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Creepage and Clearance in Transformers: Practical Guidance from IEC 60664-1 and IEC 61558-1

WHITE PAPER

Introduction

Increasing power density and higher operating voltages in today's converter designs are driving increasingly strict requirements for transformer insulation. As designs become smaller, it becomes a complex challenge to maintain safe creepage and clearance distances.

This white paper explains how to correctly apply IEC 60664-1 and IEC 61558-1 standards to transformer design, addressing common misinterpretations that can lead to non-compliance or certification delays.

Background

Transformer safety is governed by insulation coordination principles outlined in the IEC 60664-1 standard, which defines creepage and clearance distances, and the IEC 61558-1 standard, which applies those principles specifically to transformers. These standards help establish how insulation distances must be evaluated based on working voltage, pollution degree, and material properties.

In practice, small geometric details, such as bobbin lips, grooves, or the proximity of conductive cores often lead to incorrect spacing evaluations. Understanding when to include or exclude these features, and how to account for indirect distances through conductive parts, is essential to achieving reliable and compliant transformer designs.

Correctly Defining Creepage vs. Clearance

Creepage and clearance are distinct but related insulation parameters that define the safe electrical spacing within a transformer. In simplest terms, clearance is the shortest air distance between two conductive parts, while creepage is the shortest path along an insulating surface. Both must independently satisfy the spacing requirements set by IEC 60664-1 and IEC 61558-1 standards.

Dimension	Definition	Primary Influencing Factors	Failure Mode
Clearance (CL)	The shortest distance through the air between two conductive parts.	Working voltage, overvoltage category, altitude	Dielectric breakdown spark)
Creepage (CC)	The shortest path along the surface of a solid insulating material between two conductive parts.	Working voltage, pollution degree, material CTI	Tracking (conductive path formation)

Pollution Degree Selection in Practice

IEC 60664-1 defines pollution degree as a classification of the environmental conditions that influence surface contamination and, therefore, creepage distance requirements. Pollution degree is not a design variable chosen arbitrarily by the transformer designer; it is typically determined by the end application and operating environment specified by the equipment standard or system integrator.

In practice:

- **Pollution degree 1** applies to environments where no pollution or only dry, non-conductive pollution is present (e.g., sealed or hermetically protected assemblies).
- **Pollution degree 2** applies to most commercial, consumer, industrial, and automotive electronics, where only non-conductive pollution is expected, but temporary conductivity may occur due to condensation.
- **Pollution degree 3** applies to harsher industrial environments where conductive pollution or dry non-conductive pollution that becomes conductive due to condensation is expected.

For most power electronics applications, including consumer, industrial, and automotive electronics, pollution degree 2 is specified. While this selection is often implicit, it directly affects creepage requirements and the associated value of dimension X (as discussed in the next section). Designers must therefore confirm the applicable pollution degree early in the design process, even when pollution degree 2 is assumed by default.

Measurement and the Role of Dimension X

Misinterpretation often arises when designers include small grooves, lips, or barriers in their insulation measurements. According to IEC 60664-1 (Clause 6.2 and Annex A), the gap between the screw head and the wall of a recess is ignored when it is smaller than the specified dimension X. When the gap is equal to or greater than X, the recess is considered effective, and the creepage distance is measured along the recess. This rule applies broadly to any feature smaller than the specified dimension X, which depends on pollution degree (Subclause 4.6.2):

Pollution Degree	Dimension X (Minimum Value)
1	0.25 mm
2	1.0 mm
3	1.5 mm

In transformer design, Example 10 from IEC 60664-1:2007 (Figure 1) corresponds to situations where a bobbin baffle, rib, or lip appears to extend the distance between windings but the gap is too small to be recognized under the standard. If the feature height or width is less than X, it is to be ignored, and the measurement is taken directly across the recess—not along it.

Rules for Applying Dimension X (Creepage)

- **Groove is Effective:** If the groove's width is equal to or larger than dimension X, then the creepage distance is measured along the groove's contours.
- **Groove is Ignored:** If the recess width is less than dimension X, then the recess is assumed to be bridged by contamination, and the creepage distance is measured as a straight line across the groove.

A critical point of non-compliance arises when designers confuse this rule: dimension X is a width-based check for creepage. It does not apply to the height of a baffle, nor does it affect the straight-line clearance measurement.

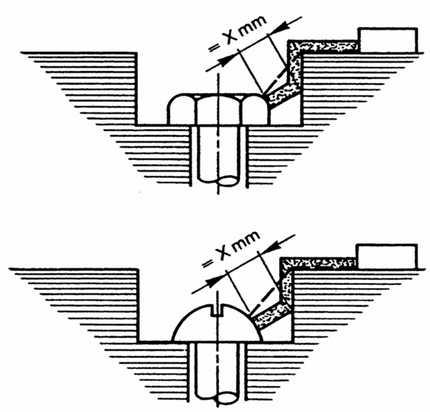

Figure 1. | Example 10 from IEC 60664-1:2007

Indirect Distance via Conductive Floating Parts

IEC 60664-1 (see Figure 2) and IEC 61558-1 mandate that when a conductive floating part, such as an ungrounded transformer core, is situated between two circuits (e.g., Primary and Secondary), the insulation distance must be evaluated in series. The total required isolation measurement is the sum of the distances across the two individual gaps.

Requirements for Isolation via an Indirect Distance (Core)

- **Direct Distance:** The straight-line distance between the Primary (PRI) and Secondary (SEC) must meet the minimum required clearance.
- **Indirect Distance (Clearance/Creepage):** The required distance is the sum of the gap between the PRI and the CORE, and the gap between the SEC and the CORE.
- **Exception:** If the core is provided with supplementary or reinforced insulation, the indirect path is considered safely isolated, and the summation is not required.

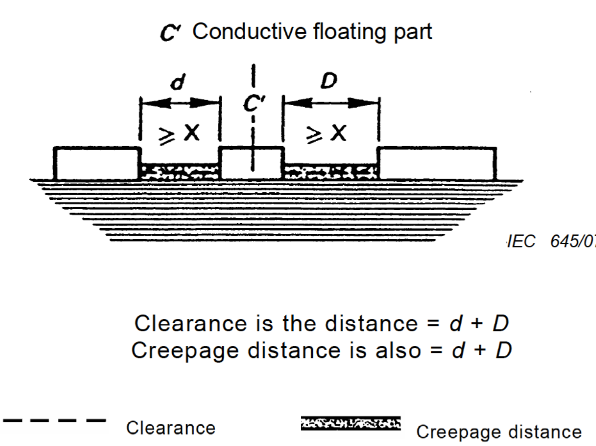

Figure 2. | Example 11 from IEC 60664-1:2007

Example: Transformer Cross-Section

Consider a transformer design that has the bobbin baffle only 0.3 mm higher than the core (Figure 3). For pollution degree 2, IEC 60664-1 specifies X = 1.0 mm. Since 0.3 mm < 1.0 mm, the recess is ignored, and the clearance is measured directly from the primary pin to the core and from the secondary pin to the core.

Thus:

- PRI – core = 1.46 mm
- SEC – core = 4.99 mm
- Total clearance = 6.45 mm

If the core is insulated, then the indirect path may be ignored. If uninsulated, both clearance measurements must be added.

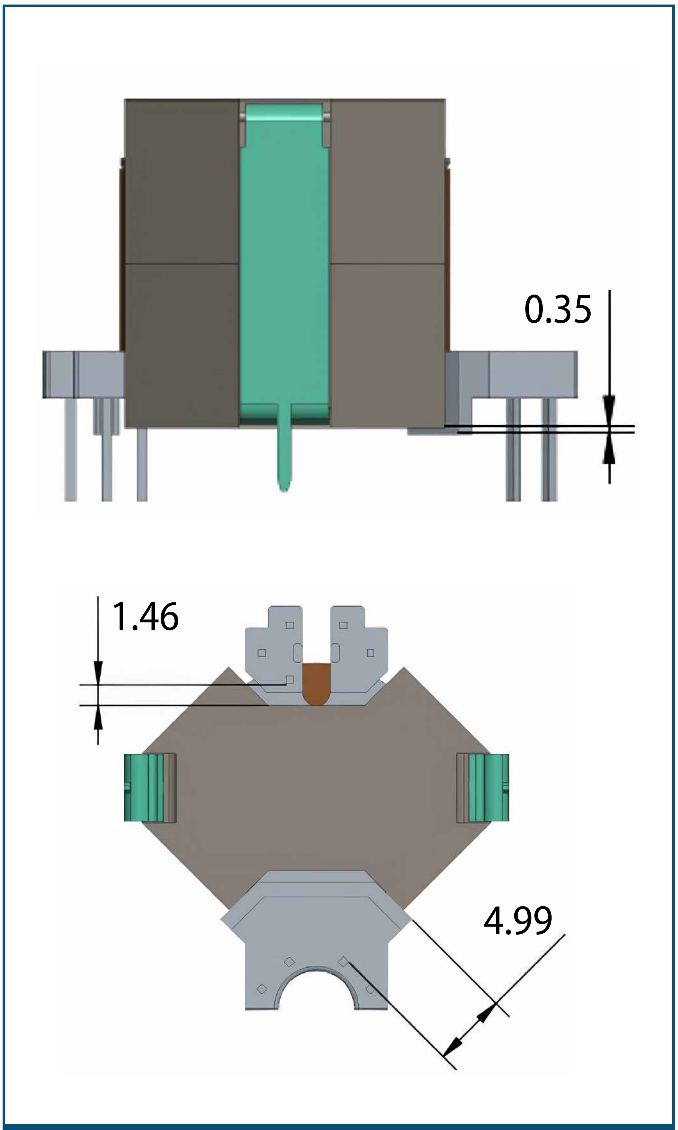

Figure 3. | Transformer cross-section

Practical IEC Guidance for Designers

The combined requirements of IEC 60664-1 and IEC 61558-1 can be applied systematically during transformer design. The following steps help ensure that creepage and clearance are evaluated correctly from the beginning:

Identify the working voltage and overvoltage category

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Confirm pollution degree

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Identify CTI/material group of the bobbin

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Apply dimension X to all geometric features

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Check both direct and indirect distances

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Verify altitude effects

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Assess high-frequency operation where applicable

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Document assumptions early

Understanding Bobbin Features

Achieving required creepage and clearance is not solely a matter of mechanical spacing; it also depends heavily on material choice and bobbin design. The bobbin is the primary insulating structure between windings, and its material properties and geometry directly influence compliance with IEC 60664-1 and IEC 61558-1.

CTI Classification and Material Groups

A bobbin's Comparative Tracking Index (CTI) determines its material group, which directly affects the minimum required creepage distance. Materials with higher CTI values offer better resistance to tracking and, therefore, permit shorter creepage distances.

Material Group	Comparative Tracking Index (CTI)	Impact on Creepage Distance
I	600 ≤ CTI	Shortest required creepage distance
II	400 ≤ CTI < 600	Moderate creepage requirements
IIIa	175 ≤ CTI < 400	Longer creepage distances required
IIIb	100 ≤ CTI < 175	Longest required creepage distances

Selecting a higher-CTI bobbin material (for example, Group I instead of Group III) enables more compact transformer designs by reducing mandatory creepage spacing.

Slotting and Barrier Geometry

Bobbin slotting and barriers can be intentionally designed to increase creepage distance by lengthening the surface path. Slots are used to increase the surface distance along the bobbin (creepage). However, their effectiveness is governed entirely by dimension X from IEC 60664-1.

Rules for Slotting and Barriers

- **Slot Effective:** If the slot width ≥ X, creepage is measured along the contour of the slot.
- **Slot Ignored:** If the slot width < X, the recess is assumed bridged by contamination and is ignored; creepage is measured straight across.
- **Barrier/Baffle Effectiveness:** Barriers increase the creepage path only if the creepage path must follow the barrier's contour. Barrier height does not affect clearance, and barriers shorter than X do not increase creepage.

This means a bobbin feature that visually appears significant may contribute nothing to the electrical distance if it does not satisfy the requirements set by dimension X.

Common Design Mistakes

Mistake	Why It Fails Certification
Misapplying dimension X	Standard requires ignoring small barriers
Assuming altitude affects creepage	It affects clearance only
Ignoring frequency effects	IEC 60664-1 assumes ≤30 kHz; above this, IEC 62368-1 may apply
Assuming potting/coating always counts	Must meet minimum thickness and CTI
Forgetting floating parts	Core/shields often create indirect paths

Conclusion

Meeting transformer insulation requirements depends on correctly applying the creepage and clearance rules defined in the IEC 60664-1 and IEC 61558-1 standards. Many compliance issues arise not from insufficient physical spacing but from misunderstandings of how features such as grooves, baffles, and conductive cores must be evaluated. By applying dimension X correctly, accounting for indirect distances through floating conductive parts, and selecting appropriate bobbin materials, designers can ensure that their transformer designs meet global safety standards without costly redesigns or delays. A systematic approach supported by accurate interpretation of the standards remains essential for achieving both compliance and long-term reliability in compact, high-performance power converters.