System Design

Syllabus

Design of hydraulic/pneumatic circuits for practical application, Selection of different components such as reservoir, control elements, Actuators, Accumulator, Intensifier, Filters, Pumps. (Students are advised to refer manufacture catalogues for design and use simulation tool like Automation Studio for analysis.)

Contents

16.1 Introduction

A hydraulic circuit is a group of components which are arranged in such a way that it can perform a specific task. As already seen at various stages of this book, the group of components comprises of energy generating components (motor, pump etc.), energy control components (control valves), energy transmitting components (pipes, hoses etc.) and energy consuming components (actuators, motors etc.).

This chapter is split into two parts, the first part is related to "How to analyse the hydraulic or pneumatic circuit ?", and second part is related to, "How to design and select the various hydraulic or pneumatic components for specific working conditions ?"

16.2 Analysis of Hydraulic and Pneumatic Circuits

SPPU : Dec.-08,13,16,17, May-14,16

There are basically two types of analysis which are involved in case of hydraulic or pneumatic circuits. They are static and dynamic analysis, which involves first developing the appropriate mathematical models for each component in the circuit and then using Pascal's law (pressure same at all points for fluid at rest) and conservation of flow to connect the components into a set of equations that describe the complete system.

By and large, students need to answer the questions on analysis, in the following way. The question is given with any hydraulic or pneumatic circuit diagram and you are asked to analyse the same.

Step I : Draw the circuit diagram as it is.

Step II : Label it according to your convenience/keep the same labels given in circuit.

Step III : Write down the list of components.

Step IV : Explain the sequence of operation.

Note : Students are adviced to practice whatever circuits studied in Unit-IV and Unit-V.

Let us directly see how to analyse the hydraulic or pneumatic circuits through following problems.

Ex. 16.1 : *Analyse the given hydraulic circuit.*

SPPU : May-14, Marks 8

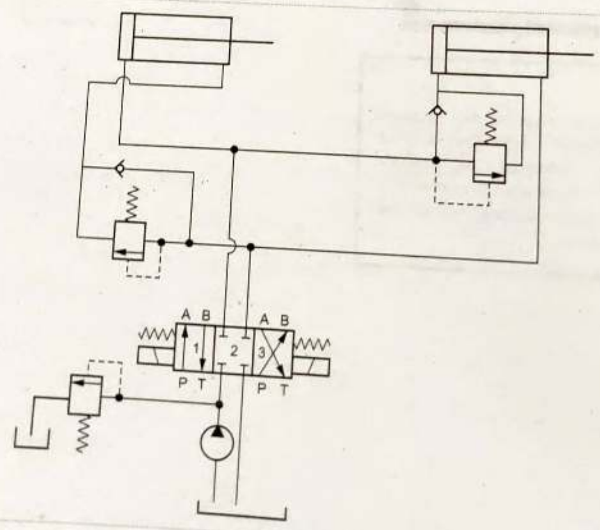

Fig. 16.1

Sol. :

Step I : Sketch of circuit

Step II : Labeling

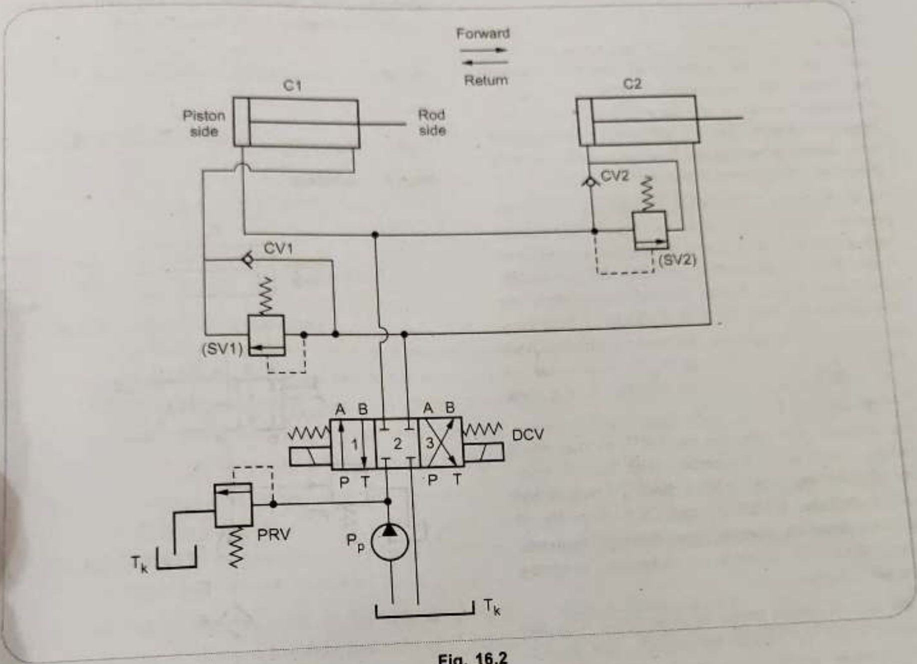

Fig. 16.2

Step III : List of components

Sr. No.	Component	Notation used	Specification / function
1.	Tank	T_k	One tank to store hydraulic oil.
2.	Pump	P_p	Hydraulic pump to pressurize hydraulic oil.
3.	Pressure relief valve	PRV	To relieve the pump pressure directly to the tank. Normally closed valve.
4.	Directional control valve	DCV	To direct the fluid according to the stroke requirements. 4/3 DCV solenoid operated and spring centered.
5.	Sequence valves	(SV1) or (SV2)	Normally closed sequence valves. Called as sequence valves, as they used for sequencing of cylinders.
6.	Check valves	CV1 and CV2	To allow flow only in one direction and restrict in other direction.
7.	Consumer / Cylinder	C1 and C2	Double acting cylinders (end users).

Step IV : Sequence of operation

1) The circuit used above is a typical circuit for the sequencing operation where two cylinders are operated at different pressures by using oil from the same source.

2) For the forward stroke of both cylinders, spool position 1 of Directional Control Valve (DCV) is used. The oil from the pump directly flow towards the piston side of consumer 1 (C1), which begins it's forward stroke, at the same time oil tries to flow through Sequence Valve 2 (SV2) but due to higher force setting of spring no flow is possible towards piston side of Cylinder/Consumer 2 (C2).

3) As the Cylinder 1 completes it's forward stroke, the pressure starts rising inside the supply line due to back pressure, which opens the contact of Sequence Valve (SV2) to allow flow towards the piston side of Cylinder 2 (C2). Hence it's starts completing the forward stroke. The oil from Cylinder 1 (C1) flow (from rod side) back to the tank through Check Valve 1 (CV1) and DCV (B to T). Also used oil from Cylinder 2 (C2) flows directly to the tank through DCV (B to T).

4) The solenoid now operates the DCV, so that spool position 2 will be in connection with various lines. The oil from the pump flows directly towards rod side of Cylinder 2 (C2) through DCV (P to B). At the same time oil tries to flow through Sequence Valve 1 (SV1) but unable to do so because of spring force set at higher valve.

5) At the end of return stroke of Cylinder 2 (C2), the pressure build up inside the supply line due to back pressure, which opens the Sequence Valve 1 (SV1) and allows the flow through it. Hence Cylinder 1 (C1) now takes it's reverse stroke.

6) The used oil from piston side of Cylinder 2 (C2) flows through Check Valve 2(CV2) towards tank through DCV (A to T) and the oil from piston side of Cylinder 1(C1) flows directly to the tank through DCV (A to T).

7) Hence this circuit is a sequence circuit of two cylinders where the sequence of stroke is as follows,

Cylinder 1 (C1) forward (extend)

Cylinder 2 (C2) forward (extend)

Cylinder 2 (C2) return (retract)

Cylinder 1 (C1) return (retract). Also can be written as C1+C2+C2–C1–

Note : Further problems on analysis are solved below. In order to avoid repeatation Step I and Step II of answers are shown directly in the examples only.

Ex. 16.2 : *Analyse the given hydraulic circuit.*

Sol. :

Step I : Sketch of circuit

Step II : Labeling

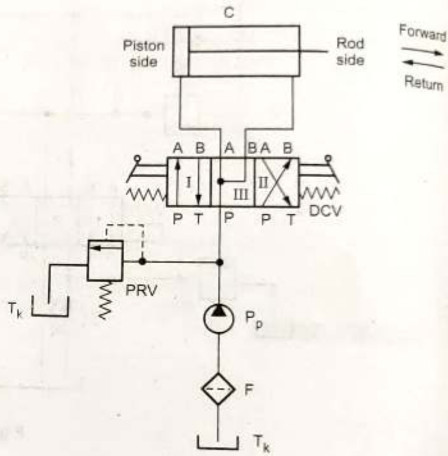

Fig. 16.3

This is a application of regenerative circuit which is used for the drilling machine. The three positions of DCV will give the three operations on the Cylinder (C).

a) Spring centered position (III) is used for rapid advance because of it's regenerative connection.

b) Spool position - I of DCV is used for slow feed when actual drilling starts on the work piece.

c) Spool position - II of DCV is used for the retraction of piston.

Step - III : List of components

Sr. No.	Component	Notation used	Specification / Function
1.	Tank	T_k	A tank to store hydraulic oil.
2.	Filter	F	To remove unwanted particles from oil.
3.	Pump	P_P	Hydraulic pump to pressurize hydraulic oil to required level.
4.	Pressure relief valve	PRV	Normally closed valve opens when system pressure crosses set limit.
5.	Directional control valve	DCV	4/3 spring centered, lever operated, having closed tank port at spool position-III.
6.	Consumer/Cylinder	C	Double acting cylinder.

Step IV : Sequence of operation

1) Spool position-III of DCV, which is a normal position of DCV is used for the rapid advance of tool towards work piece. In this position, the pressurised oil from the pump flows towards the piston side of Consumer / Cylinder (C) through DCV (P to A). At the same time used oil from the rod side flows back with the forward stroke and regenerate with the pressure line which increases oil flowing towards piston side and hence rapid advance takes place.

2) At the engagement of tool with the workpiece, the DCV is shifted by using lever to spool position I. Here oil from pump flows to the cylinder (piston side) through DCV (P to A), but the used oil from rod side instead of regenerating flows back to the tank through DCV (B to T) and hence slow feed of tool takes place still the end of stroke.

3) The tool is retracted back to the original position by shifting spool position to the II. Here oil from pump flows directly towards rod side of Cylinder (C) through DCV (P to B). And used oil from the piston side flows back to the tank through DCV (A to T).

16.3 Design and Selection of Hydraulic / Pneumatic Circuit Components

SPPU : Dec.-11,12,14,15,16, May-07,13,14,16,17

The primary objective of any system design is to obtain system with higher efficiency. This efficiency of system depends upon careful selection and proper assembly of several components to perform a specific function. So designing and selecting of components for hydraulic or pneumatic systems plays a very important role in it's actual performance. There are basically three important considerations in designing a hydraulic or pneumatic circuits.

(1) **Safety** : The system should be designed in such a way that it will take care of safety of both man and machine.

(2) **Efficient performance** : The system should work efficiently and perform specific task as designed and intended.

(3) **Cost** : The system should be affordable for the particular applications. Pneumatic systems are usually used for the low cost automations.

16.3.1 Other Design Considerations

Any hydraulic or pneumatic circuit design should be able to fulfill following requirements.

(1) Execute the desired function.

(2) Simple to maintain.

(3) Longer life.

(4) Less running cost.

(5) Proper integration etc.

16.3.2 Pre-requisite for Design

The designer of the hydraulic/pneumatic system should have knowledge of various aspects of applications. For example, he must design the system according to maximum load requirement that may encounter in the operation. In general, the designer must have information regarding following,

(1) System pressure :

It is the maximum operating pressure that is necessary for the system operation. Usually system is designed to provide higher pressure than maximum operating pressure.

(2) Type of end user/consumer :

There are various types of actuators available for utilizing fluid energy. The selection of particular actuator depends upon application requirements. With a particular actuator, the parameters need to be considered are as follows,

a) Linear actuators : Need to know the force and speed during the extension as well as retraction stroke. Also one has to select the cushioning (if needed), sealing etc.

b) Semi-rotary actuators : The parameters like angle of rotation, speed, torque required, cushioning, sealing etc. must be known. ($\theta < 300°$)

c) Rotary actuators : Some parameters required to know are acceleration and deceleration requirements, speed, torque, sealing requirements etc.

(3) Type of controls :

There are various control methods available to choose from, like manual, mechanical, hydraulic, pneumatic, electrical or combination. Apart from this control valve logic can differ from application to application.

(4) Sequence of operation :

There are various operations which includes in a system. These operations are interdependent and can be controlled by either,

a) Event based sequence, or b) Time based sequence.

(5) Operating conditions :

Following are few operating condition parameters that affects the design as well as component selection,

a) Location : The system must be designed by considering it's location. Heavy systems must be having good foundation or stability. The system must be fire proof if the system need to be used in fire hazardous environment.

b) Surrounding/Ambient conditions : The system should sustain various ambient conditions. For example in cooler region the hydraulic oil should be selected in such a way that it has cloud point very low. If the environment is dusty and corrosive, proper care must be taken in preventing components from dust and corrosive media.

c) Noise level : Some of the requirements may be having lower noise and clean operation etc. These can be achieved by adding various measures.

(6) Other requirements :

The other requirements which may need to considered are,

a) Type of operation : continuous or intermittent.

b) Level of automation

c) Daily hours of operations.

16.3.3 Components Selection

{sound design calculation

Depending upon application, the components must be selected. Whatever components used in the circuit must be selected on the basis of sound design calculations. These components are selected from the manufacturer's catalogue, which is given component wise in the following tables,

(1) Suction strainer :

This is nothing but the capacity of the suction strainer to pass the oil through it. This is given in terms of liters per minute (lpm) or meter cube per second (m^3/sec). Refer the Table 16.1. The model need to be selected is from S1, S2 and S3.

Model	Flow capacity (lpm)
S1	38
S2	76
S3	152

Table 16.1 : Suction strainer models

(2) Oil reservoir :

The oil reservoir is selected on the basis of it's storage capacity required for the particular operation. The storage capacity of the reservoir is far more than the actual oil needed to execute the operation. Generally it is minimum four times the capacity of pump. One can select the reservoir capacity 2 to 3 times of maximum flow rate.

(2 to 3)Q

Model	Capacity (lit.)
T1	40
T2	100
T3	250
T4	400
T5	600

Table 16.2 : Oil reservoir models

(3) Pressure gauge :

In general, dial range of pressure gauge to be twice the working pressure. e.g. If the working pressure is 15 bar, one must choose a pressure gauge of range 0 - 40 as shown in Table 16.3.

PG = 2×W.Pre

Model	Range (bar)
PG1	0 - 25
PG2	0 - 40
PG3	0 - 100
PG4	0 - 160

Table 16.3 : Pressure gauge models

(4) Selection of pump :

The hydraulic pump is selected on the basis of the pressure to be generated and the flow rate or delivery of the pump.

Model	Pressure (bar)	Delivery (m^3/sec)
P1	65	12×10^{-3}
P2	75	2×10^{-3}
P3	75	6×10^{-3}

Table 16.4 (a) : Hydraulic pump models

In case of vane pump, following table can be used to select a model.

Model	Delivery (lpm)		
	At 0 bar	At 35 bar	At 70 bar
P1	8.5	7.1	5.3
P2	12.9	11.4	9.5
P3	17.6	16.1	14.3
P4	25.1	23.8	22.4
P5	39	37.5	35.6

Table 16.4 (b) : Vane pump models

(5) Pressure relief valve :

Pressure relief valve are choosen on the basis of the working pressure and the flow rate of the pump.

Model	Flow range (lpm)	Maximum working pressure (bar)
R1	11.4	70
R2	19	210
R3	30.4	70
R4	57	105

Table 16.5 : Pressure relief-valve models

(6) Flow control valve :

The flow control valves are selected on the basis of the maximum working pressure and the flow range. Table 16.6 shows the typical models along with the specifications.

Model	Maximum working pressure (bar)	Flow range (lpm)
F1	70	0 - 4.1
F2	105	0 - 4.9
F3	105	0 - 16.3
F4	70	0 - 24.6

Table 16.6 : Flow control valve models

(7) Directional control valve :

This is also selected on the basis of maximum working pressure and the flow capacity. The three different models are given in the Table 16.7.

Model	Maximum working pressure (bar)	Flow capacity (lpm)
D1	350	19
D2	210	38
D3	210	76

Table 16.7 : Directional control valve models

(8) Check valve :

This is also selected by using maximum working pressure and flow capacity. These models are shown in Table 16.8.

Model	Maximum working pressure (bar)	Flow capacity (lpm)
C1	210	15.2
C2	210	30.4
C3	210	76

Table 16.8 : Check valve models

(9) Pilot operated check valve / Sequence valve :

Here also the selection is done using maximum working pressure and flow capacity, as shown in Table 16.9.

Model	Maximum working pressure (bar)	Flow capacity (lpm)
PO1	210	19
PO2	210	38
PO3	210	76

Table 16.9 : Pilot operated check valve models / sequence valve models

(10) Cylinder (Maximum working pressure : 210 bar)

The cylinder can be selected from following models A_1, A_2, A_3, A_4 or A_5. Depending upon application requirement you may select any model. As you go on increasing bore diameter, cylinder becomes safe for use, however it becomes bulky and expensive also. Table 16.10 shows these models -

If cyl. dia increases → safty in(
→ But increse in size caus
increase in cost & Bul

Model	Bore diameter (mm)	Rod diameter (mm)
A1	25	12.5
A2	40	16
A3	50	35
A4	75	45
A5	100	50

Table 16.10 : Cylinder models

(11) Motor models :

Sometimes, it is asked to select motor also for a particular application. In such a case following table will be given.

Model	Pressure (bar)	Volume displacement (m^3/rev)
M1	70	0.5×10^{-4}
M2	70	2×10^{-4}
M3	70	5×10^{-4}

Table 16.11 : Motor models

Note :

1) If you sum up all the parameters that are required to be calculated for the selection of any component listed above. These will be,

   a) Flow rate or delivery rate (lpm) [For both stroke].

   b) Maxing working/operating pressure (bar) [For both stroke]

   c) Power required (Watt)

2) Always select over capacity model. For example if you want to select suction strainer and the calculated value of flow capacity comes to be 39 or 40 (lpm). Then select model S2 instead of S1. It's preferred to have over capacity model than under capacity model. [Refer Table 16.1].

Selection criteria for system :

In short the selection criteria for hydraulic and pneumatic system can be as follows.

- Stroke
- Force
- Type of motion [Linear/Angular]
- Speed
- Size
- Service
- Sensitivity
- Safety and reliability
- Energy cost
- Controllability
- Handling
- Storage

16.3.4 Rough Design and Selection Procedure for Hydraulic System

Following is the stepwise design produce that need to be followed to calculate various system parameters and do the selection based on them.

Step I : Design of cylinder

Case (a) : We know the basic formula that co-relate area and pressure,

$$F_{ext} = p_{ext} \times A_p \quad \text{... (I)}$$

If suppose, force is given for the extension stroke and the pressure required to generate that force is also mentioned, then calculate area of piston (which is nothing but area of cylinder) from above formula. Here,

$$A_p = \frac{\pi}{4} D_p^2 \quad \text{... (II)}$$

Select model corresponding piston diameter (D_p).

Case (b) : Now, sometimes, pressure is not mentioned in the problem so in such a cases, select the model of cylinder in initial stage only and from force and model selected calculate the working pressure.

Step II : Flow rate / discharge

The formula used to calculate discharge is,

$$Q = A_p \times v_{ext} \quad \text{... (III)}$$

Where, Q = Discharge, m^3/s.

A_p = Cylinder area, m^2

v_{ext} = Velocity during extension stroke, m/s.

$$\boxed{v_{ext} = \frac{X \rightarrow \text{Stroke length}}{t \rightarrow \text{Time taken}}}$$

Some times following case may arrives,

Case (c) : Here forward stroke is divided into two parts like fast stroke and slow stroke (feeding). Then calculate, two different velocities and flow rates as follows,

i. For first part of forward stroke.

$$v_{ext1} = \frac{x_1}{t_1} \begin{matrix} \rightarrow \text{Distance moved during this part} \\ \rightarrow \text{Time taken} \end{matrix}$$

$$\therefore \quad Q_{ext1} = A_p \times v_{ext1}$$

ii. for second part of forward stroke,

$$v_{ext2} = \frac{x_2}{t_2} \begin{matrix} \rightarrow \text{Distance moved during this part} \\ \rightarrow \text{Time taken} \end{matrix}$$

$$\therefore \quad Q_{ext2} = A_p \times v_{ext2}$$

Stroke length and time taken will be mentioned in the problem itself.

Here select the maximum speed to calculate the flow rate, that means,

$Q_{ext1} = A_p \times v_{ext1}$ should be considered for further calculation, as it will take care of safety aspect.

Step III : Reapeat the same calculations for return stroke

Here,

$$p_{ret} = \frac{F_{ret}}{(A_p - A_r)} \quad \text{... (IV)}$$

Where, A_r = Rod area, m^2

$(A_p - A_r)$ = Annulus area, m^2

F_{ret} = Force encountered during return/retraction stroke

p_{ret} = Pressure, N/m^2,

Calculate the flow rate from,

$$Q_{ret} = (A_p - A_r) \times v_{ret} \quad \text{... (V)}$$

$$Q_{ret} = \frac{\pi}{4}(D_p^2 - D_r^2) \times v_{ret} \quad \text{... (VI)}$$

Where, D_p = Piston diameter, m

D_r = Rod diameter, m

v_{ret} = Speed during retraction stroke, m/s.

$$= \frac{X}{t} \begin{matrix} \rightarrow \text{Stroke length} \\ \rightarrow \text{Time taken} \end{matrix}$$

Note : For selecting the components, consider following,

a) Maximum working pressure p (it may be during forward stroke or return stroke).

b) Maximum discharge/flow rate Q (it may be during forward stroke or return stroke).

Step IV : Power

Calculate the power considering maximum p and maximum Q.

$$\therefore \quad \text{Power} = p \times Q, \text{ Watt.} \quad \text{... (VII)}$$

maximum

Step V : Selecting different components

From the above calculated values select the various components used in the hydraulic system. Just take care of following points while selecting components.

(1) Don't select under capacity component model. e.g. If you want to select pressure gauge for the maximum working pressure 27 bar, then instead of selecting near valued under capacity Pressure Gauge PG1, go for selecting PG2 of range (0 - 40 bar). [Refer Table 16.3]

(2) In case of oil reservoir, take the maximum flow rate multiplied by the factor 3 as it's capacity. e.g. If the maximum flow rate is 45 lit/s or lit/m, then reservoir oil capacity required will be 45 × 3 = 135 lit. Refer Table 16.2, select the reservoir mode I_3 of capacity 250 lit.

Reservoir cap. = 3 × Q lit

Step VI : Component selection summary

You can present the selected components along with their capacity in tabular form as shown below in Table 16.12.

Component	Model selected	Model capacity
Suction strainer	S1 / S2 / S3	... lpm
Oil reservoir	T1 / T2 ... / T5	... lit
Pressure gauge	PG1 / PG2 ... / PG4	... bar
Hydraulic pump	P1 / P2 ... / P5	... lpm, ... bar
Pressure relief valve	R1 / R2 ... / R4	... lpm, ... bar
Flow control valve	F1 / F2 ... / F4	... lpm, ... bar
Directional control valve	D1 / D2 / D3	... lpm, ... bar
Cylinder	A1 / A2 / ... / A5	D_p = ... mm, D_r = ... mm

Table 16.12 : Component selection summary

Ex. 16.9 : *A machine slide is moved by means of hydraulic cylinder. The motion of the cylinder is as follows.*

a) *Initially it moves through a distance of 200 mm against the load of 12 kN in 3 seconds.*

b) *It is followed by the working stroke of 100 mm against an effective load of 35 kN. The feed rate during this part of the stroke is required to be between 0.5 to 1 m/min.*

c) *Use regeneration for retraction. Meter-in circuit is used for speed control. Draw and design the hydraulic circuit. Mention the selection requirements of flow control valve, check valve, pressure relief valve, pump, strainer and reservoir.*

A. Motor

Model	Pressure (bar)	Volume displacement (m^3/rev)
M1	70	0.5×10^{-4}
M2	70	2×10^{-4}
M3	70	5×10^{-4}

B. Pump

Model	Pressure (bar)	Delivery (m^3/s)
P1	65	12×10^{-3}
P2	75	2×10^{-3}
P3	75	6×10^{-3}

C. DCV

Model	Pressure (bar)	Delivery (m^3/s)
D1	100	12×10^{-3}
D2	90	2×10^{-3}
D3	85	6×10^{-3}

D. Check valve

Model	Pressure (bar)	Delivery (lpm)
C1	85	12
C2	100	2
C3	80	6

E. Relief valve

Model	Pressure (bar)	Delivery (lpm)
R1	100	12
R2	110	2
R3	105	6

Sol. :

SPPU : Dec.-13, Marks 18

Step I : Circuit diagram for the above operation

Note : The point mentioned in question.

i) Meter-in circuit is used for speed control.

ii) Forward stroke is split into two parts i.e. 200 mm length travel and 100 mm length travel.

The circuit diagram for the given system is as follows, which is similar to that of transverse and feed circuit.

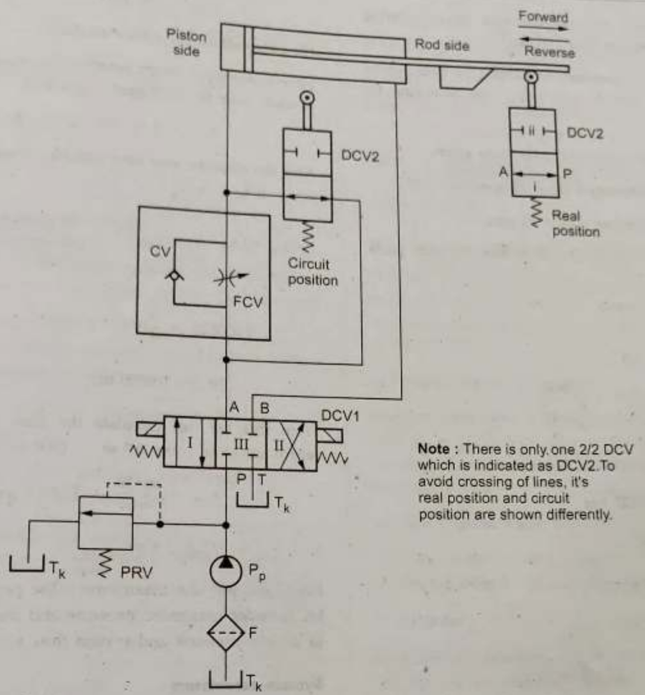

Fig. 16.10 : Hydraulic circuit for the problem

Step II : Design stage

Given, X_1 = 200 mm = 0.2 m, X_2 = 100 mm = 0.1 m

t_1 = 3 sec. , F_{ext1} = 12 kN, F_{ext2} = 35 kN, v_{ext2} = 0.5 to 1 m/min

(A) Calculations for forward stroke :

It is mentioned in the problem that initial movement is through distance of 200 mm against the effective load of 12000 N (12 kN) in 3 seconds, so extension speed will be,

$$v_{ext1} = \frac{0.2}{3}$$

$$= \frac{X \rightarrow \text{ Distance moved during this part}}{t \rightarrow \text{Time taken}}$$

$$\therefore \quad \boxed{v_{ext1} = 0.067 \text{ m/s}}$$

For the second part of 100 mm, the feed rate is mentioned between 0.5 to 1 m/min.

V_{ext2} = 1 m/min = 0.0167 m/s $\because$ Selecting maximum feed rate for safety point of view.

Now, there are two ways to design further,

Way : 1) Consider any one model of cylinder and calculate the pressure generated from (p_{ext} = F_{ext}/A_p).

Scanned with CamScanner

OR

Way : 2) Calculate the cylinder area by considering maximum working pressure 210 bar.

Note : This is first problem, so solving by both ways. Students are adviced to follow any one according to their comfort.

Way : 1) Selecting model "A5" from data given,

$\therefore$ Bore/piston diameter = D_p = 100 mm

Rod diameter = D_r = 50 mm.

Now, calculating pressure and flow rate for both parts of forward stroke.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

a) For first part :

$$\therefore \quad p_{ext1} = \frac{F_{ext1}}{A_p} = \frac{12000}{\frac{\pi}{4}(0.1)^2}$$

$$\boxed{\begin{aligned} p_{ext1} &= 15.27\times 10^5\ N/m^2 \\ p_{ext1} &= 15.27\ \text{bar} \end{aligned}}$$

Flow rate for this part,

$$Q_{ext1} = A_p v_{ext1}$$

$$= \frac{\pi}{4}D_p^2\times v_{ext1}$$

$$Q_{ext1} = \frac{\pi}{4}(0.1)^2\times 0.067$$

$$\boxed{\begin{aligned} Q_{ext1} &= 5.26\times 10^{-4}\ m^3/s \\ Q_{ext1} &= 31.55\ \text{lpm} \end{aligned}}$$

Note : $1\ m^3/s = 60\times 10^3$ lpm

b) For second part of stroke :

$$p_{ext2} = \frac{F_{ext2}}{A_p} = \frac{35000}{\frac{\pi}{4}\times(0.1)^2}$$

$$\boxed{\begin{aligned} p_{ext2} &= 44.56\times 10^5\ N/m^2 \\ p_{ext2} &= 44.56\ \text{bar} \end{aligned}}$$

Flow rate for this part,

$$Q_{ext2} = A_p\times v_{ext2} = \frac{\pi}{4}(0.1)^2\times 0.0167$$

$$\boxed{\begin{aligned} Q_{ext2} &= 1.312\times 10^{-4}\ m^3/s \\ Q_{ext2} &= 7.87\ \text{lpm} \end{aligned}}$$

(B) Calculations for return stroke :

Here to calculate return velocity, the maximum flow rate is taken from forward stroke, which is

$$Q_{ret} = 5.26\times 10^{-4}\ m^3/s = 31.55\ \text{lpm}.$$

Also the effective area here will be the annulus area which is $(A_p - A_r)$.

$$\therefore\ Q_{ret} = (A_p - A_r)\times v_{ret}$$

For complete stroke of 300 mm, same speed and flow is maintained.

$$0.000526 = \frac{\pi}{4}(0.1^2 - 0.05^2)\times v_{ret}$$

$$\therefore \quad \boxed{v_{ret} = 0.0893\ m/s}$$

From this we can calculate the time required for the return stroke to cover 0.3 m (300 mm) distance.

$$\therefore \quad v_{ret} = \frac{\text{stroke}}{\text{time}} \quad \therefore\ \text{Time} = \frac{0.3}{0.0893}$$

$$\boxed{\text{Time} = 3.35\ \text{sec}}$$

Here, just put the maximum value parameters together i.e. consider maximum pressure and maximum flow rate as system pressure and system flow rate or discharge.

System parameters :

a) Maximum working pressure

$$p_{ext2} = p = 44.56\ \text{bar}$$

(During second part of forward stroke)

b) Maximum flow rate

$$Q_{ext1} = Q = 5.26\times 10^{-4}\ m^3/s = 31.55\ \text{lpm}$$

(During the first part of the forward stroke).

From this we can calculate the power required by the system,

$$\therefore \quad \text{Power} = P = 44.56\times 10^5\times 5.26\times 10^{-4} = p\times Q$$

$$\boxed{P = 2343.85\ \text{Watt}}$$

$P_f(Q_{min}) = 2 \times Q_{max}$

Way : 2) Considering maximum working pressure = 210 bar.

$$\therefore \quad p_{ext} = \frac{F_{ext}}{A_p} \qquad \text{Take maximum force} = 35 \text{ kN}$$

$$\therefore \quad A_p = \frac{35 \times 10^3}{210 \times 10^5}$$

$$A_p = 1.67 \times 10^{-3}$$

$$\therefore \quad \frac{\pi}{4} D_p^2 = 1.67 \times 10^{-3}$$

$$\therefore \quad \boxed{D_p = 0.046 \text{ m} = 46 \text{ mm}}$$

Note : As assumed maximum pressure value decreases, the piston diameter increases, when load/force is constant.

Here the model will be selected is A3 whose piston diameter = 50 mm and rod diameter = 35 mm.

From here onwards follows the same procedure followed in the way : 1).

Further one can write the abstract of the design calculation in tabular form as follows.

Sr. No.	Stroke Parameter	First part of forward stroke (Area : A_p)	Second part of forward stroke (Area : A_p)	Return stroke (Area : $A_p - A_r$)
1.	Force (kN)	12	35	-
2.	Area (m^2)	0.00785	0.00785	0.00589
3.	Pressure (bar)	15.27	44.56	-
4.	Discharge (lpm)	31.55	7.87	31.55

Step III : Selection of components

Following component models are selected.

1) Oil reservoir :

By thumb rule, reservoir capacity should be 2 to 3 times the maximum flow rate.

$$\therefore \quad \text{Capacity} = 3 \times Q = 3 \times 31.55$$

$$\boxed{\text{Capacity} = 94.65 \text{ lit.}}$$

Refer Table 16.2, the model of reservoir selected is **T2**.

2) Suction strainer :

Maximum flow rate is 31.55 lpm hence from Table 16.1 selecting model **S1** as suction strainer.

3) Pump :

From the Table 16.4 (a) selecting model **P1** for flow rate 0.5×10^{-3} m^3/s and pressure of 44.56 bar.

Note : Pump minimum lpm can be also calculate as, 2 × Maximum flow rate and then you can select different model.

4) Directional Control Valve (DCV) :

Both the DCV's are selected from the Table 16.7 on the basis of maximum working pressure (44.56 bar) and maximum flow rate (31.55 lpm). So the selected model of DCV is **D3**.

5) Pressure Relief Valve (PRV) :

Pressure relief valve is also selected from P = 44.56 bar and Q = 31.55 lpm. Hence the selected model that satisfies these two requirement is **R4** which is taken from Table 16.5.

6) Flow Control Valve (FCV) :

The flow control valve satisfying the system conditions is selected from Table 16.6. The model selected is **F4**.

7) Cylinder :

It is already selected by considering safety at pressure 210 bar. Hence model **A5** is selected.

Finally you can put these selected components in tabular form.

Component	Model selected	Model capacity
Oil reservoir	T2	100 lit.
Suction strainer	S1	38 lpm
Pump	P1	12×10^{-3} m^3/s, 65 bar
Directional control valve	D3	76 lpm, 210 bar
Pressure relief valve	R4	57 lpm, 105 bar
Flow control valve	F4	0 - 24.6 lpm, 70 bar
Cylinder	A5	D_p = 100 mm, D_r = 50 mm

Table 16.13 : Component selected for the application