6.4 Exercise B: Gear Pump

Objective

To investigate the performance characteristics of a Gear pump

Method

Running the Gear pump (C3-MKII-21) 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 (Gear 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 a Gear pump

Gear pumps are one of the most common types of pump used in hydraulic fluid power applications and oil pumping systems. The main characteristics of a gear pump are:

High pressure at low flow rate

Positive displacement so self priming

Able to pump highly viscous fluids

Accurate output that is directly proportional to pump speed

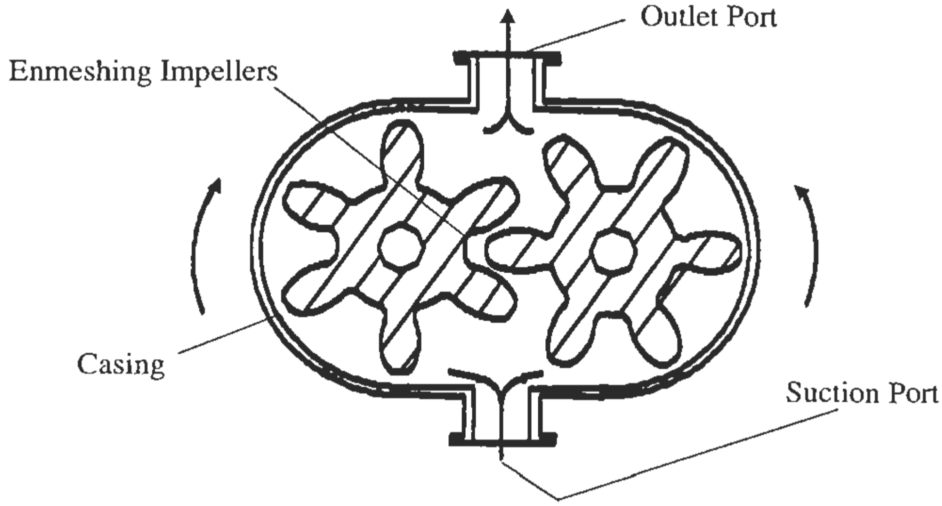
No inlet or outlet valves required for sealing

Gear pumps are not suitable for high flow rate applications and they become inefficient when pumping low viscosity fluids. Because close tolerances are necessary for the gear pump to operate efficiently this type of pump is not suitable for pumping fluids containing solid particles that could cause the pump to seize or wear rapidly.

The Gear pump is a positive displacement pump that consists of a casing incorporating two close-fitting gear-shaped impellers. The meshing of the teeth, where the gears meet, means that the fluid entering the suction port is trapped in the spaces between the teeth at the periphery both impellers and is carried around the impellers to be discharged through the outlet port. (See the diagram below.)

The flow from the gear pump is continuous without pulsations but a high frequency ripple can occur as the individual pockets of fluid discharge. Leakage past the faces and the tips of the impellers increases as the discharge pressure is increased. The result is a slight reduction in flow rate and Volumetric efficiency as the operating pressure increases.

Extremely high pressure can be generated by a Gear pump if the outlet is totally restricted so a pressure relief valve is incorporated in the discharge pipework to limit the maximum pressure to 60 m head (6 Bar) to protect the pump and system.



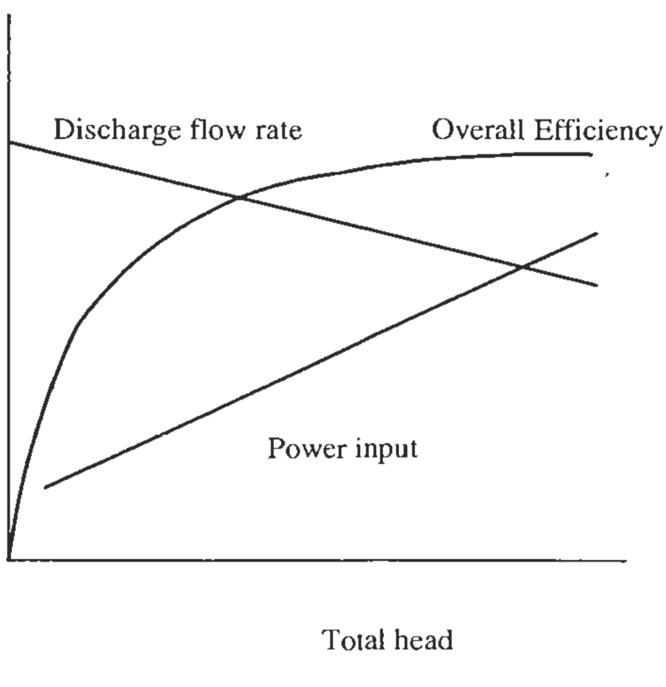
Schematic diagram of a Gear Pump

Characteristics curves of a Gear Pump

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

- Discharge flow rate (Q) against Total head (H_t)
- Power input to the pump (P_m) against Total head (H_t)
- Overall Pump Efficiency (E_o) against Total head (H_t)
- Volumetric Pump Efficiency (E_v) against Total head (H_t)

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



Calculations

Total Head

As for the centrifugal pump, the total head can be calculated as follows

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 $p_{in} = p_3$ = fluid pressure at inlet in N/m^2

$p_{out} = p_4$ = 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 $H_v = 0$

and $H_e = 0$ m for the Gear pump.

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

The fluid friction losses in the pump itself require a hydraulic efficiency E_h to be defined as:-

$$E_h = \frac{\text{Hydraulic power gained by fluid } (P_h)}{\text{Power supplied to the gears } (P_g)} \times 100\%$$

where

$P_h = \rho g Q H_t$

where

Q = volume flow rate in m^3/s

Further, the mechanical losses in the bearings etc. require a mechanical efficiency E_m to be defined as:

$$E_m = \frac{\text{Power supplied to the gears } (P_g)}{\text{Power supplied by the motor } (Pm)} \times 100\%$$

The overall efficiency $E_o = E_h.E_m$

$$E_o = \frac{\text{Hydraulic power gained by fluid } (P_h)}{\text{Power supplied to the motor } (P_m)} \times 100\%$$

Volumetric Efficiency

Theoretically, at a constant speed, positive displacement pumps should produce a constant flow rate independent of the outlet pressure. However, the clearances necessary for the pump to operate mean that there cannot be a complete seal between the impellers and the casing. Hence there will be some leakage and not all the fluid entering the pump inlet will be transferred to the fluid outlet. The amount of leakage will increase as the Total head increases.

Each pump will have a theoretical maximum volume of fluid which it can transfer in a single cycle. For the gear pump, a single cycle can be taken as one complete revolution of the gears and the theoretical maximum volume is the total volume of the spaces between the teeth for the two impellers.

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

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

V_{th} for the C3-MKII-21 Gear pump is typically 1.7143E-7.

To allow for manufacturing tolerances etc. the value of V_{th} can be determined for the C3-MKII-21 Gear pump from the average flow rate when the outlet valve is fully open (lowest value of Total 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, Overall efficiency 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.

Equipment Set Up

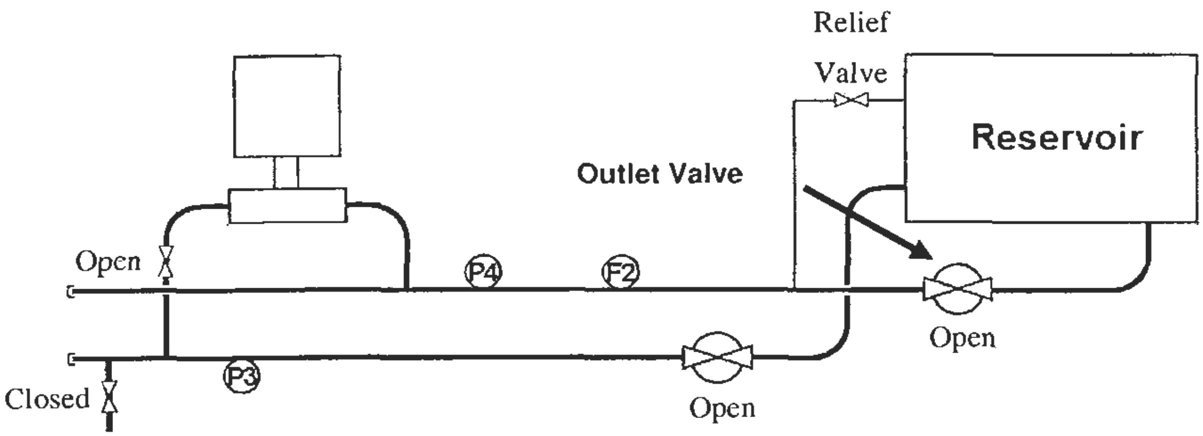
The Gear pump is permanently fitted to the C3-MKII and no changes are required for this experiment. It is necessary to retain the end-caps on the unused pipe ends to the left of the gear pump unless an additional pump has been connected at this point.

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 then run the Gear experiment and check that IFD:OK is indicated in the bottom right hand corner of the screen.

Set the valves as shown in the following diagram:



If the Turbine pump is installed in position 4, ensure that the inline isolating valve and vent valve at the top of the pump volute are fully closed to prevent inaccurate results because of leakage through the Turbine pump.

Procedure

Use the outlet valve only to adjust the discharge from the Gear 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 75 mm from the top then press the 'Exit' key.

Press the 'SELECT' key until 'Gear 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 3 to increase the pump speed to 100%.

If using the control panel for sensor output readings:

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

If using the optional computer software for taking sensor readings:

If using the optional software then the temperature of the working fluid must be entered in the box provided on the mimic diagram. Then use the icon to record all the sensor values on the results table.

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

Close the outlet valve slightly to give an increase in outlet pressure. Take another set of sensor readings.

Continue to close the outlet valve in steps, taking sensor readings at each step, until the valve is fully closed with the flow returning to the reservoir via the pressure relief valve. Take one set of readings at this setting.

If time is available, further sets of results may be taken at different speed settings, for example 80%, 60% etc. This pump will continue to operate at very low speed.

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_{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	E_v
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 Q 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 Flow Rate against Total Head, Mechanical Power against Total Head, and Overall Efficiency against Total Head.

On the same graph, plot the Volumetric Efficiency against Total Head.

Conclusion

Describe the trends in the pump performance characteristics as the Total Head increases. Compare the results to the example given in the theory section. Discuss the implications of the shape of the performance curves when selecting a gear pump for an application.

Describe the shape of the curve for Volumetric efficiency. Compare this to the curve for Overall efficiency.

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