Example 1.14
Design a car crushing system. The crushing force required is such that a 15 cm diameter cylinder is required at a working pressure of 126.5 kg/cm². Time for crushing is about 10 s and the stroke required to flatten the car is 254 cm. Compare the power required by the circuit without and with accumulator.
Accumulator details:
- It is a gas-loaded accumulator
- Time taken for charging = 5 mm
- Initial pressure of charging (pre-charged), \( p_1 = 85 \text{ kg/cm}^2 \)
- Charged pressure of accumulator, \( p_2 = 210 \text{ kg/cm}^2 \)
- Minimum pressure for crushing, \( p_3 = 126.5 \text{ kg/cm}^2 \)

Solution: Given
- Diameter of piston = 15 cm
- Distance traveled in 10 s = 254 cm
- Distance traveled in 1 s = 25.4 cm
- Therefore, the stroke velocity, \( v = 25.4 \text{ cm/s} \)
- Pressure required to crush = 126.5 kg/cm²

**Circuit requirements without accumulator**

Area of piston = \( \frac{\pi}{4}D^2 = \frac{\pi}{4}15^2 = 176.71 \text{ cm}^2 = 176.71 \times 10^2 \text{ mm}^2 \)

Volume of flow,

\[ V = \text{Area} \times \text{Stroke} = 176.71 \times 10^2 \times 2540 = 4,488,434 \text{ mm}^3 = 4.488 \times 10^2 \text{ m}^3 \]

Flow rate

\[ Q = \frac{V}{10} = 4.488 \times 10^2 / 10 = 4.488 \times 10^{-3} \text{ m}^3 / \text{s} \]

Power required

\[ P = Q \times p = 4.488 \times 10^{-3} \times 126.5 \times 10^4 = 56773.2 \text{ W} = 56.77 \text{ kW} \]

If accumulator is not used, the flow rate of 4.488 \( \times 10^{-3} \text{ m}^3 / \text{s} \) is required from a pump with capacity of 56.77 kW.

**Circuit requirements with accumulator:**

Time taken for charging the accumulator = 5 mm

Initial pressure of charging (pre-charged), \( p_1 = 85 \text{ kg/cm}^2 \)

Charged pressure of accumulator, \( p_2 = 210 \text{ kg/cm}^2 \)

Minimum pressure for crushing, \( p_3 = 126.5 \text{ kg/cm}^2 \)

This can be shown by the diagram shown in Fig. 1.29.

The pressure relation in the accumulator can be given as

\[ p_1 v_1 = p_2 v_2 = p_3 v_3 \] (at a constant temperature)

Let us first equate

\[ p_2 v_2 = p_3 v_3 \]

Rearranging we get
\[ v_3 = \frac{p_2 v_2}{p_3} \]

Substituting the values of \( p_2 \) and \( p_3 \), we get
\[ v_3 = \frac{210 \times v_2}{126.5} = 1.66v_2 \]

We know that the oil supplied by the accumulator after charging is \( v_3 - v_2 \).
This is used for the cylinder displacement for crushing.
The amount of oil required for crushing with the given constructional details as calculated above is \( 4488 \times 10^{-2} \) m\(^3\).
Therefore, equating the above volume required, we get
\[ v_3 - v_2 = 4.488 \times 10^{-2} \text{ m}^3 \]
\[ \Rightarrow 1.66 v_2 - v_2 = 4.488 \times 10^{-2} \text{ m}^3 \]
Solving the above relation, we get
\[ v_2 = 0.068 \text{ m}^3 \]
and
\[ v_3 = 1.66 \times 0.068 = 0.1129 \text{ m}^3 \]
Now
\[ p_1 v_1 = p_2 v_2 \]
\[ \Rightarrow v_1 = \frac{p_2 v_2}{p_1} \]
Substituting known values, we get
\[ v_1 = \frac{(210 \times 10 \times 10^4 \times 0.068) / (85 \times 10 \times 10^4)}{0} = 0 \text{ m}^3 \]
While charging the accumulator, the oil pumped is
\[ v = v_1 - v_2 = 0.168 - 0.068 = 0.1 \text{ m}^3 \]
Time taken for charging the accumulator (given) = 5 min = 300 s.
Therefore, the flow rate is
\[ Q = \frac{v}{t} = \frac{0.1}{300} = 3.33 \times 10^{-4} \text{ m}^3/\text{s} \]

Charged pressure (given) \( p = 210 \times 10^7 \) N/m\(^2\)
Power required
\[ P = Qxp = 3.33 \times 10^{-4} \times 210 \times 10^7 = 7 \text{ kW} \]
Power required without accumulator = 56.77 kW
Power required with accumulator = 7 kW
The circuit to do the crushing can be seen in Fig. 1.30.
Example 1.15
A pump delivers oil at a rate of 18.2 gallons/min into the blank end of a cylinder of diameter 75 mm (Fig. 1.31). The piston contains a 25 mm diameter cushion plunger that is 25 mm; therefore, the piston decelerates over a distance of 25 mm at the end of the suction stroke. The cylinder drives a load of 7500 N that slides on a horizontal bed with coefficient of friction = 0.1. The pump relief valve pressure setting is 5.5 N/mm². What is the pressure acting due to cushioning deceleration?

Solution: Pump flow rate is

\[ Q = \frac{18.2 \text{ gallons/min(GPM)}}{3.785 \times 10^{-3} \times 60} = 80.15 \text{ m}^3/\text{s} \]

Note: 1 gallon = 3.785 L, 1 L = 1000 cc = 10⁻³ m³
Piston diameter = 75 mm
Plunger diameter = 25 mm
Plunger length = 25 mm
Load acting = 7500 N
Friction coefficient (\( \mu \)) = 0.1
Relief pressure \( p_1 \) = 5.5 N/mm²
This can be visualized in Fig. 1.31.
Velocity of extension until cushioning=$v_1$
Final velocity at the end of extension stroke=$v_2=0$ (if smoothly it stops)
The velocity of extension until cushioning is given by
$$v_1 = \frac{Q}{A}$$
Area of the piston blank is
$$A = \left(\frac{\pi}{4}\right)(D^2) = \left(\frac{\pi}{4}\right)\left(\frac{75}{100}\right)^2$$
So
$$v_1 = \frac{80.15 \text{ m}^3/\text{s}}{\left(\frac{\pi}{4}\right)\left(\frac{75}{100}\right)^2} = 0.2598 \text{ m/s}$$
The final velocity $v_2=0$. Writing the equation of motion
$$v_1^2 = 2axs$$
the deceleration due to the cushioning effect can be given as
$$a = \frac{v_1^2}{2xs} = \frac{0.2598^2}{2 \times 2 \times 10^{-3}} = 1.349 \text{ m/s}^2$$
Now equating the forces on the piston we get
Blank end force–Rod end force–Frictional force + Inertial force = 0 
\[ \text{Blank end force = } p_1 \times (\pi/4)D^2 \]
\[ \text{Rod force = } p_2 \times (\pi/4)(D^2 - d^2) \]
\[ \text{Frictional force } = \mu \times w \]
\[ \text{Inertial force } = \text{Mass } \times \text{Acceleration} \]
Substituting all the values in Eq. (1.8), we get
\[ \text{Blank end force } = 5.5 \times 10^6 \times (\pi/4) \times (0.075)^2 - [p_2 \times (\pi/4) \times ((0.075)^2 - (0.025)^2)] - (0.12 \times 7500) \]
This gives
$$p_2 = 6216183.35 \text{ N/m}^2 = 6.22 \text{ N/mm}^2 = 6.22 \text{ MPa}$$
This is the pressure required during deceleration due to cushion effect.
**Example 1.16**

A double-acting cylinder is used in a regenerative circuit as shown in Fig. 1.32. The relief valves is set at 7.5 N/mm², the piston area is 150 cm², the rod area is 40 cm² and the flow is 20 gallons/min. Find the cylinder speed and load-carrying capacities for various DCV.

![Diagram](image)

**Figure 1.32**

**Solution:** Given data

- Pump flow $Q_p = 20$ gallons/min = $[(20 \times 3.785 \times 10^{-3})/60] \text{ m}^3/\text{s}$
- Piston area $A_p = 150 \times 10^{-4} \text{ m}^2 = 150 \times 10^2 \text{ mm}^2$
- Rod area $A_r = 40 \times 10^{-4} \text{ m}^2 = 40 \times 10^2 \text{ mm}^2$
- Relief pressure $p = 7.5 \text{ N/mm}^2$

Now

Center position of the DCV = Center position of the valve – Regenerative forward stroke

Velocity = Pump flow/area of the rod

Velocity in the forward stroke = $\frac{Q_p}{A_r}$

= $\frac{20 \times 3.785 \times 10^{-3}}{60 \times 40 \times 10^{-4}}$

= 0.315 m/s

(Recollect from the regenerative circuit that because pressure acts on both sides, the load carrying capacity is less.) The load-carrying capacity, that is, the force that can be applied is

$F_i = p \times (A_p - (A_p - A_r))$

= $7.5 \times 40 \times 10^2$

= 30000 N

= 30kN

We shall consider the left envelop of the DCV. In this position, the cylinder extension is similar to the regular double-acting cylinder where the pump flow is diverted to the blank side (without regeneration).

Velocity in the forward stroke = $\frac{Q_p}{A_p}$

= $\frac{20 \times 3.785 \times 10^3}{60 \times 150 \times 10^2}$

= 0.08411 m/s
The force that can be carried in this position is
\[ F_{f(normal)} = p \times (A_p) \]
\[ = 7.5 \times 150 \times 10^2 \]
\[ = 112500 \text{ N} \]
\[ = 112.5 \text{ kN} \]

Now we consider the right envelop of the DCV, when the cylinder retracts as a regular double-acting cylinder.

Velocity during the return stroke:
\[ V = \frac{Q_p}{A_p - A_r} \]
\[ = \frac{20 \times 3.785 \times 10^{-3}}{60 \times (150 \times 10^2 - 40 \times 10^2)} \]
\[ = 0.1147 \text{ m/s} \]

The force that can be applied would be less than the forward stroke because the rod reduces the actual piston area to do work:
\[ F_{f(normal)} = p \times (A_p - A_r) \]
\[ = 7.5 \times (150 \times 10^2 - 40 \times 10^2) \]
\[ = 82500 \text{ N} \]
\[ = 82.5 \text{ kN} \]

**Example 1.17**
Two double-acting cylinders are to be synchronized connecting them in series as shown in Fig. 1.33. The load acting on each cylinder is 4000 N. Cylinder 1 has the piston diameter 50 mm and rod diameter 20 mm. If the cylinder extends 200 turns in 0.05 s, find the following:

(a) The diameter of the second cylinder.
(b) The pressure requirement of the pump.
(c) The capacity of the pump assuming the efficiency of the pump to be 85% and overall efficiency of the system as 90%.
Solution:
Force on both cylinders $p = 4000$ N
Diameter of the piston of cylinder 1 $D_1 = 50$ mm
Diameter of the rod of cylinder 1 $d_1 = 20$ mm

(a) Diameter of second cylinder

Pressure on the rod side of cylinder 1 = Pressure of fluid leaving cylinder 1

\[
p_{\text{rod}} = \frac{\text{Force}}{(\text{Area of piston 1} - \text{Area of rod 1})} = \frac{p}{(A_{p1} - A_{r1})}
\]

\[
= \frac{4000 \times 4/\pi \times (D_1^2 - d_1^2)}{4000 \times 4/\pi \times (50^2 - 20^2)} = 2.425 \text{ N/mm}^2
\]

Also, for serial synchronizing circuits.
Pressure of fluid leaving cylinder 1 = Pressure of fluid coming into cylinder 2
Pressure of fluid coming into cylinder 2 = 2.425 N/mm$^2$

\[
= \frac{\text{Force}}{\text{area of the piston of cylinder 2}}
\]

So

\[
1.425 = 4000 \times 41 \times D_2^2
\]

\[
\Rightarrow D_2 = 45.825 \text{ mm}
\]

(b) The pressure requirement of the pump
Let us now determine the pressure required at the piston side of cylinder 1:

\[ F_1 = 4000 \text{ N} = \left(\frac{\pi}{4}\right) \times D_1^2 \times p_1 - \left(\frac{\pi}{4}\right) \times (D_1^2 - d_1^2) \times p_2 \]

Substituting the known values, we get

\[ 4000 \text{ N} = \left(\frac{\pi}{4}\right) \times 50^2 \times p_1 - \left(\frac{\pi}{4}\right) \times (50^2 - 20^2) \times 2.425 \]

We get \( p_1 = 4.074 \text{ N/mm}^2 \).

Length of the cylinder \( L = 200 \text{ mm} \)

Time taken to extend \( 200 \text{ mm} \) = 0.05 s

Efficiency of the pump = 0.9

Efficiency of the system = 0.85

The forward stroke velocity is

\[ v_f = \frac{L}{t} = \frac{200}{0.05} = 4000 \text{ mm/s} \]

The flow rate required from the pump is

\[ Q = \text{Area of the piston of cylinder 1} \times v_f \]

\[ = \left(\frac{\pi}{4}\right) \times D_1^2 \times v_f \]

\[ = \left(\frac{\pi}{4}\right) \times 50^2 \times 4000 \]

\[ = 7.85 \times 10^{-3} \text{ m}^3/\text{s} \]

(c) Capacity of the pump

Let us now calculate the pump capacity in kW:

Input capacity in kW

\[ \frac{p_1 Q}{\eta_{pump} \eta_o} = \frac{4.074 \times 10^6 \times 7.85 \times 10^{-3}}{0.9 \times 0.85} = 41.805 \text{ kW} \]

Output capacity of the pump = \( Q \times P \)

\[ = 7.85 \times 10^{-3} \times 4.074 \times 10^6 \]

\[ = 31.981 \text{ kW} \]

Example 1.18

A high–low circuit uses a low-pressure pump of 1.4 N/mm\(^2\) and a high-pressure pump of 12.6 N/mm\(^2\). The press contains eight cylinders and the total load of the press is 5600 kN. The length of cylinder is 200 mm whereas the punching stroke is only for 6 mm. The time for lowering is 0.05 s and the time for pressure build-up and pressing is 0.03 s. Determine the following:

(a) The piston diameter of cylinder.
(b) Pump flow rates.
(c) Total motor capacity.
(d) If a single pump of 12.6 N/mm\(^2\) is used, find the kW capacity required.

Solution:

(a) Piston diameter of cylinder

Number of cylinders = 8
Total force = 5600 kN
High-flow pump pressure= 1.4 N/mm$^2$ = $p_{\text{high}}$ = 1.4 x10$^6$ N/m
Low-flow pump pressure= 12.6 N/mm$^2$ = $p_{\text{low}}$ = 12.6 x10$^6$ N/m
Stroke length, $L$= 6 mm
Force acting in one cylinder= Total load/Number of cylinders
= 5600000 / 8
= 700000 N
Pressure during punching = 126 N/mm$^2$

Piston diameter of the cylinder,
\[ D^2 = 700000 \times 4 (\pi \times 12.6) \]
\[ \Rightarrow D = 266 \text{ mm} = 0.266 \text{ m} \]

(b) Pump flow rate

The flow requirements of the low-pressure pump:

Stroke velocity = Stroke length/time taken
= 6/0.05 = 120 mm/s = 0.120 m/s

Flow from the low-pressure pump= Area x Stroke velocity
= ($\pi/4$) x (0.266$^2$) x 0.120
= 0.00667 m$^3$/s

Power output is
\[ P_{\text{low}} = Q_{\text{low}} \times p_{\text{low}} \]
\[ = 1.4 \times 10^6 \times 0.00667 \text{ W} = 9.338 \text{ kW} \]

When the pressure of oil is increased in a compartment, the volume changes. Usually,
Volume change = $\frac{1}{2}$% of initial volume for 70 bar

Compressed volume = $\frac{1}{2}$% of ($\pi/4$) x $D^2$ x $L$
= 0.005 x ($\pi/4$) x (0.266$^2$) x 0.006
= 1.667 x10$^{-6}$ m$^3$

This volume is compressed because of the difference in the pressure level of the high- and low-pressure pumps:

Difference in pressure = 12.6 – 1.4 N/mm$^2$ = 11.2 x10$^6$ N/m$^2$

Therefore, the volume change for 11.2 x10$^6$ N/m$^2$ is
11.2 x10$^6$ x 1.667 x10$^{-6}$ / 70 x10$^6$ = 2.6558 x10$^{-6}$ m$^3$

Therefore, the flow from the high-pressure pump
\[ Q_{\text{high}} = 2.6558 \times 10^5 / 0.03 \text{ (volume/time taken)} \]
\[ = 8.85 \times 10^{-5} \text{ m$^3$/s} \]

(c) Motor capacity

Hence, the power output is
\[ P_{\text{high}} = Q_{\text{high}} \times p_{\text{high}} \]
\[ = (8.85 \times 10^{-5}) \times (12.6 \times 10^6) \]
\[ = 1.115 \text{ kW} \]

The total kilowatt capacity required is
\[ P_{\text{high}} + P_{\text{low}} = 9.338 + 1.115 = 10.453 \text{ kW} \]

(d) If a single pump is used, capacity requirement
Instead, if a single pump with high-pressure capacity is required, then

\[
\text{Flow required} \ (Q_{\text{combined}}) = \text{Flow from the low-pressure pump} + \text{flow from the high-pressure pump}
\]

\[
= 0.00667 + 8.85 \times 10^{-5} \text{m}^3/\text{s}
\]

\[
= 0.00676 \text{m}^3/\text{s}
\]

The power capacity required for the above pump is

\[
\text{Power capacity} = Q_{\text{combined}} \times p_{\text{high}}
\]

\[
= 0.00676 \times 12.6 \times 10^6
\]

\[
= 85157.1 \text{ W}
\]

\[
= 85.157 \text{ kW}
\]

From the above calculations, it is evident that when a high–low circuit is used instead of a single high-pressure pump, the power requirement is reduced considerably.

**Example 1.19**

A high–low circuit with an unloading valve is employed for press application. This operation requires a flow rate of 200 LPM for high-speed opening and closing of the dies at the maximum pressure of 30 bar. The work stroke needs a maximum pressure of 400 bar, but a flow rate between 12 and 20 LPM is acceptable. Determine the suitable delivery for each pump.

**Solution:** A high–low circuit uses a high-pressure, low-volume pump and a low-pressure, high-volume pump. During closing or opening, both the pumps supply fluids. During work stroke, the high-pressure pump alone supplies fluid. Power requirement is the same for both processes.

Theoretical power required to open or close the dies is

\[
P = \frac{200 \times 10^{-3} \times 30 \times 10^6}{60} = 10000 \text{ W}
\]

To utilize this power for the pressing process, the flow required is calculated. We know that

\[
\text{Power} = \text{Flow} \times \text{Pressure}
\]

\[
10000 = Q \times 400 \times 10^5
\]

Solving we get

\[
Q = 2.5 \times 10^{-3} \text{m}^3/\text{s}
\]

\[
= 2.5 \times 10^{-4} \times 60 \text{ m}^3/\text{min}
\]

\[
= 15 \times 10^{-3} \text{m}^3/\text{min}
\]

\[
= 15 \text{ LPM}
\]

This is acceptable. Therefore, the delivery of the high-pressure, low-volume pump = 15 LPM. The delivery of the low-pressure, high-volume pump = 200 – 15 =185 LPM. An equivalent single fixed displacement pump having a flow rate of 200 LPM and working at a pressure of 400 bar requires a theoretical input power of 133.3 kW.

**Example 1.20**

A press with the platen weighing 5 kN is used for forming. The force required for pressing is 100 kN and a counterbalance valve is used to counteract the weight of the tools. The cylinder with a piston diameter 80 mm and a rod diameter 60 mm is used. Calculate the pressure to achieve 100 kN pressing force.
**Solution:**

Weight of the tools = 5 kN = $5 \times 10^3$ N

Full bore area $= \frac{\pi}{4} \times 0.08^2 = 0.005$ m$^2$

Annulus area,

$A_p - A_t = \frac{\pi}{4} \times (0.08^2 - 0.06^2) = 0.0022$ m$^2$

Pressure required at rod side to balance tools is

$$\frac{5 \times 10^3}{0.0022} \times 10^{-5} = 22.7 \text{ bar}$$

Suggested counterbalance valve setting $= 1.3 \times 22.7 = 29.5$ bar

Pressure at full bore side to overcome counterbalance $= 29.5 \times \frac{0.0022}{0.005} = 13$ bar

Pressure to achieve 100 kN pressing force at full bore side $= \frac{100 \times 10^3 \times 10^{-5}}{0.005} + 13 = 213$ bar

**Example 1.21**

In a meter-in circuit, a cylinder with 100 mm bore diameter and 70 mm diameter is used to exert a forward thrust of 100 kN, with a velocity of 0.5 m/min. Neglect the pressure drop through the piping valves. If the pump flow is 20 LPM, find the following:

(a) Pressure required at the pump on extend.
(b) Flow through the flow-control valve.
(c) Relief-valve setting.
(d) Flow out of the pressure-relief valve.
(e) System efficiency during extend.

**Solution:** Both $Q$ and $q$ are being used. Kindly check for correctness

(a) Force needed during extend, $F = 100$ kN. Therefore, the pressure required at pump on extend $p'$ is

$$p' = \frac{100 \times 10^3}{\frac{\pi}{4} \times 0.1^2} = 127 \text{ bar}$$

(b) Velocity during extend, $v = 0.5$ m/min.

Flow through the flow control valve is

$$q = v \times A_p$$

$$= 0.5 \times \frac{\pi}{4} \times 0.1^2$$

$$= 3.9 \times 10^{-3} \text{ m}^3/\text{min}$$

$$= 3.9 \text{ LPM}$$
(c) Relief-valve setting, \( p = 127 + 10\% \) (127) = 140 bar

(d) Flow out of the pressure-relief valve is
\[
q' = Q - q = 20 - 3.9 = 16.99 \text{ LPM}
\]

(e) System efficiency is
\[
\frac{p'q}{pq} \times 100 = \frac{127 \times 3.9}{140 \times 20} \times 100 = 17.6\%
\]

**Example 1.22**
A hydraulic intensifier is meant to enhance the fluid pressure from 50 to 200 bar. Its small-cylinder capacity is 23 L and has a stroke of 1.5 m. Find the diameter of the larger cylinder to be used for this intensifier.

**Solution:**
The capacity of small cylinder \( Q = \text{Area of small cylinder} \times \text{Stroke} \)

Diameter of the small cylinder is
\[
d = \left( \frac{Q \times 4}{\pi \times s} \right)^{\frac{1}{2}} = \left( \frac{10^3 \times 23 \times 4}{\pi \times 1.5} \right)^{\frac{1}{2}} = 0.140 \text{m} = 140 \text{mm}
\]

Let \( p_s \) be the supply pressure and \( p_i \) be the intensifier pressure. Then intensification ratio is
\[
\frac{A_s}{A_i} = \frac{p_s}{p_i} = \frac{D_i^2}{d^2} = \frac{200}{50}
\]

\[\Rightarrow \frac{D}{d} = 2\]

Diameter of larger cylinder is
\[
D = 2 \times d = 2 \times 140 = 280 \text{ mm}
\]

**Example 1.23**
A punch press circuit with five stations operated by five parallel cylinders is connected to an intensifier. The cylinders are single-acting cylinders with spring return and the piston diameter of the cylinder is 140 mm. The cylinders are used for punching 10 mm diameter holes on sheet metal of 1.5 mm thickness. The ultimate shear strength of sheet material is 300 MN/m\(^2\). The punching stroke requires 10 mm travel. If the intensification ratio is 20 and the stroke of the intensifier is 1.3 m, determine the following:

(a) Pressure of oil from the pump.
(b) Diameter of small and large cylinders of intensifier.

**Solution:**
(a) Pressure of oil from the pump

The force required to punch the hole is
\[ F = \text{Shear area} \times \text{Shear strength} \]
\[ = \pi \times \text{Diameter of hole} \times \text{Thickness of sheet} \times \text{Shear strength} \]
\[ = \pi \times 10 \times 10^{-3} \times 1.5 \times 10^{-3} \times 300 \times 10^6 \]
\[ = 14137 \text{ N} \]

Pressure developed at the load cylinder is
\[ \frac{F}{A} = \frac{14137}{\frac{\pi}{4} \times (0.14)^2} = 9.2 \text{ bar} \]

This is the pressure developed by the intensifier. The pressure from the pump is the pressure exerted on the large cylinder of intensifier.

Pump pressure
\[ p_i = p_s \times \left( \frac{A}{A_s} \right) = 9.2 \times \frac{1}{20} = 0.46 \text{ bar} \]

(b) Diameter of small and large diameter

Volume of oil required in the cylinders during punching stroke is
\[ V_{oil} = 5 \times \text{Area of cylinder} \times \text{Punch stroke} \]
\[ = 5 \times \frac{\pi}{4} \times 0.14^2 \times 10 \times 10^{-3} = 7.7 \times 10^{-4} \text{ m}^3 \]

This is supplied by the intensifier. Now

Area of small cylinder \times Stroke of intensifier = 7.7 \times 10^{-4} \text{ m}^3

So

Area of small cylinder \[ A_s = \frac{7.7 \times 10^{-4}}{1.3} \]

Also

Area of larger cylinder \[ A_L = \text{Intensification ratio} \times A_s \]
\[ = 20 \times 5.9 \times 10^{-4} \]
\[ = 0.118 \text{ m}^2 \]

Diameter of the small cylinder is
\[ d = \left( \frac{5.9 \times 10^{-4} \times 4}{\pi} \right)^{1/2} = 0.027 \text{ m} \]

Diameter of the larger cylinder
\[ D = \left( \frac{0.0118 \times 4}{\pi} \right)^{1/2} = 0.122 \text{ m} \]

Example 1.24

A double-acting cylinder is hooked up in a regenerative circuit for drilling application. The relief valve is set at 75 bar. The piston diameter is 140 mm and the rod diameter is 100 mm. If the pump flow is 80 LPM, find the cylinder speed and load-carrying capacity for various positions of direction control valve.

Solution:

Center position of the valve: Regenerative extension stroke
Cylinder speed $= \frac{Q_p}{A_p} = \frac{\left(80 \times 10^{-3}\right)}{\left(\frac{60}{\pi \times 0.1^2}\right)} = 0.169 \text{ m/s}$

Load-carrying capacity is

$$p \times A_p = 75 \times 10^5 \times \frac{\pi}{4} \times (0.1)^2 = 58905 \text{ N}$$

Left position of the valve: Extension stroke without regeneration:

$$\text{Cylinder speed} = \frac{Q_p}{A_p} = \frac{\left(80 \times 10^{-3}\right)}{\left(\frac{60}{\pi \times 0.14^2}\right)} = 0.86 \text{ m/s}$$

Load-carrying capacity is

$$p \times A_p = 75 \times 10^5 \times \frac{\pi}{4} \times (0.14)^2 = 115453 \text{ N}$$

Right position of the valve: Retraction stroke

$$\text{Cylinder speed} = \frac{Q_p}{A_p - A_t} = \frac{\left(80 \times 10^{-3}\right)}{\left(\frac{\pi}{4} \times 0.14^2 - 0.1^2\right)} = 0.177 \text{ m/s}$$

Load-carrying capacity is

$$p(A_p - A_t) = 75 \times 10^5 \times (0.14^2 - 0.1^2) = 56548 \text{ N}$$

Example 1.25
Two double-acting cylinders are to be synchronized by connecting them in series. The load acting on each cylinder is 4000 N. If one of the cylinders has the piston diameter 50 mm and rod diameter 28 mm, find the following:

(a) The diameter of the second cylinder.
(b) Pressure requirement of the pump.
(c) Power of the pump in kW if the cylinder velocity is 4 m/s.

Solution: The area of second cylinder is

$$A_{p2} = A_{p1} - A_t = \frac{\pi}{4} \times (0.05^2 - 0.028^2) = 1.35 \times 10^{-3} \text{ m}^2$$

Diameter of the second cylinder is

$$D_{p2} = \sqrt{\left(\frac{A_{p2} \times 4}{\pi}\right)} = \sqrt{\left(\frac{1.35 \times 10^{-3} \times 4}{\pi}\right)} = 0.041 \text{ m}$$

The pump supplies oil to the first cylinder, so the pressure requirement of the pump is
\[ p_1 = \frac{F_1 + F_2}{A_{p1}} = \frac{4000 + 4000}{\frac{\pi}{4} (0.05)^2} = 40.7 \text{ bar} \]

Cylinder velocity = 4 m/s
Flow requirement of pump
\[ Q = \frac{\pi}{4} \times 0.05^2 \times 4 = 7.85 \times 10^{-3} \text{ m}^3/\text{s} \]
Power of pump in kW
\[ p_1 \times Q \times 1000 = \frac{40.7 \times 10^5 \times 7.85 \times 10^{-3}}{1000} = 32 \text{ kW} \]

**Example 1.26**

A pump delivers 60 L/min, the system maximum working pressure is 250 bar and the return line maximum pressure is 80 bar. Select suitable tubes. Use the data provided in Table 1.1: Cold-drawn seamless CS tubes (DIN 2391/C) (DIN is a German Standard).

<table>
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<th>Outer Diameter × Wall Thickness</th>
<th>Approximate Weight</th>
<th>Maximum Working Pressures (bar)</th>
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**Solution:**

**Return line:** Select a velocity of 1.0 m/s. Now

\[
\text{Flow area} = \frac{\text{Discharge}}{\text{Velocity}} = \frac{60 \times 10^{-3}}{60} \times \frac{1}{1.0} = 0.001 \text{ m}^2
\]
Now

Inner diameter of tube = \( \left( \frac{0.001 \times 4}{\pi} \right)^{1/2} \times 0.001 \times 4 \times \pi \) = 0.035m = 35 mm

Select a standard tube size of inner diameter 36mm, outer diameter 42 mm and wall thickness 3mm. This has a safe working pressure of 101 bar, so it is suitable for the return lines.

**Delivery lines:** Select a velocity of 3.5m/s. Now

Flow area = \( \left( \frac{60 \times 10^{-3}}{60} \right) \times \frac{1}{3.5} = 2.857 \times 10^{-4} \) m²

Inner diameter = \( \left( \frac{2.857 \times 10^{-4} \times 4}{\pi} \right) = 0.019 \) m = 19 mm

Select a standard tube size of inner diameter 19mm, outer diameter 25 mm and wall thickness 3mm. This has a safe working pressure of 297 bar and is suitable for the delivery lines.

**Example 1.27**

A flow control valve has a controlled flow \( C_v \) of 10.5 LPM/\( \sqrt{\text{bar}} \) and a free flow \( C_v \) of 32.4 LPM/\( \sqrt{\text{bar}} \). Determine the pressure drop across the valve in both the controlled flow and free flow directions. The system has a flow rate of 19 L/min and uses standard hydraulic oil of specific gravity 0.9.

**Solution:** Pressure drop in the controlled flow direction

\[ \Delta p = \frac{Q^2}{C_v^2} \times SG = \frac{19^2}{10.5^2} \times 0.9 = 2.94 \text{ bar} \]

Pressure drop in the free flow direction

\[ \Delta p = \frac{Q^2}{C_v^2} \times SG = \frac{19^2}{32.4^2} \times 0.9 = 0.309 \text{ bar} \]

**Example 1.28**

A cylinder has to exert a forward thrust of 150 kN and a reversible thrust of 15 kN (Fig. 1.34). The retract speed should be approximately 5 m/min utilizing full pump flow. Assume that the maximum pump pressure is 150 bar. Pressure drops over the following components and their associated pipe work are as follows:

- Filter = 3 bar
- Direction control valve (each flow path) = 2 bar

Determine the following:

(a) Suitable cylinder (assume 2:1 ratio; piston area to rod area).
(b) Pump capacity.
(c) Relief-valve setting pressure.
Solution:

(a) Back pressure at the annulus side of cylinder is 2 bar. This is equivalent to 1 bar at the full bore end because of the 2:1 area ratio. Therefore, Maximum available pressure at the full bore end of cylinder = Maximum pump pressure – (Pressure drops + Back pressure)

\[ = 150 - 3 - 2 - 1 \]

\[ = 144 \text{ bar} \]

Now

\[ \text{Full bore area} = \frac{\text{Load}}{\text{Pressure}} = \frac{150 \times 10^3}{144 \times 10^9} = 0.0104 \text{ m}^2 \]

Piston diameter\[ = \left( \frac{4}{\pi} \times 0.0104 \right)^{1/2} = 0.115\text{m} = 115\text{mm} \]

Now select a cylinder with 125mm bore ×90 mm rod diameter. So

Bore area = 12.26 \times 10^{-3} \text{ m}^2

Rod area = 6.3 \times 10^{-3} \text{ m}^2

This is approximately in the 2:1 ratio.

(b) Now

Flow rate required for a retract speed of 5 m/min (full pump flow) = (Bore area – Rod area) \times \text{Retract velocity}

\[ = (12.26 \times 10^{-3} - 6.35 \times 10^{-3}) \times 5 \]
= 0.02955 m³/min
= 29.55 L/min

(c) We have
Pressure to overcome the load while extending = \frac{150 \times 10^3}{12.26 \times 10^6} = 12.2 \times 10^6 \text{ N/m}^2 = 122 \text{ bar}
Pressure drop over the direction control valve P to A = 2 bar
Pressure drop over the direction control valve B to T (because of 2:1 area ratio 2 bar \times \frac{1}{2} = 1 bar
Pressure drop over the filter = 3 bar
Therefore,
Pressure required at the pump during the extend stroke = 122 + 2 + 1 + 3 = 128 bar
Pressure to overcome load during retraction = \frac{15 \times 10^3}{(12.26 \times 10^{-3} - 6.35 \times 10^{-3})} = 2.5 \times 10^6 \text{ N/m}^2 = 25 \text{ bar}
Pressure drop over the direction control valve P to B = 2 bar
Pressure drop over the direction control valve A to T (because of the 2:1 area ratio, 2 bar \times 2 ) = 4 bar
Pressure drop over the filter = 3 bar
Therefore,
Pressure required at the pump during the retract stroke = 25 + 2 + 4 + 3 = 34 bar
Relief-valve setting = Maximum pressure + 10\% = 128 + (0.1 \times 128) = 141 \text{ bar}

Example 1.29
A press cylinder having a bore diameter of 140 and a 100 mm diameter rod is to have an initial approach speed of 5 m/min and a final pressing speed of 0.5 m/min. The system pressure for a rapid approach is 40 bar and for final pressing is 350 bar. A two-pump, high–low system is to be used. Both pumps may be assumed to have the volumetric and overall efficiencies of 0.95 and 0.85, respectively. Determine the following:

(a) The flow to the cylinder for the rapid approach and final pressing.
(b) Suitable deliveries for each pump.
(c) The displacement of each pump if the drive speed is 1720 RPM.
(d) The pump motor power required during the rapid approach and final pressing.
(e) Retract speed if the pressure required for retraction is 25 bar maximum.

Solution: A high–low circuit uses a high-pressure, low-volume pump and a low-pressure, high-volume pump.
(a) The flow to the cylinder rod for the rapid approach is
\[ Q_{\text{rapid}} = \text{Bore diameter } \times \text{Velocity of initial approach} \]
\[ = \frac{\pi}{4} \times 0.140^2 \times 5 = 0.077 \, \text{m}^3/\text{min} = 77 \, \text{LPM} \]
The flow to the cylinder for final pressing is
\[ Q_{\text{high pressure}} = \text{Bore diameter } \times \text{Velocity of final pressing} \]
During final pressing, only a high-pressure, low-volume pump supplies fluid. The high-volume pump delivery is 
\[ Q_{\text{rapid}} - Q_{\text{high pressure}} = 77 - 7.7 = 69.3 \text{ LPM} \]

(c) The displacement of a low-volume pump 
\[ D_{p,\text{high pressure}} = \frac{Q_{\text{high pressure}}}{N_p \times \eta_v} = \frac{7.7}{1720 \times 0.95} = \frac{4.7 \times 10^{-3}}{} = 4.7 \text{ mL} \]

The displacement of a high-volume (low pressure) pump 
\[ D_{p,\text{low pressure}} = \frac{Q_{\text{low pressure}}}{N_p \times \eta_v} = \frac{69.3}{1720 \times 0.95} = \frac{42.3 \times 10^{-3}}{} = 42.4 \text{ mL} \]

(d) Pump motor power required during the rapid approach: 
\[ P_{\text{low pressure}} \times \frac{Q}{\eta_o} = \frac{40 \times 10^5 \times 0.077}{60 \times 1000 \times 0.85} = 6.04 \text{ kW} \]

Pump motor power required during final pressing: 
\[ P_{\text{high pressure}} \times \frac{Q_{\text{high pressure (low volume)}}}{\eta_o} = \frac{350 \times 10^5 \times 0.0077}{60 \times 1000 \times 0.85} = 5.3 \text{ kW} \]

(e) We have 
Retract speed = \[ \frac{Q}{\frac{\pi}{4} (D^2 - d^2)} = \frac{4 \times 0.077}{\frac{\pi}{4} (0.140^2 - 0.100^2)} = 10.2 \text{ m/s} \]
Objective-Type Questions

Fill in the Blanks

1. In a regenerative circuit, the speed of extension is greater than that for a regular double-acting cylinder because the flow from the ______ regenerates with the pump.
2. For two cylinders to be synchronized, the piston area of cylinder 2 must be equal to ______ between the areas of piston and rod for cylinder 1.
3. Meter ______ systems are used primarily when the external load opposes the direction of motion of the hydraulic cylinder.
4. One drawback of a meter ______ system is the excessive pressure build-up in the rod end of the cylinder while it is extending.
5. Fail–safe circuits are those designed to prevent injury to operator or damage to ______.

State True or False

1. In a regenerative circuit, when the piston area equals two-and-a-half times the rod area, the extension and retraction speeds are equal.
2. The load-carrying capacity for a regenerative cylinder during extension equals pressure times the piston rod area.
3. When two cylinders are identical, the loads on the cylinder are not identical, and then extension and retraction can be synchronized.
4. When a load pulls downward due to gravity, in such a situation a meter-in system is preferred.
5. A machine intended for high-volume production uses rapid traverse and feed circuits.

Review Questions

1. List three important considerations to be taken into account while designing a hydraulic circuit.
2. What are the advantages of a regenerative circuit?
3. Explain the regenerative circuit for a drilling machine.
4. With the help of a neat sketch, explain the pump-unloading circuit.
5. With the help of a circuit diagram, explain a double-pump hydraulic system (Hi–Lo circuit).
6. Explain the application of a counterbalance valve.
7. Explain the application of a pilot check valve for locking a double-acting cylinder.
8. Explain the speed control circuit for a hydraulic motor.
9. What are the conditions for the two cylinders to be synchronized?
10. What is a fail-safe circuit?
Answers
Fill in the Blanks

1. Rod end
2. Difference
3. In
4. Out
5. Equipment/machine

State True or False

1. False
2. True
3. False
4. False
5. True