

## PUMP AND MOTOR CALCULATIONS FOR ROTARY DRIVES

Useful power in a hydraulic system is a product of flow and pressure, minus inefficiencies (losses). When selecting a pump and/or motor for a specific application the relationships between flow, displacement, speed, torque and pressure, and the influence of inefficiencies must be considered. The following guidelines and calculations can be applied to all rotary drives.

### System pressure

The first variable to consider is maximum available system pressure. If modifications are being made to an existing system the maximum working pressure may be constrained by existing components, such as the pump, valving or power of the prime mover, or other system design considerations. In a new application, the maximum system pressure can be determined at the outset. Factors to consider are cost, component size and weight, duty cycle, reliability and service life. High-pressure systems (3600-6000 psi / 250-400 bar) typically require the application of piston-type pumps and motors, which are generally more expensive than normal pressure (2100-3500 psi /150-250 bar) gear or vane type units.

Once nominal system operating pressure has been determined, assuming that the drive speed and torque required for the application are known, the logical starting point for the system design calculations and component selection is the motor.

### Motor displacement

The shaft torque produced by a hydraulic motor is a product of its volumetric displacement per revolution and the differential pressure ( $\Delta p$ ) across its ports. It is important to consider that the pressure at the outlet port of a motor, such as charge (boost) pressure in closed loop circuits, or pressure drop caused by valves, filters, coolers and plumbing in open loop circuits, reduces the effective working pressure and therefore available torque. As  $\Delta p$  decreases, output torque decreases, assuming displacement remains constant. Hydraulic motor manufacturers publish output torque figures, which are typically expressed in lb-ft/psi or Nm/bar for each displacement size. In the absence of this data the motor displacement required to achieve the desired shaft torque can be calculated using the following formula:

$$V_m = \frac{T_m \times 75.4}{\Delta p \times \eta_{hm.m}}$$

Where

$$\begin{aligned} V_m &= \text{motor displacement (in}^3\text{/rev)} \\ T_m &= \text{motor torque (ft/lb)} \\ \Delta p_m &= \text{operating pressure difference across motor ports (psi)} \\ \eta_{hm.m} &= \text{motor hydraulic/mechanical efficiency (0.90 – 0.95)} \end{aligned}$$

In metric units

$$V_m = \frac{T_m \times 62.83}{\Delta p \times \eta_{hm.m}}$$

Where

- $V_m$  = motor displacement (cm<sup>3</sup>/rev)
- $T_m$  = motor torque (Nm)
- $\Delta p_m$  = operating pressure difference across motor ports (bar)
- $\eta_{hm.m}$  = motor hydraulic/mechanical efficiency (0.90 – 0.95)

#### Motor speed and flow rate

Once the motor displacement has been determined, according to the required torque and available pressure, the required motor shaft speed will then determine the flow rate required. This can be calculated using the following formula:

$$Q_m = \frac{V_m \times n_m}{231 \times \eta_{vol. m}}$$

Where

- $Q_m$  = flow rate required by motor in US gallons per minute
- $V_m$  = motor displacement (in<sup>3</sup>/rev)
- $n_m$  = motor shaft speed in rpm
- $\eta_{vol. m}$  = motor volumetric efficiency (0.85 – 0.97)

In metric units

$$Q_m = \frac{V_m \times n_m}{1000 \times \eta_{vol. m}}$$

Where

- $Q_m$  = flow rate required by motor in litres per minute
- $V_m$  = motor displacement (cm<sup>3</sup>/rev)
- $n_m$  = motor shaft speed in rpm
- $\eta_{vol. m}$  = motor volumetric efficiency (0.85–0.97)

Before confirming motor selection, check that the required torque is developed within the manufacturer's maximum permissible working pressure and the required shaft speed is within the maximum permissible rpm. As a general rule, small displacement motors have higher maximum permissible shaft speeds than large displacement motors.

### Pump displacement

The pump displacement required to deliver the necessary flow rate will be dependant on the drive speed available from the prime mover i.e. pump shaft rpm. Prime mover type and operating speed need to be determined at this stage. If a single pump is required to operate several functions simultaneously, the pump must be capable of delivering the sum of the individual flows required by each function. To calculate pump displacement use the following formula:

$$V_p = \frac{Q_m \times 231}{n_p \times \eta_{vol. p}}$$

Where

- $V_p$  = pump displacement (in<sup>3</sup>/rev)
- $Q_m$  = flow rate required by motor in US gallons per minute
- $n_p$  = pump shaft speed in rpm
- $\eta_{vol. p}$  = pump volumetric efficiency (0.85 – 0.97)

In metric units

$$V_p = \frac{Q_m \times 1000}{n_p \times \eta_{vol. p}}$$

Where

- $V_p$  = pump displacement (cm<sup>3</sup>/rev)
- $Q_m$  = flow rate required by motor in litres per minute
- $n_p$  = pump shaft speed in rpm
- $\eta_{vol. p}$  = pump volumetric efficiency (0.85 – 0.97)

Before confirming pump selection, check that the projected shaft speed and working pressure are within the manufacturer's permissible limits. As a general rule, small displacement pumps have higher maximum permissible shaft speeds than large displacement pumps.

### Drive power

With pump displacement and shaft speed now established, the power required from the prime mover to drive the pump can be calculated. When determining the power rating of the prime mover, it is important to allow for the power requirement of all pumps that are to be driven by the prime mover, including charge (boost) pumps for closed loop circuits and auxiliary circuit pumps. Pump drive power can be calculated using the following formula:

$$P = \frac{p \times (V_p \times n_p)}{395934 \times \eta_{t.p}}$$

Where

- P = power in horsepower
- p = operating pressure in psi
- V<sub>p</sub> = pump displacement (in<sup>3</sup>/rev)
- n<sub>p</sub> = pump shaft speed in rpm
- η<sub>t.p</sub> = pump overall efficiency (0.8 – 0.9)

In metric units

$$P = \frac{p \times (V_p \times n_p)}{600000 \times \eta_{t.p}}$$

Where

- P = power in kiloWatts
- p = pressure in bar
- V<sub>p</sub> = pump displacement (cm<sup>3</sup>/rev)
- n<sub>p</sub> = pump shaft speed in rpm
- η<sub>t.p</sub> = pump overall efficiency (0.8 – 0.9)

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