6.3 Exercise A: Centrifugal Pump

Objective

To investigate the performance characteristics of a Centrifugal pump.

Method

Running the Centrifugal pump (C3-MKII-20) under different operating conditions (by throttling the discharge valve) in order to obtain its operating characteristics.

Repeating this at different operating speeds to give a family of performance curves when plotted graphically.

Equipment Required

C3-MKII Multi Pump Test Rig (Centrifugal Pump fitted permanently).

Optional Equipment

Armfield C3-MKII-304 Data Logger with educational software.

Thermometer suitable for fluid temperature measurement (not supplied).

Theory

Description of the Centrifugal pump

The Centrifugal pump is the type of pump most commonly used for pumping water or similar liquids of low viscosity. The main characteristics of a Centrifugal pump are:

High flow rate at moderate pressure

Output can be varied simply using a valve (closing the valve does not cause problems)

Not self priming so the pump suction should be flooded at all times

Output that falls with increasing system pressure and reducing pump speed

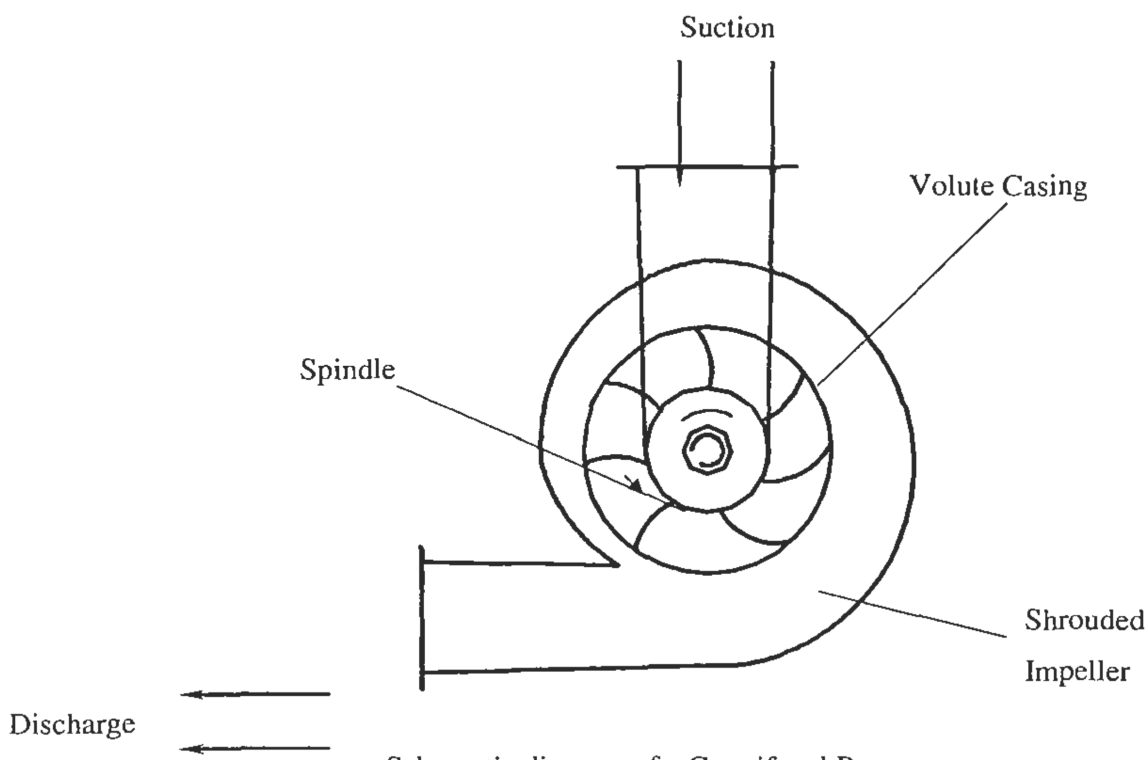
Simple design with no close tolerances necessary and no inlet or outlet valves required for sealing

Performance can be adjusted by changing impeller diameter etc.

The Centrifugal pump supplied consists of a single impeller incorporating radial blades that rotates inside a snail-shaped volute casing. Water enters axially at the eye of the impeller, spirals outwards and discharges around the impeller circumference into the volute casing. As the fluid passes through the pump, energy is imparted to it by the blades of the impeller resulting in fluid leaving the impeller with an increase of both pressure and velocity.

The Centrifugal pump is not inherently self-priming but on the C3-MKII it is installed so that it operates with a flooded suction, i.e. the pipework upstream of the pump and the pump volute will fill with water from the reservoir when the suction control valve is opened. The discharge from the pump is returned to the reservoir via a flow control valve and paddle-type flowmeter.

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



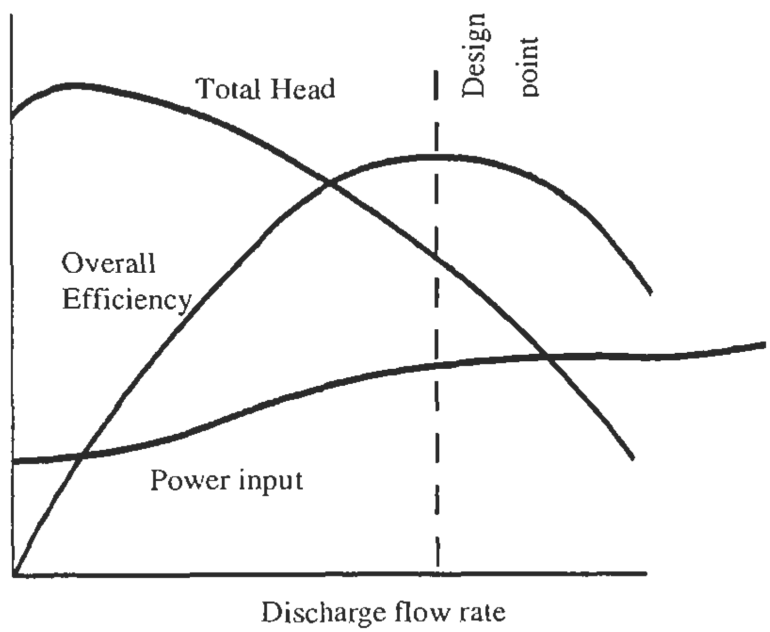
Schematic diagram of a Centrifugal Pump

Characteristic Curves

The operating characteristics of a centrifugal pump are best illustrated using graphs of the pump performance. The most commonly used graphical representations of Centrifugal pump performance are:

- Total Head produced by the pump (H_t) against discharge flow rate (Q)
- Power input to the pump (P_m) against discharge flow rate (Q)
- Overall Pump Efficiency (E_o) against discharge flow rate (Q)

Curves for a typical Centrifugal pump are shown in the diagram below:



Note that the Total head decreases but the Power input increases as the Discharge flow rate increases. For this type of pump the Power input is minimum at zero flowrate which is why it is usual to start a Centrifugal pump with the outlet control valve fully closed.

The Overall efficiency curve shows how the pump is most efficient over a relatively small range of flow rate. When selecting a pump for a particular application it is sensible to choose the pump that will be at or near its maximum efficiency when at its normal operating condition (head/flow from the pump matches the head/flow in the system at the design point).

Calculations

Total Head

The change in total head produced as a result of the work done by pump can be calculated as:

H_t = Change in static head + change in velocity head + change in elevation

$= H_s + H_v + H_e$

where

H_s = Change in static head $= \dfrac{(p_{out} - p_{in})}{\rho g}$

where $p_{in} = p_1$ = fluid pressure at inlet in N/m^2

$p_{out} = p_2$ = fluid pressure at outlet in N/m^2

H_v = Change in velocity head $= \dfrac{(V_{out} - V_{in})^2}{2g}$

where V_{in} = fluid velocity at inlet in m/s

V_{out} = fluid velocity at outlet in m/s

In this application the fluid is incompressible and the cross sectional area at both pressure tappings is the same so $V_{in} = V_{out}$ and $H_v = 0$

H_e = Change in elevation = Vertical distance between inlet and outlet sensors

but $H_e = 0$ m (because both sensors calibrated to read 0m with reservoir full)

Power Input

The mechanical power input to the pump may be calculated as:

$$P_m = \frac{2\pi NT}{60}$$

where

N = rotational speed of pump in revolutions per minute
(N = reading% x 2800 RPM)

T = shaft torque in Nm (Reading indicated in mNm)

Overall Pump efficiency

The overall efficiency of the pump is an indication of how well the power input to the pump (the motor power input) is transferred to the process fluid (the hydraulic power produced). It may be calculated as:

$$E_o = 100 \times \frac{P_h}{P_m} \%$$

where

P_h = hydraulic power imparted to fluid

$= \rho g Q H_t$ Watts

where Q = volume flow rate in m^3/s

The Total head, Power input and Overall efficiency should be calculated from the appropriate measured values and plotted against the volume flow rate, Q, through the pump. Different sets of curves should be plotted at each setting of the pump speed.

Equipment Set Up

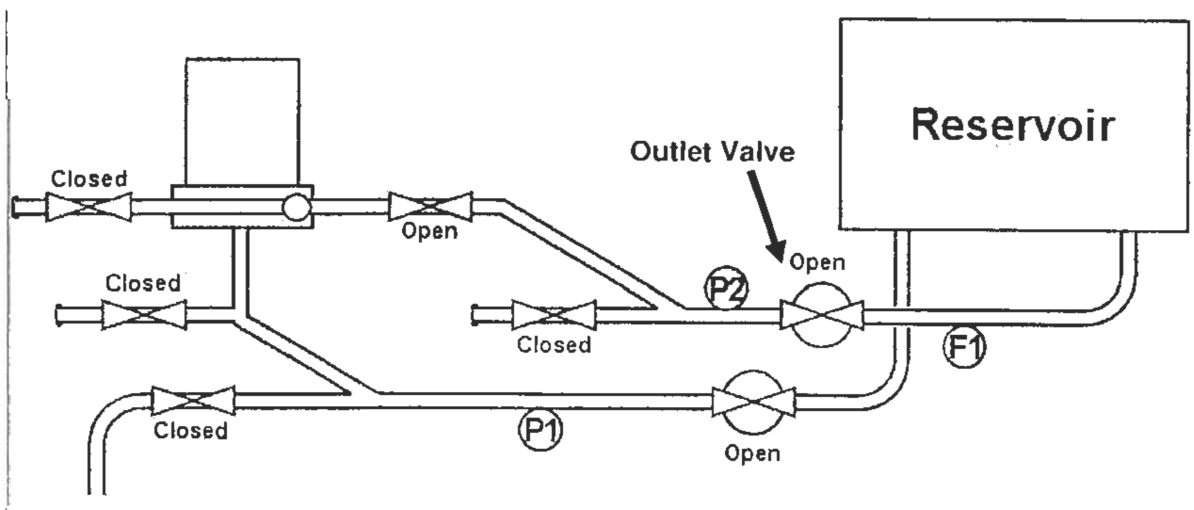
The Centrifugal pump is permanently fitted to the C3-MKII and no changes are required for this experiment. It is advisable to retain the end-caps on the unused piping unless additional pumps have been connected to the low pressure system.

Check that the reservoir on the C3-MKII has been filled with clean water and that the equipment is connected to an appropriate mains electricity supply.

If a thermometer is available remove the reservoir lid and measure the temperature of the water. Remove the thermometer and replace the reservoir lid.

If using the optional C3-MKII software, check that the USB cable is connected to the PC. Load the C3-MKII software, run the Centrifugal pump experiment then check that IFD:OK is indicated in the bottom right hand corner of the screen.

Set the valves as shown in the following diagram:



Procedure

Use the outlet valve only to adjust the discharge from the Centrifugal pump. The other valves should remain open or closed throughout the experiment, as marked on the diagram above. Start with the outlet valve fully closed.

Switch on the mains supply to the equipment, and switch on the power switch on the electrical console. The control panel on the front of the equipment will illuminate. Check for any warning messages – if 'Low water level' is displayed fill the reservoir to approximately 75 mm from the top then press the 'Exit' key.

Press the 'SELECT' key until 'Centrifugal Pump' is displayed then press the 'ENTER' key.

The pump will be run at maximum speed for the first part of this experiment. Press the 'SELECT' key until 'Pump Speed' is displayed then use the '↑' key for Pump 1 to increase the pump speed to 100%.

If using the control panel for sensor output readings:

At each setting of the outlet valve record the reading from each of the sensors by scrolling through the available parameters using the 'SELECT' key.

If using the optional computer software for taking sensor readings:

Enter the temperature of the working fluid in the box provided on the mimic diagram. At each setting of the outlet valve click the icon to record all of the readings from the sensors into the results table.

With the pump running at 100% speed, gradually open the outlet valve and allow the pump and pipework to fully prime. When the flow is steady record a set of readings from the sensors, namely;

Motor speed
Flow rate
Inlet pressure
Outlet Pressure
Motor Torque

Gradually close the outlet valve until the flow rate falls slightly, allow the conditions to settle then record another set of readings.

Continue to close the outlet valve in steps, taking readings from all of the sensors at each step, until a flow rate of 0 l/min is reached. Take one set of readings for zero flow conditions.

If time is available, additional sets of results may be taken for different pump speed settings, for example at 90%, 80% etc. until the flow stops with the flow control valve fully open.

The effect of suction losses can also be investigated by taking sets of readings with the inlet to the pump restricted by gradually closing the inlet isolating valve.

If using the software then create a new results sheet for each set of data using the icon. Alternatively, different groups of students may each produce results for a different speed setting to produce a full range of characteristic curves.

With the outlet valve fully closed press the 'Exit' key on the control panel to stop the pump.

If using the software, save your results using 'Save As...' from the File menu. Use a descriptive filename such as the date, equipment and exercise, so that the results can be easily retrieved later if required.

Results

If not using the optional software then you will need to obtain a value for the water density, ρ from the table in section 6.3. If a thermometer is not available assume the value to be 998 kg/m^3 corresponding to a water temperature of approximately 20°C.

Record the measured values under the following headings:

p_{in}	p_{out}	F	T	N	t	ρ
kN/m^2	kN/m^2	l/min	mNm	RPM	°C	kg/m^3

Record the calculated variables under the following headings:

Q	H_s	H_e	H_v	H_t	P_m	P_h	E_o
m^3/s	m	m	m	m	Watts	Watts	%
		0	0				
		0	0				
		0	0				

Remember to convert the sensor outputs into the correct units before using them in calculations. Pressures should be in N/m^2 (Pa), the Flow rate in m^3/s, Torque in Nm and Speed in RPM. If using the software, this is done automatically by the computer.

Plot graphs of Total head against Flow rate, Mechanical power against Flow rate, and Overall efficiency against Flow rate for each speed setting of the pump.

Conclusion

Compare the graphs obtained against the example given in the Theory section.

Comment on the efficiency figures obtained, and mark on the head/flow curve the point of maximum pump efficiency. This point indicates the *duty point* or normal operating capacity of the pump at maximum efficiency

If results were taken at a range of speed settings, describe the similarities and differences of the characteristic curves obtained at each constant speed. Suggest the optimum operating speed of the pump, and explain the reasoning behind the choice.