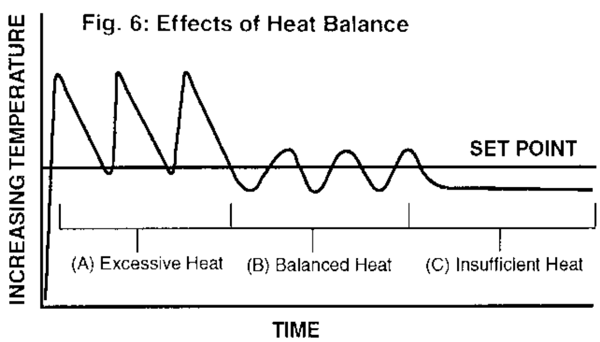
ature overshoot at the work. The control selected should have compensating features (PID) for this situation *(Fig. 5b)*.

Where the heat demand is steady, the sensor should be placed closer to the heat source. The short distance between the heat source and control sensor will allow minimal thermal lag and reduced potential for temperature overshoot and undershoot. Temperature changes are quickly detected *(Fig. 5c)*.

When a system is both steady and variable, placing the sensor mid-way between the heat source and the work will reduce thermal lag. Some overshoot and undershoot will occur. For this arrangement, the control should also have compensating features (PID) *(Fig. 5d)*.

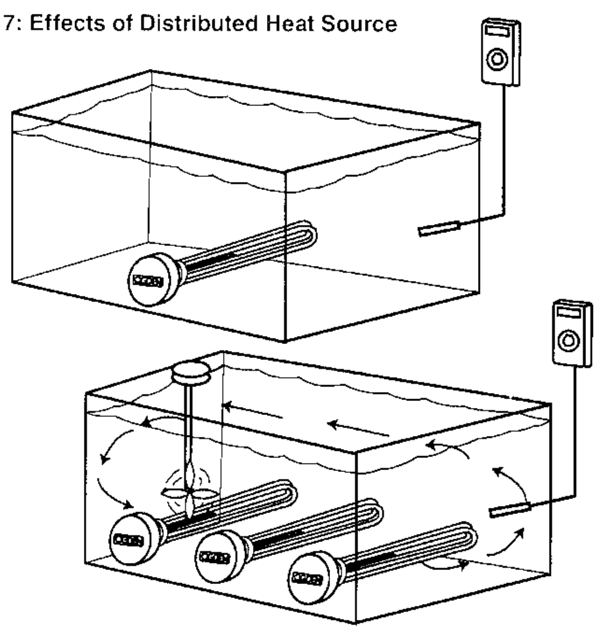
Matching the wattage requirement of the system with the capacity of the heat source will also help to achieve the best possible temperature control *(Fig. 6)*. When the desired operating temperature (set point) is reached, the heat source should be on 50% of the time. Heat loss from the thermal system, voltage fluctuations, changes in ambient temperatures, and other process upsets can also affect heat balance. Allowances need to be made for these factors when determining wattage requirements and the heat source.

Fig. 6: Effects of Heat Balance



In general, if after system start-up the heat source is on more than 60% of the time, the wattage rating should be increased. If the heat source is on less than 40% of the time, the rating should be decreased. Heat conductivity is most efficient when good contact exists between the heat source and the material being heated. Rather than one large heater, several smaller rated heaters to better distribute heat throughout the system will further reduce temperature gradients *(Fig. 7)*.

Fig. 7: Effects of Distributed Heat Source



SELECTION OF TEMPERATURE CONTROL

The temperature control may be the first suspect if a system fails to perform to expectations. As can be seen, there are many factors to be considered in designing an accurately controlled thermal system. However, the control does have an exceptional responsibility in maintaining system accuracy and can compensate for inefficiencies and errors in other parts of the system.

Certain applications such as radiant heating can maintain adequate control with manual adjustments. An Open Loop temperature control system requires continual process monitoring by an operator.

An autotransformer or variac adjusts the voltage input from 0–100% to the heat source.

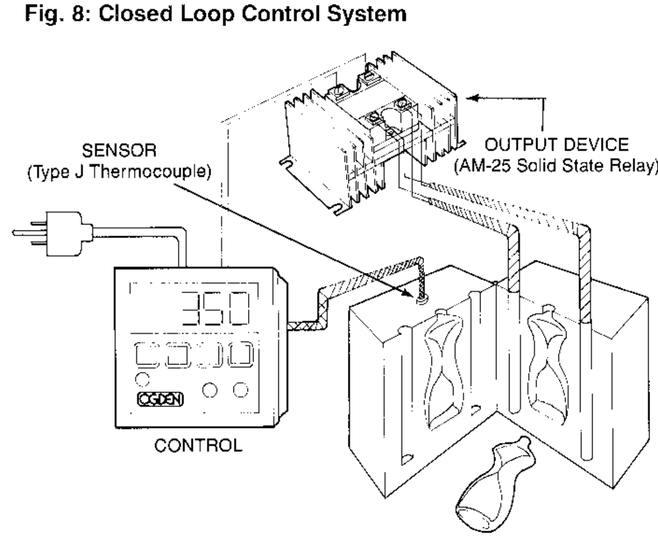
An infinite control or simmerstat provides a range of control from off to full heat by switching at short, definite time intervals.

Timers control direct current to the heat source based upon intervals of time.

A trial and error method, most process control requirements are too sophisticated for Open Loop systems.

A Closed Loop Control System utilizes a feedback sensor to automatically monitor the process temperature. The control interprets the signal from the sensor then directs the output device to switch power on or off to the heat source. The output device is either an electro mechanical relay, mercury displacement relay, solid state relay (SSR) or silicone controlled rectifier (SCR). The sensor in an electronic control system is a thermocouple, RTD or thermistor. See each catalog section for complete description.

Fig. 8: Closed Loop Control System



Control accuracy in the following discussion will refer to the control's capabilities, not including factors existing in the rest of the thermal system.

Resolution sensitivity is one measure of control accuracy. Expressed as a percentage of the controls temperature range, resolution sensitivity is the amount of temperature change that must occur before the control reacts.

Speed of response is the time needed for a temperature change occurring at the sensor to be translated into control action.

Indication and set point accuracy are expressed in degrees or percent of temperature range. Indication accuracy is the possible amount of error between the temperature displayed and the actual temperature. Set point accuracy is the possible error between the temperature set point and the actual temperature being controlled.

Indication and set point resolution is expressed the same as accuracy and is the smallest change that can be indicated or set.

Repeatability is the measure of the maximum sensor or deviation that can occur among output measurements under identical conditions at two or several different times.

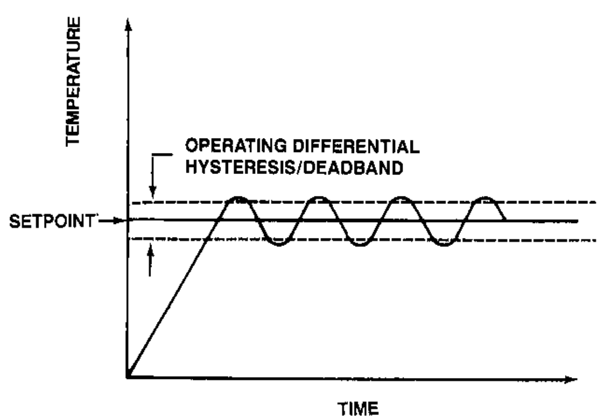
The selection of the proper control is determined by examining the previous factors, what type of accuracy is required, and cost. It is possible to set-up a control system utilizing an electronic control for almost the same cost as a much less sensitive mechanical thermostat. For that reason, plus superior accuracy, electronic controls should be considered for most applications.

Features include LED indications, digital set points and, in some models, the ability to tune the control to compensate and respond to process upsets and variables for a specific application.

CONTROL MODES

The action of an On/Off control mode is that the output device is either full on or full off. Full heat is applied whether the process temperature is 5° or 50° below set point. The operating differential or hysterisis is designed into the control (in some cases, the hysteresis is adjustable), and is the area between the on and off switching points where there is no control action. Temperature is always controlled around the set point and overshoot and undershoot will exist in On/Off controls. The extent will depend upon all other characteristics of the thermal system *(Fig. 9)*.

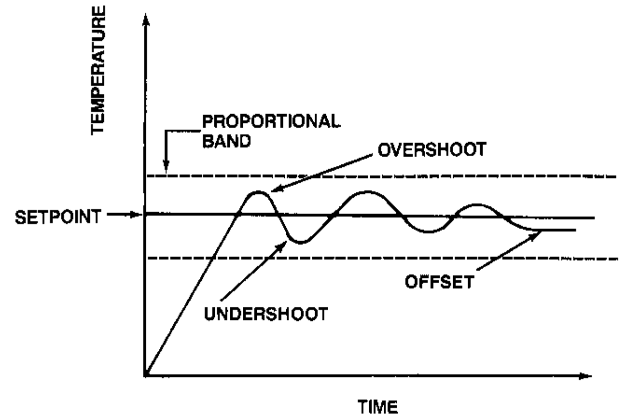
Fig. 9: On-Off



If the system requires greater accuracy than an on/off control, time proportioning will provide more precise process temperature control. Time proportioning occurs within a range of temperatures called the proportioning band. The proportioning band is either a fixed percentage of the temperature range or is adjustable. In the center of the proportioning band is the set point. When the process temperature enters the proportioning band, the output device is switched on and off at the established cycle time (2 seconds, 20 seconds or adjustable). "On time" is a greater percentage of cycle time at the lower span of the band. As the set point is approached, "Off time" is increased. The change in output delivered provides a throttling effect and less temperature overshoot *(Fig. 10)*. The cycling will continue until equal on and off times exist.

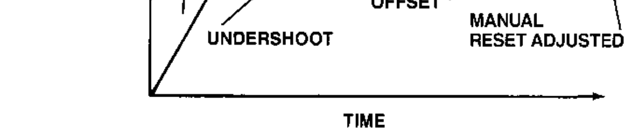
When a current input signal is used, such as 4–20 milliamps to control an SCR or valve, then the control mode is true proportional. In true proportioning, the controlled element (SCR or valve) can be from 0–100% on or open, as required by the size of the deviation from the set point.

Fig. 10: Time Proportioning



An inherit limitation in both time and true proportioning is that the system stabilizes at a temperature below or above the set point. A sudden increase in the amount of material being processed or ambient temperature changes can also cause this offset. If the offset cannot be tolerated, a manual reset dial on many controls can be adjusted to bring the process temperature to the set point *(Fig. 11)*. An automatic reset or integral mode is a compensating feature on many controls that will adjust for the offset condition. The integral function involves moving the proportional band towards the offset to escort the process temperature back to the set point. The correction is made according to the size and the time involved for the reset to occur. Anti-reset windup by design allows the integral function to occur only in the proportional band, preventing a large reset action that would result in large over and undershoots during system start-up or work load changes.

Fig. 11: Time Proportioning with Manual Reset



An anticipating function that measures the rate or time involved in a change in process temperature is derivative or rate. The derivative determines the size of the corrective action to be taken, causing an increase in the proportioning action to slow the change.

The integral and derivitive modes work together to prevent over and undershoots in proportioning controls during system start-up or work load changes *(Fig. 12)*.

While proportional, integral, and derivitive (PID) modes suggest that these functions would be automatic, adjusting or tuning is required. Although it is theoretically possible to calculate the PID constants appropriate for a particular application, constants are selected by taking measurements and making adjustments. Each particular ETR Temperature Control User Manual contains information for control set-up, parameter selection and adjusting. Automatic or self tuning controls are microprocessor based and contain computer software that automatically calculates and sets the best PID parameters based upon the dynamics of the particular application. As manual tuning efforts are time consuming and require experienced personnel, automatic tuning controls may be cost effective. Often these controls can interface with computers, bringing process temperature into computer integrated manufacturing systems.

Fig. 12: PID—Time Proportioning with Integral and Derivative

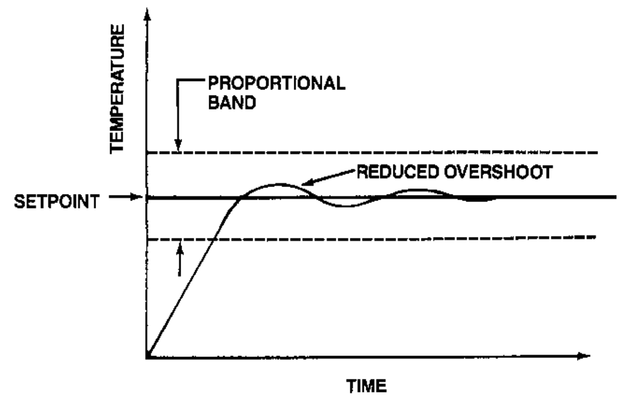


Fig. 13: Response of a Typical Control System Using Various Control Modes