water through the pipes [9]. The accelerometers are located equal distance from each other along the length of 3 cm inner diameter. As the result, the pipe was run at four flow rates from 0 to 3.08 L/s and excited up to 55 kHz. The moving internal flow caused of excited pipe and change in axial wave number that converted to flow rate. The entire data that has been collected have been analyzed by Gaussian mathematical method and compared to the histogram of actual flow rate. It was found that 12% uncertainty as the rest is coincided with the actual rates [6]. In this study, the same method of measuring the vibration but the location of accelerometer is different.

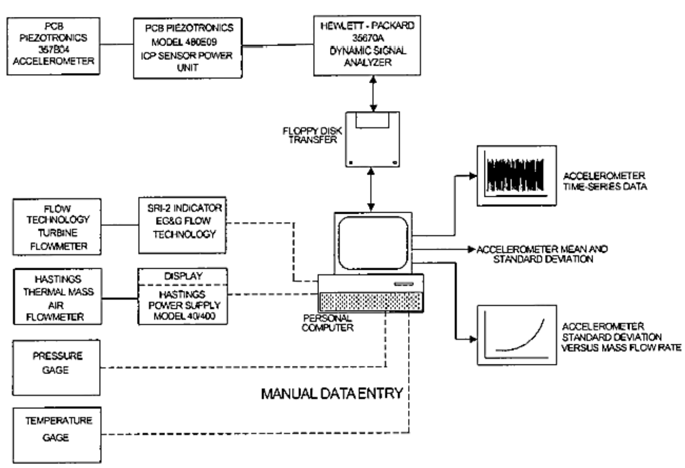


Figure 2.5: Data Acquisition Schematic **[6]**

For the instrumentation in order to collect the data, Evans et al. is used PCB Piezotronics Model 352B68 piezoelectric accelerometer to measure pipe vibration in the test section as shows in figure 2.5. The repeatability of 6 ±0.5% of reading, and linearity of 6 ±0.5% of reading to measure water flow through the test section [6]. The flow loop test section consists of a 6.1m interchangeable section of pipe. There are five different test sections were used. The first three sections, to investigate the effects of material properties on the signal noise–flow rate relationship were nominal 0.0762 m (3 in) diameter schedule 40 pipe made of clear PVC, 304/304 L stainless steel, and aluminum. Two other test sections, to determine the effects of pipe diameter where one of 0.1016-m (4 in) nominal diameter clear PVC and the other of 0.0381m (1.5 in) diameter stainless steel were used. The accelerometer was mounted on the top of the pipe test section 2.34 m (92 in) downstream of the inlet.

The accelerometers were placed on opposite sides of the test section (forward and back) at the seven or five axial locations along the length of the test section by Thompson [10]. In order to measure the average fluid velocity through each test section, the continuity equation was used. The equation is based only on the square of the ratio of the return leg diameter to test section diameter and a measure of the average velocity through the return leg of the flow loop.

The data acquisition system was used by Evans et al to collect the data signal of the test section. The accelerometer data was initially acquired using various sample rates and timespans. Based on these results, a 2 s time span and a sample rate of 2048 samples/s were used to acquire the data presented [6]. The anti-aliasing filters were used to a cut off frequency of 800 Hz. Fast Fourier Transform was used to convert the frequency domain from accelerometer time series data.

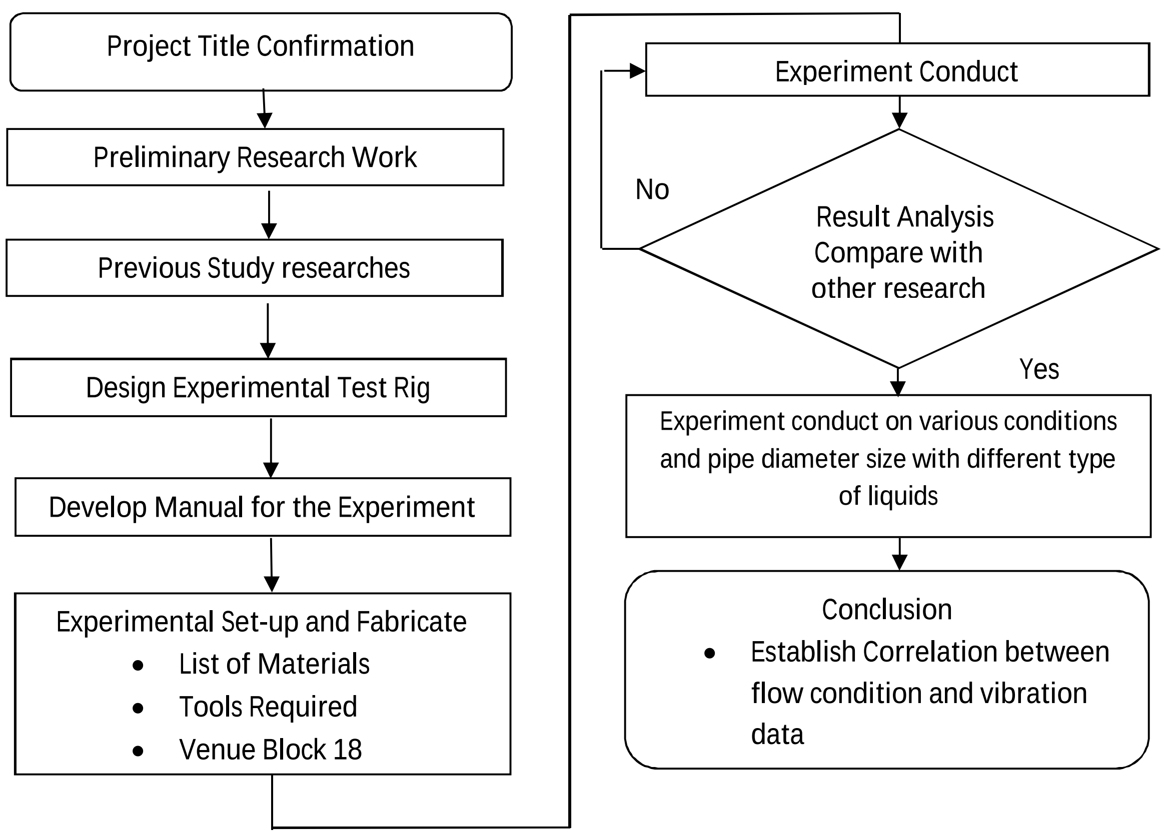
Ten data sets were averaged in the frequency domain and the data were transformed back to the time domain [6]. Initially, 50 data sets were used to compute the average. But only10 data sets were required in the averaging since there is no significant changes at all flow rate that has been set for the experiment. Evans et al was used standard deviation of the frequency domain average time series signal to compare with the flow rate. Fourteen flow rates between 400 and 1,500 l/m were used for all data sets for the test sections. The flow steps were repeatable within a ±2 l/m range. The flow rate was held relatively constant with a maximum fluctuation of ±1 l/m during testing. Therefore, results in a less than 1% error in the flow rate input.

Yakut and Sharin (2004) experimental facility was used a calibrated condenser microphone with a 13 mm diameter, low-pass filter, ADA-converter card (ADA2210 RTD) and a computer to measure pressure amplitude of the vortex wave was. The microphone was placed at a characteristic distance of D/2 from the outlet at the center of the test pipe. For this case, microphone is has limitation of using compared to accelerometer [7].

CHAPTER 3
METHODOLOGY

This chapter discusses about how the project would be carried out. It includes the method of research, tools, components, and software involved.

3.1 Project Flow Chart



After confirmation of the project title, preliminary research is done to study fluid structure interaction and internal flow to find the correlation between pipe flow and vibration. Further research is made to study the experiment facility which is related to the project. Then, experimental test rig is designed and follow by development of the manual for the experiment.

The materials and tools required are listed for the experiment set-up. The confirmation of the experiment location is confirmed at Block 18. After the experiment is fabricated, the experiment is conducted based on the development of the procedure. The result is compared with the previous research which is related in this experiment. If the data is not meet the result expectation, experiment need to be redone until the result is satisfied. Afterward, the conditions are varied based on the discussion of the experiment project. All the data is collected for the establishment of correlation between flow conditions with vibration data.

3.2 Gant Chart

The table 3.1 and table 3.2 below consist of the details of the project through the first semester.

Table 3.1: Gantt Chart for First Semester

No	Details	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■					MID SEMESTER BREAK							
2	Literature review			■	■	■	■		■	■	■	■	■	■	■
3	Design Experimental Test Rig									■	■	■			
4	Develop Manual for the Experiment												■	■	■

Table 3.2: Key milestone First Semester

No	Milestone	Month
1	Title Selection Confirmed	Week 2
2	Completion of Design Experimental Test Rig	Week 11
3	Completion of Develop Manual for The Experiment	Week 14

The table 3.3 and table 3.4 below consist of the details of the project through the second semester.

Table 3.3: Gantt Chart for Second Semester

No	Details	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Experimental Set-up							MID SEMESTER BREAK							
2	Experimental Conduct														
4	Results Analysis														
5	Discussion														
6	Conclusion														

Table 3.4: Key Milestone Second Semester

No	Milestone	Month
1	Completion of Design Experimental Test Rig	Week 11
2	Completion of Experimental Conduct	Week 6
3	Completion of Result Analysis:	Week 10
4	Completion of Discuss	Week 12
5	Completion of Conclusion	Week 14.

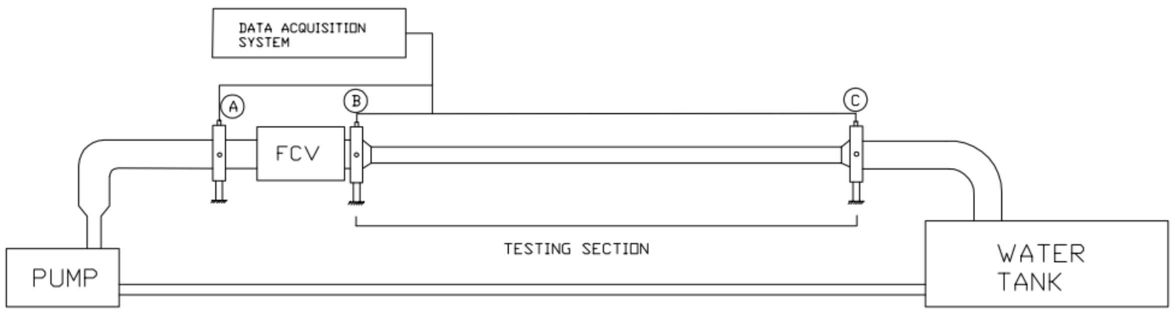
3.3 Experiment Test Facility

3.3.1 Water Loop Flow

Experimental work is conducted as shows schematically in figure 3.1 and figure 3.2 is the actual experiment rig used.Water was circulated through the loop via Pedrollo centrifugal pump with 0.37 kW and driven by 0.5 hp motor. The pump was placed on the rubber pad to reduce the vibrations of the pump. The pump will be propelled at maximum power in this experiment. The pump inlet and outlet is fed by 3.004 cm diameter. After the pump outlet, the pipe diameter is expands to 4.540 cm.

Then the pipe was attached to 4.540 cm and the gate valve is located. The function of the gate valve is used as a scaling simulation in this experiment. The turbulent flow is produced as the variation of the gate valve range opening during the experiment is conducted. Franciscus stated that, the turbulent flow and local flow instabilities produced in the pipe connector, elbows, pumps and valves [11].

After the turbulent flow produced, the flow then passes into a test section, as shown in the figure 3.1. The flow passes test section with 4.540 cm pipe flow to the water tank. Data is collected before the gate valve. The data are also taken before and after the test section to compare the data on the various diameter of the pipe and materials of the pipe. The friction factor of the surface roughness and heat changes is neglected due to small changes in this experiment set-up.



A, B, C.   Accelerometer on vertical and horizontal axis

Figure 3.1: Schematic Diagram of flow loop

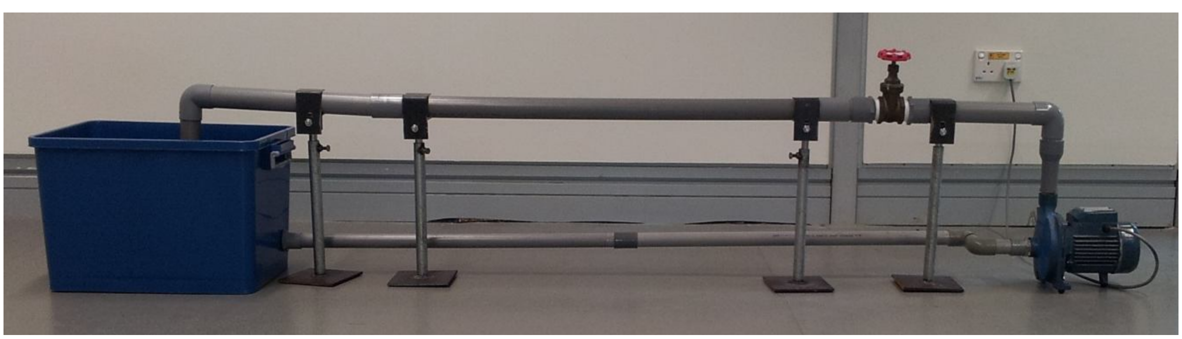


Figure 3.2: Experiment Set Up

3.3.2 Test Sections

The test sections consist of diameter interchangeable sections of 0.0454m, 0.03004m and 0.02494m .The 4.540 cm pipe is reduced by the using socket reducer to connect with different diameter pipe. This section would cause vibration as the turbulent flow produced after passing to the gate valve. This allows the investigation of pipe vibration affects the different range of valve opening and diameter pipe different. The fully developed region is L/D=30, therefore the pipe length is estimated based on the pipe diameter size. Table 3.5 shows the detail of the testing section used in this experiment.

Table 3.5: Internal pipe diameters and wall thickness for experiment with PVC pipes

Pipe Length	D (cm)	t (cm)
120cm	4.540	0.139
75 cm	3.004	0.176
60 cm	2.494	0.103

The test sections are supported from the floor mount using rigid stand to hold the pipe. The pipe support is designed for the accelerometer can be attached at various axial locations between the test sections and the other one will be placed before the gate valve. Besides, the pipe support has been designed with the adjustment of the high and as well as pipe clamp size in order to be fit with different diameter of pipes. The differences of accelerometer position would allow exploring the behavior of the pipe vibration. In this case, the set-up cannot be affected by any vibration from instrumental equipment. Figure 3.3 is conducting experiment equipped with accelerometer on the pipe support for testing section of 4.540 cm diameter pipe. Testing section of 3.004 cm diameter pipe has been used as figure 3.4. Figure 3.5 is conducting experiment equipped with testing section using 2.494 cm diameter pipe

Figure 3.3: Experiment equipped with accelerometer on the pipe support for testing section of 4.540 cm diameter pipe

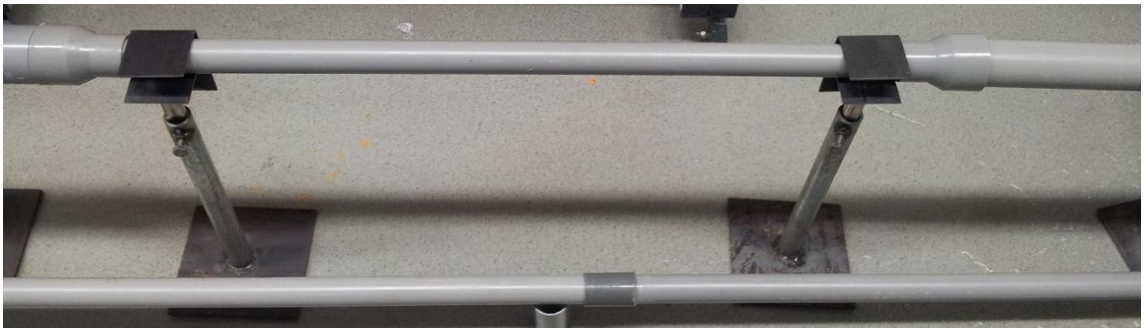


Figure 3.4: Testing Section using 3.004 cm diameter pipe

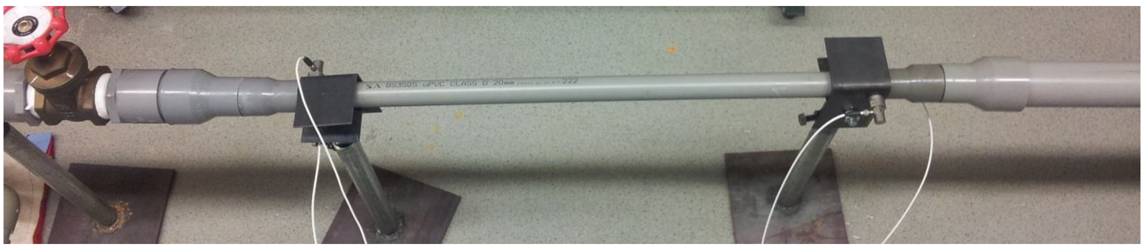


Figure 3.5: Testing Section using 2.494 cm diameter pipe

In the experiment, the gate valve type is used as scaling simulation. It is important to determine the percentage of opening valve during execution. The range of opening gate valve is varying by 10 percent of decrement from 100 percent opening on the variation on the diameter pipe and different type of fluids. All the data is collected to compare and study the effect of each variable with the different range of opening valve. In order to determine the percentage of the valve by apply the scale on the valve handle.

Total angle degree of rotating of handle valve is determined from fully shut off to fully wide open of gate valve. Table 3.6 below shows the calculation to determine the range of opening valve. The clear illustration of the opening valve can be seen in the figure 3.6 below.

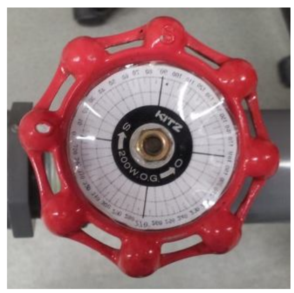


Figure 3.6: 360 degree scale on the valve handle

Table 3.6: The range of opening valve percentage

Opening (%)	Calculation of angle degree	Angle degree of rotating of handle valve	Angle degree of rotating of handle valve
10	0.1 x 2800	280	280^o
20	0.2 x 2800	560	1 full turning and 200^o
30	0.3 x 2800	840	2 full turning and 120^o
40	0.4 x 2800	1120	3 full turning and 40^o
50	0.5 x 2800	1400	3 full turning and 320^o
60	0.6 x 2800	1680	4 full turning and 240^o
70	0.7 x 2800	1960	5 full turning and 160^o
80	0.8 x 2800	2240	6 full turning and 80^o
90	0.9 x 2800	2520	7 full turning
100	1.0 x 2800	2800	7 full turning and 280^o

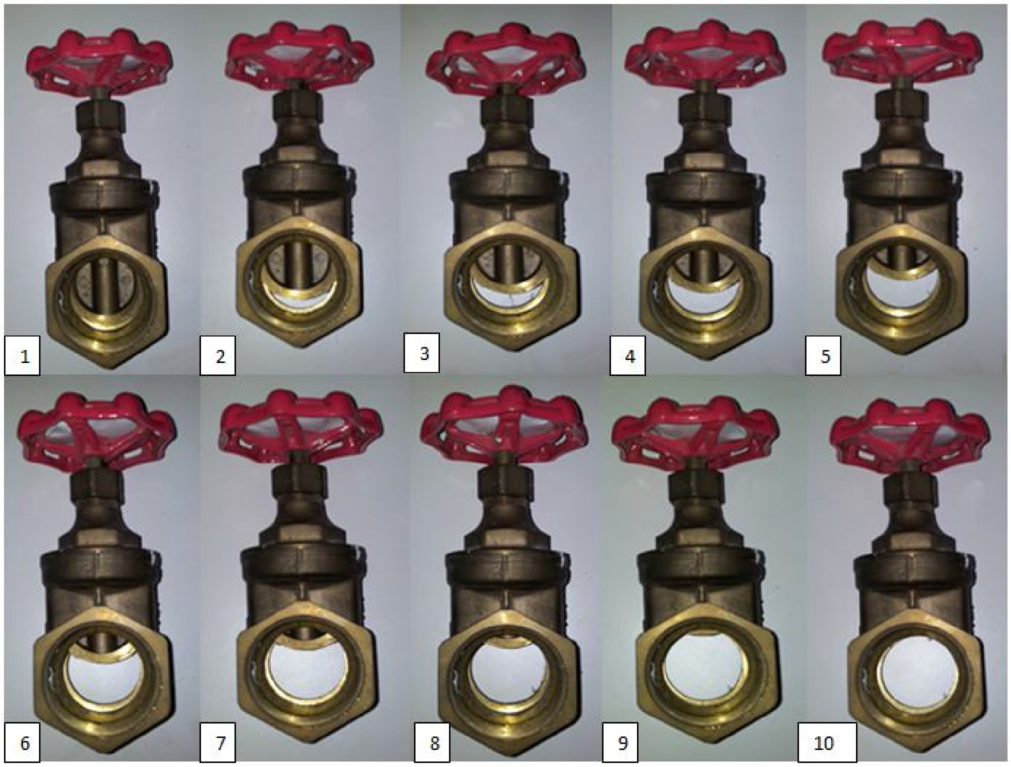


Figure 3.7: Range of valve opening used for experiments 1)10% opening, 2)20% opening, 3)30% opening, 4)40% opening, 5)50% opening, 6)60% opening, 7)70% opening, 8)80% opening, 9)90% opening and 10)100% opening.

The various range of valve opening can be clearly seen based of figure 3.7. The opening of range is simulates to the scale formation inside the pipe walls. The valve opening range shows the increment of 10 percent from 10 percent opening to 100 percent full opening**.**

3.3.3 Fluid

Fluid is one the effect to study in this experiment. There are three different type of fluid and every each has different value of density. The characteristic of the fluid shown is at 20^{o}C from table 3.7 below.

Table 3.7: Type of Fluid Density

Type of fluids	Density (kg/m^3)	Viscosity (kg/ms)
Water	1000	0.001
Diesel	832	0.072
Palm Oil	885	0.106

3.3.4 Test Measurement Transducers

Six PCB Model 352C33 accelerometers with a measurement range of ±490 m/s^2, a resolution of 0.0015 m/s^2, and sensitivity of 10.2 mV (m/s^2) are used to measure pipe wall vibration. Accelerometers are placed on horizontal and vertical axis of the test section before the test section and after the test section. Besides, the accelerometers are placed before the gate valve as figure 3.8 shows the point of accelerometers mounted on the pipe support.

Figure 3.8: Accelerometer position on the pipe clamp support

3.3.5 Data Acquisition and Recording System

A PC-based data acquisition system consisting of a multi-channel National Instruments cDAQ-9172 and Analog Input Modules 9215 is used to collect vibration signal as shown in figure 3.9. The National Instruments LabVIEW 2011 Signal Express software is used to process the data collect. Based on the Evans, the 10 data sets average shows indiscernible compare to 50 data sets used at all flow rates [6].The average of 10 data sets is required for each experiment conducted and samples rate of 25,600 samples/s were used to acquire the data presented. The same accelerometer position, sample rate, and flow rates were used in the testing of the three test sections by using three types of fluids. Standard deviation of the accelerator signal is analyzed to compare with range of opening of the valve.

Figure 3.9: Data Acquisition, cDAQ-9172 and Analog Input Modules 9215

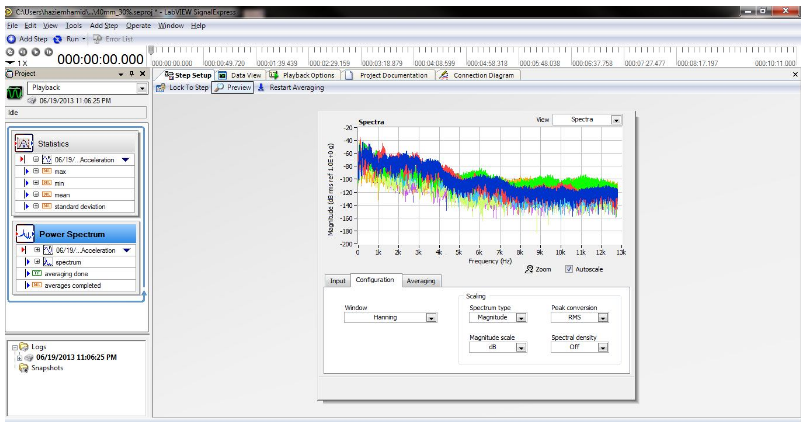
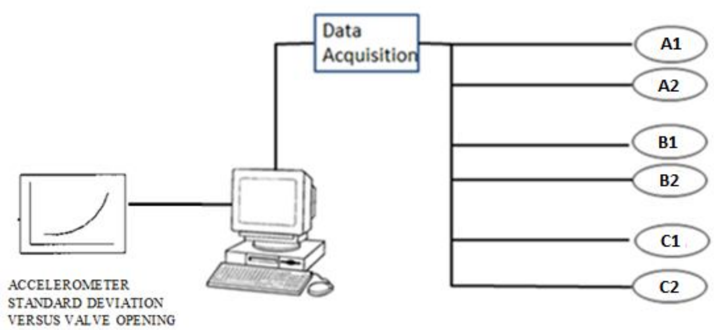


Figure 3.10: National Instruments LabVIEW 2011 Signal Express Interface

National Instruments LabVIEW 2011 Signal Express Interface is installed to collect the signal vibration as figure 3.10.The schematic of data acquisition set-up is used as figure 3.11.



A1, B1&C1: Pipe Vertical Axis of Accelerometer
A2, B2&C2: Pipe Horizontal Axis of Accelerometer

Figure 3.11: The Schematic of Data Acquisition Set- Up

3.4 Experiment Procedure

3.4.1 Measuring the variations of condition flow in pipes

1. Install the diameter pipe of 4.540 cm to the test section.
2. Switch on the centrifugal pump.
3. The valve is adjusted to 10% opening.
4. Let the system flow about 3 minutes to allow the fluid flow in pipes stabilizes.
5. All the reading of the accelerometer sensor is recorded for 10 minutes.
6. Then repeat step 3 until 5 with the range of opening valve by 10% increment.

3.4.2 Measuring the influences of pipe diameter size

1. Switch off the centrifugal pump.
2. Install the diameter pipe of 4.540 cm of PVC pipe to the test section.
3. Switch on the centrifugal pump.
4. The valve is adjusted to fully 10% opening.
5. Let the system flow about 3 minutes to allow the fluid flow in pipes stabilizes.
6. All the reading of the accelerometer sensor is recorded for 10 minutes.
7. Then repeat step 3 until 5 with the range of opening valve by increment of 10%.
8. Then repeat step 1 until 7 with the 3.004 cm and 2.494 cm.
9. All the data is recorded to analyze.

3.4.3 Measuring the influences effects of types of fluids

1. Switch off the centrifugal pump
2. The fluid has been changed by using diesel for the experiment.
3. Then repeat the step of measuring the influences of pipe diameter of turbulent flow from 2 until 9.
4. The fluid has been changed and replaced with the palm oil for the experiment later on.

3.5 Experiment Set Up Requirement

The detail list of the equipment used for the experiment rig construction can be referring as below. The table 3.8 is consists of quantity of material, brand of the equipment and materials, and specification of the equipment.

Table 3.8: Equipment for Experiment Rig

Equipment	Quantity	Brand	Specification	Remarks
Pump	1 Unit	PEDROLLO	Flow rate 90 L/min	To move the fluid
			Head 22-14 m	
			0.37 kW	
			0.5 hp	
Gate Valve	1 unit	KITZ	1.5 in	To control the flow of pipe
PVC Pipe	6m (approximately)	PVC pipe	1.5 in	For Testing Section/ Experiment Set Up
	6m (approximately)	PVC pipe	1 in	For Testing Section/ Experiment Set Up
	2m	PVC pipe	0.75 in	For Testing Section
	2m	PVC pipe	0.5 in	For Testing Section
	1 unit	PVC Tank connector	1 in	To connect pipe with water tank
	3 unit	PVC Elbow	1.5inch	To bend the flow
	3 unit	PVC Reduction Socket	0.5 in X 1.5in	To attach different size of diameter pipe
	3 unit	PVC Reduction Socket	0.75 in X 1.5in	To attach different size of diameter pipe
	3 unit	PVC Reduction Socket	1in X 1.5in	To attach different size of diameter pipe
	2 unit	PVC Thread Socket	1.5in	To attach pipe to gate valve
Water Tank	1 unit	Storage	54 x 39 x 36mm	Store water

Table 3.9: Instrumentation for Data Collection

Equipment	Quantity	Brand	Specification	Remarks
Accelerometer	6 unit	PCB Piezotronic	±490 m/s^2	To collect the data signal from test section
			resolution of 0.0015 m/s2	
			sensitivity of 10.2 mV (m/s2)	
Data Aquistion	2 unit	Analog Input Modules	Model 9215	To collect the data signal from accelerometer
	1 unit	Multi-channel National Instruments	Model cDAQ-9172	To combine data output from analog input
Computer	1 unit	Labview Software	Signal Express 2011	To produce the data

The detail list of the instrumentation equipment used for data collection can be referring as table 3.9 above. It consist of quantity of materials, brand of the equipment and materials used, and specification of the instrumentation used for collecting the data. Table 3.10 show the list of tool required during experiment rig construction.

Table 3.10: Tools Require for Experiment Rig

Equipment	Quantity	Brand	Specification	Remarks
Handsaw Cutting	1 unit	Adamark	-	For pipe cutting
PTFE Tape	2 unit	TTC	12mmx 0.175mm	To seal the pipe

CHAPTER 4

RESULT & DISCUSSION

The results and analysis are presented in two sections. First, experimental data will be compared with a frequency analysis and acceleration signal noise to show that the data follows expected trends. The data that identifies the relationship between acceleration signal and flow rate will then be presented and discussed

4.1 Frequency Domain Analysis by Comparing the Peak Amplitude on Frequency by Different Opening Range

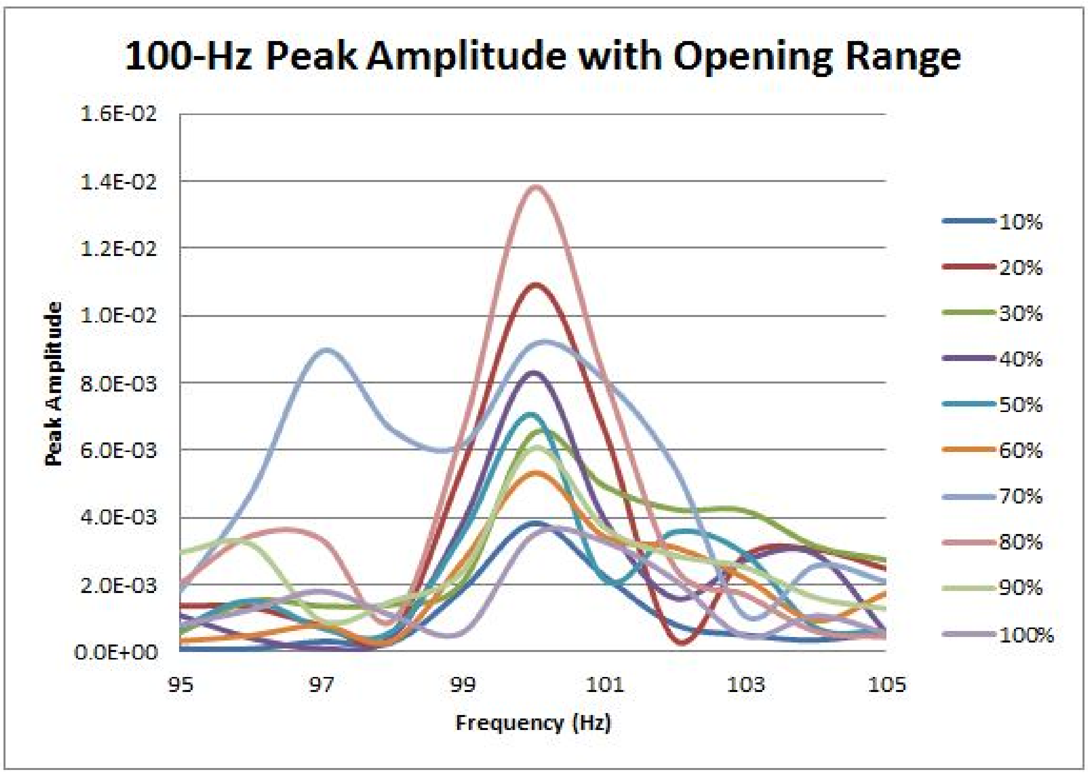


Figure 4.1: Frequency domain plots of the accelerometer data with various opening range for 3.004 cm pipe diameter using water at point A

The figure 4.1 is show the ability to determine the percentage of valve opening range based on natural frequency shifts; frequency domain plots of the accelerometer data for the various flow rates were generated. By comparing the main peaks for each opening range as shown in figure 4.1, the shift of natural frequency due to opening range is no appear. All of the opening range peaks at 100 Hz except for 100%, 70%, 50% and 30% where the peaks are slightly different. These differences in frequency in opening range would make system with a very low sensitivity. This data is shown to contain multiple peaks and difficult to distinguish under various opening range. It is also noted that the certain frequency peaks can be identified because they follow the expected trends. In the other hand, certain opening range appears unpredicted due to random shift. This experiment discovers method another method to determine valve opening range by using the standard deviation of acceleration signal noise to study the correlation of these parameters.

4.2 Acceleration Signal Noise Analysis by Comparing of the Vertical and Horizontal axis signal on the Various Range of Opening

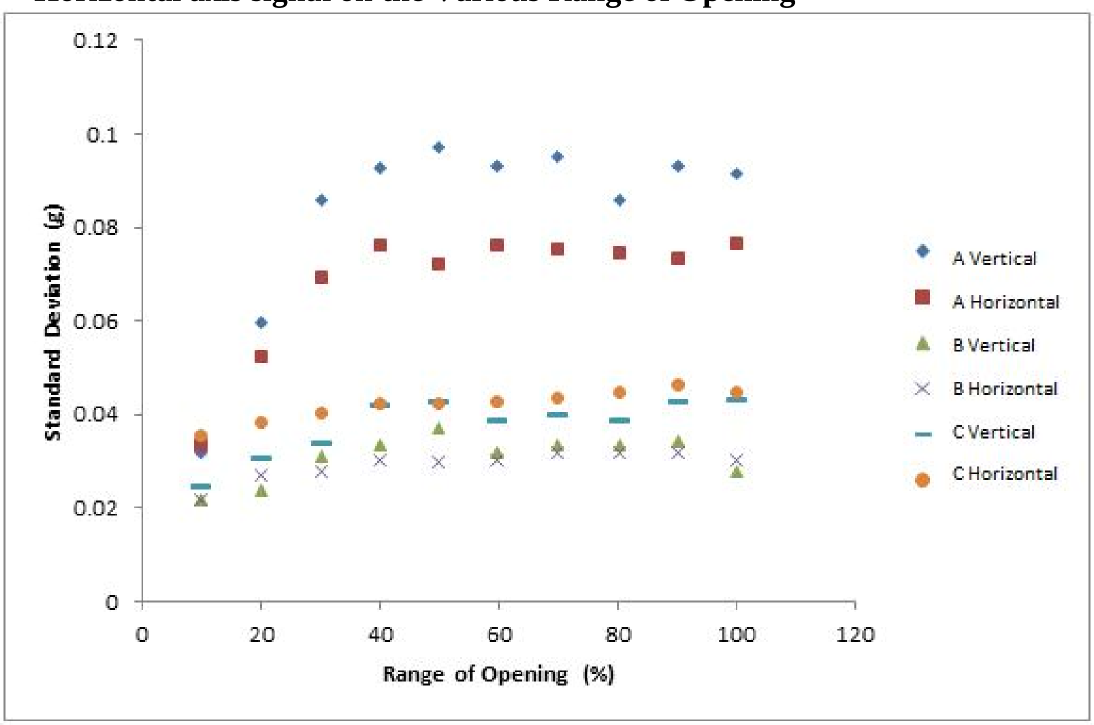


Figure 4.2: Acceleration signal noise versus various range of valve opening of each point for 3.004 cm diameter pipe using water

Based on the figure 4.2, it illustrate the standard deviation of the acceleration averaged time-series signal, versus range of opening of the valve. The average data of 10s of standard deviation signal noise is used to plot the data over various range of opening. From the graph is clearly showed that the signal of the vertical and horizontal axis of B and C are slightly no differences compared to A point. The reason is due to fluid carry turbulent is acting on the vertical axis of point A compared to horizontal as the range of opening is varying. Small opening of the valve lead to collision of fluid on that area as the fluid has been flowed by the pump. The fluid motion induced random turbulent which consists of kinetic energy effect on the vertical axis on pipe wall which depend on the inner valve geometry. Therefore, the correlation of scaling formation size can be understand as the reading on vertical axis is higher compared to horizontal axis signal noise of the pipe wall .

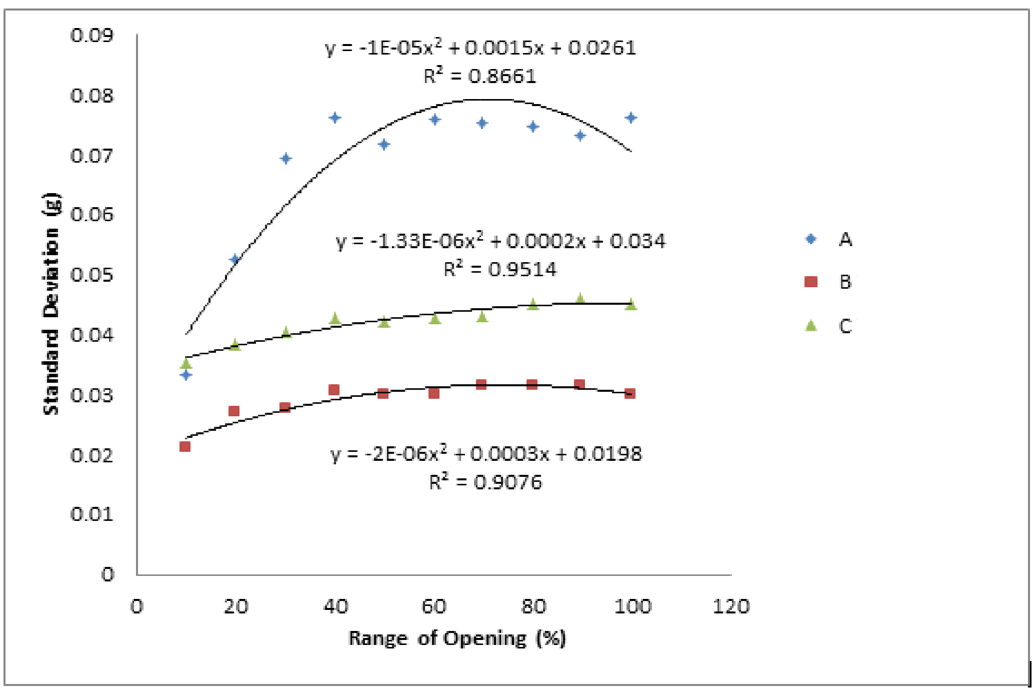


Figure 4.3: Acceleration signal noise versus various range of valve opening of each point for 3.004 cm pipe diameter using water for horizontal axis

From the observation of figure 4.3, the points indicate the experimental data and the solid lines represent a second-order least squared fit to the data. The equation for the curve fit and the R^2 value for the fit are also shown as part of each figure. It shows the value of R^2 for each point is for point B is 0.09076 and point C is 0.9514 but the value at point A is drops to 0.886. This is due to pump pulsation and random turbulent motion on that area compared to points B and C. Besides, point C somehow show high acceleration signal noise as the fully developed of turbulent region in the pipe compared to point B. These readings clearly explain that the accelerometer location mounted can identify the location scaling formation inside the pipe flow.

The figure 4.3 also shows the trend of line curvature, where each of these line have shown peak readings at 75 percent range of valve openings. These curves illustrate that a system has same consistency of the peak acceleration signal noise over various the range of opening valve. The percentage of scaling formation has same trend without effect the location of point measure.

4.3 Acceleration Signal Noise Analysis by Comparing the Range of Valve Opening on Various Accelerometer Mounted Location

The graph has high value of standard deviation of acceleration where the value of point A is highest followed by the values of point C and values point B. A. S. Thompson has stated that the kinetic energy in the flow was converted into dynamic pressure near the wall [10]. The dynamic pressure fluctuations of the flow are porportional to the kinetic energy. Because of turbulent pipe flow induces pressure fluctuations at the wall, the acceleration signal rate produced is high during the experiment conducted.

The fluid velocity is increased as it passes through the small valve opening and produces low pressure dynamics. The low turbulent which consist low kinetic energy as the low volume of fluid produced and low acceleration signal noise is recorded. Therefore the readings of the standard deviation of position B is the lowest compared to the other readings in this experiment.

4.4 Acceleration signal noise analysis by comparing the various range of valve opening on various pipe size diameter

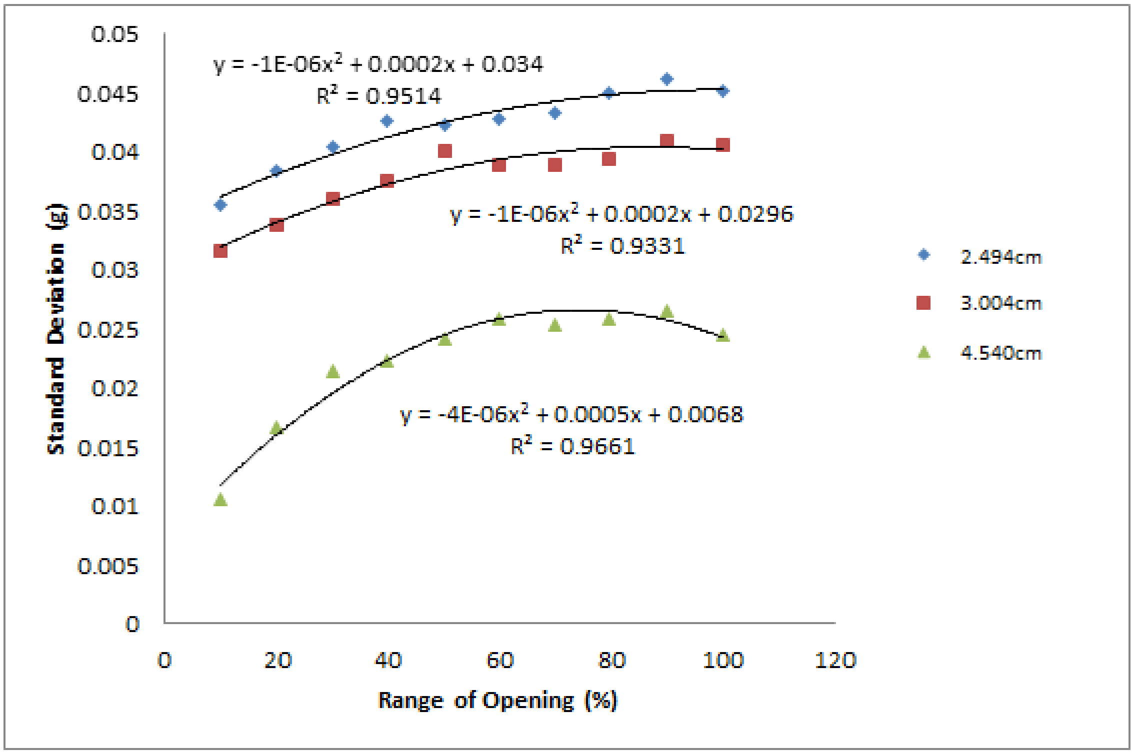


Figure 4.4: Acceleration signal versus range of valve opening of 2.494cm, 3.004cm and 4.540cm diameter pipe using water at point C on horizontal axis

Pipe diameter was another system parameter that was considered to likely change the shape of the acceleration flow rate curve based on figure 4.4. In the experiment, it consisted of comparing the results of a 2.494 cm, 3,004 cm and 4.540 cm diameter pipe. The data for these three diameters are shown in figure 4.4 shows that the 4.540 cm pipe diameter has lowest acceleration signal noise values follow by 3.004 cm and 2.494 cm respectively. It is believe that because of limitations in the flow system which induced different acceleration signal noise. The kinetic energy in pipe smaller pipe gives the higher value of acceleration signal noise. The difference between the curves in this case is more significant as is the change in pipe diameter.

4.5 Acceleration signal noise analysis by comparing the range of valve opening on various fluids

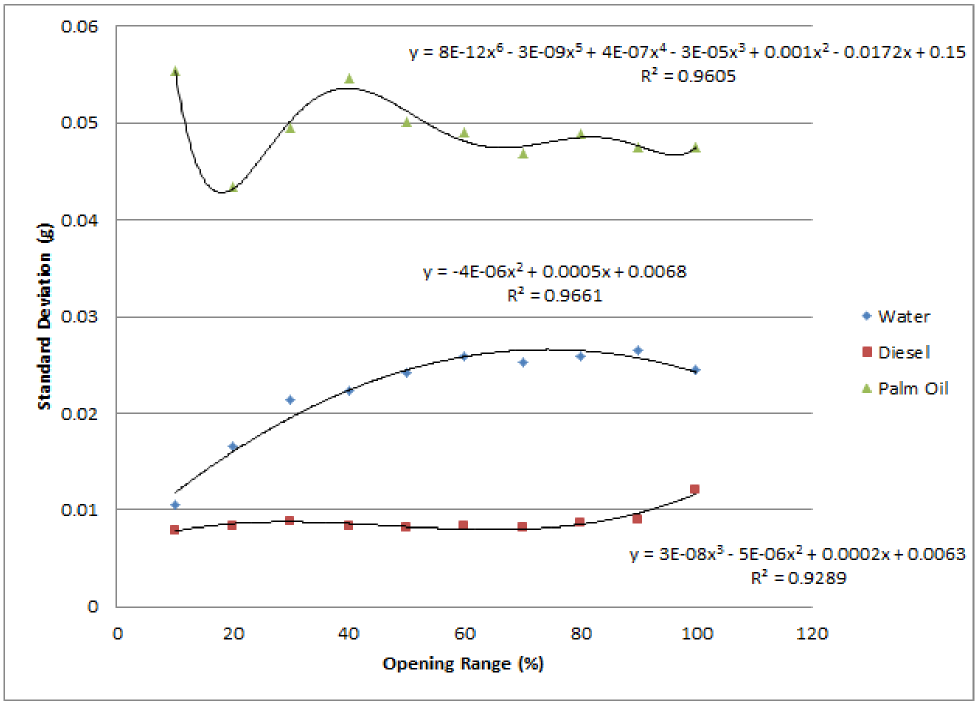


Figure 4.5: Acceleration signal versus range of valve opening of each point for 4.540 cm diameter pipe using different types of fluids at point C horizontal axis

Figure 4.5 shows the comparison of types of fluids effect on the vibration at point C. It is clearly seems shown that the palm oil is the highest and followed by water and diesel respectively. This plot clearly indicates that the types of fluids properties significantly change the shape of the curve and would need to be accounted in the development of a measurement technique. It is believed that due to different characteristic of the fluid which appears different acceleration signal noise. Besides the limitation of instrument pressure transducer and thermometer, the changes of viscosity of the fluid can be study thoroughly for future works. By neglecting the changes of viscosity of the fluid, viscosity of the fluid affect the signal as the highest viscosity value is palm oil and highest vibration acting on the pipe wall. This is illustrates the relationship of viscosity of the fluid proportionally to the acceleration signal on the pipe wall.

CHAPTER 5

CONCLUSION

In the experiment objective of various ranges of opening valve on different diameter and type of fluids has been successfully achieved. It can be concluded that the signal from an accelerometer mounted to the surface of a pipe has a strong relationship to various flow condition of pipe. Based on the measurement, the types of fluids and pipe size diameter have effects on the relationship. There is high signal noise value as the before fluid flow entering the valve due to high turbulent on that particular area. The low signal noise reading appears as the fluid flow through after the valve. It is believed due to low kinetic energy of turbulent. Besides the pipe smaller diameter is proportional to the high signal noise. The different types of fluids show different pattern to each other. The high viscosity is the factor of producing high signal noise between the different types of fluids. The signal noise method has a potential technique to analyze the vibration signal for pipe fluid induced vibration.

CHAPTER 6
RECOMMENDATIONS

In this experiment study only focuses on the various condition flows, difference pipe diameter and type of fluids use in the experiment. Besides, the experiment test rig is important to equip by thermometer and pressure transducer as the characteristic of fluid viscosity is changing by the heat from the pump. Future studies should employ more pipe materials and an extended range of pipe thickness as theoretical it would affect the changes of acceleration signal readings. It is recognized that conducting the several experiments necessary to characterize the fluid induced pipe vibrations are limited because of the limited number of elements that can varied and due to cost both in time and money. The advantage of a numerical study is that it gives the ability to change the fluid and pipe parameters with relative ease. Finally, the monitoring vibration system can be developed to monitor the pipe flow. The advantage of the development is that the low downtime and high cost can be avoided for maintenance purposed at the related industrial.

CHAPTER 7

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