TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

LABORATORY MANUAL ON FLUID MACHINE

For
Fluid Machine EG615ME
Bachelor's Degree in Mechanical Engineering

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PREFFACE

The lab manual is specially designed for the Mechanical student of Tribhuvan University Institute of Engineering Pulchowk Campus. I would like to thank Head of Mechanical Engineering Department Mr. Ram Chandra Sapkota for providing opportunity to prepare this LABORATORY MANUAL ON FLUID MACHINE.

REFERENCES

1. Instruction manual, Multi Purpose Test Rig With Ram Pump Accessories Unit, C3-00, Armfield Ltd.England,1995-12-8

2. Instruction manual, Piston pump test set, Plant and Partners ltd, Oakland Park, Wokingham, Berks, 1996-1-6

3. Instruction manual, Frances Turbine system R16, Armfield Ltd.England,1995-09-10

4. Instruction manual, Pelton Turbine system R15, Armfield Ltd.England,1995-11-06

5. Instruction manual, Hydraulic bench part 2 with P6101 Auxiliary pump test on Centrifugal pumps, G. Cussons Ltd., Great Clower Street, Manchester M7 IRH, England.

EXPERIMENT 1

VARIOUS TYPES OF PUMPS

INTRODUCTION

The conversion of mechanical energy into fluid energy by machines is of major concern to most engineers and technicians. The types of hydraulic machines available for this conversion vary considerably in principle and design. The selection of the correct pump for a particular application is essential for efficient, satisfactory operation.

The Armfield Ntulti Pump Test Rig allows students to measure the operating characteristics of the following pumps:

1. Centrifugal Pump
2. Axial Flow Pump
3. Gear Pump
4. Turbine Pump

These pumps are all mounted in a self-contained unit (C3-11).

Actual measurements which can be made using the Multi-Pump Test Rig, are: Pump Head, Rate of Flow, Pump Speed and Torque.

All measurements are in the S.I. system of units.

In order to obtain satisfactory operation of the equipment and valid test results, it is important that the Multi-Pump Test Rig is correctly installed and commissioned in accordance with the instructions set out on Pages 9-14 in this manual.

EQUIPMENT DESCRIPTMENT:

The e equipment is mounted on a metal framework provided with a plastic laminate covered working surface. A hinged, wire-mesh door incorporating a latch and electric safety interlock is provided to give access to the dynamometer motor and to the pumps for belt changing. Removable wire-mesh screens guard the remainder of the framework. Four nylon castors are fitted to provide mobility, with adjustable feet to raise the wheels clear of the ground for operating and levelling. The following components are housed in the framework and the measuring devices are incorporated in an instrument panel mounted on the working surface.

A pedestal type, Centrifugal Pump with a shrouded impeller running on an extension of the main spindle, supported on double ball bearings.

An Axial Flow Pump with the propeller running in an acrylic casing with fine clearances between propeller and casing.

A positive displacement Gear Pump with cast casing and two gear-shaped rotors fitted with a non-adjustable pressure relief valve.

A Turbine Pump (also known as a re-generative or peripheral pump) with a straight bladed impeller in an annular casing and a drive shaft supported on two grease packed ball races.

The pump drive motor is a O.55kW drip-proof, trunnion mounted, d.c. shunt wound motor and has two shafts fitted with taper lock bushes and timing belt pulleys. An electronic tachometer mounted in the instrument panel indicates the motor speed, detected by a non-contracting sensor on one shaft of the motor.

The Torque Balance is connected to the motor by a rigid link and comprises a measuring beam, graduated with dual scales calibrated directly in Newton metres. The pivoting beam is balanced to zero via an adjustable screwed counter-weight. Two sets of weights are provided to measure low and high range against their appropriate scales.

A g.r.p. moulded inset in the working surface provides an open channel and volumetric measuring facility.

The Channel incorporates a water stilling baffle at its entry end and weir plate carrier to accommodate the Vee notch weir and the 50mm wide rectangular notch weir. Measurements are taken via a Hook and Point Gauge.

The Volumetric Measuring Tank is fitted with a stilling baffle and incorporates a dump valve and remote actuator. The tank is situated at the exit of the water channel immediately over the Sump Tank.

The measuring tank is stepped to accommodate high or low flow rates and incorporates a remote sight tube and graduated scale, calibrated in litres of water stored. A safety overflow is incorporated spilling water directly back into the sump tank in the event of incorrect use. The Sump Tank is fitted with a drain valve which is used as the suction connection for the Ram Pump Accessory, when fitted.

Discharge from the Centrifugal, Gear or Turbine Pumps is fed to a common manifold which incorporates a flow control valve. The pump to be evaluated is chosen by opening the appropriate selector valve on the manifold. The Axial Flow Pump has an independent, combined selection and regulator valve mounted over the channel.

Each pump circuit is provided with its own discharge Pressure Gauge and the four gauges are mounted on the instrument panel.

The suction from each pump is measured via a common Vacuum Gauge centrallv mounted in the instrument panel. A manifold with four cocks provides the
relevant connection between pump and Vacuum Gauge.

Note: Larger industrial pumps will normally operate at higher efficiencies than small scale pumps used on this equipment. The principle of efficiency and changes in efficiencies with operating conditions can be clearly demonstrated.

CENTRIFUGAL PUMP

The Pedestal type, Centrifugal Pump has a shrouded impeller running on an extension of the main spindle, supported on double ball bearings. T:-is type of pump is not self-priming but operates with a flooded suction. Its single impeller rotates in the snail-shaped volute casing: Water enters the impeller axially through the eye, spirals outwards and discharges around the impeller circumference into the casing.

As the fluid passes through the impeller, energy is imparted to it by the curved blade of the impeller resulting in fluid leaving the impeller with an increase of both pressure and velocity.

The pump has a suction connected to the sump tank via a suction regulator valve. Its delivery is connected to the selection manifold and measuring system via a globe valve.

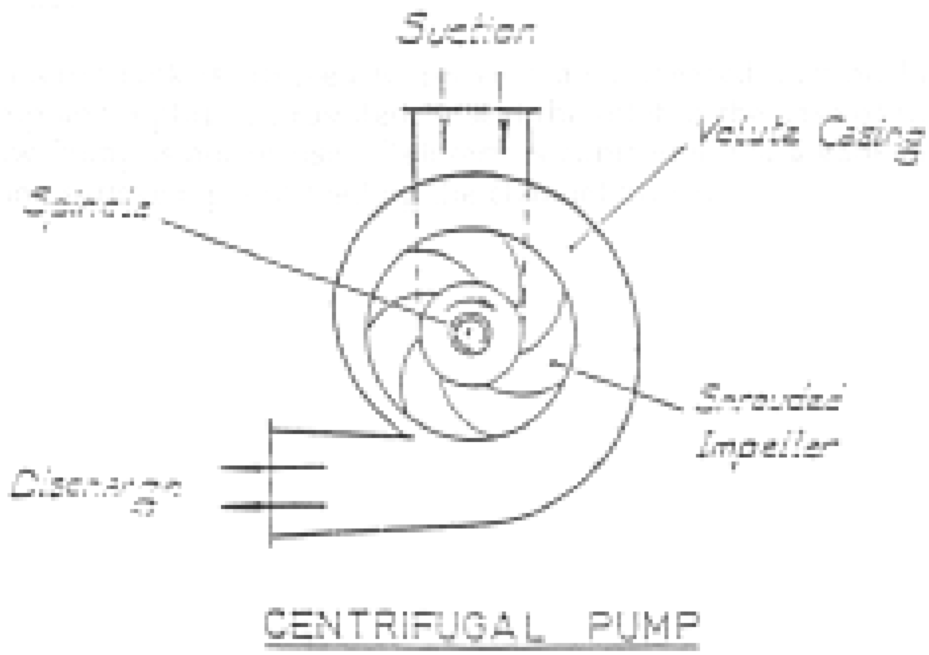


Fig. Centrifugal Pump

Centrifugal pumps are capable of transferring large volume without any dependence on valves or fine clearance and can be run against a closed valve without developing a very high pressure. They can handle a wide range of slurries, or solids in suspension, in addition to liquids with high viscosities.

The main disadvantages of centrifugal pumps are:

(a) The limitation of delivery pressure
and
(b) Their inability to p-rime themselves.

The former can be overcome by using twin, or multi-stages usually on the same spindle axis. The fitting of a self primer will eliminate the latter disadvantage.

CHARACTERISTIC CURVES

When a pump is put under test the usual objective is the determination of its characteristic curves. These curves show the relationship between rate of discharge and head, rate of discharge and power, and rate of discharge and efficiency.

THE AXIAL FLOW PUMP:

It has a 50 mm pitch propeller running in a casing with fine clearances between propeller and casing. Water enters the propeller axially through a ring of fixed inlet guide vanes. In passing through the propeller, the blades impart a whirl component into the fluid which the outlet guide vanes remove prior to the fluid entering the discharge pipe. The propeller is mounted on an extended shaft running on a plain bearing. (See diagram below).

The volumetric tank is utilised to provide an increased suction head to the Axial Flow Pump and a plug is provided to seal the inlet in the base of the tank when the Axial Flow Pump is not in use. Delivery is controlled via a gate valve mounted on the working surface top and feeding the channel direct.

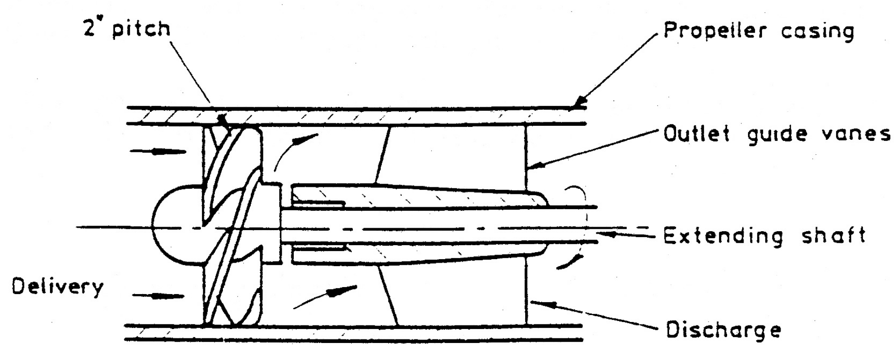


Fig. Axial Flow Pump

The Axial Flow Pump is best suited to conditions where a large discharge flow is to be delivered against a low head. Land discharge, irrigation and sewage pumping are some typical applications. The pump efficiency is comparable with that of the Centrifugal type. However, its higher relative speed permits smaller and cheaper pumping and driving units to be provided.

GEAR PUMP

The positive displacement Gear Pump has a case casing and two gear-shaped impellers, rotating with close clearance, enmeshing such that water entering the suction port is trapped in the spaces between adjacent teeth and carried round to be squeezed out and discharged through the outlet port. (see figure below).

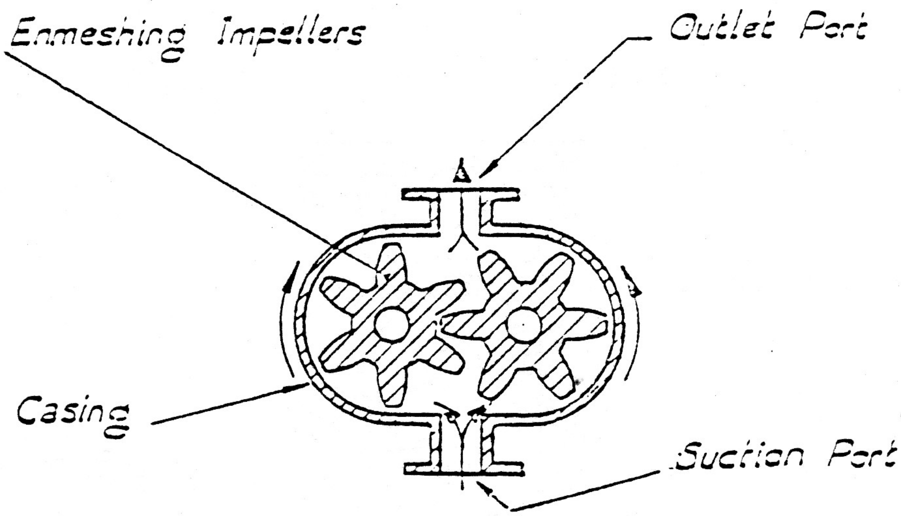


Fig. Gear Pump

High pressures are achieved with Gear Pumps and a pressure relief valve is incorporated set to 75m head, to protect the pump and system.

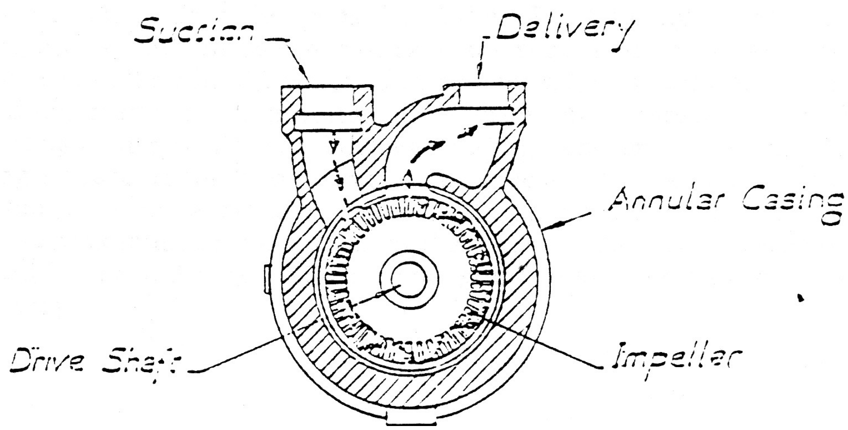
The suction port is connected directly to the sump tank and its delivery port connected to the selection manifold and measuring system via a globe valve.

An important advantage of this type of pump is that no valves are required in the suction or delivery: it is capable of pumping air, gas, or liquid without any detrimental effect and does not require priming. High pressures are possible, although the flow rates are limited.

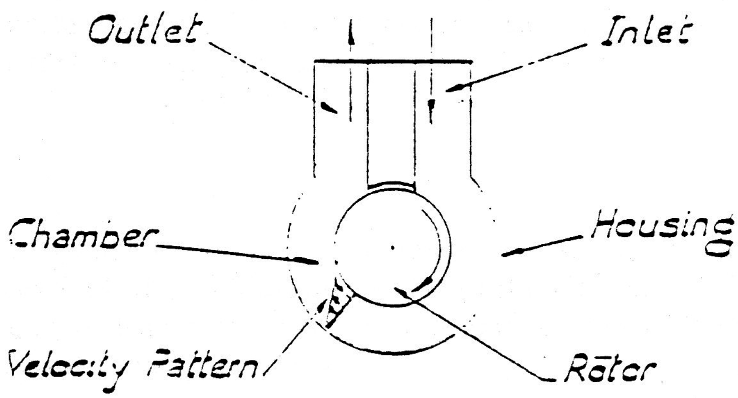
The main disadvantage of this type of pump is that very close clearances are required between the ends of the rotors and the casing. Any wear or corrosion in this region by the materials being pumped, will reduce the efficiency of the pump.

THE TURBINE PUMP (also known as a re-generative or peripheral pump):

Turbine Pump with a straight bladed impeller in an annular casing, and a drive shaft supported on two grease-packed ball races. The front cover and seal housing are cast and the impeller is machined from a blank. (see figure below).



The seal, which is of the rotary mechanical type, is self lubricating. this pump is not self-priming and operates from flooded suction. The suction is connected directly to the sump tank and its delivery is connected to the selection manifold and measuring system via a globe valve. The action of this pump in producing the transport referring to the figure shown above.



In the diagram, the rotor is shown as a cylinder. The housing is concentric with the rotor. The intake and discharge passages are separated by a seal. As t- e rotor revolves, it drags along liquid which is in contact with its surface. A viscous liquid acts as though made up of infinitely thin sheets of a substance which clings to adjacent sheets of itself, allowing however, sliding between the layers. The liquid at the housing surface adheres to it and is motionless. As the rotor rotates, liquid is carried around the chamber at velocities ranging from zero at the surface of the housing, to a maximum at the surface of the rotor. If the liquid were not so viscous there would be no delivery. The turbine pump may therefore be classified as a viscosity pump.

TEST RIG OPERATING INSTRUCTION:

These instructions are in two sections. Section A deals with general setting up requirements for the testing of all the pumps, and Section B deals with the specific setting up requirements for each pump.

SECTION A

Ensure that the test rig has been correctly installed. Refer to the DIAGRAM at the end of this section of the manual for the location of the various components on the Multi Pump Test Rig.

CALIBRATION OF TORQUE BALANCE (ITEM 6):

1. Open access door at the front of the test rig to remove the toothed driVe belt (if fitted). Release the dynamometer clamping knob (item D-A) and swing the dynamometer assembly to the right or left in order to release the toothed belt from its pulleys.
2. NOTE: Re-fitting of the toothed belt to either of the four pumps is carried out simply by reversing the above order and ensuring that the belt is correctly meshed and evenly tensioned over the pulleys, before tightening the clamping knob.
3. With the belt freed from the dynamometer, close the front access door.
4. Set the motor speed control (item 13) to zero, and switch on the motor.
5. Using the motor speed control, set the motor speed to 1000 rev/min. to allow the bearings etc. to attain running conditions. Run motor for five minutes.
6. Unscrew the lower sliding weight on the torque measurement beam and set the captive weight to the zero datum on the upper scale.
7. Adjust the position of the counterbalance weight (item 6) to set the beam horizontal, so that the engraved line on the beam is coincident with the notch in the end plate. The torque beam is now balanced to give direct torque readings, excluding motor and frictional losses etc.
8. The torque measurement beam has two scales. With the lower sliding weight removed, the top scale is used to measure in graduations of 0.1 Newton metres. With the lower sliding weight attached, the lower scale is used to measure graduations of 0.5 Newton metres.
9. Switch off Motor.

10. Open access door and re-fit the toothed drive belt between the dynamometer pulley and the pulley of the pump to be tested 10.Close the access door.
11. NOTE: There is a safety switch incorporated with the door. The motor will not operate unless the door is fully closed and latched. Check the appropriate weir (item 7) is in position in water channel. The notched weir is used when testing the axial flow pump and the 'V' notched weir is used when testing the other pumps.

MEASUREMENT OF FLOW

Measurement of flow is determined by using one of two methods.

A. The Volumetric Tank Method.
B. The Hook and Point Gauge Method.

THE VOLUMETRIC TANK METHOD:

This technique is usually used when testing the gear pump, centrifugal pump and turbine pump. It is necessary to use the Hook and Point Gauge method when testing the axial flow pump, as the volumetric tank is then in use to provide a head of water for the pump. Proceed as follows:

1. Following the Pump Operating Instructions in Section B for pumps 1, 2 and 3, ensure that the rubber plug to the axial flow pump inlet at the bottom of the volumetric tank (item 8) is firmly in position.
2. Open the dump valve (item 19). Pull the knob upwards and rotate it to retain the valve open.
3. Having followed the Pump Operating Instructions in Section B, and selected the appropriate running speed or operating pressure setting; run the pumps so that a steady flow of water is passing through the channel and into the volumetric tank.
4. The volume of water in the tank is measured directly on the sight glass scale (item 24). It will be noted that there are two scales. The lower scale which is calibrated from 0 to 6 litres is used when measuring low rates of flow, and the upper scale which is calibrated from 0 to 40 litres is used when the rates of flow are high.
5. Prepare the stopwatch set to zero.
6. Twist and lower the dump valve knob (item 19).
7. The water will now start to fill the volumetric tank. When it

reaches the zero mark on the appropriate sight glass scale, start the stopwatch.

8. Observe the sight glass scale and when measured volume of water has entered the volumetric tank, stop the stopwatch and note the elapsed time.

9. Flow Rate in litres per second = $\frac{\text{Volume in litres}}{\text{Time in Seconds}}$

10. If required, the dump valve (item 19) may now be opened and the measurement repeated. Averaging of a number of readings will improve the accuracy of determination of rate of flow.

HOOK AND POINT GAUGE METHOD

This is a vernier measuring instrument which is mounted over the water channel. It is used to measure the change of level of the water as it flows through the channel and over the weir leading to the volumetric tank. The difference in water levels is related to the rate of flow of the *water. This method of flow measurement has to be adopted when testing the axial flow pump.

Refer to the diagram of the Hook and point Gauge below. If the flow of the Axial Flow Pump is being measured, the rectangular notched weir should be used. The `V' notched weir is used when testing the other pumps. Ensure that the appropriate weir is firmly in position at the end of the water channel. Operate the pump in accordance with the instructions in Section B. When the water has filled the water channel and is over flowing the weir, switch off the pump and allow the water to find its own level in the channel. This will be level, with the bottom of the notch in the weir.

Adjust the point of the hook and point gauge to just break the surface. That is when the hook and its image just touch.

The adjustment is made by slackening the screw "A" and lowering the hook until it is near the free surface. Then use the fine adjustment nut to get the point of the hook point and its image to just touch. Release screw "B". Set the zero of the vernier in line with a convenient point on the scale, say "O"' tighten screw "B" and note the reading.

Reset the point of the gauge clear of the surface of the water and switch on the pump. At the required pressure head, or speed setting; measure the increase height of the flowing water in the manner described in the previous paragraph. Note the new reading on the scale.

Increase in depth (H) = Final scale reading - Initialscale reading.

CALCULATION OF FLOW RATE:

Rectangular Shaped Notch:

$Q = C_d \times B\ (2/3) \times (2g)^{1/2} \times H^{3/2}$

Where:
Q = flow rate in liters/sec
C_d = Coefficient of discharge = 0.6
B = width of notch g = 9.81 m/sec^2
H = increase in depth of water mm.

$Q = C_d \times (8/15) \times (2g)^{1/2} \times (\tan \theta/2) \times H^{5/2}$

Where:
C_d = a constant = 0.6
Q = flow rate in liters/sec
H = increase in depth of water mm

TEST RIG OPERATING INSTRUCTIONS

The pump to be tested is selected by opening the appropriate isolating and selection valve (item 9) in the case of the gear pump, centrifugal pump, and turbine pump; and flow valve (item 10). When operating the axial flow pump, the flow control valve (item 11) is opened. Each pump has its related pressure gauge, calibrated in metres of water. (Item 15).

A single vacuum gauge (item 16) is used to measure pump inlet manifold vacuum. Each pump is connected to the vacuum gauge via selector valve (item 17). The vacuum gauge is calibrated in meters of water.

Pump Speed Ratios:
The tachometer on the instrument panel indicates the speed in revs./min. of the dynamometer motor. In order to calculate the actual pump speed, please refer to the Pump/Motor teeth ratios in the table below:

$$\text{Pump Speed} = \text{Motor Speed} \times \frac{\text{Teeth on Motor Pulley}}{\text{Teeth on Pump Pulley}}$$

e.g. When testing the centrifugal pump the tachometer reads 960 revs./min.

Pump Speed = 960 x 23 / 17 = 1299 rev./ min.

PUMP INFORMATION TABLE

	Pump/Motor Teeth Ratio	hfax. Pump Speed Motor at 1450 Rev./min.	Bourden Pressure Gauge m.H_jO
	motor : pump		
Centrifugal Pump	23:17	1960	0 to 10
Axial Flow Pump	27: 14	2800	0 to 2
Gear Pump	23: 32	1040	0 to 75
Turbine Pump	27: 14	2800	0 to 40

TEST RIG OPERATING INSTRUCTIONS

Section B

This section deals with the specific setting up requirements for each pump.

GEAR PUMP:

1. Connect the toothed drive belt between the dynamometer motor pulley and the gear pump (item 1) as described in Section A.
2. Open dump valve (item 19) in the volumetric tank (item 8).
3. Ensure that the rubber plug to axial flow pump inlet at bottom of volumetric tank (item 8) is in position.
4. Open gear pump isolating selection valve No. 3 (item 9).
5. Open flow control valve (item 10).
6. Set motor speed control to zero (item 15).
7. Switch on motor and rotate the speed controller (item 13).
8. Pressure readings for the gear pump are taken from pressure gauge no. 3 (item 15).
9. Vacuum readings for the gear pump are obtained by opening vacuum selector valve no. 3 (item 17).
10. Shutting down procedure for the gear pump is carried out simply by reversing the above sequence of operations.

CENTRIFUGAL PUMP:

1. Connect the toothed drive belt between the dynamometer motor pulley and the centrifugal pump (item 13).
2. Open dump valve (item 19) in the volumetric tank (item 8).
3. Ensure that rubber plug to axial flow pump inlet at bottom of volumetric tank (item 8) is in position.
4. Close flow control valve (item 10).
5. Open suction regulating valve (item 12).
6. Set motor speed control to zero (item 13).
7. Switch on motor and rotate the motor speed controller (item 13) clockwise to give required rev./min.
8. Open centrifugal pump isolating selection valve no. 1(item 9).
9. Open flow control valve (item 10) and set it, and the suction regulating valve (item 12) to give the required rate of flow.
10. Pressure readings for the centrifugal pump are taken from pressure gauge no. 1 (item 15).
11. Vacuum readings for the centrifugal pump are obtained by opening vacuum selector valve no. 1(item 17).
12. Shutting down procedure for the centrifugal pump is carried out simply by reversing the above sequence of operations.

TURBINE PUMP:

1. Connect the toothed drive belt between the dynamometer motor pulley and the turbine pump (item 4), as described in Section A.
2. Open dump valve (item 19) in the volumetric tank (item 8).
3. Ensure that the rubber plug to axial flow pump inlet at bottom of volumetric tank (item 8) is in position.
4. Close flow control valve (item 10).
5. Set motor speed control to zero (item 13).
6. Switch on the motor and rotate the motor speed controller (item 13) clockwise to give required rev. /min.
7. Open turbine pump isolating and selection valve no. 4 (item 9).
8. Open flow control valve (item 10) and set it to give the required rate of flow.
9. Vacuum readings for the turbine pump are obtained by opening vacuum selector valve no. 4 (item 17).
10. Shutting down procedure for the turbine pump is carried out simply by reversing the above sequence of operations.

AXIAL FLOW PUMP

1. The axial flow pump requires a higher static head of water than the other three pumps. It therefore has to be supplied from the volumetric tank. Proceed as follows:
2. Remove the screwed cap plug covering the inlet to pump in the volumetric tank (item 8).
3. Close the dump valve (item 19).
4. Operate either the gear pump, centrifugal pump or turbine pump, to fill the volumetric tank to the point where it is overflowing into the sump tank.
5. Switch off the pump used and ensure that the flow control valve (item 10) is closed.
6. Connect the toothed drive belt between the dynamometer motor pulley and the axial flow pump (item 2).
7. Open the axial flow pump control/ regulating valve (item 11).
8. Set motor speed control to zero (item 13).
9. Switch on the motor and rotate the speed controller (item 13) clockwise to give required rev./min.
10. Pressure readings for the axial flow pump are taken from pressure gauge no. 2 (item 15).
11. Vacuum readings for the axial flow pump are obtained by opening vacuum selector valve no. 2 (item 17).
12. Shutting down procedure for the axial flow pump is carried out simply by reversing the above sequence of operations.
13. It should be noted that because the axial flow pump draws its

water supply from the volumetric tank, measurements of flow cannot be made using the flow sight glass scale (item 24). Flow measurement can however be carried out using the hook and point gauge (item 7A) - see descriptive literature provided with the hook and point gauge.

14. On the completion of experiments or tests raise the dump valve (item 19) and lock open sump tank (item 18). Close all valves. Set speed controller (item 13) to zero, and switch off supply. Disconnect electric supply via 13 Amp plug and socket.

EXPERIMENT:

OBJECT

To investigate the relationship between Pressure Head, Flow Rate, Power consume and Efficiency for a pump.

EQUIPMENT:

Armfield Multi Pump Test Rig C3-11; Test Rig; Instruction Manual; Stopwatch; Graph Paper (Linear).

METHOD:

Decide on which pump is to be tested and refer to "Test Rig Operating Instructions" section of this manual for the correct method of setting up and operation of the test rig. When the pump to be tested has been selected and the equipment prepared, proceed as follows:

1. Ensure that the dynamometer motor torque arm has been correctly set to zero. (See "Operating Instructions").
2. Switch on the test rig motor and set the motor speed to maximum - 1150 rev. / min.
3. Note the pressure variation on the appropriate pressure gauge, between a point when the control valve is fully closed to a point when the control valve is fully open. Select six equi-spaced points throughout the pressure reading range at which flow readings will be taken. The actual pressure head of the pump is the difference between the pressure gauge reading in m of water and the vacuum gauge reading in m.of water, at a particular rate of flow.
4. Adjust the control valve to the first of the selected pressure gauge readings.
5. Measure the rate of flow using the graduated sight glass on the volumetric tank and the stopwatch.
6. Tabulate this data in the results table.
7. Record the torque reading at each now rate.

8. Repeat operations (2) to (7) for two other motor speeds as required; say at 1000 rev./min. and 500 rev./min.
9. For the pump under test construct a family of curves for the various speeds at which tests were carried out, using common aces of Pump Pressure Head (vertical axis) Against Pump Flow Rate (horizontal axis).
10. For each torque reading obtained, calculate the input power consumed by the motor.
11. Power (Watts) = (2 π.N.T) / 60   Where: N = Pump rev./min. T= Torque N-m
12. NOTE: The actual pump speed for each motor speed setting may be determined by referring to the Pump Speed Ratios Table in Section A of the Operating Instructions.
13. Construct a family of curves for the various speeds at which tests were carried out, using common aces of Power (vertical axis) against Flow Rate (horizontal axis).
14. Calculate the Efficiency of the pump for each power reading obtained.

    Efficiency = Output (P1) / Input (P)
    P1 = ρg Q H1x10
    P= (2 π.N.T) / 60
    Where:
    P1 = Hydraulic Power
    Q = Rate of Flow liter/sec.
    H1 = Pump head at m of water.

15. Construct a family of curves for the various speeds at which the tests were carried out, using common aces of Efficiency (vertical axis) against Flow Rate (horizontal axis).

CONCLUSION

1. Using the data obtained, determine the most efficient operating point for the pump at a given pump speed.
2. Under what particular set of conditions was the pump under test operating at its highest efficiency?
3. Referring to the power/flow graph, should the pump under test be started with its flow valve open or closed? Explain why.
4. State three suitable industrial applications for the type of pump under test. Correlate the industrial application with the test data obtained

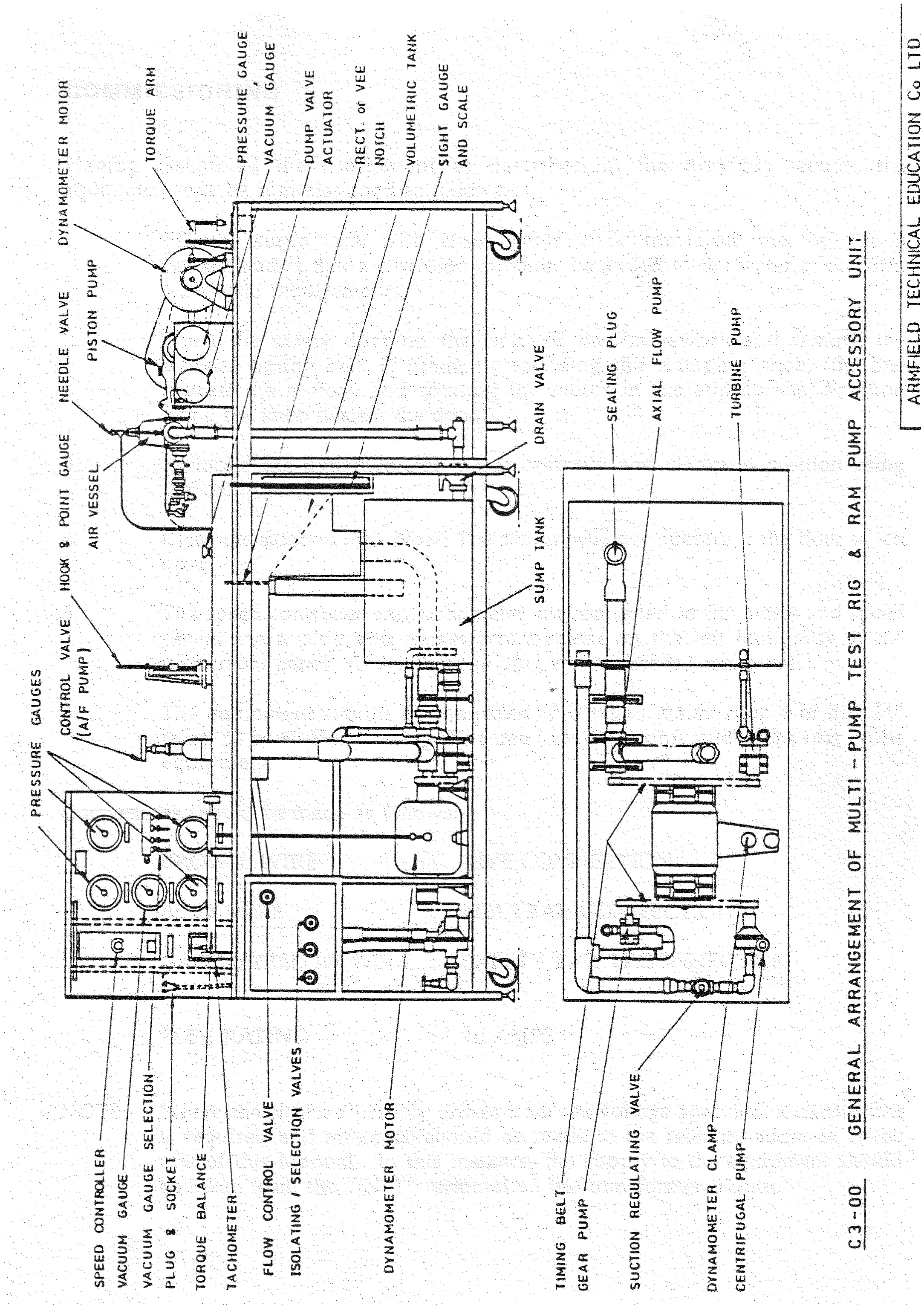
Result:

NOTE: This results table is used when testing the pump at one speed only. 1i tests at other speeds are required, further copies of this sheet should be used.

PUMP UNDER TEST:

MOTOR SPEED:______________rev/min

Reading	Pressure m of water	Vacuum pressure m of water	Pump Head m of water (P)	Volume liter	Time sec	Flow 1/sec (Q)	Torque N m	Input power W P	Hydraulic power P1
1									
2									
3									
4									
5									
6									



C3-00 GENERAL ARRANGEMENT OF MULTI-PUMP TEST RIG & RAM PUMP ACCESSORY UNIT

EXPERIMENT 2

SERIES PARALLEL PUMPS

INTRODUCTION:

Centrifugal pumps are probably the single most common pump in use and are therefore the most important type of pump to be studied in a course on the Mechanics of Fluids. Its advantages are numerous and include:

- Simplicity of construction - no valves, no piston rings, etc. High efficiency.
- Ability to operate against a variable head.
- Suitable for being driven from high speed prime movers such as turbines, electric motors, internal combustion engines, etc.
- Continuous discharge.

A centrifugal pump is one of the rotodynamic class of turbo-machines. It has an impeller (rotor) driven by a motor or (other prime mover), which is surrounded by a stationary casing (stator). The stator is basically a diffuser, that is a passage of increasing flow area, known as a volute. In very large centrifugal pumps the stator may contain internal guide vanes to improve the efficiency of the diffusion process. Typical examples of centrifugal pumps are illustrated schematically in figure 1 below,

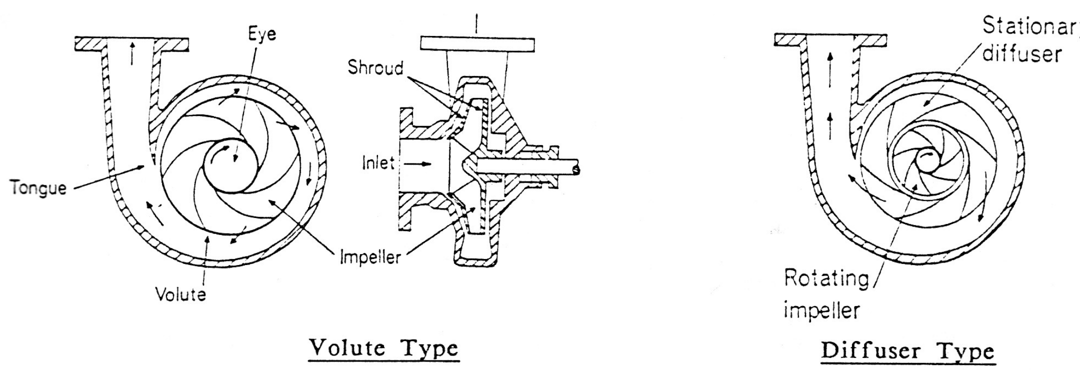


Figure I Centrifugal Pump. Volute Type and Diffuser type

The operation of a centrifugal pump relies on having relative motion (i.e. It is dynamic) between the rotating impeller and the fluid being pumped.

Water enters axial into the eve of the impellor and is accelerated both outwards (centrifugally) and rotated (tagential or whirl) by the impeller to be discharged with increased velocity and kinetic energy into the diffuser. In the diffuser the majority of the kinetic energy is converted into pressure energy.
The performance of centrifugal pumps are presented as characteristic curves plotted on a graph of head against volume flow for various rotational speeds and with contours of constant efficiency superimposed on the graph.

THEORY OF PUMP: consult fluid machine book.

CAVITATION:
In the suction conditions which occur at the inlet to centrifugal pumps and especially in high velocity regions where the increased dynamic pressure results in a decrease in static pressure, it is possible for the pressure to be very low. A situation in which the undesired effect known as cavitation can occur. The term Cavitation includes the formation, existence and subsequent collapse of bubbles which may be either air or vapour filled. Cavitation in the suction or impellor passages of a centrifugal pump promotes a drastic reduction in pump performance. More importantly the collapse of bubbles when they rach a zone of slightly higher pressure causes high impact pressure on adjacent surfaces which can cause severe damage in the form of pitting corrosion.

While pumping liquids containing dissolved gases, if the load static pressure should fall below the gas release pressure, then the gas will come out of solution forming gas bubbles. For air dissolved in water at 20°C this occurs at an absolute pressure of about 250 mbar. Similarly if the pressure should drop to the liquid vapour pressure, then the liquid will start to vapourise or boil. For water the vapour pressure at various temperatures is shown in the table below.

Temperature °C	0	10	20	40	60	80	100
Vapour pressure mbar abs	6.15	12.3	23.4	74.0	200	474	1015

To prevent cavitation in centrifugal pumps it is necessary to ensure that the lowest static pressure, to be encountered anywhere in the pump suction or impeller passages, is higher than both the vapour pressure and the gas release pressure. Otherwise either the fluid will flash into vapour or gas will come out of solution and in either case the suction flow will break down, causing the pump to cavitate and pumping action to stop.

Pump manufactures specify for their products either a maximum suction lift (abbreviated to MSL) or a required net positive suction head (abbreviated to NPSH,). These terms are illustrated in figure 3 below for both a lift pump and a pump with flooded suction.

PUMP LIFT:

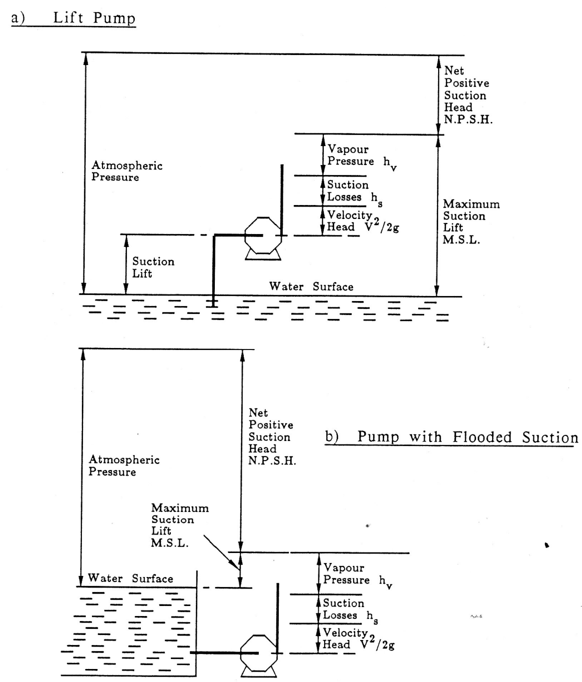


Figure 3 Maximum Suction Lift and Net Positive Suction Head.

From figure 3 it is clear that

P_a = MSL + PSH

For a lift pump the actual suction lift which can be obtained (equal to the static head) is less than the value of MSL by the sum of the fluid vapour pressure and the total frictional and dynamic losses in the pump suction system.

$h_{as} = MSL - hs - v^2/2g - hv$

The NPSH may be interpreted as the margin available to prevent cavitation. If the NPSH were to fall to zero (due perhaps to high suction losses) then the static pressure would be unable to overcome the vapour pressure and the liquid would start to vapourise.

PUMP - PIPE SYSTEM PERFORMANCE

Consider a pump-pipe system in which a pump is being used to raise water from a lower level to a higher level as shown in figure 4.

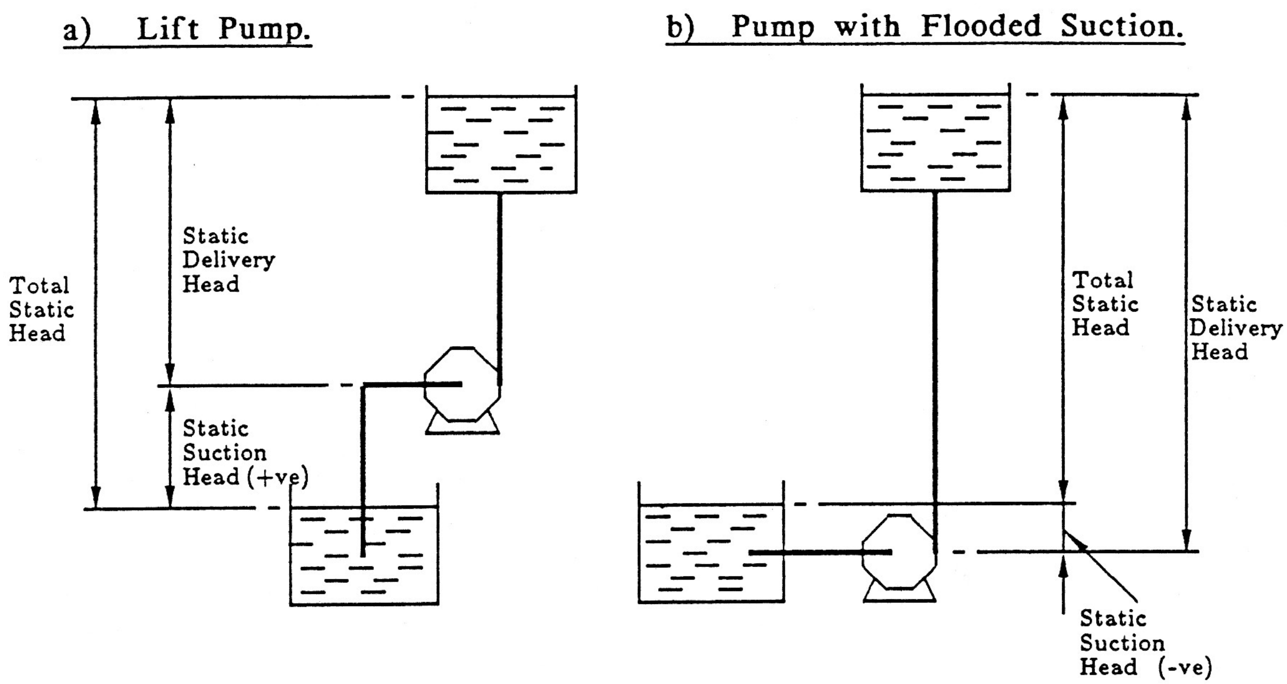


Figure 4 Pump-Pipe System Showing Static Heads.

Two examples are shown in figure 4. In the left hand illustration is a lift pump which has a positive static suction head and in the right hand view is a pump with flooded suction (i.e. a negative static suction head). In either case the total static suction head is. given by the sum of the static suction head and the static delivery head.

Under dynamic conditions, when the fluid is being pumped the pump has to overcome the pressure loss due to friction through any valves, pipes and fittings in the pipe system. This frictional head loss is approximately proportional to the square of the flow rate. The total system head which the pump has to overcome is the sum of the total static head and the frictional head. This is represented in the pipe system head-quantity curve which is superimposed on a pump characteristic in figure 5. The operating point for the pump-pipe system combination occurs where the two graphs intercept.

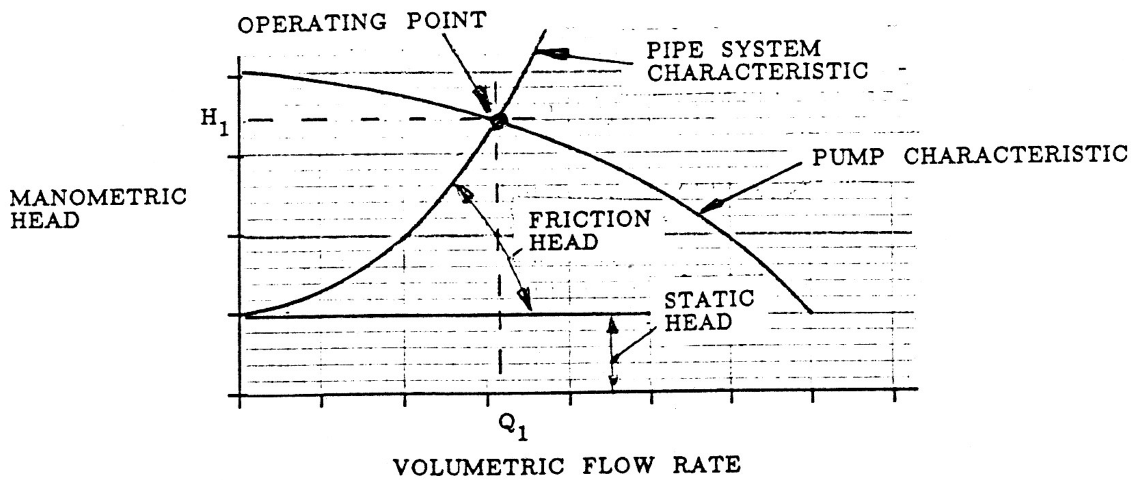


Figure 4 Pump-Pipe System operating point.

PUMP IN SERIES

If two or more centrifugal pumps are connected in series then the flow of water is common to all the pumps and passes through each pump in turn. Each pump contributes to the increase in manometric head so that the overall manometric head is equal to the sum of the contributions from each pump. Thus for `n' pumps:

$$Q = Q1 = Q2 = \ldots\ldots = Qn$$
$$H = H1 + H2 + H3 + \ldots\ldots + Hn = \Sigma Hi$$

The total head discharge characteristics for two identical pumps in series can, in theory be obtained by doubling the discharge quantity of an individual pump, although in practice the efficiencies of the two pumps in series will not remain the same when operating in series as when operating individually. This is illustrated in figure 6 below.

A typical pipe system resistance characteristic, in which head loss is proportional to flow rate raised to an index of nearly 2, is also shown superimposed on the pump characteristic of figure 6. The operating point for the pump-pipe system occurs for a single pump at the point HI - QI and for two pumps at the point H2-Q2. From this graph it can be seen that using two pumps in series increases the manometric head and consequently increases the discharge flow through the pipe system, but due to the non-linear resistance characteristic of the pipe system the manometric head for two pumps is not double that for one pump.

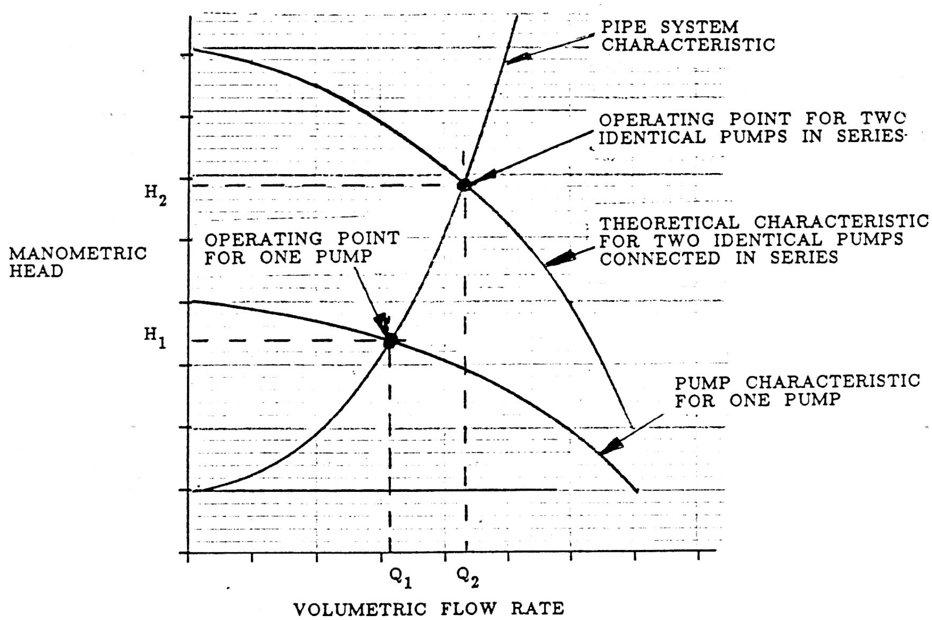


Figure 6 Characteristics of two identical pumps in series

PUMP IN PARALLEL

If two or more centrifugal pumps are connected in parallel then the increase in manometric head is common to all the pumps. Each pump contributes to the discharge flow so that the total discharge flow is equal to the sum of the contributions from each pump. Thus for `n' pumps:

$$Q = Q1 + Q2 + \dots + Qn = \Sigma Qi$$
$$H = H1 = H2 = \dots = Hn$$

The total head discharge characteristics for two identical pumps in parallel can, in theory be obtained by doubling the manometric head of an individual pump, although in practice the efficiencies of the two pumps in parallel will not remain the same when operating in parallel as when operating individually. This is illustrated in figure 7 below.

A typical pipe system resistance characteristic, in which head loss is proportional to flow rate raised to an index of nearly 2, is also shown superimposed on the pump characteristic of figure 7. The operating point for the pump-pipe system occurs for a single pump at the point H1-Q, and for two pumps at the point H2-Q2. From this graph it can be seen that using two pumps in parallel increases the discharge flow and consequently increases the manometric head to overcome the increased resistance of the pipe system at the increased flow rate, but due to the non-linear resistance characteristic of the pipe system the discharge flow for two pumps is not double that for one pump.

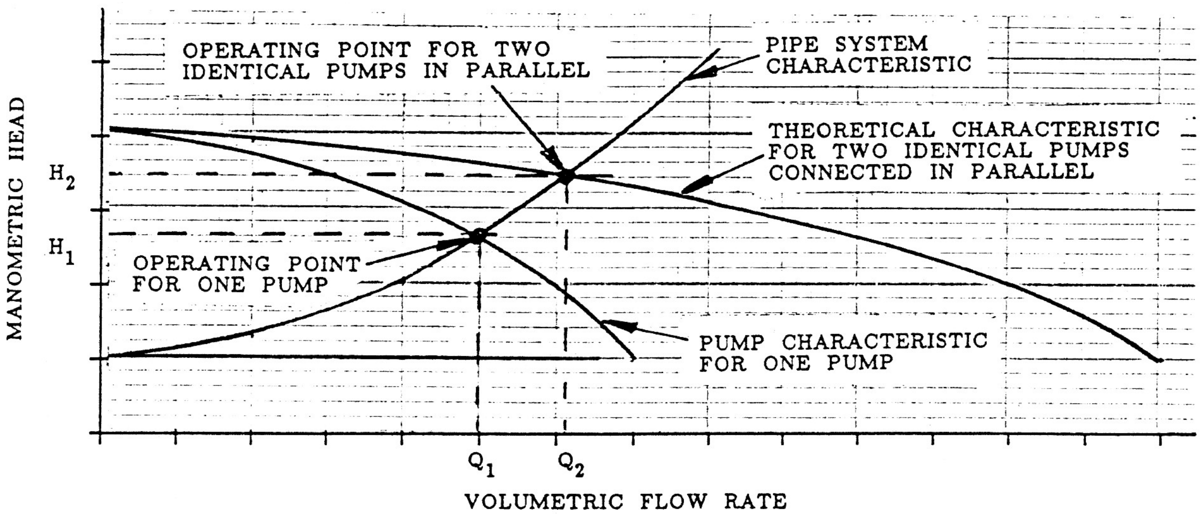


Figure 7 Characteristics of two identical pumps in parallel

EXPERIMENT I CENTRIFUGAL PUMP CHARACTERISTICS.

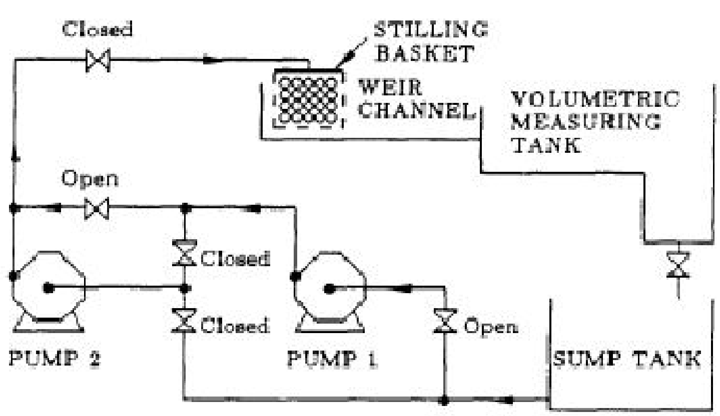
OBJECTIVE:

To determine the total head-discharge characteristics, hydraulic power and efficiency of a centrifugal pump.

a) With constant supply voltage.
b) At constant speed.

EQUIPMENT PREPARATION.

Prepare the equipment to the following specification.



- PUMP ARRANGEMENT: Single centrifugal pump discharging into the weir channel. If the Auxilliary Pump P6101 is fitted operate the isolating valves as shown.

- WATTMETER Essential for measurement of electrical power input for pump efficiency tests, connect as shown in Figure 3 on page 1-14.

- SPEED CONTROL UNIT Not essential for constant supply voltage experiment, but useful to measure pump speed. Essential for constant speed tests, connect as shown in Figure 3 on page 1-14.

EXPERIMENTAL PROCEDURE - CONSTANT SUPPLY VOLTAGE

1. Start the pump following the standard starting procedure detailed in paragraph 5.1 on page 1-29 of part 1 of the manual.
2. During this experiment adjust the pump flow by using the bench regulating valve, do not use the variable Speed Control Unit to adjust the flowrate or to correct any changes in pump speed which may occur during the course of the experiment due to changes in hydraulic power demanded by the pump. Start the test with the regulating valve fully closed. Record the pump suction and delivery pressures and the pump speed.
3. Partially open the regulating valve to allow the pump to produce a discharge flow with a pump discharge pressure some 5 to 10% less than the initial test figure. Measure the flow rate by either taking the time taken to collect a suitable volume of water in the measuring tank, or by using the Rotameter. Record the pump suction pressure, the pump delivery pressure, the flow rate and the pump speed.
4. Further readings are taken for pump heads at approximately equal increments of pump discharge pressure until the bench regulating valve is fully open.

EXPERIMENTAL PROCEDURE - CONSTANT PUMP SPEED

1. Start the pump following the standard starting procedure detailed in paragraph 5.1 on page 1-29 of part I of the manual.
2. During this experiment adjust the pump flow by using the bench regulating valve, and use the variable Speed Control Unit to correct any changes in pump speed to maintain the pump speed at the required constant value. Start the test with the regulating valve fully closed and a pump speed of 70 rev/sec. Record the pump suction and delivery pressures, and the pump speed.
3. Partially open the regulating valve to allow the pump to produce a discharge flow with a pump discharge pressure some 10 to 20% less

than the initial test figure. Adjust the Variable Speed Control Unit to maintain the pump speed of 70 rev/sec. Measure the flow rate by either taking the time taken to collect a suitable volume of water in the measuring tank, or by using the Rotameter. Record the pump suction pressure, the pump delivery pressure, the flow rate and the pump speed.

4. Further readings are taken for pump heads at approximately equal increments of pump discharge pressure until the bench regulating valve is fully open.
5. Repeat the test for pump speeds of 80 and 90 rev/sec.

RESULTS AND ANALYSIS.

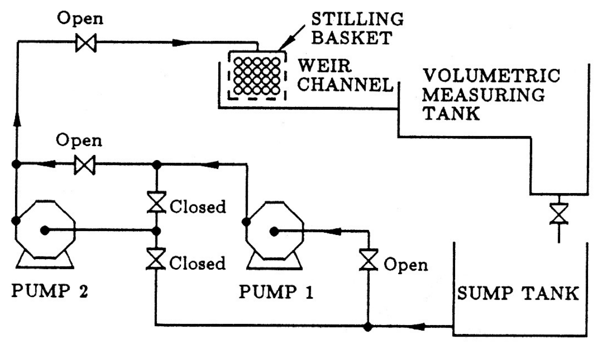
1. Results should be recorded on a copy of the single pump test sheet.
2. If the volumetric measuring tank was used then calculate the volume flow rate from: $\dot{Q} = Q/t$
3. Correct the pressure rise measurement across the pump by adding 0•07 bar to allow for the difference of 0.714 m in height between the measurement point for the pump outlet pressure and the actual pump outlet connection. Then calculate the manomctric head from: $H = (P_2 - P_1)/\rho g$
4. Calculate the hydraulic power from: $\dot{W}_h = \rho g H \dot{Q}$
5. Calculate the overall efficiency from: $\eta_o = \dot{W}_h / \dot{W}_i$
6. Plot the pump characteristics as a single graph of manometric head against volumetric flow rate for the results of the constant speed tests and the constant voltage test.
7. Plot graphs of hydraulic power and overall efficiency against flow rate for each set of results. If required this graph can be used for interpolation to provide values to enable contours of constant hydraulic power and constant efficiency to be drawn onto the pump characteristics.

EXPERIMENT 2 CAVITATION IN CENTRIFUGAL PUMP

OBJECTIVE:
To investigate the onset of cavitation and the effect of cavitation on the performance of a centrifugal pump.

EQUIPMENT PREPARATION:
Prepare the equipment to the following specification.

- PUMP ARRANGEMENT: Single centrifugal pump discharging into the weir channel. If the Auxilliary Pump P6101 is fitted operate the isolating valves as shown.
- WATTMETER Essential for measurement of electrical power input for pump efficiency tests, connect as shown in Figure 3 on page
- SPEED CONTROL UNIT Not essential for constant supply voltage experiment, but useful to measure pump speed. Essential for constant speed tests, connect as shown in Figure 3 on page 1-14.



EXPERIMENTAL PROCEDURE

1. Essential for measurement of electrical power input for pump efficiency tests, connect as shown in Figure 3 on page 1-14.
2. Not essential for constant supply voltage experiment, but useful to measure pump speed. Essential if cavitation at different speeds is to be studied, connect as shown in Figure 3 on page 1-14.
3. Start the pump following the standard starting procedure detailed in paragraph 5.1 on page 1-29 of part I of the manual.
4. During this experiment keep the bench regulating valve fully open. Use the suction valve for pump 1 to adjust the flowrate. Only use the Variable Pump Speed Control Unit if it is required to investigate the effect of speed on cavitation. Start the test with the pump suction valve fully open. Measure the discharge volume flow rate.
5. Partially close the pump suction valve to reduce the pump inlet pressure some 10 %. Observe the transparent inlet pipe for signs of vapour bubbles in the flow. Measure the volumetric flow rate and record the pump inlet and delivery pressures, and the pump speed.
6. Close the pump inlet suction valve in increments and repeat the measurements until either the valve is fully closed or the flow has reduced to zero.
7. Gradually open the pump suction valve and observe the pump suction pressure at which flow recommences and also at which all signs of cavitation disappear.
8. Repeat the test, if required, at different speeds.

RESULTS AND ANALYSIS.

1. Record the results on a copy of the single pump results sheet.
2. Determine for each speed the manometric head at which cavitation is observed and mark these points on the pump characteristic obtained in experiment one, draw contours for the commencement of and recovery from cavitation.
3. Determine the maximum suction lift for the pump at each speed.

EXPERIMENT 3 CENTRIFUGAL PUMPS IN SERIES.

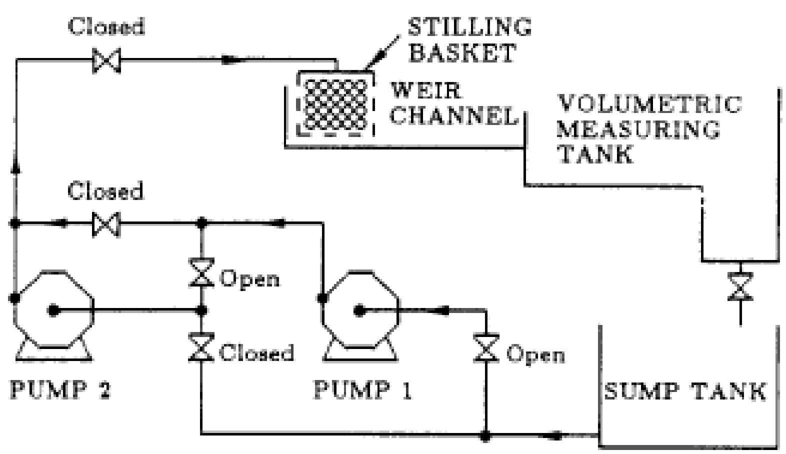
OBJECTIVE:

To determine the total head-discharge characteristics, of two identical centrifugal pumps operating in series, and to compare with the results for an individual pump.

a) With both pumps operating from the same constant supply voltage
b) With the two pumps operating at different speeds.

EQUIPMENT PREPARATION:

Prepare the equipment to the following specification.



Pump Arrangement: Two centrifugal channel with the Closed pumps connected in series discharging into the weir isolating valves as shown.

Wattmeter Essential for measurement of electrical power input for pump efficiency tests. Connect as shown in Figure 3 on page 1-14. Ideally two units will be used, one for each pump.

Speed Control Unit Not essential for constant supply voltage experiment, but useful to measure pump speed. Essential for operating the two pumps at different speeds. Connect as shown in Figure 3 on page 1-14. Ideally two units will be used, one for each pump.

EXPERIMENTAL PROCEDURE: **COMMON CONSTANT SUPPLY VOLTAGE**

1. Start the pumps following the standard starting procedure detailed in paragraph 5.1 on page 1-29 of part 1 of the manual.

2. During this experiment adjust the pump flow by using the bench regulating valve, do not use the variable Speed Control Unit to adjust the flowrate or to correct any changes in the speed of the pumps which may occur during the course of the experiment due to changes in hydraulic power demanded by the pump. Start the test with the regulating valve fully closed. Record the pump suction and delivery pressures, and the pump speeds.

3. Partially open the regulating valve to allow the pumps to produce a discharge flow with a pump 2 discharge pressure some 10 to 20% less than the initial test figure. Measure the flow rate by either taking the time taken to collect a suitable volume of water in the measuring tank, or by using the Rotameter. Record the pump suction pressures, the pump delivery pressures, the flow rate and the pump speeds.

4. Further readings are taken for pump heads at approximately equal increments of the pump 2 discharge pressure until the bench regulating valve is fully open.

EXPERIMENTAL PROCEDURE - PUMPS OPERATING AT DIFFERENT SPEEDS:

1. Start the pumps following the standard starting procedure detailed in paragraph 5.1 on page 1-29 of part 1 of the manual.

2. During this experiment adjust the pump flow by using the bench regulating valve, and use the Variable Speed Control Unit(s) to correct any changes in pump speeds to maintain the pump speeds at the reguired values. Start the test with the regulating valve fully closed and pump speeds of 70 rev/sec for pump I and 90 rev/sec for pump 2. Record the pump suction and delivery pressures for each pump.

3. Partially open the regulating valve to allow the pumps to produce a discharge flow with a pump 2 discharge pressure some 10 to 20% less than the initial test figure. Adjust the Variable Speed Control Unit(s) to maintain the pump speeds of 70 rev/sec and 90 rev/sec. Measure the flow rate by either taking the time taken to collect a suitable volume of water in the measuring tank, or by using the

Rotamqter. Record the pump suction pressures, the pump delivery pressures, and the flow rate.

4. Further readings are taken for pump heads at approximately equal increments of pump discharge pressure until the bench regulating valve is fully open.

5. Repeat the test for different combinations of pump speeds of 70, 80 and 90 rev/sec. such as

Pump 1	70	70	70	80	80	80	90	90	90
Pump 2	70	80	90	70	80	90	70	80	90

RESULTS AND ANALYSIS.

1. Results should be recorded on a copy of the two pumps results sheet.

2. If the volumetric measuring tank was used then calculate the volume flow rate. Correct the pressure rise measurement across the pumps by adding 0- 07 bar to allow for the difference of 0- 714 m in height between the measurement point for the pump outlet pressure and the actual pump outlet connection. Then calculate the manometric head for each pump. Calculate the hydraulic power and the overall efficiency for each pump.

3. Plot the combined characteristics for the two pumps in series as a single graph of manometric head against volumetric flow rate for the results of the two tests.

4. Plot graphs of hydraulic power and efficiency against flow rate for each pump for each set of results. If required these graph can be used for interpolation to provide values to enable contours of constant hydraulic power and constant efficiency to be drawn onto the pump characteristics.

5. Compare the results with those obtained using a single pump.

EXPERIMENT 4 CENTRIFUGAL PUMPS IN SERIES.

OBJECTIVE:

To determine the total head-discharge characteristics, of two identical centrifugal pumps operating in parallel, and to compare with the results for an individual pump.

a) With both pumps operating from the same constant supply voltage.

b) With the two pumps operating at different speeds

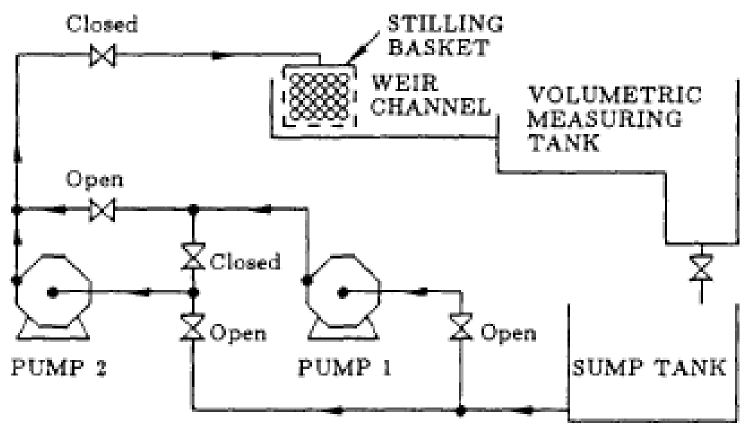
EQUIPMENT PREPARATION:

Prepare the equipment to the following specification.

PUMP ARRANGEMENT: Two centrifugal pumps connected in parallel discharging into the weir channel with the isolating valves as shown.

WATTMETER: Essential for measurement of electrical power input for pump efficiency tests. Connect as shown in Figure 3 on page 1-14. Ideally two units will be used, one for each pump.

SPEED CONTROL UNIT: Not essential for constant supply voltage experiment, but useful to measure pump speed. Essential for operating the two pumps at different speeds. Connect as shown in Figure 3 on page 1-14. Ideally two units will be used, one for each pump.



EXPERIMENTAL PROCEDURE- COMMON CONSTANT SUPPLY VOLTAGE

1. Start the pumps following the standard starting procedure detailed in paragraph 5.1 on page 1-29 of part 1 of the manual.

2. During this experiment adjust the pump flow by using the bench regulating valve, do not use the variable Speed Control Unit to adjust the flowrate or to correct any changes in the speed of the pumps which may occur during the course of the experiment due to changes in hydraulic power demanded by the pumps. Start the test with the regulating valve fully closed. Record the pump suction pressures and delivery pressures, and the pump speeds.

3. Partially open the regulating valve to allow the pumps to produce a discharge flow with a pump discharge pressure some 5 to 10% less than the initial test figure. Measure the flow rate by either taking the

time taken to collect a suitable volume of water in the measuring tank, or by using the Rotamqter. Record the pump suction pressures, the pump delivery pressures, the flow rate and the pump speeds.

4. Further readings are taken for pump heads at approximately equal increments of the pump discharge pressure until the bench regulating valve is fully open.

EXPERIMENTAL PROCEDURE- PUMPS OPERATING AT DIFFERENT SPEEDS.

1. Start the pumps following the standard starting procedure detailed in paragraph 5.1 on page 1-29 of part 1 of the manual.

2. During this experiment adjust the pump flow by using the bench regulating valve, and use the Variable Speed Control Unit(s) to correct any changes in pump speeds to maintain the pump speeds at the reguired values. Start the test with the regulating valve fully closed and pump speeds of 70 rev/sec for pump 1 and 90 rev/sec for pump 2. Record the pump suction and delivery pressures for each pump.

3. Partially open the regulating valve to allow the pumps to produce a discharge flow with a pump discharge pressure some 10 to 20% less than the initial test figure. Adjust the Variable Speed Control Unit(s) to maintain the pump speeds of 70 rev/sec and 90 rev/sec. Measure the flow rate by either taking the time taken to collect a suitable volume of water in the measuring tank, or by using the Rotamqter. Record the pump suction pressures, the pump delivery pressures, and the flow rate.

4. Further readings are taken for pump heads at approximately equal increments of pump discharge pressure until the bench regulating valve is fully open.

5. Repeat the test for different combinations of pump speeds of 70, 80 and 90 rev/sec. such as:

Pump 1	70	70	70	80	80	80	90	90	90
Pump 2	70	80	90	70	80	90	70	80	90

RESULTS AND ANALYSIS:

1. Results should be recorded on a copy of the two pump result sheet.

2. If the volumetric measuring tank was used then calculate the volume flow rate. Correct the pressure rise measurement across the pumps by adding 0• 07 bar to allow for the difference of 0.714 m in height between the measurement point for the pump outlet pressure and the actual pump outlet connection. Then calculate the manometric head. Calculate the hydraulic power and the overall efficiency for each pump.

3. Plot the combined characteristics for the two pumps in parallel as a single graph of manometric head against volumetric flow rate for the results of the two tests.

4. Plot graphs of hydraulic power and efficiency against flow rate for each pump for each set of results. If required these graph can be used for interpolation to provide values to enable contours of constant hydraulic power and constant efficiency to be drawn onto the pump characteristics.

5. Compare the results with those obtained using a single pump.

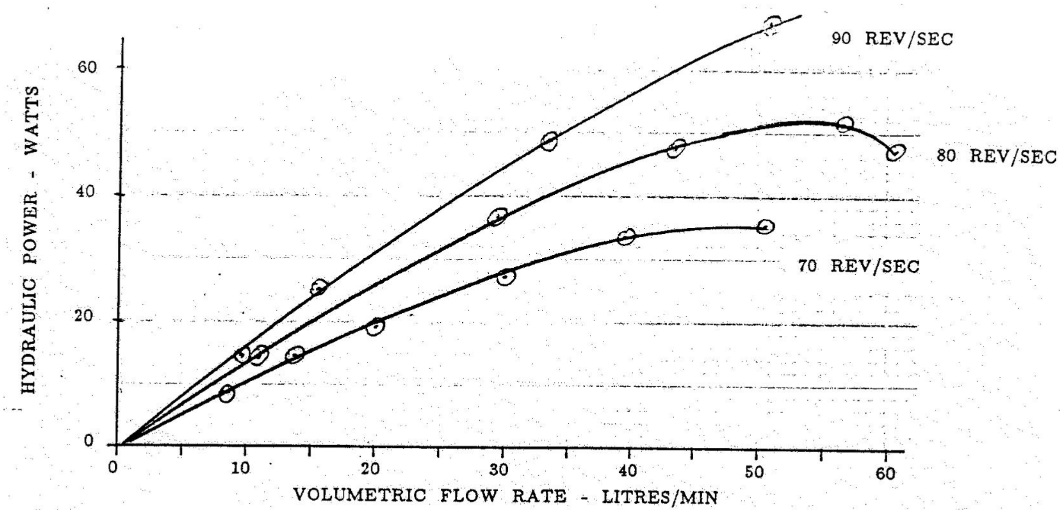
RESULTS SHEET FOR SINGLE PUMP TEST CONDITIONS: -

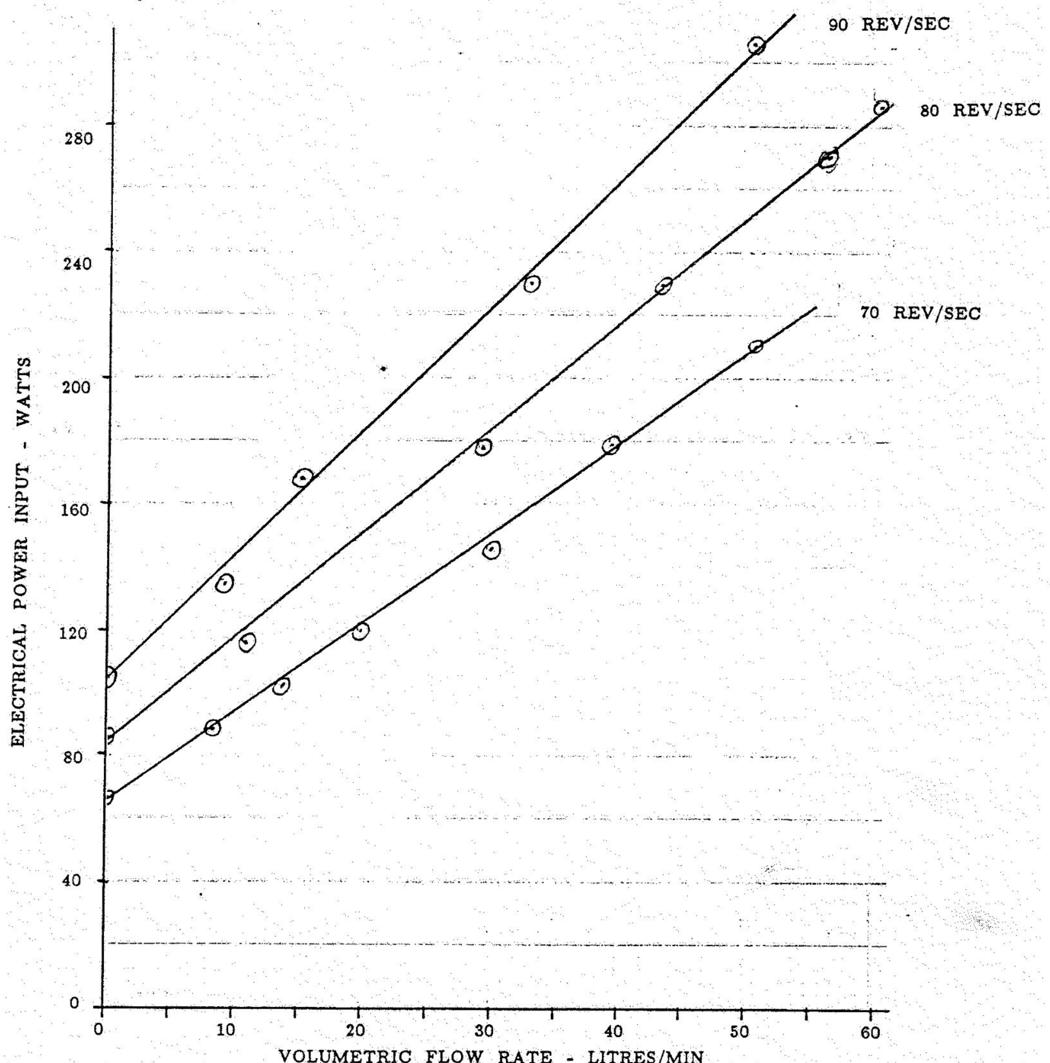
Quantity of Water Collected Q liter								
Time to Collect Water t sec								
Volume Flow Rate $\dot{Q}$ liter/min								
Pump 1 Inlet Pressure P1 bar								
Pump 1 Outlet Pressure P2 bar								
Pump 1 Speed Rev/sec								
Pump 1 Electrical Input Power $\dot{W}_i$ Watts								
Pump 1 Manometric Head H_m meter								
Pump 1 Hydraulic Power $\dot{W}_h$ Watts								
Pump 1 Overall Efficiency η_o %								

Observations : -

RESULTS SHEET FOR TWO PUMPS IN SERIES OR PARALLEL Test Conditions: -

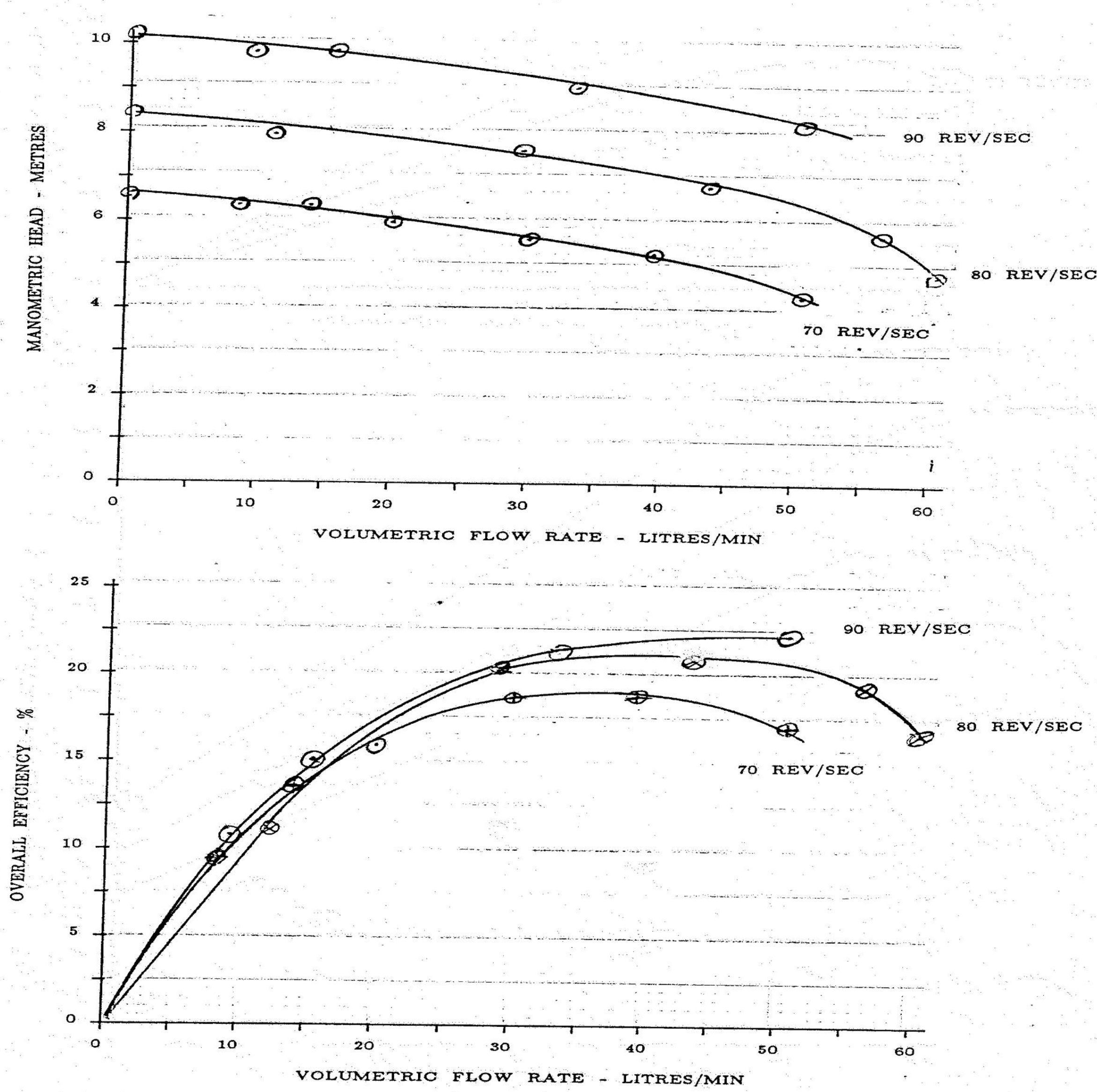
Quantity of Water Collected Q liter								
Time to Collect Water t sec								
Volume Flow Rate $\dot{Q}$ liter/min								
Pump 1 Inlet Pressure P1 bar								
Pump 1 Outlet Pressure P2 bar								
Pump 1 Speed Rev/ssec								
Pump 1 Electrical Input Power $\dot{W}_{i1}$ Watts								
Pump 1 Manometric Head H metres								
Pump 1 Hydraulic Power $\dot{W}_{h1}$ Watts								
Pump 1 Overall Efficiency η_{o1} %								
Pump 2 Inlet Pressure P1 bar								
Pump 2 Outlet Pressure P2 bar								
Pump 2 Speed Rev/sec								
Pump 2 Electrical Input Power $\dot{W}_{i2}$ Watts								
Pump 2 Manometric Head H meter								
Pump 2 Hydraulic Power $\dot{W}_{h2}$ Watts								
Pump 2 Overall Efficiency η_{o2} %								
Overall Manometric Head H meter								
Overall Hydraulic Power $\dot{W}$h Watts								
Over Both Pumps Overall								
Both Pumps Overall Efficiency η_o %								
Both Pumps Overall Efficiency η_o %								


90 REV/SEC
80 REV/SEC
70 REV/SEC
HYDRAULIC POWER - WATTS
0
20
40
60
0
10
20
30
40
50
60
VOLUMETRIC FLOW RATE - LITRES/MIN


90 REV/SEC
80 REV/SEC
70 REV/SEC
ELECTRICAL POWER INPUT - WATTS
0
40
80
120
160
200
240
280
0
10
20
30
40
50
60
VOLUMETRIC FLOW RATE - LITRES/MIN

P6100B.WP

PART 2



EXPERIMENT 3

RECIPROCATING PUMP:

GENERAL DESCRIPTION:

The test set, which is illustrated in Figure 1, has been designed as a simple self-contained unit to permit the study of the characteristics of the Piston Pump.

The pump is a horizontal single-cylinder, double-acting machine of a type that is widely used for domestic water supply to isolated homesteads. A sectional view of the pump is shown in Figure 2. The pump is driven by a 0.75 kW two-speed a.c. dynamometer motor and the power is transmitted from the motor to the pump by a toothed belt. The motor is mounted on trunnion bearings and is fitted with a spring balance for the measurement of torque and a counter for the measurement of speed.

The pump takes water from a reservoir by way of a control valve. Water is delivered by the pump through a second control valve and, after passing through a flow meter, is returned to the reservoir. The suction pressure is indicated by a vacuum gauge and the delivery pressure by a pressure gauge. The gauges are provided with needle valves to damp out pulsations. The pump is fitted with an air vessel to reduce pressure variations in the delivery pipe and with a relief valve to prevent overloading of the pump.
A simple indicator is carried by an indicator cock attached to the rear cylinder cover of the pump, and is driven by a cord that may be attached to a pin projecting from the pump crosshead.

TECHNICAL DATA:

Stuart Turner Piston Pump, Type A6	
Double acting: Cylinder bore Piston rod diameter Piston stroke	44.5 mm 11.1 mm 41.3 mm
Swept volume of pump	0.1245 litre/rev
Delivery pressure, maximum,	600 kN/m^2
Delivery quantity, nominal maximum	27 litre/min
Motor power, nominal	0.75 kW
Motor speeds, nominal	50 Hz - 750/1500 rev/min
	60 Hz - 900/1800 rev/min
Speed ratio, motor: pump	50Hz-120:18

	60Hz-120:16
Torque arm length	179 mm
Brake constant K	53.35

NOTATION:

Pump inlet static pressure	P_1 N/m^2
Pump delivery static presure	p_2 N/m^2
Volumetric rate of flow	V litre/ sec
Swept volume of pump	v litre/rev
Pump speed	N rev/min
Motor speed	n rev/min
Dynamometer brake load	FN
Brake constant	K
Power input to pump	W_1 watt
Hydraulic power of pump	W_2 watt
Losses W_1-W_2	L watt
Overall efficiency of pump	η
Mechanic efficiency of pump	η_m
Volumetric efficiency of pump	η_v
Indicated mean effective pressure	p_3 N/m^2
Indicated power	W_3 watt

THEORETICAL BACKGROUND:

The performance of a piston pump may be analysed on the basis of the steady flow energy equation. Treating the situation as a simplified case in which the working fluid is incompressible the equation per unit time may then be written:

$$p_1V-p_2V=-W_1+L$$

This equation states that the work done upon the fluid by the pump, ignoring kinetic energy and difference in level between pump inlet and outlet, is equal to the power input to the pump less losses.

The hydraulic power of the pump is given by:

$$W2=(p2-p1)V$$

The volumetric efficiency of the pump is given by:

$$\eta_v=60V/Nv$$

The overall efficiency of the pump is given by:

$$\eta = W_2 / W_1$$

The power input to the pump is given by:

$$W_1 = F\eta / K$$

The indicated work performed by the pump is given by:

$$W_3 = P_3 v N / 60$$

The mechanical efficiency is given by:

$$\eta_m = W_3 / W_1$$

TEST PROCEDURE AND OPERATING INSTRUCTIONS:

Before starting up check that both the inlet and outlet control valves are open. Switch on the motor in the low speed condition and run for a short time until air ceases to be discharged from the pump delivery. The motor may then be set to high speed if desired and the delivery valve adjusted to give any required delivery pressure.

The needle valves below the suction and delivery pressure gauges should be carefully adjusted so that the oscillation of the gauge pointers is limited to a small amplitude.

Note that, should the air vessel on the delivery side of the pump become filled with water, the noise made by the pump will increase and the indicator diagram will be distorted and show a marked variation in delivery pressure.

If shortage of air is suspected the vessel may be recharged by running the pump for a short time with the small air inlet valve beneath the pump cylinder slightly open.

To produce performance curves, a series of ten test points evenly distributed over the range of delivery pressures from zero to maximum should be chosen, one series for each of the two motor speeds. The procedure recommended for taking an individual test point is as follows:

a) Read and record suction and delivery pressures.
b) Read torque after adjusting level of spring balance so that pointer on torque arm coincides with fixed pointer.
c) Read and record tachometer measurement of speed.

d) Record flow meter reading.

A suitable laboratory sheet for recording results is shown in Figure 3.

Indicator diagrams may be taken, though it will usually be found sufficient to take two diagrams only at each speed. See below for instructions regarding use of the indicator.

The above tests should be made with the suction valve fully open, the pump delivery pressure being regulated by means of the delivery valve. It is instructive to take two further series of tests, one at each speed, with the delivery valve fully open and with various settings of the suction valve ranging from fully open to that at which delivery from the pump ceases. This test illustrates the capacity of the pump to deal with reduced inlet pressures and shows the effect of cavitation on the volumetric efficiency of the pump and also on the noise level.

While a single student can perform an experiment on the test set quite satisfactorily, it is also possible to employ up to four simultaneously. In this case one student should be responsible for recording the average values of pressure, a second should record the flow rate, the third should measure the power input and the fourth should record results, these duties being changed around between students in the course of the experiment.

NOTE: The flow meter used in some of the earlier models of the test set is calibrated in mmH_2O. The flow rate is then given by:

$$V = K_2\ H\ K_3$$

where K2 and K3 are constants and H is in mmH2O, see Data Sheet.

USE OF INDICATOR

Instructions for the Maihak Type 30 Engine Indicator are given in Appendix 2. The indicator is screwed on to the indicator cock and locked in position, ensuring that the indicator cord lies parallel to the axis on the pump cylinder when the hook is attached to the indicator driving pin that projects from the pump crosshead. Turn the pump by hand and ensure that the point of attachment of the hook to the indicator cord is correct and allows drum to rotate freely over the necessary range of movement.

To take an indicator diagram, set the pump to run at the desired speed and load and draw an atmospheric line by bringing the pencil into contact with the indicator card with the cock in closed position. Withdraw the pencil, open the cock and bring the pencil into contact : h the drum for a few revolutions of the pump. Close the cock, release the hook from the indicator driving pin and remove the indicator card. Note the test conditions on the card immediately. The indicated mean effective pressure p_3 is calculated by measuring the mean height of the indicator diagram (i.e. the mean distance between the suction and delivery lines). This may be determined either with a planimeter or graphically, making use of Simpson's Rule. The mean height multiplied by the indicator 'spring rate' gives the mean effective pressure

EXPERIMENTAL RESULTS

A typical set of test results is analysed below, the relevant equations, see above, are shown in brackets.

Electricity supply	50 Hz
Pump inlet static pressure p_1	-1 kN/m^2
Pump delivery static pressure p_2	239 kN/m^2
Discharge 60 V	27.0 1/min
Tacho Reading	1395 rev/min

Motor speed n	1393 rev/min
Pump speed N	232 rev/min
Dynamic meter brake load F	8.5 N
Power input to pump W_1	222 watt
Hydraulic power of pump $\mathbf{W_2}$	108 watt
Overall efficiency of pump η	0.486
Volumetric efficiency of pump η_v	0.935
Indicated mean effective pressure p_3	370 kN/m^2
Indicated power $\mathbf{W_3}$	178 watt
Mechanical efficiency η_m	0.80

Figure 4 shows a plot of typical test results taken at the higher speed and with minimum pump suction while Figure 5 shows a typical indicator diagram.

OBSERVATION TABLE: ROLL NO:

PISTON PUMP Teacher's signature: ________________ Date:

.

Speed ratio, Pump / Motor_________________________ V = H=

No of obs.	p_1 kN/m²	p^2 kN/m²	p_1-p_2	F N	rev.	Time sec	n rev/min	W_l watt	N rev/min	H mmH₂O	60 V Liter/min	W_2 watt	η	η_v	p_3 kN/m²	W_3 watt	η_m

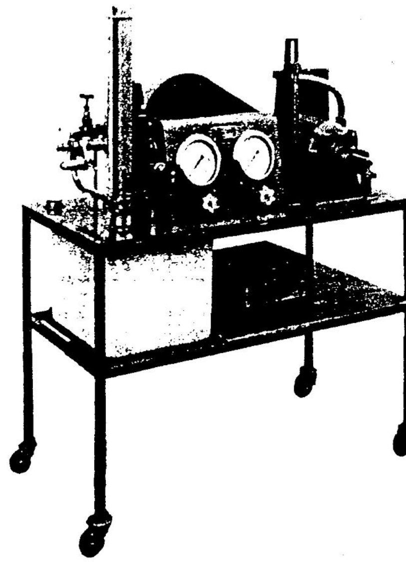


Figure 1 Overall Diagram

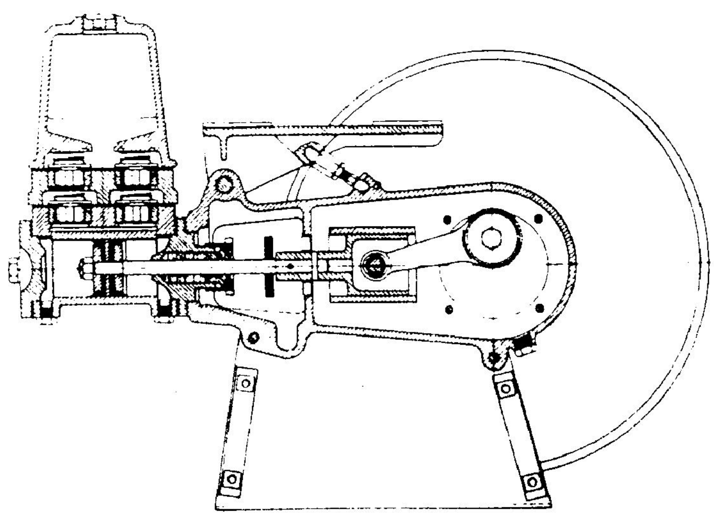


Figure 2 Sectional view of pump

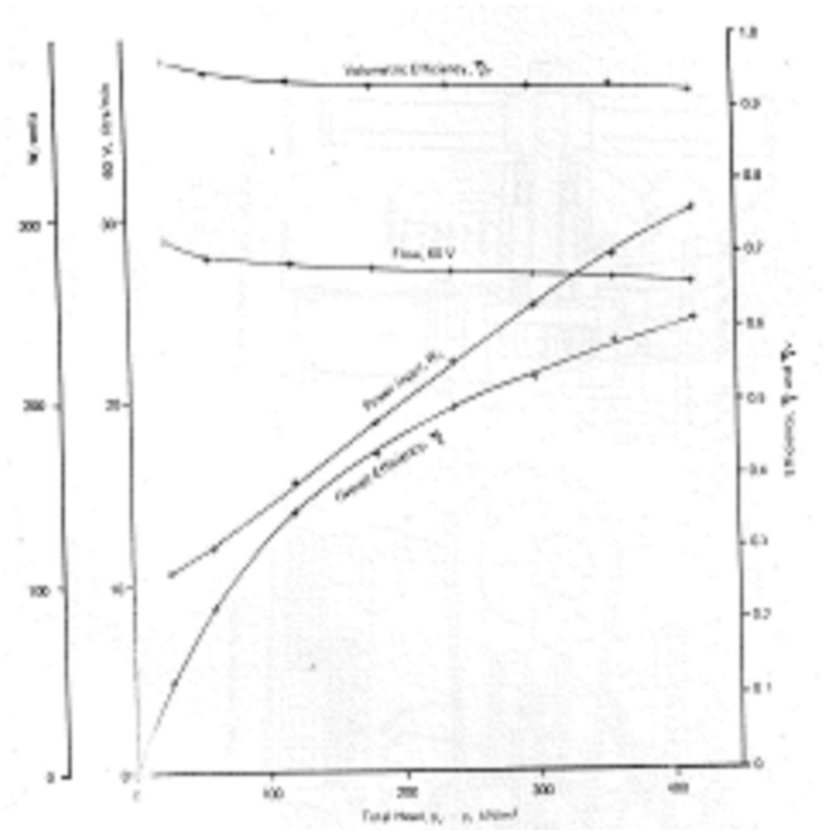
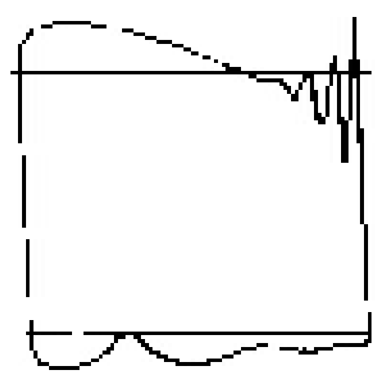


Figure 3 Performance of high speed



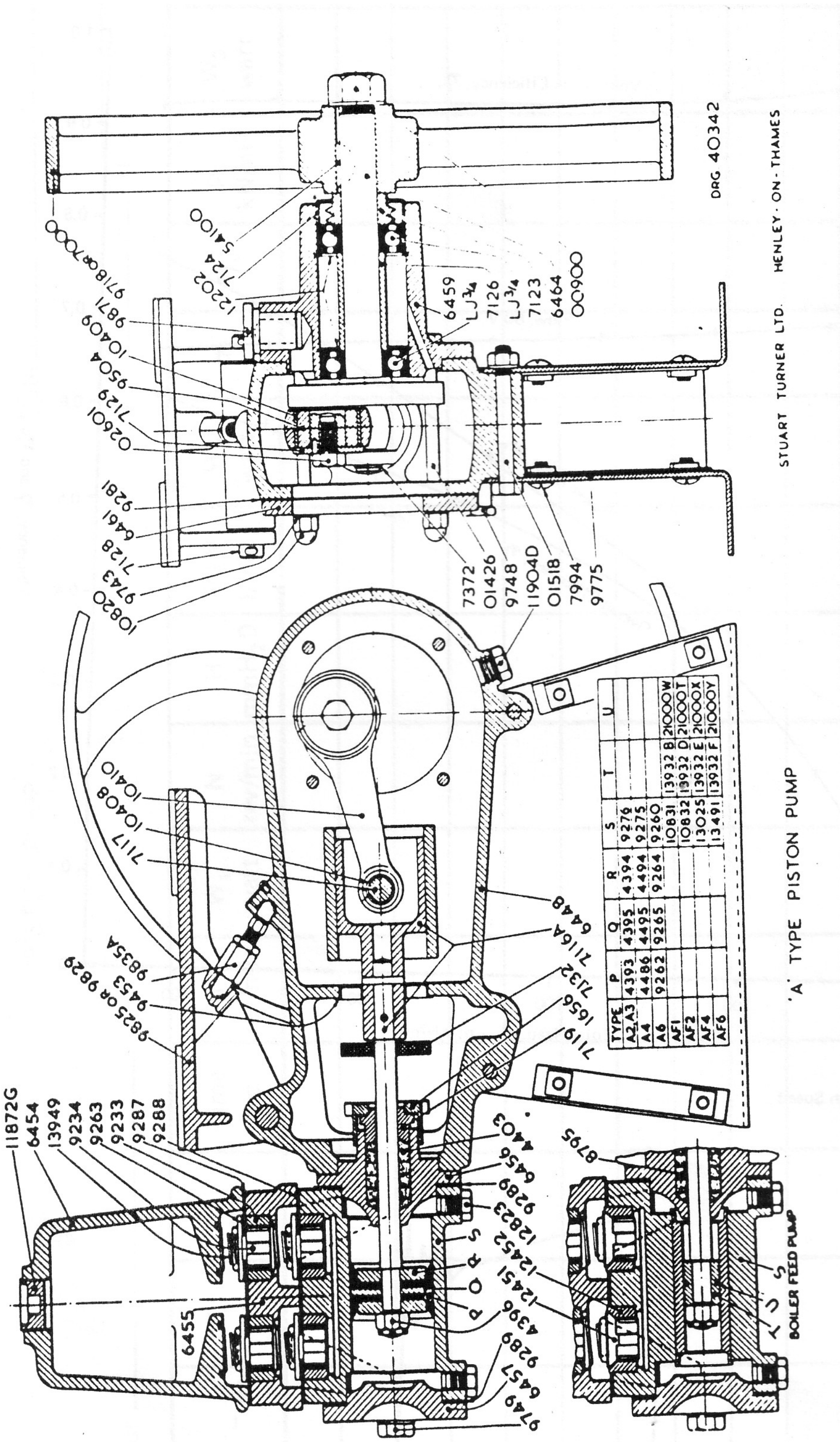
Suction pressure: p_1= -2 kN/m^2

Delivery pressure: p_2= +500 kN/m^2

Speed: N= 120 rev/min

Spring rate: 5mm = 100 kN/m^2

Figure 4 Typical Indicator diagram


'A' TYPE PISTON PUMP
STUART TURNER LTD. HENLEY-ON-THAMES
DRG 40342
BOILER FEED PUMP
TYPE | P | Q | R | S | T | U
A2,A3 | 4393 | 4395 | 4394 | 9276
A4 | 4486 | 4495 | 4494 | 9275
A6 | 9262 | 9265 | 9264 | 9260
AF1 | 10831 | 13932 B | 21000W
AF2 | 10832 | 13932 D | 21000T
AF4 | 13025 | 13932 E | 21000X
AF6 | 13491 | 13932 F | 21000Y

EXPERIMENT 4A

PELTON TURBINE:

INTRODUCTION:

Water turbines may be classified as Impulse or Reaction machines in accordance with the absence or presence of pressure changes in the fluid as it passes through the runner.

In an impulse machine the change from static to dynamic head occurs wholly in a fixed nozzle and the fluid issuing from it impinges on the moving buckets on the runner.

An impulse turbine must have free access of air to the runner and discharge into the atmosphere.

The Armfield Pelton (Impulse) turbine is an accurate replica of modern industrial machines. It is of substantial proportions allowing for comprehensive tests which may be used to predict the performance of turbines of industrial proportions.

DESCRIPTION:

All numerical references refer to diagram.

The Pelton turbine is an impulse type horizontal shaft machine, and is flexibly coupled to a disc brake dynamometer by which the output torque of the turbine is measured. The shaft speed of the turbine is directly indicated on a belt-driven dial type tachometer.

The flow of water to the turbine runner, and hence the power output, is controlled by a manually operated spear valve and nozzle. By opening this valve, the jet of water striking the runner buckets is increased in diameter thus imparting more torque to the turbine shaft. A large glass window in the casing enables the water jet and runner to be observed under operating conditions.

The water pressure in the inlet pipe is indicated on a Bourden type gauge mounted on the turbine casing.

Water is discharged from the machine through a vertical draft tube under the turbine case.

The complete turbine assembly is mounted on a substantial steel bedplate which in turn is bolted to the steel tank.

An electrically driven centrifugal pump (1) floor mounted alongside the tank draws water from the tank through a suction pipe (2) and delivers it to the turbine via a valve (3) and pipework system (4).. An electronic turbine flow meter (5) fitted in the delivery pipe indicates flow measurement directly on an analogue read-out mounted in the control cabinet. The control cabinet which is bench mounted adjacent to the equipment also incorporates a push button starter for the centrifugal pump.

Water discharging from the turbine falls into the tank and flows over the 90° vee notch (6). The height of water over the notch is measured by means of the stilling vessel (7) and the vernier type depth gauge (8).

Technical Data (Pelton)

Turbine type	:	Pelton (Impulse)
Specific speed	:	14 r.p.m.
Nominal size of runner	:	244mm pitch diameter
Design nett head	:	30.5m
Max. shaft output	:	1.55kW
Corresponding water flow	:	7 liter/sec
Optimum shaft speed	.	800 r.p.m.
Runaway speed	.	1500 r.p.m.
Turbine inlet diameter	:	65mm
Service pump rating	:	7.5kW

EXPERIMENT:

OBJECT OF EXPERIMEN:T

To measure the efficiency of the Pelton turbine at different spear valve openings.

EQUIPMENT SET-UP:

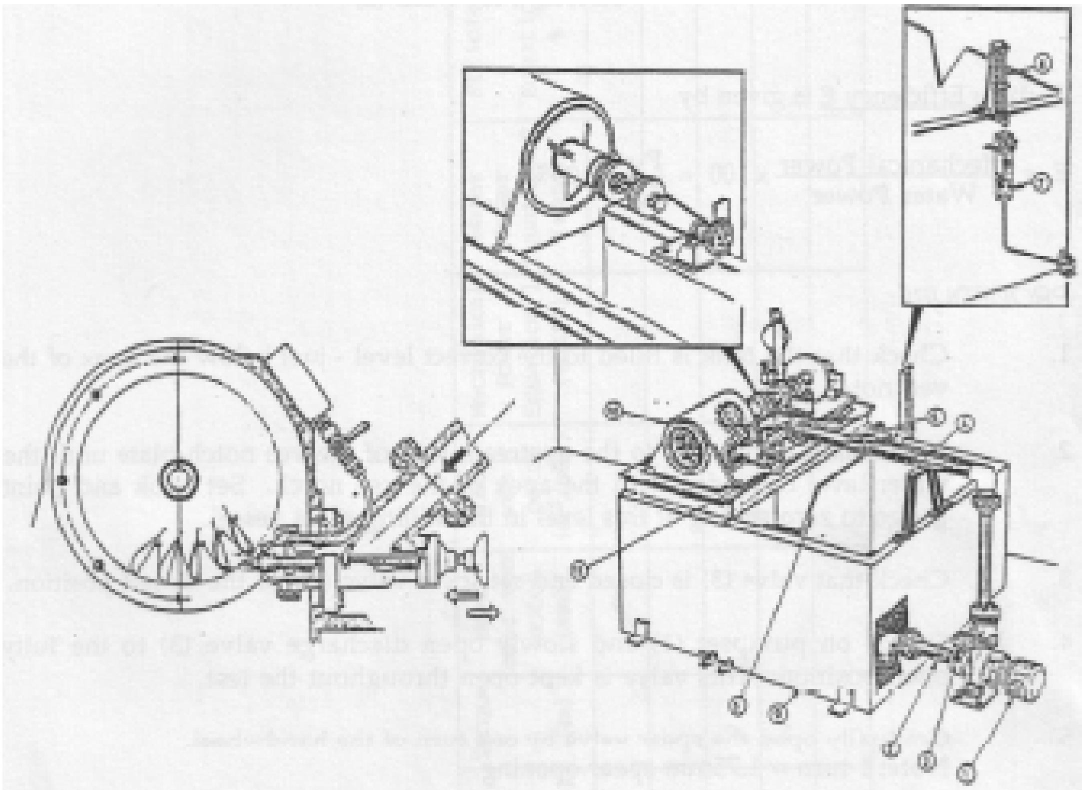


Fig. Pelton Turbine set

SUMMARY OF THEORY:

NOMENCLATURE:

P_W = Water power in watts.
P_M = Mechanical power in watts.
Q = Water flow in m^3/sec
N = Turbine shaft speed in r.p.m.
E = Turbine efficiency in %.
r = Radius of brake arm in meter=0.25m.

F = Spring balance reading in newton
P = Density of water = 1000kg/m^3.
H = Nett head of water in meter

Mechanical Power P_M is given by P_M = $2 \pi N T / 60$ watts.

where T = Torque = Fr = 0.25F Nm

P_M = $2.62NF \times 10^{-2}$ watts

Water Power P_W is given by P_W = ρgHQ watts= $9.81\ H\ Q \times 10^3$ watts

Turbine Efficiency is given by η = Mechanical Power / Water Power x 100 =(P_M / P_W)100%

PROCEDURE:

1. Check that the tank is filled to the correct level - just below the apex of the vee notch.

2. If necessary, add water to the upstream side of the vee notch plate until the water level coincides with the apex of the vee notch. Set hook and point gauge to zero setting at this level in the stilling glass vessel.

3. Check that valve: (3) is closed and set spear valve (11) to the closed position.

4. Switch on pump set (1) and slowly open discharge valve (3) to the fully open position. This valve is kept open throughout the test.
5. Gradually open the spear valve by one turn of the hand wheel. **Note:** 1 turn = 1.75mm spear opening.
6. Slowly apply load to the disc brake by turning the hand wheel in a clockwise direction until the tachometer indicates a speed of 800 r.p.m.
7. Keeping the speed steady at 800 r.p.m. (by re-adjusting the brake load if necessary), take readings of flow rate, pressure, brake spring balance load and head over the vee notch (measured by the depth gauge) and record on test sheet.
8. Increase spear valve opening in desi ed increments (say 1/2 turns of hand wheel) and at each opening when 800 r.p.m. speed is achieved (see para. 6) repeat the readings.
9. At completion of test, close spear valve. Switch off pump and close discharge valve (3).

RESULT:

TURBINE SPEED: 800rpm
Break arm radius: 0.25m

Spear Valve Opening (mm)	Inlet Pressure Head (m)	Flowmeter (m^3/sec)	Brake Load (N)	Torque' (Nm)	Head over vee notch (mm)	Flow vee notch (m^3/sec)	P_M (watts)	P_W (watts)	Efficiency (%)	Notes

EXPERIMENT 4B

FRANCIS TURBINE:

INTRODUCTION:

Water turbines may be classified as Impulse or Reaction machines in accordance with the absence or presence of pressure changes in the fluid as it passes through the runner.

In an impulse machine, the change from static to dynamic head occurs wholly in a fixed nozzle and the fluid issuing from it impinges on the moving buckets on the runner. In a reaction machine, at least a part of the change from static to dynamic head occurs in the passages of the runner which are filled by the fluid.

A reaction turbine is completely filled with water which in its passage through the runner, reacts against the vanes and discharges through the submerged draft tube.

The Armfield Francis (Reaction) turbine is an accurate replica of modern industrial machines. It is of substantial proportions allowing for comprehensive tests which may be used to predict the performance of turbines of industrial proportions.

DESCRIPTION:

All numerical references refer to diagram .

The equipment comprises a steel tank (1) on which is mounted a Francis turbine (2).

The Francis turbine is a reaction "type horizontal shaft volute cased machine of medium specific speed and is flexibly coupled to a disc brake dynamometer by which the output torque of the turbine is measured. The shaft speed of the turbine is directly indicated on a belt-driven type tachometer.

The flow of water through the machine, and hence the power output, is controlled by a number of moving guide vanes spaced around the runner. These vanes are connected by slotted levers to an operating ring which in turn is actuated by a single hand lever incorporating a gate opening indicator. A pair of 'dummy' guide vanes are provided to give a visual indication of the gate opening. The turbine pressure is indicated on a Bourdon type gauge mounted on the top of the volute case.

Water is discharged from the machine via a clear Perspex exit tube, providing visual observation of the turbine runner and guide vanes, to a bend and tapered draft tube.

The complete turbine assembly is mounted on a substantial steel bedplate which in turn is bolted to the steel tank.

An electrically driven centrifugal pump (3) floor mounted alongside the tank draws water from the tank through a suction pipe (4) and delivers it to the turbine via a valve (5) and pipe work system (6). An electronic turbine flow meter (7) fitted in the delivery pipe indicates flow measurement directly on a digital read-out mounted in the control cabinet. The control cabinet which is bench mounted adjacent to the equipment, also incorporates a push button starter for the centrifugal pump.

TECHNICAL DATA:

Turbine type	Francis (Reaction)
Nominal size of runner	150mm
Specific speed	160 r.p.m.
Design nett head	6m
Max. shaft output	2.1kW
Corresponding water flow	451 1/sec
Optimum shaft speed	1000 r.p.m.
Runaway speed	1800 r.p.m.
Turbine inlet diameter	155mm
Service pump rating	5.5kW

OBJECT OF EXPERIMENT:

To measure the efficiency of the Francis turbine at different guide vane openings.

SUMMARY OF THEORY:

Nomenclature:

P_W = Water power in watts
P_M = Mechanical power in watts
Q = Water flow in m^3/sec
N = Turbine shaft speed in r.p.m.
E = Turbine efficiency in %
r = Radius of brake arm in meter = 0.25m
F = Force applied by dynamometer in Newton = Reading (Kg) x 9.81
ρ = Density of water = $1000 kg/m^3$
H = Net head of water in meter

Mechanical Power P_M is $= 2 \pi N T / 60$ watts

where T = Torque $= F \times r = 0.25F$ Nm

P_M $= 2.62 N F \times 10^{-2}$ watts

Water Power P_W is given by P_W $= \rho g H Q$ watts

$= 9.81 HQ \times 10^3$ watts

Turbine Efficiency E is given by E $= \frac{\text{Mechanical Power}}{\text{Water Power}} \times 100 = (P_M / P_W) \times 100\%$

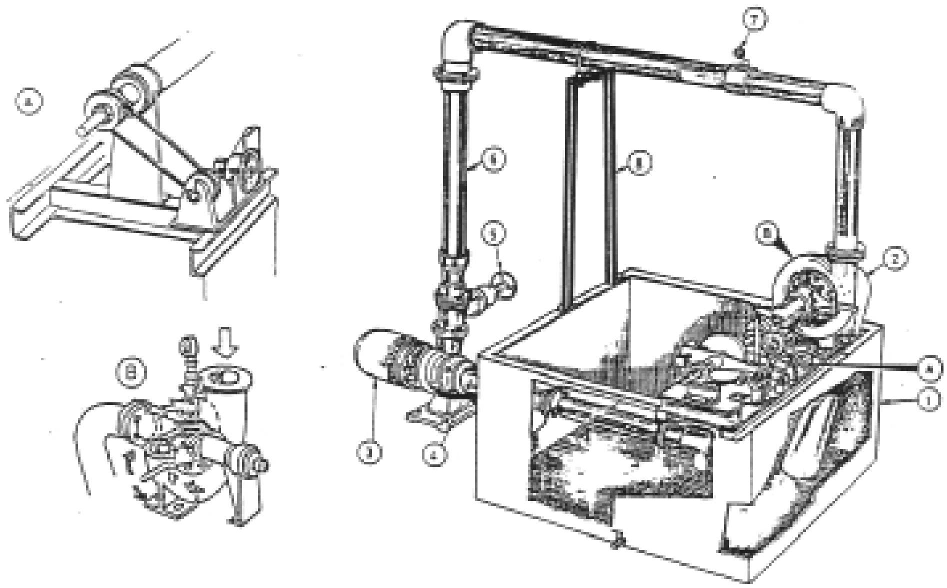


Fig. Francis Turbine Set

PROCEDURE:

1. Check that the tank is filled to the correct level.

2. Check that the valve (5) is closed and set guide vanes on the turbine to the closed position.

3. Switch on pump set (3) and slowly open discharge valve (5) to the fully open position. This valve is kept open throughout the test.

4. Gradually open the guide vanes to the 10° indicator mark on the indicator and clamp in position.

5. Slowly apply load to the disc brake by turning the hand wheel in a clockwise direction until the tachometer indicates a speed of 1000 r.p.m.

6. Keeping the speed steady at 1000 r.p.m. (by re-adjusting brake load if necessary), take readings of flow rate, pressure and brake spring balance load and record them on a test sheet. (A typical test sheet is shown on page A-3.)

7. Increase guide vane opening in increments, of say 5° and at each opening when 1000 r.p.m. speed is achieved repeat the readings.

8. At completion of test, close guide vane, switch off pump and close discharge valve (5).

RESULT:

TURBINE SPEED: 1000 rpm
Break arm radius: 0.25 m

Guide Vane Opening (degrees	Volute Pressure Head (m)	Flow (m^3/sec)	Brake Load (N)	Torque (Nm)	Mechanical Power P_M (W) (watts)	Water Power P_W (W)	Efficiency (%)	Notes
5^0								
10°								
15°								
20°								
25°								
30°								
etc.								

The end