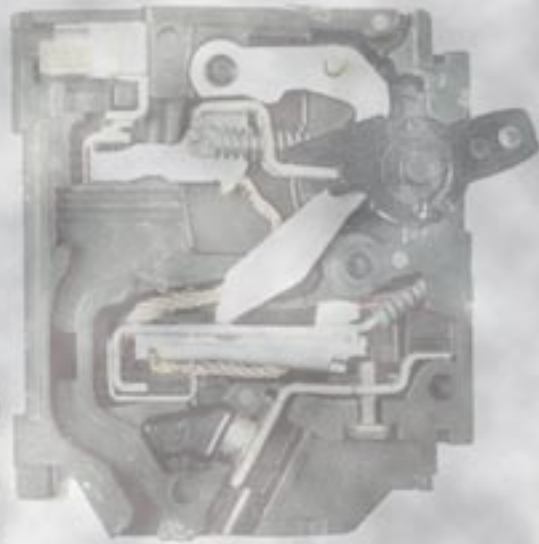


CIRCUIT BREAKER

MYTHS



Mark Goodson, PE
Mark Hergenrether, MSME
Aaron Stasonon

introduction

The circuit breaker is the basic means by which wiring is protected from both a short circuit and overload damage. Circuit breakers have replaced the fuses of yesteryear, and are desirable for both consistent performance and also for the fact that they can be reset.

A short circuit is different from an overload. NFPA 70E defines an overload as:

“Operation of equipment in excess of normal full-load rating or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault such as a short circuit or ground fault, is not an overload.”

Practically speaking, plugging twenty 150 watt light fixtures (3000 watts total) onto a 14 AWG branch circuit is an overload—we have a current of 25 amperes flowing in cabling rated at 15 amps. Shorting the hot lead to the neutral lead on this same branch circuit will cause hundreds of amps to flow—this is a short circuit, and is often accompanied by arcing and the splattering of molten metal.

The basic circuit breaker used in both residential and light commercial applications is called the T-M or Thermal Magnetic Circuit Breaker. Another term that is sometimes used is the MCCB, or Molded Case Circuit Breaker. The T-M circuit breaker has two independent trip mechanisms: thermal and magnetic. The former reacts to overloads and causes the breaker to trip, while the latter responds to short circuit fault currents.

the myths

There are several myths associated with circuit breaker operation. In this article, it is our intent to discuss each one, and explain physically the reason that each myth is just that. These myths are as follows:

1. T-M circuit breakers trip upon reaching rated current
2. T-M breakers trip immediately
3. A tripped breaker always means an electrical event has occurred
4. Breakers protect appliances and appliance cords
5. Breakers protect persons from electrical shock
6. Climate and ambient conditions have no effect on trip times
7. Circuit breakers prevent arcing
8. Circuit breakers can be used as on/off switches.

basic breaker operation and design

In order to debunk the myths it is important to understand the basic operation and design of the trip mechanisms in a circuit breaker. The thermal portion of the circuit breaker works by use of a bi-metallic strip which causes a spring-loaded latch to release and trip the breaker. The deflection of the bi-metallic strip depends on the temperature, thus the breaker has a trip temperature and it is the heat generated within the breaker that causes the temperature to rise, the faster the heat rise, the faster the breaker reaches temperature and trips. Heat is directly proportional to the power (watts), which is proportional to the square of the current ($P=I^2 \times R$)

The first (and most common) misconception is that a breaker trips when its nameplate rating is exceeded. One fire text has stated (incorrectly) that a circuit breaker will trip in several minutes with a small increase in current over its rating^[1]. Actually, a 20 amp breaker must trip at a sustained current of 27 amperes (135 percent) at less than one hour, and at 40 amperes (200 percent of wire rating) in less than 120 seconds—far different from what the cited

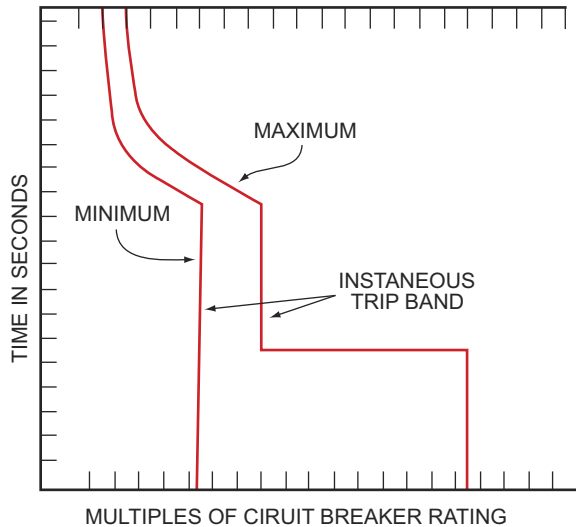
text implies. These two trip points (135 percent and 200 percent) are defined in NEMA Standard AB-1, MCCBs and Molded Case Switches^[2]. TABLE 1 lists the 200 percent allowable trip times for different size (amperage) circuit breakers. MCCBs have characteristic ‘curves’ published by their respective manufacturers. A sample of such a curve appears in FIGURE 1. Knowing the amount of current flow, as a multiple of the breaker rating, allows one to determine the minimum and maximum trip times. Usually, the allowed times (per the manufacturer’s curves) are shorter than what the NEMA spec allows.

A circuit breaker is designed to open (trip) before the energy passing through it creates enough heat in the branch circuit wiring to cause damage to the wiring. As an example, a type #12 AWG NM-B

TABLE 1

BREAKER RATING (Amperes)	ALLOWABLE TRIP TIME (Minutes at 200% rating)
0-30	2
31-50	4
51-100	6
101-150	8
151-225	10
226-400	12
401-600	14
601-800	18
801-1000	20
1001-1200	24
1201-1600	26
1601-2000	28
>2000	30

FIGURE 1: ILLUSTRATION OF CIRCUIT BREAKER TRIP CURVE



with 40 amperes (flowing on it will not cause substantive overheating in the 2 minutes allowed for the breaker to trip. The caveats here are that the wiring being protected is *branch circuit wiring* and the breaker and branch circuit wiring are appropriately sized. A residential circuit breaker is not intended to protect load wiring such as extension cords or appliance line cords that may be subjected to overloads. For example, if we assume that an extension cord is rated at 10 amperes (#18 AWG) and is carrying a load of 25 amperes while connected to a branch circuit wire that is protected by a 20 ampere T-M breaker, the 20 ampere breaker may never trip. At the same time, the extension cord is grossly overloaded, and will become damaged. Similarly, a 40 ampere breaker protecting 15 ampere branch circuit wiring (#14 AWG type NM, as an example) **will** allow damage to occur during sustained overloads, because the breaker is inappropriately sized.

The response of a conventional T-M circuit breaker is affected by the temperature of its surroundings. This means that a breaker at an ambient temperature of 110 degrees F (thermally) will trip much faster than the same breaker will in an atmosphere of 20 degrees F. TABLE 2 shows data from a Square D circuit breaker rated at 30 amperes at different temperatures. When sufficient heat is generated in the bimetallic thermostat the breaker opens. In this case, the test current was 60 amperes.

TABLE 2

TEMPERATURE (°F)	TIME (S)
20	30
36	27.9
47	26
56	24.5
69	21

The magnetic portion of a circuit breaker is sometimes called the instantaneous trip portion. Rather than having an inverse current/time relationship, the magnetic trip level is characterized by the rate of change of the current flowing (di/dt) that is, the faster the increase in current, the faster the magnetic trip time. Once the instantaneous trip level is exceeded, there is a sufficiently strong magnetic field to cause the breaker to trip. Unlike the thermal trip mechanism there is no intentionally induced delay. Furthermore, the magnetic trip level is not affected by heat, such that ambient temperatures have no effect on performance. Another difference between the magnetic and thermal functions is that NEMA AB-1 does not specify a required magnetic trip level. Rather, each manufacturer is free to specify at what range of current the breaker will react to a perceived short circuit.

One might be quick to compare circuit breakers to fuses, however; there are several salient differences between the two. Fuses are non renewable, while circuit breakers can be reset. If a fuse blows

and someone does not have a ‘like’ replacement readily available, on more than one occasion fuses have been replaced with larger size fuses—this is obviously a fire hazard. In addition, fuses are very easy to ‘bypass’; copper tubing, as an example, easily fits in a cartridge fuse holder and provides no overload protection.

relocatable power taps

Relocatable power taps, more often called power strips, all have circuit breakers present. In general, these breakers are thermal breakers, and have no magnetic trip level. They are intended to prevent damage to wiring caused by having too many appliances plugged in (i.e., too great a load), and are usually rated at 15 amperes. We mention these breakers because they are common, and yet they are very different from the T-M breaker used as a part of branch circuit wiring.

T-M measurements

Given that there are two separate trip mechanisms in a circuit breaker, we have heard the following question posed numerous times in the past, as follows:

“If we test the thermal portion of a breaker, will that ensure that the magnetic portion of a breaker is properly functioning?”

The answer is “No, the two internal mechanisms operate independently.” The reason that the question is asked is because it is much easier to test the thermal portion of a breaker than the magnetic portion. To demonstrate the independent operation, we obtained a number of T-M circuit breakers of varying sizes and various manufacturers. We tested both the thermal characteristics (all at 75 degrees F, nominal), and then tested the magnetic trip levels.

Testing was done on a custom test set, using a computer to both simulate fault currents and measure actual currents and time. Using IEEE488 protocol and operating under Agilent VEE software the computer controlled a programmable power supply (Agilent 6813A) which in turn supplied power to a high current transformer (Unitrek 600 Ampere) in which the output was connected to the breaker being tested. Current values were measured across the breaker via a digital volt meter (Agilent 34401A) and fed back to the computer in order to maintain a constant current. FIGURE 2 is a diagram of the test setup.

For the thermal characteristics, a 200 percent test current was supplied to each of the breakers (i.e., 30, 40, or 60 amperes for the 15, 20, and 30 amp breakers, respectively) and maintained until the breaker tripped. Current was continually monitored and adjusted (via software) to ensure a constant load current. The same transformer was then used for the instantaneous or magnetic trip levels testing for the breakers. The power supply was programmed to send a pulse train of

FIGURE 2: SCHEMATIC OF CIRCUIT BREAKER TESTING DEVICE

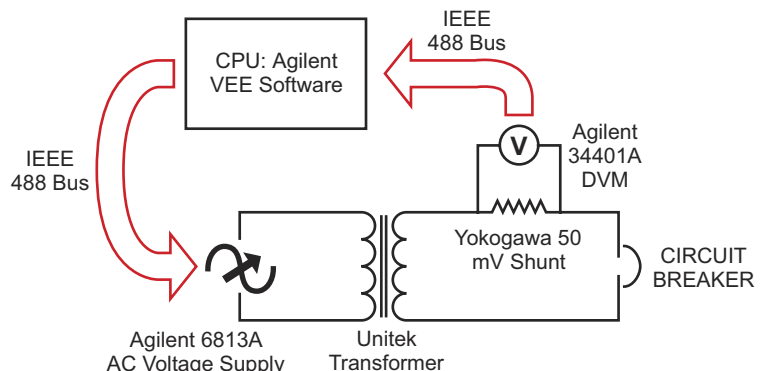


FIGURE 3: MAGNETIC TRIP LEVEL vs THERMAL TRIP TIME FOR 15 AMP BRAKER

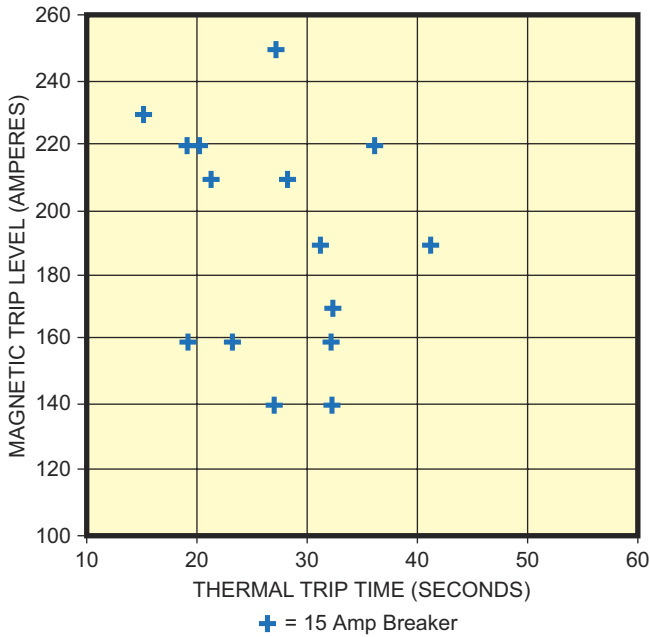


FIGURE 4: MAGNETIC TRIP LEVEL vs THERMAL TRIP TIME FOR 20 AMP BRAKER

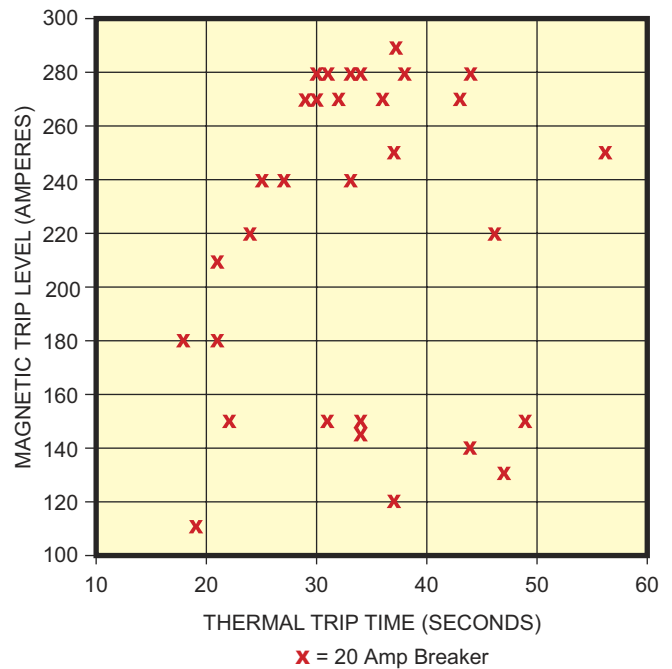
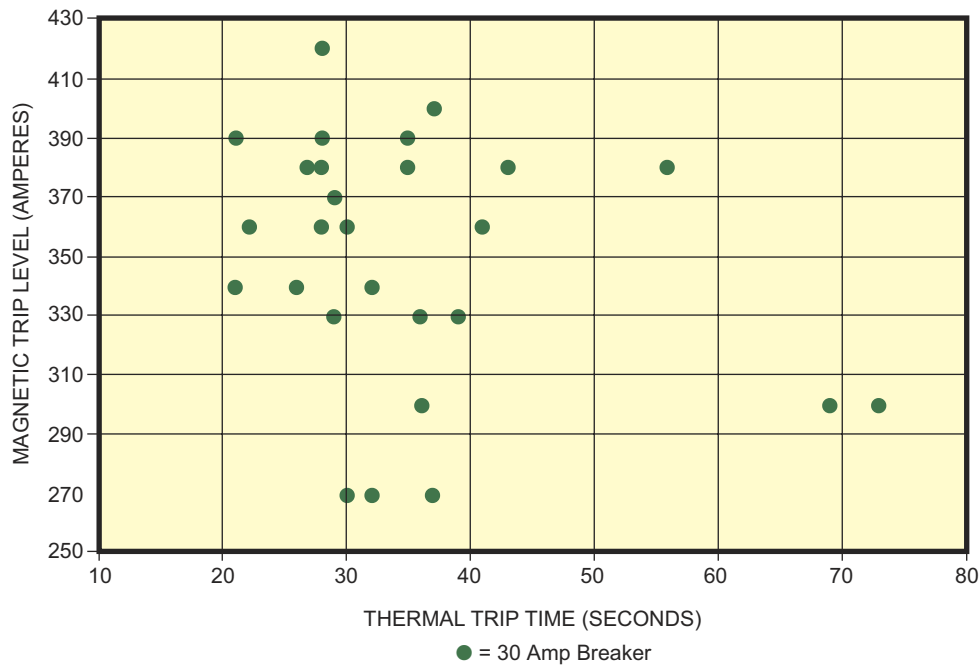


FIGURE 5: MAGNETIC TRIP LEVEL vs THERMAL TRIP TIME FOR 30 AMP BRAKER



6 constant current pulses (60 Hz sine waves, starting at zero degrees) followed by 10 seconds of wait time. Then, the current level was stepped up (increased) by 5 ampere increments and 6 more pulses were again applied. The wait time was introduced in order to ensure that the thermal portion of the breaker did not react and cause the breaker to trip.

FIGURES 3, 4, and 5 show the thermal characteristics (trip time) for each breaker as the independent variable, and the trip level (instantaneous) in amperes given as the dependent variable. As is readily apparent, there is no correlation between thermal trip times and instantaneous trip levels.

discussion

Circuit breaker performance is one data point our lab often assesses in investigating a fire. Having said that, we have been able to identify only three fires in 24 years where we felt that breaker performance was a significant factor in a loss. Two of these losses are now described:

- (1) A homeowner had done wiring on a porch light, accidentally shorting the hot lead to the ground. The type NM cable, when shorted, allowed about 90 amperes to flow on the hot and return on the ground conductor. The light switch to the porch light was turned on, and a resulting fire ensued. The hot conductor (black lead of the NM) was "sleeved" along its length in the breaker box. (*Sleeving is a condition*

in which there is damaged insulation on a conductor caused by excess current flow. A wire that is sleeved will have insulation that is charred, bubbly, and has started to deform.) The fire broke out in the attic, along the same run of NM. The breaker serving the NM would not thermally trip when tested in the lab. FIGURES 6 and 7 depict the breaker and a portion of the load wiring. The breaker is a dual breaker, and only one of the poles (the one serving the porch light) shows evidence of the overload.

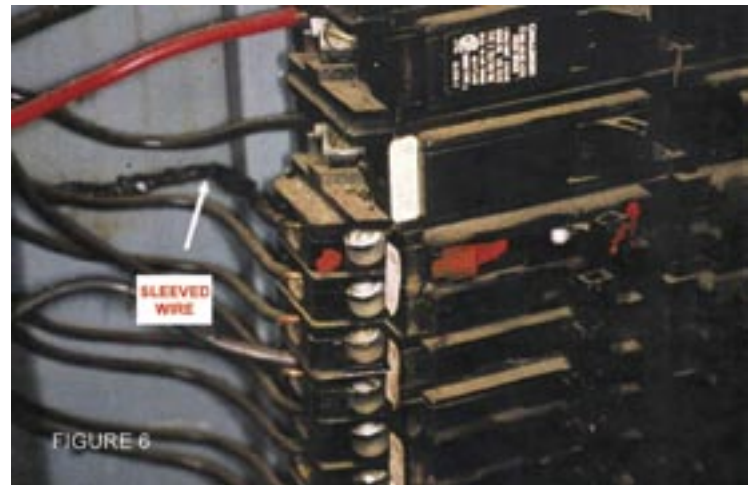
(2) A new house had its electric meter installed less than one hour prior to a fire being discovered. A 20 ampere breaker fed a length of type NM (12 AWG) that served a bedroom and ran through the attic space. Fire broke out in the attic. In the breaker box, the hot lead of the type NM was severely charred, while the conductors serving other breakers had no thermal damage. The exact fault in the attic was never identified. Regardless of the initial cause of the fault, however, the breaker never cleared the fault. Lab testing confirmed that the breaker would never trip.

A defective breaker, in and of itself, does not cause a fire. There also has to be a fault condition (either overload or short circuit, that the breaker should have cleared in a timely fashion) so as to cause a fire. In our investigations of breakers, the telltale sign indicating such a failure is an overheated branch circuit conductor (which we have referred to earlier as 'sleeved'), surrounded by conductors that are intact. If, however, the fire has thermally attacked and damaged the breaker panel, it will be very difficult to establish that a breaker was malfunctioning, unless one can find a 'solo' overheated wire in another part of the building that has not sustained fire/thermal damage.

The NEC requires that electrical components be used per their listing (2002 NEC Article 110-3b)^[3]. We have successfully argued that this includes the installation of circuit breakers. As an example, a 20 ampere MCCB with an instantaneous trip level of 180 amperes was used to power an office cubicle located ~ 270 feet from the breaker panel. The feed consisted of #12 THHN, 3 conductors. On such a long run the resistance of the wire has considerable effects. In this case, with a bolted fault (solid short), the current level was measured at the cubicle as being ~ 130 amperes. It is clear that this level of short circuit would never cause the instantaneous trip feature of the breaker to be activated. Regrettably, a gentleman was electrically shocked by the cubicle, when the hot conductor energized the cubicle's frame. The duration of shock was increased because of the breaker's inability to rapidly clear the fault. The fault was eventually cleared by the thermal portion of the breaker, which in the opinion of the neurologist, had a substantial effect on the man's injuries. Had the branch circuit wiring been appropriately sized, the breaker could have cleared the fault much faster. The smaller wire (#12) and the long distance prevented sufficient fault current to flow so as to allow the instantaneous trip function to clear the fault. (Note: While a 20 ampere breaker is appropriate for protecting #12 wiring, the excess length of the branch circuit run dictates a larger wire size)

One of the properties of breakers with thermal trip mechanisms is that they can be tripped from the heat of a fire—even with no load. Years ago, a fire occurred in a trash can in an office, brought on by the careless disposal of smoking materials. The breaker panel for the building was also in the same office, and its steel door protected the breakers from direct flame impingement. One investigator noted that all of the breakers were tripped, and concluded (erroneously) that a large electrical event occurred, bringing on the fire. The reader is also referred to the previous article by one of the authors, wherein ambient temperatures and their effect on breakers is discussed^[4].

Even though we have seen breaker malfunctions on very few occasions, our advice is to collect the breaker(s) at a fire scene, if it



is supplying power to a suspect appliance or branch circuit wiring. Moreover, we also ask that several inches of load wire be collected from the panel. In this way, one could look at the conductor and determine if it is appropriately sized, and also if it has received damage from excess current values. Given that it is easy to inadvertently move a breaker handle during an investigation, we also routinely photograph and then mark (with a paint marker) the position of all breakers prior to opening a breaker panel to inspect it internally.

myths dispelled

Having discussed basic breaker operation and having demonstrated the independence of the thermal and magnetic mechanisms it is now easy to step through the myths and the physical reason(s) that each one is fiction.

1. T-M breakers trip upon reaching the rated current.

T-M breakers trip according to a trip curve, which includes both 135 percent and 200 percent trip times. At 135 percent of rated current, the breaker must trip in 1 hour or less. The trip curve is non linear as loads approach the breaker ratings (FIGURE 1), therefore, at even 5 percent above trip rating, there is no guarantee that the breaker will ever trip.

2. T-M circuit breakers always trip immediately.

These breakers trip thermally in seconds to minutes (depending on current level), per the published trip curve, in overload situations. In short circuit situations, trip times can be several cycles.

3. A tripped breaker always means an electrical event has occurred.

A T-M breaker reacts to overloads or short circuits. Current produced by the overload causes the breaker to heat internally and then trip. An external fire that places enough thermal energy into the breaker can also cause the breaker to trip.

4. Breakers protect appliances and appliance cords

T-M breakers used in buildings are rated for the size of the branch circuit. Often times the appliance wiring being fed by the branch circuit is smaller, thus has the same level of current flowing in it as in the branch circuit. Since the wire is smaller it has a higher resistance and will create substantially more heat in this cord that could cause failure of the cord.

5. Breakers protect persons from electrical shock.

A 15 ampere breaker, as an example, will trip in less than 2 minutes when 30 amperes is flowing. Electrical shock can occur with current in the .010 to .030 ampere range, with cardiac function being altered in less than 1 second. T-M breakers are not sensitive to currents this small.

6. Climate and ambient conditions have no effect on trip times.

T-M breakers work (in part) by the generation of heat internally. In a cold atmosphere, breakers will trip slower from overload situation; just the opposite is true in a warm atmosphere.

7. Circuit breakers prevent arcing.

T-M circuit breakers can react to the currents associated with arcing, but will not prevent the arcing. A short between a hot and a neutral in branch circuit wiring can easily allow several hundred amperes to flow, with resultant arcing. The T-M breaker will then trip in several cycles (depending on breaker rating and amount of current), but the arcing will have already occurred.

8. Circuit breakers can be used as on/off switches.

T-M breakers are complex mechanical devices, not meant for tens-of-thousands of operational cycles. However, there is one class of T-M breaker that can be used as an on/off switch, and this breaker will always be labeled as SWD (switching duty). SWD breakers are often used to control fluorescent lighting in offices and factories.

conclusions

The intent of this article is to dispel some of the myths regarding circuit breakers, as well as give examples of how a circuit breaker is intended to function. What we have seen is as follows:

1—A circuit breaker is only intended to protect branch circuit wiring

2—A circuit breaker has two separate mechanisms, thermal and magnetic

3—There is no correlation between thermal and magnetic performance for a given breaker

4—A breaker does not trip necessarily once its rating is marginally exceeded, nor does it trip immediately

5—Thermal portions of breakers are affected by ambient temperatures

6—A breaker is not intended to prevent electrical shock

7—A breaker does not prevent arcing

8—Circuit breakers are not to be used as on/off switches.

9—Breakers can trip from external heat

We are hopeful that our readers can use this information as part of their investigation into fires that possibly have electrical aspects. ●

REFERENCES

- [1] IAII/NFPA User's Manual for NFPA 921, 2001. Page 77.
- [2] NEMA AB-1, MCCBs and Molded Case Switches.
- [3] NFPA 70, National Electrical Code, 2002.
- [4] Goodson, M.E., *Circuit Breaker Performance in Depressed Temperatures*, Fire & Arson Investigator, July 2001.

ABOUT THE AUTHORS—

Mark Goodson, PE

Mark Goodson is the principal of Goodson Engineering of Denton, Texas. He is a PE licensed in multiple states. Formerly an engineer with both Rockwell and TRW, he has been consulting in electrical and mechanical matters since 1984. He holds a BSEE from Texas A&M, and then trained in forensics at University of Texas Southwestern. From 1989-1991 he served as a Court Special Master in Dallas. His specializations include electrical, mechanical, and electrical shock issues.

Mark Hergenrether, MSME

Mark Hergenrether is a consulting engineer with Goodson Engineering. He was formerly associated with Sandia Labs. He holds both BS and MS degrees in mechanical engineering, received from Oklahoma State University. His areas of specialization include material science, heat transfer, combustion, and data acquisition.

Aaron Stateson

Aaron Stateson is a student at Texas A&M, studying mechanical engineering.