MENG2520 Pneumatics and Hydraulics

Module 3 – Hydraulic Equipment

-Hydraulic Actuators

Hydraulic Equipment – Hydraulic Actuators

The actuator is the final element in the hydraulic system providing the mechanical power to the load

In this Module we will study

-Linear Cylinders

-Rotary motors

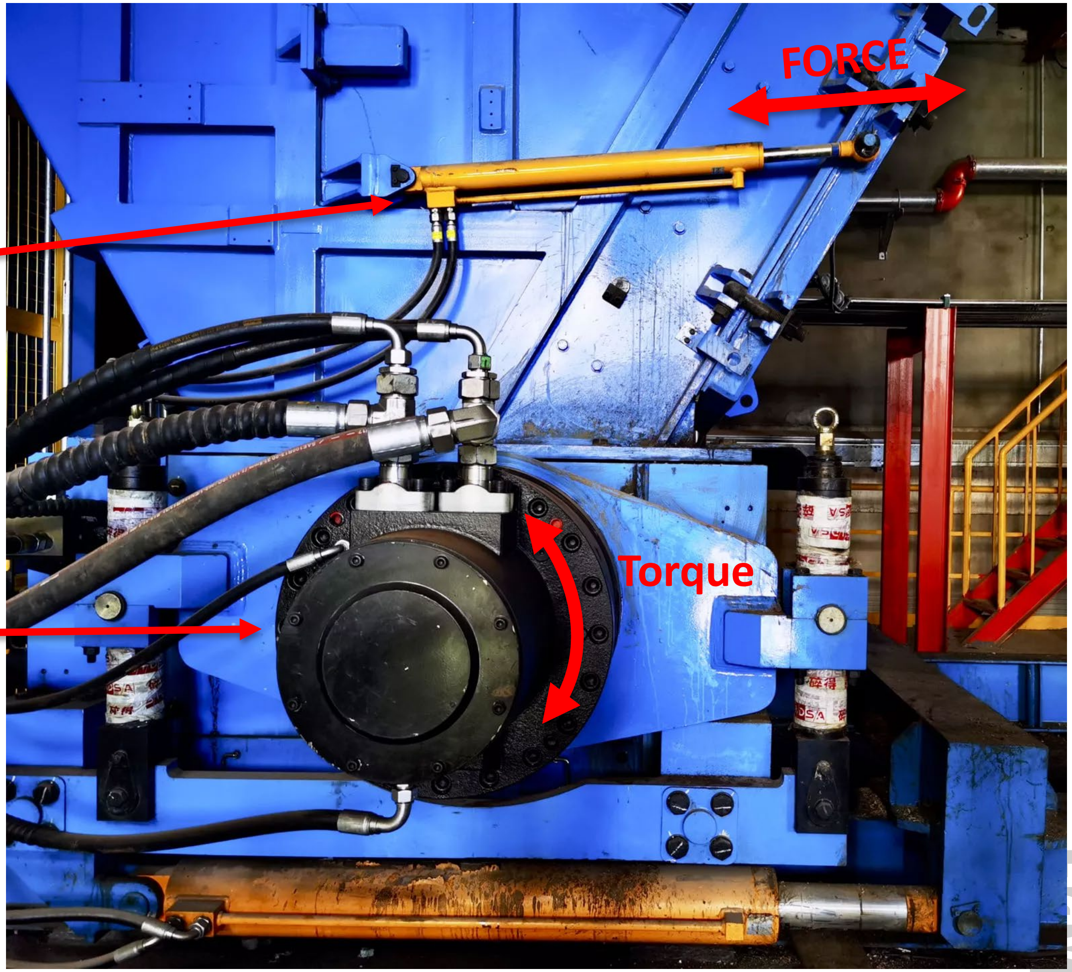
The Hydraulic Actuator

The hydraulic actuator is the device in the hydraulic system that converts the hydraulic energy from the pump into mechanical energy, acting on the load.

There are two classes of hydraulic actuators

Linear actuators: Cylinders
Produce force in a straight line motion

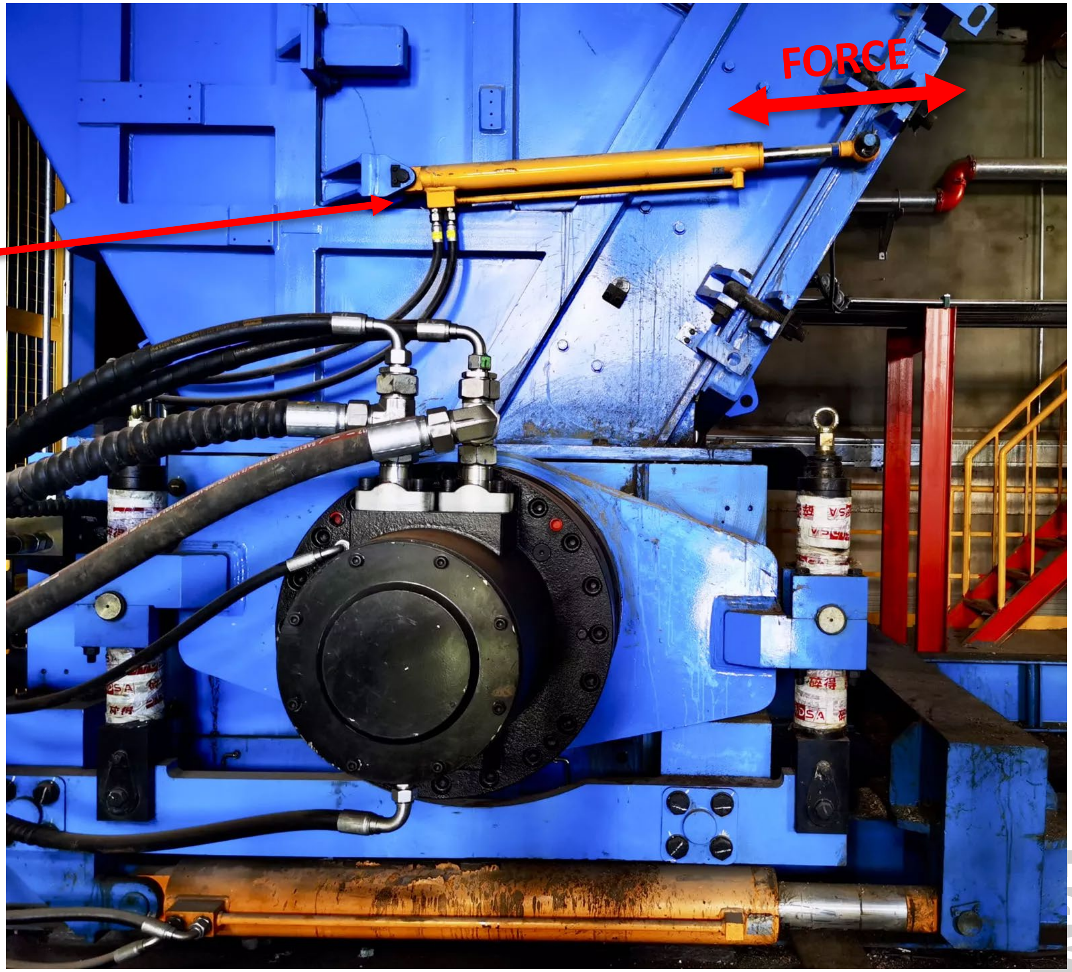
Rotary actuators: Motors
Produce torque in a rotational motion



https://www.blackbruin.com/

The Hydraulic Cylinder

Linear actuators: Cylinders
Produce force in a straight line motion



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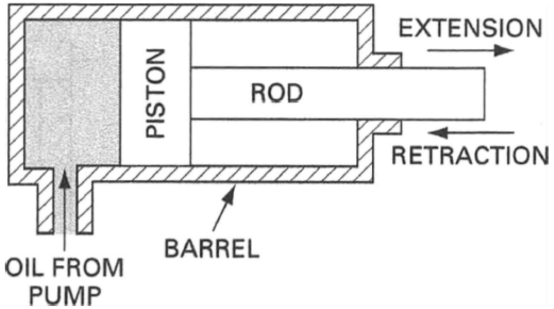
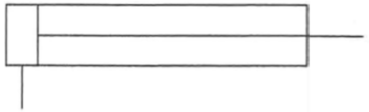
6.2 Single Acting Cylinders

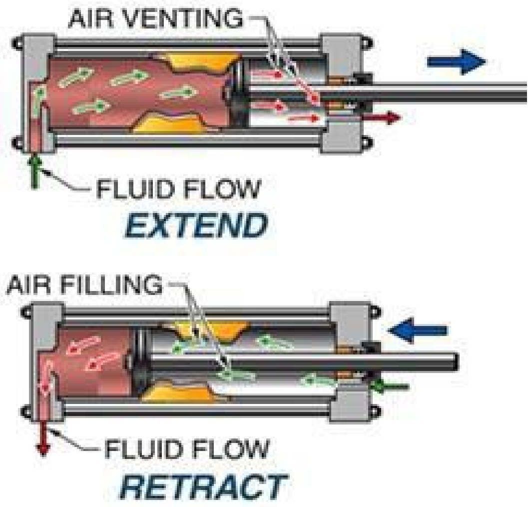
The simplest cylinder is the **single acting cylinder** which provides actuation in one direction, **extension**, and relies on gravity or an enclosed spring to retract the cylinder

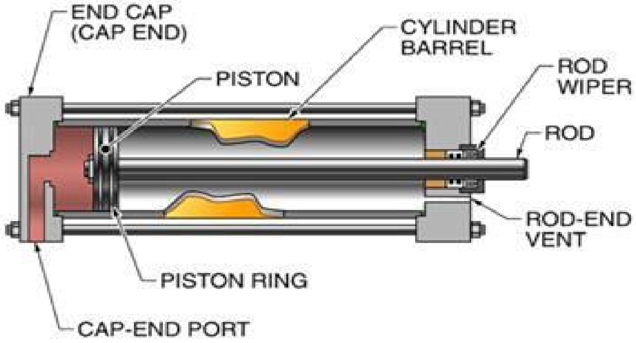


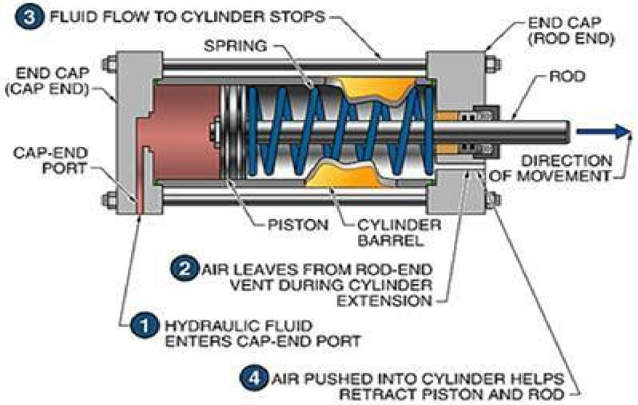
Single acting schematic symbol



Single acting with spring return schematic symbol



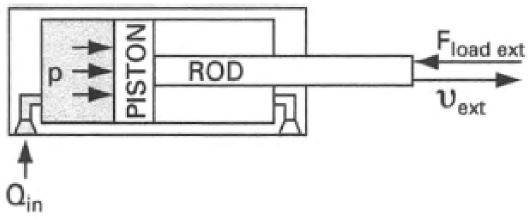


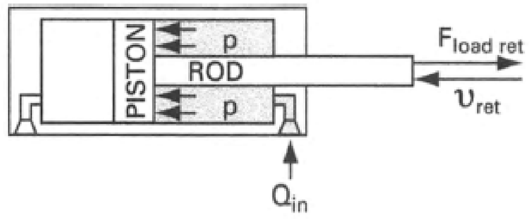


https://www.llmhandling.co.uk/category/scissor-lift-tables/static-hydraulic-lift-tables/

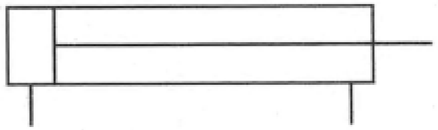
6.2 Double Acting Cylinders

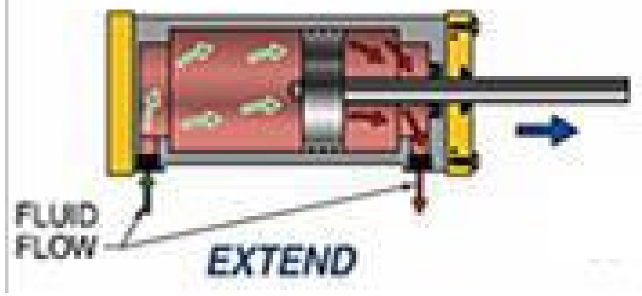
A **double acting cylinder** provides actuation in both directions, **extension and retraction , controlled by a control valve**

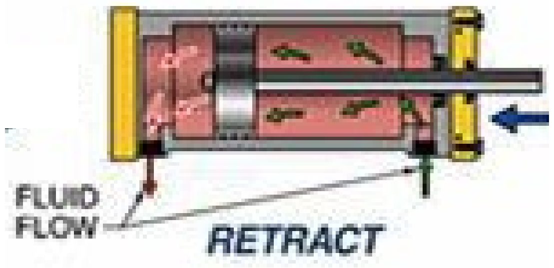




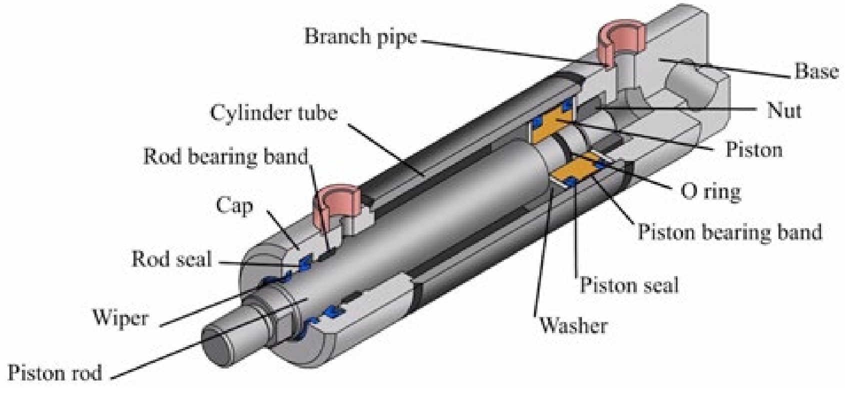
Double acting schematic symbol





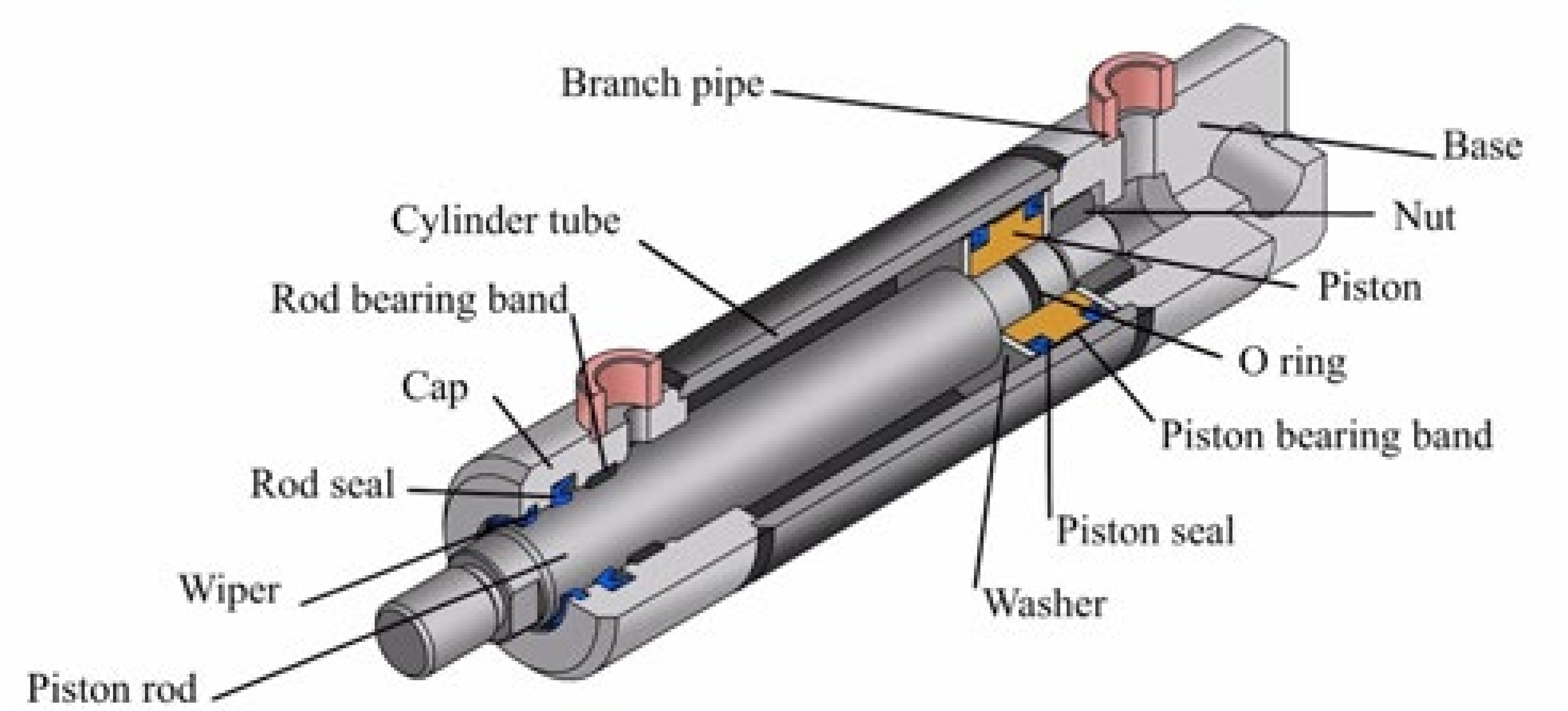


https://www.mecamaq.com/en/



https://www.yatesind.com/what-is-a-hydraulic-cylinder

6.2 Double Acting Cylinders



https://www.yatesind.com/what-is-a-hydraulic-cylinder

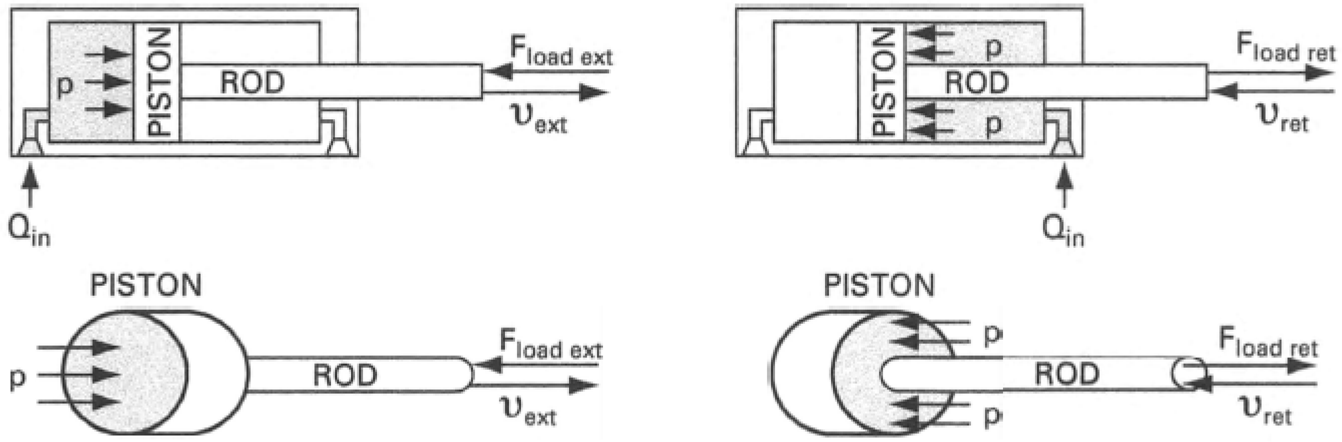
6.4 Cylinder Force

When pressurized hydraulic fluid is input to the cylinder, the fluid acts upon the surface area of the piston and produces a force

$$F_{ext}(\text{lb}) = p(\text{psi}) \times A_p(\text{in}^2)$$

And this results in the movement of the piston at a certain speed

$$v_{ext}(\text{ft/s}) = \frac{Q_{in}(\text{ft}^3/\text{s})}{A_p(\text{ft}^2)}$$



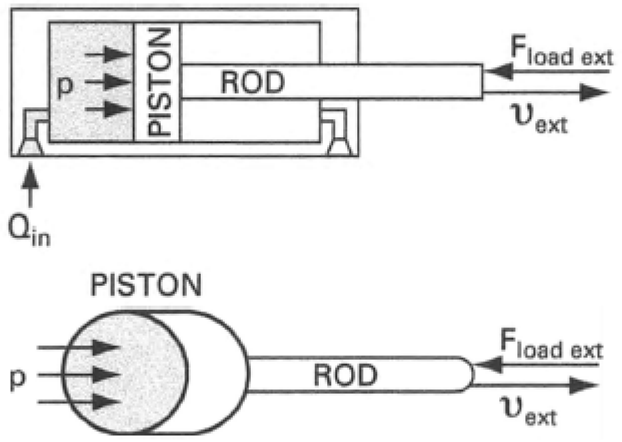
6.4 Cylinder Force

As can be seen, the area of the piston exposed during extension is larger than the area during retraction due to the presence of the rod, thus the force *F* and speed *v* are reduced

During Extension

$$F_{ext}(\text{lb}) = p(\text{psi}) \times A_p(\text{in}^2)$$

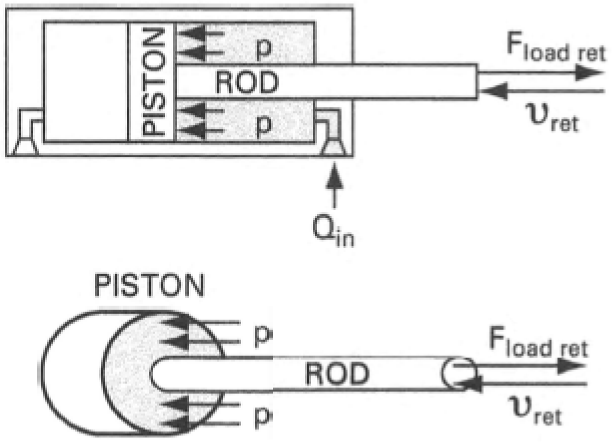
$$v_{ext}(\text{ft/s}) = \frac{Q_{in}(\text{ft}^3/\text{s})}{A_p(\text{ft}^2)}$$



During Retraction

$$F_{ret}(\text{lb}) = p(\text{psi}) \times (A_p - A_r)\text{in}^2$$

$$v_{ret}(\text{ft/s}) = \frac{Q_{in}(\text{ft}^3/\text{s})}{(A_p - A_r)\text{ft}^2}$$



A_p is the area of the piston
A_r is the area of the rod

6.4 Cylinder Power

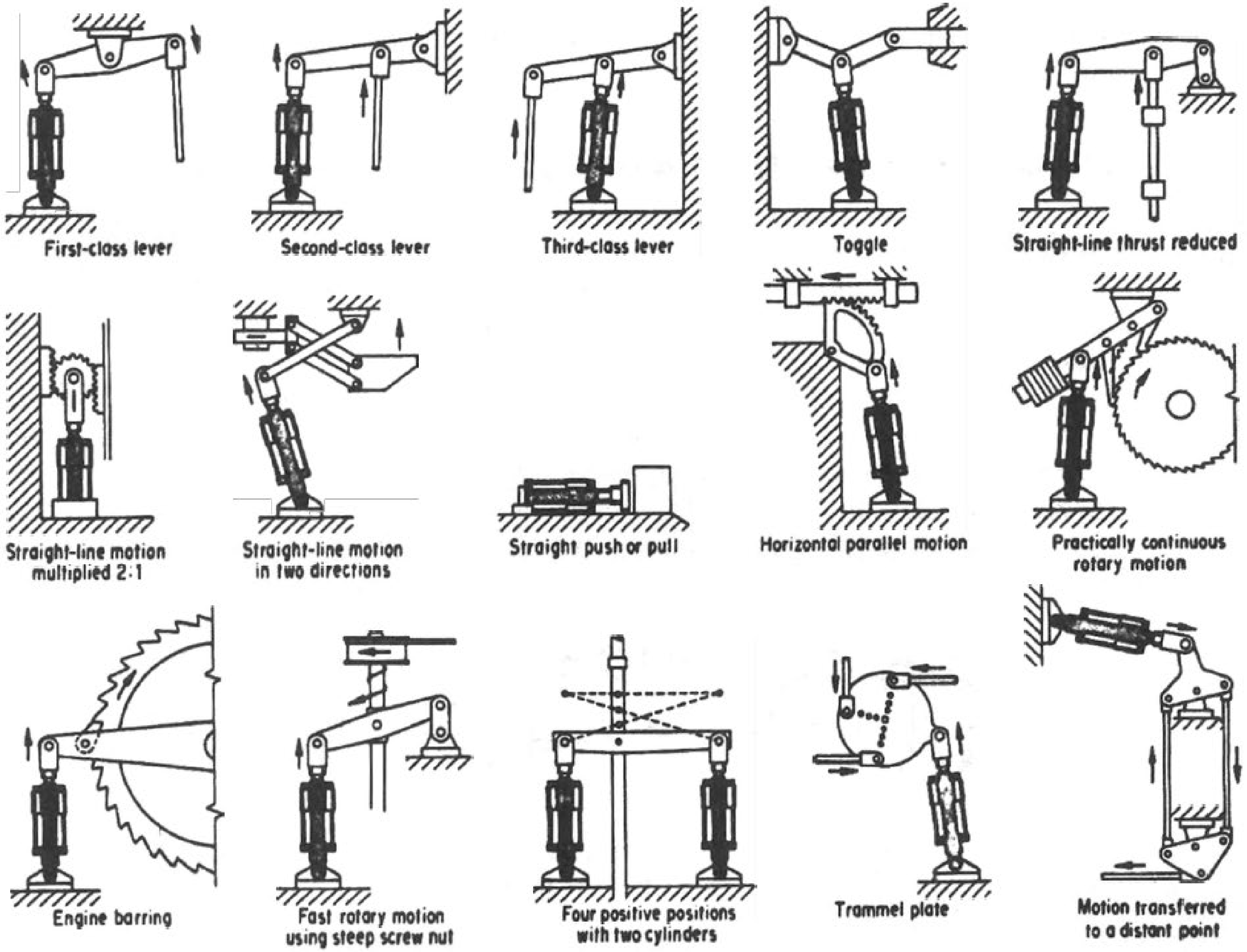
The cylinder converts input hydraulic power to output mechanical power

Mechanical HP　　　Hydraulic HP

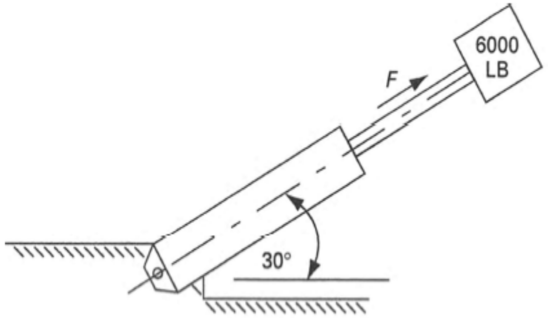
$$\text{Power (HP)} = \frac{v_p(\text{ft/s}) \times F(\text{lb})}{550} = \frac{Q_{in}(\text{gpm}) \times p(\text{psi})}{1714}$$

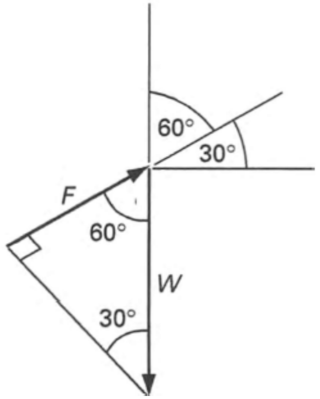
This assumes 100% efficiency, but mechanical friction and fluid leakage must also be considered

6.4 Cylinder Sample Configurations



The physical configuration and mechanics of the system must be considered when computing the forces





6.4 Cylinder Force and Power

Example: A pump supplies oil at 20 gpm to a 2-in-diameter double-acting hydraulic cylinder. If the load is 1000 lb (extending and retracting) and the rod diameter is 1 in, find

a. The hydraulic pressure during the extending stroke
b. The piston velocity during the extending stroke
c. The cylinder horsepower during the extending stroke
d. The hydraulic pressure during the retraction stroke
e. The piston velocity during the retraction stroke
f. The cylinder horsepower during the retraction stroke

a.
$$p_{ext} = \frac{F_{ext}(\mathrm{lb})}{A_p(\mathrm{in}^2)} = \frac{1000}{(\pi/4)(2)^2} = \frac{1000}{3.14} = 318 \text{ psi}$$

b.
$$v_{ext} = \frac{Q_{in}(\mathrm{ft}^3/\mathrm{s})}{A_p(\mathrm{ft}^2)} = \frac{20/449}{3.14/144} = \frac{0.0446}{0.0218} = 2.05 \text{ ft/s}$$

c.
$$\mathrm{HP}_{ext} = \frac{v_{ext}(\mathrm{ft/s}) \times F_{ext}(\mathrm{lb})}{550} = \frac{2.05 \times 1000}{550} = 3.72 \text{ hp}$$

or
$$\mathrm{HP}_{ext} = \frac{Q_{in}(\mathrm{gpm}) \times p_{ext}(\mathrm{psi})}{1714} = \frac{20 \times 318}{1714} = 3.72 \text{ hp}$$

d.
$$p_{ret} = \frac{F_{ret}(\mathrm{lb})}{(A_p - A_r)\mathrm{in}^2} = \frac{1000}{3.14 - (\pi/4)(1)^2} = \frac{1000}{2.355} = 425 \text{ psi}$$

Therefore, as expected, more pressure is required to retract than to extend the same load due to the effect of the rod.

e.
$$v_{ret} = \frac{Q_{in}(\mathrm{ft}^3/\mathrm{s})}{(A_p - A_r)\mathrm{ft}^2} = \frac{0.0446}{2.355/144} = 2.73 \text{ ft/s}$$

Hence, as expected (for the same pump flow), the piston retraction velocity is greater than that for extension due to the effect of the rod.

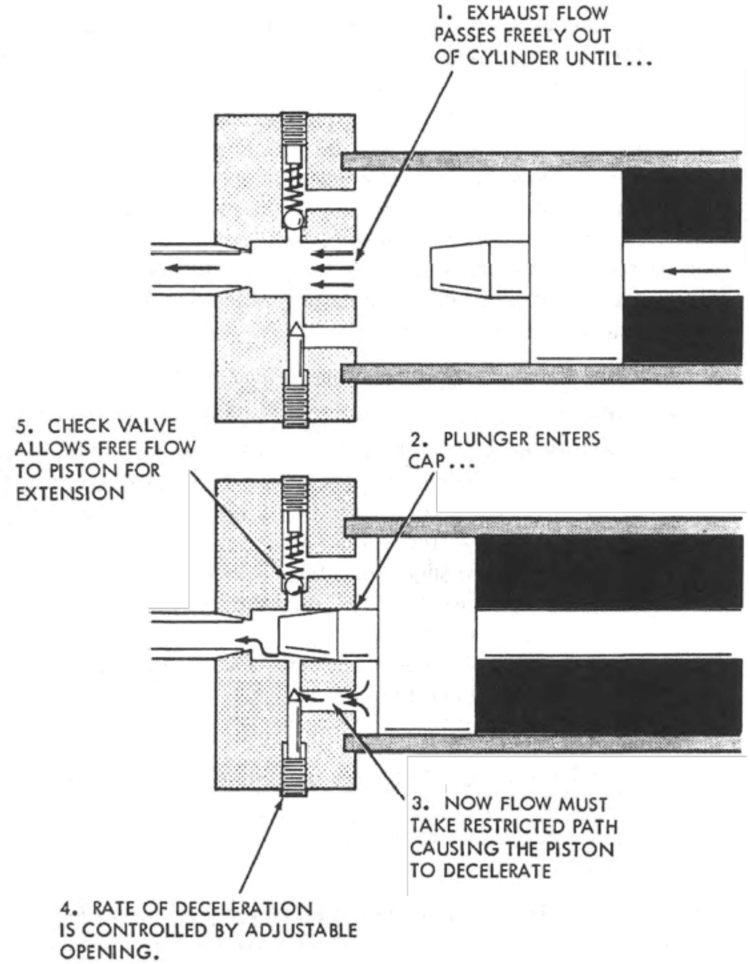
f.
$$\mathrm{HP}_{ret} = \frac{v_{ret}(\mathrm{ft/s}) \times F_{ret}(\mathrm{lb})}{550} = \frac{2.73 \times 1000}{550} = 4.96 \text{ hp}$$

or
$$\mathrm{HP}_{ret} = \frac{Q_{in}(\mathrm{gpm}) \times p_{ret}(\mathrm{psi})}{1714} = \frac{20 \times 425}{1714} = 4.96 \text{ hp}$$

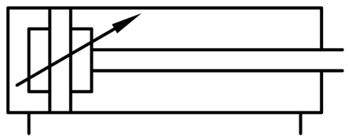
Thus, more horsepower is supplied by the cylinder during the retraction stroke because the piston velocity is greater during retraction and the load force remained the same during both strokes. This, of course, was accomplished by the greater pressure level during the retraction stroke. Recall that the pump output flow rate is constant, with a value of 20 gpm.

6.8 Cylinder Cushioning

To prevent the impact force when a cylinder reaches end of travel, **cushioning devices** may be employed to decelerate the cylinder to a stop

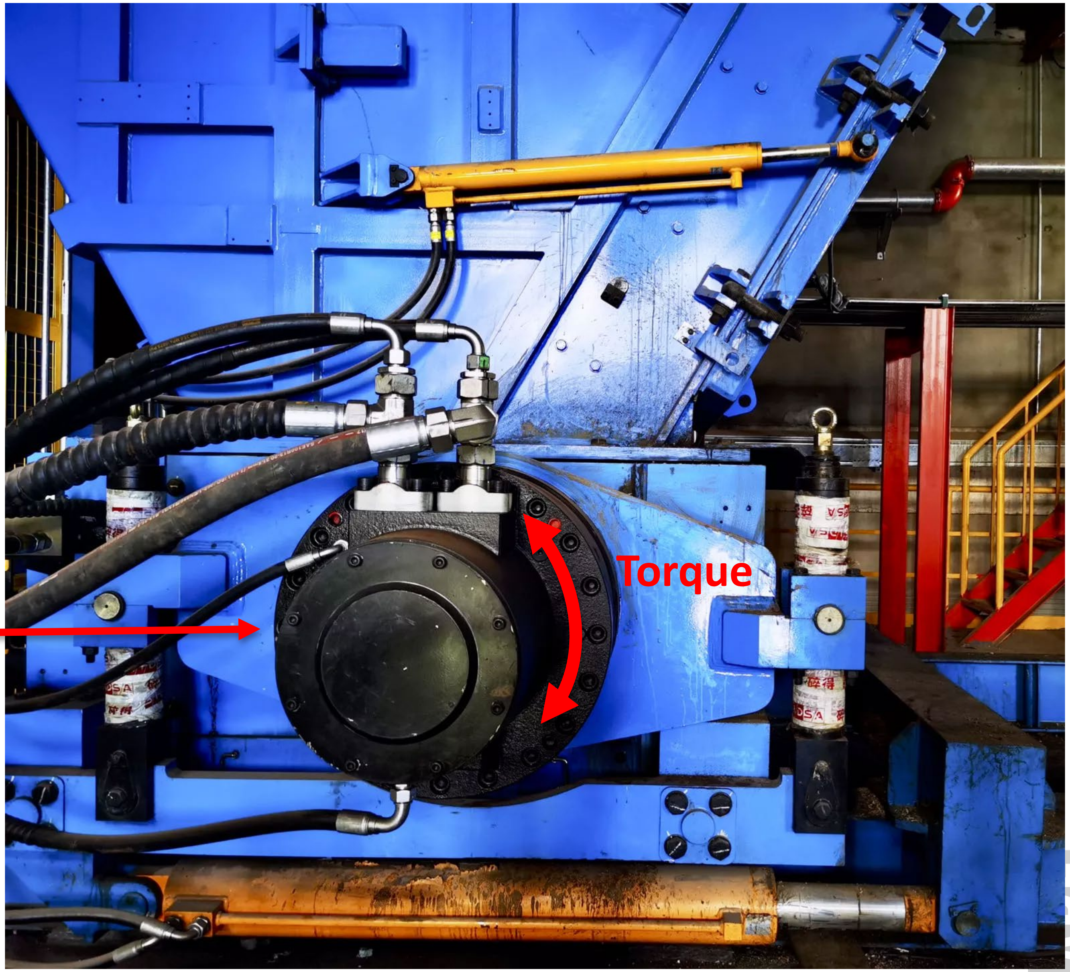


Double acting, with adjustable cushioning schematic symbol



The Hydraulic Motor

Rotary actuators: Motors
Produce torque in a rotational motion



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7.1 Hydraulic Motor

The hydraulic motor converts input hydraulic power to output rotary mechanical power
They are well suited for low speed, high torque applications

Industrial applications
Driving conveyors
Winches
Machine tool positioning
Hand tools

https://www.conveyor-manufacturer.com/roller-conveyor-R121127.html

Mobile applications
Rotating the body of an excavating machine
Vehicle drive systems
Driving farm machinery
Driving boring tools in mining equipment
Hydrostatic transmission systems

https://www.frisianmotors.com/en/shop/fm-120-mowing-deck-hydraulic-driven-circle-mower/

https://poclain-hydraulics.com/systems/traction-control-electronic-antiskid-system

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7.1 Motor Classifications

Displacement is the volume of oil required to rotate the motor one revolution (in^3/ rev.)

Displacement is inversely proportional to speed, v

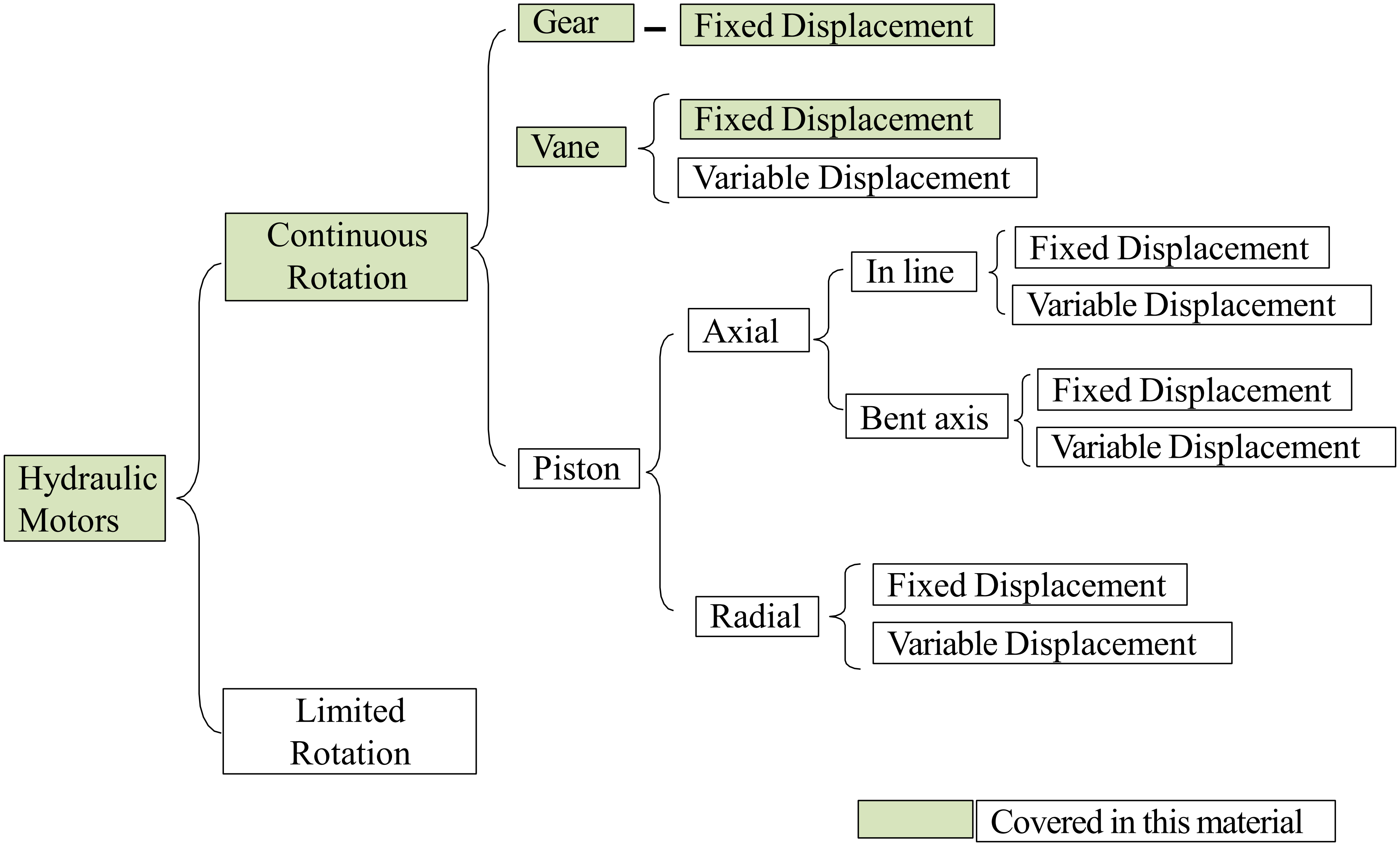
Displacement is proportional to torque, τ

Hydraulic Motors

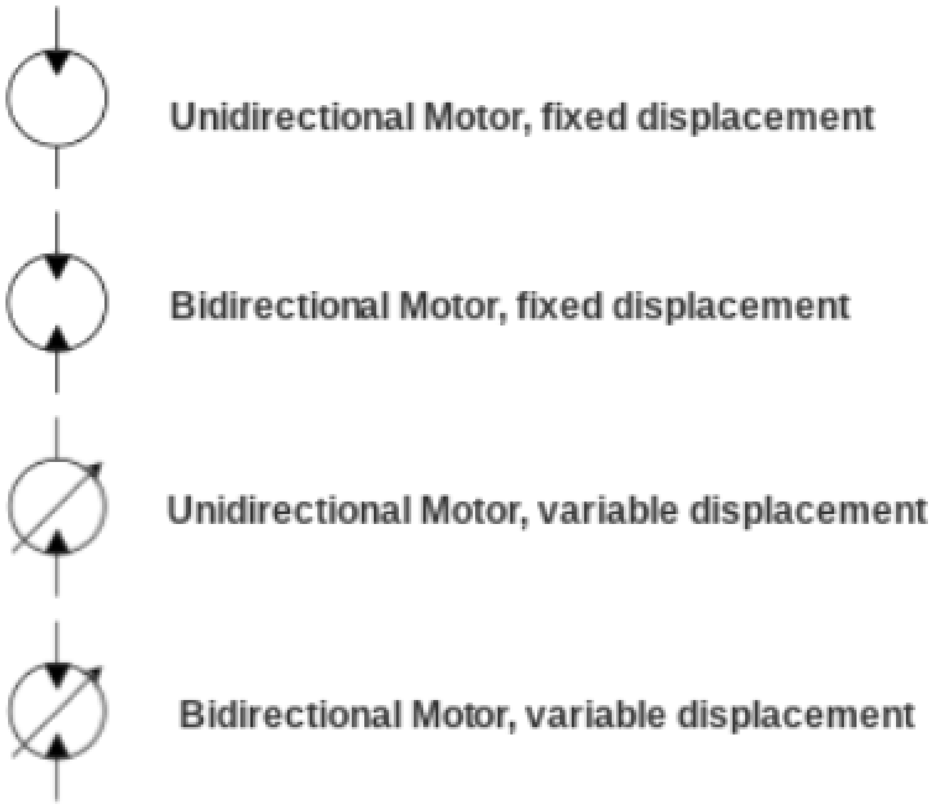
- Continuous Rotation — Rotates continuously
  - Fixed Displacement — The internal motor volume is not adjustable
  - Variable Displacement — The internal motor volume is adjustable
- Limited Rotation — Rotates forward/backward in a limited range

Covered in this material

7.1 Motor Classifications



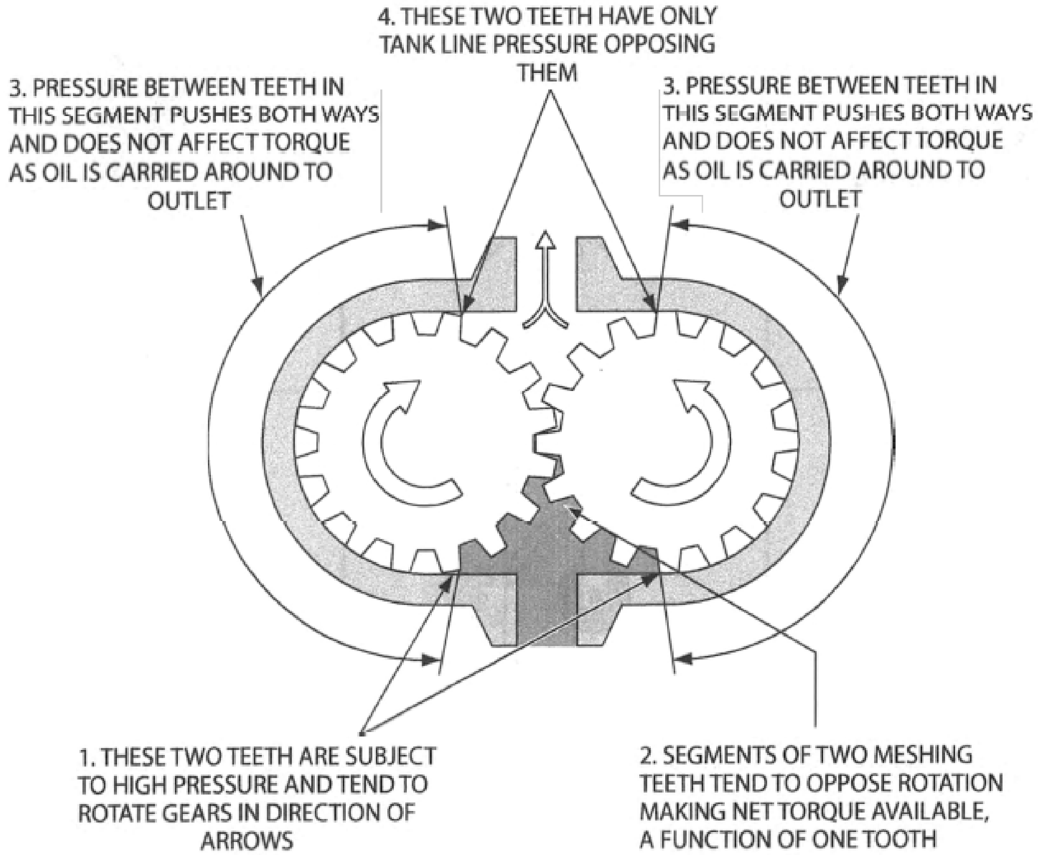
7.1 Motor Symbols

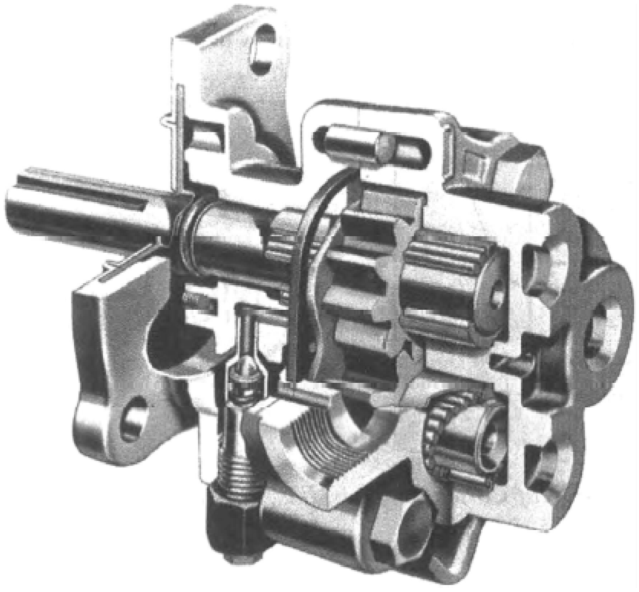


https://info.texasfinaldrive.com/shop-talk-blog/glossary-of-basic-symbols-found-in-hydraulic-circuits

7.3 Gear Motor

The hydraulic gear motor is the most common hydraulic motor
- simple design
- high tolerance to oil contamination
- least efficient (70-75%)
- lowest pressure rating

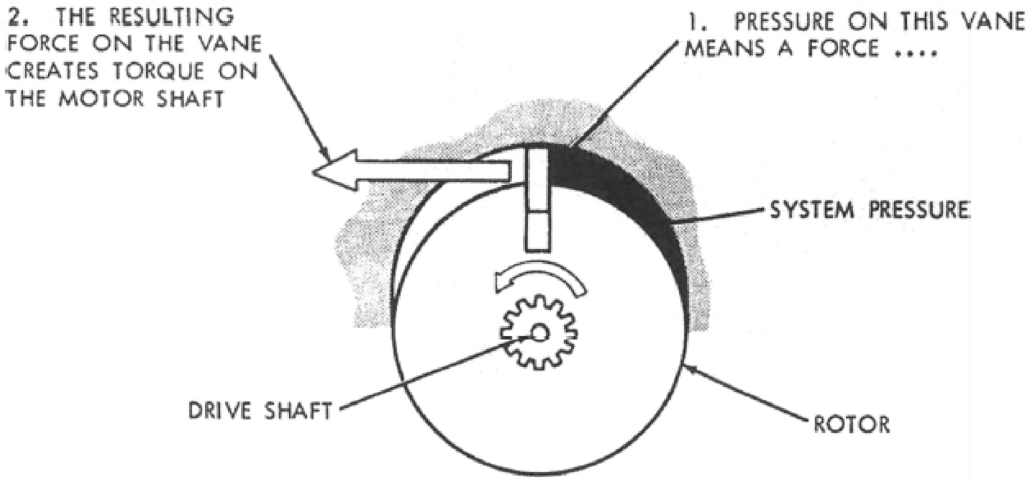


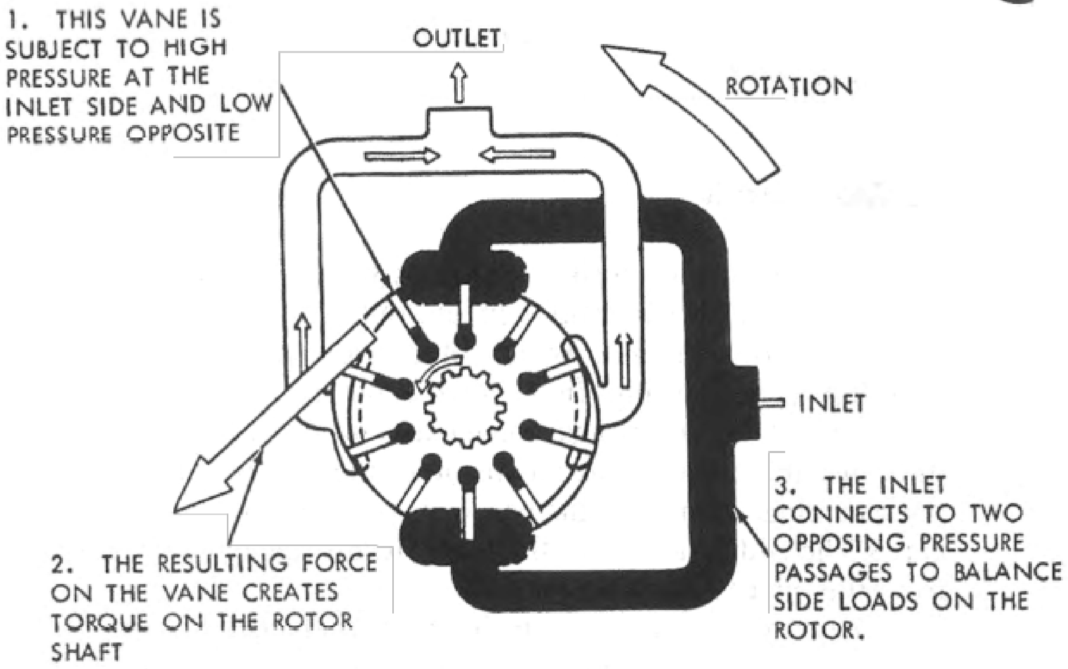


External Gear Motor

7.4 Vane Motor

The hydraulic vane motor works by the hydraulic pressure acting on the vanes
-Medium efficiency (75-85%)
-lower tolerance to oil contamination
-are always balanced to manage the internal side loads created





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7.6 Hydraulic Power

The motor converts input hydraulic power to output mechanical power

The theoretical torque (T_T) that a motor produces is

$$T_T(\text{in}\cdot\text{lb}) = \frac{V_D(\text{in}^3/\text{rev}) \times p(\text{psi})}{2\pi}$$

Resulting in a theoretical mechanical power (HP_T) of

$$\text{HP}_T = \frac{T_T(\text{in}\cdot\text{lb}) \times N(\text{rpm})}{63{,}000}$$

$$= \frac{V_D(\text{in}^3/\text{rev}) \times p(\text{psi}) \times N(\text{rpm})}{395{,}000}$$

The theoretical flow rate (Q_T) required to produce this torque is

$$Q_T(\text{gpm}) = \frac{V_D(\text{in}^3/\text{rev}) \times N(\text{rpm})}{231}$$

7.6 Hydraulic Power

Example: A hydraulic motor has a 5-in^3 volumetric displacement. If it has a pressure rating of 1000 psi and it receives oil from a 10-gpm theoretical flow-rate pump, find the motor

a. Speed

b. Theoretical torque

c. Theoretical horsepower

a. From Eq. (7-6) we solve for motor speed:

$$N = \frac{231 Q_T}{V_D} = \frac{(231)(10)}{5} = 462 \text{ rpm}$$

b. Theoretical torque is found using Eq. (7-4):

$$T_T = \frac{V_D p}{2\pi} = \frac{(5)(1000)}{2\pi} = 795 \text{ in} \cdot \text{lb}$$

c. Theoretical horsepower is obtained from Eq. (7-5):

$$\text{HP}_T = \frac{T_T N}{63{,}000} = \frac{(795)(462)}{63{,}000} = 5.83 \text{ HP}$$

7.7 Motor Performance

Motor performance is a measure of the efficiency of the motor

How well does the pump convert input hydraulic fluid power to mechanical power

$$overall\ efficiency = \frac{actual\ power\ delivered\ by\ the\ motor}{actual\ power\ delivered\ to\ the\ motor}$$

The overall efficiency η_o is a function of the volumetric efficiency η_v and the mechanical efficiency η_m

$$\eta_o = \eta_v \times \eta_m$$

7.7 Volumetric Efficiency

Volumetric efficiency η_v indicates the amount of leakage that takes place within the motor

Considering factors such as

Manufacturing tolerances

flexing of the pump casing

$$\eta_v = \frac{\text{theoretical flow-rate motor should consume}}{\text{actual flow-rate consumed by motor}} = \frac{Q_T}{Q_A}$$

Q_T is the theoretical motor flow rate

Q_A is the actual motor flow rate

Note: this is in inverse to a pump, because a motor consumes *more* oil than theoretical due to leakages within the motor

7.7 Mechanical Efficiency

Mechanical efficiency η_m indicates the amount of energy loss (other than leakage) that takes place within the motor

Considering factors such as

friction between other moving surfaces (e.g. bearings)

fluid turbulence

$$\eta_m = \frac{\text{actual torque delivered by motor}}{\text{torque motor should theoretically deliver}} = \frac{T_A}{T_T}$$

$$T_T(\text{in} \cdot \text{lb}) = \frac{V_D(\text{in}^3) \times p(\text{psi})}{2\pi}$$

$$T_A(\text{in} \cdot \text{lb}) = \frac{\text{actual HP delivered by motor} \times 63{,}000}{N(\text{rpm})}$$

Note: this is in inverse to a pump, because a motor requires *more* torque than theoretical due to friction of moving parts within the motor

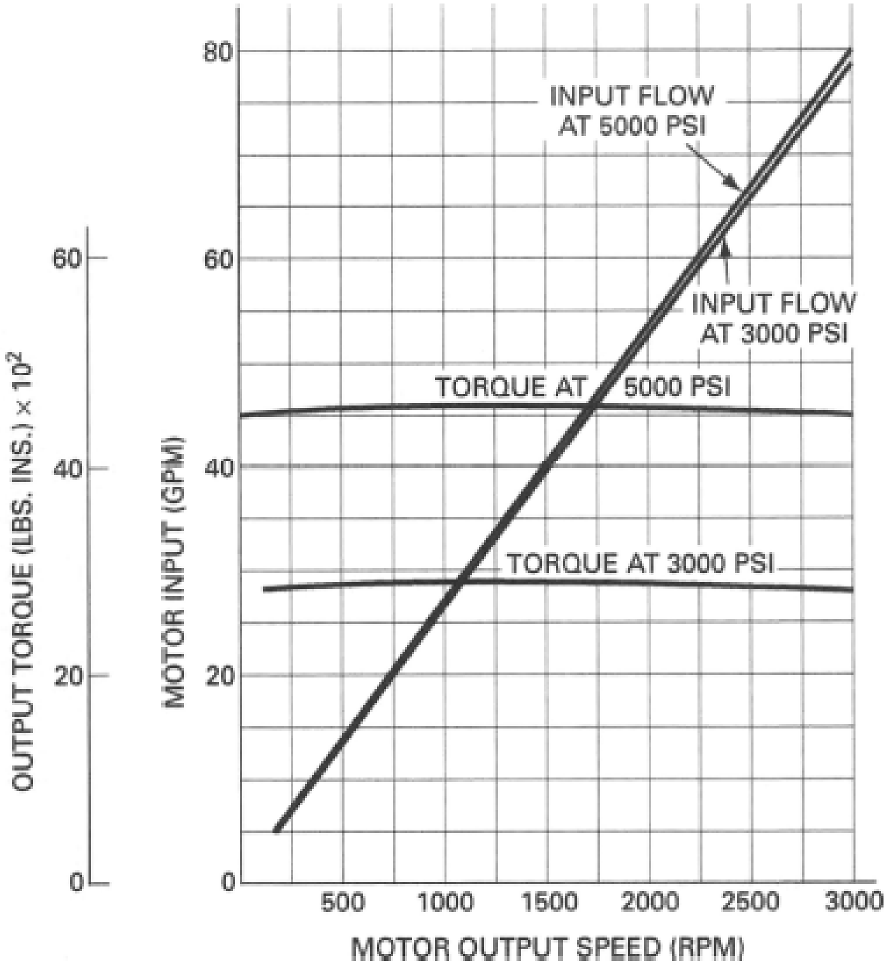
7.7 Overall Efficiency

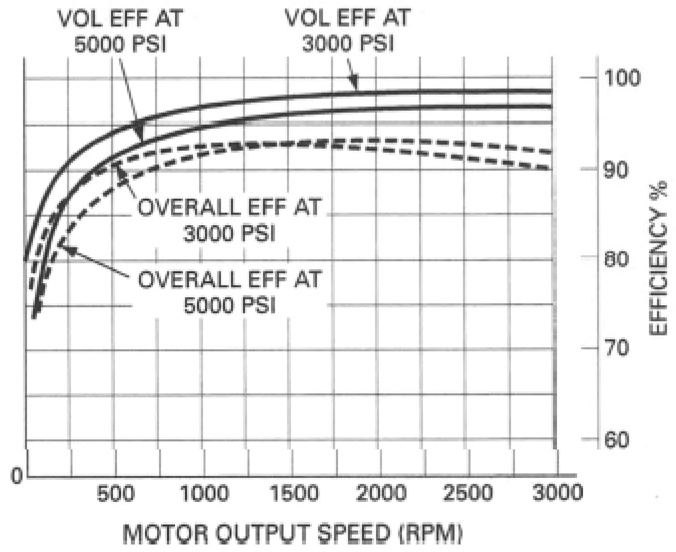
$$overall\ efficiency = \frac{actual\ power\ delivered\ by\ the\ motor}{actual\ power\ delivered\ to\ the\ motor} = \frac{brake\ power}{hydraulic\ power}$$

$$\eta_o = \frac{\dfrac{T_A(\text{in}\cdot\text{lb}) \times N(\text{rpm})}{63{,}000}}{\dfrac{p(\text{psi}) \times Q_A(\text{gpm})}{1714}}$$

p is the motor input pressure (psi)
Q_A is the motor input flow rate (gpm)
T_A is the actual torque crated by the motor (in-lb)
N is the motor speed (rpm)

7.7 Motor Performance





Performance curves for a 6 -in^3 variable displacement motor, from Abex Corp.

<u>Observations</u>

Output torque is fairly constant as speed varies. Torque depends only on pressure and displacement, not speed.

Flow rate increases linearly with motor speed

Efficiency peaks at mid-range speeds and drops off at low and high speeds

7.7 Motor Performance

Example: A hydraulic motor has a displacement of 10 in^3 and operates with a pressure of 1000 psi and a speed of 2000 rpm. If the actual flow rate consumed by the motor is 95 gpm and the actual torque delivered by the motor is 1500 in • lb, find

a. η_v

b. η_m

c. η_o

d. The actual horsepower delivered by the motor

a. To find η_v, we first calculate the theoretical flow rate:

$$Q_T = \frac{V_D N}{231} = \frac{(10)(2000)}{231} = 86.6 \text{ gpm}$$

$$\eta_v = \frac{Q_T}{Q_A} = \frac{86.6}{95} = 0.911 = 91.1\%$$

b. To find η_m, we need to calculate the theoretical torque:

$$T_T = \frac{V_D p}{2\pi} = \frac{(10)(1000)}{2\pi} = 1592 \text{ in} \cdot \text{lb}$$

$$\eta_m = \frac{T_A}{T_T} = \frac{1500}{1592} = 0.942 = 94.2\%$$

c. $$\eta_o = \eta_v \eta_m = 0.911 \times 0.942 = 0.858 = 85.8\%$$

d. $$\text{HP}_A = \frac{T_A N}{63{,}000} = \frac{(1500)(2000)}{63{,}000} = 47.6 \text{ hp}$$

Chapter Reading

Chapter 6

6.3, 6.5, 6.6, 6.7, 6.9

Chapter 7

7.2, 7.5, 7.8, 7.9