Lecture 11

HYDRAULIC MOTORS [CONTINUED]

1.12Performance of Hydraulic Motors

The performance of hydraulic motors depends upon many factors such as precision of their parts, tolerances between the mating parts, etc.Internal leakage between the inlet and outlet affects the volumetric efficiency. Friction between mating parts affects the mechanical efficiency of a hydraulic motor.

Gear motors typically have an overall efficiency of 70–75% as compared to vane motors which have 75–85% and piston motors having 85–95%.

Motor torque is divided into three separate groups:

1. **Starting torque:** The starting torque is the turning force the motor exerts from a dead stop.
2. **Running torque:** Running torque is exerted when the motor is running and changes whenever there is a change in fluid pressure.
3. **Stalling torque:** Stalling torque is the torque necessary to stop the motor.

In most hydraulic motors, the stalling and starting torques are equal. Usually, starting torque is 75–80% of the maximum design torque.

1. Volumetric efficiency: The volumetric efficiency of a hydraulic motor is the ratio of theoretical flow rate to actual flow rate required to achieve a particular speed. The motor uses more flow than the theoretical due to leakage:

$$\eta_{\mathrm{v}} = \frac{\text{Theoretical flow rate the motor should be supplied with}}{\text{Actual flow rate supplied to the motor}} = \frac{Q_{\mathrm{T}}}{Q_{\mathrm{A}}}$$

2. Mechanical efficiency: The mechanical efficiency of a hydraulic motor is the ratio of actual work done to the theoretical work done per revolution. The output torque of a hydraulic motor is less than theoretical torque due to mechanical friction between the mating parts:

$$\eta_{\mathrm{m}} = \frac{\text{Actual torque delivered by the motor}}{\text{Torque the motor should theoretically deliver}} = \frac{T_{\mathrm{A}}}{T_{\mathrm{T}}}$$

Here,theoretical torque and actual torque are given by

$$T_{\mathrm{T}} = \frac{V_{\mathrm{D}} \times p}{2\pi}$$

$$T_{\mathrm{A}} = \frac{\text{Actual wattage delivered by the motor}}{N}$$

3. Overall efficiency: The overall efficiency of a motor is the ratio of output power to input power of the motor. Output power is mechanical power output at the shaft and input power is fluid energy supplied to the inlet of the hydraulic motor:

$$\eta_{\mathrm{o}} = \frac{\text{Actual power delivered by the motor (mechanical)}}{\text{Actual power delivered to the motor (hydraulic)}}$$

$$\eta_{\mathrm{o}} = \frac{T_{\mathrm{A}} \times N}{p \times Q_{\mathrm{A}}}$$

$$= \frac{T_A \times T_T \times N}{T_T \times p \times Q_A}$$

$$= \frac{T_A \times V_D \times p \times N}{T_T \times p \times Q_A \times 2\pi}$$

$$= \frac{T_A \times Q_T}{T_T \times Q_A}$$

$$\Rightarrow \eta_o = \eta_V \eta_m$$

So

Overall efficiency = Volumetric efficiency $\times$ Mechanical efficiency

Note: The actual power delivered to a motor by a fluid is called hydraulic power and the actual power delivered to a load by a motor via a rotating shaft is called brake power.

Example 1.2

A hydraulic motor is required to drive a load at 500 rpm with 1000 Nm of torque. What is the output power?

Solution

N = 500 rpm $= \frac{500 \times 2\pi}{60} = 52.36 \text{ rad/s}$

$T_A = 1000$ N m

Now

Power $= T_A (\text{N m}) \times \text{N (rad/s)}$

$$= 1000 \times 52.36$$
$$= 52360 \text{ W}$$

The output power is 52.360 kW.

Example1.3

A hydraulic motor receives a flow rate of 72 LPM at a pressure of 12000 kPa. If the motor speed is 800 RPM, determine the actual torque delivered by the motor assuming the efficiency 100%?

Solution

Method I

Actual flow rate

$$Q_A = 72 \text{ LPM} = \frac{72 \times 10^{-3}}{60} = 1.2 \times 10^{-3} \text{ m}^3\text{/s}$$

Speed of motor N = 800 RPM. So

$$\omega = 800 \times 2\pi / 60 = 83.78 \text{ rad/s}$$

Pressure = 12000 × 10^3 Pa.

Overall efficiency can be calculated using

$$\eta_o = \frac{T_A \times N}{P \times Q_A}$$

Substituting the values we get

$$1 = \frac{T_A \times 83.78}{12000 \times 10^3 \times 1.2 \times 10^{-3}}$$

$$\Rightarrow T_A = 171.88 \text{ N m}$$

So the actual torque $T_A = 171.88$ N m.

Method II

$$\text{Hydraulic power} = pQ = 12000 \times \frac{72}{60} \times 10^{-3} = 14.4 \text{ kW}$$

$$T\,(\text{Nm}) \times \omega(\text{rad/s}) = 14400 \text{ W}$$

So

$$T = \frac{14400}{800 \times \frac{2\pi}{60}} = 172 \text{ N m}$$

Example 1.4

A hydraulic motor has a 100 cm^3 volumetric displacement. If it has a pressure rating of 140 bar and receives oil from a 0.001 m^3/s theoretical flow rate pump, find the motor (a) speed, (b) theoretical torque, (c) theoretical kW power.

Solution:

(a) Speed: We have the theoretical flow rate given by

$$Q_\text{T} = V_\text{D} \times n$$

$$\Rightarrow 0.001 = 100 \times 10^6 \times n$$

$$\Rightarrow n = 10 \text{ RPS(revolutions per second)}$$

and $N = 600$ RPM

(b) Theoretical torque

$$T_\text{T} = \frac{p \times V_\text{D}}{2\pi} = \frac{140 \times 10^5 \times 100 \times 10^{-6}}{2\pi} = 222.82 \text{ N m}$$

(c) Theoretical kW power

$$P = Q_\text{T} \times p = 0.001 \ \text{m}^3/\text{s} \times 140 \times 10^5 \ \text{N/m}^2 = 14000 \text{ W} = 14 \text{ kW}$$

Alternately,

$$\text{Power} = T_\text{T}\omega = 222.82 \times 10 \times 2\pi = 14000 \text{ W} = 14 \text{ kW}$$

Example 1.5

The pressure rating of the components in a hydraulic system is 10^5 kPa. The system contains a hydraulic motor to turn a 0.3 m radius drum at 30 RPM to lift a weight of load 4000 N as shown in Fig. 1.14. Determine the flow rate and brake power if the motor efficiency is 90%.

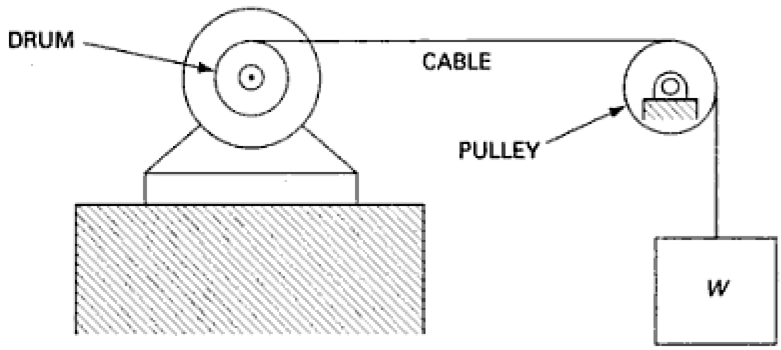

Figure 1.14

Solution: We have the theoretical torque given by

$$T_T = \frac{p \times V_D}{2\pi}$$

$$\Rightarrow 4000 \times 0.3 = \frac{10^8 \times V_D}{2\pi}$$

$$\Rightarrow V_D = 7.54 \times 10^{-5}\ \text{m}^3 = 0.0754\ \text{L}$$

Theoretical flow rate is

$$Q_T = V_D \times N = 7.54 \times 10^{-5} \times \frac{30}{60} = 0.0000377\ \text{m}^3/\text{s}$$

Power

$$P = pQ = 1 \times 10^8\ \text{N/m}^2 (0.0000377\ \text{m}^3/\text{s}) = 3770\ \text{W} = 3.77\ \text{kW}$$

Example 1.6

A hydraulic system contains a pump that discharges oil at 13.8 MPa and 0.00632 m^3/s to a hydraulic motor shown in Fig. 1.15. The pressure at the motor inlet is 12.40 MPa due to pressure drop in the line. If oil leaves the motor at 1.38 MPa, determine the power delivery by the 100% efficient motor.

(a) What torque would a hydraulic motor deliver at a speed of 1750 RPM if it produces 3 kW?

(b) If the pressure remains constant at 13.8 MPa, (i) what would be the effect of doubling the speed on the torque and (ii) what would be the effect of halving the speed on the torque?

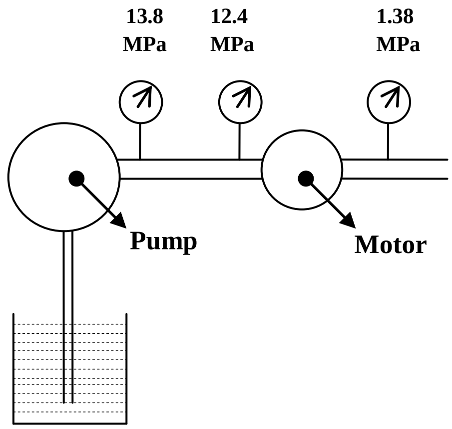

Figure 1.15

Solution: We have

$$\text{Power} = \Delta p\ Q = (12400 - 1380)\ \text{kPa} \times 0.00632\ \text{m}^3/\text{s}$$
$$= 69.6\ \text{kW}$$

Note: If the pipeline between the pump and motor is horizontal and of constant diameter, then the cause of pressure drop (12.4 − 1.38 MPa) is due to friction.

(a) We have

$$P = T \times \omega = 3000$$
$$\Rightarrow T \times \frac{2 \times \pi \times 1750}{60} = 3000$$
$$\Rightarrow T = \frac{3000 \times 60}{2 \times \pi \times 1750} = 16.37\ \text{N m}$$

(b)

(i) $T = \dfrac{pV_D}{6.28}$ .Since p and V_D are both constant, torque remains constant. This would, however, double the power.

(ii) The torque T remains constant while the power is reduced by 50%.

Example 1.7

A hydraulic motor has a displacement of 40 cm^3/rev and is used in a system with a maximum pressure of 20000 kPa. Determine the actual torque delivered by the motor assuming that it is 100% efficient.

Solution:

Displacement $V_D = 40 \times 10^{-6}\ \text{m}^3/\text{rev}$

Pressure of the system P = 20000 kPa

Theoretical torque

$$T_T = \frac{V_D \times p}{2\pi} = \frac{40 \times 10^{-6} \times 20000 \times 10^3}{2\pi} = 127.3\ \text{N m}$$

Since the motor is 100% efficient, the actual torque is equal to the theoretical torque

$$T_A = 127.3\ \text{N m}$$

Example 1.8

A motor must produce a torque of 350 Nm in a system with an operating pressure of 25000 kPa. What size motor should we select? Assume 100% efficiency.

Solution: Given $T_A = 350$ N m . Since the motor has 100% efficiency,

Theoretical torque = Actual torque

$$\Rightarrow T_T = \frac{V_D \times P}{2\pi}$$

$$\Rightarrow 350 = \frac{V_D \times 25000 \times 10^3}{2\pi}$$

$$\Rightarrow V_D = 88 \text{ cm}^3\text{/rev}$$

So we should select a motor having the displacement of 88 cm^3/rev.

Example 1.9

A hydraulic motor has a displacement of 164 cm^3 and operates with a pressure of 70 bar and a speed of 2000 rpm. If the actual flow rate consumed by the motor is 0.006 m^3/s and the actual torque delivered by the motor is 170 Nm, find (a) η_v, (b) η_m, (c) η_o and (d) actual power delivered by the motor?

Solution:

(a) We have

$$\eta_v = \frac{\text{Theoretical flow rate the motor should consume}}{\text{Actual flow rate consumed by the motor}} = \frac{Q_T}{Q_A}$$

Now $Q_A = 0.006 \text{ m}^3/\text{s}$. Theoretical flow rate is

$$Q_T = V_D \times N = 164 \times 10^{-6} \text{ (m}^3\text{/rev)} \times \frac{2000}{60} \text{ (rev/s)} = 0.0055 \text{ m}^3\text{/s}$$

So volumetric efficiency is

$$\eta_v = \frac{0.0055}{0.006} \times 100 = 91.67\%$$

(b) Mechanical efficiency is given by

$$\eta_m = \frac{\text{Actual torque delivered by the motor}}{\text{Theoretical torque motor should deliver}} = \frac{T_A}{T_T}$$

Theoretical torque,

$$T_T = \frac{p \times V_D}{2\pi} = \frac{70 \times 10^5 \times 164 \times 10^{-6}}{2\pi} = 182.71 \text{ N m}$$

So mechanical efficiency,

$$\eta_m = \frac{170}{182.71} = 93.04\%$$

(c) We have

$$\eta_o = \eta_m \times \eta_v = 0.9304 \times 0.9167 = 0.853 = 85.3\%$$

So overall efficiency is 85.3 %.

(d) Actual power is

$$T_A\omega = 170\times\left(2000\times\frac{2\times\pi}{60}\right) = 35600\text{ W} = 35.6\text{ kW}$$

Example 1.10

A hydraulic motor receives a flow rate of 72 LPM at a pressure of 12000 kPa. If the motor speed is 800 RPM and ifthe motor has a power loss of 3 kW, find the motor actual output torque and overall efficiency.

Solution: We have

$$72\text{ LPM} = 0.0012\ \text{m}^3/\text{s}$$

Now we calculate the hydraulic power given to motor using

Hydraulic power = pQ = 0.0012 $\text{m}^3/\text{s}\ \times$ 12000 = 14400 W = 14.4 kW

Actual power is obtained by subtracting the losses,

$$\text{Actual power} = T\omega = 14.4 - 3 = 11.4\text{ kW}$$

$$\Rightarrow T = \frac{11400}{800\times\frac{2\pi}{60}} = 136\text{ N m}$$

The overall efficiency is

$$\text{Overall efficiency} = \frac{11.4}{14.4} = 0.792 = 79.2\ \%$$

Example 1.11

A hydraulic motor has a volumetric efficiency of 90% and operates at a speed of 1750 RPM and a pressure of 69 bar. If the actual flow rate consumed by the motor is 0.0047 m^3/s and the actual torque delivered by the motor is 147 Nm, find the overall efficiency of the motor.

Solution: The overall efficiency is

$$\eta_o = \frac{T_A\omega}{pQ_A} = \frac{147\times\frac{1750\times 2\times\pi}{60}}{69\times 10^5\times 0.0047} = 0.83 = 83\%$$

Example 1.12

A hydrostatic transmission operating at 105 bar pressure has the following characteristics:

Pump	Motor
V_d = 100 cm^3	V_d = ?
η_v = 85%	η_v = 94%
η_m = 90%	η_m = 92%
N = 1000rpm	N= 600 rpm

Find the (a) displacement of motor and (b) motor output torque.

Solution:

(a) Pump theoretical flow rate

$$Q_{\text{T-pump}} = V_{\text{d}} \times N = \frac{100 \times 10^{-6} \times 1000}{60} = 1.667 \times 10^{-3}\ \text{m}^3/\text{s}$$

Actual flow rate

$$Q_{\text{A-pump}} = \eta_{\text{V}} \times Q_{\text{T}} = 1.667 \times 10^{-3} \times 0.85 = 1.42 \times 10^{-3}\ \text{m}^3/\text{s}$$

Actual flow from the pump is the actual flow to the motor. So for the motor

$$Q_{\text{A-motor}} = 1.42 \times 10^{-3}\ \text{m}^3/\text{s}$$

$$Q_{\text{T-motor}} = \eta_{\text{V}} \times Q_{\text{A}} = 1.42 \times 10^{-3} \times 0.94 = 1.332 \times 10^{-3}$$

So the theoretical flow rate, $Q_{\text{T-motor}} = 1.332 \times 10^{-3}\ \text{m}^3/\text{s}$. Now

$$Q_{\text{T-motor}} = V_{\text{D-motor}} \times N$$

$$\Rightarrow V_{\text{D-motor}} = \frac{Q_{\text{T-motor}}}{N_{\text{motor}}} = \frac{1.332 \times 10^{-3}}{600/60} = 1.332 \times 10^{-4} = 133\ \text{cm}^3/\text{rev}$$

So for the motor, the displacement is 133 cm^3/rev.

(b) Torque delivered by the motor

To calculate torque delivered by the motor, let us first calculate the actual power to motor

$$\text{Power}_{\text{actual to motor}} = p\,Q = 105 \times 10^5 \times 0.00142 = 14900\ \text{W}$$

Now

$$\text{Power}_{\text{actual by motor}} = \text{Power}_{\text{actual to motor}} \times \text{Mechanical efficiency} \times \text{volumetricefficiency}$$

$$\text{Power}_{\text{actual by motor}} = 14900 \times 0.94 \times 0.92 = 12900\ \text{W}$$

$$\text{Torque}_{\text{actual by motor}} = \frac{12900}{\frac{600 \times 2\pi}{60}} = 205\ \text{Nm}$$

1.13 Performance Curves for a Variable Displacement Motor

The following curves represent typical performance curves obtained for a 100 cm^3 variable displacement motor operating at full displacement.Figure1.16 gives the motor input flow (LPM) and motor output torque as a function of motor speed(RPM) at two pressure levels.

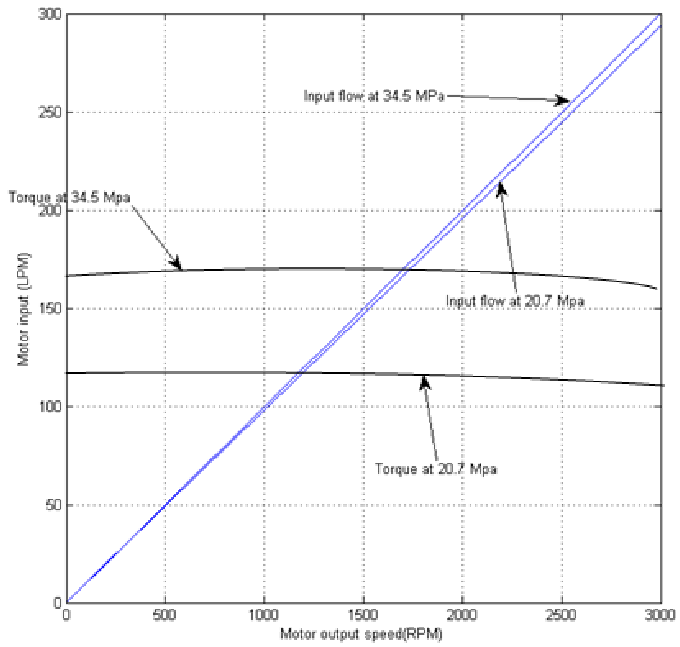

Figure 1.16 Motor input flow versus motor output torque

Figure 1.17gives the curves of overall and volumetric efficiencies as a function of motor speed(RPM) for pressure levels of 34.5 and 20.7 MPa.

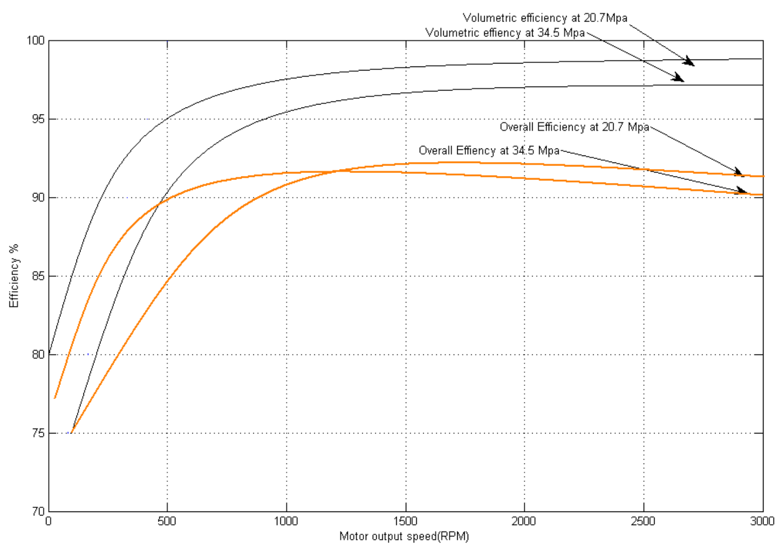

Figure1.17 Performance curves for a 100 cm^3 variable displacement motor

Objective-Type Questions

Fill in the Blanks

1. A hydraulic motor is a device which converts fluid power into _____ or converts fluid pressure into _____.
2. In an axial piston motor, the piston reciprocates _____ to the axis of the cylinder block.
3. In a radial piston-type motor, the piston reciprocates radially or _____ to the axis of the output shaft.
4. Rack and pinion rotary actuator is a commonly used design for obtaining _____ revolution actuation.
5. Gear motors typically have an overall efficiency of _____ as compared to _____ for piston motors.

State True or False

1. A hydraulic motor is a hydraulic pump which runs backward.
2. Gear motors are the most efficient and most dirt tolerant.
3. Hydraulic motors can be stalled for any length of time and their direction of rotation can be instantly reversed and their rotational speed can be infinitely varied.
4. The moment of inertial to torque ratio for a hydraulic motor is nearly 100.
5. A semi-rotary actuator allows only a partial revolution.

Review Questions

1. Differentiate between a hydraulic pump and a hydraulic motor.
2. List the advantages of a hydraulic motor over an electric motor.
3. List four important applications of hydraulic motor.
4. Explain with a neat sketch the working of gear motor.
5. Write the classification of piston motor.
6. Define volumetric efficiency, mechanical efficiency and overall efficiency of hydraulic motor.
7. Why is the actual flow rate required by a hydraulic motor higher than the theoretical flow rate?
8. Why is the actual torque output delivered by a hydraulic motor less than the calculated theoretical torque?
9. List few applications of a semi-rotary actuator.
10. Where are external gear motors used?
11. List the advantages of external gear motors.
12. What is a limited-rotation hydraulic motor? How does it differ from a hydraulic motor?
13. What are the main advantages of a gear motor?
14. Why are vane motors fixed-displacement units?
15. Name one way in which vane motors differ from vane pumps.
16. Can a piston pump be used as a piston motor?
17. Why does a hydraulic motor use more flow than it should theoretically?
18. Name four advantages of hydrostatic transmission.
19. Why does a hydraulic motor deliver less torque than it should theoretically?
20. Explain why, theoretically, the torque output from a fixed-displacement hydraulic motor operating at a constant pressure is the same regardless of changes in speed.
21. Define the displacement and torque ratings of a hydraulic motor.
22. Explain how vanes are held in contact with the cam ring in a high-performance vane motor.
23. How is torque developed in an inline-type piston?

24. If a hydraulic motor is pressure compensated, what is the effect of an increase in the working fluid?

25. Which type of hydraulic motor is generally the most efficient?