Module- 9 : Pneumatic Systems & Components

Lecture - 34 : Air Preparation- Compressor & Accessories

Introduction to Pneumatics & Air Preparation :

Contrary to the hydraulic system pneumatic systems use *pressurized compressible* fluids.
Air is the most common *compressible* fluid although some gasses are also used in pneumatic drives, specially where the gas itself is one of the product or byproduct where the system is being used.
However, air is the environment friendly, cheap, safe and readily available fluid media for pneumatics.
For general purpose actuator drives manageable with low pressure (usually below 2 MPa) pneumatic system is preferred over hydraulic system, where pressure may be as high as 80 MPa.

However, position or actuation at controlled velocity is not achievable with compressible fluids.

Pneumatic applications in such areas are rare and where hydraulic oil cannot be used due to environment reason.

Also, less accurate performance is acceptable.

In pneumatic systems compressors, typically the vane, lobe, screw or cylindrical piston type positive displacement machines, are used to compress and store the air.

The compressed and stored air (or gas) used in operatic pneumatic devices when ever required by tapping in regulated manner, the air from storage vessel/tank (normally attached to or integral with the compressor).

Usually compressor is stopped at a set higher pressure (than maximum operating pressure).

It automatically starts again when the stored air pressure reaches a minimum set value.

Usually from a centralized store air is supplied to various locations of an entire industrial plant.

After filtering and before the end applications a fine mist of lubricant is mixed to the air to prevent wear in the moving components.

Air dryer is also used to eliminate moisture from air. A muffler is put at the exhaust to reduce noise.

Fig.-1 in next slide shows a typical Pneumatic System.

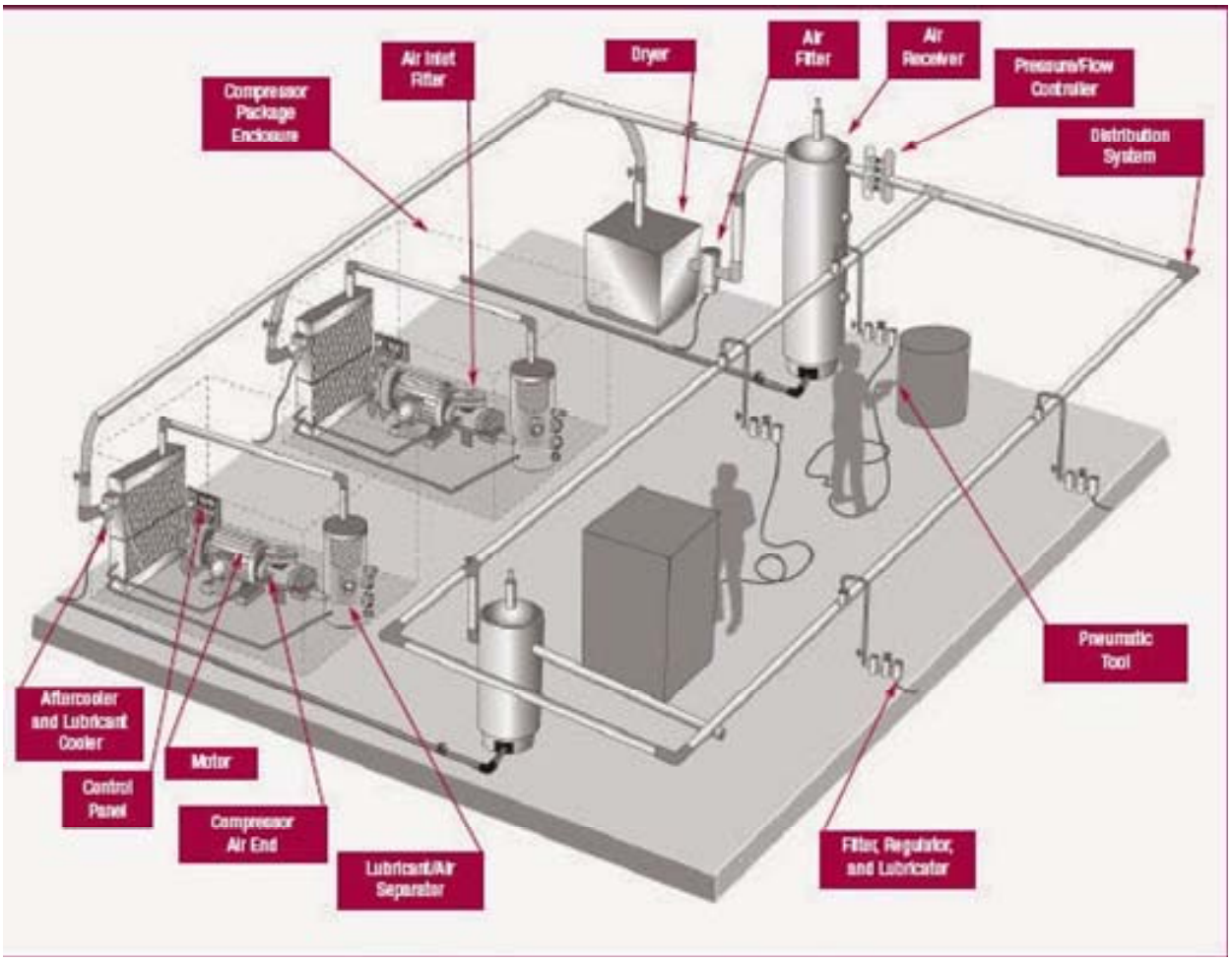


Fig.-1: Pneumatic System in a Workshop /Industry

In preparation of *useable pressurized compressible* fluids we need following major components:

1. Compressor,
2. Receiver / Reservoir Tank,
3. Starting Unloader & Controller,
4. Filters,
5. Regulators / Valves,
6. Lubricators,
7. Mufflers / Silencer,
8. After Cooler,
9. Air Dryers, and
10. Indicators (Pressure, Temperature etc.).

Type of Compressor:

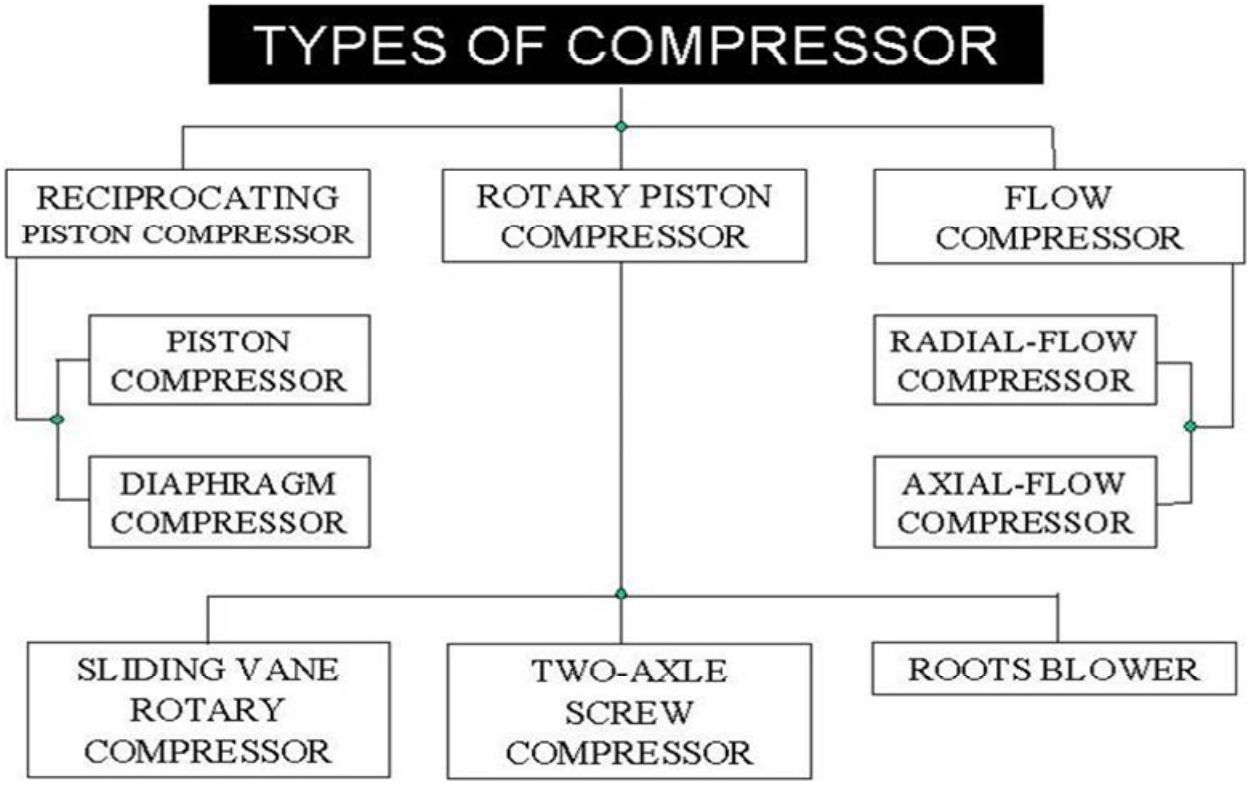


Fig. 2: Different types of compressor.

Reciprocating Type Compressors :

Reciprocating cylindrical single piston-cylinder type compressor may be of *single* or *multi* stage piston type [Fig.- 3], depending on pressure as shown below.

No. of Stages	Pressure Capacity (MPa)
1	1
2	3.5
3	17.5
4	35

To dissipate generated heat, due to molecular reaction in the air being compressed, cooling systems- 'natural air draft' to 'forced water cooling', are employed.

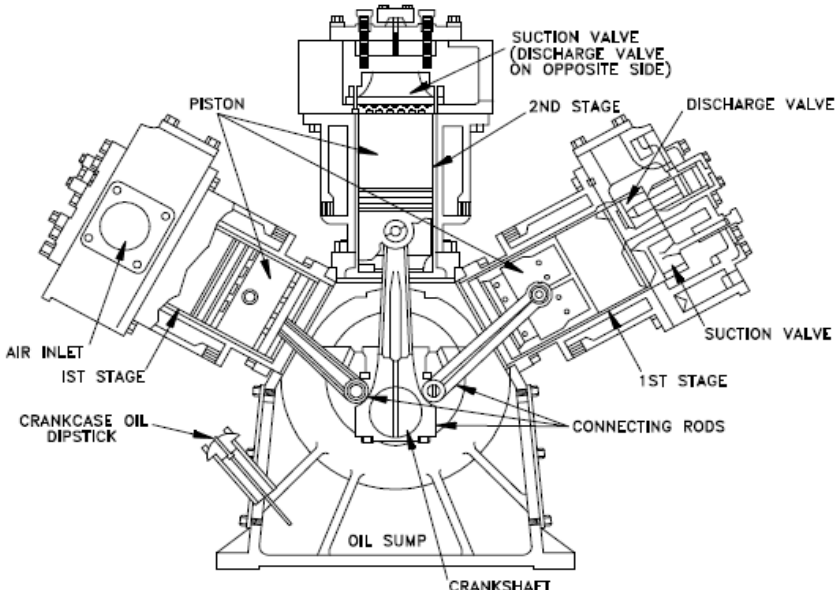


Fig.- 3 (a) : Two stage Reciprocating Compressor (Schematic View).

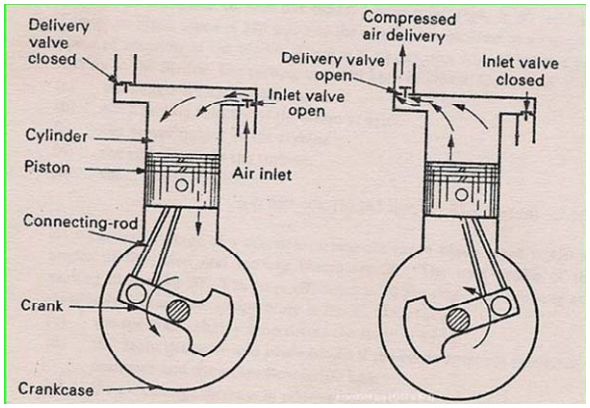


Fig.- 3 (b) : How Compression Occurs.

With a 0.54 m^3 capacity receiver (storage tank) and compressing capacity of 1.3 $m^3/$ min at 1.23 MPa (max) power of the motor is 6.25 kW typical.

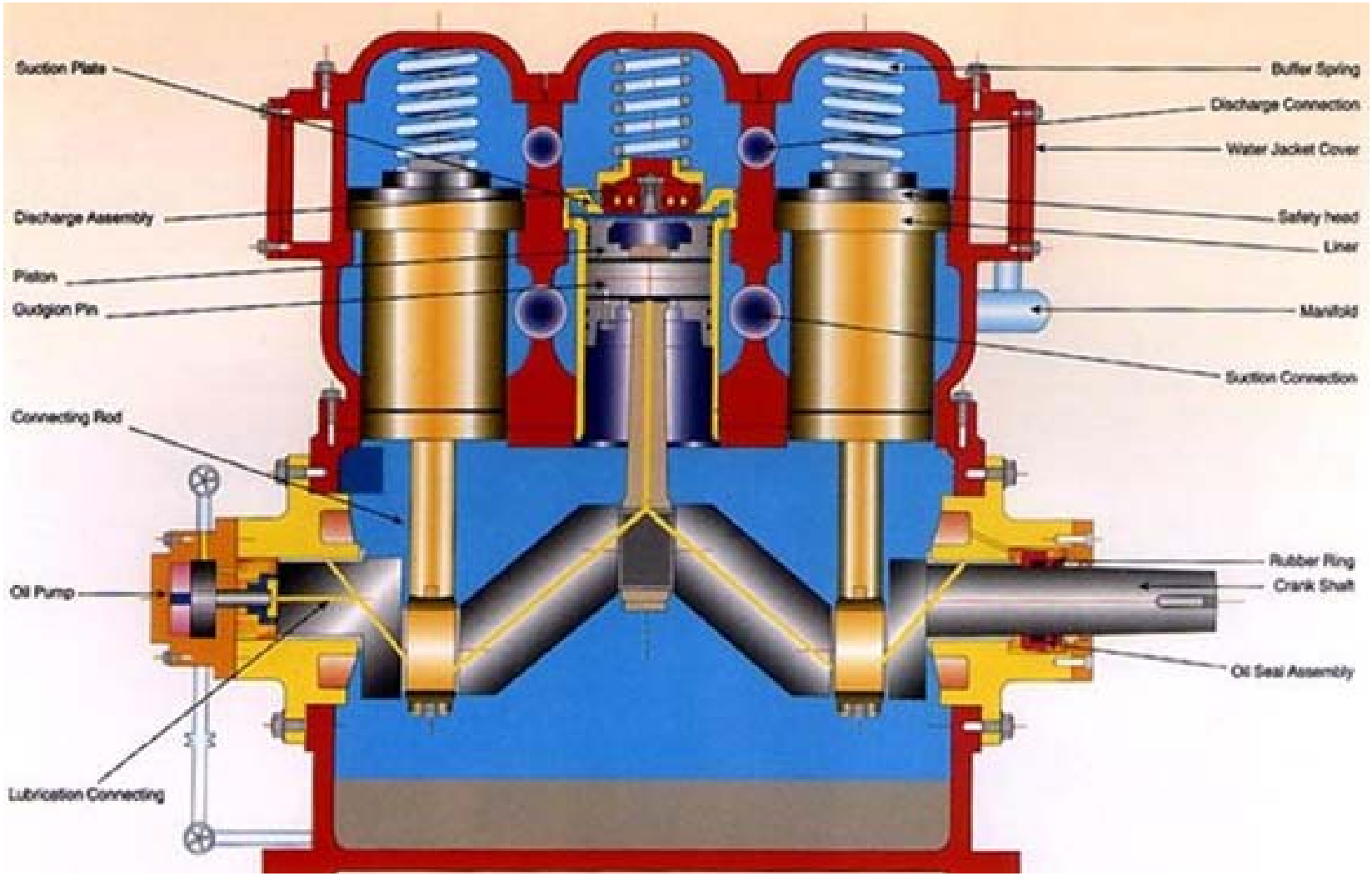


Fig.- 3 (c) : Two stage Reciprocating Compressor (Sectional View).

Compressor Starting Unloader Controls :

An air compressor is usually made auto controlled to start, run, supply pressurized air as needed, stop when receiver is filled with maximum capacity (pressure) and be ready to start again when pressure reaches at its lower limit.
A few methods are employed for such control.
Pressure switch control is one of them.
Once a pressure is established after first start up, a *starting unloader* is required to prevent the established air pressure from pushing back against the compressor , preventing it from coming up to speed.
Fig. 4 shows such an unloader control system.
When motor is off by pressure switch it also bled off the trapped air between the piston head and the receiver's check valve.
It enables the compressor to start again whenever needed.

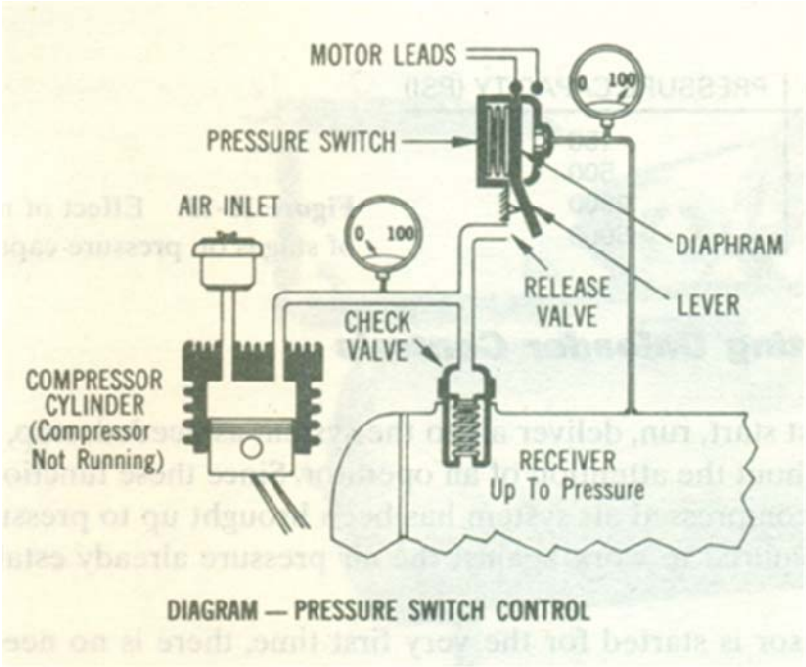


Fig. 4 : Unloader- Control with Pressure Switch [ref.- 1].

Fig. 5 shows the unloader control works on centrifugal force principle.

In such an unloader control system greater protection is ensured as the unloader valve is operated by the compressor itself rather than the pressure switch.

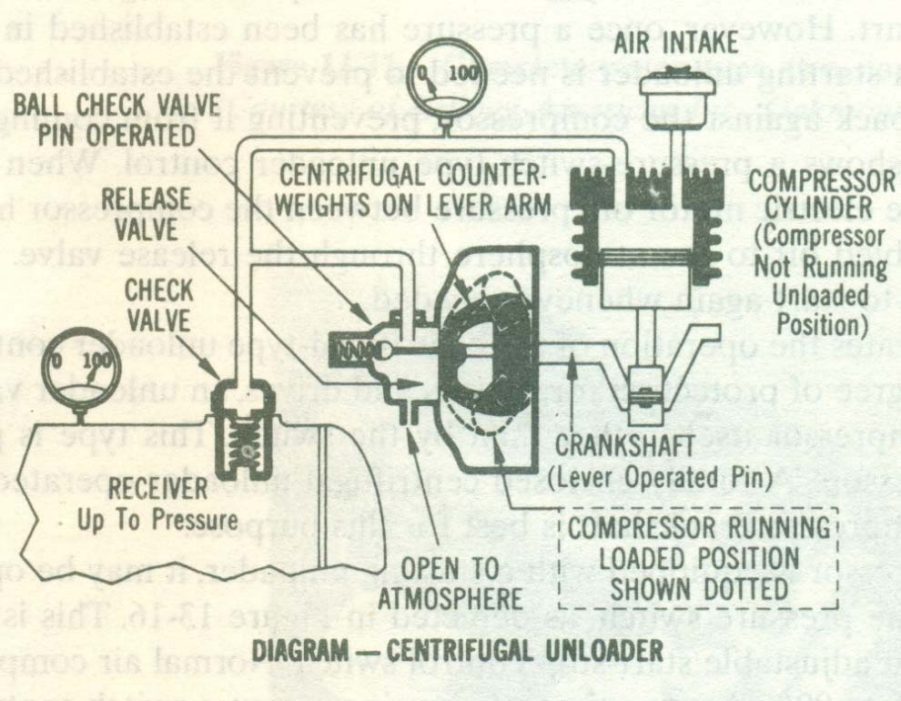


Fig. 5 : Unloader- Centrifugal load Controller [Ref. 1].

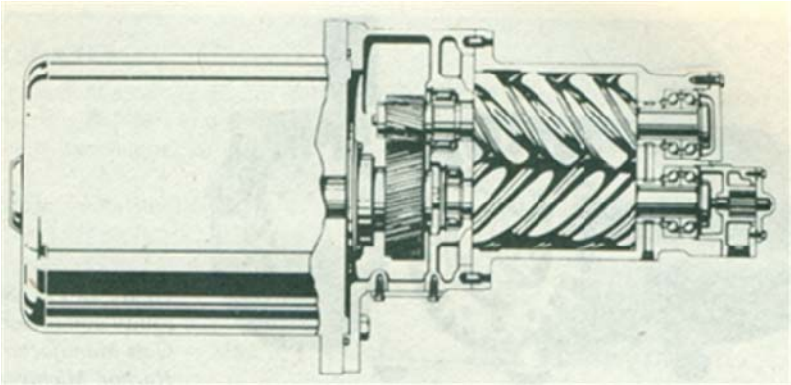
Such normal controls, described above, are used where the compressor running time is 50% to 80% of total (working) time.

For the compressor starting frequently (say within every after 6 minutes) or running time exceeds 80% of total time more sophisticated constant speed control is adopted.

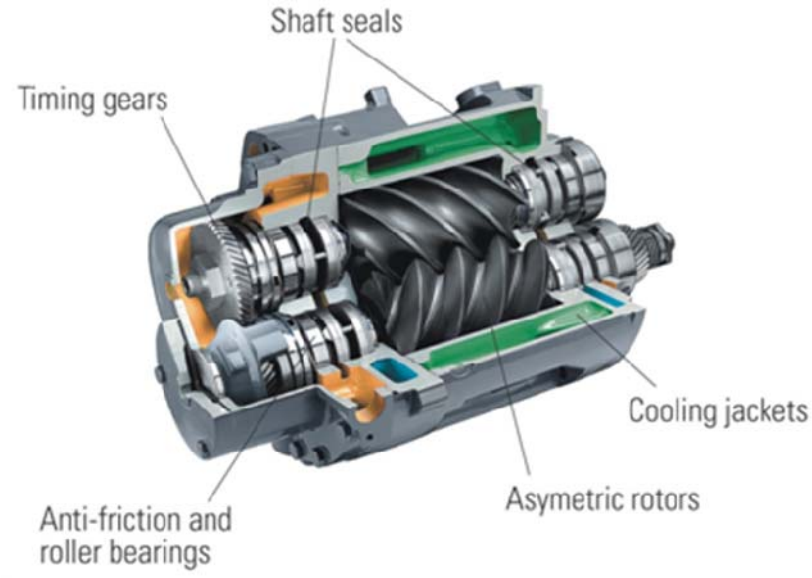
Screw Compressors :

Rotary positive displacement type compressors, such as screw (Fig. 6), gear etc. type showed better performances and longer lives than the reciprocating type compressors due to development in materials and manufacturing technologies.

As in screw type, the entrapped volume gradually squeezed to a smaller and pressurized volume for to be stored in receiver (reservoir tank).



(a) Schematic sectional view.



(b) Photographic cut View.

Fig. 6 : Screw Compressor – Single Stage [Ref. 1].

A capacity of 0.7 m^3/sec at 0.85 MPa is typical for a single stage screw compressor.

Screw Compressors :

Fig. 7 shows the cross sectional view of screw elements. It looks like Novicov gear set. In fact gear (helical) type compressor (Fig.-8) may be regarded as short screw compressor with a different inlet-outlet arrangement.

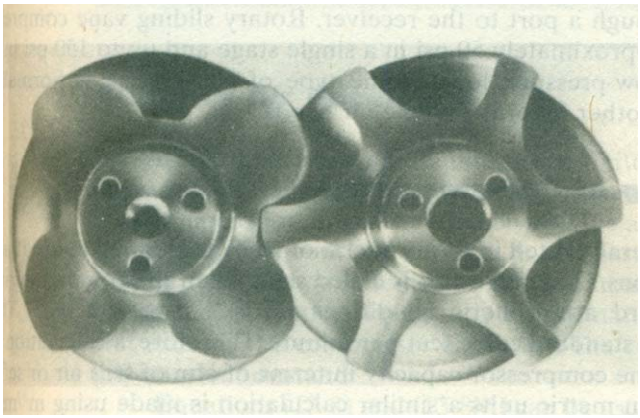
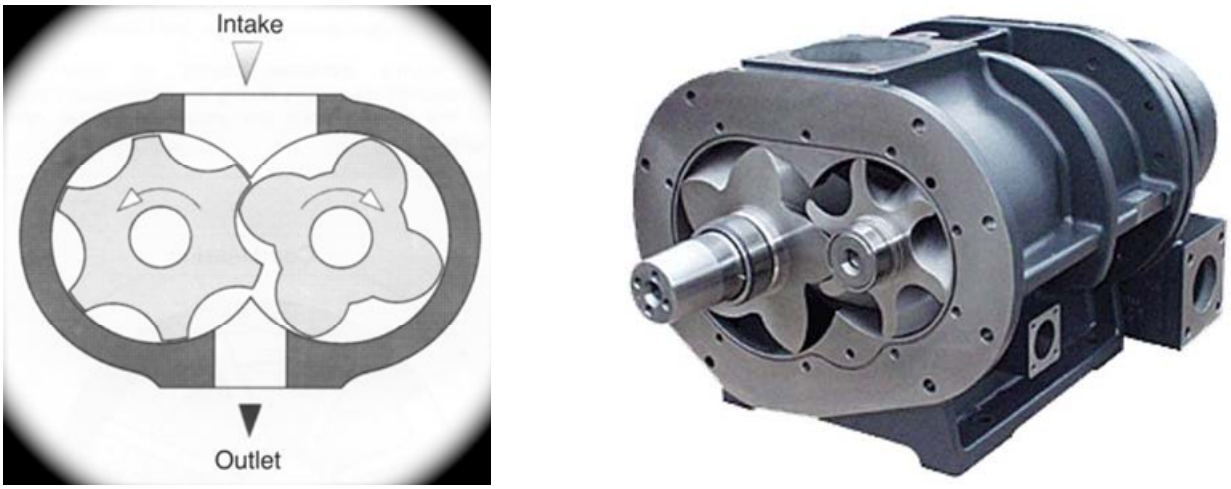


Fig. 7 : Cross sectional view of Screw Compressor with unsymmetrical profiles [Ref. 1].



(a) Schematic sectional view. (b) Photographic End View.

Fig. 8 : Gear type Compressor with unsymmetrical profiles.

Gear / Lobe type Compressors :

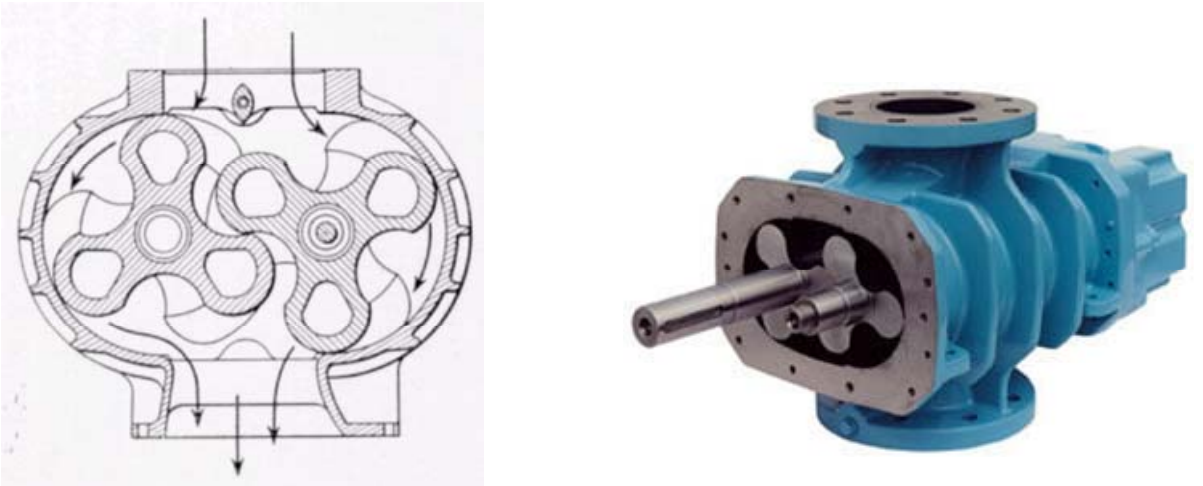
As described, screw set with much smaller length may act as also gear/lobe type compressor (Fig. 8 & 9). The inlet- outlet will different and like a gear pump.

The length (axial direction) to be considered as width of the gear and thread as tooth.

Also, the teeth may be straight and not helical.

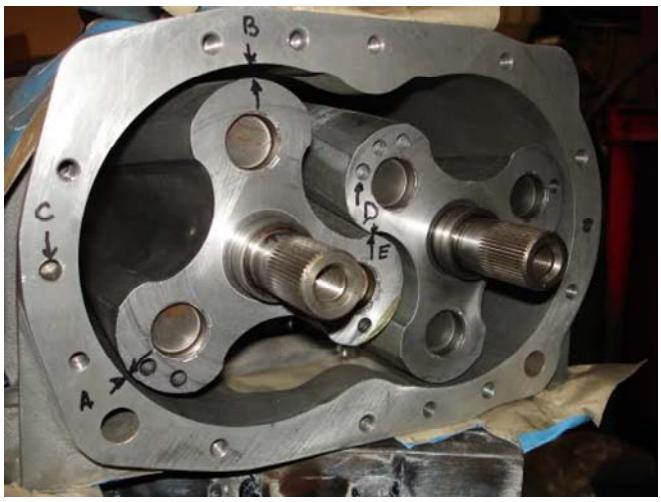
However, capacity wise the screw type is superior although has more friction.

Losses due to friction are minimized using liquid lubricant which also carry heat as well as mixed with compressed and pre-filtered air.

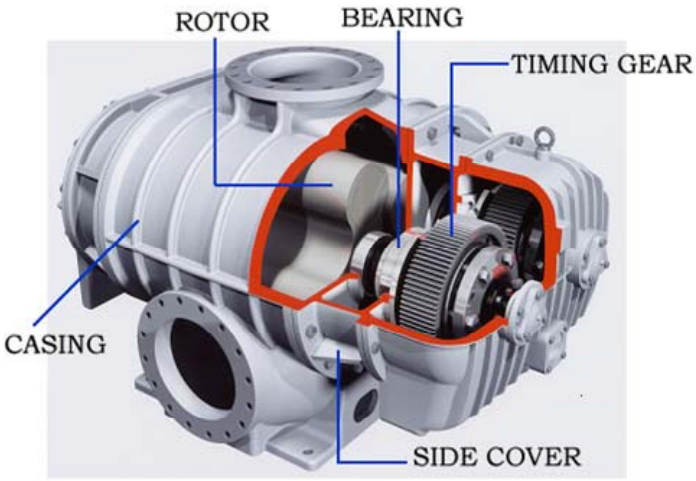


(a) Schematic sectional view. (b) Photographic End View.

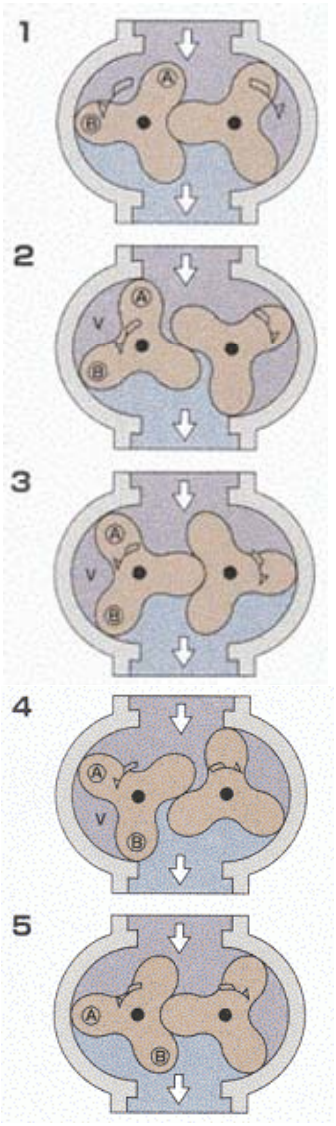
Fig. 9 : Lobe type Compressor with unsymmetrical profiles.



(a) Photographic End View.



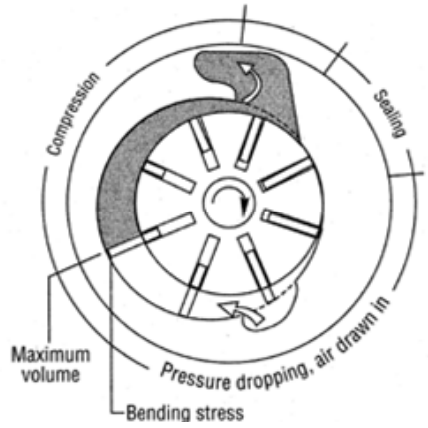
(b) Constructional Feature.



(c) Functional Sequences.

Fig. 10 : Lobe type Compressor with Symmetrical profiles.

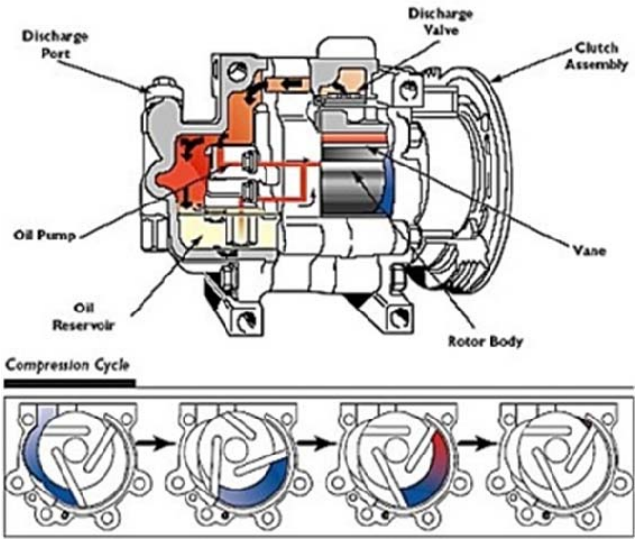
Vane Compressor:



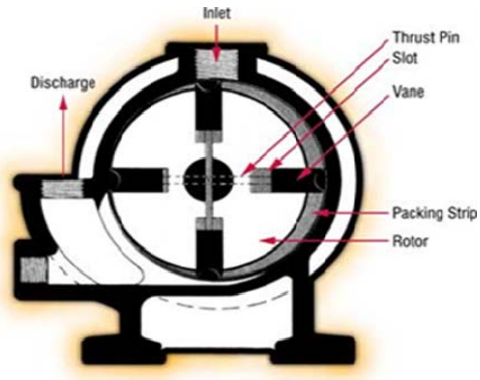
(a) :Schematic View



(b) : Photographic View.



(c) : Constructional & Functional Feature.



(d) : (Another) Functional Feature.

Fig. 11 : Vane type Compressor.

A capacity of 2.5 m^3/sec at 0.35 MPa is single stage and 1 MPa in double stage typical for a vane compressor (Fig. 11).

Air Capacity Rating of Compressor:

The rating of a compressor is usually expressed as its storage flow in rate capacity of free air i.e. at atmospheric pressure (0.101 MPa absolute) and temperature (20^{o} Celsius). The flow rate is then called standard flow rate and usually expressed as- m^3/sec (standard).

Consider the general gas law equation:

$$V_1 = V_2 \left(\frac{p_2}{p_1} \right) \left(\frac{T_1}{T_2} \right) \qquad \ldots 9.34\text{-}1$$

Where, V , p and T indicate volume, pressure and temperature respectively; and subscripts 1 and 2 represent compressor's inlet and outlet parameters.

Dividing both sides by time and with Q as the volume flow rate:

$$Q_1 = Q_2 \left(\frac{p_2}{p_1} \right) \left(\frac{T_1}{T_2} \right) \qquad \ldots 9.34\text{-}2$$

A typical numerical Example of Compressor Rating [1] :

***Problem*:** In a large scale system the air is used at a rate of $0.0142\ m^3$/sec at 0.875 MPa and 32.22^{o} Celsius . Considering atmospheric pressure and temperature as 0.101 MPa absolute and 21.11^{o} Celsius respectively, estimate the free air flow capacity of the compressor.

***Solution*:**

Substituting values in equation (9.34-2) yields to give flow of free air as:

$$\begin{aligned} Q_1 &= Q_2 \left(\frac{p_2}{p_1} \right) \left(\frac{T_1}{T_2} \right) \\ &= 0.0142 \times \frac{0.875 + 0.101}{0.101} \times \frac{273 + 21.11}{273 + 32.22} \\ &= 0.132\ m^3 / \sec \end{aligned}$$

[*Note : Absolute Temperature is taken as* - 273^{o} Celsius.]

This means that in order to have an air of 0.875 MPa and 32.22^{o} Celsius at a rate of 0.0142 m^{3}/sec by the receiver of a compressor it needs a supply of free air 0.132 m^{3}/sec at 0.101 MPa and 21.11^{o} Celsius.

Sizing of Air Receiver :

Apart from the storage of air a receiver i.e., storage tank of a compressor dampen the pressure fluctuation and supply the pressure to utilization ends at constant pressure.

In many cases among all pneumatic systems at the utilization end a few may demand the higher flow rate, at staring, which exceeds the capacity of the compressor.

A well designed receiver is capable of handling such transient situations.

A receiver size is expressed as:

$$V_r = \frac{p_a t\left(Q_r - Q_c\right)}{\left(p_{\max} - p_{\min}\right)} \qquad \ldots 9.34\text{-}3$$

Where,

t = time that receiver can supply required amount of air,

Q_r = consumption rate of pneumatic system,

Q_c = output flow rate of compressor,

$p_{\max}$ = maximum pressure level in receiver,

$p_{\min}$ = minimum pressure level in receiver, and

V_r = receiver size.

Numerical Example- Receiver size Estimation :

Problem :

a) Calculate the required size of a receiver for a system consuming 0.01 m^{3}/sec (standard) for 6 minutes between a pressure limits 0.7 MPa and 0.56 MPa, before the compressor resumes operation.

b) What size is required if the compressor has to run and deliver air at 0.002 m^{3}/sec, standard (i.e. output flow rate of the compressor) ?

Solution **:**

a) $$V_r = \frac{0.101 \times (6 \times 60) \times (0.01 - 0)}{(0.7 - 0.56)} = 2.6\ m^3$$

Note : Pressures at numerator and denominator have the same unit.

b) $$V_r = \frac{0.101 \times (6 \times 60) \times (0.01 - 0.002)}{(0.7 - 0.56)} = 2.08\ m^3$$

Note : Generally in selection of a reservoir tank (receiver) size 50% oversize is recommended consider 25% for overload and 25% for an expansion, if needed in future.

Power required to Drive a Compressor **:**

A semi empirical formula, as follows, is used to estimate the theoretical power required to drive a compressor. In recommending actual motor size, compressor's efficiency is to be considered.

$$P_{kW_{ideal}} = 3.5 \frac{p_{in} Q}{10^3} \left[\left(\frac{p_{out}}{p_{in}} \right)^{0.286} - 1 \right] kW \qquad \ldots 9.34\text{-}4$$

$$P_{kW_{motor}} = \frac{P_{kW_{ideal}}}{\eta_{com,ol}} \qquad \ldots 9.34\text{-}5$$

Where,

Q = flow rate (standard) in m^3/sec,

p_{in} = inlet atmospheric pressure in Pascal (absolute),

p_{out} = outlet pressure in Pascal (absolute), and

$\eta_{com,ol}$ = overall efficiency of compressor.

Numerical Example- Power Estimation **:**

Problem **:**

Determine the motor power required to drive a compressor, having overall efficiency of 75%, that delivering 0.047 m^3/sec (standard) at a pressure of 0.7 MPa.

Solution **:**

Given Data:

$p_{in} = 0.101 \times 10^6$ Pascal (absolute),

$p_{out} = (0.7 + 0.101) \times 10^6 = 0.801 \times 10^6$ Pascal (absolute),

$Q = 0.047$ m^3/sec, and

$\eta_{com,ol} = 0.75$

Substituting the values in eqn. 9.35-4:

$$P_{kW_{ideal}} = 3.5 \frac{(0.101 \times 10^6) \times 0.047}{10^3} \times \left[\left(\frac{0.801}{0.101} \right)^{0.286} - 1 \right] kW$$

$$= 16.61 \times [1.8 - 1] \quad = 13.3\ kW$$

Therefore, actual motor power:

$$P_{kW_{motor}} = \frac{13.3}{0.75} = 17.73\ kW$$

Recommended motor power is 18 kW.

A few essential components :

Fluid conditioners : To make the natural air more useable for pneumatic systems some essential devices are employed.
Those are (i) Filters, (ii) Regulators, (iii) Lubricators, (iv) Mufflers and (v) Air Dryers.

Air Filters : Filters (not the strainer at suction) are used to remove fine contaminants (5 to 50 μm) from air before allowing it to enter into pneumatic components like valves and actuators.

(Fig. 12) shows a typical air filter and its symbol used in circuit.

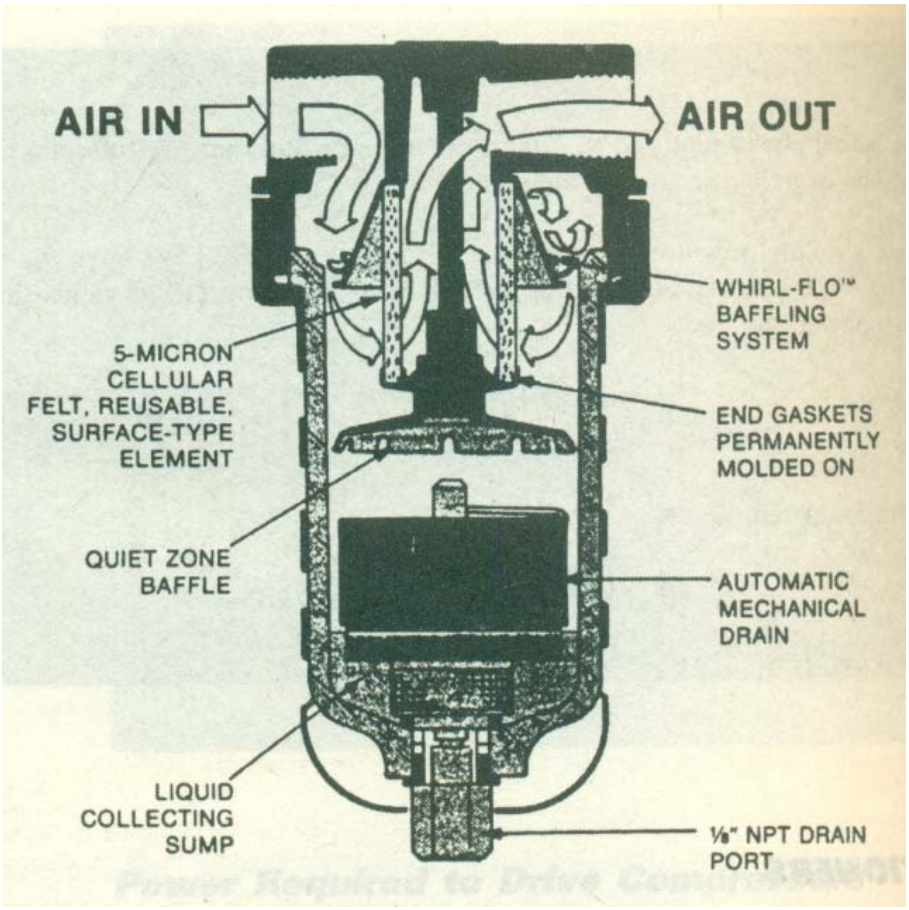


Fig. 12 : Air Filter used in Compressor. [Ref.1]

Air Pressure Regulator :

It regulates the pressure at output at a set constant value irrespective of pressure (within a range) at inlet. Design features of a regulator is shown in (Fig. 13).

A is the inlet. Compression of spring *C* is adjusted by rotating the knob *B*. Diaphragm *D* and main valve spool *E* activate, allowing inlet air to pass through seat area at *G*, to outlet at desired pressure (depends on the adjustment of knob *B*). The outlet air at downstream, being sensed by aspirator tube *F* , activates the air chamber at *H* . It regulates the spring (*C*) compression to adjust the output pressure constant. Stem *J* is lifted to relive the excess air in chamber *H*.

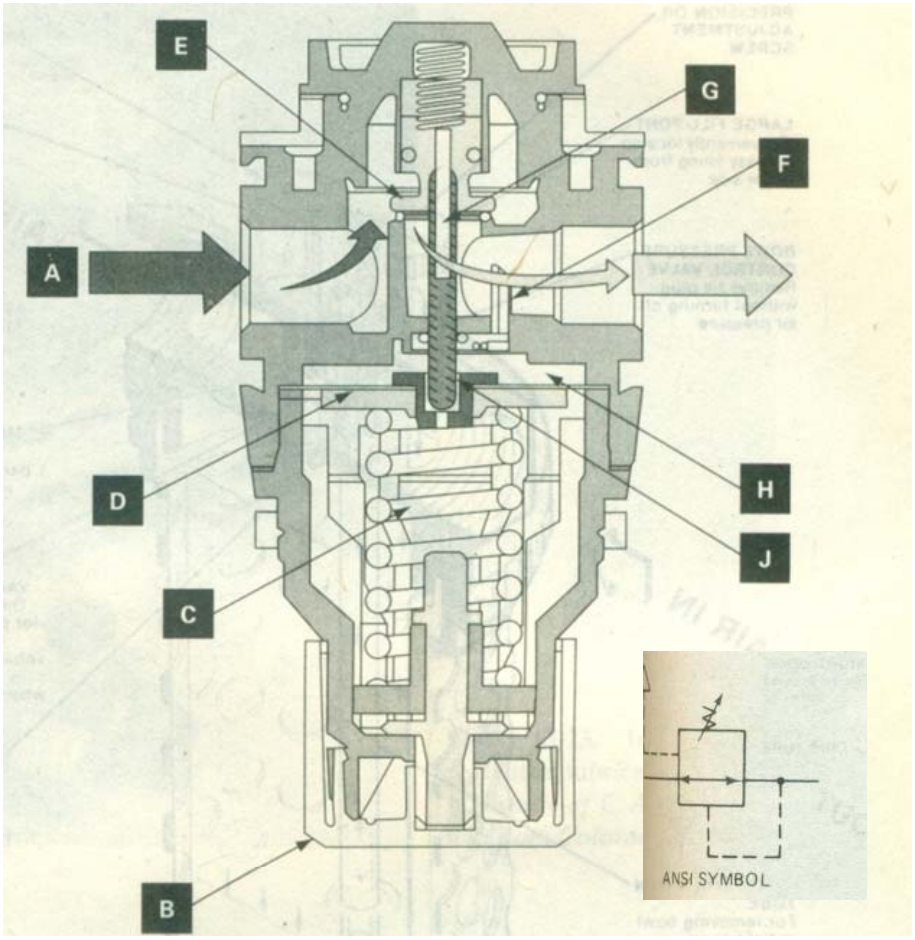


Fig. 13 : Air Pressure Regulator. [Ref.1]

Bibliography :

1. Esposito, A. Fluid Power with applications, 6th. Edn., Prentice Hall India, 2006, ISBN: 1-7758-580-0.
2. Joji, P. Pneumatic Controls, 1st. Edn., Wiley India Pvt. Ltd., 2008, ISBN: 978-81-265-1542-4.
3. Ilango, S. & Soundararajan, V. Introduction to Hydraulics and pneumatics, PHI, 2007, ISBN:978-81-203-3079-5.