Chapter 2

Pneumatic Control System

Pneumatic Control System (PCS), use compressed air to operate actuators, sensors, relays & other control equipment. Pneumatic controls are powered by compressed air, usually 15 to 20 psig pressures although higher pressures are occasionally used for operating very large valves or dampers.

PCS differ from other control systems in several ways with some distinct advantages:

1- Pneumatic equipment is inherently proportional (modulating), as air pressure can be modulated with infinite variation over the control range, but can be providing two-position control when required.
2- Many control sequences and combination are possible with relatively simple equipment. Because of their simplicity and low cost, and less maintenance cost.
3- Pneumatic equipment is suitable when explosion hazards exist.
4- The installed cost of the PCS and its materials may be lower.

Because of their simplicity and low cost, pneumatic controls are frequently found on commercial and industrial installations where more than eight or ten devices are used. If only a few control components are needed, electronic or electric controls may be less costly than pneumatic controls because an air compressor and pneumatic piping are not required.

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2-1 Basic Pneumatic Control System

A PCS is made up of the following elements: ***Compressed air supply system, mainline distribution system, branch lines***, sensors, controllers, actuators and final control elements.

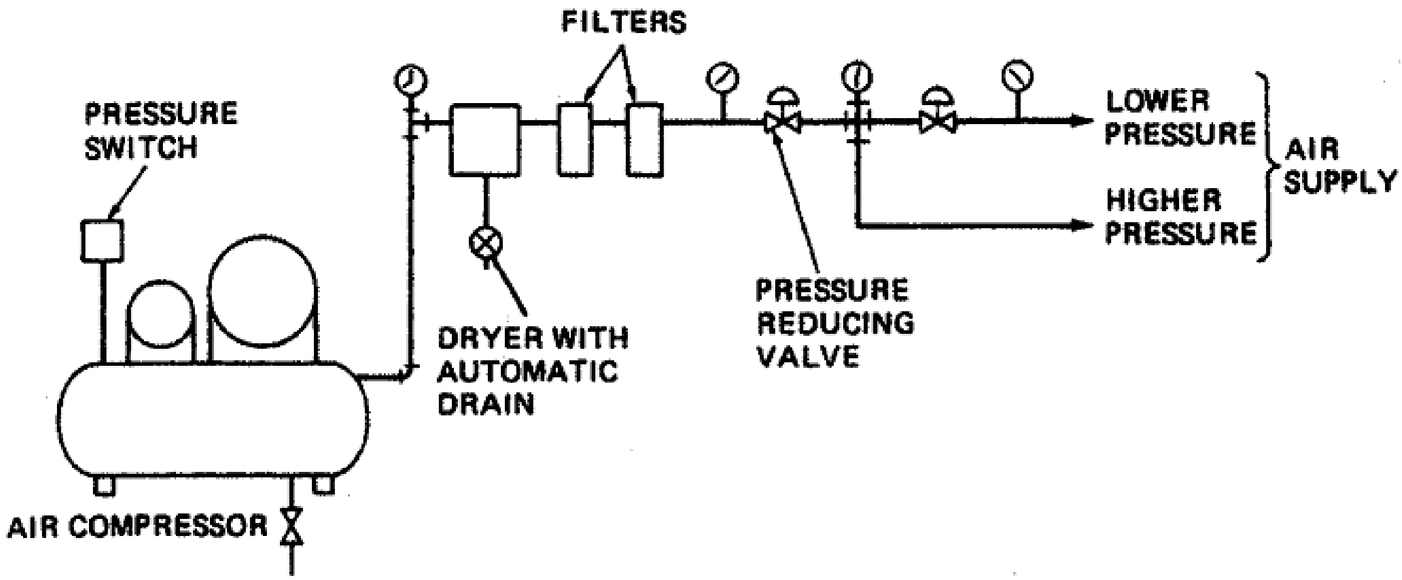

Fig.2-1 Basic Pneumatic control system

As shown in figure 2-1, the air supply for a PCS must be carefully designed***. It is importance that the air be clean and dry, free from oil, dirt, and moisture.*** Thus it is essential to use air dryers, oil separators, and high-efficiency filters. Even small amounts of dirt, oil, or water can plug the very small air passages in modern commercial pneumatic devices, rendering them useless, and to minimize maintenance on the components.

Air consumption can be estimated from use factors for the components provided by the control manufacturer. Good practice requires that the compressor have a capacity at least twice the estimated consumption.

<u>2-2 Definitions</u>:

- **Direct-acting**: A controller is direct-acting when an increase in the level of the sensor signal (temperature, pressure, etc.) results in an increase in the level of the controller output (in a pneumatic this would be an increase in output air pressure).
- **Reverse-acting** is the opposite of direct-acting; that is, an increase in the level of the sensor signal results in a decrease in the level of the controller output
- **Restrictor**: is a basic component of a PCS and is used in all controllers. *A restrictor is usually a disc with a small hole inserted into an airline to restrict the amount of air flow.* The size of the restrictor varies with the application, but can have a hole as small as 0.003”.

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- **Nozzle-Flapper Assembly:** (Fig. 2-2) is the basic mechanism for controlling air pressure to the branch line. Air supply to the nozzle escapes between the nozzle opening and the flapper. At a given air supply pressure, the amount of air escaping is determined by how tightly the flapper is held against the nozzle by sensing element such as bimetal.

  The regulated branch line pressure, a restrictor is added to the nozzle-flapper assembly (Fig. 2-3)

  With this basic mechanism, all that is necessary to create a controller is too adding a sensing element to move the flapper as the measured variable (e.g. temperature, humidity, etc.).

  In steady operation, this force will be balanced by the force created by the pressure in the nozzle. If the pressure times the area of the nozzle exceeds the force exerted by the flapper, the flapper will be pushed away from the nozzle, allowing more air to leak out and causing the pressure in the nozzle and output lines to drop until a force balance is achieved. If the flapper force exceeds the nozzle force, the flapper closes against the nozzle, and pressure builds until a force balance is reached.

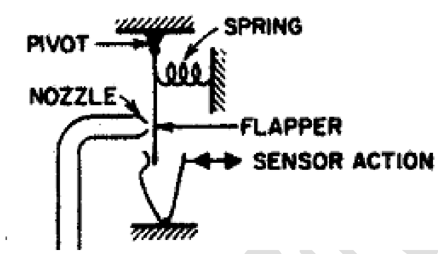


Fig. 2-2 Nozzle Flapper assemblies

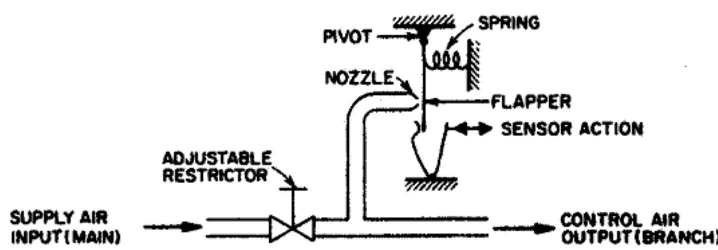


Fig.2-3 Nozzle Flapper assemblies with Restrictor

- **Pilot Bleed system** (Amplifier Relay): is a means of increasing capacity as well as reducing air consumption. The capacity amplifier that is a pilot bleed component that maintains the branch line pressure at the same value as the pilot pressure but *provides greater airflow capacity* (Fig. 2-4)

If the pilot pressure from the nozzle increases, the pilot chamber diaphragm is forced down, where open the feed valve and allows main air into the branch chamber. When the pilot pressure decrease, the pilot chamber diaphragm rises, closing the feed valve. If the pilot chamber diaphragm raises enough, it lifts the bleed valve off the feed valve disc, allowing air to escape from the branch chamber through the vent thus increasing the branch line pressure.

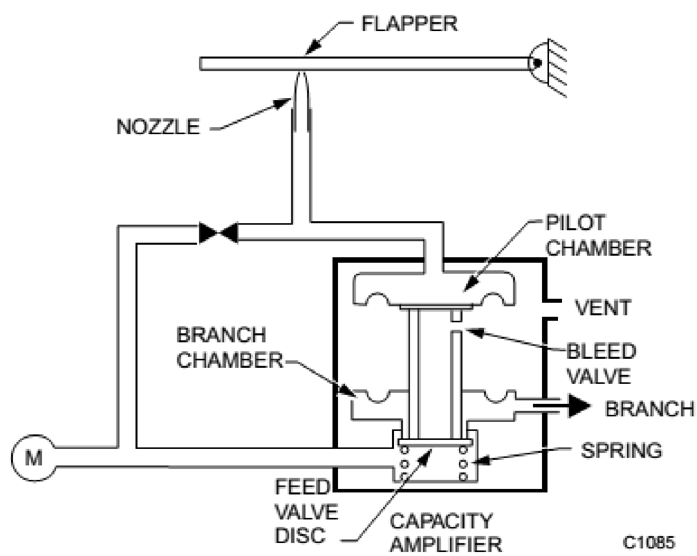


Fig. 2-4 **Pilot Bleed System with amplifier Relay**

- **Relay-Type Controller (pilot-operated Bleed type)**

The bleed-type piloted controller uses a reduced-airflow bleed-type pilot circuit combined with an amplifying non-bleed relay to produce a sensitive, fast-acting control device. The controller can be adjusted to produce a large change in output for a small change in pilot pressure, and can be provided with negative feedback for proportional action or positive feedback for two-position action.

The proportional arrangement is as shown in Figure 2-5. The orifice plate is provided to restrict the flow of air to the pilot chamber. The control port may be partially or completely restricted by the flapper valve, which is operated by the sensor.

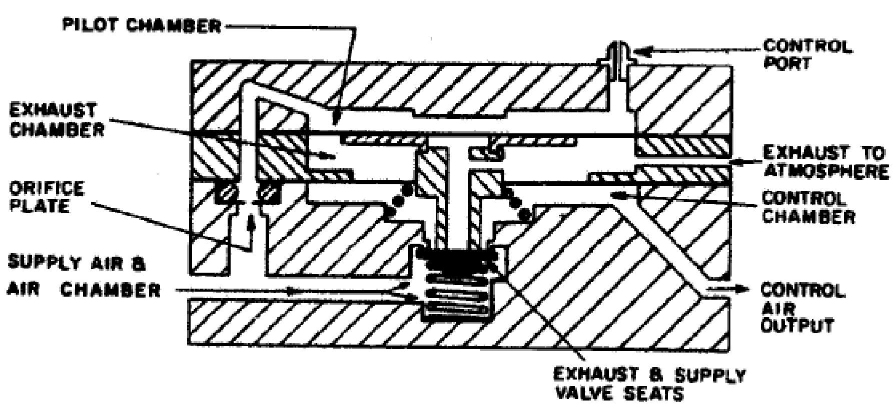


Fig. 2-5**. Proportional relay controller, pilot-bleed type.**

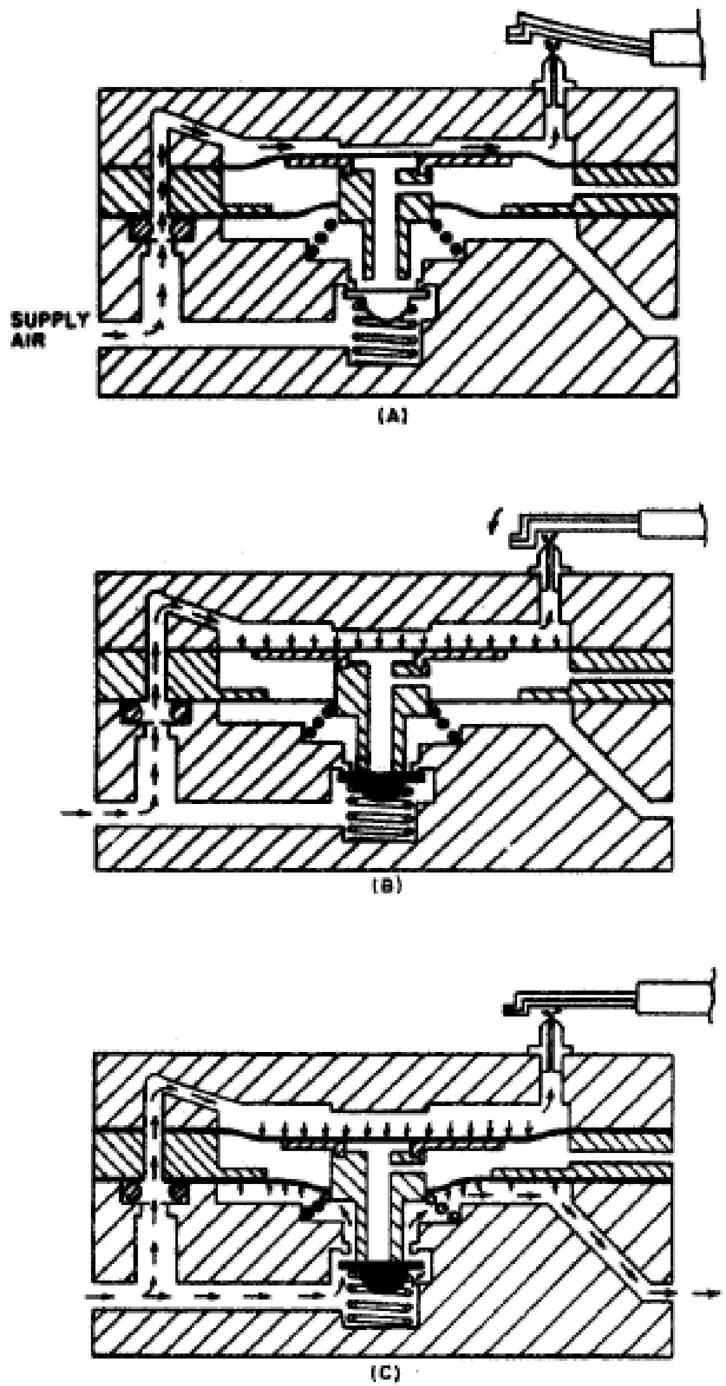
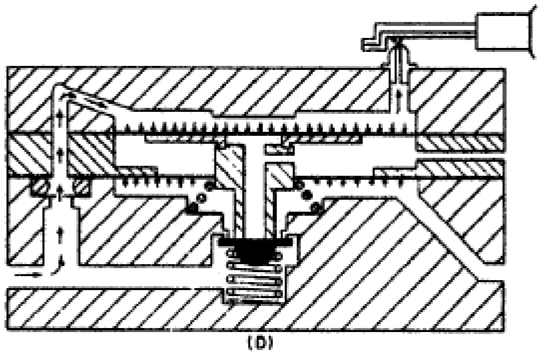


Figure Operation of proportional relay. (*Courtesy Johnson Service Company.*) (A) When the control port is open, the exhaust valve between the control and exhaust chambers is open. Thus, air in the control chamber is at zero gage or atmospheric pressure. The supply valve is held closed by a spring and supply pressure. (B) When the sensing element moves closer to the control port, pressure begins to increase in the pilot chamber. At 3 psig, pilot pressure overcomes the force of the opposing spring and closes the exhaust seat. (C) As pilot pressure continues to increase, it forces the pilot diaphragm down and opens the supply port. This allows supply air to flow to the control line.



(D)

Figure (Continued) (D) Pressure now increases in the control chamber, and acts against the control diaphragm to oppose pilot pressure. When the total of forces in each direction is equal, the supply valve is closed and the controller is balanced.

- **Signal Amplifier:** the addition of the capacity amplifier, pneumatic systems also use a signal amplifier. The signal amplifier must be very sensitive and accurate, because the input signal from the sensor may change as little as, 0.06 psi per degree Fahrenheit.

Fig. 2.6 shows the amplifier as used in a direct acting, single input proportional controller. *The signal amplifier is a three-stage proportional comparator*. In a direct-acting controller, the sensor input feeds chamber P2, where the proportional comparator unit compares it to the set point pressure in chamber P3 generated by the set point pressure reducing valve (PRV). For reverse action, inputs to the chambers P2 and P3 are reversed.

Branch line pressure is piped to the chamber P4 to provide negative feedback. The output from the proportional band potentiometer setting is connected to chamber P1 to provide positive feedback

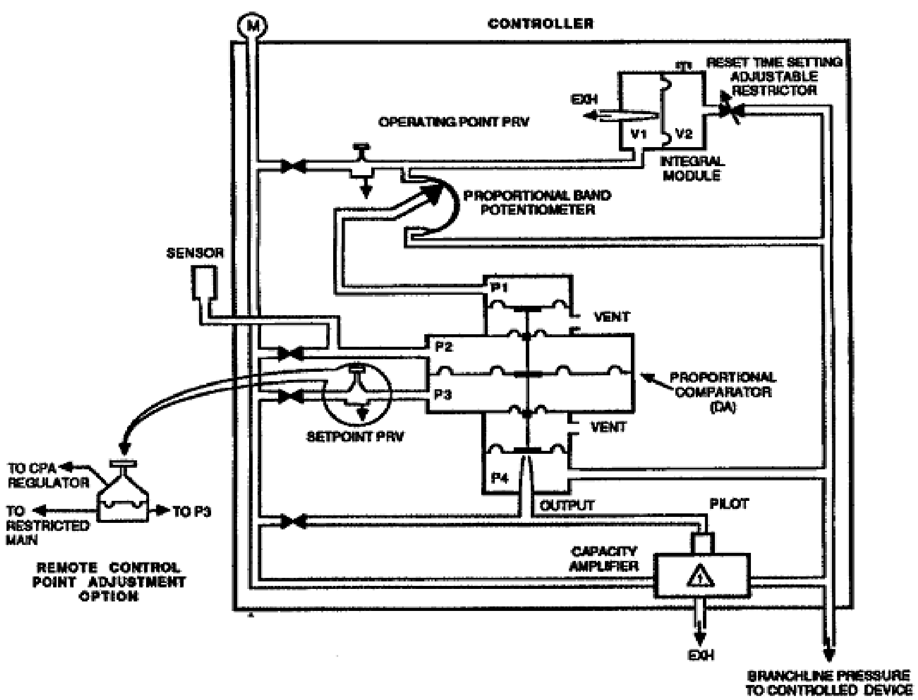


Fig 2-6 **Single amplifier in a proportional amplifier**.

- Sensor-Controller Systems: Single-input PI sensor-controller system

Figure below shows a pneumatic proportional plus integral sensor and controller system. Illustrate how the system works to achieve the integral and proportional action by an example. It is given that the sensor pressure P1 changes slowly and that the diaphragm separating chambers 2 and 3 is twice the area of the other diaphragms. Assume that the pressures in each chamber, P1, P2, P3, and P4 are initially equal at 8 psig.

Note: Make use of the **attached** sheet of the schematic diagram of a single-input PI sensor-controller system.

The controller uses stacked diaphragms to implement force balances similar to those described before. Since the diaphragm separating chambers 2 and 3 is twice the area of the other diaphragms; the force balance is:

$$P1 + 2 \times P2 = P4 + 2 \times P3$$

(1) Air coming in chamber 4 escapes through the capacity amplifier exhaust port or to the branch-line device.

- It is given that; P1=P2=P3=P4= 8 psig.
- Now suppose that the sensor pressure P2 suddenly increases to 10 psig.
- The pressure P4 would increase to 12 psig before the system reaches a **temporary balance**. The force balance is: 8 + 2 x 10 = P4 + 2 x 8; hence P4=12 psig.

(2) Due to the construction of controller; P1 = *f*(P4). Now, part of the *output pressure*, P4, is **fed back** to chamber 1 leading to an increase in pressure P1.

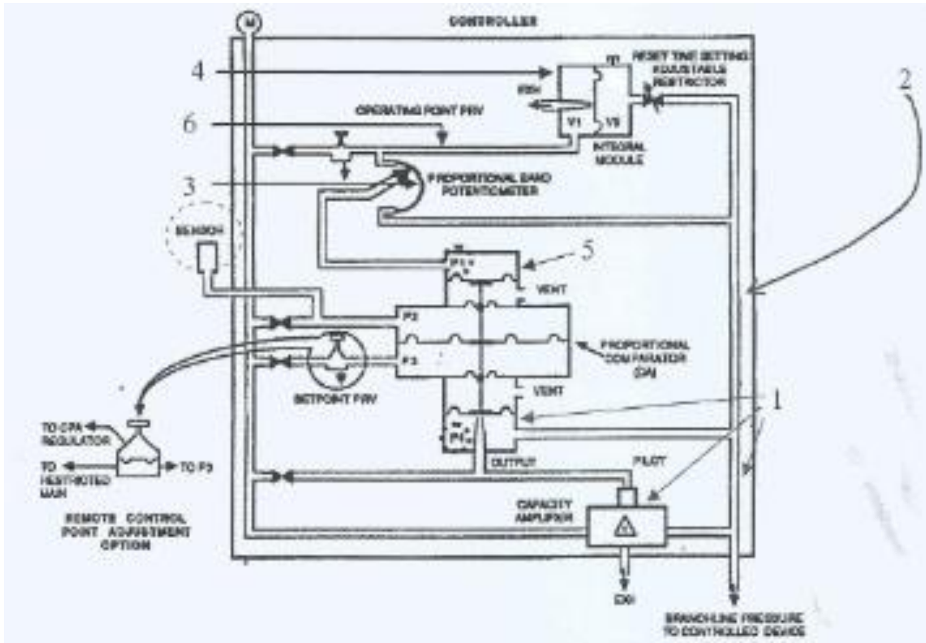
(3) Assume, proportional band potentiometer blends P4 to (1/3) P4.

(4) Assume, integral module blends P4 to (2/3) P4. The integral action contribution is delayed due to the delayed flow through the reset time setting orifice of the integrator (see figure).

(5) Then, immediately after the increase in P2; then the new P1 is; P1= (1/3) P4+ (2/3)×P1= (1/3) P4+ (2/3)×8.

(6) Integral module pressure **changes slowly** due to the orifice restriction and the diaphragm separating volumes V1 and V2.

- Then the force balance is: (1/3) P4 + (2/3) x 8 + 2 P2 = P4 + 2 P3 or P4 = 14 psig.
- Air coming in chamber 4 escapes through the capacity amplifier exhaust port or to the branch-line device.
- Now if P2 is10 psig, the output pressure P4 will cause the diaphragm separating V1 from V2 in the integral module to close the exhaust port in the integral module, resulting in a buildup of pressure from the integral module to P1.
- This will increase the pressure in P1 and result in a further increase in output pressure P4.
- However, an increase in output pressure P4 should be having the ***effect*** of ***driving*** the ***sensed variable*** toward the ***set point***.
- Let us assume that as the output pressure goes toward 13 psig, the sensor pressure finally returns to 8 psig. This new equilibrium condition has the pressures in P1 and P4 at 13 psig while the pressures in chambers 2 and 3 are equal at 8 psig.
- Notice that it is ***only*** when P2 and P3 are ***equal*** that the output pressure ***stops changing***.
- Notice further how the integral action can lead to a new steady state output pressure while forcing the controlled variable to be equal to the set point.



- **Feed and non-Bleed System (**Relay-type controller): this system of controlling branch line pressure is more complicated than the nozzle-flapper assembly but uses less air. The system consists of a feed valve that supplies main air to the branch line, and a bleed valve that exhausts air from the branch line (Fig. 2-7). Each valve consists of a ball rested on the top of a tube. A spring valve is continually tried to force the lever against the balls. A force applied by the sensing element at the sensor input point is opposed by the set point adjusted spring and lever. When the sensing element pushes down on the lever, the lever pivots on the bleed ball and allows the feed ball to rise, which allows main air into the chamber. If the sensing element reduces its force, the other end of the lever rises and pivots on the feed ball, and the bleed ball rises to exhaust air from the system.

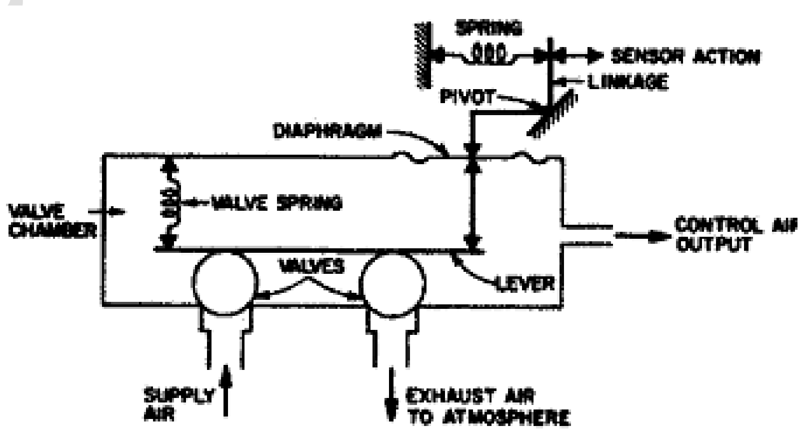
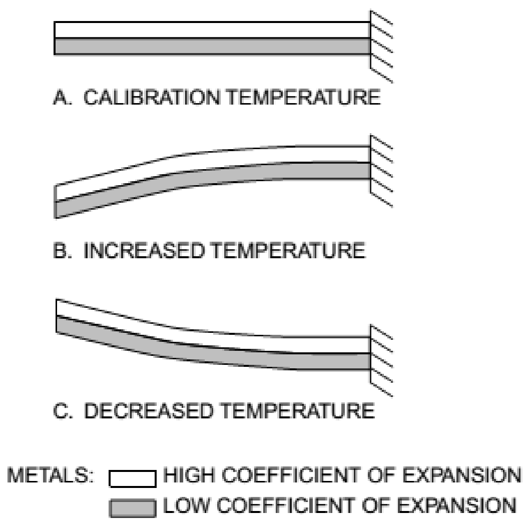


Fig. 2-7 **Feed and non-Bleed System.**

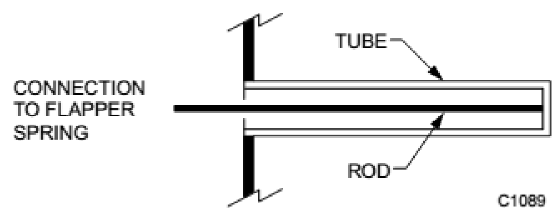
3-3 Sensing Elements:

- Temperature Sensing Elements
    - bimetal element
    - vapor-filled bellows
    - Bulb and capillary elements
- Pressure Sensing Elements
    - Diaphragms
    - Bellows
    - bourdon tubes
- Humidity-Sensing Elements

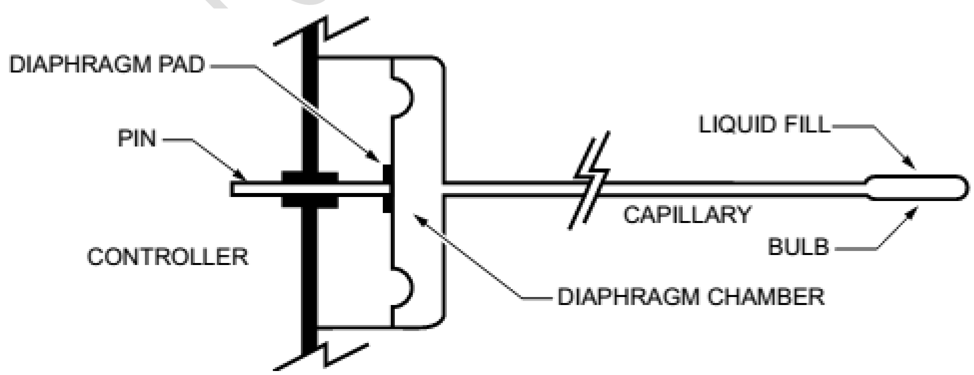
  Hygroscopic materials, which change size in response to changes in humidity



Bimetal Sensing Element.



Rod-and-Tube Insertion Sensor.



Remote-Bulb Temperature Sensor.

Fig 2-8. **Some type of sensing sensors**

- ***Temperature Sensing Elements***

Bulb and capillary elements are used where temperatures must be measured in ducts, pipes, tanks, or similar locations remote from the controller. There are three essential parts of this device: bulb, capillary, and diaphragm operating head. The fill may be a liquid, gas, or refrigerant, depending on the temperature range desired. Expansion of the fluid in the heated bulb exerts a pressure that is transmitted by then capillary to the diaphragm and there translated into movement (Figure 2-9).

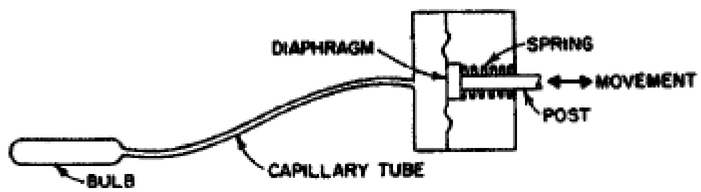


Fig. 2-9. **Bulb and capillary sensor.**

- ***Pressure Sensing Elements***

The bourdon tube (Figure 2-10), widely used in pressure gages and other pressure instruments, has a flattened tube bent into circular or spiral form. One end is connected to the pressure source, and the other end is free to move. As pressure is increased, the tube tends to straighten out, and this movement may be used, through an appropriate linkage, to position an indicator or actuate a controller.

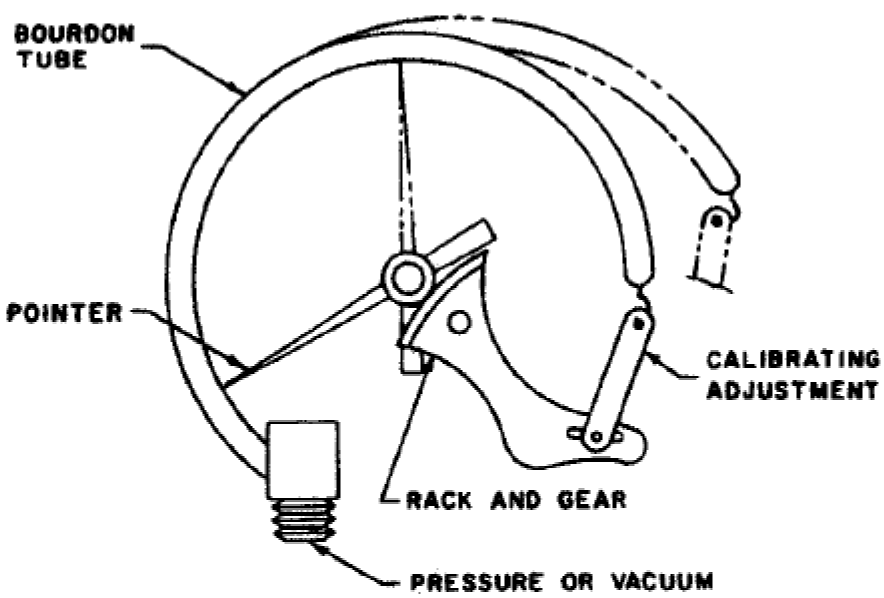


Fig. 2-10. **Pressure sensor, bourdon-tube type.**

- ***Humidity-Sensing Elements***

Used with pneumatic controls, these elements are made of hygroscopic materials, which change size in response to changes in humidity. An element similar to a bimetal is made of two strips of unlike woods glued together. The different rates of hygroscopic expansion will cause the strip to bend as humidity changes. Yew and cedar woods are frequently used for this purpose.

2-4 Relays and Switches:

Relays are used in control circuits between controller and control devices to perform function beyond the capacity of the controllers. Relays typically have diaphragm logic construction (Fig. 2-11). They are used to amplify, reverse, average, select, and switch controller outputs before being sent to valve and damper actuators, by diverting air between various system components such as valves actuators, thermostats, and damper actuators.

The controlling pressure is connected at the pilot port (P), and pressures to be switched are connected at the normally connected port (O) or the normally disconnected port (X). The operating point of the relay is set by adjusting the spring pressure at the top of the relay.

When the pressure at the pilot port reaches the relay operating point, it pushes up on the diaphragm in the control chamber and connects pressure on the normally disconnected port (X) to the common port as shown. If the pilot pressure falls below the relay set point, the diaphragm moves down, blocks the normally disconnected (X) port, and connects the normally connected port (O) to the common port.

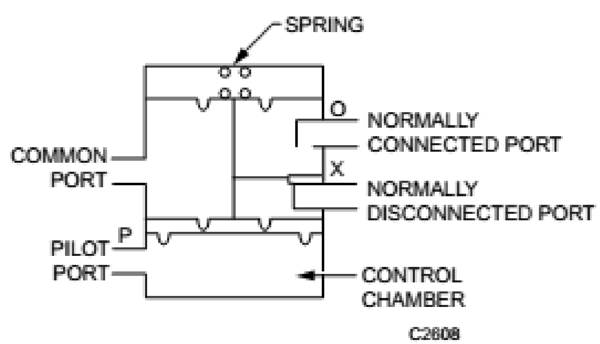


Fig. 2-11. **Typical Switching Relay**.

2-5 Throttling Range Adjustment:

A controller must always have some means to adjust the throttling range (proportional band). In a pneumatic controller, the throttling range is the change at the sensor required to change the branch line pressure 70 kPa. The set point is usually at the center of the

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throttling range. For example, if the throttling range of a temperature controller is 2 kelvins and the set point is 22°C, the branch line pressure is 20 kPa at 21°C, 55 kPa at 22°C, and 90 kPa at 23°C for a direct acting controller.

In all pneumatic systems except the sensor-controller system, the throttling range is adjusted by changing the effective length of a lever arm. In Figure 2-12, the throttling range is changed by moving the contact point between the bimetal and the flapper.

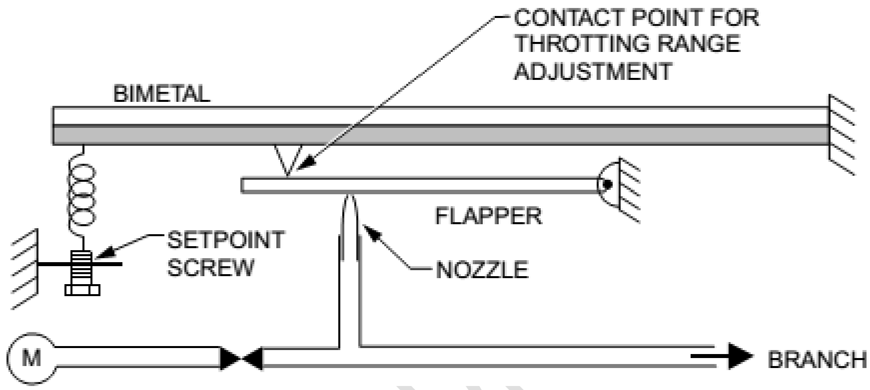

Fig 2-12 Temperature Controller with Bimetal Sensing Element

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2-6 Questions and Answers

1- What are the advantages of pneumatic control systems?

2- Draw a schematic diagram of the basic Pneumatic control system, showing the main elements?

3- Define the following: Direct-acting, Reverse-acting, Restrictor, Transducer, Pneumatic control relay, pneumatic actuator,

4- Rationalize the following:
   - The transducers are necessary with pneumatic control system?
   - The sensing bulb of bulb and capillary sensor, may be only a few inches long, as used in a pipe or a tank, or it may be as longer?
   - The compressed air used in pneumatic control system must be dry and clean?
   - Elements made of hygroscopic material are used in humidity sensors?

5- Draw showing the main parts and explain the operation of the Non - Bleed System to control branch line pressure in pneumatic control systems?

6- Draw showing the main parts and explain briefly the operation of the Bleed type controller System to control branch line pressure in pneumatic control systems?

7- Draw a diagram showing the main parts of Pneumatic proportional relay controller, pilot-bleed type?

8- Draw a diagram showing the Pilot Bleed System with amplifier Relay?

9- Draw a diagram showing the main parts of a single-input, sensor-controlling system in a balanced condition?

10- Draw and explain the operation of bulb and capillary sensor?

11- Draw a diagram showing pneumatic Reversing relay?

12- Draw a diagram showing pneumatic Relay: output is proportional to the input signal?

13- Draw a diagram showing pneumatic Relay: output is proportional to the difference between two signals?

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