All Controls Are Not Created Equal

Thermal cutoffs require extra consideration

By Andrew DeIonno

"FAMILIARITY BREEDS CONTEMPT." That well-known saying can be applied in the field of safety engineering and design when selecting components and evaluating system safety. Simple and basic protection devices, such as thermal cutoffs (TCOs), are prevalent in component applications such as motor protection and transformer protection. These devices are also primary safety devices found in a wide range of end-product applications. They are used in household appliances such as coffeemakers, clothes irons and electric heaters, and in industrial and commercial applications such as HVAC systems and industrial heating.

The theory of their operation is analogous to the way a fuse operates in a branch circuit, and the technology is easy to follow and understand. However, it is important to ensure that this component's "simple" operation does not lead to the view that it is a simple component to specify in a system. Its simple appearance may forge a "friendship" with a designer and his/her design, and may cause the designer to assume that the proper rating is a "no brainer." However, through careful attention to detail, early design testing and good engineering knowledge of component ratings, even the novice can make the right choice.

When designing a system of components into a functioning and useful machine, several considerations are accounted for in the design and development process. Several of these start as basic ideas—such as electrical ratings, mechanical tolerances, functionality and user interface—and they are coupled with specific business needs—such as cost, time to market, customer expectations and customer demand. Balancing this is a daunting task, and success or failure of a design could easily rest with the basic design and component selection.

All components need certain levels of detail during the selection phase of a design, but some need so much detail that they are not truly finalized until the design is nearly complete. A TCO is an example of such a device (Photo 1).

According to Underwriters Laboratories' UL 1020 standard, a TCO is "a temperature- or temperature-and-current-sensitive device incorporating a thermal element for protecting a circuit by opening the protected circuit when the device reaches a predetermined temperature. It is intended to 1) reduce the risk of fire, electric shock and injury to persons due to overheating of a product during abnormal operation and 2) operate only once; that is, it cannot be reset or reconditioned for reuse" [UL(b)].

Since the device is temperature-sensitive, it must be placed and sized correctly during the design and development phase of a product. The design must also allow enough margin to cover manufacturing variations of the final product in a production setting.

Anyone who has designed, tested or evaluated a heater circuit, motor protector or transformer protector has probably seen or worked directly with this component. As noted in the UL definition, a TCO has a predetermined operating temperature and is designed to interrupt an electrical circuit when this temperature threshold is exceeded, thereby preventing an overheating situation in the system. Since it cannot be reset, a TCO is usually a last line of protection in a heating load's circuit.

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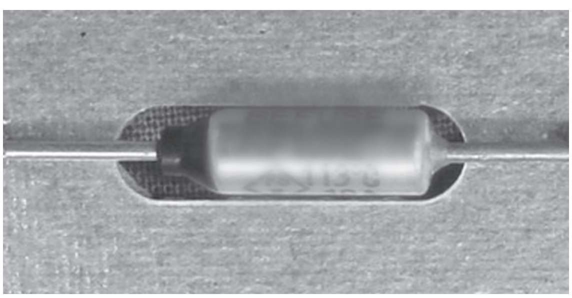
How Does a TCO Work?

A TCO has a thermal element that may be metallic or nonmetallic; when the rated operating temperature is exceeded, this element changes physical state and interrupts current flow through the TCO (Figure 1). In many circuit applications, it sees line current and is located in series with the load that it is protecting. When the TCO temperature rating is properly selected, it will interrupt current flow before the heat generation reaches a level that causes either electrical insulation breakdown or ignition of combustible materials. Since the device cannot be reset, it is an excellent way to alert the operator that the product has experienced a severe abnormal event and that a qualified service person is needed to evaluate the incident and, hopefully, correct its root cause.

A TCO has one obvious application—heater circuit protection—but it is also allowed as a protection method for motors (NFPA Article 430.32) and in certain specific transformer listings. Its use is not limited to specific types of products and, as noted, it is found in products ranging from small kitchen appliances to large industrial machines.

Photo 1: A typical TCO.



In today's fast-paced market, a novice designer/engineer may simply select a TCO based on its rated operating temperature; however, a seasoned designer knows that heater protection is usually not so simple. For example, the same design will vary in heat output from unit to unit in a sampling of identical designs from the same production line (due to manufacturing variation). Hotspots on one heater bank may not be the same as the hotspots on the next heater bank (even if they are identical in design).

Even slight changes in the TCO's location due to manufacturing variation could lead to failure of the design because the TCO might be located in a relatively cool spot. For example, if the design does not allow enough margin, this variation could allow the load to run away to the extent that electrical insulation is damaged due to temperature overshoot (Figure 2). On the other hand, if the designer selects a TCO temperature rating that is too low, it may operate during normal conditions (nuisance trip), which could frustrate customers.

Where Should a Good Designer Start?

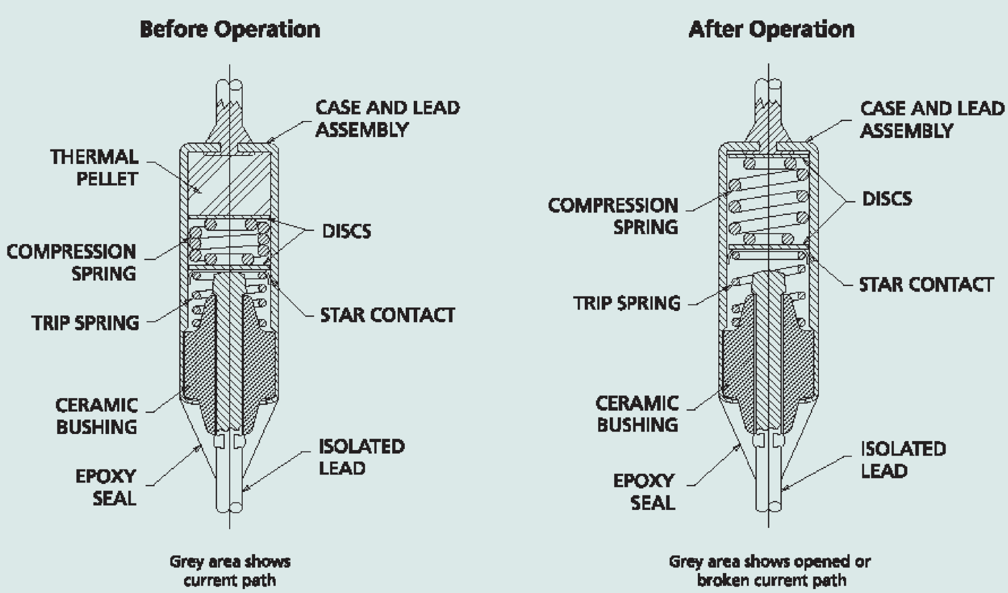
A third-party certification laboratory, such as UL, ETL Semko or MET Laboratories, will exercise the design through a set of specific normal and abnormal conditions as dictated by national standards. However, a good designer does not rely on a lab to test a design first; instead, s/he uses these tests as a basis to assess and refine the product before the lab sees it.

For example, UL Standard 1995, Heating and Cooling Equipment, provides specific normal temperature conditions (electrical, mechanical and environmental) that will stress a design [UL(a)]. One simple and immediate nonconforming condition would be operation of the TCO within the normal operating parameters of the finished product. Therefore, a designer should test and consider this factor before submitting the product to a third-party tester. At a minimum, TCO operation within normal operating conditions will be a quality problem in the field and, in the worst case, a potential liability.

Liability enters the equation because nuisance tripping in the field could prompt the user to try to repair the device with a higher-rated TCO value or to remove it from the circuit all together. Clearly, such modifications will have detrimental effects on the design. Changing the value of a TCO or removing it from the circuit could compromise the last line of protection in an abnormal event. However, in a laboratory certification, normal operation has one critical point to remember: If the primary heater controller is not certified, then the laboratory will consider it to be an

Figure 1

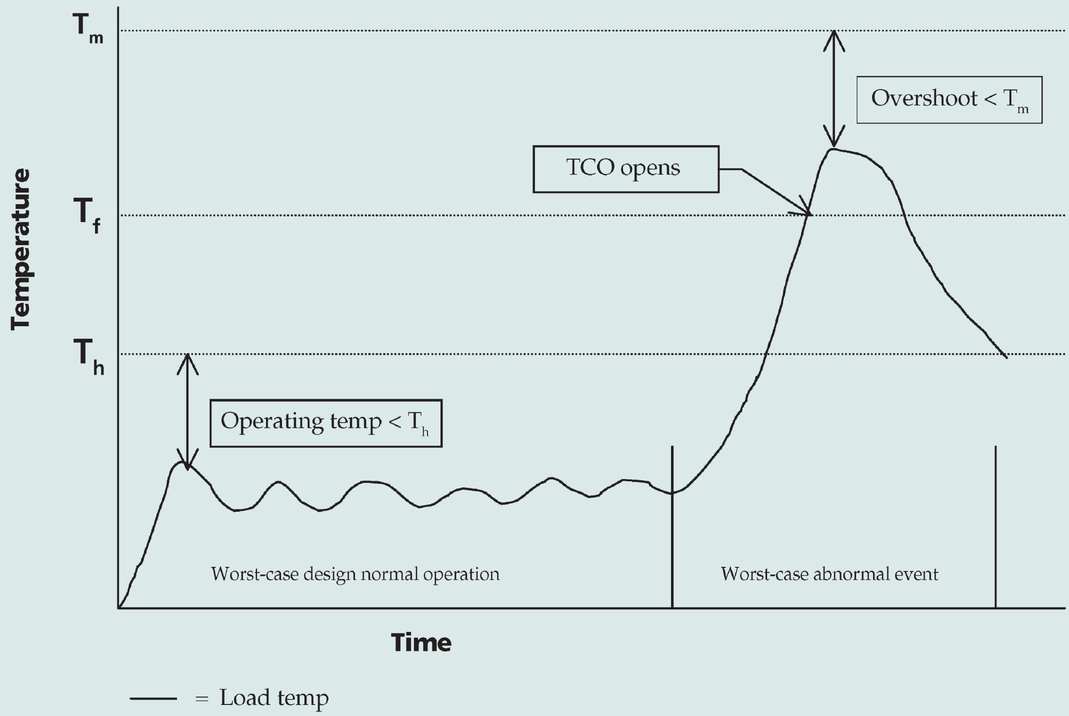
TCO: Internal Operation



Source: Therm-O-Disc Inc.

Figure 2

Graphical Representation of TCO Ratings Relative to Heat-Generating Load



unreliable device and will remove it from the circuit during the normal operation test. If this device is the only temperature-regulating device in the circuit and the laboratory removes it from the circuit during testing, then the TCO cannot operate.

On the other end, the designer must balance the abnormal operation testing required by the standard. UL 1995 has typical abnormal operation tests; some attempt to represent user neglect (e.g., blocked air inlet and blocked air outlet) and some represent component faults, such as a loss of the certified temperature indicating and regulating device (thermostat) or loss of fan cooling [UL(a)]. In these cases, the TCO must operate to safely shut down the heating system before it creates a fire or shock hazard as a result of the uncontrolled heating.

The fire indicator in UL 1995 is cheesecloth. Failure of the unit with respect to fire hazard includes ignition of the cheesecloth, or emission of flame or molten metal from the unit. The shock hazard is evaluated (for permanently connected units) by a combination of dielectric voltage withstand testing and connection of an indication fuse in the ground circuit to the product's grounded chassis. A shock hazard exists if the ground fuse opens or if the unit fails dielectric voltage withstand [UL(a)].

The third component of the balancing act for the designer is the expected (or known) misuses and abuses of the system that may occur in the field. These may be easy to evaluate based on past history, or difficult to assess because user interaction is not yet fully developed for a new concept.

In any case, the design must account for reasonable misuse and abuse. Since the TCO has such a wide range of applications, the design team must explore this interaction fully. The interaction should include items such as operator cleaning and servicing, typical operator history with servicing the product (whether the operator will treat it as an expendable item, such as a hair dryer, or will try to fix it), and level of user skill (whether the user will know how to fix it).

A good designer will have read the standards and understand the tests they require. Although this may seem like a simple matter of selecting the correct TCO operating temperature, that is not necessarily true. To illustrate, consider the following TCO ratings and recommendations based on a common TCO manufacturer's guide.

- **Maximum Open Temperature or Rated Functioning Temperature (T_f, T_F):** Maximum temperature at which the TCO changes its state of conductivity to open circuit with detection current as the only load. The rated functioning temperature is measured during a temperature rise of approximately 0.5ºC per minute.
- **Holding Temperature (T_h, T_H):** Maximum temperature at which, when applying the rated current to the TCO, the state of conductivity will not change during a period of one week.
- **Maximum Overshoot Temperature or Maxi-**

mum Temperature Limit (T_m, T_M): Maximum temperature at which the TCO, having changed its state of conductivity, can be maintained for a specified period of time, during which its mechanical and electrical properties will not be impaired.

Where to Start

The best place to start is with a solid understanding of the heat topography for the heating load (thermal map of the heater). This will help the designer identify a location and potential operating temperatures for the TCO. Several methods can be used to perform this preliminary topography; these include infrared imaging or a large array of thermocouples around the heater or heated surface in question. This process will provide an idea of what T_f should be; however, remember that the TCO must not operate during normal operation. The same or similar mapping must be developed to capture maximum normal temperatures (including any short-term overshoots) in all operating modes. With T_f selected, T_h needs to be considered because if the normal operating temperature exceeds T_h, then the TCO's thermal element could degrade and nuisance trip during the life of the product.

Similarly, if the T_f selected is too close to typical short-term temperature overshoots then the TCO life expectancy will degrade, which may lead to nuisance trips (probably not detectable by laboratory testing, but experienced by customers). Again, different normal operating modes and reasonable abnormal conditions must be carefully considered. For example, different fan speed settings will provide different heating profiles; depending on airflow patterns and air velocity, the mapping temperatures will likely be different. Also, with an air heater, poor user maintenance can lead to a filter clog. Therefore, restricted airflow should be considered by the design and testing team during product development—before submittal to a testing laboratory. The worst-case temperatures must be considered for TCO placement and selection of the TCO operating temperature.

Nothing can be taken for granted in design; a designer should also consider connection methods and heat conduction through the TCO. For example, a poor splice joint on the end of the TCO could conduct enough heat into the cutoff to nuisance trip. This must be considered and weighed with the alternatives, such as welding and soldering that could create their own thermal damage to the TCO if the production process does not employ proper safeguards.

One of the final design considerations, yet perhaps one of the most important, is the need to know the maximum overshoot temperature values (T_m) for the selected TCOs along with an approximate variation allowance from unit to unit. This means that a designer must test the worst-case abnormal condition with a statistically significant population to determine the maximum overshoot temperature. The best way to truly evaluate this is to actually impose the fault on physical units and record the results. This is a critical step in the design process because if the product's overshoot temperature exceeds T_m, it is possibile that the TCO's thermal element will degrade (lose its dielectric property) and could potentially reconnect. When this occurs, electrical current could resume flowing to the heater circuit if T_m is exceeded in an abnormal event.

At this point, the designer has determined the T_f and has sized T_f and T_h so that the TCO will not degrade and nuisance trip, and will continue to protect the heating system. In addition, the designer knows that the maximum overshoot in all abnormal conditions will not exceed the selected TCO's rated T_m. Finally, the design team has proved the design on real samples; has submitted these samples to the listing agency as part of the final design; and knows that production variation will not affect the heater circuit's abnormal safety. With this design homework complete, the team can be confident that this part of the system will not cause an increased risk of fire or electric shock under both normal and abnormal operation of the system. Because the design team has employed foresight and planning, coupled with a keen attention to detail in TCO selection, it can feel comfortable that this design is complete and can move on to the next critical component selection process.

Conclusion

Unlike other simple electrical devices, such as switches, TCOs have some unique ratings and characteristics that a designer must consider when developing a system. One consideration is quality; if the T_h or T_f rating is violated in normal operation, then the TCO may nuisance trip. This would lead to customer dissatisfaction, increased service calls and increased expenses spent on a marginal design. Another consideration is TCO location and size; if T_f is too high or T_m is too low, then the TCO may not adequately protect the system if an abnormal event arises in the overall equipment. This could cause a wide range of expenses, including damage to reputation, property damage, injury, potential product recall/repair, increased legal claims costs, increased insurance costs and loss of sales.

The designer is in an excellent position to prevent future issues with the overall product if s/he evaluates the heat-generating circuit in all modes of operation in order to accurately map the heated area. This map will greatly help the designer properly select the ratings and location for the TCO. ■

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