Brief Overview of Fluid Power

Chapter 1

(Material taken from Fluid Power Circuits and Controls, Cundiff, 2001)

Basic Circuits

- Most people have an intuitive concept of what at basic cylinder circuit or motor circuit would look like.
- Two mechanical parameters, torque (T) and shaft speed (N), are converted to two different fluid parameters, pressure (P) and flow (Q), using a pump. And then converted back to mechanical power.

Fluid Power Concept

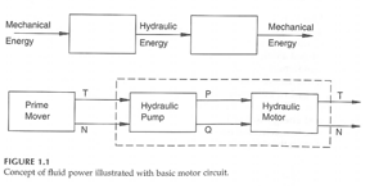


FIGURE 1.1
Concept of fluid power illustrated with basic motor circuit.

Gear Pump

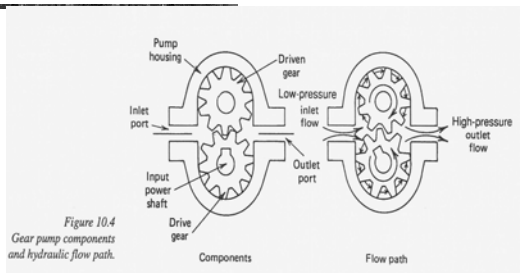
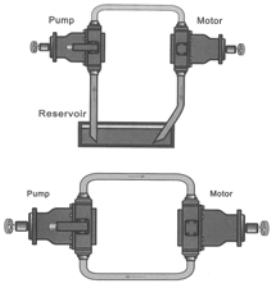


Figure 10.4 Gear pump components and hydraulic flow path.

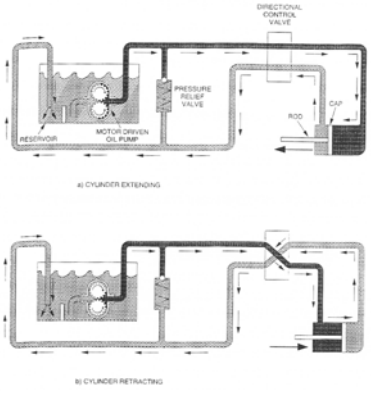
Kurtz, 1999, Machine Design for Mobile Applications

Pump Systems

- Open loop: provides cooling medium
- Closed Loop: temperature build up



Vickers, Mobile Hydraulics Manual



Lab-Volt, Hydraulic Trainer Manual

Review of Engineering Concepts

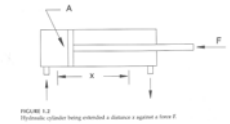
- Work done in a 1-min interval is:
  - Work = Force * Distance
  - Work = F * $2\pi rN = 2\pi TN$ (lb_f-in)
- Since power is the rate of doing work, the work done in 1 min is:
  - ***P*** = Work / t = $2\pi TN$ / 1 (lb_f-in/min)

Brief Review

- 1 horsepower is 33,000 lb_f-in / min, therefore:
  - hp = (P / 12) / 33,000
- If torque is expressed in lb_f-in and N is shaft speed in rpm, then power in hp is given by:
  - hp = $\frac{2\pi(T/12)N}{33{,}000}$
  - hp = TN / 63,025

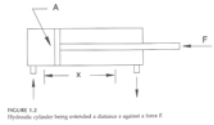
Basic Concept of Hydraulic Cylinder

- The distance moved is relative to the fluid volume delivered to the cylinder.
  - x = V / A
  - Where x = distance (in)
  - V = fluid volume (in^3)
  - A = area (in^2)

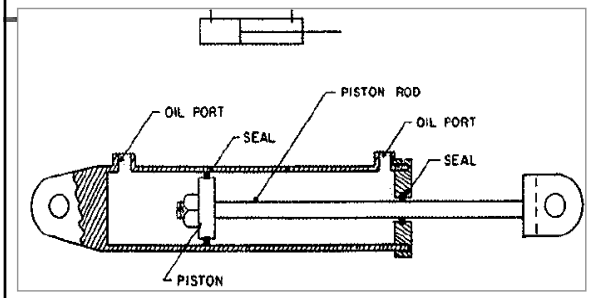


Basic Concept of Hydraulic Cylinder con't

- The force is related to the pressure developed at cap end.
  - F = pA
  - Where F = force (lb_f)
  - p = pressure (lb_f /in^2)
  - A = area (in^2)



Double-Acting Hydraulic Cylinder



Goering, 2003, Off-Road Vehicle Engineering Principles

Basic Concept of Hydraulic Cylinder con't

- Work done is given by:
  - Work = F_x
  - Work = (pA) (V / A) = pV
- Power is work per unit time
  - Power = pV / t

Basic Concept of Hydraulic Cylinder con't

- Flow is defined as volume per unit time, Q = V / t; therefore,
  - Power = pQ
- Mechanical power= T * N
- Hydraulic power = p * Q

Basic Concept of Hydraulic Cylinder con't

- The units used for pressure are typically lb_f/in^2, or psi, and the units of flow are gal/min, or GPM.
- To obtain hydraulic power with units of lb_f-ft/min:
  - P_{hyd}= 231pQ / 12
  - Where P_{hyd} = hydraulic power (lb_f-ft/min)
  - p = pressure (psi)
  - Q = flow (GPM)

Basic Concept of Hydraulic Cylinder con't

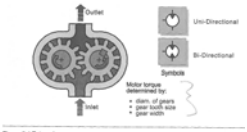
- To obtain hydraulic horsepower:
  - P_{hyd} = (231pQ/ 12) / 33,000
  - P_{hyd} = pQ / 1714

Basic Concept of a Hydraulic Motor

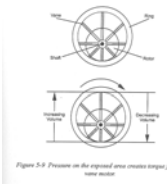
- A flow of fluid is delivered to a hydraulic motor having displacement V_m.
- The displacement of a hydraulic motor is the volume of fluid required to produce one revolution.
- Typical units are in^3/rev.
- When a flow Q is delivered to this motor, it rotates at N rpm.

Basic Concept of a Hydraulic Motor con't

- N = Q / Vm
  - Where N = rotational speed (rpm)
  - Q = flow (in^3/min)
  - V_m = displacement (in^3/rev)



(Mobile Hydraulics Manual, Vickers 1998)



(Design Engineering Handbook, Parker 2001)

Basic Concept of a Hydraulic Motor con't

- Mechanical horsepower:
  - $P_{mech} = 2\pi TN / 33{,}000$
  - Where P_{mech} = mechanical power (hp)
  - T = torque (lb_f-ft)
  - N = rotational speed (rpm)
- Substituting for N:
  - $P_{mech} = 2\pi T(Q / V_m) / 33{,}000$
  - Where V_m = displacement (in^3 / rev)

Basic Concept of a Hydraulic Motor con't

- If the units for flow are GPM, and the units for torque are lb_f-in:
  - $P_{mech} = \frac{2\pi T / 12(231Q / V_m)}{33{,}000}$
  - $P_{mech} = \frac{2\pi TQ / V_m}{1714}$

Basic Concept of a Hydraulic Motor con't

- Hydraulic horsepower is proportional to the product of pressure drop and flow.
  - hp = $\frac{\Delta pQ}{1714} = \frac{2\pi TQ / V_m}{1714}$
- Solving for torque:
  - T = $\frac{\Delta pV_m}{2\pi}$
  - Where T = torque (lb_f-in)
  - Δp = pressure drop across motor (psi)
  - V_m = displacement (in^3 / rev)

Basic Circuit Analysis

- The fluid power circuit has four components.

1. Pump. The pump develops a flow of fluid through the circuit.
2. Relief Valve. The relief valve protects the circuit. If the pressure rises high enough to offset the spring force keeping the valve closed, the valve opens, and flow returns to the reservoir, thus limiting the maximum circuit pressure.

Basic Circuit Analysis con't

3. Directional control valve (DCV). The DCV directs the flow of fluid based on its position.
4. Cylinder. The cylinder converts hydraulic energy into a force acting over some distance, known as the stroke.

Figure 1.3

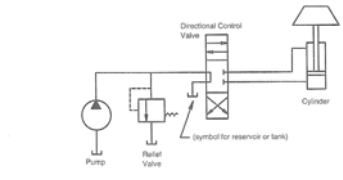
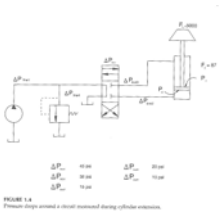


FIGURE 1.3
Basic circuit to extend cylinder.

Basic Circuit Analysis con't

- Pressure drop occurs as fluid flows through a section of hose, fitting, valve, or actuator.
- These individual pressure drops must be summed to calculate the total pressure required to achieve the functional objective.



Efficiency

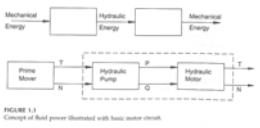
- Some energy is “lost” in hydraulic systems; the input mechanical energy is not delivered as output mechanical energy.
- Mechanical energy at one location is delivered to a second location.

Efficiency con’t

- If this transfer could be done with a gearbox, typical efficiencies would be:
  - Single reduction gearbox: 98 - 99%
  - Double reduction gearbox: 96 – 97%
  - Triple reduction gearbox: 95%
- Typical efficiency for a hydraulic pump to convert mechanical energy to hydraulic energy is 85%.

Efficiency con’t

- Overall efficiency of circuit in Figure 1.1, ignoring pressure drops, is then:
  - 0.85 * 0.85 = 0.72
- This means that only 72% of the input mechanical energy is delivered as output mechanical energy.



Summary

- Key advantages of fluid power are:
  1. High power density (high power output per unit mass of system)
  2. Control (speed of actuators easily controlled)
  3. Not damaged when overloaded (relief valve opens to protect system).
  4. Flexible power delivery very attractive in mobile applications.

Summary con’t

- The key disadvantage is the inefficiency.
- *A fluid power option should not be used unless the advantages offset the inefficiency.*