6.8 Exercise F: Diaphragm Pump

Objective

To investigate the performance of a Diaphragm pump

Method

Running the Diaphragm pump (C3-MKII-25) under different operating conditions (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

Diaphragm Pump (Option C3-MKII-25)

Volumetric Tank (Option C3-MKII-40)

Optional Equipment

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

Thermometer suitable for fluid temperature measurement (Not supplied)

Theory

Description of a Diaphragm Pump

A diaphragm pump is a reciprocating positive displacement pump. At its most basic, a diaphragm is flexed backwards and forwards inside a chamber which is fitted with an inlet valve and an outlet valve. Rotary motion in the gearbox is converted to reciprocating motion at the diaphragm. As the diaphragm is pulled the inlet valve opens and fluid is drawn into the chamber. As the diaphragm changes direction and is pushed, the inlet valve closes, the outlet valve opens and the fluid inside the chamber is forced through the outlet. The flow and pressure at the outlet of the pump therefore vary throughout the cycle, peaking at mid stroke and stopping during the suction phase.

Diaphragm pumps typically have good efficiency and can develop moderately high pressures. They are usually self-priming. They are also a simple and robust design and cope well with continuous use. They are relatively expensive, however, compared to some other types of pump, and the cyclic pulsation of the flow and pressure can be a problem. Flexing of the diaphragm under pressure can change the pumping characteristics slightly as the outlet pressure increases so diaphragm pumps are not ideal for applications that require precise control of flow rate.

Characteristic curves of a Diaphragm Pump

The operating characteristics of a diaphragm pump may be described using graphs of pump performance. The most commonly used graphical representations of pump performance for a positive displacement Diaphragm pump are:

- Volume Flow Rate (Q) against Maximum Outlet Head (H_o)
- Power Input to the pump (P_m) against Maximum Outlet Head (H_o)
- Pump Volumetric Efficiency (E_o) against Maximum Outlet Head (H_o)

Equipment Set Up

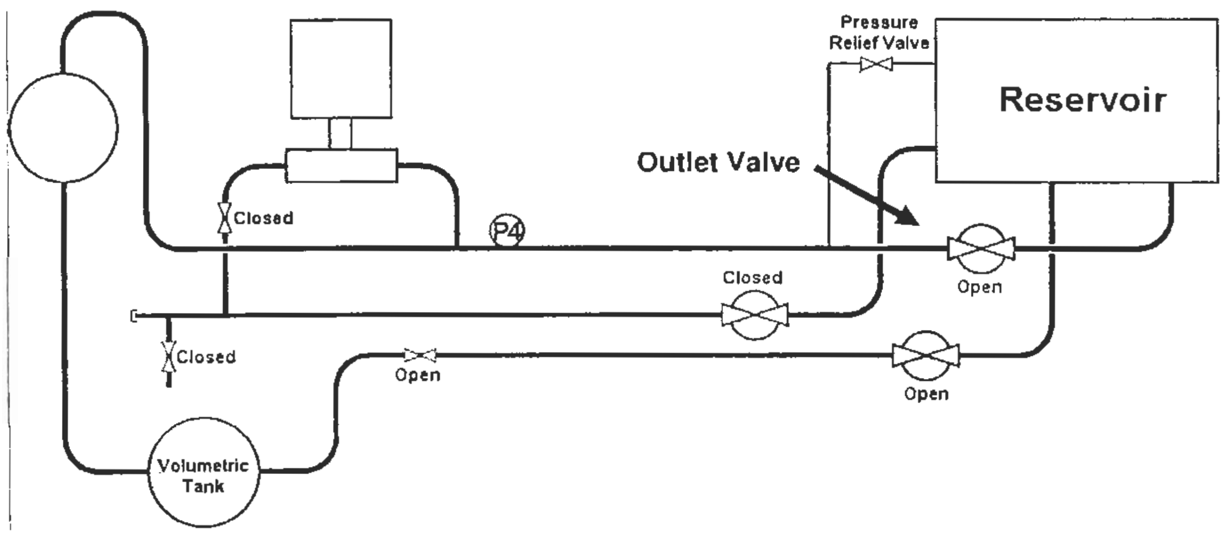
Check that the reservoir on the C3-MKII has been filled with clean water and that the equipment is connected to an appropriate mains electricity supply.

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. Run the C3-MKII software and check that IFD:OK is indicated in the bottom right hand corner of the screen.

The Diaphragm Pump should be installed in the space on the end of the support rails, beside the standard Gear Pump, and connected to the high pressure water supply system. Check that the base of the pump is securely fastened to the C3-MKII frame and that all pipework is connected and secured. Open pipe ends should be fitted with the end caps supplied.

Set the valves as shown in the following diagram:



The outlet pressure of the diaphragm pump pulses with the action of the pump, making direct pressure measurement difficult. For this reason, Armfield recommends that the pump is used with the optional volumetric tank. This tank should be fitted and connected as described in the Operation section of the C3-MKII instruction manual.

Calculations

Maximum Outlet Head

Because the head from the pump is continuously changing during the cycle, the Maximum Outlet Head H_o is used to determine the performance of the pump.

$$H_o = \frac{Max \quad value \quad of \ p_4}{\rho g}$$

where p_4 = fluid pressure at outlet in N/m^2

Input Power

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

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

where

N = rotational speed of pump in revolutions per minute
= reading (%) x 1400 RPM

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

Overall Efficiency

Because the flow and pressure are continuously changing throughout the cycle it is not possible to determine the hydraulic power so the overall efficiency cannot be calculated.

Volumetric Efficiency

Theoretically, at a constant speed, positive displacement pumps should produce a constant average flow rate independent of the outlet pressure. However, the diaphragm can flex at high operating pressure and valves are necessary to seal the inlet or outlet from the pump. Hence there can be some leakage and not all of the fluid entering the pump inlet will be transferred to the fluid outlet. The amount of leakage can increase as the Maximum Outlet Head increases.

Each pump will have a theoretical maximum volume of fluid which it can transfer in a single cycle. The theoretical ideal flow rate through the pump can be defined as

$$Q_{ideal} = V_{th}.N$$

where

V_{th} is the theoretical volume flow (m^3/s) per RPM, and

N is the motor speed in RPM

The volumetric efficiency of the pump can then be calculated as

$$E_v = 100 \times \frac{Q}{Q_{ideal}}$$

To allow for manufacturing tolerances etc. the value of V_{th} can be determined for the C3-MKII-25 Diaphragm pump from the average flow rate when the outlet valve is fully open (lowest value of Maximum Outlet Head) with the pump operating at 100% / 1400 RPM.

At this condition V_{th} = Q (measured in l/min) / 60000 / 1400

V_{th} = 1.1905E-8 x Q (measured in l/min)

The Volume flowrate, Power input and Volumetric efficiency should be calculated from the appropriate measured values and plotted against the Total Head. Different sets of curves should be plotted at each setting of the pump speed.

Procedure

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

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 50 mm from the top then press the 'Exit' key.

Press the 'SELECT' key until 'Cyclic Pumps' 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 4 to increase the pump speed to 100%.

The pressure and flow are not constant in a cyclic pump such as the Diaphragm pump. For this reason the method for determining these two parameters is different from the other pumps. The procedure also differs according to whether the control panel or optional computer software is used. Refer to the procedure under the appropriate heading:

If using the control panel for taking sensor readings:

Take readings from the sensors by scrolling through the available parameters with the 'SELECT' key.

Measuring the average flow rate:

After each adjustment of the outlet control valve allow the flow conditions to stabilise then close the valve at the inlet to the Volumetric tank. As the water level falls below the top level sensor a timer is automatically started. As the water level falls below the bottom level sensor the timer is automatically stopped. The average flowrate is calculated and displayed on the Control Panel and should be recorded. Open the inlet valve to the Volumetric tank as soon as the water level falls below the bottom level sensor. The tank will refill and can be used to measure the flowrate again when the level is above the top level sensor.

Measuring the maximum outlet pressure:

The pressure at the outlet from the pump is continually rising and falling during the cycling of the pump so the maximum pressure achieved is retained in a memory until manually reset by the operator. After each adjustment of the outlet control valve allow the flow conditions to stabilise then press 'Reset' on the Control Panel to update the maximum pressure reading. The maximum pressure reading can be 'Reset' repeatedly until a required setting has been achieved by adjusting the outlet valve. Record the value of the maximum pressure.

If using the optional computer software for taking sensor readings:

Measuring the average flow rate:

After each adjustment of the outlet control valve allow the flow conditions to stabilise then close the valve at the inlet to the Volumetric tank. As the water level falls below the top level sensor a timer is started. As the water level falls below the bottom level sensor the timer is stopped and the average flowrate is calculated and displayed on the mimic Diagram. Open the inlet valve to the Volumetric tank as soon as the water level falls below the bottom level sensor. The tank will refill and can be used to measure the flowrate again when the level is above the top level sensor. The calculated flowrate is added to the table of results.

Measuring the maximum outlet pressure:

The pressure at the outlet from the pump is continually rising and falling during the cycling of the pump so the maximum pressure achieved is retained in a memory until manually reset by the operator. After each adjustment of the outlet control valve allow the flow conditions to stabilise then click 'Reset' on the Mimic Diagram to update the maximum pressure reading. The maximum pressure reading can be 'Reset' repeatedly until a required setting has been achieved by adjusting the outlet valve.

When the average flow rate and maximum outlet pressure have been obtained use the icon to record all the sensor values on the results table.

After taking an initial set of readings close the outlet valve slightly then repeat the appropriate procedure above. Continue closing the outlet valve and taking readings until the outlet valve is full closed - a pressure relief valve will limit the maximum pressure to 60 m (6 Bar) to protect the pump and pipework.

If time is available, further sets of results may be taken at different pump speed settings, for example 90%, 80% etc. If using the software then create a new results sheet for each set of data using the icon.

Fully open the outlet valve then stop the pump by pressing 'Exit' on the control panel.

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_{out}	Vol	Time	T	N	t	ρ
kN/m^2	m^3	Sec	mNm	RPM	°C	kg/m^3
	0.01012					
	0.01012					
	0.01012					

Record the calculated variables under the following headings:

Q	H_o	P_m	P_h	E_o	Q_{th}	E_v
m^3/s	m	Watts	Watts	%	m^3/s	%

Remember to convert the sensor outputs into the correct units before using them in calculations. Pressure 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 Volume Flow Rate, Mechanical Power and Volumetric Efficiency, all against Maximum Outlet Head.

Conclusion

Describe the shapes of the graphs obtained and comment on the point of maximum efficiency.

If results are available for different constant speed settings, compare the characteristic curves obtained. Describe any similarities and differences. Suggest the optimum speed setting for the pump and explain the reasons for this choice.

Give examples of the wide range of diaphragm pump designs and applications that are possible.

Discuss the specific advantages of a diaphragm for each of those applications. Suggest other types of pump that might be useable in each application, if any, and explain why a diaphragm pump may be chosen instead of an alternative.