for the controller to move the controlled device through its complete stroke, from one extreme to the other. It is often adjustable to meet job requirements.

Set Point is the value at which the controller is set and represents the desired value of the controlled variable.

Control Point is the actual value of the controlled variable at which the instrument is controlling. It will vary within the throttling range of the controller according to the demand on the system and other variables.

Offset is the difference between the set point and the actual control point under stable conditions. This is sometimes also called *drift, deviation,* or *droop.*

5. *Proportional plus Automatic Reset Action,* Fig. 5 combines floating action with proportional action to achieve both the stability of proportional control, with a relatively wide throttling range, and the invariable control point of floating control. The system functions the same as proportional action, the automatic reset serving to shift the control point back to the set point whenever any offset occurs.

Reset rate is the number of times per minute the proportional action is duplicated by the reset action, and usually is expressed as *repeats per minute.* The reset rate in most controllers is adjustable and must be carefully matched to the system characteristics to avoid unstable operation. Because automatic reset is necessarily slow-acting, it should be used only when load changes are of reasonably long duration and when the maximum offset resulting from proportional control alone is outside of acceptable limits.

Figs. 4 and 5 show the results of rather abrupt demand changes, which usually result in two or three cycles before stability is restored. More gradual demand changes will result in a smoother curve.

AUTOMATIC CONTROL SYSTEM COMPONENTS

In addition to controllers and controlled devices, many control systems include auxiliary apparatus such as switches and relays of various kinds, clocks or timers, thermometers, gages, pilot lights, and other indicators for observing the operation of the system. Only those more commonly used will be described here.

Controllers

Automatic controllers have both a measuring element and a controlling element.

The *measuring element* measures changes in the controlled variable and produces a proportional effect on the controlling element. This effect usually is a change in position, force or electrical resistance.

The *controlling element* converts the effect produced by the measuring element into an effect suitable for operation of the controlled device. (In self-contained controllers the measuring element produces a force which is directly applied to the controlled device. In pneumatic, or electronic controllers the controlling element regulates the application of energy such as compressed air or electricity.)

Types of Measuring Elements

Temperature measuring elements usually consist of (1) a bimetal strip, (2) a rod and tube of dissimilar metals, (3) a sealed bellows, with or without a remote bulb or (4) an electrical resistance.

1. A *bimetal element* is composed of two thin strips of dissimilar metals fused together. Because the two metals have different coefficients of thermal expansion, the element bends as the temperature varies and produces a change in position. Depending on the space available and the movement required, it may be in the form of a straight strip, U-shaped, or wound into a spiral. This element finds its most common application in room thermostats, but is also used in insertion and immersion thermostats.

2. A *rod-and-tube element* consists of a high-expansion metal tube inside of which is a low-expansion rod with one end attached to the rear of the tube. The tube changes length with changes in temperature, causing the free end of the rod to move. The rod-and-tube element is commonly employed on certain types of insertion and immersion thermostats.

3. A *sealed bellows-element* is either vapor filled, gas filled, or liquid filled, after being evacuated of air. Changes of temperature cause changes in pressure or volume of the gas or liquid, resulting in a change in force or a movement. This element is often employed in room thermostats.

A *remote-bulb element* is a sealed bellows or diaphragm to which a bulb or capsule is attached by means of a capillary tube, the entire system being filled with vapor, gas or liquid. Changes of temperature at the bulb result in changes of pressure or volume which are communicated to the bellows or diaphragm through the capillary tube. The remote-bulb element is useful where the temperature measuring point is remote from the desired thermostat location. It usually is provided with fittings suitable for insertion into a duct or into a pipe or tank.

4. A *resistance element* is made of wire whose electrical resistance changes with temperature changes. It is used with electronic controllers. It is available in forms suitable for measuring room temperature or for insertion into a duct or into a pipe or tank.

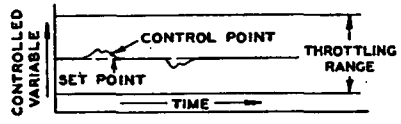


FIG. 5. PROPORTIONAL PLUS AUTOMATIC RESET CONTROL SHOWING HOW CONTROL POINT IS RETURNED TO SET POINT AFTER A LOAD CHANGE

Humidity measuring elements are made of (1) hygroscopic organic materials or (2) an electrical resistance.

1. An *organic element* usually is made of human hair, wood, paper, or animal membrane. Changes in relative humidity cause the element to expand and contract.

2. A *resistance element,* for use with electronic controllers, frequently consists of a thin coating of hygroscopic salt on an insulating form. The resistance of the salt varies with the relative humidity.

Pressure measuring elements can be divided into one of two general classes depending upon pressure range.

1. For pressures or vacuums measured in pounds per square inch or inches of mercury, the element usually is a bellows, diaphragm, or Bourdon tube. One side of the element may be open to atmosphere in which case the element responds to pressures above or below atmospheric. A differential pressure element has connections to both sides so that it will respond to the difference between two pressures.

2. For low ranges of pressure or vacuum which are usually measured in inches of water, such as the static pressure in an air duct, the measuring element may be an inverted bell immersed in oil, a large slack diaphragm, or a large flexible metal bellows. The element usually is of the differential type, and when employed in conjunction with orifices, pitot tubes, and similar accessories, may be used to measure flow, velocity or liquid level as well as static pressure.

Measuring elements for other purposes, such as flame detection or for measuring smoke density, specific gravity, CO_2, CO, etc., often are necessary for the complete control of a heating, ventilating or air conditioning system.

Types of Controlling Elements

Controlling elements differ because some regulate the application of pneumatic energy while others regulate the application of electrical energy. They also differ according to the type of control action produced.