

# Product safety testing limits risk of shock, fire, and injury Part 2

David Lohbeck - March 15, 2013

It is essential for product design engineers to predetermine potential hazards and risks posed by the electrical products under their development. Product safety standards mandate the product design and test rules for mitigating unforeseen adverse circumstances from electrical products. Knowledge of the appropriate safety standards and adherence to testing requirements are of paramount importance in order for companies to offer safe products. Safety standards do not address the functionality of the product; instead they focus on safety design and testing. Product design engineers should not focus solely on functionality, but must be well versed in designing their products in accordance with the relevant safety standards. The relevant safety standard for test and measurement equipment (TME) is IEC 61010-1 and for information technology equipment (ITE) the standard is IEC 60950-1.

Safety standards dictate the requirements for products to remain safe during the normal operating condition of the product as well as during an abnormal single fault condition. Standards also require products to operate safely within a minimum set of environmental conditions, such as an ambient temperature range of 5 °C to 40 °C and supply voltage fluctuations up to  $\pm 10\%$ . For example, temperature tests are performed at the specified temperature range of the manufacturer, and at least the minimum range, specified in the relevant standard, to limit the risk of burn injuries or fires. Abnormal tests are performed to verify that the product will remain safe even when there is a fault condition, such as blocked cooling vents or a component short.

Five electrical product safety tests were covered in Part 1. In Part 2 we will cover the following mechanical product safety tests and routine, production, safety testing:

- Temperature Test
- Cooling Abnormal Test
- Component Abnormal Test
- Enclosure Impact Test
- Routine Tests – Withstand and Continuity

(Refer to Part 1 of the article for important safety terms and definitions used in this article.)

## Temperature Test

A product enclosure or part that has excessive surface temperatures can burn the user. Additionally, if a component or plastic material gets too hot it can soften, burn a person, or cause fire ignition. Touchable surface temperature limits are shown in **Table 1**. Maximum operating temperatures (MOTs) apply to components/materials including those that carry, support, or contain hazardous voltage or current. As an example, a plastic enclosure has two temperature ratings, maximum surface temperature and its MOT. An internal PCB or connector has one temperature limit, its MOT.

**Note:** Flame classifications, such as V-0, V-1, and HB, are plastics flammability ratings and are not addressed in this article.

<b>TABLE 1 SURFACE TEMPERATURE LIMITS IN NORMAL CONDITION</b>		
<b>Part</b>	<b>TME Limit, °C (IEC 61010-1:2010)</b>	<b>ITE Limit, °C (IEC 60950-1:2005)</b>
<b>Outer Surface of Enclosure (unintentional contact)</b>		
a) metal, uncoated or anodized	65	70
b) metal, coated (paint, non metallic)	80	—
c) plastics	85	95
d) glass and ceramics	80	80
e) small areas that are not likely to be touched	100	100
<b>Knobs and handles (normal use contact)</b>		
a) metal	55	55
b) plastics	70	75
c) glass and ceramics	65	65
d) non-metallic parts that are held for short periods	70	85

**Table 1 Notes:**

- Temperature limits at 40 °C ambient for TME and 35 °C ambient for ITE.
- Abnormals, single faults, condition value is 105 °C at 40 °C /35 °C for surface temperature.
- TME standard, IEC 61010-1, allows raising the temperature limit by the amount by which the maximum rated temperature exceeds 40 °C. As an example, you can raise the temperature limits by 15 °C for a 55 °C rated product. The product shall also meet the limits in the table at 40 °C ambient.
- Touchable surfaces that are intended to heat for processing or heating of materials, such as a document laminators which cannot be guarded, are permitted to exceed the values and are marked with the Hot Surface Caution symbol in a prominent position adjacent to the hot part.

Two common surface temperature limits are 65 °C for metal (TME) and 85 °C for plastics (TME) during the normal operation of the product. The temperature limits increase to 105 °C (TME) during an abnormal operation test condition. Surface temperature limits are specified in the standards.

Plastic components and materials MOTs are specified in safety certifications and reports issued by independent safety certification bodies (CBs). A typical MOT for an FR-4 PCB is 130 °C and the MOT for PVC wire insulation is typically 80/90/105 °C. Obtain the safety certificates/reports from a safety CB to verify the MOT. Manufacturers can supply these.

Temperature results are determined by measuring the temperature and adding the rise above room ambient to the rated ambient value of 40 °C for TME and 35 °C for ITE or adding the rise to the products maximum rated ambient temperature if greater than 40 °C /35 °C.

Follow these steps for the Temperature Test:

- 1) Set up the test sample for operation at maximum configuration and power consumption:  
All accessories, plug-in PCB cards installed, and outputs loaded to achieve maximum power draw.
- 2) Analyze accessible enclosure surfaces and critical components to identify the hottest locations on touchable surfaces and critical components/materials, including internal components and materials.
- 3) Attach thermocouples (TCs) for measurements:
  - a) Affix TCs to several locations on the enclosure for surface measurements, such as on the hottest metal and plastic surfaces including enclosure top, sides, bottom, and air openings.

- b) Affix TCs to the hottest plastic materials and internal components, and where temperature rise could exceed the materials/components MOT.
- 4) The test sample is energized, and temperatures monitored, until the temperatures stabilize and for a one hour minimum:
  - a) Minimum normal product ambient rating is 40 °C for TME and 35 °C for ITE.
  - b) Temperature limits (**Table 1**) are based on a 40 °C /35 °C room ambient as required in the standards.
- 5) Perform the temperature test:
  - a) Make and record measurements at +10% and -10% of the products voltage rating.
  - b) Temperature chambers may be used, especially when the temperature rating of the product exceeds 40 °C (TME) or 35 °C (ITE). Cooling due to chamber air circulation should be minimized.
- 6) Record measurements at room ambient:
  - a) Add temperature rise to 40 °C/TME or 35 °C/ITE, or Add temperature rise to products temperature rating if greater 40 °C /35 °C.
7. Test Results: The measured temperatures of touchable surfaces, components, materials, and transformers<sup>2</sup>, must not exceed the temperature limits.

Notes about the above:

- Refer to **Table 1** for surface temperature limits at normal operation condition.
- Refer to the components/materials safety certification or report for its MOT limit values.
- The change-of-resistance method can be used to calculate temperatures of transformer windings when application of TCs is not practical. Refer to IEC 60950-1 for calculation. Refer to the applicable product safety standard for windings temperature limits.

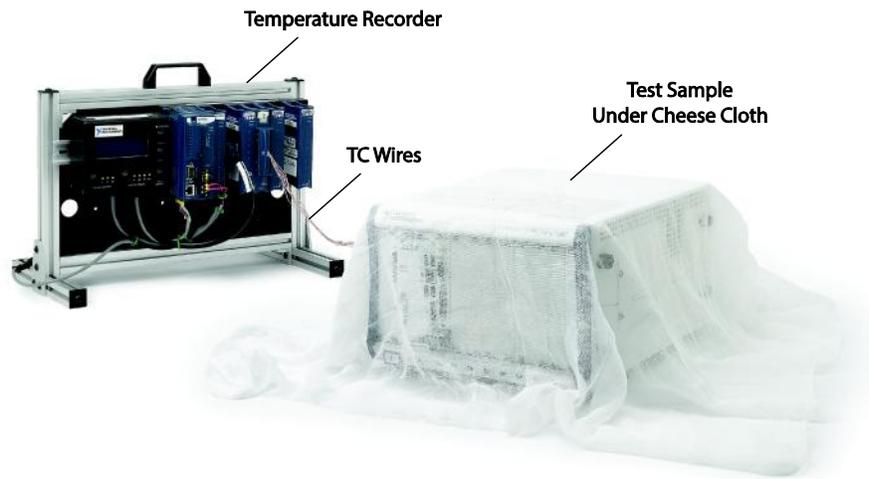
### Cooling Abnormal Test

Products must operate without posing a burn or fire hazard in normal and abnormal conditions. Abnormals are applied one at a time, single faults. One such abnormal is an inoperative fan that restricts air cooling causing the product temperature to rise. If the fan stops or air is restricted, blocked, temperatures can rise causing component failures, plastic enclosures can soften, or the product can catch fire, which could spread to the surroundings. To determine if fire can propagate beyond the enclosure, abnormals are performed with the test sample placed on wood with cheesecloth on the unit and tissue paper below. Refer to **Figure 1**.

Follow these steps for the Cooling Abnormal Test:

1. Set up the test sample for maximum configuration and loading with voltage/current to generate maximum temperatures.
  - a. Check temperatures at  $\pm 10\%$  of the voltage rating range to identify maximum temperatures.
  - b. Use highest identified temperatures for tests.
2. Attach TCs to the max temperature locations on the test sample in preparation for temperature measurements as described in the Temperature Test section.
3. Place the test sample on a soft wood surface with tissue paper under and cheesecloth over the test sample.
4. Perform cooling abnormal tests, faults, and record the results observed:
  - a. Fan(s) are stalled and air inlets blocked (TME standard IEC 61010-1 only requires a blocked air inlet test when there are air filters; the stalled fan test is still required.), one at a time, until a further change as a result of the fault is unlikely.
  - b. If several fans share a common power source, the common fans are stopped by interrupting the source power.
  - c. Temperatures recorded after temperatures have stabilized for a one hour minimum.
  - d. If there is an indication that shock, fire, or injury to persons may eventually occur, the test is continued four hours unless one of the hazards occurs, thereby resulting in a test failure.
5. Test Results:
  - a. During and after the test, there can be no excess temperature, such as 105 °C for surface temperatures.
  - b. There can be no access to hazardous voltage; no voltages > 50 Vrms, 70 Vpk, and 120 Vrms.

- c. No molten metal, burning insulation, or flaming particles can fall on the resting surface of the product, and no charring or glowing.
  - d. No melting of insulation that could cause a hazard.
  - e. No flaming of the cheesecloth or tissue paper.
6. Repeat Tests:
- a. After the test (TME & ITE), the test sample shall pass a repeat of the Dielectric Voltage Test, without humidity preconditioning (Basic values per **Table 1** in Part 1).
  - b. After the test (TME), the test sample shall pass a repeat of the Limit Values Test; measured voltage shall be 50 Vrms, 70 Vpk, and 120 VDC.



**FIGURE 1 Test Setup for Abnormal Tests**

### Component Abnormal Test

Electrical components can fail in various ways, such as in a short or open fault condition. Depending on the component and circuit location, a component fault can cause increased voltage and current, leading to a potential electric shock or burn hazard. If there is enough energy, current, a fire can result from component faults at almost any voltage, even extra-low voltages of 3.3 VDC, 5 VDC, and 12 VDC. Higher voltages, such as 120/230 VAC, can cause larger currents and more severe shocks and risk of fire. Shorts are the most common component abnormal tests.

Examples of components that are faulted include capacitors, resistors, and any non-certified components that are relied on for safety, such as non-certified thermal cut-outs. These components are not considered reliable as they can break down, short. When basic insulation is required between circuits, the insulation not meeting basic is also bridged as an abnormal test. A fault test can be repeated several times when the result is inconclusive. It may be best to have fault testing follow other tests because it can be destructive.

Follow these steps for the Component Abnormal Test:

1. Analyze the product and its schematic diagram to identify key faults, such as component shorts, which are likely to result in a safety hazard.
2. Attach TCs to the test sample and components in preparation for temperature measurements as described in the Temperature Test section.
3. Set up the test sample for operation at maximum configuration, power consumption, and loading with input voltage/current set to result in the worst case hazard:
  - a. All accessories, plug-in PCB cards installed, and outputs loaded to achieve maximum power draw.

- b. The combinations of test conditions can be different for different faults, which are selected to achieve the highest voltage, current, temperature, or other hazard as a result of the applied fault.
4. Perform component abnormal test with short or open component, whichever is worse, and record the temperature and results.
  - a. Apply faults one at a time, while the product is energized, until a further change as a result of the fault is unlikely.
  - b. Perform abnormals until the product temperatures have stabilized and for a one hour minimum.
  - c. If there is an indication that shock, fire, or injury to persons may eventually occur, the test is continued for four hours unless one of the hazards occur, thereby resulting in test failure.
5. Test Results:
  - a. During and after the test, there can be no excess temperature, such as 105 °C for surface temperatures.
  - b. There can be no access to hazardous voltage; no voltages > 50 Vrms, 70 Vpk, and 120 Vrms.
  - c. No molten metal, burning insulation, or flaming particles can fall on the resting surface of the product, and no charring or glowing.
  - d. No melting of insulation that could cause a hazard.
  - e. No flaming of the cheesecloth or tissue paper.
6. Repeat Tests:
  - a. After the test, the test sample shall pass a repeat of the Dielectric Voltage Test, without humidity preconditioning (Basic values per **Table 1** in Part 1).
  - b. After the test, the test sample shall pass a repeat of the Limit Values Test; measured voltage shall be 50 Vrms, 70 Vpk, and 120 VDC.

Note: Additional abnormal tests may be required depending on the product design and whether non-certified safety-critical components are used. Other possible abnormal tests include transformer secondary shorts and overload, outputs shorts and overload, voltage mismatch, protection interlock open and short, loss of cooling liquid, temperature controller override, locked motor, and protective conductor interruption. Refer to the applicable safety standard for these and other abnormal tests and requirements.

## Enclosure Impact Test

Product enclosures must have adequate structural integrity to resist mechanical impact that could occur in normal use. The impact test is a dynamic stress test performed to determine if the product enclosure protects users from electric shock, skin burn, fire, mechanical, or other safety hazards after impact testing. Each easily touched enclosure surface is subjected to a 5 joule impact force by a 50 mm diameter, 500 g, steel sphere. Levels below 5 J are allowed for fixed or other equipment (when the equipment is installed so it cannot be easily touched by the general public).

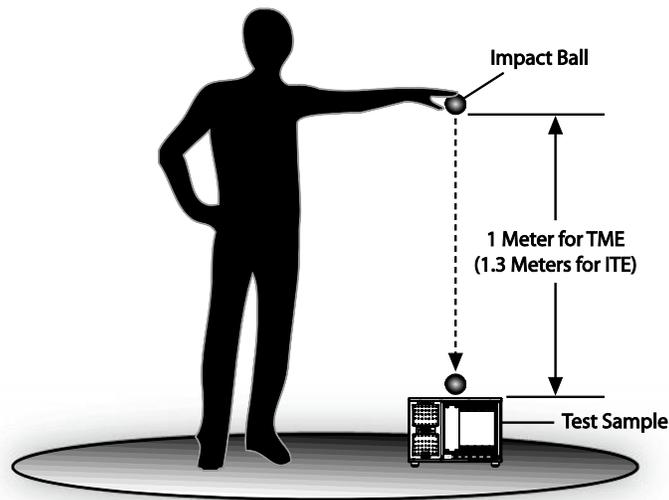
The impact test is performed by dropping a sphere, ball, from a 1m distance for TME (1.3m for ITE) onto each accessible side of the test samples enclosure. Swinging the ball into the test sample is also an alternative impact test. The drop test is most commonly performed. The impacts are applied to points on accessible surfaces that would likely cause a hazard if damaged. The product is held firmly against a rigid support during the test. The impact test can be performed with the product on its side, 90° to its normal position, to allow either the drop or swing impact method. **Figure 2** shows the vertical ball drop impact against a horizontal surface.

Products with non-metallic, plastic, enclosures can soften at temperatures above 70 °C or become brittle at temperatures below 2 °C. Products with temperature ratings above 70 °C are impact tested after they have been stored, heated, at 70 °C for 7 hours. Plastic enclosures of products rated below 2 °C are impact tested after they are cooled to the product's minimum rated temperature. Plastic enclosure impact tests are performed within a maximum of ten minutes following the heating and cooling preconditioning.

Follow these steps for the Impact Test:

1. Select either the drop test, shown in **Figure 2**, or the swing impact test method (not shown).

2. Perform impact tests:
  - a. Impact any point on surfaces that are easily touched during normal use.
  - b. Perform the impact test on each side where worst damage and resulting hazard could occur.
  - c. Subject parts and components forming part of the enclosure to impact also.
3. Test Results:
  - a. Verify that there are no cracks in the enclosure that could cause a hazard.
  - b. No access to hazardous LIVE electrical parts or circuits.
  - c. Moving parts shall remain unexposed.
  - d. Spacing clearances shall not be less than their permitted values.
  - e. No leaks of corrosive or harmful substances.
  - f. Internal wire insulation shall remain undamaged.
  - g. Safety barriers shall not have been damaged or loosened.
  - h. There shall be no damage that could cause a spread of fire.
4. Repeat Tests: After the test, the test sample shall pass a repeat of the Dielectric Withstand Voltage Test, without humidity preconditioning, for the required insulation; Basic or Double/Reinforced, as applicable.



**FIGURE 2: Impact Test Ball Drop**

Note: Additional rigidity tests may be required, such as a 30 N static rigidity and edge fall. Hand-held and direct plug-in products undergo a one meter drop test. Refer to the applicable safety standard.

### **Routine Production Tests- Withstand and Continuity**

Once a product has passed type testing, it is time to go into production where routine testing is performed. Routine tests are performed on 100% of products, typically at the end of the manufacturing line. The purpose of routine testing is to uncover manufacturing workmanship and assembly defects that can increase the risk of electric shock or fire. The two most common routine tests are dielectric voltage withstand (hipot) and ground continuity (ground bond). Routine withstand and continuity tests are performed at lower voltages and currents, and test times, than the type tests, which were covered in Dielectric Voltage Withstand Test (Hipot) and Grounding Continuity Test sections, Part 1.

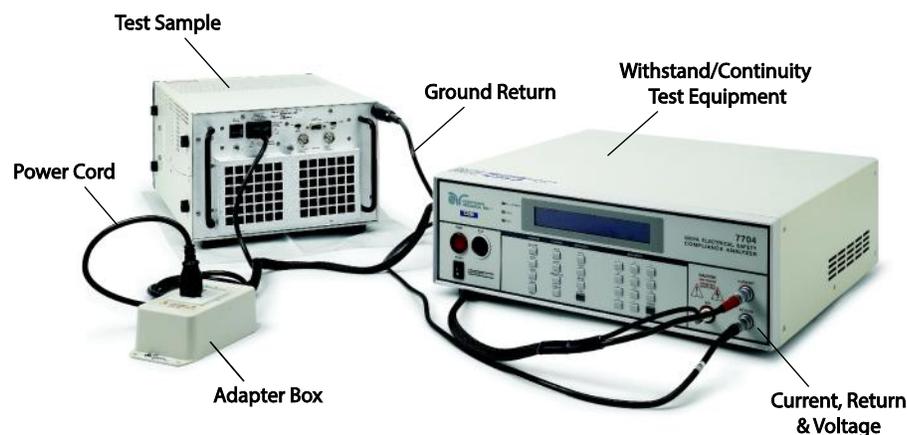
Routine withstand tests are required for hazardous LIVE voltage rated products with metal enclosures. Certification Bodies, such as UL, CSA, VDE, TUV and others, require routine testing for safety certifications and marks.

Manufacturing defects can result in insulation breakdown between LIVE voltage circuits and user accessible metal enclosures, resulting in a shock or fire hazard. The routine withstand test is used to discover manufacturing defects such as damaged components, insulation pinholes, weak wire crimps, and loose screws. The withstand test is performed between MAINs voltage input lines/terminals (L/N) connected together and accessible conductive parts, including the protective earth (PE) ground terminal. The production test unit is isolated from any external grounding.

Accessible conductive parts and enclosures must be properly grounded to protect users in the event a hazardous LIVE conductor or part contacts the enclosure. Poor ground bonding can occur when there are broken wires, loose grounds, and corrosion or paint between structural members and covers. A shock or fire hazard can result in this case. The routine continuity test determines the product's protective bond integrity of accessible conductive parts. The continuity test is performed between the PE ground pin of the product inlet, or screw terminal for fixed cord products, and all user accessible conductive parts/enclosures. There are two continuity tests from which to choose: a resistance test (<1 A) and ground continuity test (25/40 A). The latter ground continuity test option is more effective at uncovering workmanship defects. Refer to **Figure 3** for the routine withstand/continuity test diagram.

Follow these steps for the Routine Withstand and Continuity Tests:

1. Set up the routine withstand and continuity test per **Figure 3**.
  - a. The test sample is unenergized during the test.
  - b. Set the test samples power switch in the ON position
  - c. Set the hipot test equipments voltage ramp for 5 seconds maximum and dwell for 2 seconds minimum for TME or 1 second minimum for ITE.
  - d. Set the hipot test equipments voltage for AC or DC with values per **Table 2**.
  - e. Set the ground continuity test equipments current for 25 A.  
Note: The alternative resistance test (< 1 A) may be used instead of the 25A test.
2. Perform the routine withstand and continuity tests.
3. Test Results:
  - a. Withstand: There shall be no flashover or breakdown during the withstand test.
  - b. Continuity: Impedance between the PE terminal and enclosure shall not exceed 0.1 for the 25 A test.  
Note: The alternative resistance test (< 1 A) can be used to verify continuity.
  - c. Test equipment shall not indicate a failure for the withstand or continuity test.



**FIGURE 3** Routine Withstand and Continuity Test Setup

Table 2 ROUTINE WITHSTAND TEST VALUES FOR MAINS CONNECTED EQUIPMENT <sup>1,2</sup>		
Input Rating, VAC/DC	VAC Test Voltage	VDC Test Voltage
TME: 150	840	1,200
TME: >150 300	1,400	2,000
TME: >300 600	2,200	3,100
ITE: 150	820	1,159
ITE: >150 300	1,350	1,900
ITE: >300 600	2,200	3,100

<sup>1</sup> Test values are for MAINs overvoltage Category II products. AC or DC test voltage allowed.

<sup>2</sup> Measurement circuits test voltages, non-Mains, not shown above. TME measurement circuits withstand values are calculated by multiplying the input rating by 1.5 with 350 VAC/500 VDC minimum.

**OPERATOR SAFETY CAUTION** – Routine testing is performed in production areas that are accessible to test operators and bystanders. Lethal voltages, currents, and arc flash are generated during routine testing. Only skilled operators, who are aware of the hazards, should perform the tests. To protect the test operator and bystanders, use an enclosure that covers the entire test setup and product. A safety interlock system must automatically disconnect all LIVE voltages when the cover is opened.

## Conclusion

Product safety type testing at the design phase, as well as routine testing during the production process, helps ensure that the product remains safe during its normal operation and under abnormal fault conditions. The ten tests covered in Part 1 and Part 2 of this article are some of the most fundamental safety tests, but are only a small subset of the tests in the product safety standards. As stated in Part 1, the actual number of required tests is dictated by the design, rating, use environment, and potential hazards of the product, as well as by the applicable product safety standard.

The guidance provided in Part 1 and Part 2 of this article helps product designers garner a more thorough understanding of product safety by becoming familiar with the relevant safety standards and test methodology. Designing their products with safety requirements in mind enables designers to produce products with limited risk of electric shock, burn injuries, fires, explosions, and other harm. Remember, electricity is like the genie in the bottle. By following the relevant safety standards, keeping the power of electricity safe in a harnessed environment is an achievable goal of safe product design.

**Note:** This article is an introduction and overview of product safety testing. Product safety standards take precedence over any information presented in this article. Always refer to the relevant product safety standard(s) for design and testing requirements for your product.

Artwork by Chris Hamberlin National Instruments

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### About the Author

*David Lohbeck is Principal Safety Engineer at National Instruments (Austin, Texas). Lohbeck is also an ANSI Lead Assessor and Technical Expert where he assesses product Certification Bodies (CBs) and CB Test Laboratories (CBTLs). Previously he has worked for Motorola, Dell and TUV in the field of international product safety, machine safety, and electromagnetic compatibility (EMC). Lohbeck has published numerous articles on safety and EMC, and has been honored as a EDN Innovation Finalist in the “Best Contributed Article” category for his Sept 2004 article entitled Safety isolation protects users and electronic instruments and for his 2006 article Hazardous-voltage primer. David Lohbeck is author of CE Marking Handbook: A Practical Approach to Global Safety Certification (eBooks.com).*

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