Set of guidelines for conceptual design focusing on electrical safety of refrigerators

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Abstract: Very often, within Brazilian companies product design procedures, the verification and the product approval, considering the defined requirements stated at the beginning of the project, occur only in the late stages of product development just before starting the production. Therefore, any problem originated from non-conformities to the design requirements specification is only informed to the design team too late in the development process causing several hindrances from cost and schedule point of view. The aim of this research is to propose a set of guidelines for electrical safety in order to be applied during the conceptual design stage of domestic refrigerators supporting the product development team to take decisions for defining the conceptual solutions that comply with the design requirements from the beginning of the project statement. The aim of this research is to provide an approach that allows to reduce the reworks during and, mainly, at the final stages of the product development process. Thus, it is expected that the dimensioned and developed design solution will increase its likelihood of being approved in the final evaluation.

Keywords: electrical safety, design guidelines, household appliances.

1. Introduction

With the constant increment in the exportation of electro-electronics products, the need for the Brazilian goods to comply with the global market requirements is evident. Amongst several of them, the compliance with electrical safety requirements is usually mandatory.

The electrical safety in home appliances is a requirement that companies that trade in the global market cannot afford to mismatch. The demand for exporting in order to remain competitive has obliged Brazilian companies to redesign and improve their products portfolio, not only to observe internal regulations and satisfy local customers, but also to conform to international standards on electrical safety.

The international standards, countries regulations and companies' policies related to electrical safety are, generally speaking, complex and numberless. Somehow, the design teams must analyse and implement them into products, when the development process takes place.

This paper aims at describing a proposed set of guidelines that addresses electrical safety to be consulted during the conceptual design phase of domestic refrigerators. With the help of these guidelines at the conceptual design stage, it is envisaged to mitigate or, at least, minimize injuries and risks to the health of the final customers, as mentioned by Hammer (1993). Additionally, if an electrical safety requirement is not implemented into a product, collateral damages can be induced, such as: material losses due to an accident, customer dissatisfaction with the product and company, amongst others.

This research has been conducted considering a field study in a company that is leader and reference in manufacturing refrigerators. Their products and procedures have been thoroughly studied.

The case study to verify the suitability of those proposed guidelines has been carried out within the mentioned company, considering its scope and design team.

The framework of this paper is organized in five sections. Section 2 presents the front end of the product process development and discusses the importance of product requirements definition. Section 3 describes the model proposed and the guidelines devised. The model assessment, based on an experimental application, is

shown in section 4. Finally, the concluding remarks are provided in section 5.

2. Product development process and product requirements

2.1. Product development

With the constant increment in the international competition, reduction in the products lifecycle, fast technological changes and strict customer demands, to correctly approach the product development process is essential for companies' survival. Additionally, they should master this process for providing a difference to their products, since quality and price are already taken for granted.

Literature provides several sources for describing the product development process, such as: (PAHL; BEITZ, 1996), (ROZENFELD et al., 2005), (CROSS, 2000), (ULRICH; EPPINGER, 1995), (OTTO; WOOD, 2001). Usually, they contemplate the whole product lifecycle development, involving from product planning to propose an adequate means for disposing the product. One of the crucial stages in this process is the conceptual design, which will be discussed briefly in the next section.

2.2. Conceptual Design

It is during conceptual design, that the transformation of product specifications (derived from product requirements that should reflect the customer demands) into a viable product concept. This stage requires from the design team: i) critical thought; ii) innovative ideas; iii) formulation of creative questions and generation of suitable answers; iv) clear and thorough understanding of systems functions; and v) focus on the customer.

According to Pahl and Beitz (1996), the conceptual design defines a solution principle for a design problem, which can be resulted from following the specific steps. Thus, this stage should contemplate the identification of essential problems with its correspondent translation into a set of function and sub-functions. Next, the search for solution principles for each function should be conducted, allowing the combination of them in several concepts (according to PUGH, 1991), the highest the number of concepts, the better. Closing this stage, the alternative with the best potential, considering technical and economic criteria, should be elicited to advance to the embodiment stage.

Ullman (1997) advocates that a conceptual design ill defined can impact negatively in the product's final cost, schedule accomplishment and customer's demands fulfillment.

Once a potential alternative solution is identified and chosen, the embodiment design takes place. At this stage, it is usual that the design team would consult a set of guidelines in order to ensure consistency to the constructive structure that reflects the conceptual solution defined.

Next section encompasses a brief examination on the guidelines themes.

2.3. Guidelines: an overview

2.3.1. Introduction

Guidelines can be defined as means to orient, conduct or direct the course of action, based on a model that represents a specific situation. Their main aim is to provide support to a designer (or design team) when facing a decision making process.

There are several applications that can use guidelines (e.g. guidelines to search specific subjects, guidelines for assembling and disassembling devices, amongst others). The main advantage of their use is saving time, since the information is arranged in such a way that the user can easily detect the subject aimed.

In the design arena, the guidelines are usually employed after the conceptual design phase is finished, thus providing support to the design team only when the conceptual solution is defined. This is a gap identified on the existing guidelines. This research addresses this limitation and seeks to develop a set of guidelines to support the conceptual design stage when developing a new product.

2.3.2. Existing models for guidelines

The literature review allows identifying several design guidelines related to product development that can be consulted for structuring the aimed approach. This section describes briefly types of guidelines, their characteristic and differences.

According to Pahl and Beitz (1996), the guideline shown in Figure 1, presents a set of recommendations to address specific requirements when considering the manufacturing process of cold extrusion. The drawings enclosed should be consulted by the design team when taking decisions during the embodiment design. Additionally, the guideline indicates the process stage addressed (i.e. To = tooling; Ex = extrusion) and the objectives intended (i.e. Q = quality improvement; C = Cost reduction).

Another approach to present a design guideline is proposed by Davis (2001) and can be seen in Figure 2. In this case, a text briefly describes the context considered. The text is supported by a set of figures and diagrams which must be enough to clarify the main issues on the subject.

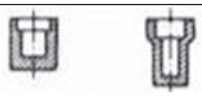
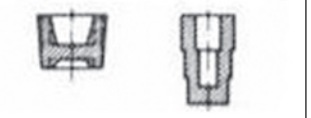
PS	Guidelines	Objective	Wrong	Right
To Ex.	Avoid undercuts	Q C		
Ex.	Avoid tapers and excessively small diameter differences	Q		
Ex.	Provide rotationally symmetrical parts without material protrusions, otherwise split and join	Q		
Ex.	Avoid sharp changes in coss section, sharp edges and fillets	Q		
Ex.	Avoid small, long or lateral holes and thread	Q		

Figure 1. Design guidelines for components manufactured employing cold extrusion, according to Pahl and Beitz (1996).

There are also guidelines that are uniquely descriptive. An example is presented in Table 1, where a set of design requirements should be observed considering the safety issues.

From the guidelines described it is possible to summarize their characteristics and differences as shown in Table 2.

2.3.3. Guidelines critical analysis

The examined guidelines present several limitations which highlights the need to devise a better mechanism to provide reference material to be consulted by the product development team, mainly during conceptual design stage.

- when considering the design development of domestic refrigerators the electrical safety aspects are on high demand. It has been observed that a guideline to address this issue during conceptual design is relevant because:
- the inexistence of a guideline for electrical safety focused on domestic refrigerators;
- the available guidelines are designed to be used after conceptual design stage is finished;
- in certain guidelines, the information is confuse and can lead to misunderstandings;
- there are several guidelines that are superficial and with unclear information;
- usually, the information is generic and out of focus; and

"An example of this type of problem can be seen in Figure 1b. Diagram 1 illustrates what could happen if the two individual connectors were used to assemble the terminals very closely. An adequate distance (X) on the connection points can be reduced to the dimension (Y) (which is below the minimum required for this type of connection). In this kind of situation, a well conducted test would depend of a very rigorous quality control. Thus, diagram 2 presents the result of the connectors placed in a alignment within an insulator. The dimension (X) is respected for this assembly. The advantages of using plugs and pre-formed sockets are well documented."

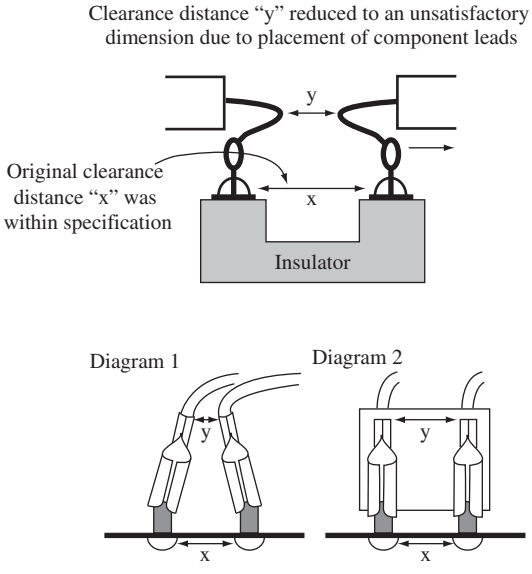


Figure 2. Design guidelines for setting the separation distance. Source: adapted from Davis (2001).

- in several cases, they do not present the reasons for providing the orientation inside the guideline, neither the approval criteria, once the recommendation is followed.

Therefore, considering that: i) the importance of using guidelines during product design has been identified and well documented; ii) the available guidelines present certain limitations, as described; iii) the domestic refrigerator, as a product, is highly regulated by international standards and laws; iv) the electric safety of domestic refrigerators is one of the most important issues to be addressed during the product development; and v) the inexistence of guidelines that can be used during conceptual design; next section presents a model for producing guidelines that can be consulted during the conceptual design stage.

Table 1. Guidelines for safety requirements, in a descriptive form.

Item	Requirement
1	Ensure that the design is safe with respect to the actions of gravity and balance
2	Ensure that the design and operation procedures are safe with respect to the maintenance of high energy springs
3	Ensure that a wrong assembly of components, that can cause accidents, is avoided
4	Ensure that the design and operation procedures are safe with respect to the maintenance of elements related to electricity and high pressure fluids
5	Ensure that the design depicts safety during periodical inspection activities by suitable accessibility and visibility

3. Model for devising guidelines focused on electrical safety

3.1. Introduction

The variety and number of electric safety requirements are large and are originated from several sources. Thus, the first stage in this work involved to search for diverse requirement structures and classify them into two basic categories: i) internal requirements: this encompasses those requirements derived from company's internal standards and procedures. Additionally, best practices and formal expertise (design history and time to develop a product) are considered; and ii) external requirements (since they come from outside the company): these are related to the legal demands and international standards, as well as those examples extracted from literature.

3.2. Companies internal requirements

3.2.1. Internal standards

The majority of companies produce requirements that are described in internal technical documents, to complement those that are obtained/demanded externally. These requirements are, usually, related to the application of specific components in a product that is being developed and is particular to the manufacturer.

The examined company, object of this study, complies with several internal standards. Amongst them, there are those related to the electric safety (see an example in Table 3).

Usually, the verification of compliance with these requirements occurs at the end of the development stage,

Table 2. Comparison amongst the types of guidelines studied.

Proposed by guideline	Advantages	Disadvantages
Pahl and Beitz (1996)	Uses examples	It is limited to an example that is correct and the other one, which is incorrect
	Presents the right and the wrong approach to fulfill a specific requirement	
	Provides drawings to illustrate the examples	Provides a superficial overview, without details
	Requirements are stated simply and objectively	
	Association between objectives based on references	
Davis (2001)	Uses examples	It is limited to an example that is correct and the other one, which is incorrect
	Presents the right and the wrong approach to fulfill a specific requirement	
	Provides drawings to illustrate the examples	
	Detailed requirement description	
Dhillon (1996)	Not identified	Generic and superficial
		Without examples
		Without graphic representation (drawings)

when the product presents conditions to be validated (i.e. tools have been defined and the final components are specified).

From Table 3, the following advantages of using internal requirements can be envisaged: i) specific rules considering a defined topic; and ii) formal statement what has to be accomplished. On the other hand, the next limitations can be observed: i) the requirements are based in tests; ii) a physical product/prototype is needed for checking the requirements compliance; iii) the assessment is conducted after ending the design phase; iv) difficulties in understanding "what should be examined during design" to implement the requirement; v) the internal requirement can be interpreted in different ways; and vi) usually, these internal requirements are described in textual form, without drawings, tables and graphs (that could help in interpreting them).

3.2.2. Practices adopted

As times goes by, companies have acquired expertise on how to deliver safe products, which has led to the development of customized methodologies, standard procedures and formal methods. The success in their use usually depends on the experience of the personnel involved in the development activities.

This section describes a guideline that has been elaborated in the studied company, after years of developing and producing refrigerators. This guideline is used for assessing the electric safety of a product during its development and just before its production starts. The approach is based on a set of questions divided into themes related to the systems and product's cycle of use. The results of this preliminary assessment can be found in Table 4.

Table 5 presents an excerpt of an approach that is available within the studied company to address electric safety. In this case, again it is possible to foresee advantages, which are: i) topic segmentation; ii) formalization of what should be achieved; iii) defined criteria for approval; iv) checklist format; and v) a proposed sequence for performing the assessment. However, the following disadvantages are depicted: i) there are topics based in tests, which demand the existence of a product or prototype; ii) there are limitations to perform the assessment during conceptual design; and iii) the topics are described using the questions format, without providing drawings and graphs to help the interpretation.

Table 3. Examples of internal requirements, as defined by the documents of the studied company.

Standard	Checking approach	Objective
Standard A	Test with knife probe	To verify if the knife* probe can contact the alive parts either without the need of removing non-detachable parts or removing those parts.
Standard B	Test with choke tube	To verify if detachable parts, without use of any tool, can enter inside a choke tube**.
Standard C	Analysis of forced failure	To verify is the electric connections, after starting the combustion process, propagates fire outside the product. Additionally, it is verified if the fire is contained inside the product until is completely extinguished

*Knife probe: this is an object that simulates a knife of normal use (i.e. dimensions, and features) and its used for testing; and **Choke tube: this device simulates a children throat (i.e. dimensions, format) and its used for testing.

3.3. External requirements

3.3.1. Laws and standards

Nowadays, there are several laws and standards ruling the electric safety of small appliances (where the domestic refrigerators are included). These standards are closely related to the countries demands where the product is going to be marketed.

Table 6 presents the standards that focus on household refrigerators and freezers and are observed during product development by the examined company.

Table 7 presents an excerpt of some electric safety requirements based on Standards managed by the International Electrotechnical Commission (IEC). These standards are largely employed by the studied company when developing their products.

Table 8 contains the available levels of approval that can be found in the IEC Standards which should be applied accordingly.

Based on the examples of requirements shown in Table 7 the following advantages can be depicted: i) pecific standard for a subject; ii) formal declaration of what should

Table 4. Levels of approval, considering the adopted practices in the studied company.

Symbol	Meaning	Description
AC	Acceptable	The proposed design is acceptable for production
AR	Required action	The approval is conditional. The product is acceptable as being safe, however, additional actions to confirm the initial observation have to be taken
U	Not acceptable	The production of the proposed design cannot be started
NA	Not applicable	The requirement is not applicable to the examined product

Table 5. Excerpt of requirements that represent the practices adopted by the studied company.

Topic	General risks	Status
Installation	The grounding is adequated to the available conditions?	
	Is there a possibility to revert the polarity?	
	Is there a protection device against electric surge?	
	Is there an electric extension available?	
Customer exposition	Is the customer exposed to electric elements?	
	Is there access to alive parts with the standard knife?	
	Are there slots in the panel that allow access to electric contacts during the usual product operation?	
	Can the existent barriers be removed without tools, so the electric contacts can be accessed?	
	Can condensation cause loss of current?	
	Can the changing of light bulbs be conducted safely by the final user?	
	Can the cleaning be conducted safely by the final user?	
	Is there any loss of current when performing cleaning with and without buttons, contactors and other removable parts?	
	Is it possible to reinstall incorrectly any of those removable parts after cleaning?	
Improper use	Is the product safe even when the customer does not follow the correct sequence of operation?	
	Is the product safe even when the customer uses in adequately the controls?	
	and so on	

Table 6. International standards observed by the studied company.

Standard	Title	Market addressed
IEC 60335-1	Household and similar electrical appliances -Safety – Part 1: general requirements	International
IEC 60335-2-24	Household and similar electrical appliances – Safety – Part 2 - 24: Particular requirements for refrigerating appliances	International
EN 60335-1	Household and similar electrical appliances -Safety – Part 1: general requirements	Europe
EN 60335-2-24	Household and similar electrical appliances – Safety – Part 2 - 24: Particular requirements for refrigerating appliances	Europe
NZ/AS 60335-1	Household and similar electrical appliances -Safety – Part 1: general requirements	New Zealand and Australia
NZ/AS 60335-2-24	Household and similar electrical appliances – Safety – Part 2 - 24: Particular requirements for refrigerating appliances	New Zealand and Australia
UL 250	Standard for safety Household refrigerators and freezers	The United States

Table 7. Excerpt of electric safety requirements from IEC standards.

Clause	Requirement	Result	Veredict
8	Protection to avoid access to alive parts		
8.1	Adequate protection to avoid accidental contact to alive parts		
8.1.1	The requirement can be mapped to all positions and removed detachable parts		
	Insertion or remotion of light bulbs. Protection to avoid contact with alive parts of light bulbs		
	To use the test device B from IEC61032: without contact with “alive” parts		
8.1.2	To use the test device 13 from IEC61032, between the gap sin domestic households class 0 and apparells/construction class: without contact with alive parts		
and so on			

be accomplished. On the other hand, the weak points identified are: i) most of requirements are based on tests; ii) a physical product is needed to conduct the assessment; iii) the assessment is conducted after the design is finished; iv) difficulties to understand how to implement the requirement into the product; v) several interpretations can occur; and vi) textual description, without drawings, tables and graphs to improve the standard understanding.

3.3.2. Electric safety guidelines: points of view

There are several design guidelines available in literature (PAHL; BEITZ, 1996; DAVIS, 2001; DHILON, 1996; HAMMER, 1993).

Table 8. Levels of approval available for the IEC Standards.

Symbol	Meaning	Description
P	Pass	The proposed design fulfills the requirement
F	Fail	The proposed design does not fulfill the requirement
NA	Not applicable	The requirement does not apply to the product

Amongst those guidelines explored by Hammer (1993), which can be employed during product development, a careful analysis on the one related to electric safety was conducted (Table 9). The main characteristic of this guideline is a sequence of questions that have to be manifested during the product development.

3.4. Proposed guideline focusing on electric safety

3.4.1. Introduction

The need to develop a guideline for electric safety in household refrigerators that can be applied during the conceptual design stage has been identified and documented.

Nowadays, there are several difficulties in using those guidelines available in the studied company as well as in the literature, standards and best practices (Table 10).

Therefore, it is identified an opportunity to develop a set of guidelines that minimize these limitations and can offer to the design team the needed information during conceptual design of household refrigerators. With these guidelines it is expected:

Table 9. Requirements to electric safety, according to Hammer (1993).

Item	Requirement
a	The levels of tension and current are sufficient to cause damage due to electric surge?
b	Is there any point where a person can touch a exposed wire when the product is plugged?
c	Is a double insulation for an electric tool or household employed instead of a grounding system?
d	How long does it take for a capacitive circuit to discharge? Is there any specific advice signalling this effect?
e	Are there means for disconnecting the energy power when a component repair or substitution is being conducted?
f	The product and its components are carefully grounded?
g	Is there a mechanism to unplug the energy when someone has access to the inner part of a product and could be subjected to a electric surge?
h	Are the contacts, connectors and electric devices distributed with either barriers or insulation to protect someone that could touch them?
i	Are the wires and cables protected against pressing, cutting, friction or other risks that could damage the insulation?
j	Is the design of each connector well defined so the user will not have contact with alive parts when a normal unplugging occurs with the product energized?

Table 10. Drawbacks found in the available standards that work as guidelines.

Source	Parameter
External standards	Difficult interpretation
	Variety of standards
	Many times they are generic and scattered
	Usually, they are employed after the conceptual design stage
	Most of requirements are based on tests
	They need a physical product to perform the assessment
	Usually, they are presented in a textual form
Internal standards and adopted practices	Most of requirements are based on tests
	The assessment can be performed during the conceptual design stage, but only fulfills few requirements
	Use of questions without the help of drawing, schemas and graphs
	Absence of orientation to the design team on how to fulfill the requirement during conceptual design

- to minimize the chances of occurring problems during the development of household refrigerators;
- to reduce the rework activities that nowadays hinders the development process in the studied company;
- to fulfil the standards requirements when the validation process takes place;
- to induce the attitude on the design team of "doing right, from the first time" (i.e. from the conceptual design stage); and
- to produce formal requirements so anyone in the design team can consult the proposed guidelines.

To better understand the information presented in the proposed guidelines, the household refrigerator has been divided into subsystems that interface with electric components or elements, as shown in Figure 3.

In each subsystem there are electric components that are interconnected, where individually or when assembled, they should comply with the electric safety requirements. As illustrated in Table 11, each subsystem performs a function in the product. Additionally these subsystems contain several associated components.

To ensure that the final user does not have accidentally access to any part or component energized (i.e. manually or using any conventional object), which would lead to an unsafe situation, several kinds of barriers are devised to contain the mentioned electric components.

According to Cotrim (1992), it is very important to observe that a person is subjected to danger not only by touching an energized element (i.e. a direct contact with an alive part) or a mass under tension (indirect contact) but also when he/she touches a component that presents an electrical potential different from the reference one (i.e. the danger is derived from the difference of potential). As a general rule, the designers should consider that people can always touch components at their houses (e.g. floor or walls) that show a defined electrical potential (i.e. usually, the ground). Thus, any contact with an element in a different potential can be very dangerous.

The proposed guideline should orient the design team to address during the conceptual design stage which features these barriers should present. Moreover, validation tests can be suggested employing computational approaches. Finally, the guideline must contain all references (i.e. based on an international standards, literature or practices from the company) that supply detailed information to design team on the subject.

3.4.2. Fields for the proposed guideline and types of electrical protection

From the literature review and field research it has been observed that the proposed guidelines should contain a set of fields, as follow: i) form number; ii) brief description of the requirement to be fulfilled; iii) description of the parameters of the requirement, considering the customer; iv) drawing/sketch/schema presenting a potential solution that addresses the requirement adequately; v) Proposed test indication (that can validate the solution); vi) Source that supports the indication of the proposed test; vii) Brief description of the proposed test; and viii) Description of the approval

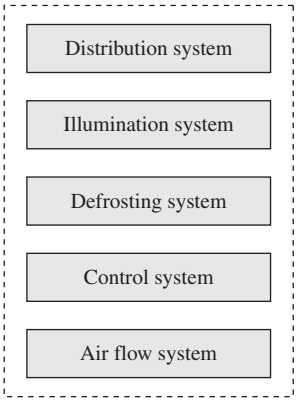


Figure 3. Diagram that shows the subsystems that integrate a household refrigerator.

Table 11. Household refrigerator subsystems functions and components.

System	Function	Associated components
Distribution	To interconnect the electric components and electronic controls. Additionally, it is responsible for supplying energy to the product	Supplying power cable
		Electric wires
		Connectors and terminals
Illumination	To supply light to the internal compartment of the product	Light bulb
		Light bulb connector
		Illumination box
Defrosting	To defrost periodically the ice as the product is used	Electric resistance
		Thermal fuse
Control	To manage the compressor and other electric components, as well as to receive and distribute information to the final user	Thermostat
		Electronic control
		Electronic interface
		Temperature sensor
Air flow	To manage and supply the air flow for a specific compartments and between the compartments	Electronic damper
		Motor-ventilator set

criteria for the proposed test. The distribution of these fields in the proposed guideline model can be seen in Figure 4.

Figure 5 presents an indication of different types of electrical protection that should be encompassed by the proposed set of guidelines.

From the considerations stated in the previous sections, it is possible to devise a structure that can define the profile of the proposed guideline, which will be addressed in the next section.

3.4.3. Proposed structure for the guideline for electric safety

The structure of the proposed guideline is shown in Figure 4. This layout has been devised in order to facilitate of consulting the information deployed. A set of nine different guidelines for electric safety has been instantiated following the structure presented in Figure 4. Table 12 contains a summary of each guideline proposed. This table can also be used to facilitate the process of consulting the set of guidelines during the process of developing a product, following the next steps:

- identify the contact type (i.e. direct or indirect) demanded by the solution being developed;
- identify what is the mean by which the contact with "alive" parts can occur (e.g. hands, tools, knife, other item);
- from the above information, identify the guideline number; and
- conduct a careful analysis of the solution depicted in the respective guideline.

Figure 6 contains an instance of a guideline (Guideline number 3, in this case). This guideline proposes a potential solution for fulfilling a requirement of electric safety (i.e. to protect the customers against accidental contact by a knife (or similar item) on existing electrical parts in a domestic refrigerator).

In this guideline it is possible to observe the following aspects:

- the solution proposed to fulfil the requirements consists of a physical barrier with openings in such a way that the distance between the "alive" part and a knife is enough to ensure the aimed safety;
- the gage for testing the openings (if they should exist in the final design) are clearly specified;
- a full overview of the testing procedures is provided. The source of the requirement (associated standard) and the approval criteria are well defined;
- an illustration that can be paralleled to the proposed solution is shown; and
- a general view to the development team of what should be accomplished during the conceptual design stage, observing the electric safety, is provided.

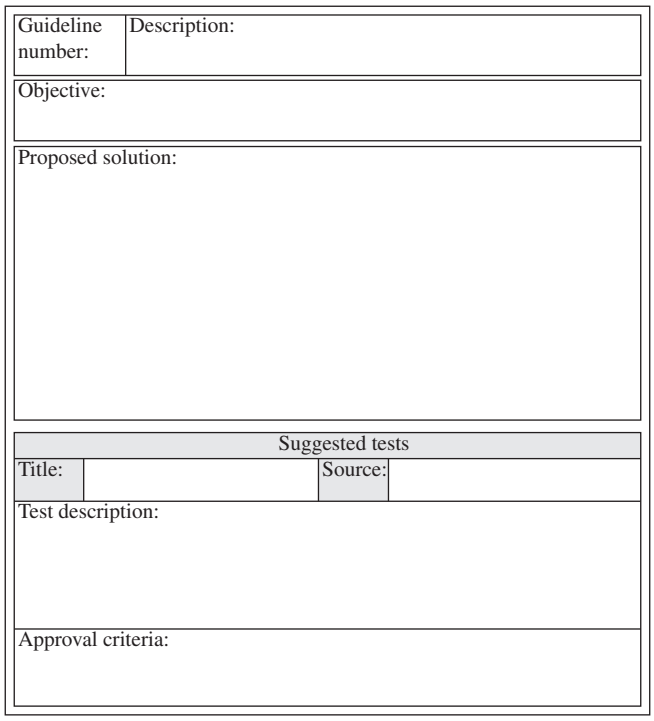


Figure 4. Structure for the proposed guideline.

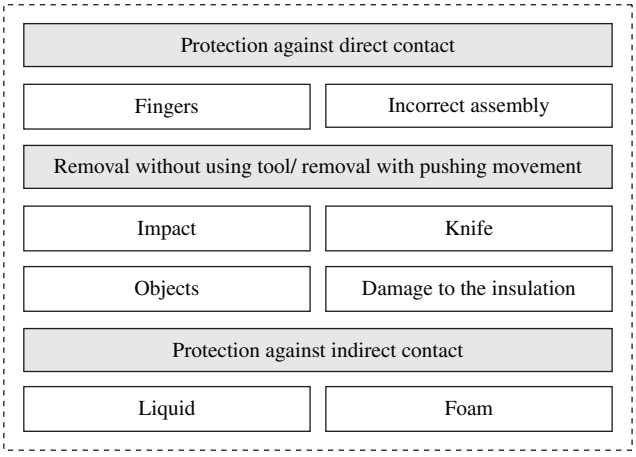


Figure 5. Types of protection that should avoid contact with electric parts and components.

The set with the remaining eight proposed guidelines can be found in the Appendix A.

Table 13 presents the improvements addressed by the proposed set of guidelines. Thus, it is envisaged that the proposed set of guidelines is capable of overcoming the identified limitations and can be a useful tool for the development team to focus on the electric safety of household appliances. Additionally, Table 13 signals which aspects should be addressed in further researches.

Table 12. General view of each of the nine guidelines proposed.

Number guideline	Description	Objective	Standard reference	Contact type
1	Provide suitable protection for “alive” parts against accidental contact	To protect the customers against accidental contact of their hands on existing electrical parts in a domestic refrigerator	IEC 60335-1	Direct
2	Provide suitable protection for “alive” parts against accidental contact	To protect the customers against accidental contact by tools (or similar items) on existing electrical parts in a domestic refrigerator	IEC 60335-1	Direct
3	Provide suitable protection for “alive” parts against accidental contact	To protect the customers against accidental contact by a knife (or similar item) on existing electrical parts in a domestic refrigerator	Internal standard	Direct
4	Provide suitable protection for “alive” parts against the entrance of liquid substances	To protect the customers against contact with energized parts due to the flow of liquid substances into “alive” parts	IEC 60335-1	Indirect
5	Provide suitable protection for “alive” parts against the entrance of liquid substances	To protect the customers against contact with energized parts due to the flow of foamy substances into “alive” parts	UL 250	Indirect
6	Design physical barriers for electric parts that can support impacts	To protect the customers against contact with “alive” parts due to the rupture by impact of the physical barriers	UL 250	Direct
7	Design physical barriers for electric parts that can only be removed by employing specified tools	To protect the customers against contact with “alive” parts due to the removal of physical barriers without using specified tools	IEC 60335-1	Direct
8	Design physical barriers for electric parts that do not damage the electric insulation	To protect the customers against contact with energized parts due to the damages caused to the insulation of cables and electric components, mainly during assembling /disassembling of physical barriers	IEC 60335-1	Direct
9	Design physical barriers for electric parts that cannot be assembled incorrectly	To protect the customers against contact with “alive” parts due to the access to these parts once the physical barriers have been assembled incorrectly	IEC 60335-1	Direct

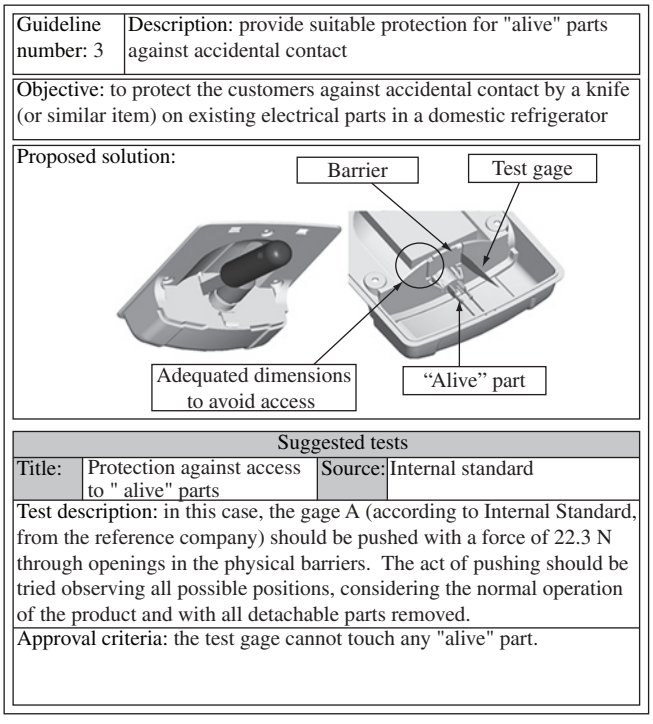


Figure 6. Guideline number 3.

In order to verify the usefulness of the proposed set of guidelines, a field assessment has been conducted and will be described in details in the next section.

4. Model assessment and obtained results

In order to verify the acceptance and efficiency of the set of proposed guidelines an assessment activity has been designed and implemented. Three experienced designers (i) product development analyst senior, with twenty-seven years of experience; ii) product designer, with ten years of experience; and iii) Product development analyst, with ten years of experience) that work in the examined company participated in the assessment. The main aim of the activity was to collect how the participant would rank the: i) importance of the proposed guidelines for their activity; ii) the clarity of the provided information in the guidelines; and iii) the usefulness of these guidelines for their daily activities.

The approach adopted consisted of:

- presenting a standard design scenario of a household refrigerator;

- a brief explanation on how to consult the set of guidelines; and
- a brief instruction on the procedures to fill the questionnaire.

The assessment occurred in a scheduled time, lasting up to four hours. After the activity, a questionnaire composed of 11 questions was applied. Figure 7 presents one of the questions included in the questionnaire.

4.1. Obtained results

The three participants in the assessment were able to easily to consult the guidelines provided (i.e. the time to produce the answer for the questions derived from the scenario was less than a minute). Additionally, the answers presented could be considered adequate (since different solutions could be generated). Considering the questionnaire, the three participants answered that they fully agree in more that 70% of the questions.

From the answers given it is possible to infer:

- the participants considered the set of guidelines simple and easy to understand;
- the use of guidelines during the conceptual design stage was well understood and accepted; and
- the participants, in written statements, showed strong will to employ the proposed guidelines for their product development activities.

Table 13. The addressing of identified limitations by the proposed set of guidelines.

Source	Limitations	Proposed set of guidelines
(PAHL; BEITZ, 1996) (DAVIS, 2001) (DHILLON, 1996)	There is not a specific set of guidelines that address electric safety in household appliances	↑
	The proposed guidelines are designed to be used after the conceptual design stage is completed	↑
	The information deployed by the available guidelines are very often confuse and provide multiple interpretation (generating doubts in its use)	↑
	In several cases, the guidelines present superficial content, without delivering the essential information to the development team	↑
	In most cases, the information are generic and it is not focused on a specific subject	↑
	Usually, they do not present the approval criteria (i.e. what would make the guideline recommendation to be acceptable) Additionally, usually the reasons for proposing the guideline are not clearly stated	↑
Internal standards provided by the company examined	The recommendations are only based in tests	→
	It is necessary to have a physical product to perform the tests	→
	The tests and assessments occur only at the final stages when the product is already consolidated	↑
	Difficulties to address the issue (and to accomplish the requirements) at the design stage	↑
	The standard can be interpreted in different ways	↑
	The standard description usually contains only texts (i.e. without drawings, graphs, tables), which causes difficulties during the consulting process	↑
Adopted practices	There are requirements that are dependent on tests. Thus, the physical product must exist to proceed the verification	→
	There are few requirements that can be checked during the conceptual design stage	↑
	Usually, the practices adopted frame the requirements via questions (i.e. inform of texts, without the help of drawings and schemas)	↑
External standards	The requirements verification is based on tests	→
	It is necessary to have a physical product to perform the tests	→
	The tests and assessments occur only at the final stages when the product is already consolidated	↑
	Difficulties to address the issue (and to accomplish the requirements) at the design stage	↑
	The standard can be interpreted in different ways	↑
	The standard description usually contains only texts (i.e. without drawings, graphs, tables), which causes difficulties during the consulting process	↑

Key	Description
↑	The proposed guideline overcomes the limitations identified
→	The proposed guideline partially addresses the limitations identified
↓	The proposed guideline does not addresses the limitations identified

Additionally, the participants also identified topics that must be addressed in further versions of the guidelines.

- the participants suggested to couple to the guidelines a form containing the terminology and the description of the meaning of the terms;
- the level of details in the drawings/ schemas should be increased; and
- from the customer point of view, the objective should be stated more clearly.

These preliminary results indicate that the proposed guidelines fulfil the objective state earlier in this work, which is to provide support for the design team during the conceptual design phase. The fact that the guidelines are addressed to a specific topic (i.e. design of household refrigerators) does not limit their usefulness. On the contrary, the gap identified during this important stage of the design process was carefully examined. The guideline structure is consistent and responds well to the demands of the design team.

5. Closing remarks

The evolution of Brazilian exports in the last years has been largely reported. Additionally, the need for the companies that manufacture household appliances to be apt to launch products that comply with electric safety standards has been recognized.

The importance of using guidelines during the product development process has been highlighted from those guidelines available in literature and in the examined company. It has been noticed that these guidelines are usually being used during the embodiment design stage, when the conceptual solution is already consolidated. Several times, this can mean rework and produce impacts on the lead-time and costs.

It has been observed the inexistence of guidelines that can be used during the conceptual design stage, mainly those related to the electric safety.

An extensive (but not exhaustive) review on the available literature has identified advantages of using guidelines during the product development process, but also has highlighted several limitations (e.g. usage late in the design process). Additionally, a careful study on the internal (company's) and external standards that regulate the electric safety issue has been structured. Finally, a field observation on the approaches employed by the design team when designing household refrigerators has been conducted.

A model and a set of nine instantiated guidelines that address electric safety on household appliances have been proposed, seeking to fulfil the weak aspects observed as well as respecting the elements already considered adequate to be framed in a guideline.

A preliminary assessment of the model and guidelines proposed indicate that they have the potential to be applied during the conceptual design stage, mainly for household refrigerators.

Finally, the participants were capable of mastering the use of these guidelines as well as they indicated topics that should be improved, what can be addressed in further researches.

3) The proposed guideline can help to prevent future problems with the product certification by regulation bodies?
( ) I disagree
( ) I partially agree
( ) I fully agree

Comments:

Figure 7. Excerpt of the questionnaire applied in the assessment activity.

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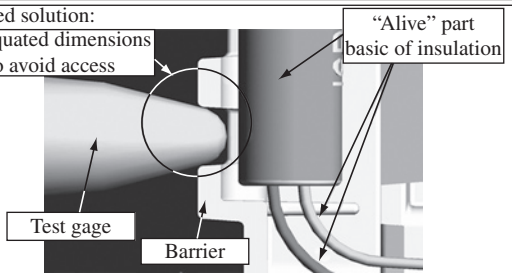
APPENDIX

Next, the eight guidelines that form the proposed set are illustrated. Usually, they are displayed in an A4 size. However, here for the sake of saving space they are presented scaled.

Guideline number: 1	Description: provide suitable protection for "alive" parts against accidental contact

Objective: to protect the customers against accidental contact by hand on existing electrical parts in a domestic refrigerator

Proposed solution:



Suggested tests			
Title:	Protection against access to "alive" parts	Source:	Internal standard

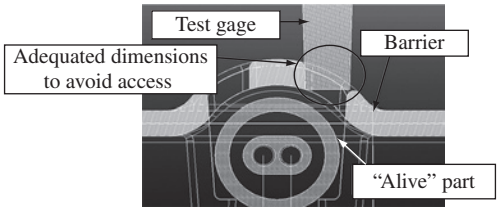
Test description: in this case, the gage B (according to IEC 61032) should be pushed with moderate force through the openings in the physical barriers. The act of pushing should be tried observing all possible positions, considering the normal operation of the product and with all detachable parts removed. When the gage cannot enter the openings the test should be conducted with a force of 20 N (minimum).

Approval criteria: the test gage cannot touch any "alive" part and the basic insulation.

Guideline number: 2	Description: provide suitable protection for "alive" parts against accidental contact

Objective: to protect the customers against accidental contact by tools (or similar item) on existing electrical parts in a domestic refrigerator

Proposed solution:



Suggested tests			
Title:	Protection against access to "alive" parts	Source:	IEC 60335-1

Test description: in this case, the gage recommended by test 13 (according to IEC 61032) should be pushed with moderate force through the openings in the physical barriers. The act of pushing should be tried observing all possible positions, considering the normal operation of the product and with all detachable parts removed. When the gage cannot enter the openings the test should be conducted with a force of 20 N (minimum).

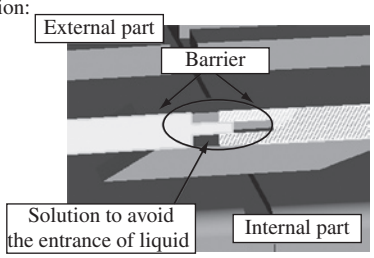
Approval criteria: the test gage cannot touch any "alive" part

Figure 1. Set of guidelines (part I).

Guideline number: 4	Description: provide suitable protection for "alive" parts against the entrance of liquid substances

Objective: to protect the customers against accidental contact with energized parts due to the flow of liquid substances into "alive" parts

Proposed solution:



Suggested tests			
Title:	Resistance to humidity	Source:	IEC 60335-1

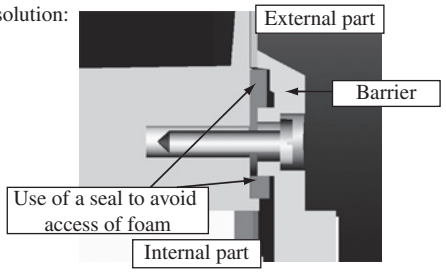
Test description: in this case, the test consist of dropping a container with water mixed with 1% of NaCl, during one minute. The detachable parts must be removed before the test is run.

Approval criteria: the household must support the test of dieletric stiffness. Additionally, no water signs should remain in the insulartest gage cannot touch any "alive" part.

Guideline number: 5	Description: provide suitable protection for "alive" parts against the entrance of foamy substances

Objective: to protect the customers against accidental contact with energized parts due to the flow of foamy substances into "alive" parts

Proposed solution:



Suggested tests			
Title:	Cleaning test	Source:	UL 250

Test description: in this case, the test consist of saturating a sponge of approximate size of 41.3 x 76.2 x 127.0 mm in a specified solution. After that, the sponge should be pressed six times, with a force varying from 8.9 to 13.4 N, against each barrier. The sponge must be resaturated after the third passage. The detachable parts must be removed before the test is run.

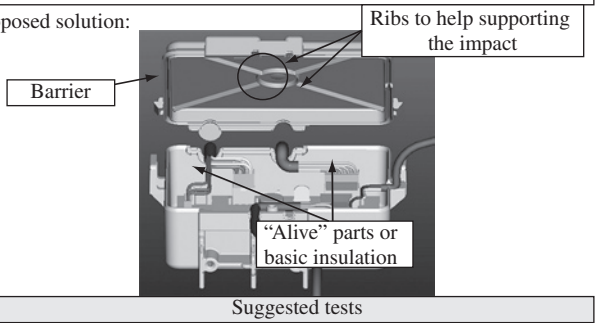
Approval criteria: the loss of current should not be higher than 0.5 mA.

Figure 2. Set of guidelines (part II).

Guideline number: 6	Description: design physical barriers for electric parts that can support impacts

Objective: to protect the customers against accidental contact with "alive" parts due to the rupture by impact of the physical barriers

Proposed solution:



Suggested tests			
Title:	Impact test	Source:	UL 250

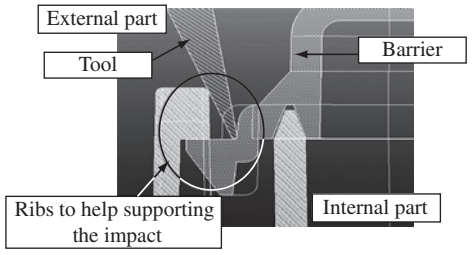
Test description: in this case, the barrier must support an impact of 6.8 J. Three samples must be tested.

Approval criteria: after the impact, there cannot be reduction in the separation distances. Additionally, "alive" parts and insulation cannot be exposed.

Guideline number: 7	Description: design physical barriers for electric parts that can only be removed by employing specified tools

Objective: to protect the customers against accidental contact with "alive" parts due to the removal of physical barriers without using specified tools

Proposed solution:



Suggested tests			
Title:	Constructive	Source:	IEC 60335-1

Test description: in this case, the barrier must be assembled and disassembled ten times before the test is conducted. After that, a force of 50 N must be applied for 10 s in the less favourable direction, employing the test gage 11, according to IEC 61032

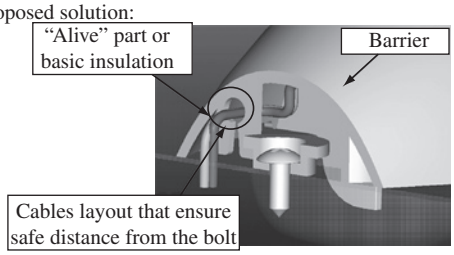
Approval criteria: the barrier must remain locked in its position and cannot become a detachable part.

Figure 3. Set of guidelines (part III).

Guideline number: 8	Description: design physical barriers for electric parts that do not dameage the electric insulation:

Objective: to protect the customers against contact with energized parts due to the damages caused to the insulation of cables and electric components, mainly during assembling/dissassembling of physical barriers

Proposed solution:



Suggested tests			
Title:	Constructive	Source:	IEC 60335-1

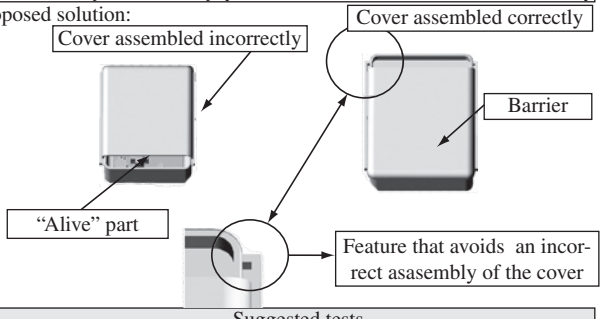
Test description: in this case, it is necessary to inspect the means and features that can damage the electric insulation during the assembling and disassembling activities, mainly those related to the maintanance demands

Approval criteria: during the barrier assembly and disassembly the electric insulation and components must not be damaged

Guideline number: 9	Description: design physical barriers for electric parts that cannot be assembled incorrectly

Objective: to protect the customers against contact with "alive" parts due to the access to these parts once the physical barriers have been assembled incorrectly

Proposed solution:



Suggested tests			
Title:	Constructive	Source:	IEC 60335-1

Test description: in this case, it is necessary to inspect the means and features that can allow access to the "alive" parts due to assemblying incorrectly the barriers

Approval criteria: barriers cannot be assembled in such a way (thus, incorrectly) so "alive" parts can be accessed

Figure 4. Set of guidelines (part IV).