Feature Article

Calculating Creepage and Clearance Early Avoids Design Problems Later

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One of the most common errors uncovered by product safety engineers stems from manufacturers and designers failing to fully investigate a product's creepage and clearance distances.

It is not unusual for manufacturers to find that a product fails the creepage and clearance distance test because of miscalculations or simply because the distance between two components was overlooked. Design engineers, especially printed circuit board (PCB) designers, are often not aware of the reasons for using creepage and clearance distances. Selecting the appropriate tables in the standard and applying them properly to a design are key to avoiding problems later.

Last-minute failure can also arise because design engineers do not seek input from the product safety engineers in the early design stages. Designers sometimes assume that all safety issues relating to creepage and clearance have been addressed, only to discover spacing problems once the product is built.

Basic Definitions

Creepage Distance. Creepage is the shortest path between two conductive parts (or between a conductive part and the bounding surface of the equipment) measured along the surface of the insulation. A proper and adequate creepage distance protects against tracking, a process that produces a partially conducting path of localized deterioration on the surface of an insulating material as a result of the electric discharges on or close to an insulation surface. The degree of tracking required depends on two major factors: the comparative tracking index (CTI) of the material and the degree of pollution in the environment. Used for electrical insulating materials, the CTI provides a numerical value of the voltage that will cause failure by tracking during standard testing. IEC 112 provides a fuller explanation of tracking and CTI.[1] Tracking that damages the insulating material normally occurs because of one or more of the following reasons:

- Humidity in the atmosphere.
- Presence of contamination.
- Corrosive chemicals.
- Altitude at which equipment is to be operated.

Clearance Distance. Clearance is the shortest distance between two conductive parts (or between a conductive part and the bounding surface of the equipment) measured through air. Clearance distance helps prevent dielectric breakdown between electrodes caused by the ionization of air. The dielectric breakdown level is further influenced by relative humidity, temperature, and degree of pollution in the environment.

When designing a switch-mode power supply for use in information technology (IT) equipment, a typical rule of thumb is to allow an 8-mm creepage distance between primary and secondary circuits, and a 4-mm distance between primary and ground. If these dimensions are allowed for during the design stage, there is a high probability (95%) that no failure will occur with respect to creepage or clearance when the final product is submitted for test.

Working Voltages. A working voltage is the highest voltage to which the insulation under consideration is (or can be) subjected when the equipment is operating at its rated voltage under normal use conditions. The appropriate creepage and clearance values can be determined from the figures provided in the relevant tables in EN 60950.[2] These values must sometimes be calculated. To use Tables I–IV (2H, 2J, 2K, and 2L of the standard), the following factors must be considered: determination of working voltages, pollution degree of the environment, and the overvoltage category of the equipment's power source.

When measuring working voltages, it is important to measure both peak and root-mean-square (rms) voltages. The peak value is used to determine the clearance, and the rms value is used to calculate creepage. For example, if one measures a peak voltage of 670 V between two pins of a switching transformer in a switch-mode power supply, the clearance distance between primary and secondary circuits must be calculated using Table I. If the unit is powered via 240 V mains and has a pollution degree of 2, the figures in the center row (marked 300 V rms sinusoidal) and center column (since the mains voltage is >150 V and < 300 V) are used to establish the required clearance distance. In this case, the value for reinforced insulation is 4 mm. One then turns to Table II (Table 2J of EN 60950), which provides additional clearance based on the working voltages and pollution degree. (The middle column was used for calculating this example.) The appropriate row in that column covers the actual repetitive peak insulation working voltage. In this example, the value would be 0.8 mm for reinforced insulation. Adding the two figures together gives a total of 4.8 mm clearance distance. Similarly, if a voltage of 337 V rms was measured between the two pins of the switching transformer, Table IV (2L of the standard) must be used to calculate the creepage distance between the primary and secondary circuits. Assuming pollution degree 2 and material group IIIb, the required creepage distance for basic insulation would be 3.5 mm using linear interpolation. For reinforced insulation, the values for creepage distances are double the values provided in the table for basic insulation. In this case, the required creepage for reinforced insulation would be 7 mm.

	Funtional, Basic, and Supplementary Insulation						
Working Voltage V Rms or Dc	Pollution Degree 1	Pollution Degree 2			Pollution Degree 3		
	Material Group	Material Group			Material Group		
	I, II, IIIa, or IIIb	I	II	IIIa, or IIIb	I	II	IIIa, or IIIb
<50	Use the clearance from the appropriate tables	0.6	0.9	1.2	1.5	1.7	1.9
100		0.7	1.0	1.4	1.8	2.0	2.2
125		0.8	1.1	1.5	1.9	2.1	2.4
150		0.8	1.1	1.6	2.0	2.2	2.5
200		1.0	1.4	2.0	2.5	2.8	3.2
250		1.3	1.8	2.5	3.2	3.8	4.0
300		1.6	2.2	3.2	4.0	4.5	5.0
400		2.0	2.6	4.0	5.0	5.6	6.3
600		3.2	4.5	5.3	8.0	9.5	10.0
800		4.0	5.6	8.0	10.0	11.0	12.5
1000		5.0	7.1	10.0	12.5	14.0	16.0
Linear interpolation is permitted between the nearest two points, the calculated spacing being rounded to the next higher 0.1-mm increment.							

Table IV. Table 2L of the standard provides minimum creepage distances (creepage distances in millimeters).

The use of these tables is explained in sections 2.10.3–2.10.4 of EN 60950. Measurements should be accurate and repeatable and should also consider the end application.

Pollution Degrees and Overvoltages

Pollution degree is divided into four categories. The following definitions are based on those in IEC 60664.[3]

- **Pollution degree 1.** No pollution or only dry, nonconductive pollution occurs. The pollution has no influence (example: sealed or potted products).
- **Pollution degree 2.** Normally only nonconductive pollution occurs. Occasionally a temporary conductivity caused by condensation must be expected (example: product used in typical office environment).
- **Pollution degree 3.** Conductive pollution occurs, or dry, nonconductive pollution occurs that becomes conductive due to expected condensation (example: products used in heavy industrial environments that are typically exposed to pollution such as dust).
- **Pollution degree 4.** Pollution generates persistent conductivity caused, for instance, by conductive dust or by rain or snow.

The overvoltage, also known as installation, category is also divided into four categories according to IEC 60664.

- **Overvoltage category I.** Signal level (special equipment or parts of equipment), with smaller transient overvoltages than overvoltage category II.
- **Overvoltage category II.** Local level (appliances and portable equipment), with smaller transient overvoltages than overvoltage category III.
- **Overvoltage category III.** Distribution level (fixed installations) with smaller transient overvoltages than overvoltage category IV.
- **Overvoltage category IV.** Primary supply level (overhead lines, cable systems, etc.). This category is not relevant to most product standards.

Typically, most standards are based on conditions being pollution degree 2 and overvoltage category II. It is important to note that as working voltage, pollution degree, overvoltage category, and altitude increase, the creepage and clearance distances also increase. The altitude is particularly important when testing to EN 61010.[4]

Creepage and Clearance in Practice

Each part of a circuit must be studied to determine the necessary insulation grade. Table 2G in EN 60950 describes common applications of insulation. For example, establishing the required creepage and clearance between a primary circuit and an ungrounded safety extra low voltage (SELV) circuit requires reinforced insulation. By measuring and establishing both the working voltage and the pollution degree, the appropriate row and column in Table 2H (and if necessary Table 2J) determine the minimum clearance distance needed. For one test, the internal components and parts in both primary and secondary circuits are subjected to a steady force of 10 N, and certain minimum clearance distances must be maintained during the test.

Because the primary circuit is an internal circuit connected directly to the external supply mains, this circuit typically contains hazardous voltage. A secondary circuit, which has no direct connection to primary power, may or may not be hazardous. Nonhazardous circuits are classified as SELV.

Dc input products, however, can be treated in one of two ways. They can be considered as being fed by an extra-low-voltage circuit, or as hazardous secondary voltages. This would mean that the clearances could be calculated using Table III rather than Table I, requiring slightly smaller clearance distances. Dc input products can also be considered as being fed by SELV secondary circuits, depending upon the end application. If isolation is needed, then Table III of the standard is used. However, if isolation is not required in the end application, then clearances are waived, and only operational insulation is required.

Simple Design Tips

As IT products continue to get smaller, it is more important than ever to have a good and calculated PCB design that not only reduces electromagnetic interference emissions, but that also reduces creepage and clearance problems. Where shortage of space on a PCB is an issue, especially between primary and SELV circuits, techniques such as slots or grooves can be used to attain desired creepage distance. Slots must be wider than 1 mm; otherwise, they are not considered acceptable. For a groove (>1 mm wide) the only depth requirement is that the existing creepage plus the width of the groove and twice the depth of the groove must equal or exceed the required creepage distance. The slot or groove should not weaken the substrate to a point that it fails to meet mechanical test requirements.

Another solution is to design the PCB so that components are mounted flat on the board rather than positioned vertically. This layout overcomes problems that might arise from the 10- N push test required in EN 60950. A minimum of 8 mm separation between primary and secondary circuits also prevents problems. When semiconductors operating at hazardous voltages are mounted on grounded or floating heat sinks, certain precautions must be taken to ensure compliance with EN 60950. If heat sinks happen to be live (and they can be), they should be marked accordingly to warn service personnel. Generally, a semiconductor's plastic enclosure is considered as operational (necessary for correct operation of the equipment) or, in some cases, as only basic insulation. Therefore, depending on the heat sink's grounding arrangement, the semiconductor requires either basic or reinforced insulation.

It is equally important to consider creepage and clearance even when using UL-recognized power-switching semiconductors. Although these products carry a recognition mark, the manufacturer's data sheets must be examined to ensure that the components are suitable for the intended application.

The working voltages of the circuit must be taken into account. Transistors with built-in reinforced insulation (body thicker than 0.4 mm) must also still meet the spacing requirements at their legs. Some designers mistakenly assume that UL certification eliminates the need for further examination.

Troubleshooting

In some cases—in particular for switch-mode power supplies—the design topology can lead to the need for higher creepage distance in the switching transformer. In such situations, the use of a wider margin tape (also known as saddle tape) may not be practical; therefore, the use of multilayer insulated wire (also known as triple-insulated wire) is highly recommended. When using triple-insulated wire, it is important to remember that such wire must satisfy the requirements described in Annex U of EN 60950. Lack of adequate creepage and clearance distance between a component in a primary circuit to a component in the SELV circuit is a common cause of product failure. A typical short-term solution is to place an insulating material, such as Mylar sheet, with appropriate thickness and dielectric withstand voltage, between the two parts, ensuring that the sheet is mechanically secure. Room-temperature vulcanizing sealant, a silicone paste cured at room temperature, or a similar material, is used not only as a means of bonding components together for mechanical purposes, but also to overcome clearance problems. However, materials that are used to compensate for clearance problems must be UL recognized, particularly if a product is to be sold in North America.

Conclusion

Calculation and measurement of creepage and clearance distances are among the most important parts of all safety standards, and therefore it is important for design engineers to consult the product safety engineers throughout the design stages to avoid any failure at the test house before a product is launched into the market.

Creepage and clearance distances not only apply to the PCB, but also to the components (especially magnetic components) that are mounted on the PCB. It is also important to note that as working voltage, pollution degree, overvoltage category, and altitude increase, both the creepage and clearance distances also increase.

References

1. IEC 112:1979, "Method for Determining the Comparative and the Proof Tracking Indices of Solid Insulating Material under Moist Conditions," International Electrotechnical Commission, Brussels.

2. BS EN 60950:2000, "Safety of Information Technology Equipment," British Standards Institute (BSI), United Kingdom.

3. IEC 60664:1980 "Insulation Co-ordination within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment," International Electrotechnical Commission, Brussels.

4. BS EN 61010-1:1990, "Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use, Part 1: General Requirements," BSI, United Kingdom.

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