Optimizing Thermoelectric Temperature Control Systems

INTRODUCTION

Thermoelectric coolers (TECs) are used in a variety of applications that require extremely stable temperature control. System design can be complex, but improved system performance can be well worth the effort. Laser diode systems that require narrow linewidths (cancer treatments, spectroscopy, gas sensing, etc.) combine low noise laser current sources with high performance temperature control to achieve required stabilities. Detector systems approaching the noise floor also use precision temperature control to increase responsivity and reduce noise and wavelength drift. Small, TEC based portable refrigerators and sample coolers relieve some of the need for environmentally harmful chemical coolants.

Because of their solid-state construction, these small devices are very reliable and relatively easy to use. Excellent temperature stabilities can be achieved if the system is assembled properly. Designers must have a good understanding of thermal management techniques and carefully select the thermoelectric module, temperature sensor, and controller before attempting to build high performance systems. Optimized temperature control will reduce temperature instability due to thermal transients and load changes, and in many cases, shorten the system's settling time.

This technical note will provide a practical step-by-step guide to thermoelectric cooler system design with rule of thumb approximations that work with most loads.

As always, some loads may be different and require special considerations. We have included a basic troubleshooting guide that covers the majority of problems our customers have encountered over time.

SYSTEM COMPONENTS

In a typical TEC system, current flow through the TEC pumps heat from one plate surface to the other (see **Figure 1**). Based on the Peltier effect, this makes one plate cold and the other hot. If current direction is reversed, the hot and cold sides also reverse. The TEC is mounted between the heatsink and the device being cooled with a sensor to monitor temperature. The controller uses the temperature sensor feedback to adjust the current flow through the TEC to maintain the device at the desired temperature.

In the following sections, each component is reviewed in detail.

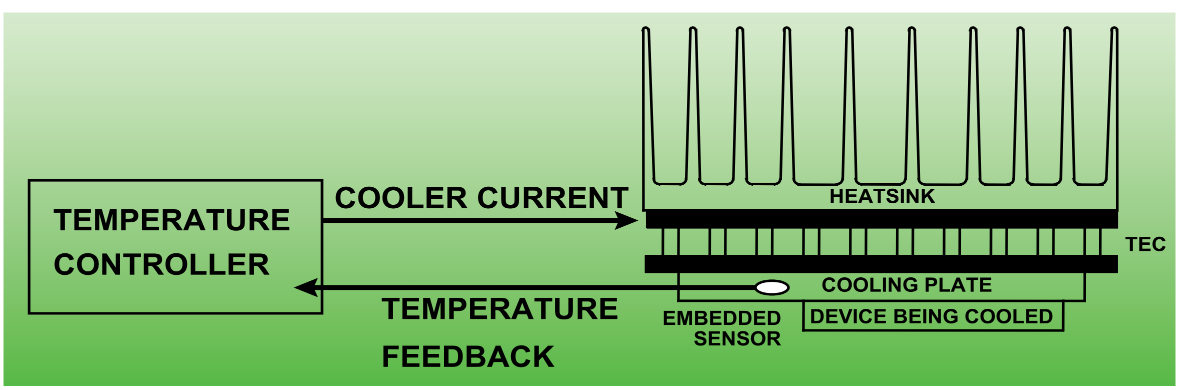

Figure 1. A simple thermoelectric control system uses feedback from a temperature sensor to maintain a device at constant temperature.

THERMOELECTRIC SELECTION

Many times designers select TEC modules without thoroughly considering the controller. Before purchasing a TEC module, make sure the controller can supply the power required to bring the device to the desired temperature and maintain a stable operating temperature. The sections on *Controller Selection* and *Optimizing the Proportional, Integral, Differential (PID) Controller* describe problems that may arise from selecting an incompatible TEC and controller.

When selecting a TEC, three load parameters must be defined: the maximum temperature of the TEC hot face during operation in Celsius (T_H), the minimum temperature of the TEC cold face during operation in Celsius (T_C), and the amount of heat absorbed at the cold face of the TEC in Watts (Q_C). Given these operating parameters, performance graphs from the TEC manufacturer are used to identify an appropriate cooler.

Application Note *AN-TC09: Specifying Thermoelectric Coolers* describes practical tools for selecting thermoelectric coolers for your system in further detail.

DETERMINE T_H

T_H is determined by the system's expected maximum ambient temperature ($T_{AMBIENT}$) and the efficiency and capacity of the heatsink assembly. For small thermal loads with sufficient heatsinking, assume that $T_H = T_{AMBIENT} + 5°C$. For larger thermal loads or if the heatsink is marginal, assume $T_H = T_{AMBIENT} + 15°C$. Typically, these estimates provide adequate margin for a good thermal design.

DETERMINE T_C

T_C is determined by the maximum deviation from ambient temperature and the geometry of the cooling plate. For small thermal loads, T_C can be estimated to be equal to the minimum cold temperature of the load. If the thermal load is larger or the thermal path length from the TEC to the device being cooled is longer than 1", assume T_C is five degrees below the desired device temperature.

CALCULATE HEAT LOAD DISSIPATION

Q_C is determined by combining the active and passive heat loads that must be pumped from the device and cooling plate to the heatsink. The active heat load is defined as the power dissipated by the device being cooled, and is generally equal to the input power to the device. For electronic devices, the heat load power dissipation can be calculated as:

$$Q_{active} = \frac{V^2}{R} = VI = I^2R$$

where Q_{ACTIVE} is the active heat load in Watts, V is the voltage across the device in Volts, R is the device resistance in ohms, and I is the current through the device in amps.

The passive or parasitic heat loads consist of radiation, convection, and conduction. In most applications, the conduction heat loss from sensor connections and cooling plate mounting is negligible and can be ignored. The following equation determines the worst-case passive heat load for most applications.

$$Q_{passive} = Q_{rad} + Q_{conv} + Q_{cond} = F\varepsilon\sigma A(T_H^4 - T_C^4) + hA(T_H - T_C) + \frac{kW}{L}(T_H - T_C)$$

F = Shape Factor (assume a worst case value of 1)	h = Convective heat transfer coefficient (W/m²ºC) (assume the value for air at 1 atm. of 21.7)
ε = Emissivity (assume a worst case value of 1)	k = Thermal conductivity of the material (W/mºC) (assume the value for copper of 386)
σ = Stefan-Boltzman constant (5.667×10^{-8} W/m²K⁴)	W = Cross-sectional area of the material (m²)
A = Area of the cooled surface (m²)	L = Length of the heat path (m)
T_H = Maximum temperature of the TEC hot face during operation (K)	T_C = Minimum temperature of the TEC cold face during operation (K)

EXAMPLE

For example, assume we have a 3mW laser diode in a standard 9mm can package, mounted to a 1" x 1" x 1/8" square cooling plate (0.001 m^2 - top surface + 4 edges). The hot surface will be about 10°C above room temperature, and the device temperature needs to be 15°C, so T_H=35°C and T_C=15°C. If the laser diode's forward current is 50mA and the forward voltage is 1.8V, the active heat load will be:

$$Q_{active} = V_f I_f = (1.8V)(50mA) = 90\ mW$$

Assuming negligible heat transfer due to conduction the passive heat load will be:

$$\begin{aligned} Q_{passive} &= (5.667 \times 10^{-8})(0.001)[(308)^4 - (288)^4] \\ &\quad + (21.7)(0.001)(308 - 288) \\ &= 0.554 \text{ Watts} \end{aligned}$$

The heat pumped from the TEC's cold surface is:

$$Q_C = Q_{active} + Q_{passive} = 0.644 \text{ Watts}$$

Note that for small thermal loads, the passive heat loss is typically several times larger than the power dissipated by the device being cooled.

Given these three parameters, the performance charts from TEC manufacturers will guide you to a module with sufficient capacity. A typical single stage TEC module can maintain a maximum temperature differential of 64°C (T_H - T_C). Designs requiring larger differentials must use cascaded TEC modules (where two or more TECs are stacked on top of each other). Many manufacturers offer pre-assembled cascaded configurations.

CONTROLLER SELECTION

The controller's output power capacity is limited by its maximum voltage and current capacity and internal power dissipation. Thermoelectric temperature controllers have either voltage or current source outputs to drive the TEC. Because current source output stages are more common in commercially available controllers, we focus our discussion on their drive limitations. The maximum output voltage of a current source is generally referred to as "compliance voltage."

A controller's compliance voltage can be calculated as:

$$V_{compliance} = \frac{P_{max}}{I_{max}}$$

The following example illustrates the constraints that compliance voltage places on driving a TEC.

Compliance Voltage Example: Consider using a controller with a 2A, 12W capacity with a TEC that requires 6W (Q_C) to maintain the device at 15ºC (T_C) with a 35ºC heatsink temperature (T_H). We select a TEC with maximum current of 2A and maximum output power of 10W, which appears to meet the load and controller requirements.

When we consider the controller's compliance voltage, we determine the incompatibility between the controller and the TEC. The compliance voltage is calculated from the controller specifications as given above.

$$V_{compliance} = \frac{12\ W}{2\ A} = 6\ V$$

Using values of T_C, T_H, and Q_C, we review the manufacturer's selection/performance graphs and determine that the TEC must be supplied with a current of 1.8 A at 8.5 V to maintain temperature.

Once the TEC voltage exceeds the 6V compliance voltage limit, the output current will be a function of the compliance voltage and impedance of the TEC. In this case, the TEC will exhibit an approximate impedance of (8.5V / 1.8A) or 4.7Ω. The output current will be limited to (6 V / 4.7 Ω) or 1.3 A. This clearly is not sufficient current to maintain the desired temperature. A different TEC module or controller must be selected. The controller can only source its maximum current to loads with impedance less than:

$$R_{max} = \frac{6\ V}{2\ A} = 3\ \Omega$$

The controller's compliance voltage should be close to the V_{MAX} rating of the selected TEC for maximum use of the TEC's power pumping capacity.

Once a TEC and controller are matched to deliver the necessary power, other performance specifications should be considered. These include rated stability, temperature coefficient, control loop type, TEC protection features, and sensor compatibility.

There is no industry standard load configuration for manufacturers to rate temperature stability of controllers.

Usually, the load is optimized for the controller and the stability measurement is taken at one temperature using a specific sensor. Inquiries to the manufacturer should determine the size and type of thermal load controlled and whether the testing was done in an environmental chamber or in a standard ambient air environment. Once the manufacturer's test conditions and thermal load are determined, compare them to your own system and derate the performance accordingly. PID controllers are designed with analog electronics because digital PID loops tend to radiate noise into the device being cooled.

The final parameter to consider is the protection offered to the TEC. The controller should provide a TEC current limit function. When this current limit is set correctly, it should limit the output current at or below I_{MAX} of the TEC. This protects the TEC from being damaged. As we will see in a later section, the current limit can also be used in optimizing the controller's performance.

The sensor feedback signal and sensor placement directly affect the controller's ability to maintain a stable device temperature. Most controllers can use a wide variety of sensors. The controller should be compatible with the type of sensor required by the system design.

SENSOR SELECTION

The temperature sensor must provide an appropriate electrical signal to the controller. Selection should be based on at least four parameters: linearity, temperature range, sensitivity, and physical size. The requirements of the application will drive the choice of sensor.

The most common precision sensor is the negative temperature coefficient (NTC) thermistor. Other temperature sensors include platinum and copper RTDs (Resistance Temperature Detectors), and integrated circuit sensors such as the LM335 from National Semiconductor and the AD590 from Analog Devices. These are Positive Temperature Coefficient (PTC) sensors. **Table 1** rates these sensors relatively.

Table 1. Common Temperature Sensor Types with Relative Ratings

SENSOR TYPE	LINEARITY	RANGE	SENSITIVITY	SIZE
Thermistor	Poor	-80 to +150ºC	Best	Best
RTD	Good	-260 to +850ºC	Poor	Good
LM335	Best	-40 to +100ºC	Good	Poor
AD590	Best	-55 to +150ºC	Good	Poor

THERMISTORS

The popularity of thermistors is mainly due to their sensitivity, size, and cost. Thermistors change several hundreds of ohms per degree Celsius. Most thermistor beads are the size of match heads, or smaller, allowing them to be precisely mounted to the device being cooled. The resistance of a thermistor decreases nonlinearly with increasing temperature, however. This property and the narrow temperature sensing range (typically 50°C maximum) are limitations for this sensor. The temperature-resistance relationship can be approximated using the Steinhart-Hart equation.

$$\frac{1}{T} = A + B\ln(R) + C[\ln(R)]^3$$

T is in Kelvin, R is in ohms, and A, B, and C are Steinhart-Hart constants specific to the thermistor. This equation will provide a ±0.01°C accuracy throughout the thermistor's temperature range. These sensors can be used in systems requiring stabilities greater than 0.001°C. For the most part though, thermistors are suitable for fixed point systems where they repeatedly go from ambient to one fixed temperature.

RTDS

Unlike thermistors, the resistance of an RTD increases linearly with temperature. Because RTDs only change fractions of an ohm per °C, they are only suitable in designs requiring no better than 0.05°C stabilities. RTDs do become nonlinear towards their range limits. Typical accuracies for a 100Ω platinum RTD are ±1.3°C at the range limits, and ±0.5°C within the mid range.

LINEAR INTEGRATED CIRCUIT SENSORS

The LM335 and AD590 integrated circuit sensors provide excellent linearity over their operating ranges. These sensors are three terminal devices available in TO-92 (plastic package) or TO-46 (metal can package). The LM335 changes 10mV for every degree Kelvin. This sensor will have a 2.88V output at room temperature (25°C) and a maximum typical error of 4°C and a 0.3°C nonlinearity over the range of operation. The AD590 provides a current output of 1mA per degree Kelvin. Error over the sensor range is 2°C and they are linear to 0.25°C. If this sensor current is applied to a 10kΩ resistor it provides a 10mV/°C transfer function similar to the LM335. These devices are suitable in designs where stabilities no better than 0.01°C are required, but a wide range of temperature will be measured.

INTEGRATING COMPONENTS

The most critical aspect of system design, once the components are chosen, is the mechanical assembly. If the heatsink is not sufficient, or thermal conduction between components is poor, the system may not only be unstable but also has the potential to damage components.

HEATSINK SELECTION

Only natural convection heatsinks will be considered in this section. The heatsink absorbs the power pumped from the TEC cold surface and heat generated by the TEC itself. Heatsink performance affects the maximum temperature range of the system and temperature stability. Many times, heatsinks are large blocks of aluminum or copper. Although these are capable of absorbing large amounts of power, once the block has heated to temperature, it does not efficiently dissipate its energy to the ambient environment. Good heatsink design includes finned extrusions for efficient heat transfer. The more surface area, the better the heat dissipation. If a heatsink is under-designed for its application, the system may go into a condition called thermal runaway. When the TEC heatsink cannot dissipate the power being pumped to it fast enough, the temperature of the cold face increases. Sensing this rise, the controller will increase its output current to compensate. Increased current pumps more power into the heatsink, further heating the TEC cold face. This vicious cycle continues until the controller reaches its current limit. The load is no longer controlled and cannot be maintained at the desired temperature.

The heatsink should be able to dissipate the power generated by the device and cooling plate (Q_C) and the power generated by the TEC (Q_{TEC}). A conservative estimate of $Q_{heatsink}$ can be calculated as follows:

$$Q_{heatsink} = Q_C + Q_{TEC} = Q_C + I_{MAX}V_{MAX}$$

where I_{MAX} is the TEC input current resulting in the greatest ΔT (Amps), and V_{MAX} is the voltage at ΔT (Volts). This allows for the fact that much more power is dissipated in reaching the desired temperature than maintaining it.

Using the value of T_H used for TEC selection, the heatsink capacity can be selected. For best results, select the heatsink with the minimum thermal resistance (TR) to maintain the TEC hot plate temperature below T_H. The thermal resistance for a heatsink is defined as its rise in temperature for every Watt of power absorbed.

The thermal resistance can be calculated as:

$$TR = \frac{T_H - T_{ambient}}{Q_{heatsink}}$$

MOUNTING FOR GOOD THERMAL CONDUCTION

The TEC module can be mounted to the heatsink with one of three methods: Thermal Epoxy, Compression Mounting, or Solder Mounting. The TEC manufacturer can recommend proper mounting for specific modules. If its dimensions exceed 3/4" on a side, the mechanical stress caused by the different thermal expansion rates of the TEC and heatsink tend to break the TEC's ceramic plate. Compression mounting is the only suitable mounting method for larger TEC's. Thermal grease is not rigid and allows both surfaces to move independently of each other. If the load is to be hermetically sealed, the solder method should be used since most thermal epoxies and heatsink compounds outgas in a vacuum. When mounting with heatsink compound, a thin layer, enough to fill in any air gaps, is necessary. Rotate the TEC back and forth, squeezing out any excess heatsink compound. Do not compress the TEC with more than 150 pounds of torque per square inch of TEC area. A "snug" fit is sufficient. When soldering the TEC to the heatsink, be careful not to exceed the maximum temperature to the TEC module (typically 136°C). If the soldering temperature exceeds the melting temperature of the solder used to mount the thermocouple junctions, the TEC may fall apart.

The device being cooled can be directly mounted to the TEC or a cooling plate can be used for mounting.

When installing a cooling plate, limit its mass and the distance between the device being cooled and the TEC. This will facilitate faster settling times and more stable operation. Positioning the temperature sensor as close to the cooled device as possible generally improves accuracy, but potentially at the loss of stability if the thermal lag across the cooling plate (distance from the TEC to the sensor) is too great.

THERMALLY ISOLATING THE LOAD

Greater temperature stability can be achieved by reducing the effects of passive heat loads. Insulating the load with closed cell foam insulation or hermetically sealing the device chamber are two ways of reducing radiation and convection losses. Gaps between the heatsink and cooling plate should also be insulated. Very little can be done to reduce active heat load variations. In systems requiring the device to control below the dew point, a dry gas, such as N2, needs to be added to the chamber to reduce condensation.

INTRODUCTION TO PID CONTROL

ERROR AMPLIFIER

The error amplifier section provides the difference between the setpoint temperature and the actual temperature of the load device as sensed by the temperature sensor. This difference is known as the error term. This error term is fed to the PID processor. The range of the setpoint temperature signal and the gain of the temperature sensor amplifier typically determine the temperature range of the controller for a given sensor.

The sensitivity of the error amplifier is determined by the temperature sensor amplifier gain and the sensitivity of the temperature sensor. For example, the error terms generated when using a 10kΩ thermistor and an AD590 at 15°C are quite different. With a thermistor current source of 100μA, the 10kΩ thermistor will produce on the order of 76 mV/°C variation on the error term around 15°C. The AD590 with a 10kΩ sense resistor will change the error term by 10 mV/°C. The AD590 will allow you to operate over a wider temperature range than the thermistor, but the thermistor will be more sensitive to temperature changes.

OUTPUT POWER AMPLIFIER

Most thermoelectric temperature controllers use a Linear Bipolar Current Source output stage. This allows the controllers to take full advantage of the TEC's capability to heat and cool. To reduce cost, a unipolar output stage can be used if the ambient environment conditions are well defined and the temperature setpoint is sufficiently lower or higher than ambient. The output power stage can be a linear voltage source but still should provide some sort of current limit to protect the TEC.

PID PROCESSOR

The PID processor section consists of a proportional gain amplifier, an integrator, and a differentiator, all of which can be implemented using simple op-amp circuits. In most PID controllers, the integrator time constant (T_I) and differentiator time constant (T_D) are fixed and only the proportional gain is variable. Both for simplicity and noise immunity, the derivative term is often not included.

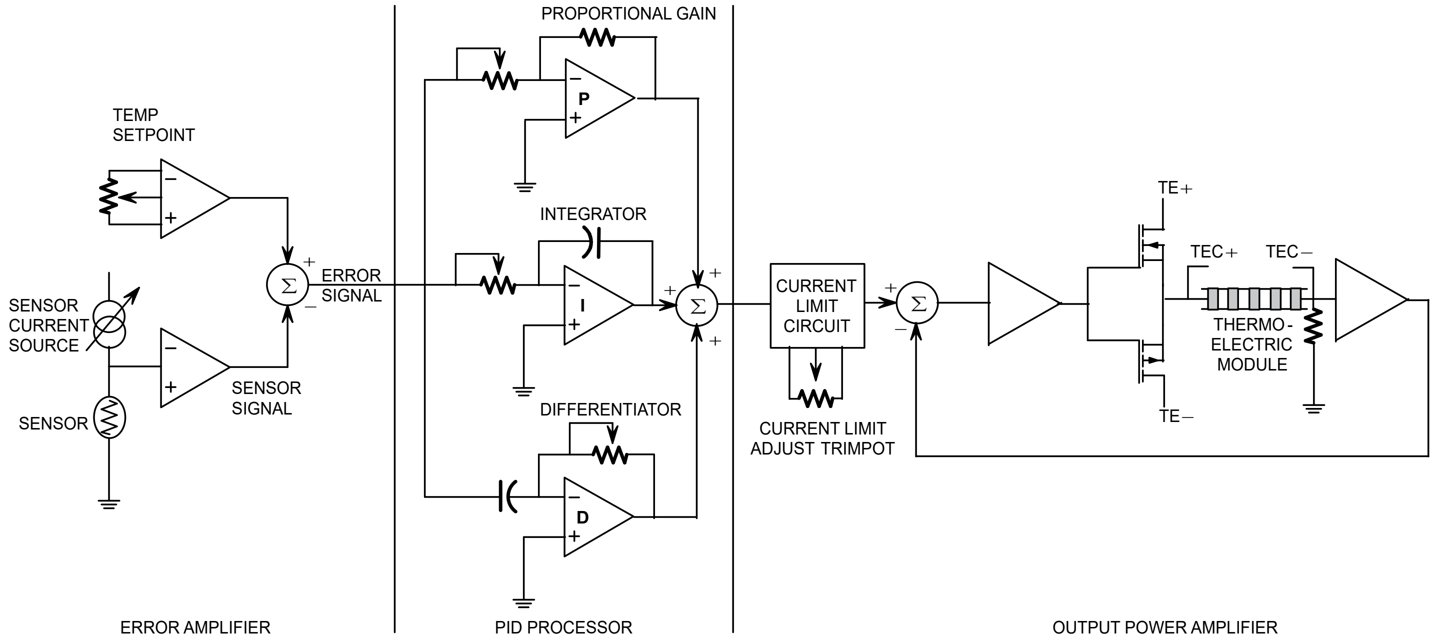

Figure 2. PID Loop Containing Error Amplifier, Power Output Amplifier and PID Processor

PID control systems usually come in one of two standard forms, independent or dependent, depending on how the proportional gain is applied. Note the difference is in whether the proportional gain k_P is applied to only the error value or to the integral and derivative terms as well.

INDEPENDENT FORM:

$$y(t) = k_P e(t) + k_I \int_0^t e(\tau)d\tau + k_D \frac{d}{dt} e(t)$$

DEPENDENT FORM:

$$y(t) = k_P\left(e(t) + k_I \int_0^t e(\tau)d\tau + k_D \frac{d}{dt} e(t)\right)$$

where $e(t)$ is the error signal, k_P, k_I, and k_D are the gains applied to the proportional, integral and derivative values, and $y(t)$ is the output of the controller. The integral and derivative gains are usually expressed as time constants. For the independent form: $T_I = 1/k_I$ and $T_D = k_D$. For the dependent form: $T_I = k_P/k_I$ and $T_D = k_P k_D$. The diagram for PID controllers shown above in **Figure 2** is in the independent form.

Simpler control loops utilize only the proportional gain stage. Proportional controllers are inherently stable for low gains, but cannot produce a zero error between the temperature setpoint and sensor feedback. A non-zero error must be maintained to produce a finite output control signal. The addition of the integrator function reduces the error to zero. The integrator produces a finite output even when the error term is zero because the output of the integrator is a function of past errors. Past errors charge up the integrator to some value that will remain, even if the error becomes zero. The addition of the derivative term can increase stability of the loop by increasing the dampening. Since the addition of the integral term usually results in larger overshoots due to integrator windup, PI or PID controllers with adaptive control loops or anti-windup circuitry are preferable.

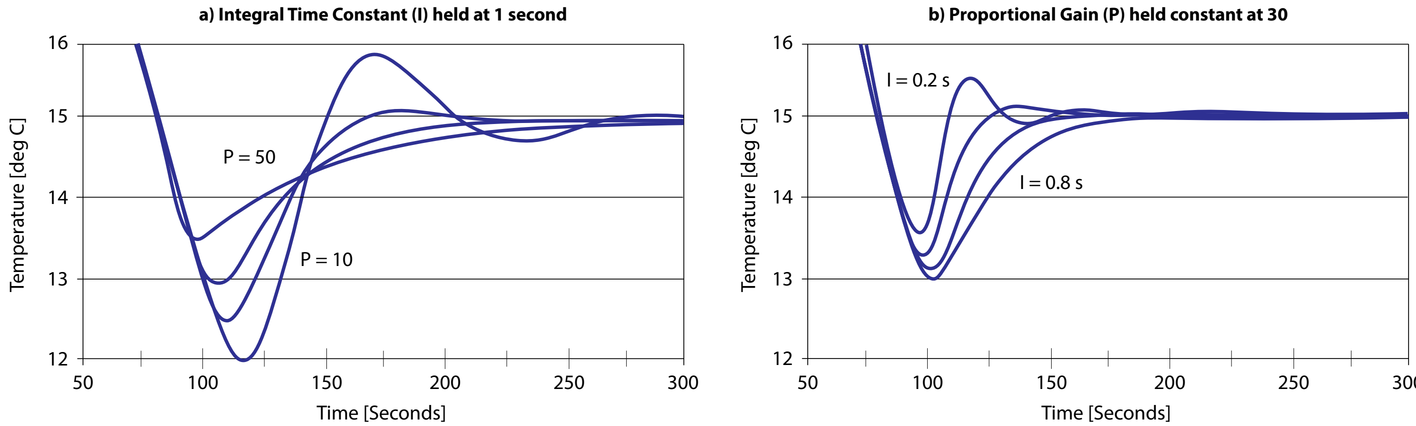

Figure 3. Examples of trade-offs that arise when optimizing variables such as proportional gain and integral time constant.
a) Holding integral time constant at 1s and varying the gain from 10 to 50 increases the system's damping coefficient.
b) Keeping the proportional gain at 30 and varying the integral time constant from 0.2 to 0.8s increases the overshoot.

SET INITIAL P, I, AND D TERMS

There are a number of techniques for setting the control terms. The technique introduced here can be used with just the system to be tuned and some kind of data logging device. As can be seen in **Figure 3a** and **Figure 3b**, changes to the proportional gain can result in effects that are very much like those due to changes in the Integral term. Also, increasing the proportional gain can improve settling and stability up to a point, but too much proportional gain can actually cause oscillations. This fact is used in the tuning method described below.

THE NICHOLS-ZEIGLER METHOD

As mentioned above, it is best to try to adjust one control parameter at a time. For a first-order-with-delay system such as most thermal systems, the Nichols-Zeigler (N-Z) method gives a fairly reliable estimate for the system parameters. If the integral and derivative terms can be disabled, this is one of the better trial and error methods. Some analog controllers fix the Integral term, but it may be possible to defeat the integral by shorting across the integrating capacitor. In any case, tuning should be accomplished around a temperature midway between ambient and the desired setpoint. This should average out the variations in overall system gains between the two temperatures.

First, the proportional gain should be set in the middle of the gain range. The proportional gain should then be increased in steps. After each step, apply a small change to the setpoint. With sufficient proportional gain, the temperature will begin to exhibit damped oscillation as exhibited in **Figure 4**. If the system begins to oscillate on the first try, reduce the gain in steps until the system exhibits the damped response shown in **Figure 4**. The proportional gain value that just starts oscillations is referred to as the critical gain k_C. The optimal proportional gain will be about half of this value. If the controller proportional gain cannot be increased to the level necessary to drive the system into oscillation, then it may not be the appropriate device for the load. Operating any linear controller near its maximum settings can result in non-linear response.

Next, estimate the period of the oscillation. Further increases in the proportional gain will result in sustained oscillations with a period referred to as the critical period T_C. The estimate of the critical period made from the damped oscillations will usually be within 10% of the critical period and good enough for the initial tuning estimates.

Using the independent control form of the PID controller, the initial estimate of the P gain, k_P, will be 0.5 kC. The initial I term k_I, will be k_P/T_C. The equivalent integrator time constant will be T_C/k_P. In the example of **Figure 4**, the critical gain is approximately 70, so the initial proportional gain k_P will be set at 35. The critical period is approximately 25 seconds, so the initial integrator gain would be estimated at about 1.4, or the integrator time constant T_I would be about 0.71 seconds. In this case the typical default value of 1 second would be appropriate.

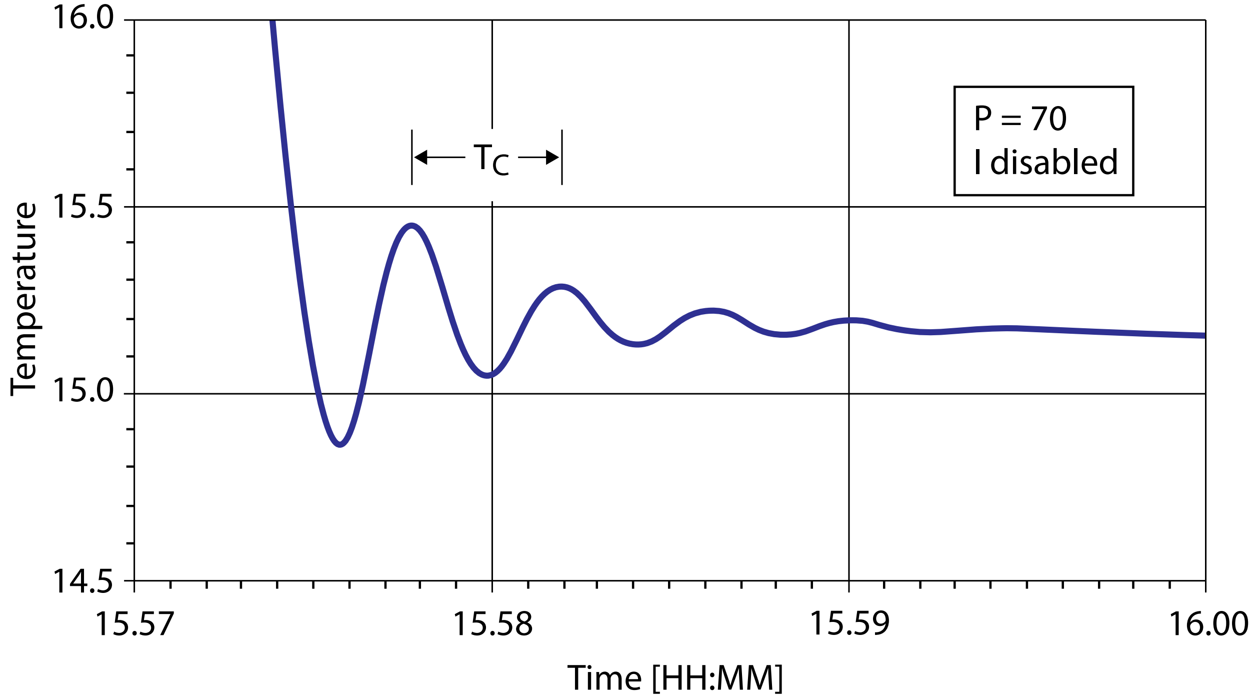

Figure 4. Find the critical proportional gain (k_C) necessary to cause the temperature to begin damped oscillations. The oscillation period is T_C.

Using the dependent form, the initial proportional gain will again be k_P, but the integral term will be $1/T_C$.

The N-Z method rules were themselves the result of trial and error for numerous systems exhibiting first-order-with-delay characteristics. The fact that the delay in thermal systems is really due to heat diffusion requires a few extra considerations. Most notably, the time constant produced by the N-Z method will often be shorter than optimal for typical thermal loads. Also, thermistors and other temperature sensors themselves have time constants on the order of one second. It is not generally advisable to set the control time constant to less than that of the sensor.

If the sensor is physically located far from the TEC, or there are several thermal boundaries due to material interfaces, the controller time constant will need to be set longer and the integral gain reduced.

If the D term is used, its initial value can be estimated to be in the range $k_P T_C/8$. If the system exhibits inversion, as many TECs do, the use of derivative control should be avoided as fast changes in current due to noise response could destabilize the load.

INVERSION

Many thermal systems exhibit inversion, a condition in which the system responds in the opposite direction to the desired control function. In TECs this usually shows up as a short period of heating when a step increase in cooling current is applied. The heating effect can last for several seconds. As shown in **Figure 5**, switching the TEC current from about 0.3 A of heating current to 3.5 A of cooling current, produces a pronounced inversion effect. Different TEC systems will respond differently.

If inversion occurs, the use of derivative control should be avoided. There is the possibility that a rapid heating disturbance due to turning on a laser may result in a rapid increase in the cooling current, causing an additional heating effect from the inversion.

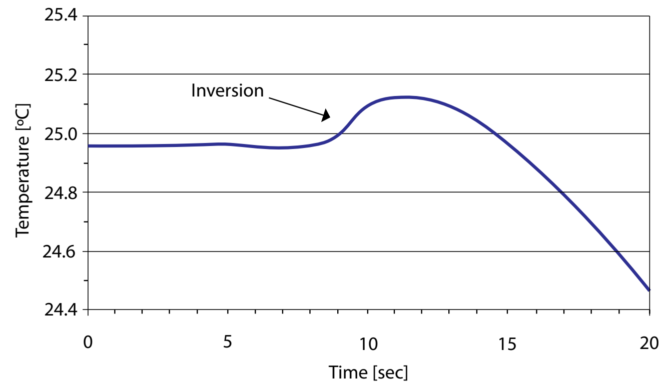

Figure 5. Inversion is the term for the system initially responding in the opposite direction from that commanded by the control signal.

ANTI-WINDUP

Some PID controllers have an extra compensation feature to keep the Integral term from accumulating excess error during the time when the controller is experiencing current limit. This is termed “anti-windup.” It can be implemented in several ways, including clamping the integral at some value or simply initializing it to zero during the limit condition (**Figure 6**).

While the anti-windup compensation will make the system less susceptible to non-optimal tuning of the integral term, it will not correct for excessive proportional gain. Too much proportional gain can cause virtually any thermal system to oscillate.

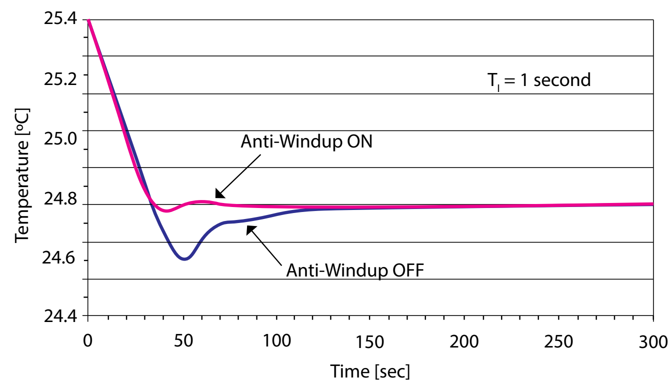

Figure 6. Comparison of response with and without anti-windup

AUTOTUNE & INTELLITUNE

Many temperature controllers use Autotune to calculate the best PID parameters based on different algorithms of the temperature controller design. Wavelength's proprietary IntelliTune® algorithm characterizes the TEC / Sensor system's response to the termperature controller and then automatically adjusts the PID control values as setpoint, tuning mode, or bias current are changed. Application Note *AN-TC13: IntelliTune vs. Conventional Autotune* shows the benefits of using Wavelength's Intellitune® when not manually tuning the PID coefficients.

TROUBLESHOOTING

Because the rules given here are general rules of thumb, some tweaking may be necessary to account for special load circumstances. The following list details common problems, their definitions, and suggestions for solving them.

CYCLING

The load temperature varies repetitively around the setpoint without settling at a stable temperature.

1. The sensor may have a poor thermal bond to the load. When the sensor is not firmly attached to the load a thermal time delay will exist. The controller is responding to a delayed error signal that may not be representative of existing conditions. Bond the sensor to the load with thermal epoxy, or at least fill in any air gaps with thermal grease. If the sensor doesn't fit snugly in its mounting hole, the extra epoxy required to hold it may also induce a thermal lag.

2. The sensor may be too far from the TEC, or the thermal mass of the TEC and cooling plate may be too large. Either problem causes a thermal time delay. This can be solved by moving the sensor closer to the TEC, reducing the mass of the cooling plate, or increasing the heat pumping capability of the system by using a larger TEC or a controller with greater power capacity.

3. The current limit may be set too low. The system will respond slowly to the controller output, so the controller will overcorrect for temperature variations. If the current limit must be set low due to power restrictions, then the integrator time constant must be increased.

LONG SETTLING TIME

The settling time is very dependent on the load configuration. If the load temperature crosses the setpoint more than twice before settling, it may be underdamped. If the load doesn't cross the setpoint after overshooting, it may be overdamped.

1. If the system is underdamped, try increasing the integrator time constant.

2. If the system is overdamped, try reducing the proportional gain.

LARGE OVERSHOOT

When first cooling, the temperature will drop below the setpoint. Large overshoot is a problem if the device being cooled can be damaged by too low a temperature.

1. Increase the proportional gain or decrease the integrator time constant (see Optimizing the PID Controller **page 8**).

2. Reduce the sensor time delay. Either reduce the thermal mass in the cooling plate or provide a shorter thermal path between the temperature sensor and load.

3. Impove thermal bond to sensor.

4. Increase the sensitivity of sensor. Either choose a sensor with better resolution or increase the sensor signal.

POOR TEMPERATURE STABILITY

Non-cyclical variations around the setpoint occur.

1. The load may be exposed to large ambient temperature fluctuations. If possible, isolate the load with closed cell foam or hermetically seal the assembly.

2. When the sensor is a long distance from the device being cooled or not properly thermally connected, the sensor will not accurately track its temperature. Reposition the sensor, and insure a good thermal bond.

3. If the TEC is not flat against the heatsink or cooling plate, or thermal grease or epoxy does not completely fill air gaps, then the TEC module can lift and swell, changing the heat pumping capacity as the surface area connected to the heatsink varies.

THERMAL RUNAWAY

The heat produced by the TEC and load is not removed quickly enough. The sensor detects increased temperature and the cooling current through the TEC is increased, causing more power to be dissipated by the TEC, further increasing the temperature.

1. This can be caused by insufficient TEC heatsinking. Select a heatsink with a lower thermal resistance or force air across the heatsink.

2. The current limit may be set higher than the TEC can handle. If too much current flows through the module, it can overheat, possibly melting the solder joints and damaging the TEC.

3. If the ambient temperature is too high, the heatsink capacity is reduced. Either increase the capacity of the heatsink or consider forcing airflow across it.

NOISE ON THE LOAD

Many temperature controlled devices are electronic components capable of picking up electrical noise. Since the sensor and TEC are typically located near the load, they can radiate noise onto the device being cooled. Ferrite beads and filter capacitors can be added to the thermistor and TEC leads to minimize radiation effects, and shielded cables should be used.

KEYWORDS
autotune, autotune pid, autotune pid temperature controller, digital pid temperature controller, ntc thermistor, pi temperature controller, pid temperature controller, tec controllers, temperature controller, temperature controls, temperature sensor, thermistor, thermistors, thermo electric, thermo-electric, thermoelectric, thermoelectric control, thermoelectric controller, thermoelectric controllers, thermoelectric cooler, thermoelectric coolers, thermoelectric cooling, peltier device, peltier cooler, heat pump

REVISION HISTORY

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REV.	DATE	NOTES
A	June 2000	Initial Release
B	July 2003	Renumbered & Standardized
C	October 2005	Updated Optimizing Section
D	July 2020	Updated to Technical Note format