BASICS OF TEMPERATURE CONTROL

This summary is concerned with temperature control, but the principles outlined apply equally to the control of any process variable (pressure, humidity, level, flow, etc.). A process control loop consists of a sensor to measure the process variable, a controller and an actuator device e.g.. Contactor, fuel valve or thyristor drive, but we will take the particular case where the variable is temperature. A temperature controlled system is composed of four essential elements which all affect its performance:

1) the LOAD (or work)	the material or object that needs to be maintained at a particular temperature; the load may be steady, i.e. one object at a constant temperature for a long period, or variable/cyclic which is common in an industrial process.
2) the HEAT SOURCE	the device(s), usually a heater of some kind, which provides heat to the load; some applications may need cooling in which case a compressor may be switched; however we will assume a 'hot' system for the purposes of these notes
3) the SENSOR	measuring the temperature of the load and feeding this information back to the controller
4) the CONTROLLER	a device which controls the heat flow to the 'load' by adjusting power output from the 'heat source' according to the information received from the 'sensor'. The 'controller' will compare the temperature measured by the 'sensor' with the desired 'load' temperature (the Set-Point) and increase heater power if the sensed temperature is too low, or decrease power if the sensed temperature is too high. The heat source, the sensor and the controller form the classic control loop mentioned above, and together act upon the load.

COMMON TERMS USED IN MEASUREMENT AND CONTROL

Accuracy: Accuracy is the degree of conformity with the established standard, hence accuracy zero corresponds to the ideal value.

Tolerance: Tolerance corresponds to the value of inaccuracy in manufacture and is accepted within stated values.

Resolution: Resolution is the minimum value that an instrument can record without uncertainty.

Sensitivity:	Sensitivity is a general term for ratio of response (in time or magnitude) to a signal or stimulus.
Error:	Error indicates the divergence from the theoretical or ideal value.
Repeatability:	Repeatability indicates the probability of repeating measurements in the same conditions and obtaining equal results.
Hysteresis:	Hysteresis is the maximum difference for the same measured quantity between the upscale and downscale readings during a full range excursion in each direction.
Stability:	Stability is the ability of an instrument to maintain the measurement accuracy over a specified time period.
Temperature Coefficient:	The temperature coefficient is a measure of the change of a parameter as a result of a change in ambient temperature.

PRACTICAL CONSIDERATIONS

In practice there are several obstacles to perfect temperature control - one of these is cost, as high precision temperature control requires highly sensitive measuring instruments and frequent re-calibration to tell just how good the control is. Trying to attain the last fraction of a degree of accuracy can be very expensive, so in most situations it is best to be realistic; a sandwich toaster doesn't need the same control as a crystal growing oven.

The main measures of accuracy are the size of temperature swing in the load (thermal bandwidth) and the stability of its mean (average) temperature. These are affected by many factors :

A) Thermal Lag	the time delay for a temperature change in one part of the system to show up in other parts of the system; this varies considerably with the operating temperature, ambient conditions, mass & conductivity of the load etc.
B) Temperature Gradients	the variations in temperature between different physical parts of the system at any given instant.
C) Sensor Location	placement of the sensor in relation to the heat source and the load.
D) Controller Sensitivity & Speed Of Response	these contribute to the inherent accuracy of the controller and determine its suitability for any application.

E) Heat Balance

for temperature control to be possible, there must be more heat available from the heat source than is actually required to maintain the desired temperature and replace losses.

TYPES OF CONTROL

Having established the basic requirements for a temperature control system, we can see that the load temperature (or process temperature) is compared by the controller with the required value or set-point, set by the user. The controller automatically adjusts the power to the heat source to achieve no error between process temperature and set-point. The type of control action affects the performance achieved. There are two main types, On/Off and PID control, with additional special cases of Auto-tune and Fuzzy logic.

A) ON/OFF CONTROL

This is the simplest form of control and is the least expensive; it takes little account of thermal time constants and simply switches the heater off or on as the process temperature passes through the set-point. This will usually result in continual oscillation around the set-point (hunting) due to the switching hysteresis. It is used where high accuracy isn't needed, or for an over or under temperature alarm.

B) PID CONTROL

Proportional plus Integral plus Derivative control is typically used in high accuracy situations - basic proportioning control means that the controller 'recognises' the size of the deviation from the set-point and adjusts the power output accordingly. This prevents oscillation around the set-point, and the integral and derivative parameters add extra accuracy, with little or no offset or overshoot when they are correctly tuned. The P, I and D parameters can usually be adjusted (or 'tuned') by the user to give the optimum control for the particular conditions of their system.

C) AUTO-TUNE

In this type of control, the controller has onboard logic which will enable it to automatically select the optimum values for the Proportioning, Integral and Derivative parameters; it does this by monitoring the rate of temperature rise of the system and the subsequent response to heat input. The operator doesn't normally need to alter any settings on the controller.

D) FUZZY LOGIC

The controller automatically and gradually decreases or increases the internal set-point until the process stabilises at the desired operating temperature; this results in the elimination of overshoot/ undershoot.

MORE ABOUT CONTROL THEORY

With **ON/OFF CONTROL**, the controlled element (heater, valve etc.) can only be on or off, there is no halfway house and the size of the corrective action is unrelated to the temperature deviation. This leads to the oscillation described above. Some controllers have an adjustable differential, which changes the width of the dead zone between switching off and on. A narrower differential will give smaller temperature swings, but will increase cycling rates and cause increased wear on mechanical relays, heater elements etc. Thus, differential needs to be adjusted to give the lowest cycling rate that gives an acceptable temperature bandwidth.

In **PROPORTIONING CONTROL**, the control action can be varied between 0 and 100% of the available response, being tailored to the size of the temperature deviation measured by the sensor. This is particularly helpful where, for example, a work cycle involves the addition of large amounts of cold material, which cool the system down so that it needs rapid heat-up. A large injection of heat would lead to huge overshoot without some form of proportioning action.

The width of the proportioning band should be set to just exceed the limits of any normal high or low temperature excursions in the system. If the proportional band is too narrow, oscillations resembling on/off control will occur; if too wide, control will be stable but sluggish, probably with an offset at equilibrium. Most controllers feature 'manual reset' which corrects the offset by biasing the proportional band up/down so that the band is in the correct place once tuned.

An offset in the control temperature can be compensated by incorporating an Integral parameter, which positions the proportional band for the correct power output to achieve equilibrium at set-point. (**PI control**). A further addition of the Derivative function (to give **PID control**) can provide anticipatory control and a fast reaction to disturbances. This is a derivative of the error between actual temperature and set-point temperature with respect to time; it is typically set to a value approx. 15% of the I value.

POWER CONTROL

HELPFUL HINTS ON CONTROL

1) Rapid cycle time gives better control and prolongs heater life, but shortens output relay life (though a solid state relay avoids this problem)

2) Proportioning band should be adjusted so that oscillations just cease; a wide band gives stable control but increases offset from desired setpoint.

3) A properly adjusted Integral parameter eliminates offset; if too fast, oscillation will develop, too slow will give poor response.

4) Too much Derivative will cause oscillations, too little will result in overshoot.

5) For system start-up, use a large time value for the Integral parameter (so that you basically have proportional control). Adjust this step-wise until offset is eliminated with minimal oscillation around the set-point. Then adjust the Derivative parameter so that any outside disturbances to the system are corrected rapidly but without oscillations.

IMPORTANT SAFETY NOTE: when dealing with temperature control systems, it is important to consider the possible effects of a malfunction in any part of the system - any one of many possible malfunctions could cause a dangerous situation if the heating is left permanently switched on. This could be a fault in the sensor, controller, connecting wiring or other outside interference.

OUTPUTS

The controller output has to be interfaced to the heat source (or other actuating device) and this is done by various methods, the choice of which depends on the type of process and equipment being used;

A) Relay O/P used in on/off or time proportioning modes to switch contactors etc.; electromechanical relays are inexpensive, small, usually housed within the controller, but can have limited life if cycled rapidly - where more rapid switching is needed a solid state relay is recommended.

B) SSR O/P (Solid State Relay) this is a switching device which contains 2 SCR's (silicon controlled rectifiers) or a single triac complete with a zero voltage crossover or synchronising drive circuit; it usually takes the form of a potted assembly having no moving parts to wear out, and can be either ac or dc input type.

C) Analogue where continuously variable control is needed, a **OUTPUT** linear DC voltage or current output can be used; 4- 20mA,
0-5V, 0-10V, 1-5V are all standard outputs and are used for e.g. control valve actuators, thyristor drives etc. which vary the power to the load.

POWER CONTROL

The output relays of temperature controllers are capable of switching currents typically 8, 16 or 20 Amps depending on the model of controller. Most heater loads however, are
typically more than the controller's relay can handle. For these applications solid state relays or Thyristor power controllers depending on the type of load and the type of control required, need to be incorporated within the control system.

SOLID STATE RELAYS

These devices work in exactly the same way as mechanical relays but have no moving parts. The input to these devices are either typically 3 to 32VDC or 90 to 280VAC and will switch loads up to 90 Amps. The advantage of SSRs over mechanical devices are; no moving parts to wear out, fast response, handles high in-rush currents and no contact bounce.

THYRISTOR POWER CONTROLLERS

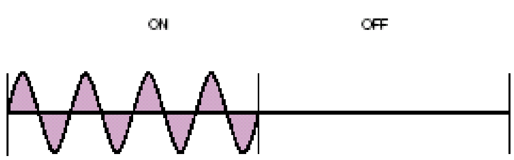
Thyristor is the generic name for a SCR or Triac. These devices are used for very large
loads up to 1000 Amps and generally include other functions such as current limiting, soft start, fusing etc.

FIRING CIRCUITS

The devices just described can incorporate special firing circuitry to produce smoother and more accurate control of the load.

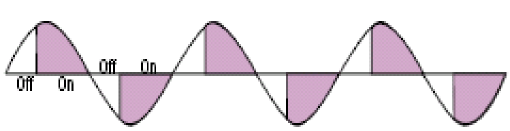
BURST FIRING

This is the most basic and cheapest method to provide variable electrical output power for the control of temperature. This is achieved by triggering the device ON and OFF in multiples of complete mains cycles. This type of control is suitable for loads whose load resistance does not change very much with temperature.



PHASE ANGLE

This type of control is a more precise method of switching. The device conducts for only part of the AC supply cycle. Therefore if low power is required the device conducts for a small portion of the AC cycle, similarly if half power is required the device is not triggered to conduct until it is 50% of the way through half of a mains cycle. This type of triggering is ideal for low inertia heaters such as lamps and air heater.



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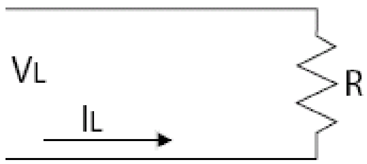
LOAD CONFIGURATIONS

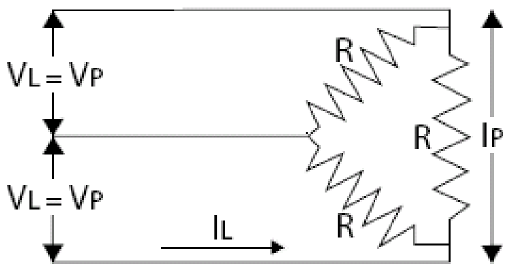
W_t= Total power	R = heater resistance
V_P = phase voltage	I_P = phase current
V_L = line voltage	I_L = line current

Single Phase, Line And Neutral Or Line And Line



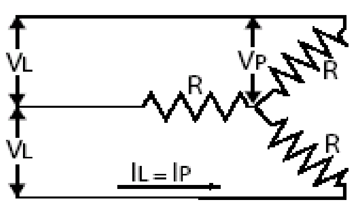
$W_t = V_L \times I_L$ or V_L^2/R

Three Phase, Three Wire, DELTA Configuration



$W_t = 1.73V_L \times I_L$ or $3 \times V_L^2/R$
Where $I_L = 1.73 \times I_P$

Three Phase, Three Wire, STAR Configuration



W_t= $1.73V_L \times I_L$ or $3 \times V_L{}^2/R$
Where $V_L = 1.73 \times V_P$

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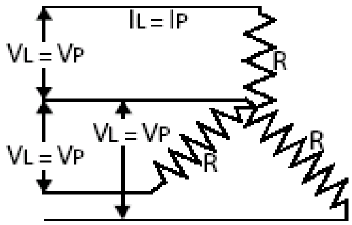
Three Phase, Four Wire, STAR Configuration



$W_t = 3 \times V_L \times I_L$ or $3 \times V_L{}^2/R$
Where $V_L = V_P$ and $I_L = I_P$

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