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Temperature Control
Tuning a PID (Three Mode) Controller

Tuning a temperature controller involves setting the proportional, integral, and derivative values to get the best possible control for a particular process. If the controller does not include an autotune algorithm, or if the autotune algorithm does not provide adequate control for the particular application, then the unit must be tuned using trial and error.

The following is a tuning procedure for the OMEGA CN2000 controller. It can be applied to other controllers as well. There are other tuning procedures which can also be used, but they all use a similar trial and error method. Note that if the controller uses a mechanical relay (rather than a solid state relay), a longer cycle time (20 seconds) should be used when starting out.

The following definitions may be needed:

1) Cycle time - Also known as duty cycle; the total length of time for the controller to complete one on/off cycle. Example: with a 20 second cycle time, an on time of 10 seconds and an off time of 10 seconds represents a 50 percent power output. The controller will cycle on and off while within the proportional band. → Atuador com modulação de largura de pulso (PWM)
2) Proportional band - A temperature band expressed in % of full scale or degrees within which the controller's proportioning action takes place. The wider the proportional band, the greater the area around the setpoint in which the proportional action takes place. This is sometimes referred to as gain, which is the reciprocal of proportional band.
3) Integral, also known as reset, is a function which adjusts the proportional bandwidth with respect to the setpoint to compensate for offset (droop) from setpoint; that is, it adjusts the controlled temperature to setpoint after the system stabilizes.
4) Derivative, also known as rate, senses the rate of rise or fall of system temperature and automatically adjusts the proportional band to minimize overshoot or undershoot.

A PID (three mode) controller is capable of exceptional control stability when properly tuned and used. The operator can achieve the fastest response time and smallest overshoot by following these instructions carefully. The information for tuning this three mode controller may be different from other controller tuning procedures. Normally a SELF TUNE feature will eliminate the need to use this manual tuning procedure for the primary output; however, adjustments to the SELF TUNE values may be made if desired.

After the controller is installed and wired:

1. Apply power to the controller.
2. Disable the control outputs if possible.
3. For time proportional primary output, set the cycle time. Enter the following value:

CYCLE TIME 1

5 SEC (Only appears if output is a time proportional output. A smaller cycle time may be required for systems with an extremely fast response time.)

Then select the following parameters:

PR BAND 1 ________5% (PB) → $k_p = 20$
RESET 1 __________0 R/M (TURNS OFF RESET FUNCTION)
RESET 2 __________0 R/M → $k_i = 0$
RATE 1 ___________0 MIN (TURNS OFF RATE FUNCTION)
RATE 2 ___________0 MIN → $k_d = 0$

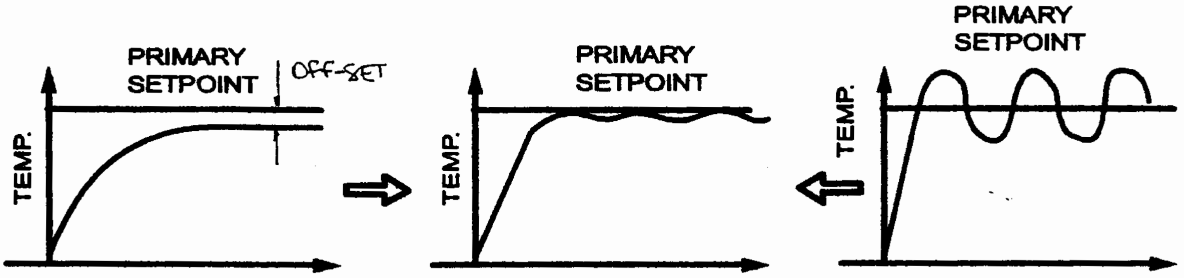
NOTE

On units with dual three mode outputs, the primary and secondary tuning parameters are independently set and must be tuned separately. The procedure used in this section is for a HEATING primary output. A similar procedure may be used for a primary COOLING output or a secondary COOLING output.

A. TUNING OUTPUTS FOR HEATING CONTROL → 1º MÉTODO DE MALHA FECHADA

1. Enable the OUTPUT(S) and start the process.
2. The process should be run at a setpoint that will allow the temperature to stabilize with heat input required.
3. With RATE and RESET turned OFF, the temperature will stabilize with a steady state deviation, or droop, between the setpoint and the actual temperature. Carefully note whether or not there are regular cycles or oscillations in this temperature by observing the measurement on the display. (An oscillation may be as long as 30 minutes.)

The tuning procedure is easier to follow if you use a recorder to monitor the process temperature.



Divide PB by 2 if you observe this.

This is close to perfect tuning.

Multiply PB by 2 if you observe this.

Figure 1. Temperature Oscillations

4. If there are no regular oscillations in the temperature, divide the PB by 2 (see Figure 1). Allow the process to stabilize and check for temperature oscillations. If there are still no oscillations, divide the PB by 2 again. Repeat until cycles or oscillations are obtained. Proceed to Step 5.

   If oscillations are observed immediately, multiply the PB by 2. Observe the resulting temperature for several minutes. If the oscillations continue, increase the PB by factors of 2 until the oscillations stop.

5. The PB is now very near its critical setting. Carefully increase or decrease the PB setting until cycles or oscillations just appear in the temperature recording.

   If no oscillations occur in the process temperature even at the minimum PB setting of 1%, skip Steps 6 through 11 below and proceed to paragraph B.

6. Read the steady-state deviation, or droop, between setpoint and actual temperature with the "critical" PB setting you have achieved. (Because the temperature is cycling a bit, use the average temperature.)

7 Measure the oscillation time, in minutes, between neighboring peaks or valleys (see Figure 2). This is most easily accomplished with a chart recorder, but a measurement can be read at one minute intervals to obtain the timing.

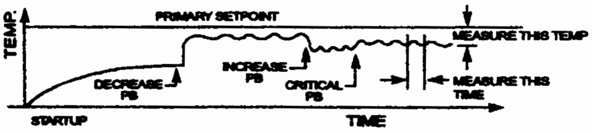


Figure 2. Oscillation Time

8. Now, increase the PB setting until the temperature deviation, or droop, increases 65%.

   The desired final temperature deviation can be calculated by multiplying the initial temperature deviation achieved with the CRITICAL PB setting by 1.65 (see Figure 3) or by use of the convenient Nomogram I (see Figure 4). Try several trial-and-error settings of the PB control until the desired final temperature deviation is achieved.

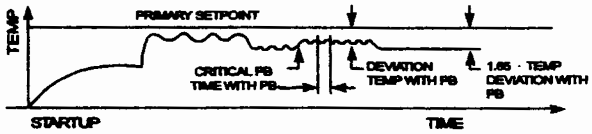


Figure 3. Calculating Final Temperature Deviation

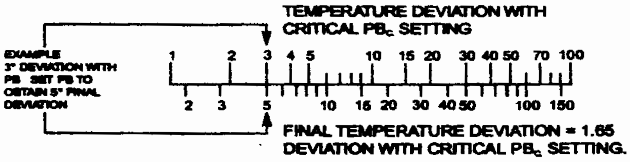


Figure 4. Nomogram I

9. You have now completed all the measurements necessary to obtain optimum performance from the Controller. Only two more adjustments are required - RATE and RESET.

10. Using the oscillation time measured in Step 7, calculate the value for RESET in repeats per minutes as follows:

$$\boxed{\text{RESET} = \frac{8}{5} \times \frac{1}{T_o}} \rightarrow K_i$$

Where T_o = Oscillation Time in Minutes.
OR Use Nomogram II (see Figure 5):

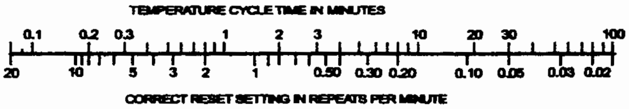


Figure 5. Nomogram II

Enter the value for RESET 1.

11. Again using the oscillation time measured in Step 7, calculate the value for RATE in minutes as follows:

$$\boxed{\cancel{\text{RESET}} = \text{RATE} = \frac{T_o}{10}} \rightarrow K_d$$

Where T_o = Oscillation Time
OR Use Nomogram III (see Figure 6)

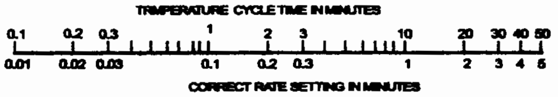


Figure 6. Nomogram III

Enter this value for Rate 1.

12. If overshoot occurred, it can be eliminated by decreasing the RESET ~~time~~ gain. When changes are made in the RESET value, a corresponding change should also be made in the RATE adjustment so that the RATE value is ~~equal to:~~

$$\boxed{\text{RATE} = \frac{1}{6 \times \text{Reset Value}}} \rightarrow K_d = \frac{1}{6}\left(\frac{1}{K_i}\right)$$

i.e., if reset = 2 R/M, the
RATE = 0.08 min.

13. Several setpoint changes and consequent RESET and RATE time adjustments may be required to obtain the proper balance between "RESPONSE TIME" to a system upset and "SETTLING TIME." In general, fast response is accompanied by larger overshoot and consequently shorter time for the process to "SETTLE OUT." Conversely, if the response is slower, the process tends to slide into the final value with little or no overshoot. The requirements of the system dictate which action is desired.

14. When satisfactory tuning has been achieved, the cycle time should be increased to save contactor life (applies to units with time proportioning outputs only (TPRI)). Increase the cycle time as much as possible without causing oscillations in the measurement due to load cycling.

15. Proceed to Section C.

Tuning a PID Controller Cont'd

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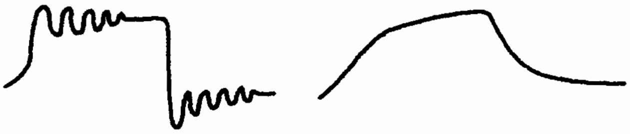
B. TUNING PROCEDURE WHEN NO OSCILLATIONS ARE OBSERVED

1. Measure the steady-state deviation, or droop, between setpoint and actual temperature with minimum PB setting. maximum Kp
2. Increase the PB setting until the temperature deviation (droop) increases 65%. Nomogram I (see Figure 4) provides a convenient method of calculating the desired final temperature deviation.
3. Set the RESET 1 to a high value (10 R/M). Set the RATE 1 to a corresponding value (0.02 MIN). At this point, the measurement should stabilize at the setpoint temperature due to reset action. Ki Kd
4. Since we were not able to determine a critical oscillation time, the optimum settings of the reset and rate adjustments must be determined by trial and error. After the temperature has stabilized at setpoint, increase the setpoint temperature setting by 10 degrees. Observe the overshoot associated with the rise in actual temperature. Then return the setpoint setting to its original value and again observe the overshoot associated with the actual temperature change. undershoot

   Excessive overshoot implies that the RESET and/or RATE values are set too high. Overdamped response (no overshoot) implies that the RESET and/or RATE values are set too low. Refer to Figure 7. Where improved performance is required, change one tuning parameter at a time and observe its effect on performance when the setpoint is changed. Make incremental changes in the parameters until the performance is optimized.
5. When satisfactory tuning has been achieved, the cycle time should be increased to save contactor life (applies to units with time proportioning outputs only (TPRI)). Increase the cycle time as much as possible without causing oscillations in the measurement due to load cycling.



RESET OR RATE TOO HIGH   RESET OR RATE TOO LOW

Figure 7. Setting RESET and/or RATE

C. TUNING THE PRIMARY OUTPUT FOR COOLING CONTROL

The same procedure is used as for heating. The process should be run at a setpoint that requires cooling control before the temperature will stabilize.

D. SIMPLIFIED TUNING PROCEDURE FOR PID CONTROLLERS

The following procedure is a graphical technique of analyzing a process response curve to a step input. It is much easier with a strip chart recorder reading the process variable (PV).

1. Starting from a cold start (PV at ambient), apply full power to the process without the controller in the loop, i.e., with an open loop. Record this starting time.

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2. After some delay (for heat to reach the sensor), the PV will start to rise. After more delay, the PV will reach a maximum rate of change (slope). Record the time at which this maximum slope occurs and the PV at which it occurs. Record the maximum slope in degrees per minute. Turn off system power.
3. Draw a line from the point of maximum slope back to the ambient temperature axis to obtain the lumped system time delay Td (see Figure 8). The time delay may also be obtained by the equation:

   Td = time to max. slope-(PV at max. slope - Ambient)/max. slope
4. Apply the following equations to yield the PID parameters:

   Pr. Band = Td x max. slope x 100/span = % of span
   Reset= 0.4 / Td = resets/minute
   Rate = 0.4 x Td = minutes
5. Restart the system and bring the process to setpoint with the controller in the loop and observe response. If the response has too much overshoot, or is oscillating, then the PID parameters can be changed (slightly, one at a time, and observing process response) in the following directions:

   100/Kp Ki
   Widen the proportional band, lower the Reset value, and increase the Rate value. → Kd

Example: The chart recording in Figure 8 was obtained by applying full power to an oven. The chart scales are 10°F/cm, and 5 min/cm. The controller range is 100 to 600°F, or a span of 500°F.

Maximum slope = 18°F/5 minutes
= 3.6°F/minute

Time delay = Td = approximately 7 minutes.

Proportional Band = 7 minutes x
3.6°F/minutes x 100/500°F = 5%. → Kp = 20

Reset = 0.4/7 minutes = 0.06 resets/minute → Ki = 0,06 min

Rate = 0.4 x 7 minutes = 2.8 minute → Kd = 2,8 min

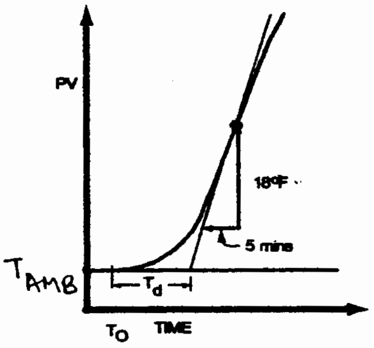

Figure 8. System Time Delay