Hydraulics motors

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Introduction

- The actuators are classified as motors and cylinders that are used in the hydraulic systems to utilize the pump output as their input power.
- The energy delivered to the hydraulic system by the pump is generally utilized to run the linear device (cylinder) or rotary device (motor).
- The pump converts mechanical power from an electric motor into fluid power.
- The motors perform opposite functions of the pump.
- The hydraulic motor converts fluid power into mechanical power in the form of rotation
- (angular displacement) of the shaft by converting the fluid pressure into torque.
- This rotation is continuous in the case of hydraulic motor and it exerts limited rotation in the case of torque motor
- Hydraulic motor produces rotation of shaft and torque when high-pressure fluid is supplied

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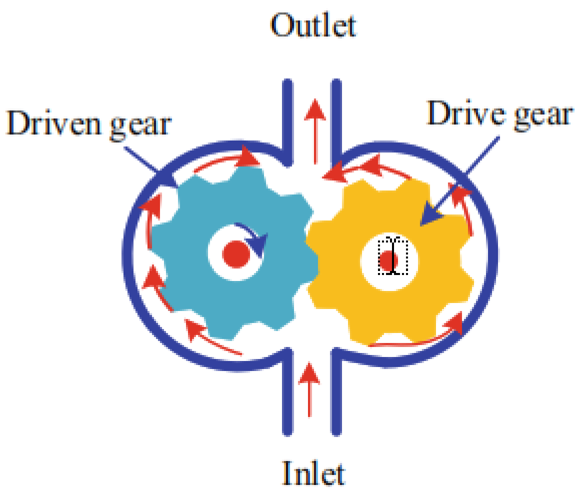
Classification of Hydraulic Motor

The hydraulic motor is designed for working pressure at both sides of the motor. The motor can be classified as fixed and variable displacement. Increasing the displacement of a motor decreases the speed and increases the torque. Similarly, decreasing the displacement increases the speed and decreases torque. Most of the hydraulic motors are positive displacement types. Hydraulic motors are classified into gear, vane, and piston types. However, gear, piston, and vane motors are considered into the fixed displacement group.



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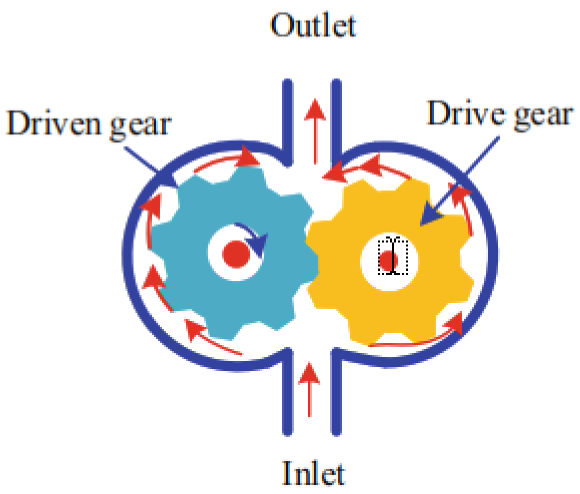
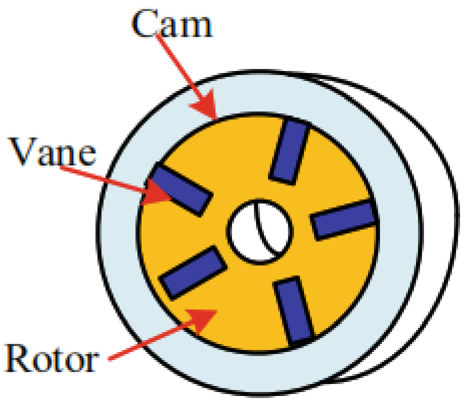
Gear Motor

Both gears have the same number of teeth. The high-pressure fluid enters into the inlet of the motor. Then it flows around the surface between the gear teeth and the wall housing and to the outlet of the motor. The surface area between the gear teeth and wall housing has less resistance, so that fluid passes easily. Gear motor has low weight, a simple design, and medium pressure. It is used in agricultural machinery to drive conveyor belts, distribution plates, etc.



Vane Motor

The vane motor is a positive displacement motor that develops output torque on its shaft by allowing fluid to act on the vanes. This motor consists of vanes, housing with an eccentric bore that runs a rotor with associated vanes that comes in and out. This action creates an unbalanced force of the pressurized fluid on the vanes. As a result, the rotor of the motor rotates in one direction. The vane motor has high operating efficiency but not as much as the piston motor. However, the vane motor is less costly than the piston motor.



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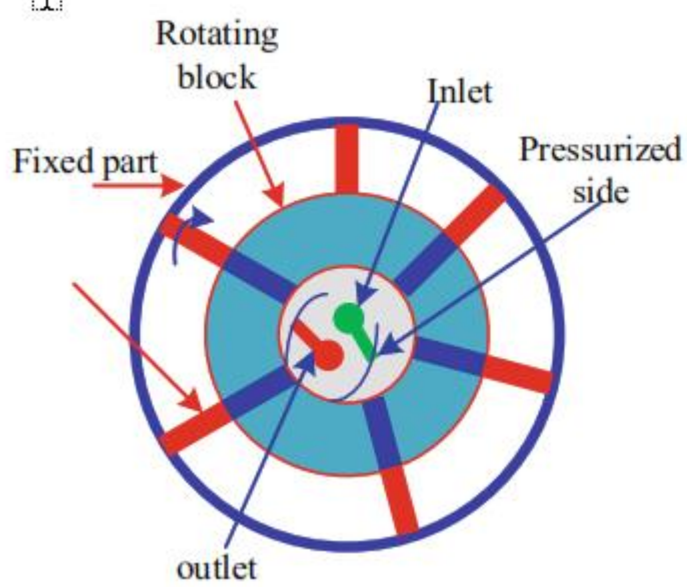
Piston Motor

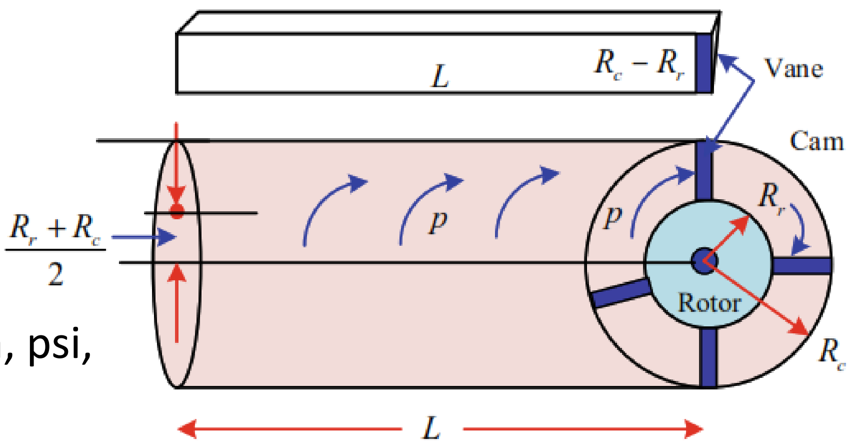
The piston motor is available in low-speed high torque (LSHT) and high-speed low torque (HSLT). The motor bore contains the number of pistons that are reciprocating to each other. The pressurized fluid enters through the inlet that pressed the series of pistons inside the barrel with a fixed angle with the swashplates. These pistons push against this angle which creates the rotation of the swashplate that is connected to the output shaft of the motor.



Motor Torque

The torque is one of the key features of a hydraulic motor. The output torque is produced by the pressure difference between incoming and outgoing hydraulic fluid and displacement during one revolution of the shaft. A hydraulic vane motor with a cam, rotor, and vane is shown in figure below. The outer part is known as a cam and the inner part is known as a rotor. The rotor rotates when the fluid pressure acts on the vane. For a single rotation of a vane, consider the following :

L is the length of the vane in m, i
Rc is the cam radius in m, in.,



Rr is the rotor radius in m, in.,
p is pressure acting on the vane in Pa, psi,
T is the torque capacity in N.m, in.lb,
A is the area of the vane.

Motor Torque

Due to a hydraulic pressure acted on a vane, the force is calculated as:

$$F = pA$$

The area of the vane is calculated as:

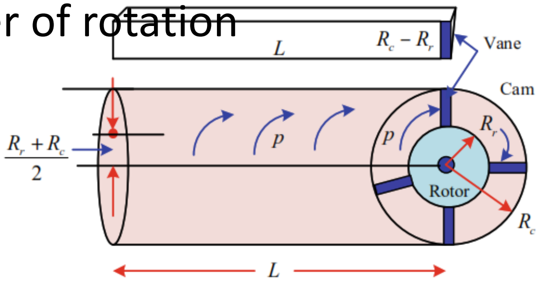
$$A = (R_c - R_r) \times L$$

Substituting:

$$F = p(R_c - R_r)L$$

The torque capacity of a hydraulic motor is calculated by using the force and the distance of the center of rotation, the distance of the center of rotation (dr) is calculated as:

$$d_r = \frac{R_c + R_r}{2}$$



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Motor Torque

The torque capacity of a hydraulic motor is calculated as,

$$T = F \times d_r$$

Substituting

$$T = p(R_c - R_r)L \times \frac{R_c + R_r}{2}$$

$$T = \frac{pL}{2}(R_c^2 - R_r^2)$$

The volumetric displacement is calculated as

$$v_d = \pi(R_c^2 - R_r^2) \times L$$

Substituting

$$T = \frac{p\, v_d}{2\pi}$$

Note: torque capability of a hydraulic vane motor can be calculated if other parameters are given

Motor Speed

The speed of a hydraulic motor depends on the amount of flow coming out from the pump and the displacement of the motor. The speed of the motor is directly proportional to the flow rate and inversely proportional to the motor displacement. Mathematically, it can be expressed as:

$$N = \frac{Q}{V_m}$$

$$Q = V_m N$$

Where,
N is the motor speed in rev/min,
V m is the motor displacement in $in.^3$/rev,
Q is the flow rate in $in.^3$/min, m^3/min.

However, in a metric unit, equation is revised as: $Q = \frac{V_m N}{1000}$

Motor Power

The motor converts fluid flow from the pump output into a rotational speed at its shaft. Later on, this rotational speed is used to do work. In this case, the motor shaft needs to couple with a load shaft to transmit the power. To derive the power of the motor, the following unit conversions need to be included:

The unit in rad per second (rad/s) is converted in the following ways:

$$\text{rad/s} \times \text{s/min} \times \text{rev/rad} = \text{rpm}$$

But, the radian and revolution is related as:

$$2\pi \text{ rad} = 1 \text{ rev}$$

Substituting

$$N \text{ rad/s} \times \text{s/60s} \times \frac{1}{2\pi} \text{rev/rad} = N \text{ rpm}$$

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

Motor Power

The shaft power of the motor is equal to the product of the torque (T) and the rotational speed (N). Mathematically, it is expressed as,

$$P_s = T(\text{ft-lb}) \times N(\text{rad/s}) = \frac{2\pi}{60} T_A \times N(\text{rpm}) = \frac{T \times N}{60/2\pi} = \frac{T \times N}{9.549} \text{ W}$$

Using the conversion factor 1 HP=550 ft-lb/s = 746 N-m/s (W) to modify Eq.

$$P_s = \frac{T \times N}{9.549 \times 550}$$

$$P_s = \frac{T \times N}{5252} \text{ HP}$$

where the torque (T) is in ft-lb. Then it is converted to in-lb and Eq. is modified as:

$$P_s = \frac{T \times N}{5252 \times 12} \text{ HP}$$

$$P_s = \frac{T \times N}{63025.35} \text{ HP}$$

Motor Power

In general, the output power of the motor is,

$$P_s = \frac{T \times N}{63025} \quad \text{HP}$$

In the metric unit, from Eq., the output in kilowatts is expressed as:

$$P_s = \frac{T \times N}{9.549} \text{ W} = \frac{T \times N}{9.549 \times 1000} \text{ kW}$$

$$P_s = \frac{T \times N}{9550} \text{ kW}$$

Motor Efficiency

The motor efficiency is calculated to know how the fluid input horsepower is converted to the useful output brake horsepower. The efficiency of the motor is classified as volumetric, mechanical and overall efficiency. In a motor, mechanical and volumetric losses are considered. Mechanical losses occurred due to wear and friction. Whereas the volumetric losses occurred due to leakage. The volumetric efficiency is defined as the ratio of theoretical flow rate (QT) motor should consume to the actual flow rate (QA) consumed by the motor. Mathematically, the volumetric efficiency is expressed as:

$$\eta_v = \frac{Q_T}{Q_A}$$

The theoretical flow rate of a motor is related to the motor displacement and the rpm. From Eq., this relation is expressed as:

$$Q_T = \frac{V_m N}{231}$$

Motor Efficiency

Substituting Eq.

$$\eta_v = \frac{\frac{V_m N}{231}}{Q_A}$$

$$\eta_v = \frac{V_m N}{231 \, Q_A}$$

As there are wear and friction losses in a motor, the actual torque (T A) is always less than the theoretical torque (T T). The mechanical efficiency is defined as the ratio of the actual torque to the theoretical torque. Mathematically, the volumetric efficiency is expressed as,

$$\eta_m = \frac{T_A}{T_T}$$

Motor Efficiency

The theoretical torque is calculated as:

$$T_T = \frac{p\, v_d}{2\pi}$$

Due to frictional losses, the actual torque is always less than the theoretical torque. From Eq., the expression of actual torque is written as,

$$T_A = \frac{P_s}{N} \times 63025$$

where,
T is in lb-ft,
N is in rpm,
Ps is in HP.

Motor Efficiency

The actual torque in the SI unit is expressed as,

$$T_A = \frac{P_s}{N} \times 9550$$

where,
T is in N-m,
N is in rpm,
Ps is in kW.

Substituting equations

$$\eta_m = \frac{\frac{P_s}{N} \times 63025}{\frac{p\, v_d}{2\pi}}$$

$$\eta_m = 395997.75 \frac{P_s}{N\ p\ v_d}$$

Motor Efficiency

The overall efficiency of a motor is defined as the output horsepower power (OHP) available at the shaft to the hydraulic horsepower (HHP) applied as an input. Mathematically, it is expressed as:

$$\eta_o = \frac{OHP}{HHP} = \eta_v \times \eta_m$$

The power is defined as the work done (W) per unit time (t) and it is expressed as:

$$P = \frac{W}{t} = \frac{F \times d}{t}$$

Replacing d/t with the velocity, v in Eq.

$$P = F \times v$$

Again, substituting F=pA

$$P = pA \times v$$

Motor Efficiency

According to the continuity equation, substituting Q=Av

$$P = pQ$$

where p is the fluid pressure in psi or lb/in.^{2} and Q is the flow rate in in.^{3}/min. The unit of the power will be in.lb/min.

Let us consider 1 hp is equal to 396,000 in.lb/min and 1gpm is equal to 231 in.^{3}/min. Therefore, multiplying by 231 to flow rate in gpm and dividing by 396,000 to corresponding Eq. to convert in horsepower (HP). This simplification can be written as,

$$HHP = \frac{pQ}{1714}$$

In the SI unit,

$$P_{\mathrm{H}} = \frac{pQ}{60000}$$

where the pressure is in kPa, the flow rate is in lpm and the hydraulic power is in kW.

Motor Efficiency

The overall efficiency is expressed as the output power at the shaft to the hydraulic power input to the motor and it is expressed as,

$$\eta_o = \frac{P_s}{P_H(HHP)}$$

Substituting Eqs.

$$\eta_o = \frac{\frac{T \times N}{5252}}{\frac{p \times Q}{1714}}$$

Equation reduces to,

$$\eta_o = 0.326 \frac{T \times N}{p \times Q}$$

where,
T is in lb-ft,
N is in rpm,
P is in psi,
Q is in gpm.

THANK YOU FOR YOUR ATENTTION!