Chapter 2 Basic units, terms and definitions for fluid power applications

2.1 Introduction

The objective of this Chapter is to simply define some nomenclature and terms that are often used in hydraulics and fluid power. Some of these terms are very obvious but seeing how they are expressed unit wise in the SI and English system is very useful.

2.1.1 <u>Pressure and force</u>

Consider the linear actuator:

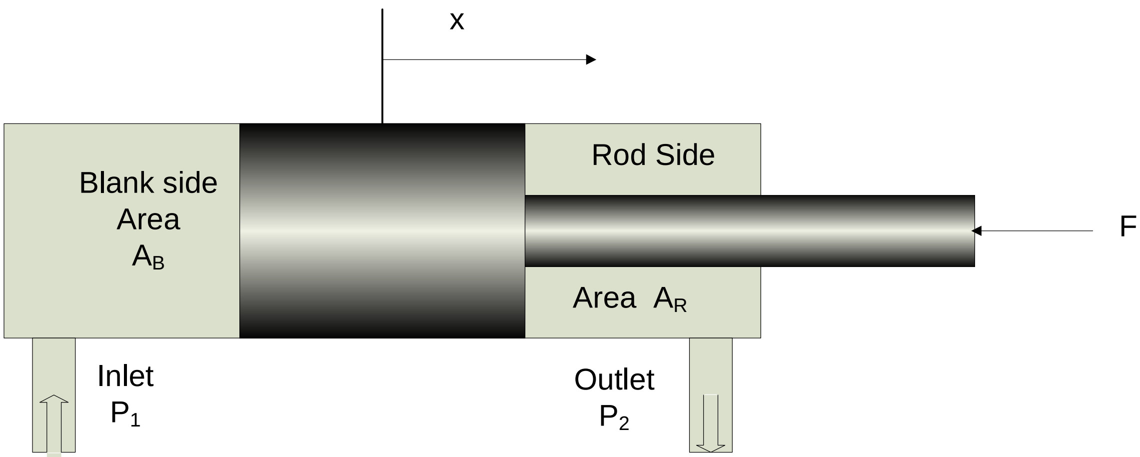

Figure 2.1 Linear actuator (Force)

The basic relationship between pressure and force is

P*A = F

For the single rod actuator, the force equation becomes:

$$P_1 \ A_B - P_2 \ A_R = F$$

where F is the sum of all forces that act on the rod internal to the actuator (friction for example) and external to the actuator (inertial effects, external friction, external loads such as gravity etc.)

If $A_R = A_B$, that is a double rod cylinder, then the force equation becomes

$$(P_1 - P_2)A_B = F$$

Units

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Force Newtons (N)	lb_f
Pressure N/m^2, Pa, MPa. Bars (.1MPa)	psi, Bars (14.7 psi)

Conversion
1000 psi = 6.895 MPa = .069 Bars

2.1.2 Flow and velocity

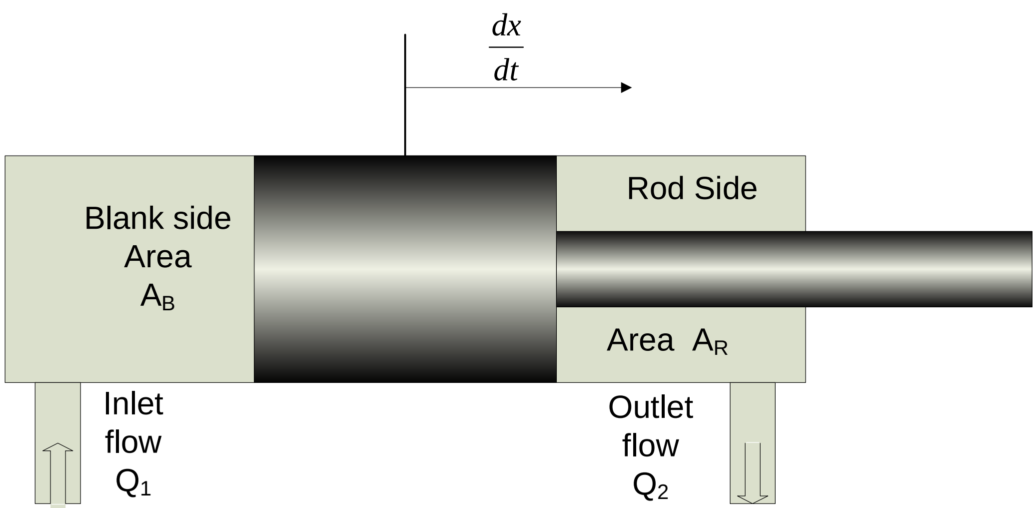

Figure 2.2 Linear actuator (Flows)

The general relationship between flow and velocity is

$$Q = A\frac{dx}{dt}$$

For the single rod actuator, flow into the actuator is related to the velocity by: $Q_1 = A_B \frac{dx}{dt}$	Flow out of the actuator is related to the velocity by: $Q_2 = A_R \frac{dx}{dt}$

For a double rod actuator, $A_B = A_R = A$ and hence

$$Q_1 = Q_2 = A\frac{dx}{dt}$$

Units

Velocity m/sec, m/min	ft/sec, in/sec
Flow l/min, l/sec, m^3/min,m^3/sec	gpm(US), in^3/min, in^3/sec

Conversion

1 gpm = 231in^3/min = .00379m^3/min
= 3.79l/min
1l/min = .263gpm(US)

2.1.3 Pressure and Torque

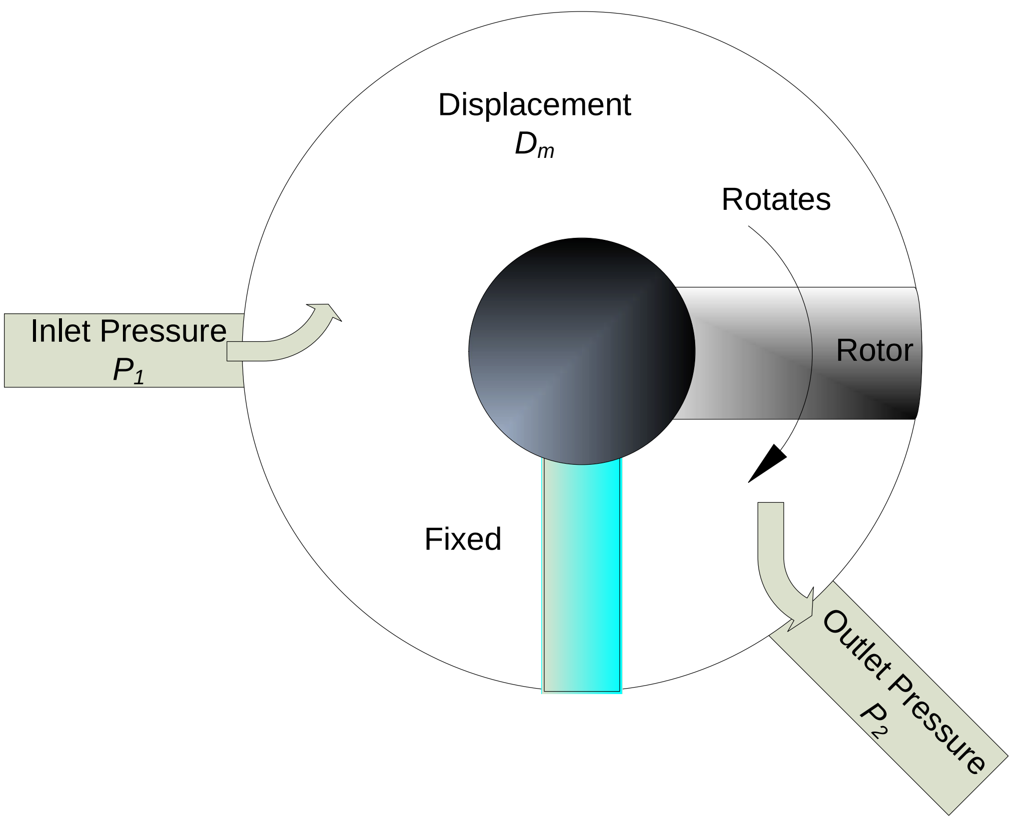

Figure 2.3 Rotary actuator (Torque considerations)

For rotary actuators, the linear "area" we see in a linear actuator is replaced by a term defined as the displacement "D_m" which is defined as the total volume of fluid displaced per revolution. Rotary actuators behave like symmetrical (double rod) linear actuators in that the "area" on either side of the rotor is the same.

We know that torque is the product of a force times a moment arm (F*r). Since pressure is force times the surface area of the rotor, the relationship between pressure and torque becomes:

$$Torque = P_{pressure\ drop\ across\ the\ rotor} * A_{rotor} * moment\ arm$$

But this is not a convenient way to express this. So manufactures specify a term for rotary actuators, pumps or motors in terms of the displacement D_m and the relationship is given by:

$$\text{Torque} = (P_1 - P_2) * D_m$$

However, we must be very careful here. D_m is defined as volume per revolution, which in this equation means that our units will not cancel out. To show this, consider:

$Torque\ (Nm) \equiv pressure\ (\frac{N}{m^2}) * D_m\ (\frac{m^3}{rev})$ which does not give us the right units because the units of revolutions does not cancel out. Thus we must modify our equation somewhat to reflect that we want volume per radians (that is 2π rad = 1 revolution)

$$Torque\ (Nm) \equiv pressure\ (\frac{N}{m^2}) * D_m\ (\frac{m^3}{rev}) \frac{rev}{2\pi\ rad}$$

$$Torque\ (Nm) = \frac{(P_1 - P_2) D_m}{2\pi} (Nm)$$

Units

Torque Nm	ft lb_f, in lb_f
Displacement m^3/rev l/rev m^3/rad m^3/rev	in^3/rev in^3/rad

Conversion
1 Nm = 1.356 ft lb_f
1 l/rev = .001m^3/rev = 61.02545 in^3/rev
1 in^3/rev = 0.01639 l/rev

2.1.4 Flow and angular velocity

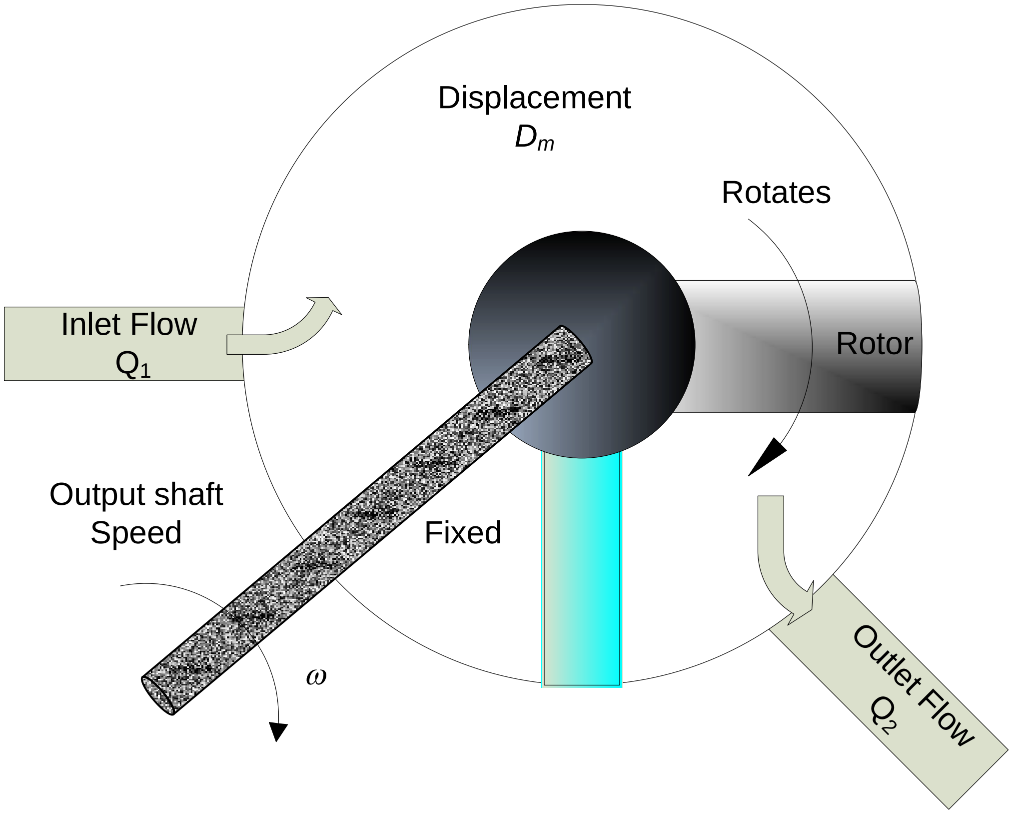

Figure 2.4 Flow and angular velocity for a rotary actuator (motor, pump)

Flow and the shaft angular velocity are also related by the displacement of the unit D_m. If the fluid compressibility effects are neglected, flow into and out of the rotary unit is given by:

$$Q_1 = D_m \ \omega$$

$$Q_1 (\frac{m^3}{\min}) = D_m \ (\frac{m^3}{rev}) \ \omega \ (\frac{rev}{\min})$$

Flow out of the rotary unit

$$Q_2 = D_m \ \omega$$

$$Q_2 (\frac{m^3}{\min}) = D_m \ (\frac{m^3}{rev}) \ \omega \ (\frac{rev}{\min})$$

$$Q_1 = Q_2 = Q = D_m \ \omega$$

Units

Angular Velocity metric rad/sec, rad/min, rev/sec, rev/min	English rad/sec, rad/min, rev/sec, rev/min

Conversion
1 rpm = 2 π rad/min

2.1.5 Work

Work is force times distance

Work = F*S

= $(P_1 \; A_1 - P_2 \; A_2) * x$ for a linear actuator, x being the displacement of the rod

≡ N *m (joules)

= $(P_1 - P_2) \; D_m * \theta$ for a rotary unit, θ being the angular displacement of the unit (in rads)

≡ $\frac{Nm}{rad} \; rad$

Units

Metric Work Nm (joules)	English Work ft lb_f

Conversion
1 Nm (or joule) = 1.356 ft lb_f

2.1.6 Energy

Energy = ability to do work and has the same units as work [Nm (Joules) or ft lb_f]

Units

Metric Work	English Work
Nm (joules)	ft lb_f

Conversion
1 Nm (or joule) = 1.356 ft lb_f

2.1.7 Power and Horsepower

Power = rate at which work is being done or rate at which energy is expended

$$= \frac{dW}{dt}\left(\frac{Nm}{\sec}\right)$$ which is called watts in the metric system

$$= \frac{dW}{dt}\left(\frac{ft\ lb_f}{\sec}\right)$$

Fluid power = pressure *flow

= P*Q

$$\equiv \frac{N}{m^2}\frac{m^3}{\sec} \equiv \frac{Nm}{\sec} \text{ or } \frac{ft\ lb_f}{\sec}$$ in the English system

Units

Metric Power	English Work
Nm/sec (watt)(or joules/sec)	ft lb_f / sec

Conversion
1 Nm/sec (watt)(or joule/sec) = 1.356 ft lb_f/sec

In Fluid Power applications, we usually specify power in terms of **horsepowe**r or **metric horsepower**.

For linear systems (in most common units):

Metric Horsepower = Force (N) *velocity (m/sec) / 746

$$= \frac{\text{Power (watts)}}{776}$$

English horsepower = Force (lb_f) *velocity (ft/sec)/550

$$= \frac{\text{Power} \left(\frac{ft\ lb_f}{\text{sec}}\right)}{550}$$

For rotary systems (in most common units):

Metric Horsepower = Torque (Nm)*angular velocity (rpm) / 7121

$$= \frac{\text{Power Nm rpm}}{7121}$$

English Horsepower = Torque (ft lb_f)*angular velocity (rpm) / 5252

$$= \frac{\text{Power } ft\ lb_f \text{ rpm}}{5252}$$

$$= \frac{\text{Power } in\ lb_f \text{ rpm}}{63025}$$

For fluid power systems, it is most convenient to express horsepower in terms of the **most common** units of pressure and flow:

$$\text{Fluid horsepower} = \frac{\text{pressure (MPa)} * \text{flow (l/min)}}{44.760}$$

$$= \frac{\text{pressure (psi)} * \text{flow (gpm(US))}}{1714}$$

Metric Horsepower	English Horsepower
$\frac{\text{pressure (N/m}^2\text{)} * \text{flow (l/min)}}{44.760}$ $\frac{\text{Pressure (bars)} * \text{flow (l/min)}}{600}$	$\frac{\text{pressure (psi)} * \text{flow (gpm(US))}}{1714}$