Pipe surge and water hammer experiment

The objective of the work undertaken was consisted two separate experiments, pipe surge and water hammer. These are both caused by a reduction in the flow rate within a pipe. They are two alternative dissipations of the kinetic energy of the fluid into another form of energy – pressure in the case of the water hammer, and potential energy in the case of the surge shaft.

The surge shaft is a device used as a way of avoiding pressure surges which accompany the water hammer effect, by allowing the fluid up a shaft near the valve, thus absorbing the pressure exerted by the fluid on the valve and the pipe. The aim of these two experiments was to compare the results with the theory derived from Newton’s Second Law of Motion.

Introduction

Pipe Surge

Water pipelines and distribution systems are subjected to surges almost daily, which over time can cause damage to equipment and the pipeline itself. Surges are caused by sudden changes in flow velocity that result from common causes such as rapid valve closure, pump starts and stops, and improper filling practices. Pipelines often see their first surge during filling when the air being expelled from a pipeline rapidly escapes through a manual vent or a throttled valve followed by the water. Being many times denser than air, water follows the air to the outlet at a high velocity, but its velocity is restricted by the outlet thereby causing a surge. It is imperative that the filling flow rate be carefully controlled and the air vented through properly sized automatic air valves. Similarly, line valves must be closed and opened slowly to prevent rapid changes in flow rate. The operation of pumps and sudden stoppage of pumps due to power failures probably have the most frequent impact on the system and the greatest potential to cause significant surges.

If the pumping system is not controlled or protected, contamination and damage to equipment and the pipeline itself can be serious. The effects of surges can be as minor as loosening of pipe joints to as severe as damage to pumps, valves, and concrete structures. Damaged pipe joints and vacuum conditions can cause contamination to the system from ground water and backflow situations. Uncontrolled surges can be catastrophic as well. Line breaks can cause flooding and line shifting can cause damage to supports and even concrete piers and vaults. Losses can be in the millions of dollars so it is essential that surges be understood and controlled with the proper equipment.

Water Hammer

Water hammer is the formation of pressure waves as the result of a sudden change in liquid velocity in a piping system. Water hammer usually occurs when a fluid flow start or stops quickly or is forced to make a rapid change in direction. Quick closing of valves and stoppage of pump can create water hammer. Valve closing in 1. 5s or less depending upon the valve size and system conditions causes an abrupt stoppage of the slow. Since liquid is not compressible, any energy that is applied to is instantly transmitted. The pressure waves created at rapid valve closure can reach five times the system’s working pressure. If not considered for, this pressure pulse will rapidly accelerate to the speed of sound in liquid, which can exceed 1200 m/s, causing burst of the pipeline and pump causing as well as fracture in the pipe fittings. For this reason, it is essential to understand under what conditions these pressure waves are produced and reduce the pressure rise as much as possible in a piping system.

Risk assessment

In experimental work there are always some risks to everyone in the lab, hence a health and safety briefing before commencing the labs. These will aware people to the potential risks and the appropriate steps to reduce the likelihood of accidents. Therefore it is crucial to follow the advice of the staff supervising at all times and use the protection equipment provided.

There are different hazard around in the lab, identifying them is important.

There are people doing other experiments at the same time in the lab, make sure what the worst situation can happen with it.

Therefore knowing where is the closest fire exit is important, or the short route to get out the build.

Making sure there are not wire on the floor, incase people fell over it.

Make sure that all the equipments going to be used are safe.

Connecting the equipments correctly to prevent short circuit.

Make sure that the load is not too heavy to left.

When loading the equipment, be careful it might fell on to someone’s toe.

Be aware of anything caught into the equipment

When leaving the lab make sure things are placed back to the original place, and all equipments are switched off.

There are ways to prevent it happen.

Make sure you know the risk of the experiment.

Ask others to help to set up, if not sure what the equipment does.

Do not leave anything unattended.

Not lift anything heavy alone or with equipment’s help.

Wear PPE

Methodology

Pipe Surge

The equipment is set up as shown Figure 4 – 1, where the head loss can be measured. The static head (hs) is recorded through the level on the surge shaft when there is no flow, this will be the datum level throughout the experiment. Then adjusting the gate valve and supply control valve, so that there is a steady of water flowing into the sump tank, where the new reading in the surge shaft is the velocity head (hv). Then the gate valve is close and wait for the oscillations to stop, once it is stopped the lever is opened to operated gate valve and the water level should drop back to the same value for the velocity head.

The value of hs and hv are used to calculate the head loss due to friction which is hs – hv = hf. The flow rate will be needed by closing the dump tank to find the quantity of water in the tank in 60 seconds. More reading should be taken for better accuracy. The flow rate should not be changed for the rest of the experiment.

The maximum and minimum surge heights are measure by the oscillations and the time between the gate valves is quickly closed. The same procedure is repeated but the time taken between the surges passing the datum point is measured.

Water Hammer:

Follow the Appendix 8 -1 to set the equipment up. Where the water hammer flow control valve should be fully open and the surge shaft valve is fully closed, then the measurement of the volumetric flow rate will be taken and thus calculate the flow velocity. The volumetric flow rate can be measure using the same procedure as Pipe Surge. Then the fast acting valve is release to stop the flow of water instantaneously causing a pressure pulse to travel up and down the pipe. This is instantaneous closures which mean closure less than 2L/c, i. e. the valve is closed before a reflected wave reaches the valve again, as this will give us the same pressure rise as an instantaneous closure. These pulses are captured on the oscilloscope where we record the average amplitude, time base and the duration of the pulse. The time lags between the two pressure transducers are also recorded.

For the second half of this experiment, the oscilloscope setting is changed so that the time base setting is increased to 25ms/div. Once it is set up, the same procedure will be repeated as before. The fast acting valve is release and records the average amplitude value and duration of the pulse for the traces that are on the oscilloscope.

Discussion

When comparing the values gained experimentally to the values predicted from the equations, tabulated in table 6 -1, it can be observed that the predicted flow rates and the period of oscillation are both quite similar with their experimental values. The reason for the slight difference in flow rates is partly due to the fact that the equation that we needed to use to find the flow rate had two unknown values in it, Q and hf. The equation that we used was:

The experimental value of frictional head loss is used so that the predicted flow rate can be calculated. The experimental value of Q is used for calculating the theoretical value for frictional head loss by substituting this value in to the equation

However this value would have accumulated more errors and therefore the value would be further away from the experimental value.

From Figure 6 – 1 the time period is about 8 seconds can be observed, whereas the predicted value is 7. 5705 seconds. The discrepancy between the two numbers is most likely to be as a result of human error, when timing the points of max and min surge and also when the surge crosses the datum a time factor needs to be taken into consideration for the time taken between the person saying when to stop the timer and the other person actually pressing the button. This time delay could easily explain the half second difference between the two values.

When comparing the difference between the experimental and predicted values for maximum surge height, the first predicted value is hugely different to the actual value achieved. The reason for this is because the equation gives the max surge from the static head assuming that there are no losses due to friction, therefore the equation will need to be adjust to take into consideration of the effects of friction.

This acts as a correction factor. The reason why it need to be use, because the initial head loss which is due to friction, this is the difference between the static head and the velocity head which is much lower than the static head therefore the initial max amplitude should be taken away.

Throughout the effects of friction is important as dealing with a small bore system whereas in reality surge shafts have diameters in meters. The effects of friction can be assumed negligible, as long as the initial head at the valve is assume the same as at the reservoir. However in the flow frictional losses are relatively large, this can be seen in the fact that there is a large difference between the static head and velocity head. This is partly due to the small diameter of the pipe, as the friction occurs at the walls and if the diameter of the pipe is small then the area in which the fluid is unaffected by the friction is going to be smaller. In order to take the effects of friction in to account, the equation of the max amplitude must start from the velocity head therefore the head loss due to friction can also be taken into consideration.

Water Hammer

From observing Figure 5 -1 the single pressure wave, it varies slightly to the symmetrical smooth square shown as in the Fluid Mechanics Lab Manual. The pulse shown on the oscilloscope showed an unsymmetrical, rough rectangle. This irregularity of the line is as a result of not all the kinetic energy being transferred into potential energy, which is the pressure pulse, and the remaining energy being lost in the form of heat, sound and strain. The strain loss is where the compression of the water tries to expand the pipe, i. e. constant volume therefore change the cross sectional area. The reason of that assumption is the irregular graph as when deriving the equations as assumed that the kinetic energy lost is equal to the energy gained in the form of the pressure pulse, this does not take into consideration the effects of energy losses like heat noise and deformation.

In another part of the experiment, the pressure transducer set up halfway along the pipe. i. e. 1. 5meters away from the valve; this meant there is a time lag between the first wave and the second wave giving the opportunity to measure the speed of sound in water. Firstly the time lag need to be calculated, using 0. 75 per division. In the first set up the time axis for the oscilloscope to 2. 5milliseconds per division, therefore the time lag is 1. 5 milliseconds. The time lag should roughly be a quarter of the time period, so it is as expected the time lag is 1. 5625 milliseconds, which is very close to what experimentally gained therefore suggesting that the value has a slight error but not as significant error that the value can’t be used to work out Ce. As a result the value of the time lag in the equation can be used

An experimental value was given for the speed of sound in the water/pipe system which is 960m/s. This value is used to calculate the time it takes a single pressure pulse to travel a complete circuit of the pipe, in this case 6 meters, and the value is 4. 523 milliseconds compared to 6. 25 milliseconds from the sketch. The difference between these two values could be due to not reading the number of divisions accurately enough and also where the measure of the period from, both of which could have made the result closer to the result calculated. However the discrepancy might also be due to pulse travelling further than it is assumed. For the calculations, assumption is made that it is just travelling the length of the pipe, however the pulse might travel some distance into the header tank instead of being reflected back at the edge. This would then account for why the measured time period is longer, as it could be travelling further than the 6 meters as assumed.

When looking at the table 6 -2 for the water hammer experiment, the predicted and experimental values for the speed of sound in water can be compared, peak pressure and also the duration of the first pulse. There is not much difference the experimental and predicted values of speed of sound in the water/pipe system, this indicates that the experiment went well and that the calculations and therefore the equations used are correct. However there is a significant difference between the peak pressure and also the duration of the pulse, it is quite likely that measured the duration of the pulse inaccurately as determined a rough value for how many divisions the period was, likewise with the amplitude of the pulse. Furthermore when calculating the experimental velocity of sound in water the time lag was used as the time in the equation and the time lag again was measured by reading how many divisions it took up and as a consequence was open to human error in reading it.

From Figure 5 – 1 can be observe several reflected pressure waves. When the pulse is reflected as a low pressure wave, the pulse is going lower than the original start point. The pressure wave is actually reaching the vapour pressure of water and as a consequence the water is boiling and evaporating creating bubbles, this causes a vacuum to be created thus slowing down the pulse. The energy created from the boiling water soon dissipates and when there are not enough bubbles to slow down the pulse then a second pulse starts and the whole process repeats itself. The fact that the pulse is slowed down in the pressure trough by the vacuum and bubbles means that the pulses are not symmetrical.

Studying the Figure 5 – 1 more closely, on the second pulse wave there is a small spike half way between the first pulse and the second pulse can be observe, this could be due to a number of reasons but the most likely is that it is the pulse that has been reflected back from the back of the Header tank. Ideally the experiment would be set up such that the header tank has a big enough change in volume and pressure compared to the pipe that it would act as a discontinuity and reflect the pulse back straight away. However in this case some of the pulse could be being reflected from the back wall of the header tank. This would also explain why there is a difference between some of our experimental and predicted results for the speed of sound in water, as we could be assuming that the distance travelled by the pulse is slightly shorter than it travelled in reality, thus having different values when calculating C. The reason why the amplitudes of the pulse wave are not symmetrical is partly due to the vaporisation of the water and also as a consequence of friction, as the flow is slowed the frictional head loss also reduces and so the head at the valve increases to the equilibrium position of the static head, that is why the amplitudes converges towards the static equilibrium can be observe.

Conclusions

In conclusion, the results between theoretical and experimental were similar and close to each other. However, the slight discrepancies might due to human error, e. g. not recording the time as accurately and also the effects of friction will need to be taken in consideration. Therefore if the experiment is repeated to get better accuracy for the result can be more reliable to use.

References

Fluid Mechanics Laboratory Manual

Level 1 and 2 notes on unsteady flow

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