Rajiv Gandhi University of Knowledge Technologies Basar

LABORATORYMANUAL

FLUID MECHANICS ENGINEERING LAB

LIST OF EXPERIMENTS

CLOSED CIRCUIT VENTURIMETER TEST RIG

&

ORIFECE METER TEST RIG

INTRODUCTION

The Closed Circuit self-sufficient portable package system calibration test rig for Venturimeter is

primarily designed to study and calibrate the flow meter like orifice meter. This unit has several

advantages like this does not require any foundation, trench work etc. so that you can conduct the

experiment keep the unit anywhere in the laboratory.

GENERAL DESCRIPTION

The apparatus consists of (1) Venturimeter (2) Piping system (3) supply pump set (4) Measuring tank

(5) Differential manometer (6) Sump

CONSTRUCTIONAL SPECIFICATION

FLOW METERS

Consists of Venturimeter of size 25 mm provided for experiments. The meter has the adequate cocks

also with them.

PIPING SYSTEM

Consists of a set of G.I. piping of size 25 mm with sufficient upstream and downstream lengths

provided with separate control valves and mounted on a suitable stand. Separate upstream and

downstream pressure feed pipes are provided for the measurement of pressure heads with control

valves situated on a common Pipe for easy operation.

SUPPLY PUMP SET

Is rigidly fixed on sump. The mono block pump with motor, operating on single phase 220/240 volts 50

Hz AC supply.

MEASURING TANK

Measuring tank with gauge glass and scale arrangement for quick and easy measurement.

DIFFERENTIAL MANOMETER

Differential manometer with 1 mm scale graduations to measure the differential head produced by the

flow meter.

SUMP

Sump to store sufficient water for independent circulation through the unit for experimentation and

arranged within the floor space of the main unit.

BEFORE COMMISSIONNING

1. Check whether all the joints are leak proof and water tight.
2. Fill the manometer to about half the height with mercury
3. Close all the cocks, pressure feed pipes and manometer to prevent damage and over loading of the manometer.
4. Check the gauge glass and meter scale assembly of the measuring tank and see that it is fixed water tight and vertically.
5. Check proper electrical connections to the switch, which is internally connected to the motor.

EXPERIMENTS

The apparatus is primarily designed for conducting experiments on the coefficient of discharge of flow meters. Each flow meter can be connected to the manometer through the pressure feed opening and the corresponding cocks.

While taking readings, close all the cocks in the pressure feed pipes except the two (Down-stream and upstream) cocks which directly connect the manometer to the required flow meter, for which the differential head is to be measured. (Make sure while taking reading that the manometer is properly primed. Priming is the operation of filling the manometer upper part and the connecting pipes with water and venting the air from the pipes).

First open the inlet gate valve of the apparatus. Adjust the control valve kept at the exit end of the apparatus to a desired flow rate and maintain the flow steadily.

The actual discharge is measured with the help of the measuring tank. The differential head produced by

the flow meter can be found from the manometer for any flow rate.

A. Determination of Coefficient of Discharge by Using Venturi Meter.

Aim: -

To calibrate a given venturimeter and to study the variation of coefficient of discharge of it with discharge.

Apparatus: -

- Venturimeter,
- Manometer,
- stop watch,
- experimental set-up.

Procedure: -

1. Start the motor keeping the delivery valve close.

2. The water is allowed to flow through the selected pipe by selecting the appropriate ball valve.

3. By regulating the valve control throw flow rate and select the corresponding pressure taping s (i.e. of venturimeter).

4. Make sure while taking readings, that the manometer is properly primed. Priming is the operation of filling the manometer's upper part and the connecting pipes with water by venting the air from the pipes. (Note down the difference of head "h" from the manometer scale.)

5. Note down the time required for the rise of 10cm (i.e. 0.01m) water in the collecting tank by using stop watch.

Calculate actual discharge using below formula.

Discharge: - The time taken to collect some 'x' cm of water in the collecting tank in m³/sec. (Qact)=

$$\frac{A \, X R}{t}$$

where

A = area of the collecting tank in m² (0.3m X 0.3m)

R = rise of water level taken in meters (say 0.1m or 10cm)

t = time taken for rise of water level to rise 'r' in 't' seconds.

6. Using difference in mercury level "h"

calculate the theoretical discharge of venturimeter by using following expression.

$$Q_{th} = a_1 a_2 \sqrt{2gh} / \sqrt{a_1^2 - a_2^2}$$

Where,

h- Difference of head in meter of water = $(h_1-h_2)(S_n/S_o - 1) = (h_1-h_2)\, 12.6/100$ m

a1 - area of venturi at inlet

a2 - area of venturi at throat

g -Acceleration due to gravity

d1 -Inlet diameter in meters.

d2 -Throat diameter in meters.

7. Calculate the coefficient of discharge of venturimeter (Cd):

$$Cd = Qact / Qth$$

8. Repeat the steps 3 to 7 for different sets of readings by regulating the discharge valve.

S. No.	Venturi inlet diameter d1	Throat Diameter d2
1.	25mm	13.5 mm

TABULAR FORM

S. No.	Time for (10 cm) raise of water level in sec.	Actual discharge Qa	Differential head in mm of mercury			Theoretical discharge = Qt	Cd = Qt/Qa
			h1	h2	h		
1							
2							
3							
4							
5							

Result: -

B. Determination of Coefficient of Discharge by Using Orifice Meter.

Aim: -

To calibrate a given Orifice meter and to study the variation of coefficient of discharge of it with discharge.

Apparatus: -

- Orifice meter,
- manometer,
- stop watch,
- experimental set-up.

Procedure: -

1. Start the motor keeping the delivery valve close.
2. The water is allowed to flow through the selected pipe by selecting the appropriate ball valve.
3. By regulating the valve control the flow rate and select the corresponding pressure tapings (i.e. of orifice meter).
4. Make sure while taking readings, that the manometer is properly primed. Priming is the operation of filling the manometer's upper part and the connecting pipes with water by venting the air from the pipes.

- Note down the difference of head "h" from the manometer scale.

5. Note down the time required for the rise of 10cm (i.e. 0.01m) water in the collecting tank by using stop watch.

- **Calculate actual discharge using below formula.**

Discharge: - The time taken to collect some 'R' cm of water in the collecting tank in m^3/sec.

$$Qact = A \times R / t$$

Where:

A = area of the collecting tank in m^2 (0.3m X 0.3m)

R = rise of water level taken in meters (say 0.1m or 10cm)

t = time taken for rise of water level to rise 'r' in 't' seconds.

6. Using difference in mercury level "h"

- **calculate the theoretical discharge of venturimeter by using following expression.**

$$Qth = a1a2\sqrt{2gh} / \sqrt{a1^2 - a2^2}$$

Where,

h- Difference of head in meter of water = (h1-h2) (Sn /So – 1) = (h1-h2) 12.6/100 m

a1 - area of orifice at inlet

a2 - area of orifice.

g -Acceleration due to gravity

d1 -Inlet diameter in meters.

d2 -Throat diameter in meters.

7. Calculate the coefficient of discharge of Orifice meter (Cd):

$$Cd = Qact / Qth$$

8. Repeat the steps 3 to 7 for different sets of readings by regulating the discharge valve.

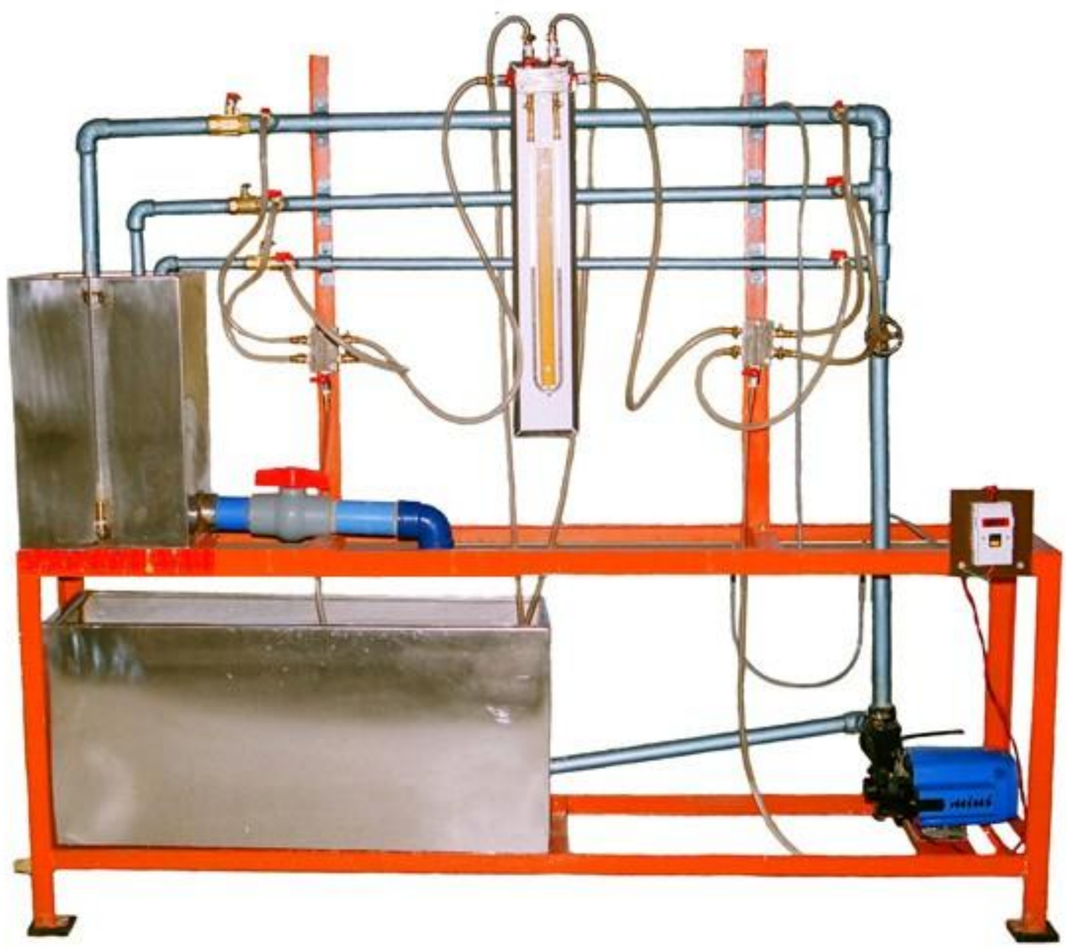
S. No.	Venturi inlet diameter d1	Throat Diameter d2
1.	25mm	14 mm

TABULAR FORM

S. No.	Time for (10 cm) raise of water level in sec.	Actual discharge Qa	Differential head in mm of mercury			Theoretical discharge = Qt	Cd = Qt/Qa
			h1	h2	h		
1							
2							
3							
4							
5							

Result:

2.CLOSED CIRCUIT PIPE FRICTION APPARATUS



INTRODUCTION

The Closed Circuit Self- sufficient portable package system Apparatus for frictional losses in pipes is primarily designed for conducting experiments on the frictional losses in pipes of different sizes. This unit has several advantages like, this does not require any foundation, trench work, etc, and so that you can conduct the experiments keeping the unit anywhere in the laboratory soon after receiving the equipment.

GENERAL DESCRIPTION

The unit consists mainly of 1) Piping System 2) Measuring Tank 3) Differential Manometer 4) Supply

pump set 5) Sump.

CONSTRUCTIONAL SPECIFICATION PIPING SYSTEM

Piping System of size 15 mm, 20 mm and 25 mm dia. With tapings at 01-meter distance and a flow

control valve.

MEASURING TANK

Measuring tank is provided to measure the discharge of water from the unit.

DIFFERENTIAL MANOMETER

Differential manometer with 01 mm scale graduations to measure the loss of head in the pipe line.

SUPPLY PUMP SET

Supply pump set is rigidly fixed on the sump. The pump set is mono block pump with 0.5 HP motor

operating on single phase 220 volts 50 Hz AC supply.

SUMP

Sump is provided to store sufficient waters for independent circulation through the unit for

experimentation and arranged within the floor space of the main unit.

BEFORE COMMISSIONING

- Check whether all the joints are leak proof and watertight.

Close all the cocks on the pressure feed pipes and Manometer to prevent damage and overloading of the manometer.

- Check the gauge glass and meter scale assembly of the measuring tank and see that it is fixed water tight and vertical.
- Check proper electrical connections to the switch, which is internally connected to the motor.

EXPERIMENTS

The apparatus is primarily designed for conducting experiments on the frictional losses in pipes of different sizes. Three different sizes of pipes are provided for wide range of experiments. Each individual pipe can be connected to the Manometer through the pressure feed pipes having individual quick operating cocks. While taking reading close all the cocks in the pressure feed pipe except the two (upstream and downstream) cocks, which directly connect the manometer to the required pipe for which the loss in head has to be determined. (Make sure while taking readings, that the manometer is properly primed.

Priming is the operating of filling the Manometer upper part and the connecting pipes with water venting the air from the pipes). First open the inlet gate valve of the apparatus. Adjust the control valve kept at the exit end of the apparatus to a desired flow rate and maintain the flow steadily.

The actual discharge is measured with the help of the measuring tank. For each size of the pipe the area of cross section of flow can be calculated from the known diameter of the pipes.

From these two valves and the average velocity of stream through the pipe can be calculated.

The actual loss of head is determined from the Manometer readings. The frictional loss of head in pipes is given by the Darcy's formula

The friction coefficient indicates 'f '.

2.Determination of Head loss Due to Friction in Pipes.

Aim: -

To calculate the Darcy's friction factor for a given pipe line.

Apparatus: -

- experimental set-up,
- stop watch.

Procedure:-

1. Start the motor keeping the delivery valve close.
2. The water is allowed to flow through the selected pipe by selecting the appropriate ball valve.
3. By regulating the valve control the flow rate and select the corresponding pressure tapings.
4. Make sure while taking readings, that the manometer is properly primed. Priming is the operating of filling the Manometer upper part and the connecting pipes with water venting the air from the pipes.

- Note down the loss of head "hf" from the manometer scale.

5. Note down the time required for the rise of 10cm (i.e. 0.1m) water in the collecting tank by using stop watch.

- **Calculate discharge using below formula.**
- **Discharge**: - The time taken to collect some 'x' cm of water in the collecting tank in m^3/sec.

$$Q = A \times R / t$$

Where:

A = area of the collecting tank in m² (0.3m X 0.3m)

R = rise of water level taken in meters (say 0.1m or 10cm)

t = time taken for rise of water level to rise ‘r’ in ‘t’ seconds.

6. Calculate the velocity of the jet by following formula

$$V = \text{Discharge/ Area of the pipe} = Q/A \quad \text{m/sec}$$

Where,

- A = cross sectional area of the pipe= $\Pi d^2 /4$
- d = pipe diameter

7. Calculate the coefficient of friction for the given pipe by

$$h_f = 4fLv^2 /2gd$$

Where,

hf - Loss of head of water = (h1-h2)(Sn /So – 1) = (h1-h2) 12.6/100 m
f - Co-efficient of friction for the pipe
L - Discharge between sections for which loss of head is measured (1 meter)
v - Average velocity of flow in m/sec
g - Acceleration due to gravity 9.81m/sec
d - Pipe diameter in meters

(d1=25mm, d2=20mm, d3=12.7mm)diameter of pipes

8. Repeat the steps 2 to 7 for different sets of readings by regulating the discharge valve.

Tabular form

s.no	Ø of pipe	Area (a)	Time for rise of 10 cm water	Discharge	Velocity	Loss of Head (hf)	Co-efficient of friction (f)

RESULT:

3.BERNOULLI’S THEOREM APPARATUS

Verification of Bernoulli's theorem

Proposition1:
Bernoulli's Theorem
For a steady, continuous, in compressible, non-viscous fluid flow, the total energy or total head remains constant at all the sections along the fluid flow provided there is no loss or addition of energy.

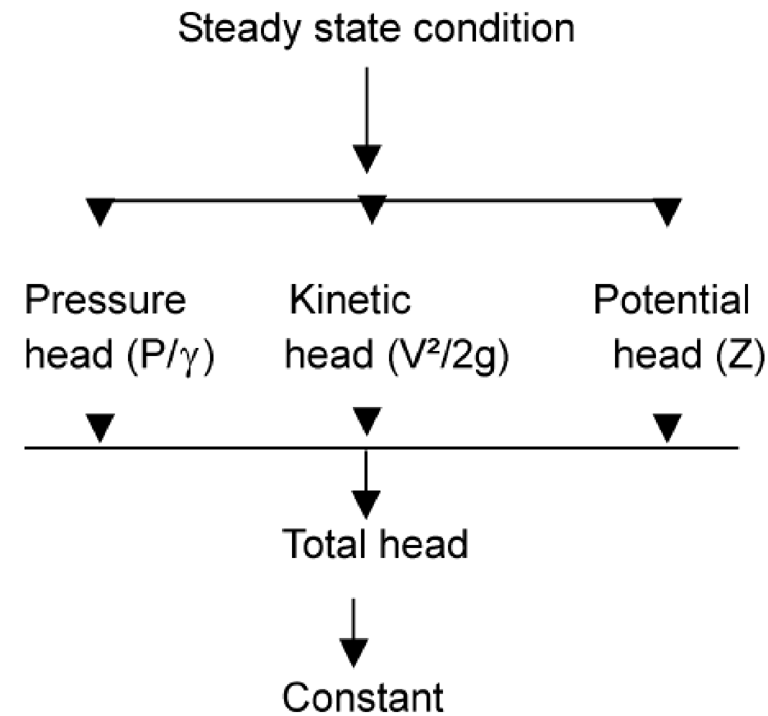
$$P/\gamma + V^2/2g + Z = \text{Total head} = \text{constant}$$

Where P/γ = Pressure head (m)
$V^2/2g$ = Velocity or kinetic head (m) ($V = Q/A$ = m/s)
Z = Potential head (Height above some assumed datum level)

Proposition 2:
Application of Bernoulli's Theorem

Bernoulli's equation is based on Euler's equation of motion. It is applicable to flow of fluid through pipe and channel. In Euler's equation the force of viscosity is neglected. Bernoulli's equation is required to be modified if the flow is compressible & unsteady.

Concept Structure

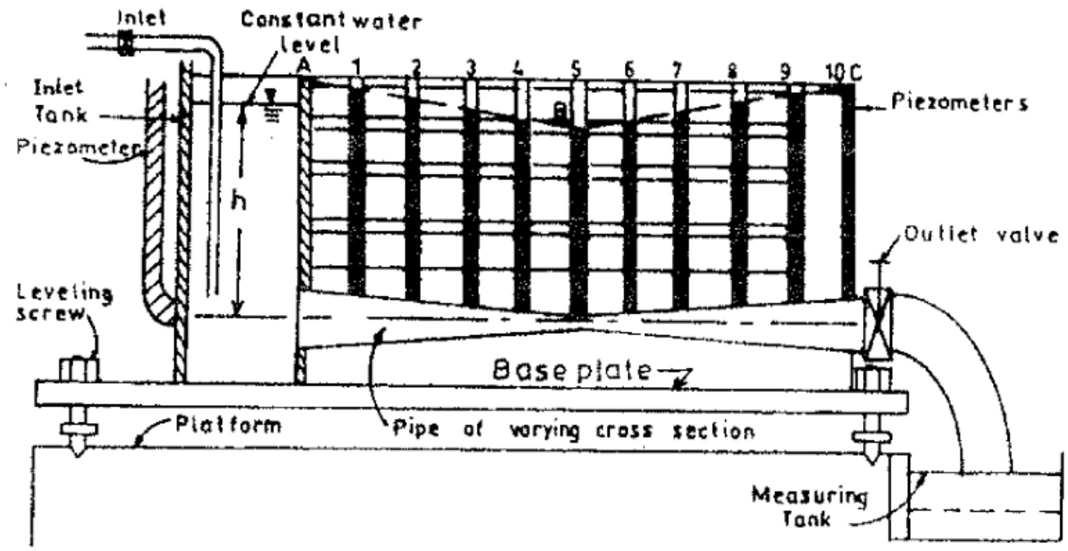


BERNOULLIS THEOREM APPARATUS

INTRODUCTION

The closed circuit self-sufficient portable package system Bernoulli's Theorem Apparatus does not require any foundation, trench work, etc., so that you can conduct experiment with keeping the unit anywhere.

Diagram



GENERAL DESCRIPTION

The unit consists of supply chamber and experimental duct made out of SS sheet. The interlinking duct is smoothly varying in cross section so that the velocity of flow changes gradually for the purpose of experiments with minimum of friction loss and loss the due to turbulence. Piezometer tubes are provided at suitable intervals along with duct for the measurement of pressure head at various points. A flow control valve is provided at the exit of the duct for adjusting and keeping different flow rates through the apparatus. A collecting tank is provided for the measurement of rate of flow. Piezometer tubes are provided at suitable intervals along with duct for the measurement of pressure head at various points. A flow control valve is provided at the exit of the duct for adjusting and keeping different flow rates through the apparatus. A collecting tank is provided for the measurement of rate of flow. The unit consists a sump of size 1250 x 300 x 300 mm height and a monoblock pump, capacity is 0.5 HP, single phase 220 V, 2800 RPM and pump of size 25 mm to discharge about 15 LPM at 30 m total head.

Verification of Bernoulli's equation

AIM:

To verify the bernoulli's equation

Apparatus: -

- experimental set-up,
- stop watch.

EXPERIMENT

The apparatus is fitted with Piezometer tubes and scales at 9 cross sectional points, along the experimental duct at suitable intervals for measurement of pressure head. The area of flow section

A.is written on each one of these seven sections. The velocity of flow (V) can be calculated at each of these sections from the flow rate (Q) obtained from the measuring tank that is V = Q/a form this velocity head V2 /2g can be calculated for each section.

B.For the verification of Bernoulli's Theorem, the velocity head when superposed over the hydraulic gradient gives the energy gradient must be a level line. However, in the flow of need fluid, contain losses of energy is inevitable and this can be readily seen by plating energy gradient. Such sets of readings can be taken for different flow rated by adjusting the valve kept at the outlet.

Procedure

Start the motor keeping the delivery valve close.

The water is allowed to flow through the selected pipe by selecting the appropriate ball valve.

By regulating the valve control the flow rate and adjust the two tank levels are equal following

Then take the piezometer valves

Note down the time required for the rise of 10cm (i.e. 0.1m) water in the collecting tank by using stop watch.

Calculate discharge using below formula.

Discharge: - The time taken to collect some ‘x’ cm of water in the collecting tank in m^3/sec.

$$Q = A \times R / t$$

Where:

A = area of the collecting tank in m^2 (0.3m X 0.3m)

R = rise of water level taken in meters (say 0.1m or 10cm)

t = time taken for rise of water level to rise ‘r’ in ‘t’ seconds.

Calculate the velocity of the flow by following formula

$$V = \text{Discharge/ Area of the pipe} = Q/A \quad \text{m/sec}$$

Where,

- A = cross sectional area of the pipe

A1=40 x 36, A2= 40 X 32, A3= 40 X27, A4= 40 X 25

A5=40 X 29, A6= 40 X31, A7= 40 X 34, A8= 40 X 38,

A9=40 X 40

Tabular Column

Run No.	Discharge (Q)	Piezometer Tube No.	1	2	3	4	5	6	7	8	9
1		P/γ=Pressure Head									
		V=Q/A (Velocity)									
		$V^2/2g$ (Velocity Head)									
		Z =Datum Head									
		Total Head= $P/\gamma + V^2/2g + Z$									
2		P/γ=Pressure Head									
		V=Q/A (Velocity)									
		$V^2/2g$ (Velocity Head)									
		Z =Datum Head									
		Total Head= $P/\gamma + V^2/2g + Z$									
3		P/γ=Pressure Head									
		V=Q/A (Velocity)									
		$V^2/2g$ (Velocity Head)									
		Z =Datum Head									
		Total Head= $P/\gamma + V^2/2g + Z$									

RESULT:

4.Calibration of Rota meter.

OBJECTIVE: To determine the coefficient of Discharge for closed circuit ROTAMETER apparatus.

APPARATUS REQUIRED:

- ROTAMETER apparatus
- Stop watch

Description:

The apparatus consists of a rota-meter flitted in pipe. Pipe consists of a flow control valves, inlet and outlet. Sump tank with centrifugal pump is provided for water circulation through pipe. Pressure taping s ate connected through pipe. Pressure taping s ate connected to a differential manometer. Discharge is measured with the help of measuring tank and stopwatch.

THEORY

The rota meter is a variable-area meter that consists of an enlarging transparent tube and a metering "float" (actually heavier than liquid) that is displaced upward by the upward flow fluid through the tube. The tube is graduated to read the flow directly.

PROCEDURE

1. Close the all the valves provided.
2. Fill the sump tank ¾ with clean water and ensure that no foreign particles are there
3. Open by-pass valve
4. Ensure that all ON/OFF. Switches given on the panel area at OFF position.
5. Switch on the main power supply.
6. Open flow control valve.
7. Adjust water flow rate in desired section with the help of control valve and by pass valve.
8. Measure the flow of water, discharge through desired test section using rota meter stop watch with measuring tank
9. Repeat steps7 and 8 for different flow rates of water operating control value and pass value.

OBSERVATION

- Diameter of the pipe d = 25mm
- Area of measuring tank A=300mm x 300mm.

OBSERVATION TABLE

s.no	Qthe in(LPM)	Time taken for rise of water level(sec)
1		
2		
3		
4		
5		
6		
7		
8		

SAMPLE CALCULATIONS

- Theoretical Discharge Qthe= LPM= …………….m3/sec
- Actual discharge Qa=A x R/t= …………….m3/sec
- Co-efficient of discharge Cd= Actual discharge (Qa)/Theoretical discharge(Qt).
- Error= Qth-Qact/Qth *100

RESULT TABLE

s.no	Qthe in(LPM)	Qthe in (m3/sec)	Qact in (m3/sec)	co efficient of discharge(cd)	error %
1					
2					
3					
4					
5					
6					
7					
8					

RESULT

The average Co-efficient of Discharge of the ROTAMETER

Cd=…………

DISCUSSION

5.Measurement of point velocity using pitot tube.

PITOT SATIC TUBE

OBJECTIVE: To determine the velocity coefficient of closed circuit pitot tube apparatus.

APPARATUS REQUIRED:

- Pitot tube apparatus
- Stop watch

THEORY

A pitot tube is a simple device used for measuring the velocity of flow. The basic principle used in this device is that if the velocity of flow at a particular point is reduced to zero, which is known as stagnation point, the pressure is increased due to conversion of the kinetic energy into pressure energy, and by measuring the increase in the pressure energy at the point the velocity of flow can be determined.The simple Pitot tube consists of a glass tube, large enough for capillary effects to be negligible and bent at right angles. A single tube of this type may be used for measuring the velocity of flow in an open channel. If the pitot tube is used for measuring the velocity of flow in a pipe or any other closed conduit, then the pitot tube may be inserted in the pipe as shown in fig. Since the pitot tube tube measures the stagnation pressure head (or the total head) at its dipped end. The static pressure head a pressure tap is provided at this section to which a piezometer may be connected. Alternatively, the dynamic pressure head may also be determined directly by connecting a suitable differential manometer between the pitot tube and the pressure tap meant for measuring the static pressure.

The equipment is designed as a self-sufficient system, which includes a sump tank, measuring tank and a pump with piping circuit. An acrylic duct is fitted in the line with a provision of a traversing type pitot tube. Flow through the duct can be varied with the bypass valve provided at the outlet of the pump. An inclined tube manometer is fitted across the pitot tube so measure the dynamic pressure head.

EXPERIMENTAL SETUP

Prandle type pitot tube are provided at both inlet & outlet, so that the velocity had can be determined separately. This prandle pitot tube consisting to two co-axial tubes and one coming within the other and both bend in the L shape so, that when interred inside the pipe. The tubes are parallel to the axis of the pipes at the place of measurements. The inner tube has a facing upstream, and hence measure the total head including both pressure and velocity. The outlet tube has holes at the sides so, that it measures only the pressure head, thus the difference between the two given the velocity a head separately hence, the inner and outer tubes are connected to a differential manometer to indicate the velocity head.

PROCEDURE

1. Start the pump and the water shall start flowing through the duct.
2. Allow some time for the flow to get uniform flow.
3. Note down the reading of U-tube manometer.
4. Measure the actual discharge.
5. Change the discharge and repeat the above procedure.

OBSERVATION

- Diameter of the pipe d = 25mm
- Area of measuring tank A=300mm x 300mm.

OBSERVATION TABLE

s.no	Manometer reading in terms of ccl4 column hg in (meters)			Manometer reading hw	rise of water level	time taken for rice of water level
	h1	h2	h=hg			

SAMPLE CALCULATIONS

- Manometer reading in cm of water hw=hg=……………, meter of water.
- Theoretical Velocity Vt=√2gh m/sec= …………….m/sec
- Area of the duct A= ……………m2
- Actual discharge Qa=A x R/t= ……………..m3/sec
- Actual Velocity Va= Qa/A= …………….m/sec
- Co-efficient of Velocity Cv= Velocity Actual(Va)/Velocity Theoretical(Vt).

RESULT TABLE

s.no	manometer reading 'hw' in (m of water)	Theoretical Velocity 'Vt' in m/sec	Actual Velocity'Va' (m/sec)	Co efficient of Velocity(Cv)
1				
2				
3				
4				
5				
Average velocity of co-efficient of velocity(Cv)				

RESULT

The average Co-efficient of velocity of the Pitot tube Cv=………

DISCUSSION

6.To Determine the coefficient of velocity from jet Trajectory of small Orifice.

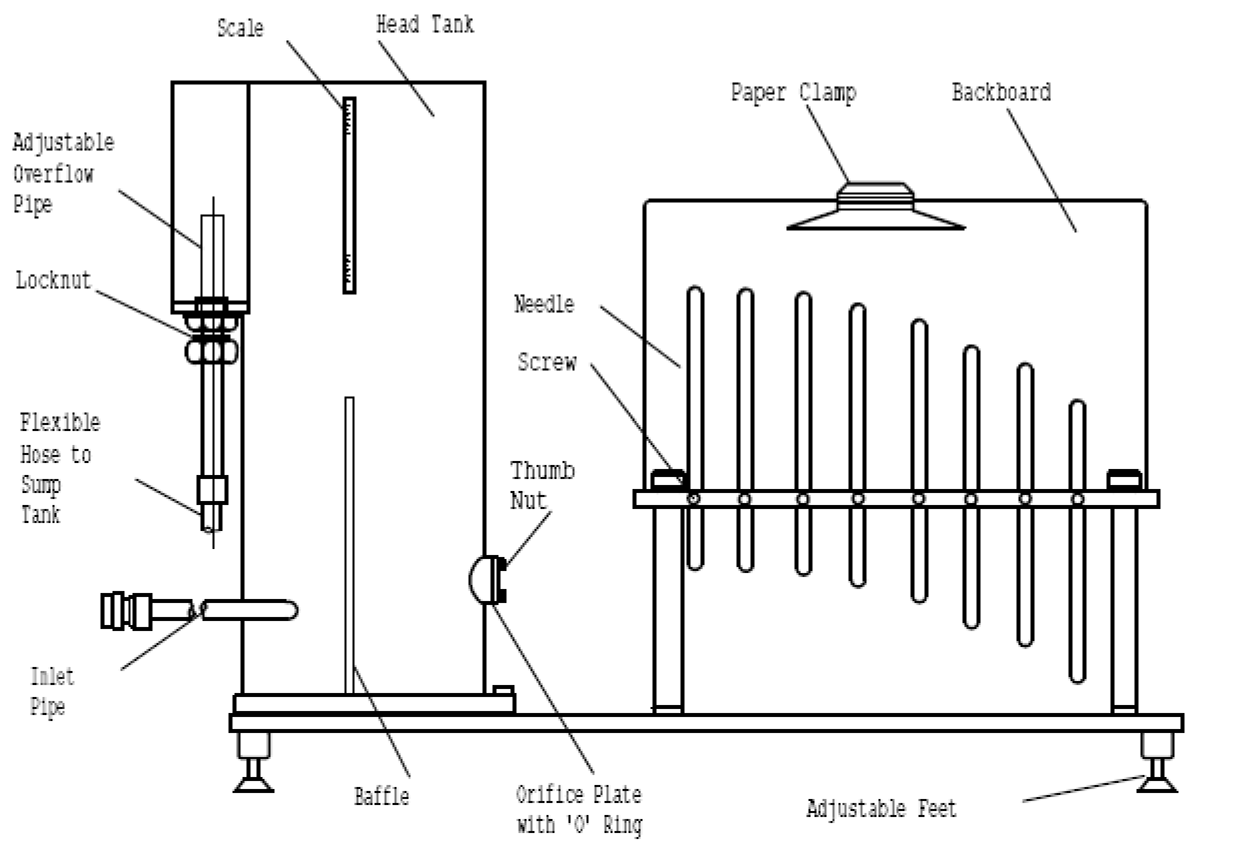
General Overview

Fluid mechanics has developed as an analytical discipline from the application of the classical laws of statics, dynamics and thermodynamics, to situations in which fluids can be treated as continuous media. The particular laws involved are those of the conservation of mass, energy and momentum and, in each application, these laws may be simplified in an attempt to describe quantitatively the behaviour of the fluid.

The hydraulics bench service module, F1-10, provides the necessary facilities to support a comprehensive range of hydraulic models each of which is designed to demonstrate a particular aspect of hydraulic theory.

The specific hydraulic model that we are concerned with for this experiment is the Orifice and Jet Apparatus, F1-17. This consists of a reservoir of water with an orifice plate set into it. A jet of water issues from this hole and its trajectory may be measured using a set of needles. A full description of the apparatus is given later in these texts.

Equipment Diagrams



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Laboratory Teaching Exercises

Index to Exercises

Nomenclature Exercise A

Name	Unit	Symbol	Type	Definition
Orifice Diameter	m	d	Measured	Orifice diameter. The diameter is measured in mm. Convert to metres for the calculation.
Head	m	h	Measured	Head in reservoir for which trajectory data has been taken. The head is entered in mm. Convert to metres for the calculation.
Horizontal Distance	m	x	Measured	Distance from the orifice of the measuring needle. The value is entered in mm. Convert to metres for the calculation.
Vertical Distance	m	y	Measured	Distance the jet has fallen from the level of the orifice. The value is entered in mm. Convert to metres for the calculation.
$(yh)^{0.5}$	m		Calculated	Allows the plotting of a straight line relationship between coefficient of velocity C_v and the horizontal distance for the jet. A graph of x plotted against $\sqrt{yh}$ will have a slope of $2C_v$
Slope		S	Calculated	Slope of x vs $\sqrt{yh}$ for each point.
Velocity Coefficient C_v			Calculated	$C_v = \frac{\text{Average Slope}}{2}$

Nomenclature Exercise B

Name	Unit	Symbol	Type	Definition
Orifice Diameter	m	d	Measured	Orifice diameter. The diameter is measured in mm. Convert to metres for the calculation.
Head	m	h	Measured	Head in reservoir for which trajectory data has been taken. The head is entered in mm. Convert to metres for the calculation.
Volume	m^3	V	Measured	Taken from scale on hydraulics bench. The volume collected is measured in litres. Convert to cubic metres for the calculations (divide reading by 1000)
Time	s	t	Measured	Time taken to collect the known volume of water
Flowrate	m^3/s	Q_t	Calculated	$Q_t = V/t = \frac{\text{Volume Collected}}{\text{Time to Collect}}$
$(h)^{0.5}$	$\sqrt{m}$		Calculated	Allows the plotting of a straight line relationship between coeffecient of velocity, C_v, and the flowrate for the jet, Q_t
Slope		S	Calculated	Slope of flow rate vs. $\sqrt{h}$ for each point.
Discharge Coefficient C_d		C_d	Calculated	$C_d = \frac{S}{A_o\sqrt{2g}}$

Nomenclature Exercise C

Name	Unit	Symbol	Type	Definition
Orifice Diameter	m	d	Measured	Orifice diameter. The diameter is measured in mm. Convert to metres for the calculation.
Area of Orifice	m^2	A_o	Calculated	Orifice area, calculated from the orifice diameter

Area of Reservoir	m^2	A_r	Given	Surface area of the reservoir including area of constant head tank. $A_r = 1.832\times10^{-2}\ m^2$
Head	m	h	Measured	Head in reservoir at time t. The head is entered in mm. Convert to metres for the calculation
Head at Start	m	h_1	Measured	Head in reservoir at time t = 0. The head is entered in mm. Convert to metres for the calculation
Time	s	t	Measured	Time since start of run
$h^{0.5}$			Calculated	Allows the plotting of a straight line relationship between coefficient of discharge, Cd, and the head loss.
Slope		S	Calculated	Slope of t vs $\sqrt{h1} - \sqrt{h}$ for each point
Discharge Coefficient C_d		C_d	Calculated	$C_d = \frac{A_R}{A_o}\sqrt{\frac{2}{g}}S$

Technical Data

The following dimensions from the equipment are used in the appropriate calculations. If required these values may be checked as part of the experimental
procedure and replaced with your own measurements.

Diameter of small orifice: 0.003m (3mm)

Diameter of large orifice: 0.006m (6mm)

Surface Area of Reservoir: AR = 1.832 x 10-2m2

Pitch of needles: 0.05m (50mm)

Exercise A - Determination of Coefficient Of Velocity From Jet Trajectory

Objective

To determine the coefficient of velocity of two small orifices.

Method

By measurement of the trajectory of a jet issuing from an orifice in the side of a reservoir under steady flow conditions (constant reservoir head).

Equipment

In order to complete the demonstration we need a number of pieces of equipment.

- The F1-10 Hydraulics Bench which allows us to measure flow by timed volume collection.
- The F1-17 Orifice and Jet Apparatus.
- A stopwatch to allow us to determine the flow rate of water.

Equipment Set Up

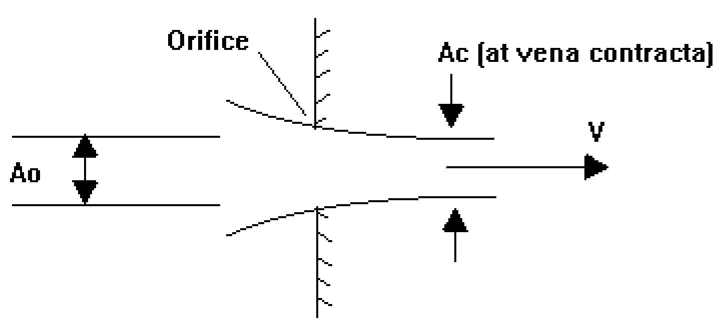
Position the reservoir across the channel on the top of the hydraulic bench and level the reservoir by the adjustable feet using a spirit level on the base. Remove the orifice plate by releasing the two knurled nuts and check the orifice diameter;

take care not to lose the O-ring seal. Replace the orifice and connect the reservoir inflow tube to the bench flow connector. For accurate results measure the actual distance from the orifice plate to the first needle (nominal distance X1 = 50mm). Position the overflow connecting tube so that it will discharge into the volumetric tank; make sure that this tube will not interfere with the trajectory of the jet flowing from the orifice. Turn on the pump and open the bench valve gradually. As the water level rises in the reservoir towards the top of the overflow tube, adjust the bench valve to give a water level of 2 to 3mm above the overflow level. This will ensure a constant head and produce a steady flow through the orifice.

Theory

From the application of Bernoulli's Equation (conservation of mechanical energy for a steady, in compressible, friction less flow): the ideal orifice outflow velocity at the jet venacontracta (narrowest diameter) is

where h is the height of fluid above the orifice.



The actual velocity is

$$v = C_v\sqrt{2gh}$$

.... (1)

Cv is the coefficient of velocity, which allows for the effects of viscosity and, therefore

Cv < 1

Cv can be determined from the trajectory of the jet using the following argument:

Neglecting the effect of air resistance, the horizontal component of the jet velocity can be assumed to remain constant so that in time, t, the horizontal distance travelled,

X = vt ...(2)

Because of the action of gravity, the fluid also acquires a downward vertical (ydirection) component of velocity. Hence, after the same time, t, (ie. after travelling a distance x) the jet will have a y displacement given by

$$y = g\frac{t^2}{2}$$

which can be rearranged to give:

$$t = \sqrt{2\frac{y}{g}}$$

........(3)

Substitution for t from (3) into (2) and for v from (1) into (2) yields the result:

$$C_v = \frac{x}{2\sqrt{yh}}$$

Hence, for steady flow conditions, ie. constant h, Cv can be determined from the x, y

co-ordinates of the jet. A graph of x plotted against $\sqrt{yh}$ will have a slope of 2Cv

Procedure

- Position the overflow tube to give a high head. Note the value of the head.
- The jet trajectory is obtained by using the needles mounted on the vertical backboard to follow the profile of the jet.
- Release the securing screw for each needle in turn and move the needle until its point is just immediately above the jet and re-tighten the screw.
- Attach a sheet of paper to the back-board between the needle and board and secure it in place with the clamp provided so that its upper edge is horizontal.
- Mark the location of the top of each needle on the paper. Note the horizontal distance from the plane of the orifice (taken as x = 0) to the co-ordinate point marking the position of the first needle.
- This first co-ordinate point should be close enough to the orifice to treat it as having the value y = 0. Thus y displacements are measured relative to this position.
- Estimate the likely experimental errors in each of the quantities measured.

- Repeat this test for a low reservoir head.
- Then repeat the above procedure for the second orifice.

TABULER

	Orifice Diameter d (m)	Head h (m)	Horizontal Distance x (m)	Vertical Distance y (m)	yh0.5 (m)
1			0.05		
2			0.1		
3			0.15		
4			0.2		
5			0.25		
6			0.3		
7			0.35		
8			0.4		

Plot x vs $\sqrt{yh}$
and determine the slope of the graph.
The velocity coefficient Cv is equal to the average slope/2.

7.Determination of coefficient of discharge under constant head (or) varying head through orifice and free jet flow.

Exercise B - Determination of Coefficient of Discharge
Under Constant Head

Objective

To determine the coefficient of velocity of two small orifices.

Method

By measurement of the trajectory of a jet issuing from an orifice in the side of a
reservoir under steady flow conditions (constant reservoir head).

Equipment

In order to complete the demonstration, we need a number of pieces of equipment.

- The F110 Hydraulics Bench which allows us to measure flow by timed volume collection.
- The F117 Orifice and Jet Apparatus.
- A stopwatch to allow us to determine the flow rate of water

Equipment Set Up

Position the reservoir across the channel on the top of the hydraulic bench and level the reservoir by the adjustable feet using a spirit level on the base. Remove the orifice plate by releasing the two knurled nuts and check the orifice diameter; take care not to lose the O-ring seal. Replace the orifice and connect the reservoir inflow tube to the bench flow connector. Position the overflow connecting tube so that it will discharge into the volumetric tank; make sure that this tube will not interfere with the trajectory of the jet flowing from the orifice. Turn on the pump and open the bench valve gradually. As the water level rises in the reservoir towards the top of the overflow tube, adjust the bench valve to give a water level of 2 to 3mm above the overflow level. This will ensure a constant head and produce a steady flow through the orifice.

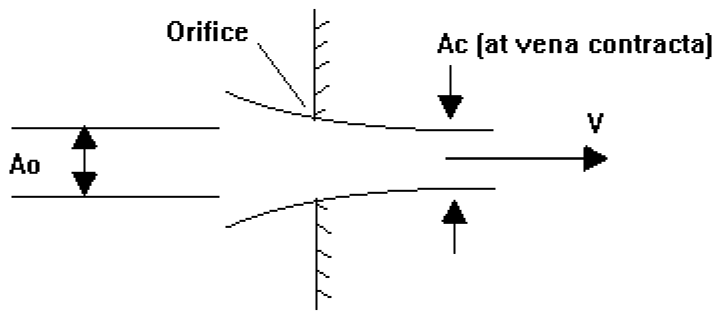
Theory

From the application of Bernoulli's Equation (conservation of mechanical energy for a steady, incompressible, frictionless flow):

the ideal orifice outflow velocity at the jet vena contracta (narrowest diameter) is

$$v_i = \sqrt{2gh}$$

where h is the height of fluid above the orifice.



The actual velocity is

$$v = C_v \sqrt{2gh} \qquad \text{.... (1)}$$

Cv is the coefficient of velocity, which allows for the effects of viscosity and, therefore

Cv < 1

The actual flow rate of the jet is defined as:

Qt = Acv

where Ac is the cross-sectional area of the vena contract a, given by:

Ac = CcAo

where

Ao is the orifice area and Cc is the coefficient of contraction and, therefore, Cc < 1

Hence

$$Q_t = C_c A_o C_v \sqrt{2gh}$$

The product CcCv is called the discharge coefficient, Cd , so finally

$$Q_t = C_d A_o \sqrt{2gh}$$

If Cd is assumed to be constant, then a graph of Qt plotted against $\sqrt{h}$ will be linear
and the slope,

Procedure

- Measure the flow rate by timed collection, using the measuring cylinder provided and note the reservoir head value.
- Repeat this procedure for different heads by adjusting the level of the overflow tube.
- The procedure should also be repeated for the second orifice.

Tabular

	Orifice Diameter d (m)	Head h (m)	volume V (m3)	Time t (secs)	Flowrate Qt (m3 /sec)	h0.5 (m0.5)
1						
2						
3						
4						
5						
6						
7						
8						

Plot flowrate Qt vs $\sqrt{h}$ and determine the slope of the graph.

The coefficient of discharge Cd can then be calculated from

$$C_d = \frac{slope}{A_o \sqrt{2g}}$$

Exercise C - Determination of Coefficient Of Discharge Under Varying Head

Objective

To determine the coefficient of velocity of two small orifices.

Method

By measurement of the trajectory of a jet issuing from an orifice in the side of a reservoir under steady flow conditions (constant reservoir head).

Equipment

In order to complete the demonstration, we need a number of pieces of equipment.

•The F1-10 Hydraulics Bench which allows us to measure flow by timed volume collection.

•The F1-17 Orifice and Jet Apparatus.

•A stopwatch to allow us to determine the flow rate of water.

Equipment Set Up

Position the reservoir across the channel on the top of the hydraulic bench and level the reservoir by the adjustable feet using a spirit level on the base.

Remove the orifice plate by releasing the two knurled nuts and check the orifice diameter; take care not to lose the O-ring seal. Replace the orifice and connect the reservoir inflow tube to the bench flow connector. Position the overflow connecting tube so that it will discharge into the volumetric tank; make sure that this tube will not interfere with the trajectory of the jet flowing from the orifice.

Turn on the pump and open the bench valve gradually. As the water level rises in the reservoir towards the top of the overflow tube, adjust the bench valve to give a water level of 2 to 3mm above the overflow level. This will ensure a constant head and produce a steady flow through the orifice.

Theory

For unsteady flow, the time, t, for the head to drop from to is given by

$$t = \frac{A_r}{C_d A_o}\sqrt{\frac{2}{g}}\left(\sqrt{h_1} - \sqrt{h}\right)$$

where Ar is the cross-sectional area of the reservoir (including the secondary chamber).

Note: This is an approximate result, which does not allow fully for the effects of flow unsteadiness.

Procedure

- For flow under a varying head, the overflow pipe is raised to obtain the maximum head, the header tank is filled to just below the top and the bench flow control valve closed and the pump stopped. Start a stopwatch when the level reaches the first convenient scale mark (noted as h1).
- You will need to take readings of the falling head (h) at 20 second intervals. You may find the easiest way of doing this is toattach a piece of masking tape immediately adjacent to the scale on the reservoir and at 20 second intervals mark the position of the falling level.
- At the end of this procedure, you can then read off the head position corresponding to the known time.
- The above procedure should be repeated using the second orifice.

Result table

	Orifice Diameter d (m)	Area of Reservoir AR (m2)	Head h (m)	Time t (secs)	h0.5 (m0.5)
1					
2					
3					
4					
5					
6					
7					
8					

Plot time t vs. $\sqrt{h}$ and determine the slope of the graph.

The coefficient of discharge Cd can be calculated from

$$C_d = \frac{-A_R}{A_o}\sqrt{\frac{2}{g}}\frac{1}{slope} \quad slope$$

Conclusion :

Is it justifiable to assume that Cd is a constant over the range of steady flows tested?

Why are the Cd values significantly less than 1.0?

Compare the Cd values obtained for the constant and falling head tests. Which value is the more reliable result?

8.Determine the surface profile of free and forced vortex and comparison their theoretical values.

General Overview

Fluid mechanics has developed as an analytical discipline from the application of the classical laws of statics, dynamics and thermodynamics, to situations in which fluids can be treated as continuous media. The particular laws involved are those of the conservation of mass, energy and momentum and, in each application, these laws may be simplified in an attempt to describe quantitatively the behaviour of the fluid.

The hydraulics bench service module, F1-10, provides the necessary facilities to support a comprehensive range of hydraulic models each of which is designed to demonstrate a particular aspect of the theory of fluid mechanics.

The specific model that we are concerned with for this experiment is the Free and Forced Vortex Apparatus, F1-23. See the Description section for a full description of the apparatus.

Equipment Diagrams

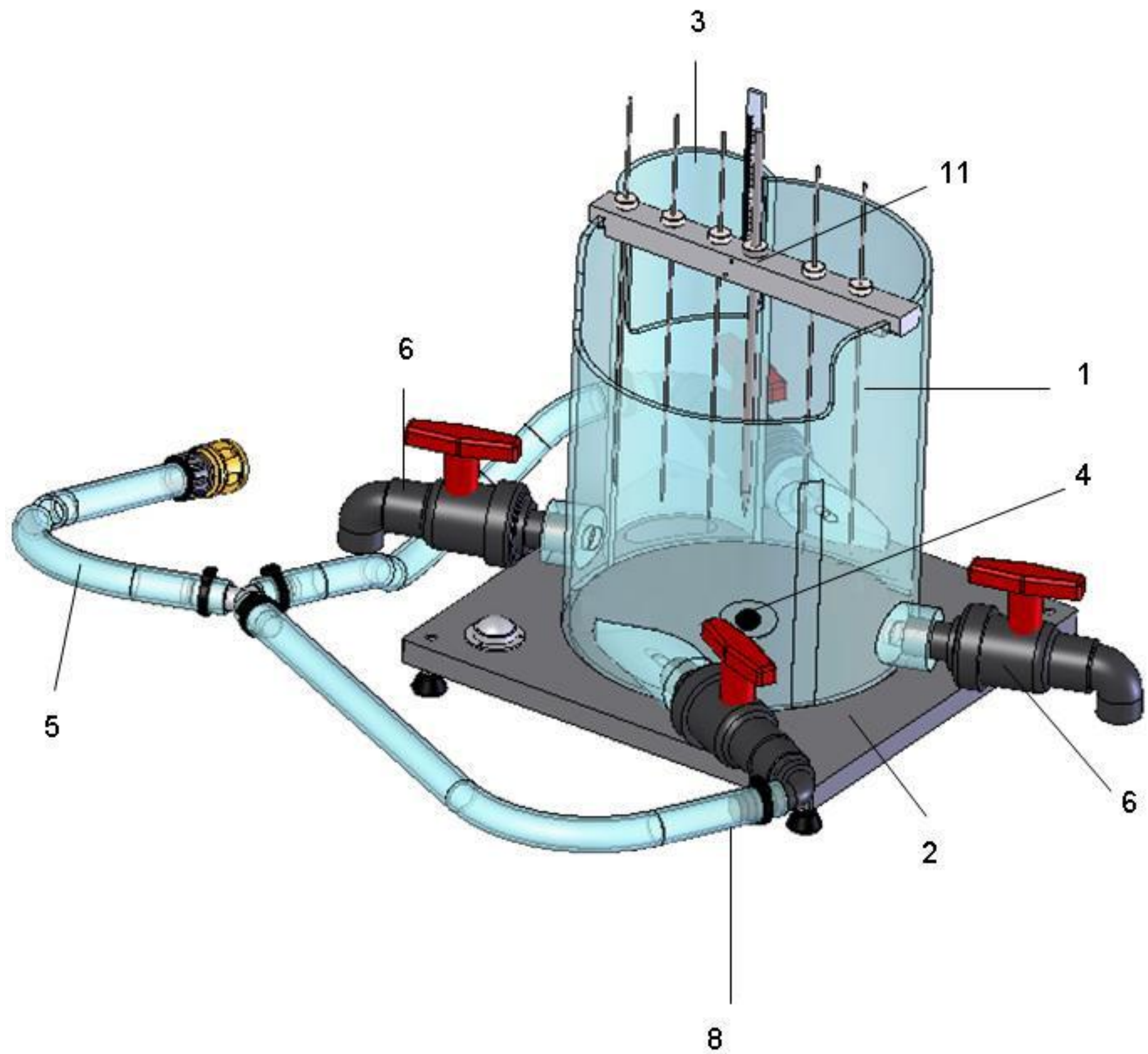


Figure 1: F1-23 Free & Forced Vortices apparatus

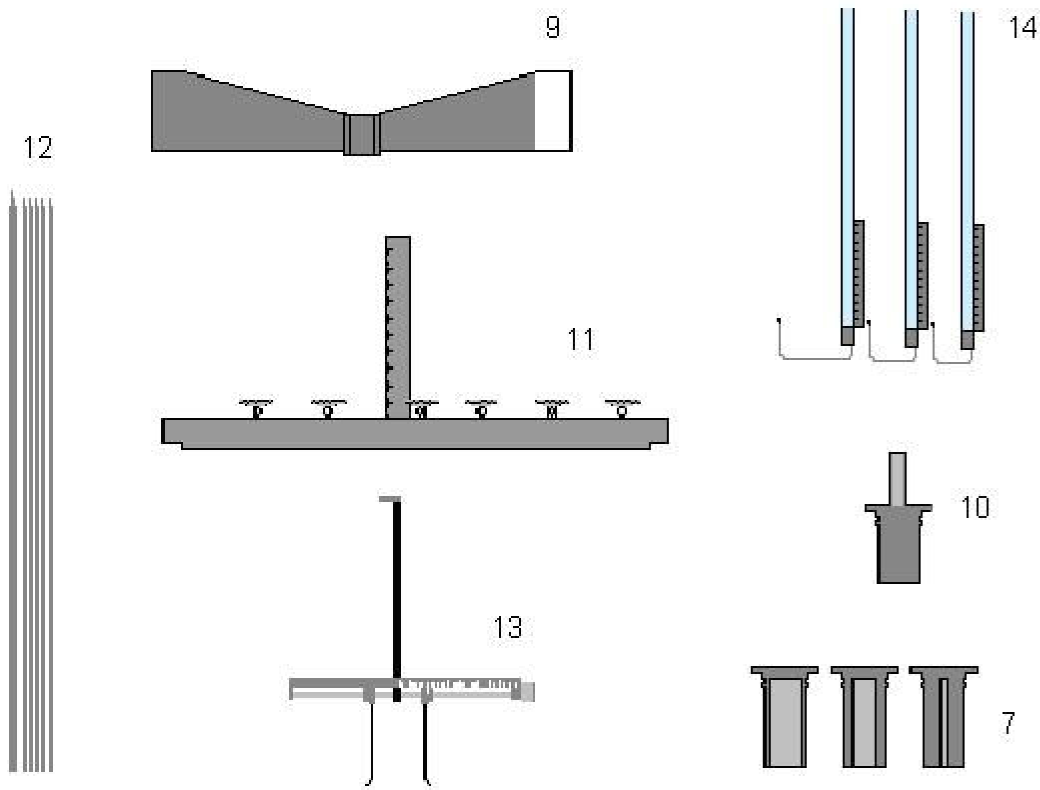


Figure 2: F1-23 Free & Forced Vortices accessories

Description

Where necessary, refer to the drawings in the Equipment Diagrams section.

Overview

The F1-23 Free and Forced Vortices apparatus consists of a clear acrylic cylinder (1) mounted on a PVC base plate (2). Four orifices with control valves in the side of the cylinder, allow the water to enter and leave, while an overflow duct prevents the level from getting too high (3). There is also a hole in the base of the cylinder (4), into which can be fitted orifices of various sizes. The whole assembly is designed to be positioned above the channel on the hydraulics bench, F1-10. The connection between these two units is given by an inlet hose with a y-divider and two quick release fittings (5).

Forced Vortex setting up

The 9mm inlet tubes in the cylinder, which are angled at 60 degrees (8), are used to create a forced vortex. The flow from these tubes impacts on a paddle which acts as a stirrer. The paddle (9) rotates on a stud mounted on a bushed plug (10) inserted in the central orifice (4), and it has a white mark on one of the sides for easy counting of the rotations. In the forced vortice, the water exits the vessel through the control valve via the 12mm orifices.

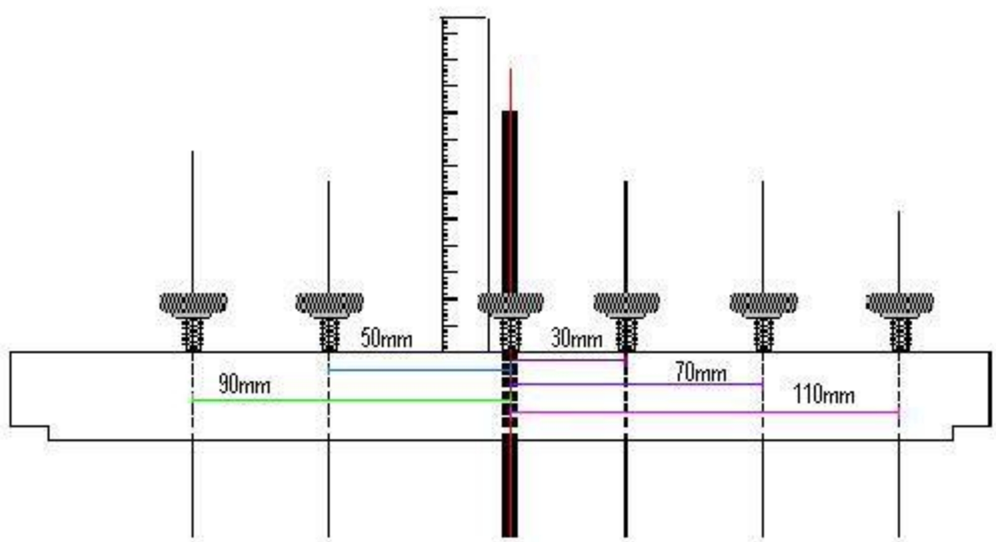
Free Vortex setting up

The two 12mm diameter inlet tubes in the cylinder, which are angled at 15 degrees (6), are used as entry tubes for the free vortex experiment. In this case, the water exits the vessel via one of the interchangeable orifices in the base of the tank. Three orifices are provided with the F1-23, having diameters of 8mm, 16mm and 24mm (7).

Bridge

A bridge piece (11) incorporating measuring needles is used to determine the profile of the forced vortex. The needles are set at fixed distances from the centre of the tank as shown in the graph below. The bridge piece is composed of 5 needles of 2mm of diameter and one 6mm-diameter needle (12). The latter performs as the centre axe of the bridge.

At adjusting the position of each of the needles to the contact surface of the vortex, the representative profile for a forced vortex can be determined.



Gauge

By replacing the measuring needles in the bridge for the gauge (13), the measurement of depth of the vortex at different radius can be found and therefore the profile of a free vortex can be represented.

Pitot tubes

Velocity heads may be visualised by the insertion of various Pitot tubes in the measuring bridge. The Pitot tubes shall be located so that the tip of the tube's arm is parallel directed to the radial movement of the vortex. Three Pitot tubes of radius arm 5mm, 25mm and 30mm (14) are included with the F1-23. The Pitot tubes bring incorporated a 50mm measuring scale which provides measurement of water elevation.

Ball Valves

Four ball valves are attached to the vessel and allow control of the water exit the cylinder. As mentioned before two different outlets angled 60 degrees (radial) and 15

degrees (tangential) create the forced and free vortices. Each valve possesses one

(1) O’ ring and one

(1) spacer which can become loose when changing the hose for inlet water. Be careful not so lose them.

Laboratory Teaching Exercises

Index to Exercises

Nomenclature

Name	Symbol	Unit	Definition
Number of rotations	n		Number of revolutions of the paddle during a timed period
Time Period	t	s	Time for count of revolutions
Speed of Rotation	ω	r.p.s	Speed of paddle
Vortex Radius	r	m	Position of needles for measuring profile, relative to the centre of the tank, or width on scale on gauge (convert to metres for calculations)
Needle Length	l_m	m	Length of needle at a given radius position, which allows the vortex profile to be plotted. Needle length is measured in mm. Convert to metres for calculations
Datum Height	z_0	m	Reference height used for calculations. For forced vortex, the datum height is the base of the vortex, taken to be zero. For free vortex, the datum height is the surface level of the water
Height from Datum	z_m	m	Vertical distance from vortex surface to datum height
Theoretical Depth	z	m	Predicted height from theory

Exercise A - Investigation of Forced Vortices

Objective

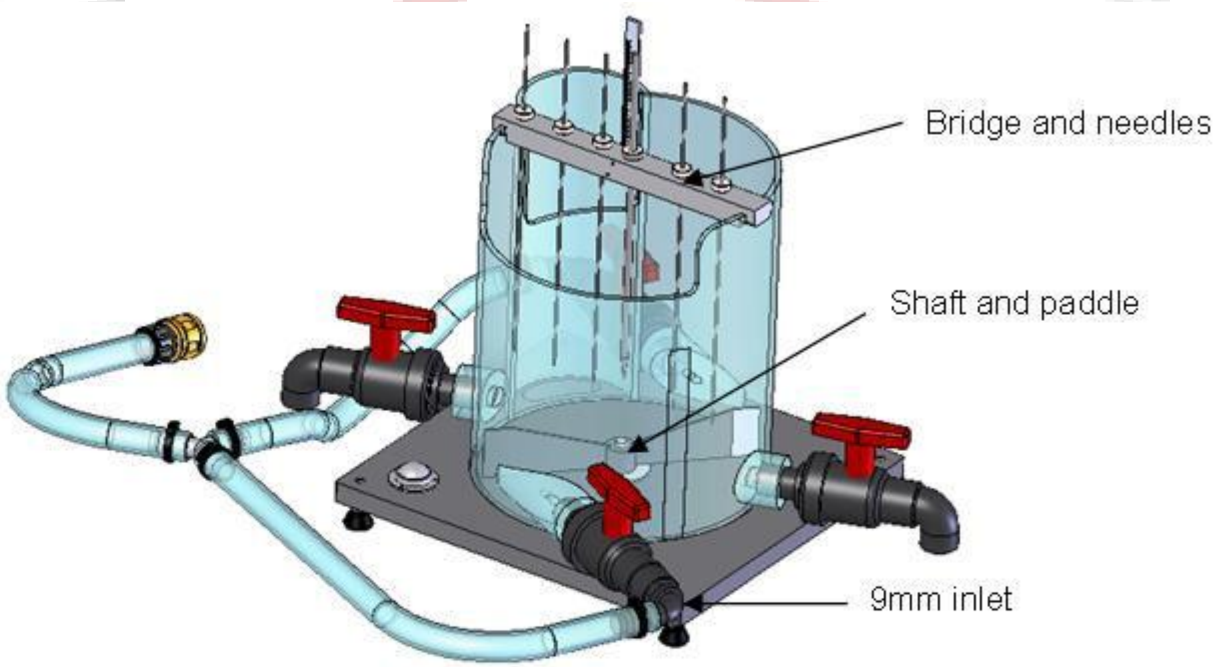
To determine the surface profile of a forced vortex, and compare with theoretical values.

Method By measuring the speed of rotation and length of needles that represent the forced vortex.

Equipment Required

- F1-10 Hydraulics Bench
- F1-23 Free and forced vortices apparatus
- A stopwatch to determine the rotation speed of the paddle .

Equipment set up



Theory

In a forced vortex, it can be assumed that all particles have the same angular velocity about the central axis. For a constant speed of rotation, ω

$$q = \omega r$$

where r is the radius of the vortex and q is the velocity of flow. The equation for the centripetal force in a vortex is:

$$\frac{\delta p}{\rho g} + \delta z = \frac{q^2}{r}\frac{\delta r}{g}$$

Substituting the equation for q into the centripetal force equation and integrating gives:

$$z = \frac{\omega^2 r2}{2g} + \text{constant}$$

From the boundary conditions (z = z0when r = 0), we get:

$$z = \frac{\omega^2 r2}{2g} + z_0$$

where z0is the lowest point of the vortex, at the centre.

Procedure

- Place the F1-23 on top of the Hydraulics Bench, over the flow channel with y-divider hose being close to the bench's easy-to-use quick release pipe connector located on the floor of the bench's top channel.

- Connect the hose with a y-divider and two quick-release fittings to the F1-23, so that flow is directed from the connector of the bench into the two 9mm inlets. Ensure that the valves on the two 12mm orifices in the F1-23 are opened.
- Press the bung with central shaft into the orifice in the base of the cylinder and locate the paddle on top of the shaft. Locate the bridge piece on the top of the cylinder, with the measuring needles inserted.
- Switch on the hydraulics bench and adjust the control valve until there is a reasonable flow into the cylinder (if there is too much water, it will escape via the overflow). It is important that the y-divider hose is completely full of water, so that the inlet flow will not have any disturbances because of air trapped in the hose. Slowly close the control valve on the bench until the level is steady.
- If it was not possible to maintain a constant level in the tank, you could allow the water level to reach the overflow level. It is significant to mention that if the steady level is reached through the overflow of water, the leaking water should always be kept within the overflow duct and at steady pouring.
- Measure the rotational speed of the vortex by counting the number of revolutions the paddle makes in a timed period.

- Adjust the position of each of the measuring needles until they just contact the surface of the vortex. Remove the bridge and record the lengths of the needles.
- Repeat the test for a number of speeds.

Results

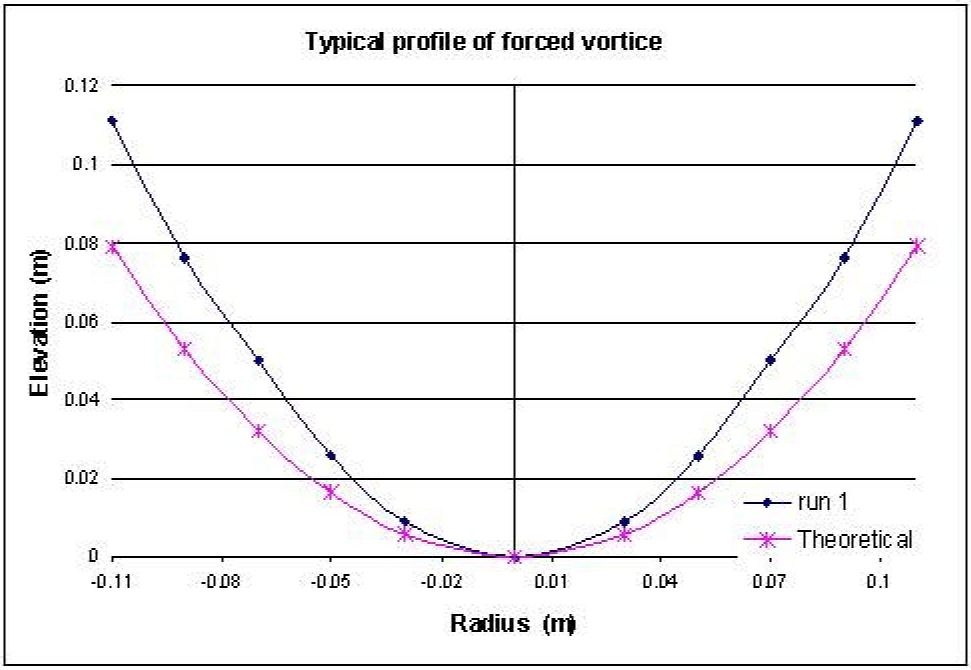
The results for each run should be recorded in a table like the one below:

Number of revolutions(n)	Time (sec)	Revs for seconds $(\dot{\omega})$

Radius r (m)	Measured needle length l_m (m)	Height from Datum z_m (m)	Calculated height* z_t (m)
0.110			
0.090			
0.070			
0.050			
0.030			
0			

*The calculated height is found using the equation above.

Plot the measured and theoretical profiles on the same axes.



Conclusions

Comment on the graphs you have plotted. Explain why there is a generally good

correlation between the theoretical and practical results.

Exercise B - Investigation of Free Vortices

Objective

To measure the profile of a free vortex, and investigate the changes in velocity head throughout the vortex.

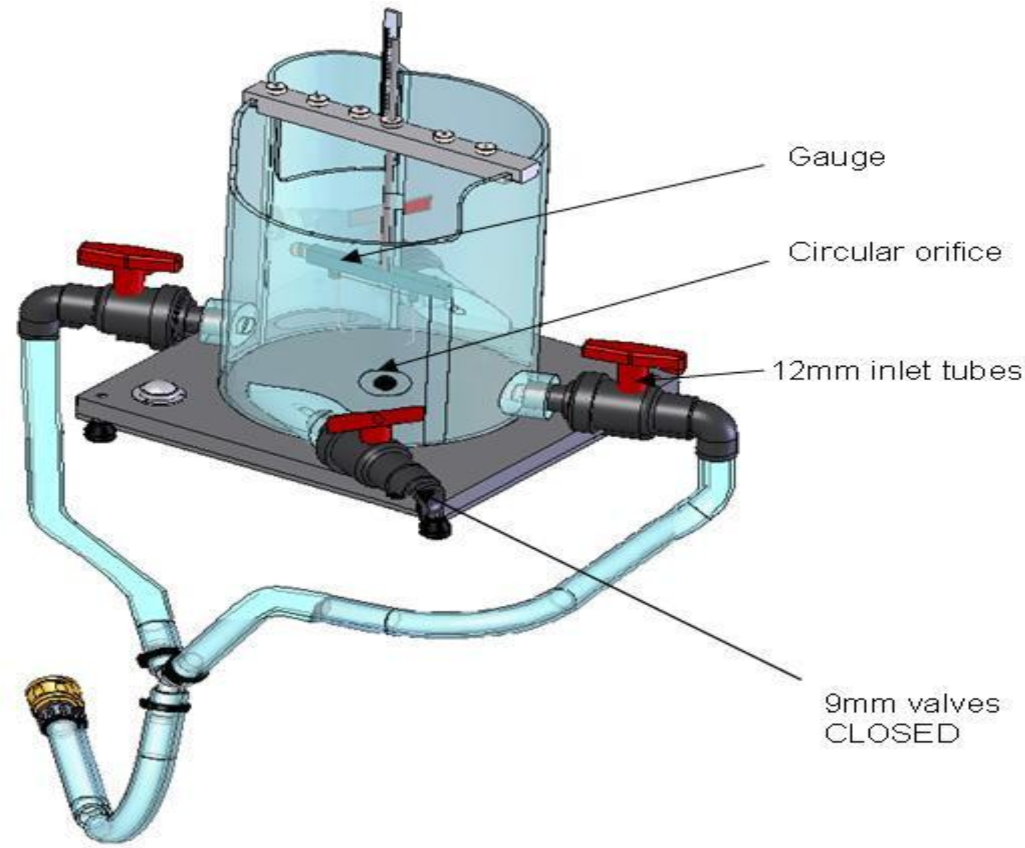
Method

By employing the Pitot tubes and measuring the elevation of water in the cylinder at different radius of the vortex.

Equipment required

- F1-10 Hydraulics Bench
- F1-23 Free and forced vortices apparatus
- Dye crystals for visualization of flow patterns with the free vortex .

Equipment setup



Theory

When water flows out of a vessel through a central hole in the base, a free vortex is formed. In a free vortex, the streamlines are concentric circles and continuity demands that the velocity only varies inversely to the distance from the axis of rotation:

$$q = \frac{k}{r}$$

Assuming steady, frictionless flow, we can apply Bernoulli's equation to the streamline:

$$\frac{p}{\rho g} + \frac{q^2}{2g} + z = \text{constant}$$

If the streamline is on the surface of the vortex, the peizometric pressure must be constant (atmospheric). Substituting the equation for velocity into the above yields:

$$z = c - \frac{k^2}{r^2 2g}$$

which is the equation to a hyperbolic curve which is asymptotic to the axis of rotation and to the horizontal through z = c.
For the Pitot tubes, the velocity is given by:

$$q = \sqrt{2gh}$$

Procedure

- Place the F1-23 on top of the Hydraulics Bench, over the flow channel with y-divider hose being close to the bench's easy-to-use quick release pipe connector located on the floor of the bench's top channel.
- Connect the hose with a y-divider and two quick-release fittings to the F1-23, so that flow is directed from the connector of the bench into the two 12mm inlets. Ensure that the valves on the two 9mm orifices in the F1-23 are closed.
- Press one of the circular orifices into the hole in the base of the cylinder. Locate the bridge piece on the top of the cylinder, with the adjustable gauge fitted.
- Switch on the hydraulics bench and adjust the control valve until the level of water in the cylinder is steady at just below the overflow. If necessary, fine

adjustment of the flow can be made using the control valve on the F1-23.

- If it was not possible to maintain a constant level in the tank, you could allow the water level to reach the overflow level. It is significant to mention that if the steady level is reached through the overflow of water, the leaking water should be always kept within the overflow duct and at steady pouring.
- Use the gauge to measure the profile of the orifice. The nature of a free vortex is such that it is unlikely that the surface edge of the vortex will settle directly above the orifice. If the vortex is not sufficiently central within the tank it will not be possible to Exercise B use both arms of the measuring gauge to plot the vortex profile. If this is the case then ensure that one arm is in the wall of the vortex and the 'unused' arm is hanging in free space within the vortex and not fouling the opposite wall.
- Repeat the test for the other two orifices. When using the large orifice, replace the profile measuring gauge with the 15mm radius arm Pitot tube. Immerse the tube until the nose is just behind the profile surface. The water level in the Pitot tube will be above the level of the surrounding water (ensure that there is no air trapped in the tube). Measure or estimate the height of the level in the Pitot tube above the free surface.
- Repeat the test with the 25mm and 30mm Pitot tubes.

- Observe how the fluid is drawn down into the vortex (is the flow circumferential or radial?). Flow patterns may be better observed by dropping some dye crystals into the water
- . Note the patterns of movement highlighted by the dye.
- Determine the effect on flow rate through the orifice if the vortex is destroyed. This can be achieved by placing an object into the core of the vortex. When using the small orifice the acrylic part of a Pitot tube may be used.

Results

The results for each run should be recorded in a table like the one below:

	r	1/r	h	v
Pitot Tubes	(m)		(m)	(m/s)
	0.015			
	0.025			
	0.030			

Plot a graph of 1/radius against velocity for the three Pitot tubes. A straight line

through the origin should have a gradient of k. Hence calculate the theoretical profile

of the free vortex from the large orifice, using the equation derived in the theory section.

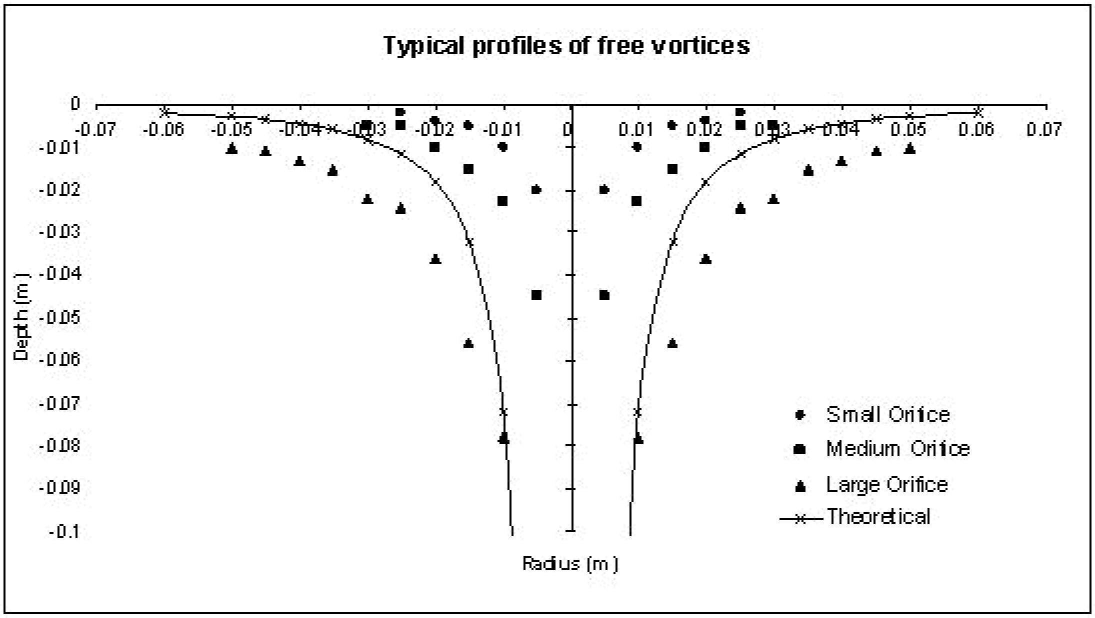
Take note of the radius and elevation of the vortices formed by the three orifices. You

could complete a table as the following:

Radius	Elevation						
	Small		Medium		Large		Theory
(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)

Plot a graph showing the measured profile of the three vortices and superimpose a

plot of the theoretical profile.



Conclusions

Comment on the graph plotted. Discuss the reasons for the discrepancies between

the experimental values and the theory.

Discuss the assumptions used in the theoretical derivation.

9.To demonstrate the phenomenon of pipe surge resulting from a change in velocity of water flowing through a pipe.

General Overview

The kinetic energy of water flowing in a pipe can be very considerable and any reduction in the flow rate when a valve partly closed at the downstream end of the system may require the dissipation of a large amount of energy. This energy dissipation is manifested as a pressure build-up in the pipeline which can have destructive effects. Reduction of the flow in a hydro-electric supply pipeline, say three miles long for example, could generate pressures sufficient to rupture the pipe or damage the control valve. Likewise, in smaller hydraulic systems, the fast closure of a valve to stop the flow completely can set up pulses of pressure many times the normal static pressure in the system and such pulses will travel back along the pipe at the velocity of sound. The accompanying noise and vibration has led to the term "water hammer" being used for this effect.

The safe dissipation of energy in a pipeline following reduction of the flow can be achieved with a surge shaft or tank fitted at the downstream end of the system.

However, Water Hammer that results from a rapid closure is difficult to dissipate and systems must be designed to prevent this phenomenon from occurring.

The Armfield Pipe Surge and Water Hammer Apparatus contains two independent pipe systems: one demonstrates pipe surge and the use of a surge shaft to attenuate changes in pressure following slow changes to the flow in a system, the other pipe system allows a detailed examination of the shock waves (Water Hammer) generated by rapid changes to the flow in a system such as a valve closing quickly. Observations made on both systems may be analysed by comparison with the relevant theory in the Laboratory Teaching Exercises section.

A single USB connection to a PC (not supplied) provides power for the three pressure transducers on the unit and allows the readings from the pressure transducers to be recorded and stored using the PC. Data logging software allows the relatively slow oscillations in the surge shaft to be viewed in real time and stored for analysis. A virtual oscilloscope allows the rapid changes in pressure, associated with water hammer, to be viewed for analysis after the event due to the short duration of pressure transients following operation of the fast acting valve.

C7-MKII Pipe Surge and Water Hammer Apparatus

Equipment Diagrams

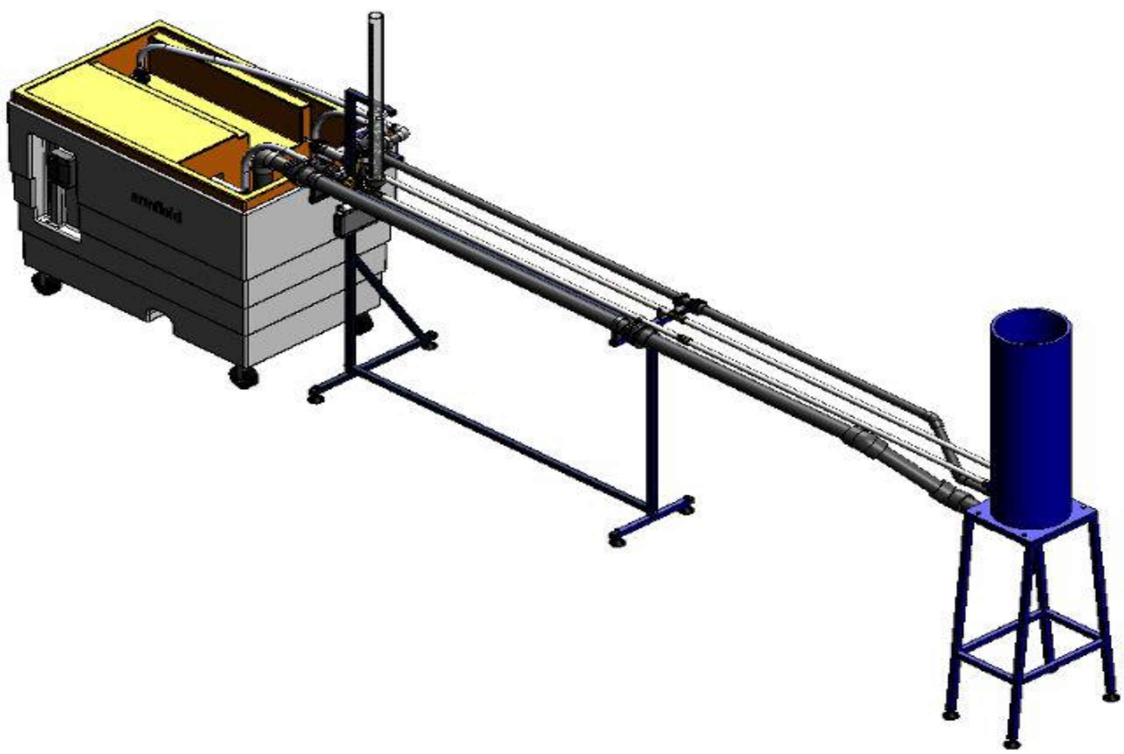


Figure 1: C7-MKII-10 Pipe Surge and Water Hammer Apparatus with F1-10 Hydraulics Bench

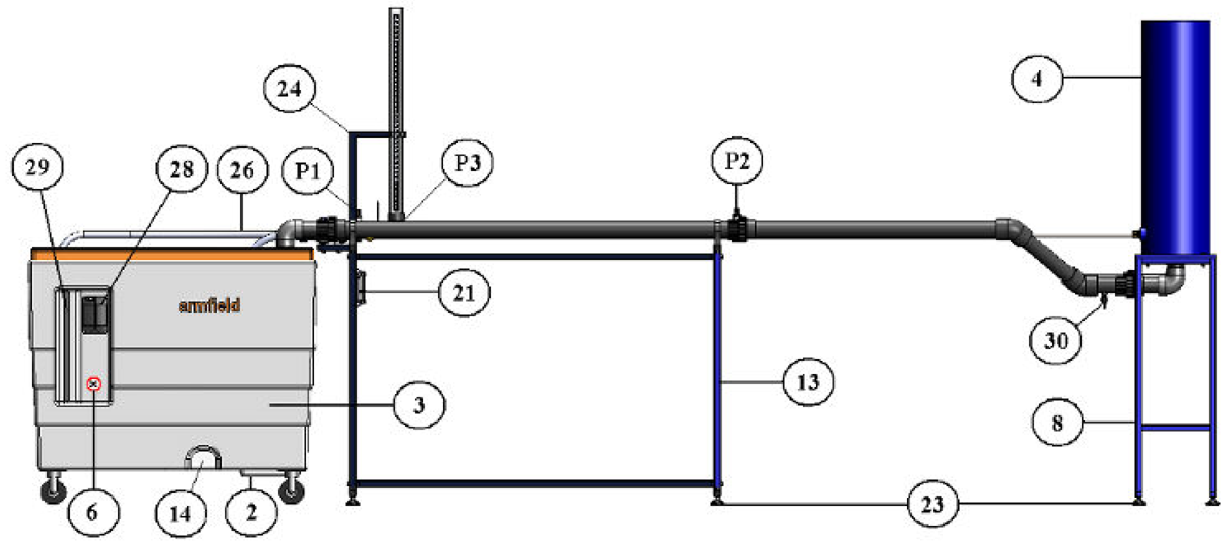


Figure 2: C7-MKII Pipe Surge and Water Hammer Apparatus (Front View)

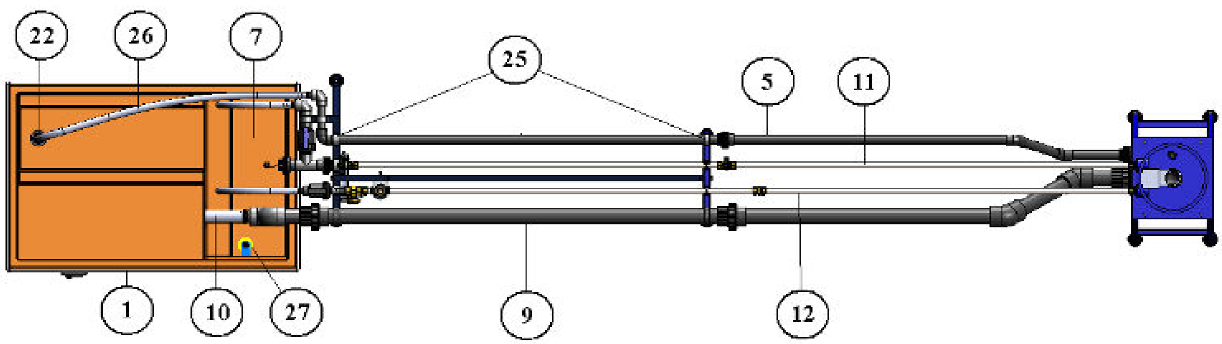


Figure 3: C7-MKII Pipe Surge and Water Hammer Apparatus (Plan View)

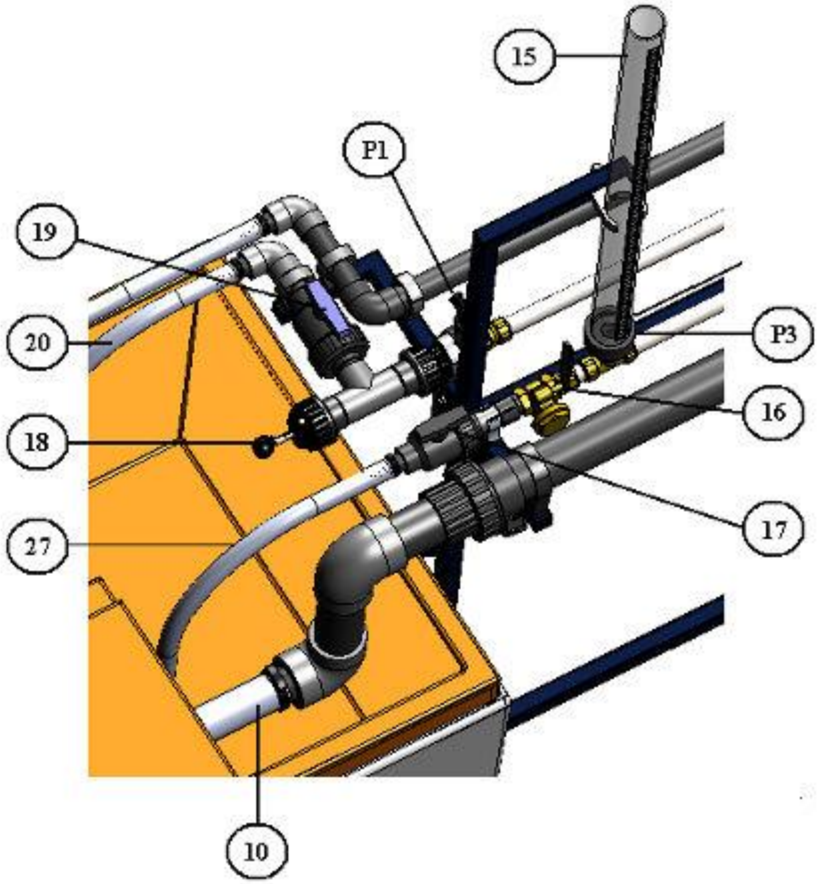


Figure 4: C7-MKII Showing the Pipe Surge and Water Hammer Control Valves

Description

Where necessary, refer to the drawings in the Equipment Diagrams section.

Overview

The C7-MKII-10 Apparatus is free-standing and designed for use in conjunction with the Armfield F1-10 Hydraulics Bench (not supplied with the C7-MKII-10). The Hydraulics Bench provides a self-contained water supply for the C7-MKII and incorporates electrical safety protection.

Where C7-MKII-10 is supplied complete with an F1-10 Hydraulics bench the product codes C7-MKII-A, C7-MKII-B and C7-MKII-G are used to define the operating voltage of the F1-10. No electrical supply is required to the C7-MKII-10 because the pressure

sensors are powered via the USB socket.

The F1-10 Hydraulics Bench

The F1-10 Hydraulics bench (1) incorporates a self priming centrifugal pump (2) which draws water from the sump tank (3) and delivers it to the C7-MKII-10 via the flow control valve (6) located on the front of F1-10 and the outlet connector (22) inside the molded channel.

The sump tank of the F1-10 is fitted with a drain valve (14) to facilitate draining. The GRP molded top on F1-10 incorporates a volumetric measuring tank (7). This tank is stepped to accommodate high or low flow rates and incorporates a stilling baffle to reduce turbulence in the tank.

A remote sight tube and scale (29) is connected to a tapping in the base of the volumetric tank and gives a continuous indication of water level inside the tank.

A dump valve, also in the base of the volumetric tank, is operated by a remote actuator (27). Lifting the actuator opens the dump valve allowing the entrained water to return to the sump tank for recycling. When lifted, a twist of 90° to the actuator will retain the dump valve to the open position.

An overflow in the side of the volumetric tank allows water to return directly to the sump tank and avoids accidental flooding of the volumetric tank. Further details about the F1-10 Hydraulics Bench can be obtained from the Instruction Manual supplied with the F1-10.

Header tank

The F1-10 Hydraulics Bench supplies water to the header tank (4) which is situated on a support stand (8) approximately 3.2 m from the F1-10. Overflow from the header tank is returned to the sump tank of F1-10 via a rigid return pipe (9) which incorporates a clear flexible tube (10) where it enters the overflow in the volumetric tank, allowing water returning to the sump tank to be viewed. This allows the flow to the header tank to be adjusted using the flow control valve (6) on the F1-10 so that the header tank remains full to the overflow without excess water returning to the sump tank.

The stainless steel pipe surge test pipe (11) and water hammer test pipe (12) are connected to outlets at the base of the header tank (4). A floor standing support stand (13), adjacent to the F1-10, supports the necessary valves and fittings associated with C7-MKII-10 and allows the C7-MKII-10 to remain assembled if the F1-10 is removed for another purpose. Flow through both systems is fed into the volumetric tank of the F1-10 via flexible tubes (20) in the pipe surge system and (27) in the water hammer system, allowing the flow rate through either system to be measured.

Pipe Surge Test Section

The pipe surge test pipe (11) is approximately 3.0m long and is supplied as two sections of stainless steel tube which are joined using compression type unions. The pipe is terminated by a lever-operated gate valve (16) which gives a relatively slow rate of closure. Flow exiting the lever operated valve passes through a ball valve (17) that allows the flow to be varied. A vertical, clear acrylic surge shaft or surge tank (15), located upstream of the lever operated gate valve, incorporates a level scale.

A tee connection at the base of the surge shaft incorporates a tapping for a low range pressure sensor (P3) that allows the transient variation in water level inside the surge shaft to be viewed and recorded using a PC. Note that the 0mm calibration on the scale is located 100mm above the centerline of the test pipe.

Water Hammer Test Section

The water hammer test pipe (12) is similarly supplied as two sections with compression type unions and terminates with a trigger operated fast-acting valve (18), Flow exiting the fast acting valve passes through a ball valve (19) that allows the flow to be varied. The unique fast-acting valve (18) is designed so that the moving shuttle inside the valve travels with the water flow, thereby enabling a very fast closure rate to be obtained.

Tappings for two high range pressure sensors are provided in the water hammer test pipe, sensor P1 adjacent to the fast-acting valve and sensor P2 mid-way along the

water hammer test pipe. These sensors allow pressure transients in the pipe to be measured following closure of the fast acting valve at the exit from the water hammer test pipe.

Laboratory Teaching Exercises

Index to Exercises

Nomenclature

Name	Symbol	Unit	Definition
General			
Density of liquid	ρ	kgm^{-3}	Typically 998 kgm^{-3}
Length of pipe	L	m	3.0m
Diameter of pipe (internal)	d	m	0.0202m (20.2mm)
Elevation of inclined pipe	k	m	= 0 m for C7-MKII because the pipe is horizontal
Acceleration due to gravity	g	Nm	9.81
Cross-section of pipe	a	m^2	$0.3204 \times 10^{-3} m^2$
Flow rate	q	m^3s^{-1}	q = V/t
Steady velocity of liquid in pipe	u_0	ms^{-1}	$u_0 = q/a$
Time	t	s	Time taken to collect volume of water V
Volume	V	litres	Volume of water V collected in the volumetric tank during time period t
Pipe Surge			
Diameter of surge shaft (internal)	D	m	0.044m (44.0mm)
Cross-section of surge shaft	A	m^2	$1.521 \times 10^{-3} m^2$
Level in the surge shaft above static level at any instant	y	m	Measured by P3 (indicated in mm)
Static Head	h_s	m	Height in surge shaft with no flow
Velocity Head	h_v	m	Height in surge shaft with flow
Head loss in pipe	h_f	m	$h_f = h_s - h_v$

Angular frequency	ω	Rads/ sec	Angular speed (Simple harmonic motion)
Time period of oscillation	T_o	s	$T_o = 2\pi\sqrt{\frac{LA}{ga}}$
Maximum level in the surge shaft above static level	Y	m	$Y = u_0\sqrt{\frac{La}{gA}} - 0.6h_f$
Water Hammer			
Bulk modulus of elasticity (for water at NTP)	K	GNm^{-2}	$K = \frac{\Delta p}{\Delta\rho/\rho}$ $= 2.15\ GNm^{-2}$ for water
Distance between pressure sensors P_1 and P_2	s	m	1.5m
Thickness of pipe wall	t_p	m	0.0009m (0.90mm)
Duration of pulse	T_d	s	$T_d = \frac{2L}{c}$
Time between successive readings	T_s	s	Measured
Velocity of sound (in free water)	c	ms^{-1}	$c = \sqrt{\frac{K}{\rho}}$
Velocity of sound (in water filled pipe)	c_e	ms^{-1}	$c_e = \sqrt{\frac{K}{\rho\left(1 + \frac{Kd}{t_p E}\right)}}$
Pressure developed	p	Nm^{-2}	$p = \rho u c_e$ (from theory)
Pressure developed by Water Hammer	p	bar	Measured P1 at valve P2 mid way along pipe

9.Exercise A - Pipe Surge

Objective

To demonstrate the phenomenon of pipe surge resulting from a change in velocity of the water flowing along a pipe.

To demonstrate the use of a surge shaft to attenuate any changes in pressure associated with pipe surge and the oscillatory characteristics of water level in a surge shaft.

To demonstrate head loss between the reservoir and the surge shaft due to friction in the pipe.

Method

By closing the lever operated valve in the Pipe Surge circuit of the Armfield C7-MKII- 10 and observing the level changes in the surge shaft. A pressure sensor continuously monitors the changes in water level in the surge shaft following closure of a valve and allows the response to be recording on a PC.

Note: The pressure variations in the pipe are relatively slow to change so the normal data logger is used to monitor the variations. The virtual oscilloscope is only required when testing the water Hammer system.

Equipment Required

- Armfield C7-MKII-10 (Pipe Surge circuit)
- F1-10 Hydraulics Bench
- Stopwatch (for timed volume collection using the volumetric tank on F1-10).

Theory

Frictionless Analysis of the Simple Surge Shaft

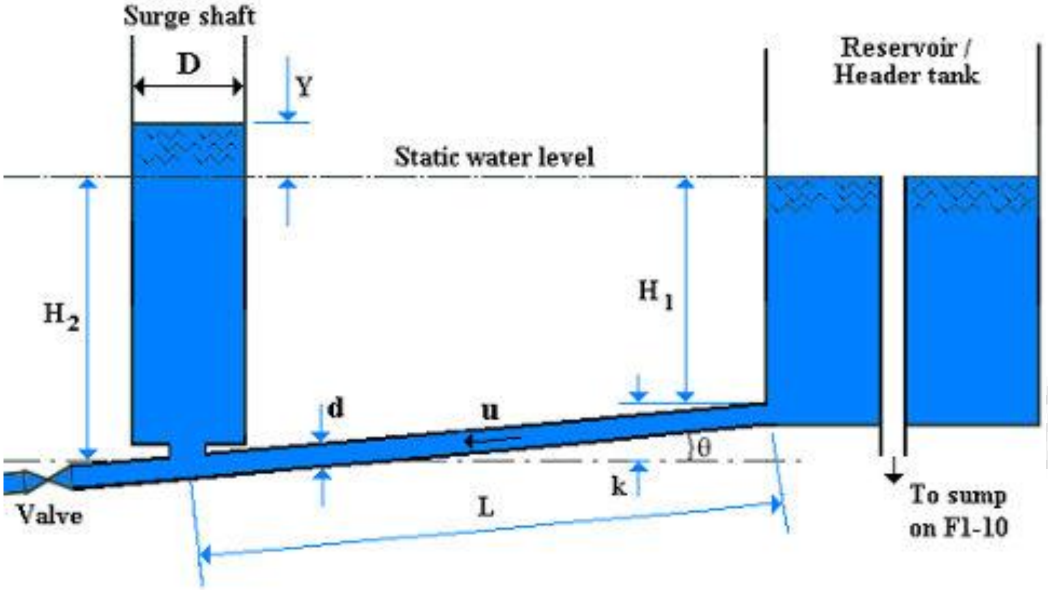


Figure A1: Schematic diagram of pipe surge system

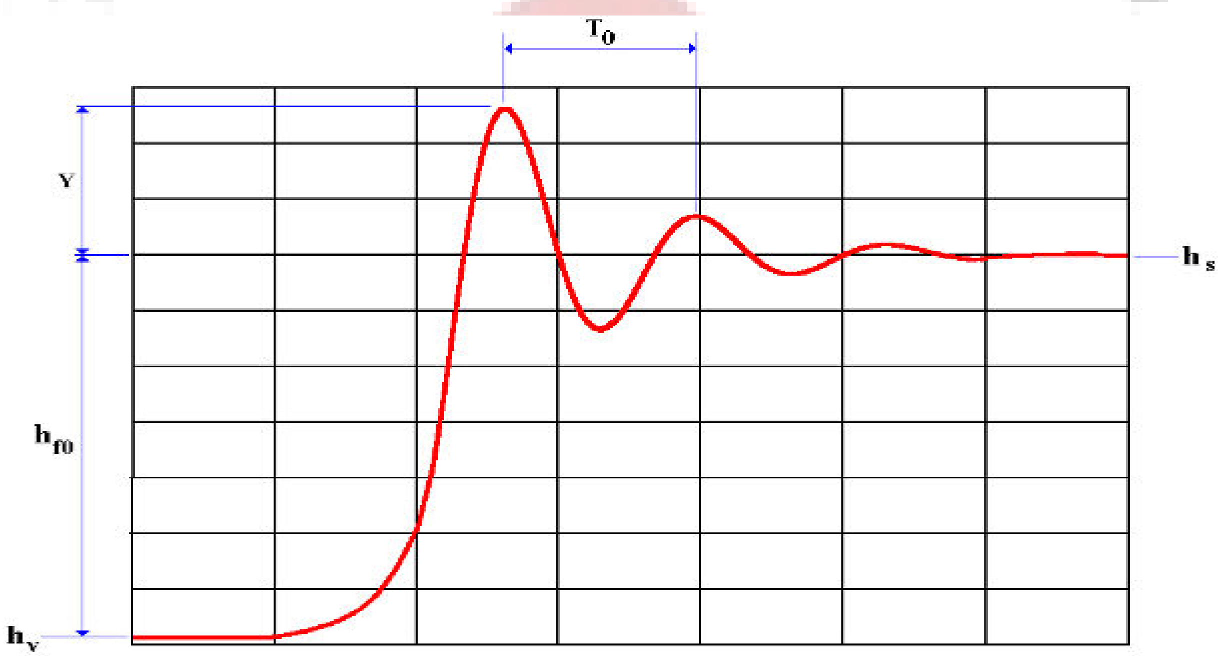


Figure A2: Height changes in surge shaft following valve closure

Note: In the case of C7-MKII-10 the pipe between the reservoir and the surge shaft is horizontal so θ = 0 and k = 0

a = cross-section of pipe (from d), and

A = cross-section of surge shaft (from D),

at any time t after the flow through the valve is changed.
Velocity in the pipe = u

Level in the surge shaft above static (reservoir) level = y

Discharge through the valve = q

Level in the surge shaft (rises or falls with velocity) = $\frac{dy}{dt}$

Applying Newton's Second Law to the motion of the water,
Mass x acceleration = force due to pressure difference at ends

+ component of weight of water

- force due to friction in pipe.

Therefore $\rho a L \frac{du}{dt} = \rho g a H_1 - \rho g a (H_2 + y) + \rho g a L \sin\theta - \rho g a h_f$

If θ is small then $L \sin\theta \approx k$ and H2 = H1 + k

Therefore $\frac{L}{g}\frac{du}{dt} + y + h_f = 0$ (1)

where hf is the head loss in the pipe
and hf = hs - hv

Note:

hs = H1 = H2 when water is stationary with valve closed

hv = H2 when water is flowing along the pipe therefore hf0 = H1 - H2

hf0 will vary with setting of flow control valve at exit from pipe

For continuity, flow in the pipe = flow into surge shaft + flow through valve i.e. $au = A\frac{dy}{dt} + q$ or $u = \frac{A}{a}\frac{dy}{dt} + \frac{q}{a}$

(2)

Substituting for u from (2) in (1)

$$\frac{L}{g}\frac{d}{dt}\left[\frac{A}{a}\frac{dy}{dt} + \frac{q}{a}\right] + y + h_f = 0 \qquad (3)$$

This is the general equation with

hf = f(u2), q = f(t) and q = f(y)

and there is no general solution.

A simplified solution is obtained if q = 0 (i.e. flow through the valve is zero) and

if the friction losses are neglected i.e. hf = 0

Equation (3) then becomes:

$$\frac{A}{a}\frac{L}{g}\frac{d^2y}{dt^2} + y = 0$$

or

$$\frac{d^2y}{dt^2}+\frac{ga}{LA}y=0 \qquad (4)$$

This is the equation for undammed SHM in the form

$$\frac{d^2y}{dt^2}+\omega^2 y=0$$ where $\omega=\sqrt{\frac{ga}{LA}}$

The periods of oscillation $T_o=\frac{2\pi}{\omega}$

Therefore $T_o=2\pi\sqrt{\frac{LA}{ga}}$ (5)

Maximum amplitude Y is found from v = yω where v is the orbital velocity for SHM.

In this case, $u=\frac{au_0}{A}$ where uo is the steady pipe velocity

$$Y=\frac{v}{\omega}=\frac{au_o}{A\sqrt{\frac{ga}{LA}}}$$

Therefore by rearranging the equation

Maximum Amplitude $Y=u_o\sqrt{\frac{La}{gA}}$ (6)

As stated previously, this result does not account for frictional effects. If friction is taken into account, the following approximate solutions apply for the case of

instantaneous closure of the valve.

Maximum surge height = Y - 0.6*hfo* *7*

Therefore maximum surge height = $Y\left(1-\frac{h_{f_o}}{3Y}\right)^2$ 7a

Equipment Set Up

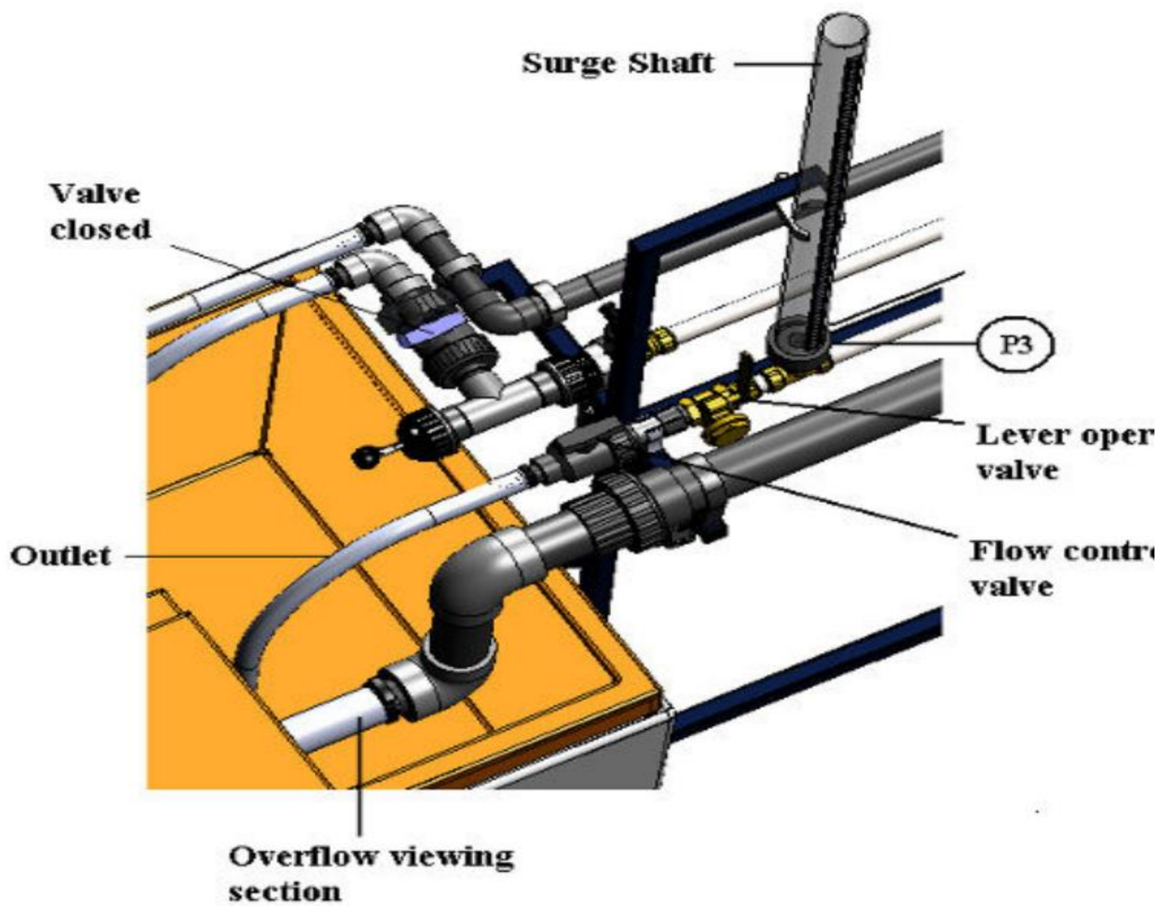


Figure A3: Components associated with pipe surge system

- Close the flow control valve in the water hammer circuit on C7-MKII-10. Close the supply control valve on F1-10.
- Open the lever operated gate valve and close the flow control valve at the end of the pipe surge circuit on C7-MKII.
- Switch on the pump using the switch on F1-10.
- Gradually open the supply control valve on F1-10 and allow the header tank to fill (indicated by the water level in the transparent surge shaft).
- When water starts to flow through the overflow viewing section (water has reached the level of the overflow inside the header tank) open the flow control valve alongside the lever operated valve. Water will flow through the test pipe and into the volumetric tank.
- Open the flow control valve and allow any trapped air to be flushed from the test pipe.
- Close the flow control valve and allow the level in the surge shaft to stabilize. Arm field Instruction Manual
- If necessary, adjust the supply control valve on F1-10 until a steady trickle of water returns to the sump tank via the overflow.
- Allow the level in the surge shaft to stabilize at this higher level then record the reading on the scale. This is the static datum hs corresponding with the level in the reservoir (no flow along the pipe so no frictional loss in the test pipe or surge shaft).

➢ A vertical strip of self-adhesive tape such as masking tape, placed alongside the scale, can be used to mark this datum for future reference.

Procedure

➢ Load the C7-MKII software then choose the Pipe Surge Demonstration. Alternatively, if the software is already open choose File then Load New Experiment followed by Pipe Surge Demonstration.
➢ The Welcome Screen will be displayed.
➢ Details about operating the software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:

➢ Display the mimic diagram then confirm that the reading from pressure sensor P3 is sensible (indicates the height of the water in the surge shaft).
➢ Ensure that the lever operated valve is fully open (lever pushed backwards). Slowly open the flow control valve so that water flows through the test pipe then adjust the flow control valve until the level in the surge shaft falls by a convenient amount below
➢ the static datum e.g. 150 mm. The difference between the level in the header tank and the level in the surge shaft

corresponds with the frictional losses in the test pipe due to the flow of water.

- Using self-adhesive tape mark the level in the surge shaft, the drop in level corresponding to the velocity head hv.
- Measure the flow rate using the volumetric tank. To do this, close the dump valve in the base of the volumetric tank while starting timing using a stopwatch. Allow a measurable quantity of water to collect in the tank (depending on the flow rate this quantity may vary, but timed collection should continue for approximately 60 seconds unless this would exceed the capacity of the volumetric tank). Record the volume collected and the time to collect then release the dump valve to allow water to flow back into the sump tank.
- Repeat this measurement three times then calculate the average flowrate from the three sets of readings obtained.
- Choose the Go icon to start recording the level on the PC then swiftly pull the lever on the lever operated valve forwards until it is fully closed.

- Observe how the water in the surge shaft rises above the static datum hs then falls below the datum and the level continues to oscillate with reducing magnitude until the level is steady at the static datum.
- When the level in the surge shaft is steady, swiftly open the lever-operated gate valve fully and observe the level

return to the level marked hs, heavily damped with little or no oscillations.

- Allow the level to stabilize and confirm that the level returns to the hv mark. If laboratory time allows, the above procedure may be repeated at different initial flowrates and corresponding values for hv.

Results

See the nomenclature section for values of the constants used.

Record your results in the following tables:

Volume Collected	Time Taken	Flow Rate	Initial Velocity	Static Head	Head in shaft with flow	Initial Headloss
V	t	q	u_0	h_s	h_v	h_{f0}
(l)	(s)	(m^3/s)	(m/s)	(m)	(m/s)	(m/s)

where

Flow rate q = V/t

Velocity u0 = q/a

Head loss hf0 = hs – hv

From the graph obtained using the data logger determine the following parameters:

Maximum Surge Height Y m

Period of oscillation T0 seconds

Determine the time period T0 and compare this with the theoretical value for T0

calculated from the equation

$$T_o = 2\pi\sqrt{\frac{LA}{ga}}$$

Determine the maximum height of the first surge following valve closure and

compare this with the theoretical value calculated from the equation:

$$Y = u_0\sqrt{\frac{La}{gA}} - 0.6h_f$$

Conclusion

The surges resulting from varying flow in a long pipe can be damaging to a system

such as the flow to a turbine where the reservoir is located high up in a mountain and

connected via a long delivery pipe.

A surge shaft allows variation in head to be dissipated by friction and protects the

pipework and system components from damage.

The resulting period of oscillation and height reached in surge shaft can be compared with theoretical values derived from basic equations.

Note: A more rigorous analysis, taking friction effects into account, may be

undertaken using a step by step solution of the differential equations which define the

motion of the fluid in the surge shaft. Friction effects are very significant in a small

bore system and should be taken into account when interpreting the experimental

observations.

10.Determination of characteristics of water hammer.

Exercise B - Water Hammer

Objective

To determine the characteristics of water hammer.

Method

By closing the trigger operated valve in the Water Hammer circuit of the Arm field C7- MKII-10 and recording the pressure changes in the test pipe using a PC with virtual oscilloscope.

Using a pressure sensor to continuously monitor the pressure changes adjacent to the fast acting valve following rapid closure of the valve.

Note: The pressure variations in the pipe are extremely short in duration so the normal data logger cannot be used to record the event. The virtual oscilloscope included in the Arm field software is used to record the measurements.

Equipment Required

- Armfield C7-MKII-10 (Water Hammer circuit)
- F1-10 Hydraulics Bench
- Stopwatch (for timed volume collection using the volumetric tank on F1-10)

Theory

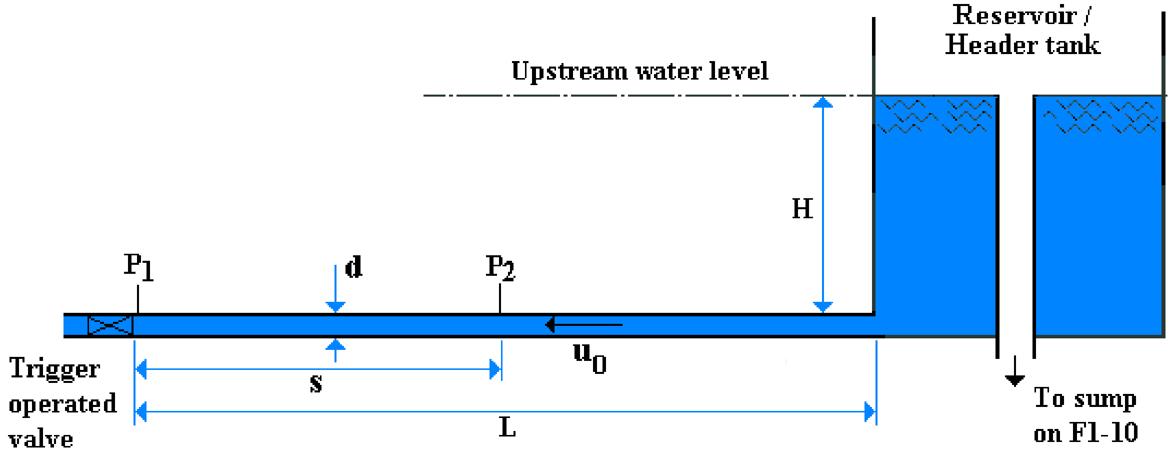


Figure B1: Schematic diagram of Water Hammer system

The kinetic energy of a moving column of liquid in a pipe is converted to potential energy in the form of pressure if the column is suddenly brought to rest by the closing of a valve. then Kinetic Energy lost = Strain Energy gained

$$\frac{1}{2}\rho\frac{\pi}{4}d^2Lu^2 = \frac{1}{2}\frac{p_2}{K}.\frac{\pi}{4}d^2L$$

Or

$$p = u\sqrt{(K\rho)} \quad (1)$$

But the velocity of sound c through water in a rigid pipe is given by

$$c = \sqrt{\frac{K}{\rho}} \quad (2)$$

substituting for K in (1)

$$p = u\sqrt{(\rho c^2 \rho)} = \rho uc \qquad (3)$$

In practice the velocity of sound is reduced because of elasticity in the pipe wall. The speed of the wave is designated ce.

Equation (2) becomes modified to

$$c_e = \sqrt{\frac{K}{\rho\left(1 + \frac{Kd}{t_p E}\right)}} \qquad 2a$$

and equation (3) becomes modified to

p = *ρuc*e (3a)

This sudden pressure rise will be transmitted from the valve down the pipe at the velocity of sound to the reservoir where it will be reflected back to the valve.

Here reflection produces a low pressure wave which will, in turn, be transmitted to the reservoir and reflected back. This sequence of events may be repeated and is illustrated in Figures B2 and B3 below, the latter illustrating the effect of energy losses in the system. The corresponding ideal sequence of events at a point along the pipe is shown in Figure B4.

There will be a time delay of sC before the first pressure pulse reaches the pressure sensor half-way along the pipe, where s is the distance between the sensors. Thus, measurement of this time delay may be used to determine the velocity of sound in the water/pipe system which should compare with that derived from the theoretical expression (3a) above.

The theoretical pressure waves of Figures B2, B3 and B4 will be dramatically modified when the normal head in the pipe is low. The negative-going pressure waves of water hammer may then reduce the pressure in the system to the vapour pressure of the liquid. The Armfield Water Hammer Apparatus has been specifically designed to do this and thereby simulate a likely real situation. The pressure waves at the valve will then ideally take the form shown in the Figure B5 where the initial pressure pulse may be expected to be similar to Figure B2 but subsequent events will be different. The first low pressure pulse falls to the vapour pressure of the liquid with the generation of gas and/or vapour bubbles (boiling) and will remain there until the bubbles collapse.

The energy is then converted into a second pressure pulse, thereby repeating the process.

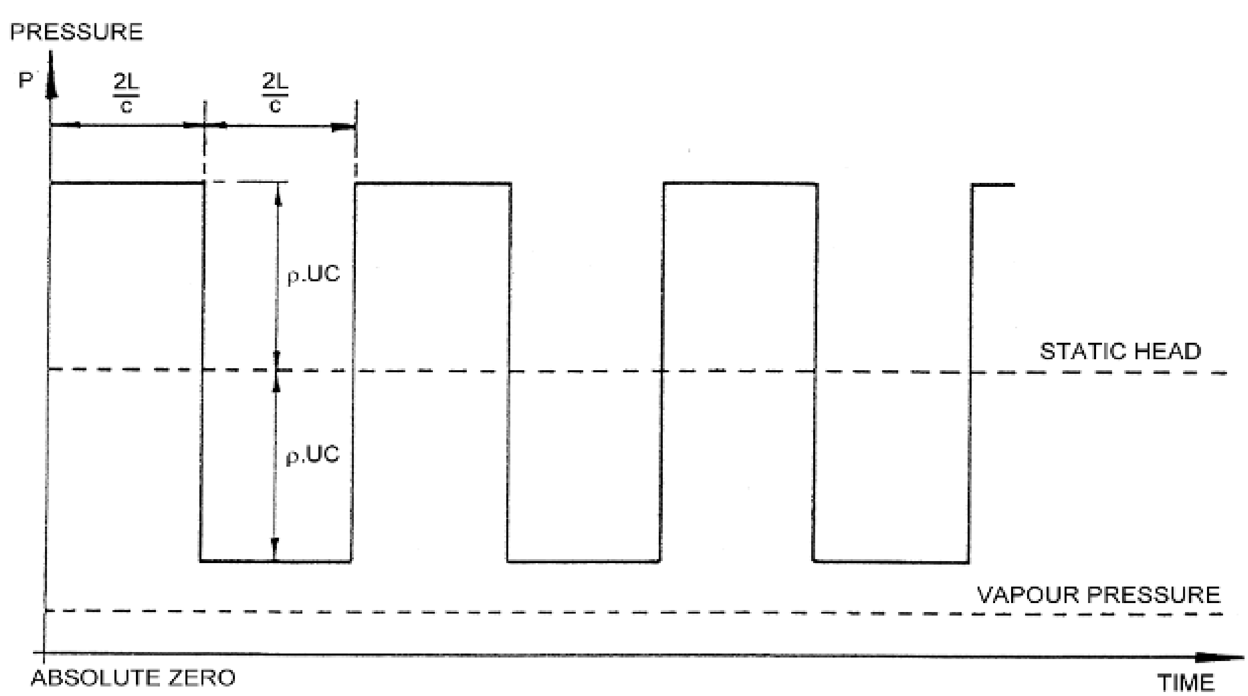


Figure B2: Theoretical Water Hammer Pressure Waves at the Valve in an Ideal System

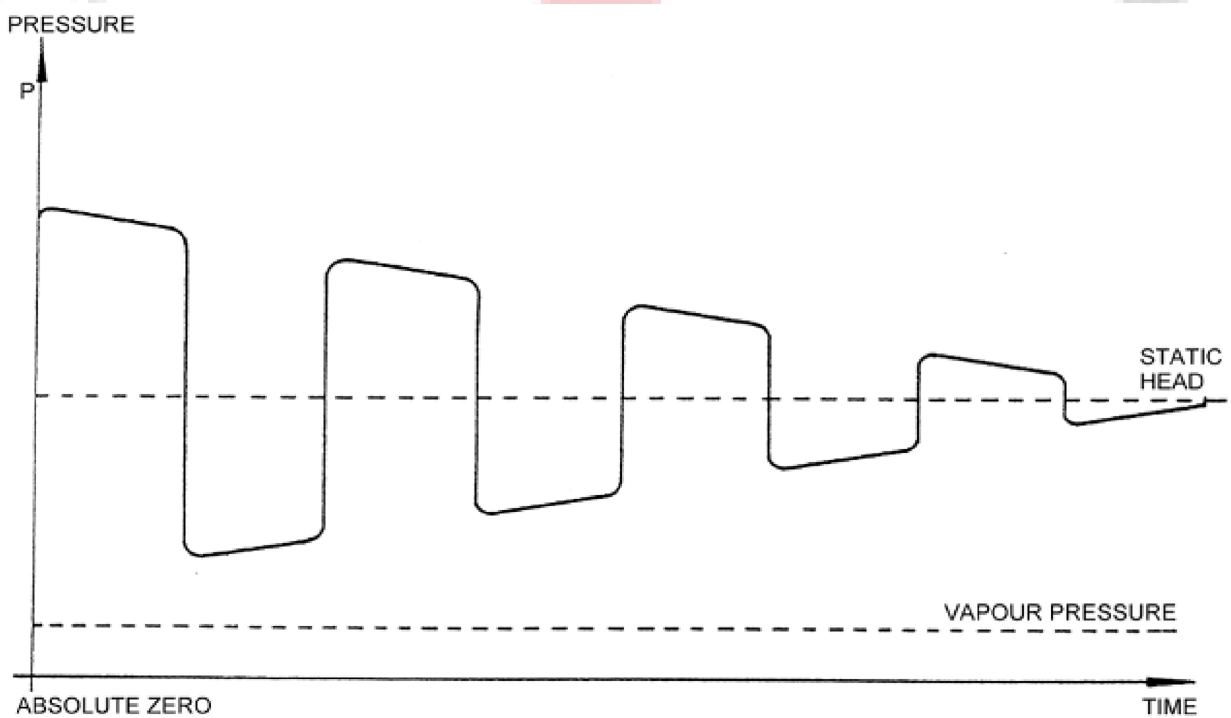


Figure B3: Theoretical Water Hammer Pressure Waves at the Valve in a Real System with Attenuation

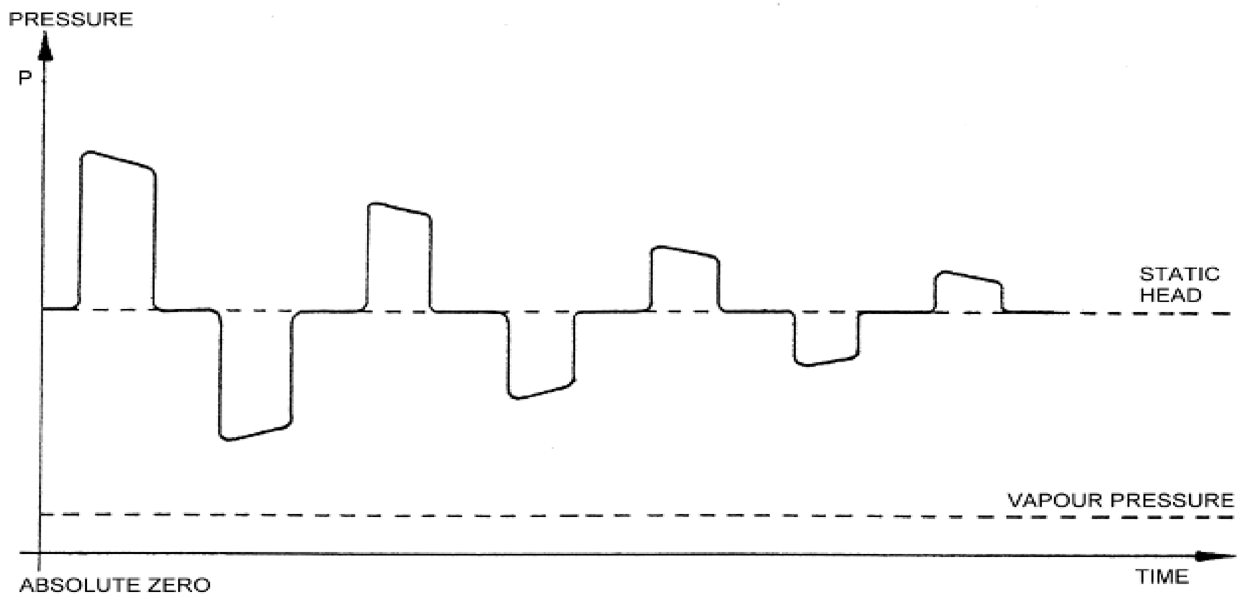


Figure B4: Theoretical Water Hammer Pressure Waves at a Point along the Pipe in a Real System with Attenuation

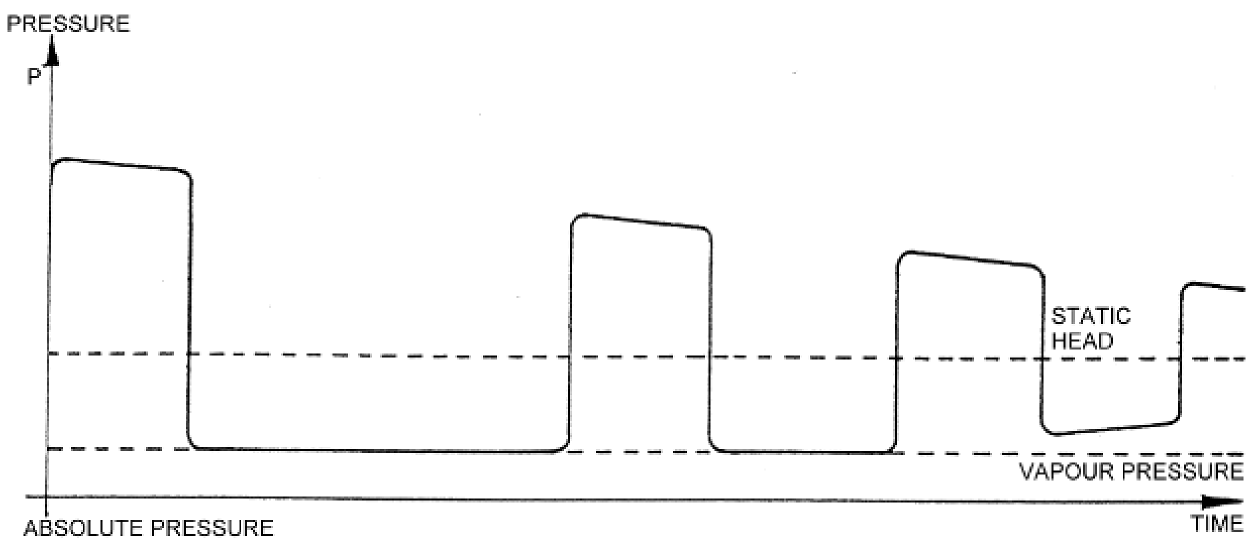


Figure B5: Water Hammer Pressure Waves at the Valve in a Real System with a Low Static Head

Interpretation of the traces obtained on the oscilloscope

In practice the violent nature of the instantaneous valve closure results in vibration in the system that is superimposed on top of the theoretical response shown in Figure B5 above. The resulting traces will look similar to the diagram below showing the alternating changes in pressure then vacuum, gradually decaying in amplitude due to friction in the system.

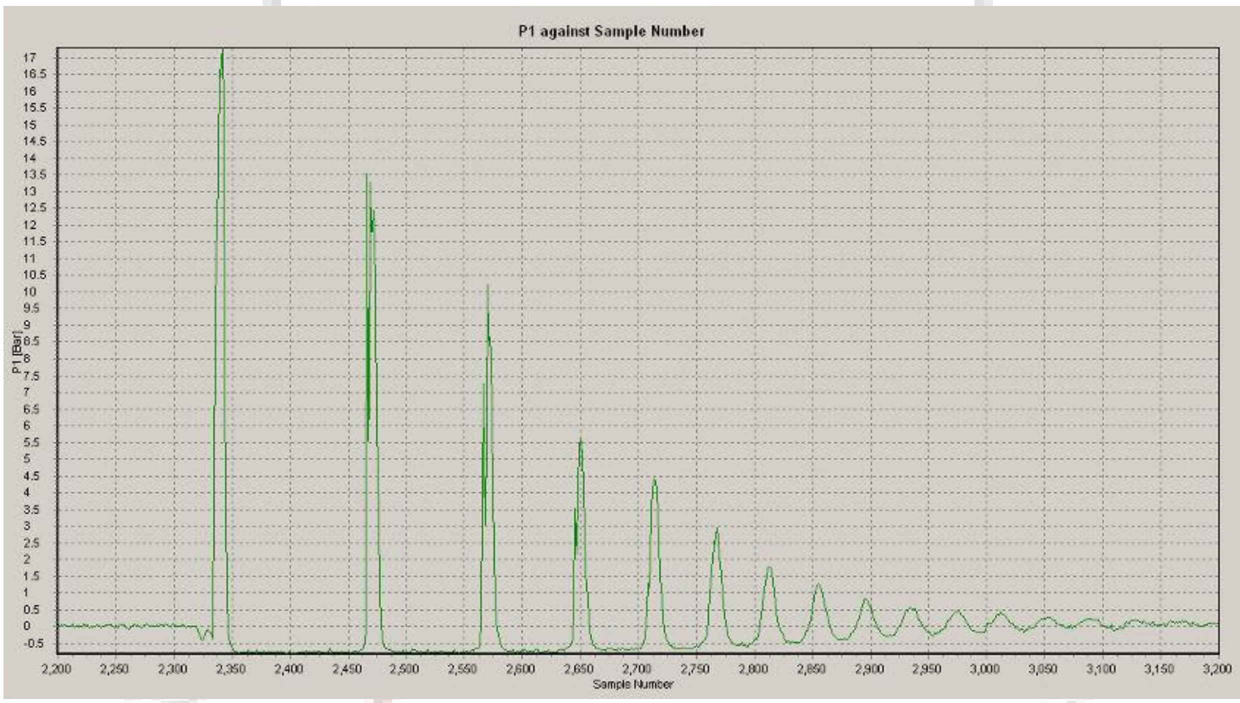
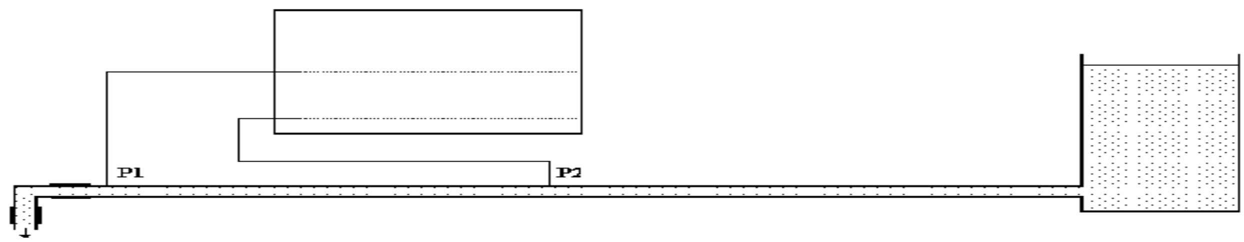


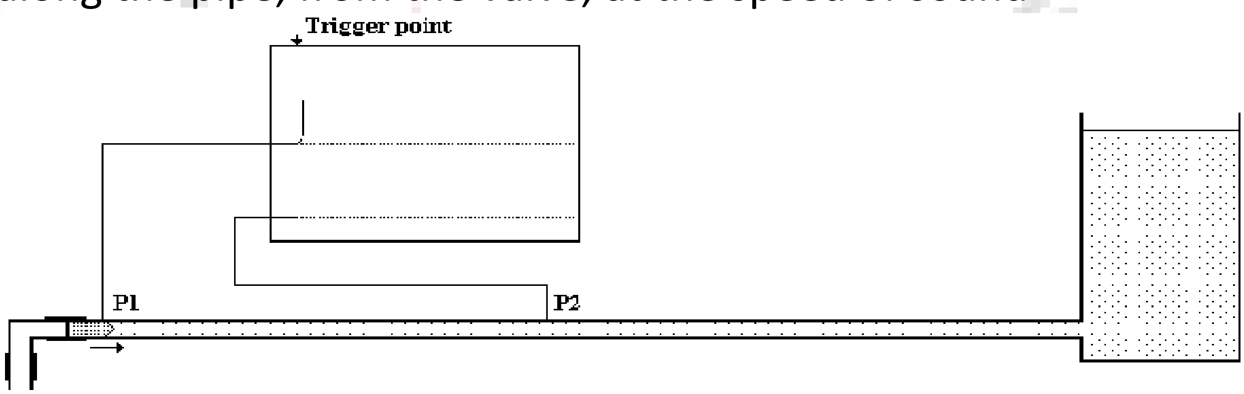
Figure B6: Typical trace showing changes in pressure at the valve due to Water Hammer

To aid understanding of the phenomena, the following diagrams illustrate the sequence of events inside the pipe in conjunction with the traces obtained on the oscilloscope, following rapid closure of the valve at the exit from the test pipe. Only the first cycle of rising pressure followed by vacuum is shown with subsequent cyclesrepeating at reduced amplitude.

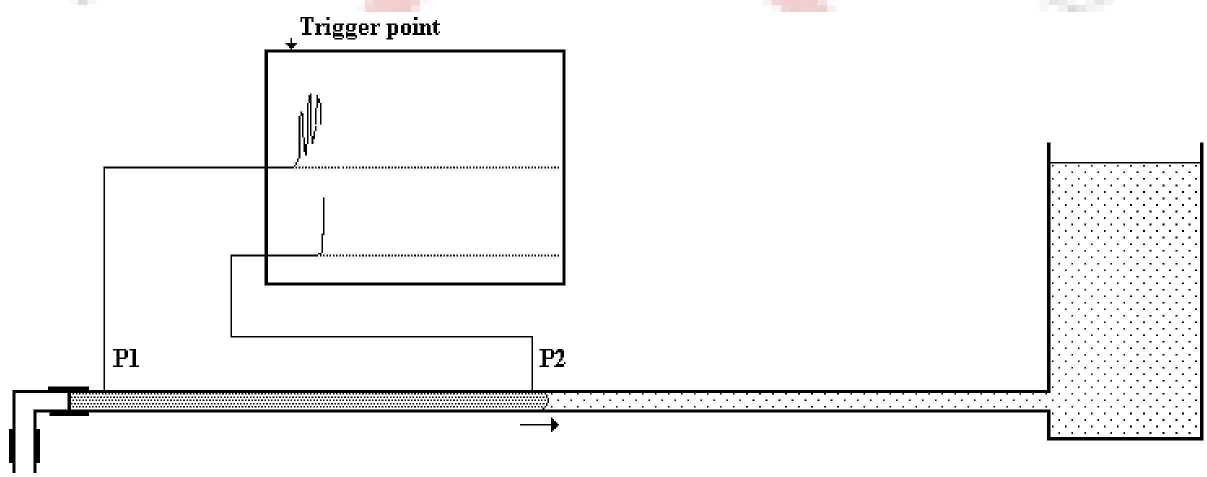
1. Valve is open and water flows steadily along the pipe. Data capture is started (Go icon)



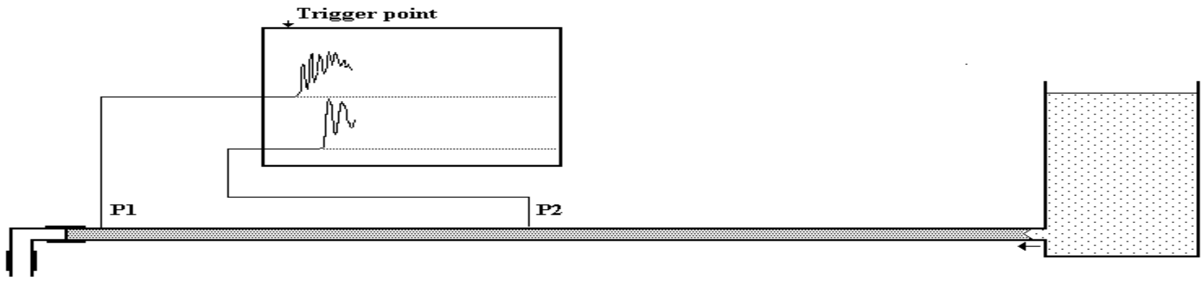
2. Valve closes rapidly stopping the flow of water instantaneously resulting in a high pressure wave that travels along the pipe, from the valve, at the speed of sound



3. Pressure wave reaches the sensor mid-way along the pipe

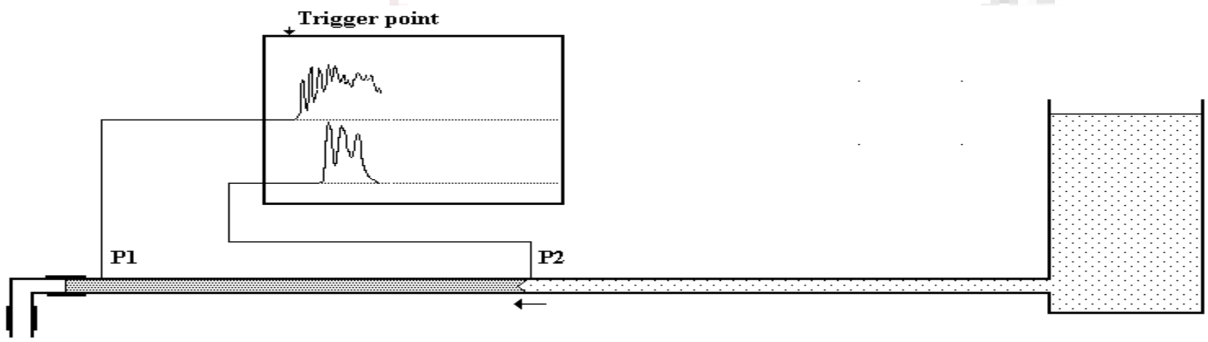


4. Pressure wave reaches the open end of the pipe and is reflecte

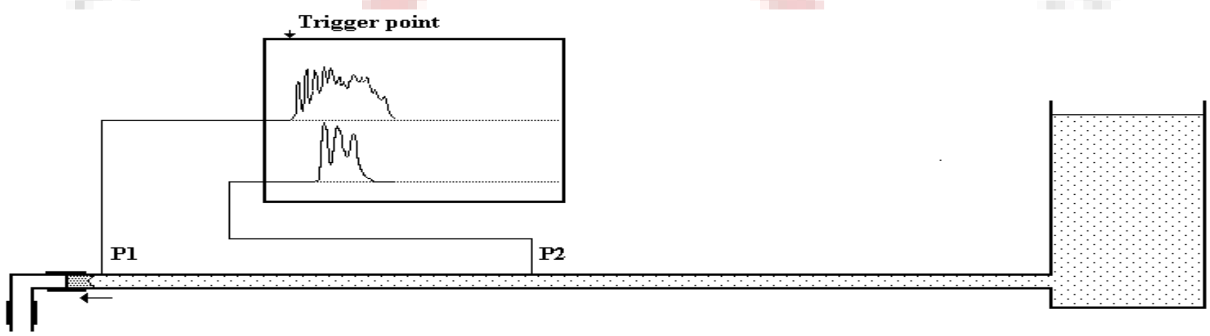


d at the change in cross section.

5. Reflected wave passes the sensor mid-way along the pipe.

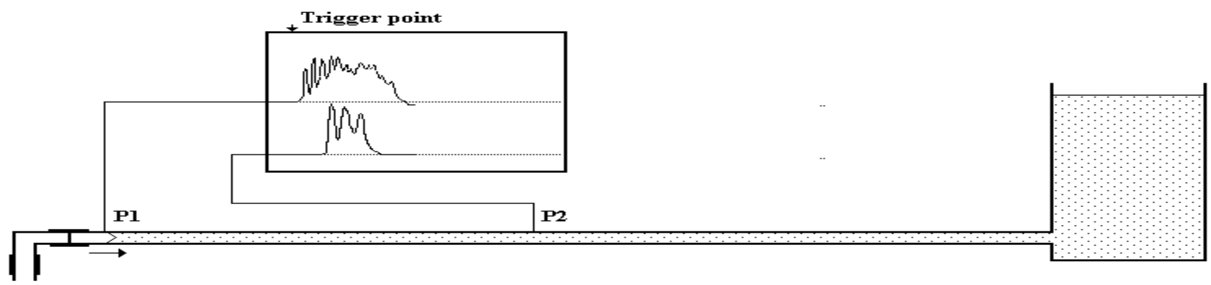


6. Reflected wave reaches the valve.

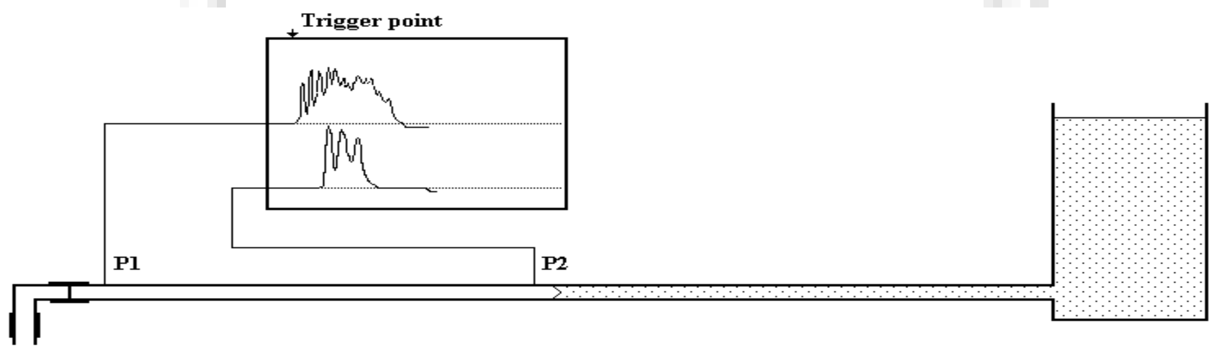


7. Wave is re-reflected as a rarefied wave (pressure reduces to the vapour

pressure of the water resulting in violent Cavitation).



8. Rarefied wave passes the sensor mid-way along pipe then continues to the end of the pipe leaving the entire pipe filled with water at its vapour pressure.



In theory, this alternating cycle of pressure and vacuum should repeat at regular intervals with reducing magnitude due to friction in the system. However, the formation of a vacuum (vapour pressure of the water) inside the pipe interrupts the process because the wave cannot propagate through the vacuum. This causes increased time delays between the successive pulses. Longer delays are incurred at the start of the process but the delays reduce as the magnitude of the vacuum phases become smaller. This effect is seen in the initial results obtained using the oscilloscope before changing the axis scales to view the first pulse as described above.

Equipment Set Up

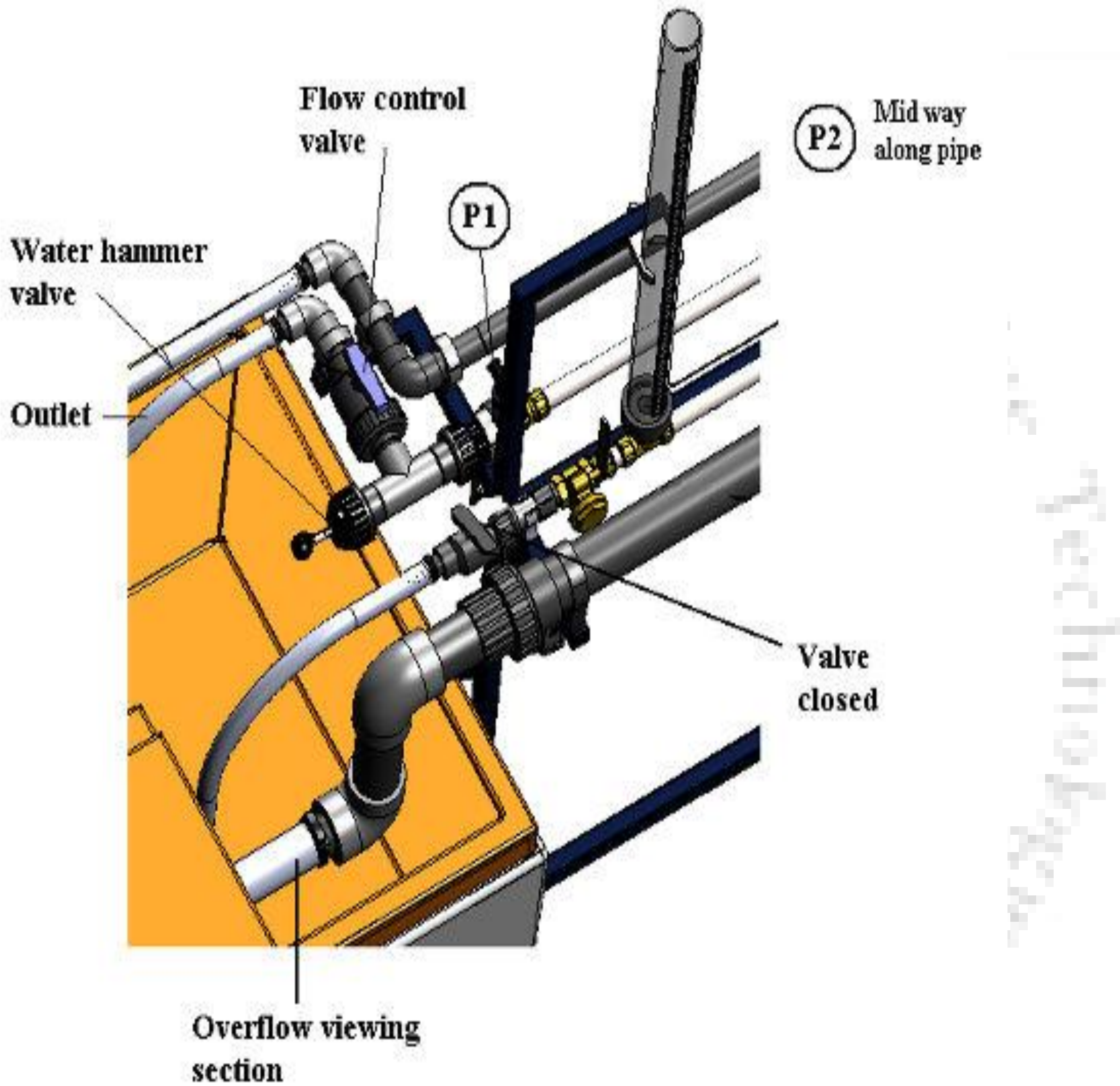


Figure B7: Components associated with water hammer system

- Close the flow control valve in the pipe surge circuit.
- Close the supply control valve on F1-10.

- Open the fast acting valve on C7-MKII by pushing the black knob inwards until it latches.
- Close the flow control valve at the end of the water hammer circuit on C7-MKII.
- Switch on the pump using the switch on F1-10.
- Gradually open the supply control valve on F1-10 and allow the header tank to fill (indicated by the water level in the transparent surge shaft).
- When water starts to flow through the overflow viewing section (water has reached the level of the overflow inside the header tank) open the flow control valve alongside the fast acting valve. Water will flow through the test pipe and flush any trapped air from the test pipe. Water should flow steadily through the test pipe and exit into the volumetric tank via the flexible outlet tube.
- If necessary adjust the supply control valve on F1-10 until a steady trickle of water
- returns to the sump tank via the overflow.

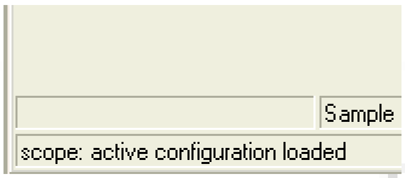
Procedure

- With water flowing steadily through the test pipe, measure and record the flowrate using the volumetric tank on F1-10 and a stopwatch. Repeat this three times to obtain an average value Refer to exercise A if details are required.
- Load the C7-MKII software on the PC then load the Water Hammer Demonstration.

- The welcome screen should be displayed.
- Details about operating the software can be obtained by choosing the 'Help' tab in the top right hand corner of the screen as shown below:

- Display the mimic diagram and observe that readings from the two pressure sensors P1 and P2 in the water hammer circuit are displayed (indicating atmospheric pressure). Although very large in comparison with pipe surge pressures, the changes in pressure associated with water hammer only last for fractions of a second so the phenomena must be recorded using a virtual oscilloscope and viewed following the event and cannot be observed in real time.
- Open the flow control (19) fully then open the fast acting valve (18) and the flow through the water hammer circuit to settle. The level in the surge shaft should remain high indicating the level in the reservoir. Confirm that a small flow of water is returning to the sump tank via the clear tube in the return pipe. If necessary adjust
  the flow control valve on F1-10 to maintain a small flow from the overflow.

- Having loaded the Water Hammer exercise on the PC, the virtual oscilloscope will be enabled indicated by a message in the bottom left hand corner of the screen:



Note: If the virtual oscilloscope is not automatically enabled or it is required to

change the settings associated with the oscilloscope then refer to the Operation

section.

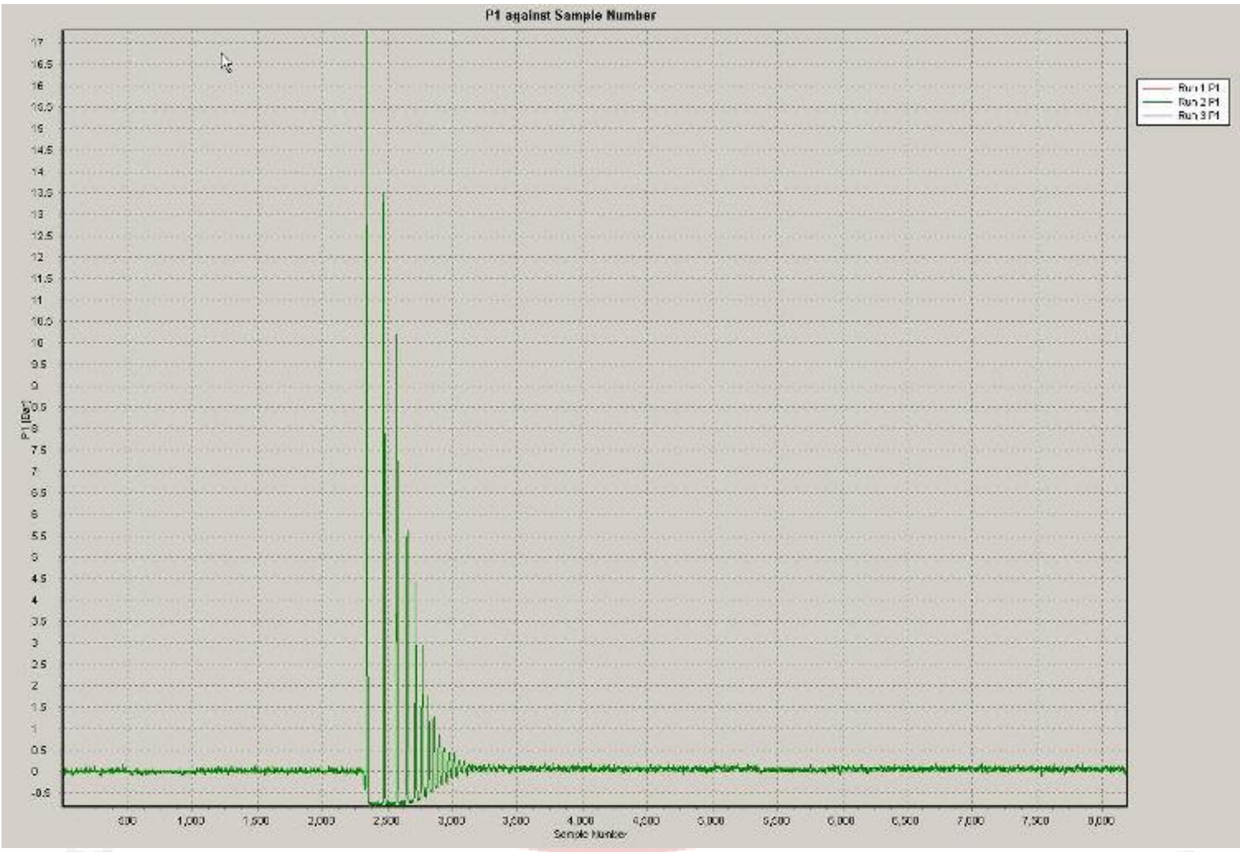
- Click the Go icon in the top tool bar to start logging data then press the trigger on the fast acting valve within approximately 2 seconds.
- Wait until the data has been recorded and processed then save the data obtained.
- Choose graphs to display the pressure transient obtained from pressure sensor P1 at the fast acting valve. For a clear view of the pressure transients change the scaling of the x axis to eliminate the unimportant information before and after the water hammer event.
- Display the traces from pressure sensors P1 and P2 on different axes to view the differences between the traces.
- If time permits repeat the run with the flow of water through the test pipe reduced by partly closing the flow

control valve adjacent to the fast acting valve. Measure the flowrate using the volumetric tank on F1-10 then create water hammer and record the responses.

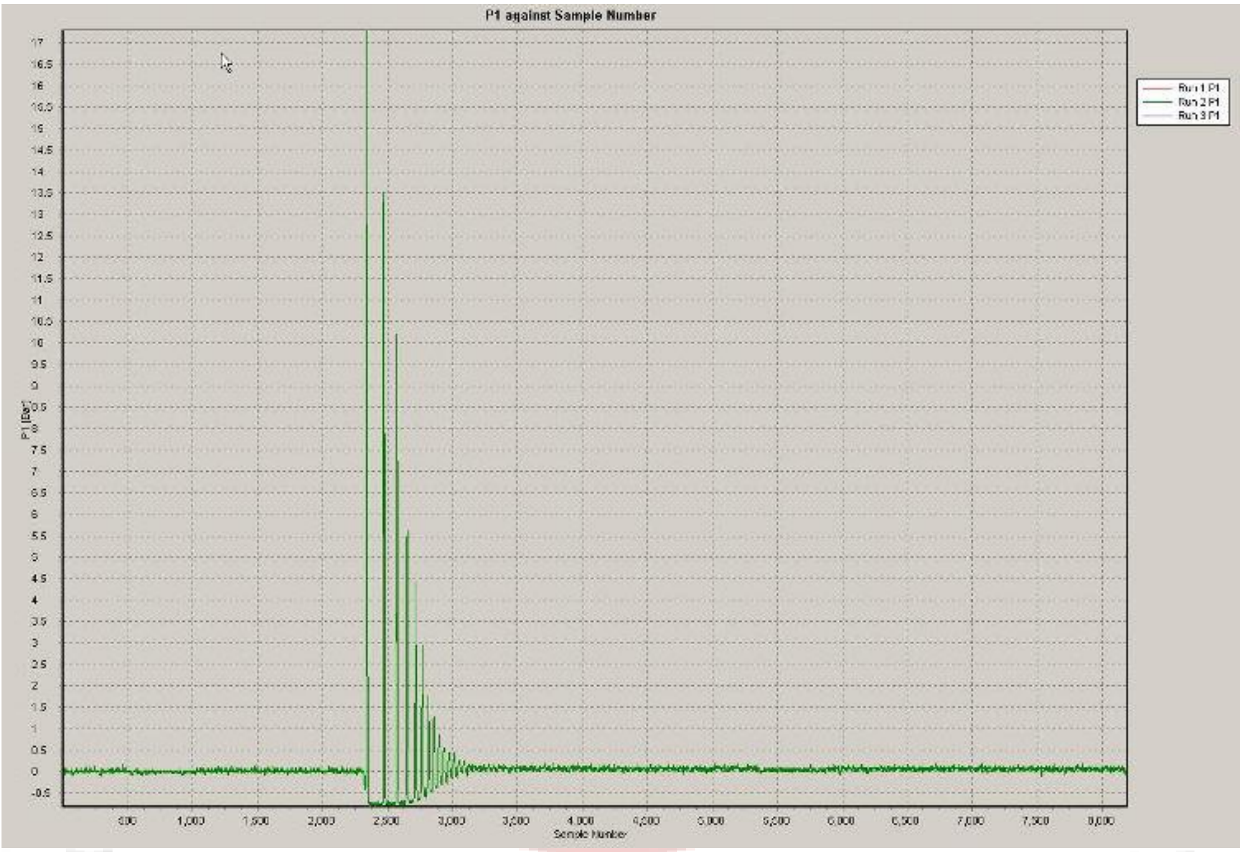
Results

The measurements from pressure sensors P1 and P2 are directly calibration in the software to give readings directly is units of Bar Gauge so that sub-atmospheric pressure is shown negative.

Note: The actual waveform obtained will be a combination of vibrations in the system superimposed on the theoretical square waveform caused by the water hammer and limitations in the speed of data sampling. An estimate of the maximum amplitude from the first pressure pulse will be sufficient for use in the calculations. The response at pressure sensor P1 should be similar to the graph shown below:



To improve the detail, adjust the sample numbers displayed along the X axis to obtain the graph shown above in Figure B5. See the nomenclature section for values of the constants used. Record your results from the volumetric tank on F1-10 in the following table:



the virtual oscilloscope is 500 micro seconds per sample (0.5 mS) so real time is simply the number of samples x 0.5 mS.

Calculate the actual speed of the pressure wave C from the equation C = s / t

For each setting of the flowrate calculate the theoretical speed of sound in the test pipe from the delay measured using the equation:

$$c_e = \sqrt{\frac{K}{\rho\left(1+\frac{Kd}{t_p E}\right)}}$$

then calculate the theoretical magnitude of the first pulse using the equation:

$p = \rho uce$

Compare the calculated values with the measured values.

Conclusion

Note: Because of the relatively short length of test pipe on C7-MKII the total event lasts for less than 500 mS but in a longer pipe the duration would be much longer.

The high pressure pulses and the cavitation caused during the sub atmospheric phase can be extremely damaging to pipework / fittings and the knocking noise created can be extremely irritating.

The phenomena of water hammer results in potentially damaging high pressure and vacuum (vapour pressure resulting in cavitation) alternating rapidly in a system that must be avoided.

The velocity of sound in the test pipe can be determined by measuring the time delay before the first pressure pulse reaches the pressure sensor mid way along the pipe.

As pipe length increases the likelihood of water hammer also increases unless the time taken for a valve to close is also increased.