University of Ljubljana
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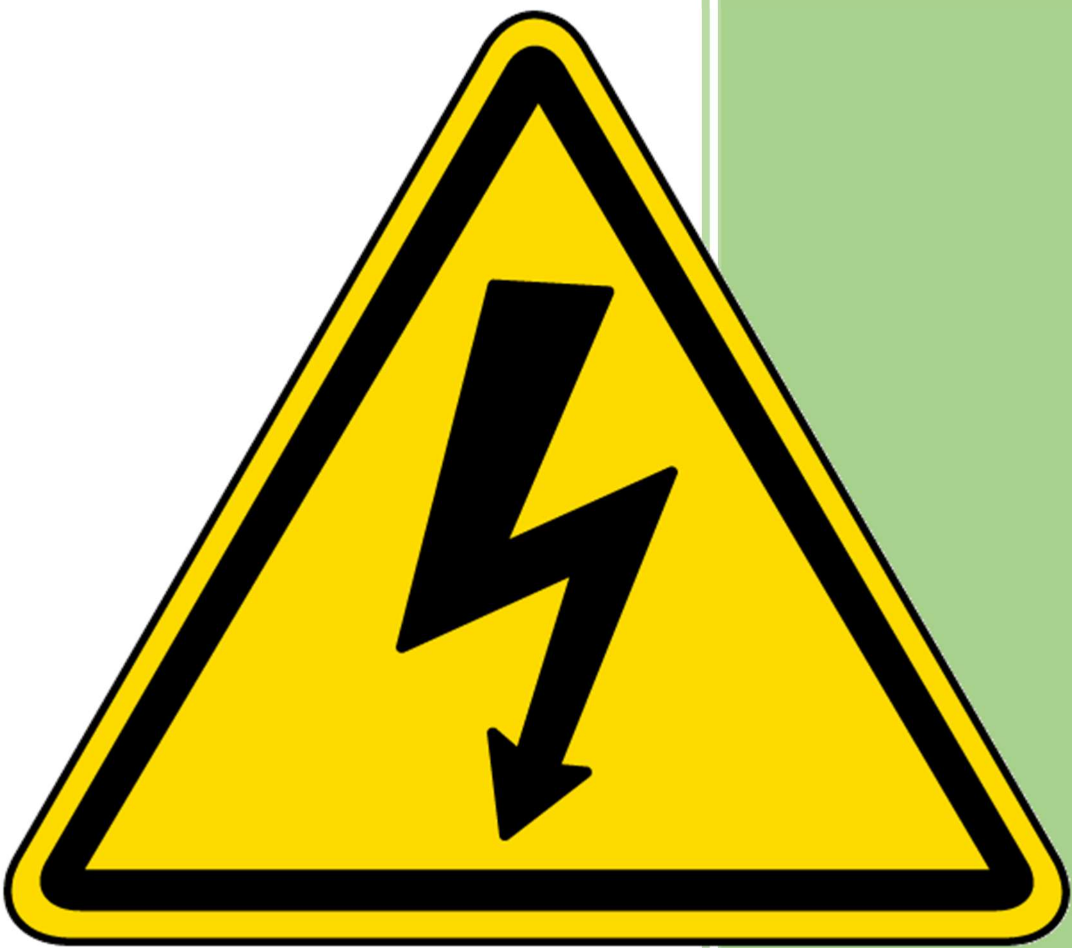
2018

# Electrical Product Safety



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21/5/2018

# Sumário

# Introduction

Electrical Product Safety is vital to help manufacturers of electrical products to comprehend the relevant elementary safety principles, to perform self-assessment of their products, to create their own customized safety reports and to meet the requirements of the Low Voltage Directive. However, solely following the guidelines as given may not be sufficient to provide due diligence defence. The requirements of the Directive must be tracked, and the manufacturer will need to decide appropriate procedures and confirmation approaches depending on production quantities, product range and ongoing innovation.

# 1.CE Marking

## 1.1 The CE Marking concept

What is CE Marking? Why is it needed? Who needs to use it? How do they obtain it?

Answering these questions continues to present difficulties for manufacturers of electrical and electronic goods yet understanding the concept of CE Marking is fundamental to successful marketing in Europe.

It should be noted at the outset that CE Marking is primarily concerned with promoting free trade and not the creation of additional legislative controls. The European Union (EU) has been working towards the concept of free trade for many years. It was one of the major influences behind the signing of the Treaty of Rome in 1957. The Treaty committed the member states of the original European Economic Community (EEC) to work toward this goal.

This was a radical concept and required each country to discard its own laws, in specific areas, and replace them with a harmonized set of European rules. This process has been a slow one, taking over 60 years so far, and there is still a long way to go. However, considerable progress has been made in harmonizing the laws pertaining to product safety. The decision to harmonize product safety laws was agreed under Article 100A of the Treaty of Rome and thus the resulting Directives are known as the 100A or New Approach Directives.

The aim of the product safety Directives is simple. If a product can satisfy the provisions of an appropriate harmonized law, then that product must be allowed free passage throughout the EU without the need for further certification or testing.

Manufacturers are able to demonstrate and declare compliance with these conditions by using CE Marking. By affixing the CE Mark, the manufacturer is making a visible statement that his equipment meets all requirements of the relevant Directives. It is important for manufacturers to understand that they themselves are responsible for ascertaining which Directives are applicable to their products. If they fail to apply a relevant Directive, they may face legal action.

## 1.2 The CE Marking Directives

The most important CE Marking Directives are:

• the Low Voltage Directive – 2014/35/EU

• the EMC Directive – 2014/30/EU

• the Machinery Directive – 2006/42/EC

These Directives, along with the others, all have certain 'standard' elements. These include:

• the scope of the Directive; this contains details of the range of products subject to the controls listed in the Directive, and perhaps more importantly those products which are exempt from its requirements

• a requirement, placed upon member states of the European Community, to ensure that only safe products are allowed into the European market place. This requires member states to consider internal control measures and policing mechanisms

• a safeguard clause to ensure that any unsafe products are prevented from entering the market place or, if any unsafe products are detected, they must be immediately withdrawn from the market

• a listing of certain essential safety requirements which form the core safety elements of a Directive. In the case of the Low Voltage Directive (LVD), these are called the 'safety objectives'

• a statement linking harmonized performance standards to the essential safety requirements and establishing the concept of the 'presumption of conformity'. If an electrical product meets the requirements of a Harmonized standard which covers all the relevant safety related issues contained in the LVD, it is presumed to conform to the 'safety objectives'

• conformity assessment requirements. These differ across the Directives and it is important to read each one carefully. Some of the Directives allow a manufacturer to self-declare compliance, while others require third party involvement. The LVD is one of the former. Manufacturers may use the standards route outlined in Figure 2.1 or manufacture their product in conformity with the essential requirements

• CE Marking requirements. Once again these differ across the Directives with regard to the CE Mark and other additional marks.

## 1.3 National implementation

The CE Marking Directives harmonize the laws of member states in order to remove barriers to trade. A Directive is simply an instruction, issued by the Council of the European Community, telling a member state to transpose the contents of the Directive into national law; failure to do so would constitute a breach of community law.

It is important to understand that the Directives themselves have no effect on individual manufacturers. The manufacturers' duty is to comply with the transposed national requirements, which, in theory, replicate the provisions of the Directive, with some additional domestic elements such as enforcement and sanctions for non-compliance.

## 1.4 Summary

The CE Marking Directives have given the EU a high-profile method of indicating a product's compliance with safety and other requirements. The European market place is slowly becoming accustomed to the new requirements and is developing an understanding of CE Marking. As a result, businesses are frequently including CE Marking requirements in their purchasing contracts. At the same time, enforcement of the law is becoming more active and prosecutions of non-compliant suppliers and the banning from sale of unsafe products are becoming commonplace.

Today, in order to continue doing business within the EU, manufacturers are being forced by legislation, market surveillance mechanisms and consumer demand to undertake some type of compliance testing and/or verification of their products. CE Marking is no longer an option, it has become a vital component of a producer's business.

# 2. Testing for safety

Manufacturers of electrical equipment who have not previously been involved with safety testing, but suddenly become aware of the Low voltage Directive's requirements, often ask themselves:

Do I really need to test?
Do I need a Certification mark?
How do I get it?
Where can I test and how long will it take?
Which standards must I test against?
How much will it cost?
How do I ensure compliance?

It is surprising to hear these questions still being asked even though the LVD has been place since 1973! In the next few paragraphs an attempt will be made to provide answers to all of these questions, and thus provide advice to help an organization decide the best course of action for its particular product range.

## 2.1 To test or not to test?

Without any doubt, testing to a recognized specification is the key element for establishing compliance with the technical requirements of the Directive. In some cases, the costumer's purchasing policy may allow no option i.e. "we will only buy tested and certificated to… by…".

Gaining independent certification can help a company avoid civil and criminal actions. In the case of a serious incident in the market where a product has caused injury – perhaps completely destroying itself in the process the ability to demonstrate that it (the marque) had been designed safely and had independently assessed can be a persuasive and sufficient defense.

Testing a representative sample from every product range would be the ideal situation for manufactures of electrical products. However, few manufacturers have the financial resources or the expertise to perform compliance tests – either 'in-house' or at a test laboratory – every time they add a new product to their range. Particularly small companies have to rely on pre-compliance tests, self -assessment or technical justifications in order to justify not testing before release of their products to the market.

If you are not one of those suppliers who rely on product self-assessment without performing any testing – your justification being based on designing safely with a good understanding of safety principles – you must appreciate that you will not have the same level of protection that complete testing to a Harmonized standard by an independent accredited test laboratory provides.

It might help you though to demonstrate due diligence and give yourself some confidence that the product is safe – thus meeting the 'essential requirements'. In any case, it is definitely better than doing nothing.

## 2.2 Do I need a Certification mark?

It is not necessary to be independently certified by a National Certification Body (NCB) in order to affix the CE Mark to a product, i.e. no other Certification mark is needed. Until a few years ago, a nationally recognized Certification mark was a mandatory requirement in most European countries for the majority of electrical products — in particular for household appliances. In the UK, both BSI (British Standards Institution) and BEAB (British Electro-technical Approvals Board) are the National Certification Bodies for the purposes of the CENELEC certification scheme (the CENELEC Certification Agreement or CCA) for the Low Voltage Directive.

The CCA scheme allows the simplified approval of products by all CCA scheme members after successful testing has been completed by any one member of the scheme. Certification for most products was never compulsory in the -UK, but that was not the case for some other countries, e.g. approval before import into Scandinavia and Switzerland was necessary. As explained above, in most cases the market (the customer) will dictate whether or not a Certification mark is required — large retailers still insist on it.

## 2.3 How do I get a Certification mark?

Certification marks are offered by all NCBs across Europe. Manufacturers may approach any of the following:

BSI or BEAB in the UK

VDE in Germany

NEMKO in Norway (test laboratories also in the UK)

FIMKO in Finland

SEMKO in Sweden

KEMA in the Netherlands

DEMKO in Denmark

and many others.

From experience it makes sense to deal with a local NCB — it can help to reduce the costs associated with both the transportation of samples, and travel to the test laboratory in cases of problems. Communications are also greatly simplified through the use of a common language and national as opposed to international telephone and fax services. When making an application, the Certification Agency will usually request:

- a completed application form -listing Safety Critical parts and their approval status
- a sample product
- spare parts - needed to replace components during fault testing
- copies of certificates of approved parts/moldings, etc.
- a set of circuit diagrams
- any relevant test reports
- a copy of the instructions of use.

Testing and approval can then proceed. Upon successful testing a test report will be issued by the laboratory and sent to the applicant together with an approval Certificate. Certification Agencies that carry out tests in accordance with the Low Voltage Directive will also (necessarily) operate a factory approval scheme whereby the manufacturing premises will be audited (normally annually) against the requirements of CCA document 201.

Certification by an NCB is also possible without the need for a factory audit, but then the NCB's approval mark cannot be affixed to the product.

## 2.4 Where to test and how long will it take?

As an alternative to product testing by a National Certification Body, manufacturers also have the option (in the UK) to apply for testing at an independent UKAS (United Kingdom Accreditation Service) accredited test laboratory. The testing will be performed to a Harmonized standard (if available) and the issued test report can be used by the manufacturer as part of his technical documentation file (Technical File) in order to provide evidence of compliance with the LVD. Choosing this route, however, precludes the right to affix a Certification mark to the product.

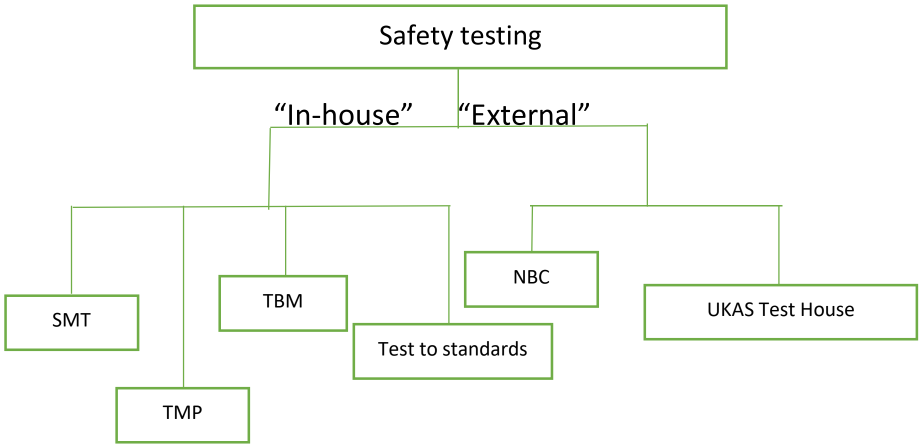


*Figure 2.1 Example of a goof earthing connection*

ERA, TRL, TUV Product Services and other laboratories in the UK offer this service.

Until a few years ago, testing by a small number of Test Houses was the only way to obtain confidence that products complied with relevant safety standards. This is now changing through the introduction of various 'in-house' testing schemes offered by an NCB such as BEAB, DEMKO, UL, etc.

Test times vary depending on the standard used and the complexity of the product. It can take as little as two weeks or as long as six to eight weeks, sometimes longer depending on the 'queue' at the Test House. Time for testing may also vary with seasonality - holiday periods in particular should be avoided.

SMT (Supervised Manufacturer's Testing scheme) - Manufacturer's test laboratory accredited by an NCB to EN 45001. Testing is performed by the manufacturer's personnel under the periodic supervision of the NCB.

TMP (Testing at the Manufacturer's Premises scheme) - Manufacturer's test laboratory accredited by an NCB to EN 45001. Testing is performed at the manufacturer's laboratory by the NCB personnel.

TBM (Testing by the Manufacturer) - Manufacturer's test laboratory accredited by an NCB to EN 45001. Testing is performed at the manufacturer's laboratory by the manufacturer and confirmed by the NCB at their own laboratory. After one year a TBM facility is normally accepted without further confirmation by the NCB.

NCB - Testing is performed either by the NCB's own laboratories or by NCB authorized laboratories (i.e. sub-contractors).

UKAS approved Test House - These are independent accredited test laboratories competent to test to Harmonized standards, e.g. ERA, TRL, etc.

As an alternative to the above, a manufacturer may, if he so wishes, perform testing in his own non-accredited laboratory. provided that he employs trained and competent personnel and has the correct (and properly calibrated) equipment. In this case the manufacturer may create his own test reports and self-certify his products. If a manufacturer, for whatever reason, does not perform full in-house or external testing, a very thorough product self-evaluation (with some minimal testing) may be acceptable. In the following chapters we will attempt to explain how to perform this evaluation and how to complete a report.

## 2.5 Which standards to test against?

Choosing a standard for safety testing requires careful consideration.

Harmonized standards exist for most product ranges. A designer should make a point of familiarizing him self with a product’s specific standard and design according to its requirements.

## 2.6 How much will it cost?

Cost will depend on the product and the applicable standard. In order to ensure that you get the best deal, follow the few simple steps given below.

Prepare an information pack containing:

- a summary of the product and its performance
- a block/interconnecting diagram showing relevant circuitry
- details of the standards against which you wish to have the product tested
- details of the approval status of critical components.

Then send it to a number of NCBs or Test Houses, requesting quotations.

With the need to perform third party testing now removed, NCBs and Test Houses have lost their monopoly. Some have become commercial organizations, and some are struggling to survive - but all have become more flexible and less costly! But beware - *some very low-cost rests do not always offer what they promise*.

Some very attractive offers are now available including the 'One Stop Shop' where testing for Electrical Safety, Electromagnetic Compatibility (EMC) and Machinery Regulations is all done using one sample at one location.

## 2.7 How do I ensure compliance?

All manufacturers of electrical equipment, irrespective of their scale of production, have to meet the requirements of the LVD and be able to demonstrate 'due diligence'. Actions which may be classed as reasonable and acceptable for one business, might be insufficient for another. To help clarify specific responsibilities, a few suggestions are made below. but these should only be viewed as *the minimum requirement*.

(i) The ideal situation' — although in practice this can only be practiced by large-scale manufacturers producing a variety of products:

• Samples from every new product range are tested (either in-house or externally). using the NCB route.

• Implement a comprehensive Production Control system including final basic electrical testing of each production unit (may include earth path continuity, dielectric strength test, insulation resistance and leakage current).

• Operate a Change Control system (changes to the original design that affect safety are be controlled and authorized).

• Operate the factory in compliance with the NCB's factory requirements.

• Arrange regular product retesting (if the same product will be manufactured for a long time).

(ii) Not all manufacturers are able to conform to all of these requirements. however; smaller organizations tend to:

• Test quite irregularly (in-house or externally), or not test at all.

• Operate a very basic production control system.

• Not have a change control system in place.

• Not obtain external factory approval.

For those companies which fall under this category and do not wish or cannot afford to deviate from their present system. it is advised that as a *minimum* requirement, they should:

• Perform some product testing or comprehensive evaluation (with some basic testing included).

• Set up a basic factory control system (paying particular attention to the final tests before dispatch) and maintain tight control over the use of safety critical components.

• Set up a Change Control system for safety critical components (at least one person from the Design, Production or Quality Control departments should be designated to carry out this task).

• Identify product safety critical areas within the plant and introduce a safety awareness program.

From the information provided above, the reader might draw the conclusion that the use of an NCB and testing according to the standards is the only way to ensure compliance with the safety objectives of the LVD. This is not strictly true — in fact, only a small proportion of manufacturers of products under the scope of the LVD follow this route. The alternatives outlined in the following chapter may be found useful.

## 2.8 Summary

It is a fact that testing to ensure conformity with all the applicable standards and regulations will not guarantee that products will be safe in all circumstances (thereby automatically freeing the manufacturer from risk of prosecution and liability damages).

A sensible test program, however, together with certification from a recognized National Certification Body, and an adequate Production Control system, will provide a first line defense should the safety of a product be called into question.

# 3. Self-evaluation route to compliance

The cost of complying with so many EU Directives has undoubtedly placed a heavy burden on manufacturing industry, particularly small business. This is cause for concern for many small organizations and many are looking for alternative ways to reduce this expense.

In order to help small businesses, meet the requirements of the LVD without incurring the additional costs incurred by external product evaluation, we have prepared some brief guidelines that could be of use to small-scale manufacturers of electrical products. It must be pointed out, however, that although what follows is considered to be best practice, it holds no legal status and it must be read in conjunction with the Low Voltage Directive.

Let us now consider the scenario where you, the reader of this guide, are the designer of a new product. You have some experience in using safety standards and you are reasonably familiar with safety principles. By following the step-by-step approach described below you should be able to design and self-evaluate/test your product and be confident of meeting the safety objectives contained in the LVD.

## 3.1 Step 1 - Finding an applicable standard/regulation

As a first step, you need to establish which safety standard or regulation is applicable to your proposed design. You should start by preparing an information pack that includes as much information about the product as possible. As a minimum it should Contain:

- the product's concept
- where it is intended to be used
- its power supply requirements
- potential market(s)
- size weight, etc.

This information could then be submitted to the local National Certification Body or a Notified Authority/Test House with a request for advice on:

- whether the equipment is included in the scope of the LVD
- the most applicable safety standard or regulation (and the latest issue).

Many organizations will not charge for such a service.

## 3.2 Step 2 - Understand the fundamental safety requirements

If a standard or regulation is applicable to your products, you should become familiar with its fundamental safety requirements. Obtain a copy (see Note below) and start by studying this document. For the novice this will be a slow, lengthy process and certainly confusing at first. To help you further, it might be advisable to create (in order) lists of the following:

- the main core requirements
- minor requirements (preferably clause by clause)
- equipment necessary to confirm your design upon completion. If at any point you feel unsure about the tests or evaluations listed in the standards, seek clarification from your NCB or a Test House.

## 3.3 Step 3 - During the design stages

Once you have read and understood the safety standard or regulation, you can now start your design. Usually the design is completed le modules, and during these early design stages consideration should, given to each module's design parameters which are critical to the final product's sale operation under normal operating conditions and under fault conditions, i.e.:

- overcurrent protection devices
- component spacing (For insulation or flammability)
- primary (high voltage) /secondary (low voltage) circuit separation
- leakage/touch currents
- insulation distance and thickness (refer to Chapter 4)
- use of approved components (see Step 5)
- etc.

These are important parameters and should be considered while the new product is still on the 'drawing board'. Retrospective design changes can be very expensive and possibly impractical to apply, so early stage considerations are paramount in saving time, effort and cost.

## 3.4 Step 4 - Test equipment considerations

Although you may think it is too early to consider what equipment you will need to verify your prototype, you may find that some specialized equipment suppliers have a long lead time for purchase or hire.

Consider what equipment you will need to carry out:

- mechanical tests (you may need specialized instruments)
- temperature measurements
- voltage, current and power measurements
- leakage currents
- flash (dielectric strength), insulation resistance and earth continuity
- etc.

For test routine guidelines, see Chapter 4, and for equipment and suppliers of test instruments. You may find that most of the equipment you will need is already available in your Design, Quality Control or Production areas — but before you decide to use them for compliance testing, ensure they are calibrated!

For specialized tests, you may of course need to purchase or hire some additional instruments or fabricate 'similar' tools in-house.

## 3.5 Step 5 - Decision on Safety Critical parts

During the design stages, you will need to consider which parts and components are important to guarantee continuing safe operation under normal operating and fault conditions.

You will need to list which components or parts are considered Safety Critical (SC) and start the selection process at this stage.

In order to achieve confidence in meeting the standards and designing a safe product, you should select only SC parts or components with external electrical safety approval, or those which meet the flammability requirements as specified in the standards.

Deciding on SC components is very critical, and in parallel with obtaining their operational specifications from the supplier (necessary if the product is to perform as intended), you should obtain confirmation their safety approval status before you decide to use them.

## 3.6 Step 6 - Prototype testing

When you have a prototype available, you should consider performing initial confirmation tests.

In an ideal situation, there should be an area specifically allocated for safety testing with its own dedicated instruments and equipment, but this is not always possible. Having collected the necessary tools and equipment as explained above, you will need to find a 'quiet corner' to start your evaluation. Begin by looking at fault testing and other tests that are affected by the circuit design; external construction tests could follow later. Using the checklist created earlier (see Step 3), perform as much testing as possible and confirm compliance to the basic safety requirements before the design moves to the next stage.

## 3.7 Step 7 - Creating an Evaluation Report

The objective of compiling an evaluation report is to prove to the manufacturer himself and to the appropriate enforcement officer that the manufacturer has:

- Taken all reasonable steps followed good engineering practice
- Made a comprehensive evaluation of the product
- Designed a safe product
- Minimized the risk of failure while in use

## 3.7 Step 8 - Testing the final product

If the product you have designed is one of a range of similar products, select the most complicated of the series and start your evaluation.

Tests should be performed in the order that you feel is most convenient or appropriate. For example, you should perform some humidity treatment (possibly in an environmental chamber) if the product is likely to be used in a humid environment, and immediately after the humidity treatment you should perform the dielectric strength test.

After the first two or three evaluations you will settle into a routine and be able to perform testing in the most convenient manner. During the testing/evaluation, you should carefully consider the aim of the tests —some of these could be:

- to identify all risks associated with your product's operation (this includes electrical and mechanical issues)
- to perform as many tests and evaluations as are necessary to ensure that all the risks have been assessed
- to gain the confidence that your product has been evaluated correctly
- to confirm that the product has passed the required tests or evaluations relevant to the particular standard or regulation
- to confirm the product has passed the principal safety objectives
- to confirm that it is 'safe' to be released to the end user.

Do not forget to perform the important tests of dielectric strength, insulation resistance, leakage current and earth continuity (if applicable).

## 3.9 Step 9 - The final act

Having evaluated your product and being satisfied that it meets the `principal safety objectives', you need to:

• prepare a Technical File

• prepare an EC Declaration of Conformity

• affix the CE Marking on your product.

## 3.10 Summary

The principal safety objectives are defined in the Low Voltage Directive. They require products to be built in such a way that electrical equipment is:

• safe

• constructed in accordance with good engineering practice

• designed to meet the safety requirements contained in the LVD.

Self-evaluation may be the only possible way for a small organization to meet the LVD and supply its products across the EU. This is recognized and accepted by the enforcement authorities. If you rely on self-certification you must take all reasonable precautions to supply a safe product, and you should therefore:

• confirm that your product is under the scope of the LVD

• search for an applicable (or closest relevant) standard for the goods produced

• become familiar with the relevant standard or regulations

• understand the standard's requirements and the safety principles listed therein

• ensure that the design work is carried out with due regard to the standard

• decide what tests can be performed 'in-house' and obtain the necessary equipment;

• perform the tests and confirm compliance

• complete a self-assessment (evaluation) report and keep it with the Technical File.

You can also help yourself further and reduce your approval costs by:

• applying only relevant standards or regulations

• evaluating your product for the environment of its intended use

• taking, the user's expectations into account

• providing sufficient warnings and detailed lists of limitations of use

• comparing it with similar products externally tested previously

• using your 'in-house' expertise.

*Finally, act in the spirit of the Low Voltage Directive — you should do everything practicable to remove any doubt about the safety of your product.*

# 4.Designing for safety

An attempt is made in this chapter to further expand upon the basic safety principles, and to assist the reader in gaining familiarity with the most common requirements quoted in safety standards. Furthermore, typical test and confirmation methods will be explained, thus making the process of self-assessment easier. However, it must be understood that the limits and test methods described in this chapter are 'typical' and (therefore) very general and cannot be used alone for any one product's complete evaluation. Detailed test methods, limits and pass/fail criteria can only be found in the product specific standard. Following the guidelines described here may therefore not be entirely sufficient to guarantee the complete and accurate product evaluation which may be necessary to ensure the supply to the user of a 'safe' product as required by the Low Voltage Directive.

Initially, the reader will need to understand that every safety standard specifies unique requirements for the testing of a particular product or product range, and for a given environment of use. It is clearly impossible to consider all of these requirements individually in this text; an attempt is therefore made to give the reader an understanding of those design and testing considerations which are applicable to most electrical products.

As mentioned already, testing according to a Harmonized standard is the best approach. However, since the interpretation and understanding of standards is an art in its own right (even experts often cannot agree on meanings and definitions), the testing has to be planned and carried out very carefully — especially if the manufacturer intends to test or evaluate against the Harmonized standard in-house, without external support.

A careful study of the requirements of the product specific standards, and due regard to the advice given in this chapter, will surely simplify the completion of a self-evaluation report.

## 4.1Definitions

*Hazardous live* — electrical condition of an object from which a hazardous `*touch current*' (electric shock) could be drawn.

*Accessible part* denotes a part that may be touched by the standard test finger.

*Creepage distance* denotes the shortest distance along the surface of an insulating material between two conductive parts.

*Clearance* denotes the shortest distance in air between two conductive parts.

*Class I* apparatus denotes an equipment in which protection against electric shock does not rely on basic insulation only, but which includes an additional safety precaution such that means are provided for the connection of accessible conductive parts to the protective (earthing) conductor in the fixed wiring installation so that accessible conductive parts cannot become live in the event of a failure of the basic insulation.

*Class II* apparatus denotes an equipment in which protection against electric shock does not rely on basic insulation only, but which includes additional safety precautions such as double insulation or reinforced insulation, there being no provision for protective earthing or reliance upon installation conditions.

*Class III* apparatus denotes an equipment in which protection against electric shock relies upon supply from an SELV circuit and in which hazardous voltages arc not generated (extracts from BS EN 60950: 1992).

*Basic insulation* — insulation applied to a hazardous live part to provide basic protection against electric shock (Class I).

*Supplementary insulation* — independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the event of failure of the basic insulation.

*Double insulation* — insulation comprising both basic insulation and supplementary insulation (i.e. is made up of two separate layers of insulation completely enclosing the live parts).

*Reinforced insulation* single insulation applied to hazardous live parts which provides a degree of protection against electric shock equivalent to double insulation.

## 4.2 Equipment classification

During the design stages of a new electrical product, the designer has to take many important factors into account (design timescales, performance criteria, manufacturing costs, etc.). One of the most important considerations when designing to meet the safety criteria is the necessary level of protection against electric shock. Asa very minimum the designer has to consider:

- the into environment of use
- the operator's background/ability
- the operator's technical understanding
- the product's external construction.

This decision should be made very early in the concept stages as it could have significant design, testing, manufacturing and cost implications.  For equipment with metal enclosures, a protective earth wire is usually provided which is electrically connected to all exposed metal parts. In this case, if the primary (basic) insulation breaks down, the grounded enclosure will then trip the circuit breaker (i.e. blow the fuse).

If an ungrounded enclosure is used (e.g. a plastic casing), the standards recognize the inherent double insulation effect, i.e. the basic insulation between the primary supply and the enclosure as well as the additional 'supplementary' insulation provided by the enclosure itself. In this case, if the basic insulation breaks down, the enclosure will act as the secondary level of protection.

The classification of the product will determine the number of layers of insulation, and their types and thickness as well as the minimum distance that needs to be achieved between live and user-accessible parts. The type of testing which will be performed at a test laboratory will also depend on the type of insulation employed.

### 4.2.1 Class I

The safe operation of Class I equipment relies on the integrity of the external installation's earth system. On Class I products, live parts operating at hazardous voltages are protected by basic insulation, while e accessible metal parts should be reliably connected to the safety earth.

Resistance between the main earth terminal and all earthed accessible parts must be typically less than 0.1Ω — the resistance of the power cord is not included in this value. For some standards, the overall resistance between the earth pin of the mains plug and the EUT (Equipment Under Test) measurement point, must not exceed 0.2Ω. EN 60950 describes a measuring method by using a 12 V AC supply at 25 A or 1.5 times the current capacity.

To help the reader with the design of a good earthing, some of the most important considerations are listed below:

• The PE conductor shall not contain switches or fuses.

• The PE conductor can be bare or insulated.

• Disconnection of the PE at one assembly shall not break the grounding to other assemblies unless the hazardous voltages are removed.

• In cases where the PE conductor is insulated, the coating should be green/yellow and should be secured to the chassis or frame via a closed-loop ring connector placed over a No. 6 (or larger) welded stud.

• For secure connection, it is advisable that a star washer be placed underneath and a lock washer on top of the ring connector.

• The PE should be secured by its own nut; other grounds can share the same stud but must be placed over the nut holding the earth ground conductor in place.

• The PE conductor must be mechanically secured before being connected to the ground pin of a coupler, e.g. an AC inlet. The same applies in cases of directly connected power cords.

• PE disconnection is not necessary unless a particular part is to be removed.

• The earthing connection conductor should be resistant to significant corrosion; the use of plastic coating might be necessary (EN 60950 gives a useful table of electrochemical potentials that exist between metals).

• All operator-accessible metal parts must be electrically and reliably connected to the earth ground.

• A fuse or another overcurrent device should generally be provided in the primary circuit and should be connected in the hot (live) supply conductor.

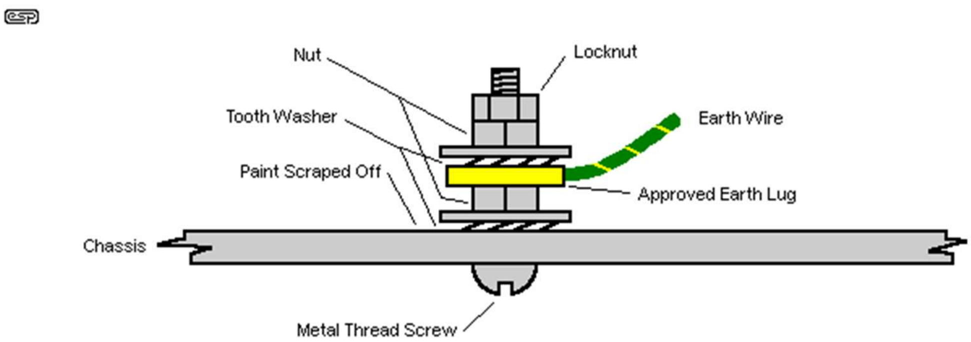


*Figure 4.1 Example of a goof earthing connection*

Testing for earth continuity must be performed as explained in Chapter 14. Equipment for this test varies in price and performance - the choice of equipment (and the purchase price) will depend on the test current requirement as specified in the product standard, and the perceived need for automated testing at the end of line.

### 4.2.2 Class II

It is not true to say that all equipment with an outer metal enclosure must be of Class I construction. If the metal enclosure is not grounded (i.e. Class II) but well protected by double or reinforced insulation, then the possibility of insulation failure (resulting in the enclosure becoming live) is negligible.

Accessible low voltage areas (typically less than 30 V AC or 60 V DC) in a Class II product which may be touched by the operator must be separated from hazardous voltage areas by full Class 11 insulation thickness, and creepage and clearance distances equivalent to denote insulation (values will vary between standards).

If an SELV (Safety Extra Low Voltage) circuit is used in a Class II product, voltages on accessible parts should not exceed typical values of 25 V AC or 60 V DC (lower voltages apply in special cases, usually depending on the environment of use).

While a Class I product relies on the integrity of its external earth system, Class II equipment is inherently safe by design. Class 11 equipment has become very common nowadays (e.g. domestic appliances, television receivers, video recorders, garden tools, electric drills, etc.), mainly because a plastic enclosure is lighter to carry and is more aesthetically pleasing.

### 4.2.3 Class III

Unlike Class 1 and Class II products where protective earth and insulation arc required to prevent the user from the risk of electric shock, Class III products rely on the use of a SELV supply having an upper limit of 50V AC or 60 V DC - reference EN 60950. This type of equipment is outside the scope of the LVD but many of the standards relevant to the LVD contain requirements for Class Ill products. Class III equipment is usually battery operated.

SELV circuits must be safe to touch under normal operating conditions and under single component failure. Accessible voltages between:

- any two parts of the SELV and
- any part of the LVD and earth shall not exceed 42.4 V peak or 60 V DC under normal or fault conditions.

EN 60950 describes three methods for designing SELV circuits, these are given below:

- Method 1: Separation of SELV circuits from high voltage circuitry by double or reinforced insulation.
- Method 2: Separation of SELV circuits from other circuitry by earthed conductive screen or parts.
- Method 3: Adequate earthing of the SELV circuits, i.e. the use of a protective earth.

Not all product construction clearly falls under just one of these three classes - some may employ a combination of two construction classes while others may combine all three. An example of this would be handheld battery-operated equipment (Class III construction) which is also provided with an add-on main operated supply or charger (Class I or II). The insulation requirements for use in Class III mode are clearly different from those in the mains powered mode.

## 4.3 Insulation

All insulation used in an equipment must be fit for purpose - it has to be made of a material with a flammability classification and material deformation properties suitable for the place of use. For example, materials used for structural purposes or for the enclosure need to be of a much higher flammability rating than the insulation of live parts. Also, insulation must not be hygroscopic (material that absorbs water or moisture) as it will fail insulation testing following humidity treatment.

### 4.3.1 Basic insulation

This is used between live parts and earthed metal parts (Class I), and between live parts of different polarities - it is required by most standards for mains operated equipment. This type of insulation is not fail-sale and should not be accessible to the user. In cases of mains operated equipment (230 V-240 V) the insulation must withstand an electric strength test (i.e. there must be no breakdown of insulation). The test voltage may be 1350 V AC or up to 2500 V peak. depending on the applicable product standard.

### 4.3.2 Supplementary insulation

This is mainly used on live parts in Class II equipment to protect the user from electric shock. Supplementary insulation is a layer of insulation in addition to basic insulation, when it cannot be considered safe on its own. It is required to withstand an electric strength test and in the case of mains operated equipment, the test voltage should be 1500 V rms. The thickness of such insulation will vary depending on the applicable standard, for example the standard for domestic electrical appliances specifies a minimum thickness of 1 mm, while the standard for domestic electronic appliances, broadcast receivers, radios, etc. specifies a mini-mum thickness of only 0.4 mm.

In summary, supplementary insulation could be:

- two layers — each passing electric strength test of 1500 V rms
- three layers — any two must pass electric strength test of 1500 V rms.

### 4.3.3 Double insulation

As explained earlier this is an insulation comprising of basic and supplementary insulation and is safe to touch (the mains power cord is a typical example of double insulation).

*Figure 4.2 Example of a double insulated wire*

### 4.3.4 Reinforced insulation

This is a single layer of insulation used to cover live parts. It can be found mostly in Class II products, and it is required to withstand an electric strength of up to 4000 V AC. As for supplementary insulation, the minimum thickness of reinforced insulation varies according to the applicable standard, it could vary from 0.4 mm (EN 60065) to 2mm (EN 60335).

Protection of the user from the risks of electric shock is paramount and the product designer must give this very careful consideration. Electrical safety standards operate on the principle that if one level of insulation fails, then there is another means of protection which is unlikely to fail.

| | Class I | | Class II | |
|---|---|---|---|---|
| | Between "live" and earthed parts | Between "live" and unearthed parts | When double insulation is employed | When reinforced insulation is employed |
| **Insulation distance** | Min. 3mm | As Class II | Between primary and secondary circuit min. 6mm (3mm+3mm) | Between primary and secondary circuit 6mm |
| **Insulation thickness** | Min. 0.4 mm or pass dielectric strength test (>1.5kV rms) | As Class II | 0.4 mm + 0.4 mm or pass dielectric strength test (>1.5kv rms) | 2mm or >0.4 mm if pass dielectric strength test (>3ks rms) |
| **Dielectric strength test** | Min 1.5kV rms | As Class II | Min 3kV rms | Min 3kV rms |

*Table 4.1 Example - values of insulation thickness, recommended distances and test levels*

This is known as the principle of 'double improbability'. A single level of insulation is therefore not sufficient to protect the user from any hazardous voltages. For a product to be safe, insulation must be provided by either:

- double insulation
- reinforced insulation or
- basic insulation + protective earth.

Confirmation testing for insulation on wiring can be performed relatively easily, using an AC high voltage source (possibly the same tester as used for end-of-line testing). The specified voltage is applied between the test cable's inner conductor and the outer part of its insulation (wrapped with metal foil or similar) for a typical duration of 1 min — insulation breakdown should not occur.

## 4.3.5 Bridging insulation

When the circuit design requires it, double or reinforced insulation separating primary from secondary circuits may only be bridged by approved components (approved for safety critical operation) where it is necessary to provide coupling or a control signal in switch mode power supply circuits.

Components likely to bridge such insulation include:

- Resistors
- Opto-couplers
- Transformers
- Capacitors

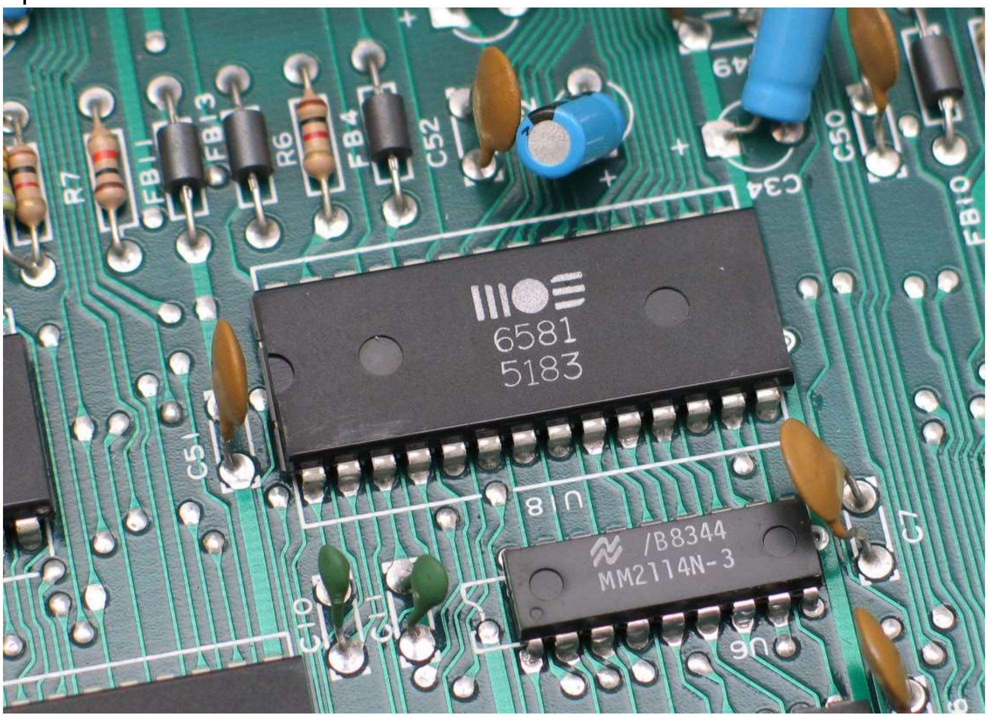


*Figure 4.3 Example of a safety component bridging the HV/LV barrier*

### 4.3.6 Creepage and clearance

Most safety standards stipulate a minimum spacing through air (clearance), and a minimum distance over surfaces (creepage) between primary (live) and secondary (low voltage) circuits. Creepage distances and clearances are dimensions which relate to possible breakdown paths between live parts and other components (see also Appendix 9). The clearance distance between two points is the shortest distance measured through air between:

- two conductive parts or
- a conductive part and bounding surface of the equipment.

To determine the equipment's minimum clearance requirements, the following have to be defined:

- the circuit, e.g. primary, secondary
- the pollution degree value (1, 2 or 3 where 2 is for normal working environments) — see Table 4.2
- the insulation working voltage
- the insulation category, e.g. basic
- whether or not the manufacturing process is subject to a quality control program.

The creepage distance is the shortest path between:

- two conductive parts or
- a conductive part and bounding surface of the equipment measured along the surface of the insulation.

To determine the equipment's minimum creepage requirements, the following have to be defined:

- the circuit, e.g. primary, secondary
- the pollution degree value (1, 2 or 3 where 2 is for normal working environments) — see Table 4.2
- the insulation working voltage
- the material group (I, II or III)
- the insulation category, e.g. reinforced. Creepage distances are not allowed to be less than the clearance.

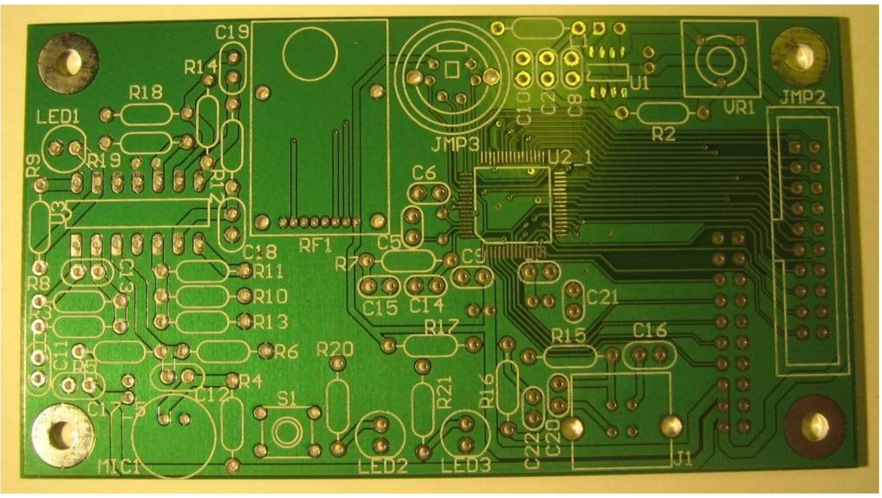


*figure 4.4 The top side of the plug low voltage printed circuit board*

Not all live parts need be surrounded or separated by a layer of insulation. If the live part is fixed in place and is a sufficient distance away from other parts, then an air gap alone may suffice. The creepage distances for basic and supplementary insulation will also depend on the material used in the Printed Wiring Board (PWB) and its

| Pollution degree | Environment |
|---|---|
| **1** | Applicable for equipment sealed to exclude dust and moisture – only possible if a hermetically sealed enclosure is used. |
| **2** | Equipment subject to non-conducting deposits and some temporary condensation – this is the most common situation. |
| **3** | Equipment subject to conductive deposits (e.g. carbon brushes), pollution and condensation. |
| **4** | Equipment subject to conductive deposits of dust and rain. |

*Table 4.2 Definitions of pollution degree*

'comparative tracking index' (CTI). As a general rule, most (PWB) materials of flammability rating 94V-0 (see Section 4.5) will be of Material Groups IIIa / IIIb - see below:

Material Group I: 600 ≤ CTI

Material Group II: 400 ≤ CTI < 600

Material Group IIIa: 175 ≤ CTI < 400

Material Group IIIb: 100 ≤ CTI < 175

Concentrating on the most common Pollution Degrees 2 and 3 and PWB Material Groups I, II and III, a table of minimum distances (in mm) given in EN 60950: 1992 is shown in Table 10.3.

Where secondary circuits are separated from primary circuits by an approved transformer, the minimum creepage and clearance distances in the secondary may, depending on the standard used, be less than those in the primary. This will depend on the security of the parts and the PWB materials used, particularly since the CTI and flammability ratings will be critical.

| Working voltage up to and including V rms or DC | Pollution degree 2 | | | Pollution degree 3 | | |
|---|---|---|---|---|---|---|
| | Material | | | Material | | |
| | I | II | IIIa & IIIb | XI | XII | IIIa & IIIb |
| 50 | 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 | 3.6 | 4.0 |
| 300 | 1.6 | 2.2 | 3.2 | 4.0 | 4.5 | 5.0 |
| 400 | 2.0 | 2.8 | 4.0 | 5.0 | 5.6 | 6.3 |
| 600 | 3.2 | 4.5 | 6.3 | 8.0 | 9.6 | 10.0 |
| 1000 | 5.0 | 7.1 | 10.0 | 12.5 | 14.0 | 16.0 |

*Table 4.3 Operational, basic and supplementary insulation - min. creepage (in mm)*

Provided that due care is taken, the measurement of creepage distance and clearance is fairly simple. If the maximum advantage is to be taken of concessions, in the standards then, due care must be taken when following of measurement. Careful handling of all equipment used for the rules these measurements is vital, as is regular calibration.

Other factors affecting creepage distances and clearances are:

- the presence of moisture
- the materials used
- the construction and topography of the surfaces
- the consequences of any failure
- the susceptibility of the power source to surges in voltage.

Allowance must also be made for production tolerances — failure to meet the limits due to manufacturing tolerances, tool wear, shrinkage. etc. is not acceptable in law.

When setting limits for creepage and clearance, factors such as those described above are taken into consideration, but most requirements are based on the experience of the committees which set the standard rather than on fundamental laws.

## 4.4 Construction - wiring

Wiring used in electrical equipment can be categorized as internal or external. Internal wires are those used inside the equipment for PWB/sub-assembly connections, while external wires are those usually carrying hazardous voltages, i.e. mains power cord.

### 4.4.1 Internal wiring

Internal wires shall be fit for purpose. When deciding the type of wire to be used, the designer needs to consider its:

- rated voltage
- rated current
- operating temperature (relative to the parts it serves and may touch)
- support and possibly clamping/securing method.

### 4.4.2 Internal wiring — mechanical fixing

Internal wires have to be 'dressed' and secured so that the point of connection will not be subjected to excessive strain, loosening or damage. The Construction must be such that if a wire becomes detached, the creepage distances and clearances are not reduced (by the natural movement of the wire) below those required in the standards (e.g. 6 mm between primary and secondary in the case of a Class II household appliance).

This requirement is met if there is no possibility of the wire becoming detached. This is arranged by wires having a mechanical as well as an electrical fixing -- examples of a mechanical fix are wires twisted together, fastened together with tape, having a wrap joint, glued to PWB, etc.


*Figure 4.5 Example - internal wiring dressing*

Soldered wires must be mechanically secured before soldering -- it must always be assumed that a solder joint by itself will fail. Wires connected to screw terminals should include a solder lug with upturned ends. For wires passed through metal guides, rounded smoothed edges or protective bushes should be used. Wires subject to movement should be protected from damage by some mechanical means, e.g. helical supports.

### 4.4.3 External wires and mains plugs

The mains (AC) power cord may either be connected to the product or supplied in a detached form; in both cases an approved type must be used. A power cord is considered safe if it is approved by the inter-national HAR or BASEC approval bodies -- it must of course be suitable for the application for which it is intended and must have the correct number of conductors, i.e.:

- two conductors for connection to a Class II product (live and neutral)
- three conductors for connection to a Class I product (live, neutral and safety earth)
- three or more for 3 phase supplies.


*Figure 4.6 Example of an approved mains lead*

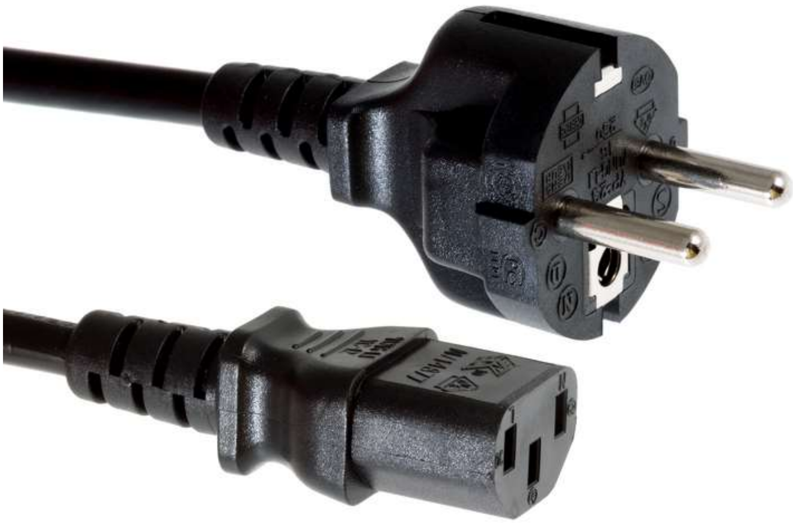

*Figure 4.7 Example of an approved mains plug*

The power cord's internal wires must also be insulated with the correct color code as explained below:

- Live conductor — Brown
- Neutral conductor — Blue
- Earth conductor — Green/Yellow.

*Note: For permanently connected equipment, the color code may be as above or as given below:*

- Live conductor — Red
- Neutral conductor — Black
- Earth conductor — Green/Yellow

The plug has to be rated to at least 125% of the rated current of the equipment, and some standards specify maximum length — this should be confirmed before deciding on the type to be used.

A fuse is connected in the 'live' side of the UK (3-pin) mains plug —attention should be paid to matching the rating of the fuse fitted to the plug and the fuse fitted in the product.

Mains (flexible) power cords for light use (e.g. household appliances) usually comply with IEC 227 (polyvinyl chloride insulated cables) or IEC 245. Conductors in power cords must be of adequate cross-sectional area such that if a short-circuit occurs in the equipment, the protection circuits in the electrical installation operate before the cord overheats.

EN 60335 specifies current ratings of mains cord conductors as given below.

| Rated current of the equipment (amp) | Nominal cross-section area ($mm^2$) |
|---|---|
| <0.2 | Tinsel cord * |
| <0.2 and <0.3 | 0.50 |
| <3.0 and <6.0 | 0.75 |
| <6.0 and <10.0 | 1.00 |
| <10.0 and <16.0 | 1.50 |
| <16.0 and <25.0 | 2.50 |
| <25.0 and <32.0 | 4.00 |
| <32.0 and <40.0 | 6.00 |
| <40.0 and <63.0 | 10.0 |

***Only to be used for cords up to 2m in length (mains plug to equipment entry point).***

Attention must be paid to the mains power cable entry to the equipment (smooth apertures will help to avoid cord damage, and bushings of insulating material must be of a durable type and should not deteriorate in normal use). An inspection check is advised, and an ageing test for bushings should be applied. The use of a cord guard is necessary in cases where the equipment is supplied with a flexible cord and is meant to be moved frequently. Tests for such cord guards will depend on the applicable standard (usually a flexing test at a certain angle and for several thousand movements).

Flexible power cords must be adequately anchored to the equipment, connecting points must be relieved from strain, and the conductors must be prevented from twisting. Cord clamps should be carefully designed so as:

- to be suitable for the power cord used
- not to damage the cord (sharp edges, too much compression, etc.)
- to withstand a pulling test (see below)
- to be made of insulating material (for Class II equipment)
- to be provided with lining (if they are of metal construction).

### 4.4.4 Internal wiring — insulation

Internal wiring should:

be of adequate cross-sectional area

be of adequate flame resistance

be protected by a layer of insulation depending on its application.

Primary or high voltage secondary wires likely to be touched by the operator or the service engineer must have a secondary level of protection, e.g. a second layer of insulation such as tubing; otherwise, the whole unit, must be provided with some other form of protection such as an interlock.

The insulation needs to withstand a dielectric strength test that will depend on the wire's application and the applicable standard. It may need to withstand only 1500 kV rms (measured between the conductor and foil wrapped on the outside of the cable).

Internal wire insulation temperature rise is normally limited to 50°C, but some internal wires may need to operate at much higher temperatures, e.g. those placed near high temperature operating parts or components — in such cases consideration must be given to:

- a reliable mechanical fixing (keep as far away as possible from the source of heat)
- the insulation material and its properties (use of low flammability grade, e.g. V2 or better)
- the possible use of additional sleeving (again with low flammability rating)
- the use of insulation which has a high temperature rating (ensure that rating is sufficient for the expected temperature rises).

Some standards require that internal wires be insulated with PVC, PFE, PTFE, FEP or neoprene, or marked with a rating of VW-1. In summary, internal wires must:

• be provided with an adequate electrical insulation

• have adequate cross-sectional area (depending on the current they will carry)

• be of the correct voltage rating

• be of an adequate temperature rating (depending on its application)

• be of a correct flammability rating (depending on the applicable standard)

• be reliably fixed — shielded from hot parts, sharp edges, etc.

• be provided by additional sleeving (if necessary) for additional electrical, temperature or flammability protection

• be provided with sufficient strain relief to avoid damage and potential short-circuit

• to be provided with lining (if they are of metal construction).

Equipment fitted with a non-detachable power cord must be fitted with a suitable means of securing the power cord, e.g. a strain relief grommet.

The power cord should not be capable its being pushed back into the equipment to the extent that the cord or its conductors be damaged, or internal parts or components become loose, displaced or damaged. It should therefore be securely fixed to the equipment; this can be confirmed by performing the following simple pulling test (see product standard for details).

A pulling force of 40 N is applied to the mains cord 100 times and for 1 second duration. During this test the power cord should not become damaged, and a maximum of 2 mm displacement of the power cord is allowed. This is checked by visual inspection and by confirming that the internal creepage and clearance distances are maintained.

Although some standards specify a pull test independent of the equipment's weight, others specify a pulling force which is weight dependent:

• 30 N (newton) for equipment of weight less than 1 kg

• 60 N (newton) for equipment of weight between 1 kg and 4 kg

• 100 N (newton) for equipment of weight greater than 4 kg.

In addition to the pull test, the mains cord is subjected to an applied torsion of 0.25 Nm for 1 min — there should no visible damage or ripple.

The values given above will vary depending on the applicable standard and the mains cord size.

### 4.4.5 Withdrawal of mains plug

There must be no risk of shock when touching the pins of the mains plug after it is withdrawn from the socket outlet. A relatively simple and typical method to confirm this point is explained below.

With the mains switch in the most unfavorable position, the pins of the plug must be measured not to be live 2 seconds after the plug has been withdrawn. The test should be repeated up to 10 times to cover the most unfavorable condition.

## 4.5 External construction

Product safety standards contain construction and performance criteria. Under normal operating conditions the construction of the product should be such that the user will not be faced with the risk of electric shock.

Depending on the standard to be followed and the product's environment of use, there are a number of different tests that can be used to assess accessibility. The object of all such tests is to ensure that live parts do not become accessible.

Test methods specified by some of the most 'popular' standards are described below:

EN 61010 - specifies that the Rigid Test Finger be applied to all surfaces including the base (some exceptions are listed) with a force of 10N. There is no need for the application of the Tapered Test Pin but the standard specifics the use of a 100 x 4 mm diameter pin for assessing vents and a 100 x 3 ram diameter probe for assessing controls.

EN 60950 - specifies that the Rigid Test Finger be applied to all surfaces of the equipment with a force of 30 N; floor standing equipment of weight >40 kg should not be tilted for this test (some exceptions are listed). The Tapered test is applied to all surfaces (without removing operator removable parts).

EN 60335 - specifies that the Rigid Test Finger be applied to all surfaces of the equipment with a force of 30 N; floor standing equipment of weight >40 kg should not be tilted for this test (some exceptions are listed). For Class II products, the Test pin is used - but not to lamp sockets with lamps removed and not to socket contacts. This standard also requires the use of some special tools such as a 30 mm diameter conical test pin.

EN 60065 - the requirements of this standard are more onerous as these products are usually of Class II construction, with plastic enclosure and used in a domestic environment where children may be playing. Some of these tests are described below.

The standard specifies that the Rigid Test Finger be applied to all surfaces including the bottom with a force of 50N and the Tapered test pin be applied to all outer surfaces. Other tests include the use of a 2 mm diameter chain for live shafts, a 100 x 4mm diameter probe for ventilation slots, a 100 x 2 mm probe for preset controls and a 100 x 1 mm wire for bushings.

The enclosure must also be resistant to external forces. It provides the first line of defense against shock, fire and other hazards. Barriers arc placed inside the enclosure which prevent the operator from reaching hazardous areas of the circuit, while guards are extra pieces mounted on the outside of the enclosure - usually to protect the operator from mechanical hazards such as fans or gears.

Plastic enclosures should be tested for strength. One possible test would be to use the Rigid Test Finger for applying inward force and a Test hook for applying outward force. The object of the exercise is to assess whether or not distances between accessible parts and live parts are reduced. Creepage and clearance distances should be maintained and live parts must not become accessible.

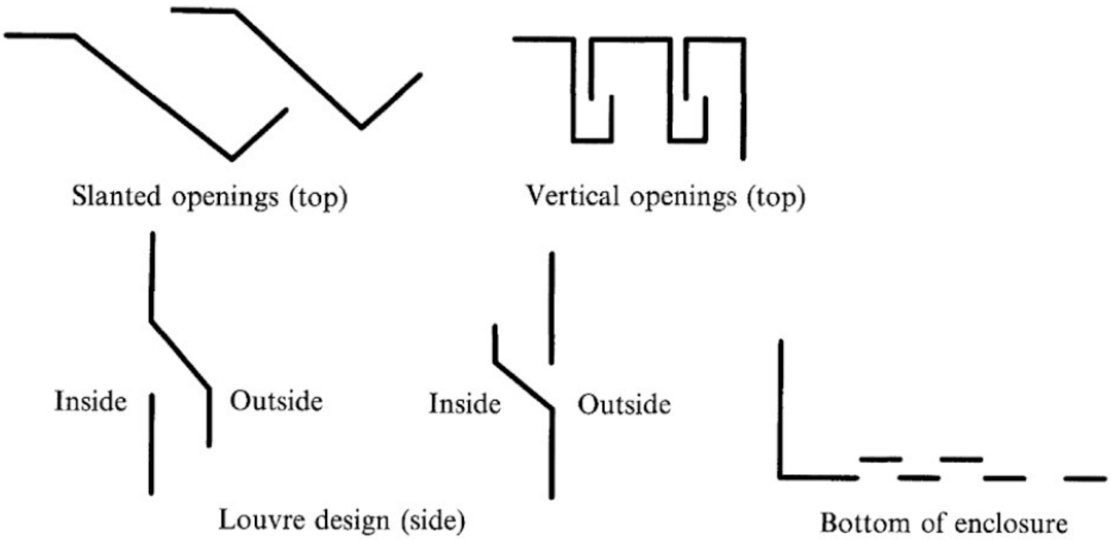


*Figure 4.8 Examples of enclosure openings*

*Note: Care must be taken during the design of the enclosure to ensure that any openings which might be necessary for ventilation or access he kept to a minimum.*

Typical dimensions of openings for ventilation are 2 mm x 15mm on the side of the enclosure, and 3 mm x 30 mm on the bottom of the enclosure. Openings for the power cord, preset controls, etc. should also be kept to a minimum. Ventilation openings directly above the power supply and other high voltage areas are not encouraged (to avoid hazard due to accidental liquid spillage).

In cases where ventilation openings above such areas are absolutely necessary, then vertical or slanted openings as shown in Figure 4.8 should be used.

### 4.5.1 Mechanical strength

Equipment must be constructed to withstand the handling expected in normal use. Most standards specify test methods for assessing conformity to mechanical strength requirements; some of these include:

*Bump test* — the equipment under test is placed on a horizontal table and raised and dropped from a set height (e.g. 5cm) a specified number of times in order to confirm the security of internal components. At the end of the test, a visual inspection is carried out — there should be no reduction in creepage and clearances.

*Vibration test* — this is applicable to portable equipment. The equipment is vibrated at a set amplitude for a short period of time. At the end of the test, the equipment must not have become unsafe due to reduction in creepage and clearance distances or the loosening of fixing screws or any other components.

Impact test - using the impact test hammer the equipment is subjected to a number of blows to every point providing protection to live parts.

The impact is also applied to windows, lenses, etc. There must be no damage affecting the safety of the product. i.e. the enclosure must not have any visible cracks, live parts must not have become accessible and insulating barriers must not have been damaged.

### 4.5.2 Mechanical stability

Equipment must be stable in use and not liable to topple over and pose risk to the operator when in use (i.e. user being crushed underneath).

A simple confirmation method is to place the equipment on a plane inclined at 10 degrees to the horizontal and rotate the product through 360 degrees. During the rotation, a force of 100N directed vertically downward at any point, on any (normally) horizontal surface (to provide the maximum overturning moment), should not cause the equipment to fall over.

For equipment more than 1 m in height and weighing more than 25 kg. a force equivalent to 1/5 of its weight (max. 250 N) should be horizontally applied up to a height of 2 m on every side; once again the equipment should not tip over. The test should be repeated with doors, drawers and other parts in the most unfavorable position.

Other tests are described in the product standard.

## 4.6 Resistance to fire

Three ingredients are needed to support fire, i.e. fuel, heat and oxygen. Therefore, in order to prevent a fire from propagating, thereby becoming a hazard, most safety standards set maximum limits on fuel content, heat and the enclosure.

Enclosure, guards and barriers must not only be resistant to external forces as described above, but also must be made of materials that are not highly combustible - such as steel, aluminum, or heat resistant tempered, wired or laminated glass. When plastics arc used as enclosures, barriers or guards, they must comply with the relevant flammability ratings a typical rating for an enclosure of a large equipment (more than 18 kg), would be 94 5V-A (94V-1 would be acceptable for smaller equipment weighing less than 18 kg).

The flammability rating of polymeric materials is mostly tested against known standards such as the most commonly used Underwriters Laboratories (UL) UL94 classification as explained below. The main tests for this classification fall into three categories:

(i) UL94HB (least stringent)

(ii) UL94V-0, UL94V-1, UL94V-2

UL94 5V-A, UL95 5V-A (most stringent).

All safety standards have different flammability requirements, this will largely depend on the product's environment of use, for example standards applicable to office and business equipment (EN 60950) have particular requirements for the flammability rating of all fire risk materials as described below.

Enclosures and large parts of the enclosure having ventilation holes designed for letting out heated air must be of slow burning or fire-retardant material; they should typically be made with UL94-V0 (or better) material.

Printed Wire Board (PWB) material on which components are mounted should be of flammability UL94-V1 or better and should be separated from less fire-resistant material by at least 13 mm of air. PWBs with a surface area of less than 25 $cm^2$ are normally exempt from this requirement.

Air filter assemblies should be constructed of materials of flammability rating UL94-V2, or HF or better.

Decorative parts (parts of the enclosure whether mechanical or electrical) should be of flammability rating HB or better.

Small external decorative parts such as mounting feet and knobs may be exempt from the requirements as they are likely to have little or no effect on the spread of a fire.

Components such as integrated circuits, opto-couplers, capacitors, etc. are also exempt if they are mounted on V-1 or better material. Internal plastics should have flammability rating UL94V-2, or HF-2 or better.

Internal wires should have flammability rating VW-1 or better.

High voltage transformers and components (above 4 kV) must be resistant to fire.

## 4.7 Electrical connections and mechanical fixings

Screw fixings which may be loosened and tightened during the life of the equipment must have adequate strength. This is usually checked by loosening and tightening the fixing screws 10 times to the specified torque (typically 1.2 Nm for enclosure screws). There must be no deterioration that could affect the safety of the product. There must he means of ensuring correct location (by a guide in the screw hole) to prevent the screw angling away from its intended fitting direction. If the fixing screws are not captive then creepage and clearance distances are checked by using a screw with a length equal to 10 times the nominal diameter of the correct screw (typically 40 mm for a 4 mm diameter screw) at the torque specified above.

There must be no reduction in creepage distances and clearances below those allowed. Stands or detachable legs supplied by the manufacturer must be supplied complete with the necessary fixing screws to prevent the possibility of the customer using fixing screws that are too long — thus reducing creepage distances and clearances.

## 4.8 Components

Components which bridge the insulation between primary and secondary circuits and provide protection against electrical shock and other hazards should he of an approved type. Some additional information about these components is also given below.

Fuse links must comply with a relevant standard, must have adequate rupturing capacity and be marked with their characteristics either on the fuse holder, or adjacent to it.


*Figure 4.9 Example of fuse marking on PWB*

Mains power switches must have an adequate contact gap and be of adequate rating. The equipment or the rack should be marked with 0 and 1 to identify the off/on positions.

Interlocks must be used if access to the inside of the equipment by the operator is necessary, e.g. to adjust moving parts, remove jammed paper, replace bulbs, etc., as during such operations, the possibility of the equipment becoming energized must be prevented. Such interlocks must open all primary current-carrying conductors that provide power to use accessible areas and be self-restoring. Interlocks must be good for the many thousands of operations and must be approved.

## 4.9 Temperature

Excessive rise in temperature can cause fires and/or damage the insulation used to isolate hazardous parts. Parts that typically exhibit temperature rise, such as transformers, relays, inductors, large electrolytic capacitors, switches, fuses (as well as the PWBs on which they are mounted), must be measured for temperature rise. Test method examples are given below.

### 4.9.1 Heating under normal operating conditions

Most standards describe a suitable test method that is intended to ensure that the equipment does not fail or become unsafe in use due to overheating. A typical test method for temperature confirmation is explained as follows.

The equipment is placed in the normal position of use and ventilation, in accordance with the instructions supplied by the manufacturer. If such conditions are not specified, then it should be placed in a cabinet (e.g. a wooden box) with a small gap between the sides of the cabinet and the equipment under test (possibly 5 cm all around). The equipment under test should (in order to determine the worst case) be connected in turn to supply voltages of 0.9 and 1.06 times the rated voltage as well as the nominal rated voltage itself. In normal operating conditions, and when a steady state has been reached (usually after 2 to 4 hours), the temperature rises are measured.

Temperature rises above ambient must not exceed a typical value of 85°C for PWBs and winding wires, and 60°C for the enclosure. The best method to measure temperature on components and PWBs, etc. is to use thermocouples these are attached to those parts of the equipment which typically operate at the highest temperature such as:

- the upper part of enclosures (usually above the power supply)
- behind front cover flaps
- between a switch mode transformer winding and core
- deflection coils (if employed)
- voltage regulators • line and frame output devices
- high current diodes
- audio output circuits, etc.
- insulation.

The enclosure is removed and the thermocouples are attached to a digital thermometer via a switch box, and the enclosure is refitted. For component testing, thermocouples should be soldered to their respective solder 'lands' on the PWB.

Elsewhere, high temperature adhesive tape may be used to attach thermocouples to the cabinet, or between transformer winding and core, etc. - in each case ensuring that the tip of the thermocouple is touching the point to be measured.

*Note: A preliminary in run and examination of the equipment may need to be made in order to determine those parts which are most likely to reach high temperatures.*

### 4.9.2 Heating under fault conditions

All safety standards require that equipment be safe under abnormal operating conditions. Electronic circuits are tested by simulating component failure that might occur during normal use, thereby causing the equipment to become unsafe. In testing, only one simulated fault or abnormal condition is applied at a time.

Protection against electric shock must exist under fault conditions. The temperature of parts acting as a support or barrier must not reach unsafe levels (levels likely to cause mechanical failure), such that live parts become accessible or creepage distances and clearances be significantly reduced.

Furthermore, parts must not reach a temperature such that there is a danger from fire or abnormal heat, or that flammable gases are emitted. The latter condition generally applies only to PWBs for which the typical limit is a 110°C rise above ambient. This temperature limit may be increased provided that an area of not more than 2 $cm^2$ of the PWB becomes heated and solder does not become molten within that area.

As already indicated, the tests are carried out by simulating component failure and ensuring that under these conditions, parts of the equipment do not exceed permitted temperature rises and do not emit flammable gases.

From the test engineer's general experience, knowledge of the product type and study of the circuit diagram, simulated fault conditions are decided and applied to the product. Measurements are then taken of the temperature rise of relevant parts by the attachment of thermocouples.

Typical examples of fault conditions to be applied are as follows:

- S/C (short circuit) of capacitors connected between supply rails and ground
- O/C (open circuit) one of all current sharing pairs of high wattage resistors and/or coils connected in parallel
- S/C audio output connections
- S/C deflection coils (if employed)
- S/C across any two junctions of high power semiconductors
- S/C across parts of bridge rectifiers
- S/C the output of power supply units
- S/C output connections of transformers.

| Part | Permissible temperature rise (°C) | |
|---|---|---|
| | Normal operating | Fault conditions |
| **Accessible parts: Knobs, handles, etc.** | | |
| **Metallic** | 30 | 65 |
| **Non-metallic** | 50 | 65 |
| **Metallic enclosures** | 40 | 65 |
| **Non-metallic enclosures** | 60 | 65 |
| ***Electrical insulators*** | | |
| **Supply cords and wiring not under mechanical stress** | 60 | 100 |
| **Printed circuit boards (depending on the type used)** | 85~120 | 110~150 |
| **Moldings (depending on the type used)** | 95~110 | 130~150 |
| **Support parts and mechanical barriers (wood and wood-based material)** | 60 | 90 |
| **Transformer winding wires (depending on type of insulation)** | 55~145 | 75~180 |

*Table 4.4 Some typical maximum permissible temperature rises*

Following each simulated test, the equipment must remain safe within the context of the standard; i.e. there must be no increased risk of electric shock, fire or mechanical hazard. In addition to overheating due to electrical component failure, other common abnormal (simulated) tests should include:

- blocked vents
- stalled fan motors
- paper jam (copiers).

Protection against excessive temperature rise and overheating in fault (or simulated fault) condition is usually provided by a total interruption of the supplied power to the equipment by employing devices such as:

- fusible links
- thermal cut-outs
- fuses
- circuit breakers.

Some typical maximum permissible temperature rises (above ambient) under normal operating and fault conditions arc given in Table 4.4, taken from BS EN 60065: 1994.

Built-in components, plugs, sockets and internal wires will have individual operating temperature requirements: these will either be marked on the component or indicated in the manufacturer's instructions - care must be taken in the design and assembly of the product so that they are not exceeded.

The values of permissible temperature rise will depend greatly on the product, the applicable standard, the environment of use (e.g. in high or low humidity location), the class of the insulating material used, the construction of the product and other factors.

Each standard will quote different values and it is up to the manufacturer to confirm that these values are not exceeded - not only during normal operation, but also throughout the assembly process (e.g. soldering), and under abnormal (fault) conditions. Only then can a decision be made as to whether the product is safe for release to the market.

## 4.10 Dielectric strength

Dielectric withstand tests are applied to all products in order to evaluate the efficiency of their electrical insulation. Also, the equipment under test must not become unsafe due to the humidity conditions which may occur in normal use and cause hygroscopic insulation to break down.

A typical test method would be to place the equipment in an environ-mental chamber for 48 hours at a typical temperature of 30°C, and 90-95% relative humidity (RH). This would be increased to 40°C for up to 7 days (same RH) for equipment that will be used in tropical conditions. Immediately upon completion of the humidity treatment, a (mains frequency) AC test voltage of a substantially sine wave form, or a DC test voltage or a combination of both with peak value as specified in the standard (e.g. 3 kV rms for a Class II product) is applied for 1 minute across:

• the mains poles of the power supply - usually by connecting the poles at the mains plug (joined together)

• accessible metal parts and/or input or output terminals (e.g. for the connection of peripheral equipment).

During the test, mains and functional switches should be placed in the 'on' position. No flashover or breakdown should occur.

Not all standards require preconditioning of the product before applying this test. Test voltage levels will vary for each product category some typical values applicable for most products are given in Table 4.5. In addition to initial approval testing, this test should be applied 100% to all finished products before dispatch.

The type test, which overstrains the insulation, is performed for a duration of 60 seconds, while the production test is performed for a minimum of 1 second.

| **Point of application of test voltage** | **Test voltage (V rms)** | | |
|---|---|---|---|
| | **Class I** | **Class II** | **Class III** |
| **Between life parts and the body (if metal)** | 1250 | 3750 | 500 |
| **Between life parts and other inaccessible metal parts** | - | 1250 | - |
| **Between inaccessible metal parts and the body (if metal)** | - | 2500 | - |

*Table 4.5 Dielectric strength test voltages*

## 4.11 Insulation resistance

The insulation resistance is measured at no less than 250 V AC or DC. Typically, a voltage of 500 V DC is applied. Some typical test points and insulation resistance values are given in Table 4.6.

In practice, the insulation resistance measurements are expected to be much higher than the values quoted above and accordingly the manufacturer's own rejection criteria should reflect this.

| Insulation to be tested | Minimum insulation resistance (MΩ) |
|---|---|
| **Between mains poles of supply** | 2 |
| **Between mains poles of supply and accessible parts and terminals** | 4 |
| **Between live parts and earthed accessible metal on Class I equipment** | 2 |
| **Between live part sand functionally insulated metal parts on Class II equipment** | 2 |
| **Between functionally insulated metal parts on the body of Class II equipment** | 5 |
| **Between live parts and metal parts on the body of Class II equipment** | 7 |

*Table 4.6 Typical insulation resistance values*

## 4.12 Earth leakage current

Excessive current flow may be hazardous to an operator. Under fault conditions (e.g. loss of protective earth, reversed polarity of the AC mains), the chassis may assume hazardous potentials and excessive leakage currents will inevitably occur. The test for earth leakage current is applied as per the method described in the applicable standard, the test voltage usually is:

• 1.06 times the rated voltage or 1.06 times the upper limit of the rated voltage range if the rated voltage or upper limit of the rated range does not exceed 250 V. This applies to equipment operating (within this limit) on DC only, single-phase DC only and for equipment which has the capability of running on both single and three phase supply.

• 1.06 times the rated voltage or 1.06 times the upper limit of the rated voltage range. divided by 1.732.

The leakage current is measured within 5 seconds after the application of the test voltage. Some typical values of maximum leakage currents are given below:

| | |
|---|---|
| All Class II equipment | 0.25 mA |
| Portable Class I equipment | 0.75 mA |
| Stationary Class 1 equipment with healing elements which are detachable or can be switched off separately | 0.75 mA/kW (5 mA max.) |
| Stationary Class I equipment | 0.75 mA/kW (5 mA max.) |
| Movable Class I equipment | 3.5 mA |
| All Class II equipment | 0.25mA |

## 4.13 Measurement and measurement equipment

Most of the tests described so far in this chapter can be carried out in-house and without major expense to the manufacturer. However, for a manufacturer to self-declare compliance with a product specific standard, an in-depth knowledge of the requirements, the adequate competence of testing engineers, and the use of accurate and calibrated instruments will be essential.

When measuring parameters such as temperature and distance, calibrated instruments with known measurement uncertainties must be used. Although the uncertainties may seem small, they can possibly make the difference between compliance and non-compliance. For example, a temperature rise measured at 58°C or more using a system with a measurement uncertainty of 3°C, should be declared to fail to comply with a requirement for a maximum permissible temperature rise of 60°C.

When designing products, it is advisable to allow comfortable margins distances (creepage and clearance), and maximum permissible temperatures. When applying fixes for safety, the designer must not overlook the following:

- the customer's expectations of the product
- the electromagnetic compatibility requirements (and how design issues impact upon compliance)
- the reliability of components (many components, equipment and controls are required to undergo an endurance test).

By using high accuracy, regularly calibrated (traceable to National standards and covering the range of use) measuring instruments, a manufacturer can have confidence in the results of confirmation tests.

## 4.14 Protection of service personnel

Special consideration is necessary where equipment is of such size and complexity that it may be necessary for service personnel to reach over, under or around uninsulated electrical or moving parts. In such cases, all parts providing risk of entrapment or high energy electrical shock should be placed so that contact or bridging is unlikely. Components such as capacitors placed in the mains circuit must either discharge to less than 50 volts in a very short time (typically within 1 second) or be marked with a warning label. Similarly, parts that would normally be expected to be at ground potential but actually are not, must also bear warning labels.

## 4.15 Other hazards

### 4.15.1 Spillage

If in normal use liquid is likely to be spilt into the equipment, the equipment should be designed so that no hazard will occur, e.g. as a result of the wetting of the insulation or of internal uninsulated parts which are live.

### 4.15.2 Overflow

Liquid overflowing from containers in the equipment (due to overfilling) should not cause a hazard during normal use - e.g. as a result of the wetting of the insulation or of uninsulated live parts. Similarly, equipment that is likely to be moved while a container is full of liquid should be protected against liquid surging out from the container.

### 4.15.3 Liquid leakage

Equipment should be designed so that liquids leaking from containers, hoses, couplings, seals, etc., do not cause a hazard — e.g. as a result of wetting of the insulation or of uninsulated live parts.

### 4.15.4 X-rays and cathode-ray tubes (CRTs) for TV and computer monitors

CRTs imply hazards from X-radiation and implosion. They must be of an approved type and tested in dedicated facilities. Twelve samples are tested in total (half after having undergone an ageing process). CRTs are tested for:

• Mechanical strength — impact from a hardened steel ball dropped from a height.

• Implosion — an area is scratched with a diamond stylus then cooled with liquid nitrogen until a fracture occurs.

• Ionizing radiation — the equipment's controls are adjusted to give maximum radiation while maintaining an intelligible picture. Radiation measurements are made after 1 hour.

### 4.15.5 Ultraviolet radiation

Equipment containing a UV light source, but which is not designed to provide external UV illumination, should not permit the unintentional escape of UV radiation that would be harmful to the operator.

### 4.15.6 Microwave radiation

Unintentional microwave radiation should not exceed safe limits (as given in the relevant product standards) in the vicinity of the equipment. In addition to the above, consideration must also be given to the effects of:

- sound pressure
- ultrasound pressure
- laser sources
- liberation of poisonous gases
- explosion and implosion.

## 4.16 Labels

Mast standards require that where danger exists, warning and caution labels be fitted to the product. Words such as DANGER, WARNING and CAUTION are to be of sufficient height and should not be placed on parts likely to be discarded.

External labels should be placed where they can be easily seen when the equipment is in its normal operating condition; labels inside doors, covers, etc. are allowed if easily opened.

Voltage and current ratings of every fuse must be marked adjacent the fuse, and a caution label added advising that only the same type of fuse should be used as a replacement. It is advisable that the exact marking a, indicated on the fuse is also placed on the caution label. If an IEC 127 fuse is used the fuse will be marked as per the example shown below:

T 5A L 250 V

The first letter or color band indicates the fuse characteristics:

T: Time-lag or Blue

TT: Long time-lag or Grey

M: Medium time-lag or Yellow

F: Quick acting or Red

FF: Very quick acting or Black

5A: current rating

L: Indicates low breaking capacity (usually glass fuse body)

H: indicate high breaking capacity (usually ceramic fuse body)

In addition to the fuse caution label, warnings are also required where:

• hot surfaces may come in contact with the operator or with service personnel

• direct plug-in units are required but not supplied

• capacitors which may hold charge could come in contact with service personnel — the warning should advise how they are to be discharged

• X-ray or other hazards (e.g. laser) may exist

• chemicals are used

• there are residual mechanical hazards.

In addition to the above (warnings to the operator), it is reasonable to warn service personnel:

• to isolate the power before removing covers if live parts will be exposed

• which parts of the equipment contain hazardous voltages.

Service personnel will make certain assumptions when maintenance or repair work is carried out. These will include:

• unmarked metalwork and components are sale to handle

• fans hidden within the equipment will be fitted with fingerguards

• any lifting operation will require only one person

• mechanical parts will not move and thereby cause risk of injury

• laser or other radiation is not present.

If any of the above conditions are not true, additional warnings will be necessary.

*Note: It is very important that safety measures be designed into the product. Reliance on operator warnings should be avoided wherever possible by (instead) ensuring that service operations (particularly when within the capability of the operator) are inherently safe. Safety interlocks which automatically interrupt power supplies, for example, are clearly preferable to labels advising the presence of high voltages if covers are removed or doors opened. Where warning labels are essential, they must of course be clear, and written in the appropriate language for the country or countries to which the product will be supplied.*

## 4.17 Markings

All markings and labels used should be indelible, legible, and placed on the exterior of the unit (excluding the bottom). The type identification marking (nameplate) should contain the following information:

• Manufacturer's (or responsible vendor's) name or trademark.

• Model number (or model name) and serial number.

• Symbol of the nature of supply, e.g. ~ for AC power supply (1).

• Rated operating voltage or voltage range (2).

• Rated maximum power in watts (W) or volt-amperes (VA) or rated current (A or mA).

• Rated frequency or range of frequencies (3).

• Warning of the presence of hazardous voltage inside and advice to the operator that only qualified personnel should access the inside of the equipment.

• Safety agency approval marks, e.g. (if applicable) the CE Marking.

• Warning of possible presence of high leakage currents (for fixed equipment).

• The double square symbol for Class II equipment ⧈.

Voltage rating may be indicated as:

• ~ or AC for alternating current supply

• ⎓ or DC for direct current supply

• 3~ for three-phase AC supply

• no marking is necessary if the equipment operates with either AC or per the examples DC supply.

The rated operating voltage can be indicated as below:

• 110V-240 V, if there is no need for voltage adjustment

• 115 V/230 V, if adjustment is necessary.

The equipment's operating frequency range can be marked as:

• 50Hz-60 Hz, if there is no need for adjustment.

• 5011460 Hz, if frequency adjustment is necessary.

Safety warning indications on the model name label should always be given in the language of the country of use.

A simple test for ensuring the durability of the rating label is to rub the label lightly for 15 seconds with a cloth soaked in water, then (in a different place) with a cloth soaked in petroleum spirit — the information on the label should remain legible in both locations, without the edges or corners curling up.

## 4.18 User instructions

Most equipment and products require instructions for use. All Class I and Class II equipment must be accompanied by user instructions detailing the method or steps necessary for connection to the supply. For Class I equipment an additional warning is necessary, i.e.:

***WARNING** — This appliance must be earthed*

Information necessary for the safe operation of the product could include:

- advice on the need for an RCD in connecting the equipment to the mains supply
- warnings regarding hazardous moving parts
- warnings regarding the presence of ultraviolet or infrared lamps
- installation instructions such as clearances for equipment to be fixed to the wall or onto the floor, etc.

User instructions must be simple to follow and be written in the native language of the user. Attention must be paid to translation if the equipment is to be marketed in many countries — a phrase in one language may mean something else in another!

It is clearly desirable, therefore, that the translation work be done by a native of each country in which the product will be sold. The preparation and supply of user instructions is an invariable requirement of almost all safety standards, and their content and accuracy will be scrutinized as part of the evaluation process when products are submitted for testing to a third party.

Instructions for use should also include a repeat of all warning labels place on the equipment with an explanation of how to minimize the risk.

## 5.Literature


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