Evaluation of Electrical Characteristics of Protective Equipment - a Prerequisite for Ensuring Safety and Health of Workers at Work

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Abstract. The protecting electrical equipment in use are subject to various factors generated by the use, maintenance, storage and working environment, which may change the characteristics of protection against electric shock. The study presents the results of research on the behaviour over time of protective characteristics of insulating covers of material of work equipment in use, in order to determine the type and periodicity of safety tests. There were tested and evaluated safety equipment with plastic and insulating rubber covers used in operations of verifying functionality, safety and maintenance of machinery used in manufacturing industries and specific services from electric, energy and food sector.

1. Introduction

Protective equipment used in electrical installations must be manufactured, imported, marketed and used only when complying with the applicable national health and safety requirements, technical regulations and good practice codes corresponding to the level of technical progress, and the conformity assessment guidelines.

Safety and health work legislation applicable to these categories of protective equipment, defined as work equipment (WE), must cumulatively meet the safety requirements of Law 245/2004 and the following conditions:

a) these products must comply with the safety and health provisions in use established by EO no.1146 / 2006 concerning the minimum safety and health requirements for the use of work equipment by workers at work;

b) these products must guarantee compliance with the technical conditions laid down in the specific Romanian standards, applicable to the certain product categories, such as: SR EN 60900: 2013 for low voltage electrical insulating hand tools, SR EN 61111: 2010 for electrical
insulating matting, SR EN 61478/2004, SR EN 61478 / A1-2004, etc.) in order to ensure compliance with the minimum safety and health requirements in Annex no.2 of EO no.1146 / 2006.

In the applicable Romanian legislation, the minimum conditions of admissibility of these product categories are ensured if complying with the Romanian standards applicable to protective equipment, depending on use conditions and the manufacturing materials, in compliance with the instructions provided by the Technical Instructions and the provisions related to the safety and health at work, established by the Law no. 319/2006 and the EO no.1146/2006, art. 4, paragraph (1), letter i) [5,9].

The research aimed to:

- Establish the necessary technical conditions for the identification of risks, evaluation and technical verification of the protective equipment used in the electrical installations, in order to prevent the professional risks generated by the external influences (normal use environments, petroleum products and mineral oils or potentially explosive oils); 
- Identify the necessary technical and safety requirements for the verification and technical inspection of these categories of protective equipment; 
- Identify the necessary technical conditions for the identification of the electrical and mechanical risks, which allows the evaluation of the behaviour in time of insulating material characteristics of protective covers for protective equipment in use, in order to determine the types and the periodicity of carrying out the safety test at the employer level; 
- Establish the necessary technical conditions for the conformity assessment in order, if necessary, to bring into conformity the protective equipment in use.

The research consisted of monitoring the behavior over time of the protective characteristics of the insulating material and insulating matting, for new protective products in order to place on the market, as well as for protective equipment in use, to determine the types and periodicity of safety tests.

### 2. Identified risk factors that influence the behavior of electrical insulating equipment in use

In electrical installations there are a variety of types of protection equipment in use, each of them suitable for certain areas of use and types of electrical installations (electrical insulating mats, electrical insulating hand tools, voltage detectors / indicators / testers, electrical insulating ladders, electrical insulating platforms, etc.). Live working protective equipment used in electrical installations is designed to protect both workers in work areas and unauthorized persons in the vicinity for electrical shock. These protective equipment must provide the designated safety function for use under the intended conditions of use, so that not to endanger exposed workers.

![Figure 1](image.png)

**Figure 1.** The identified risk share, generated by the use, maintenance, storage and environment.

Live working protective equipment used in electrical installations must guarantee, at the design and manufacturing stage, an adequate level of safety in order to comply with the occupational safety and
health requirements for protection against electric shock and protection due to external influence [1,4,6,7]. During use, the protective equipment have been found to suffer from electrical, mechanical, thermal, chemical, damage that may alter their functionality, performance characteristics and, in particular, insulating characteristics.

Also, it was found that the user has a bad influence over insulating characteristics by faulty use, storage under environmental conditions that alter the protective characteristics and the lack of cleanliness.

Figure 1 shows the share of identified risk factors generated by the use, maintenance, storage and environment that can alter the protection characteristics against electric shock.

It was found that the highest share, 30%, was due to the users’ risk factors (lack of knowledge about the use, storage and maintenance), and followed by the mechanical factors with 19% and the electric factors with 15% and environmental factors with 11%.

3. Assessing the safety characteristics of electrical insulating materials
By ensuring that the occupational health and safety conditions for the prevention of work accidents and occupational diseases, at the employer’s level, are achieved by using safe protective equipment attesting compliance with legislative and technical provisions.

The study was carried out on specimens of new protective equipment in order to assess the conformity safety characteristics of electrical insulating materials for the purpose of placing on the market and on specimens of protective equipment in use to test the safety level, to keep them in use or to withdraw from use, if the insulating material does not provide the designated electrical insulating characteristics.

Protective equipment tested and evaluated from occupational safety and health point of view, were made of insulating materials such as insulating rubber or electrically insulating covers in one or two layers, which present mechanical strength under both normal working conditions and in extreme temperatures working conditions between -20°C and + 70°C and dielectric properties ensuring the user’s protection against electric shock for live working or near live installations with a nominal voltage up to 1000 V ac. and 1500 V cc.

Many defects that may occur for the protective equipment it is of interest in the case of live working, the defects consisting in the deterioration, puncture or contamination of the insulating material cover of the protective equipment and the influence of the environment in which it is used: the influence of lubricants, raw materials from production such as water, sugar, oil and food aromas) [2,3].

In this respect, the technical and protective features against electric shock were taken into account, both the nature of the material from which the protective equipment was made and the influence of the various environmental factors in use, established by the manufacturer or the environmental conditions in which they can be used by workers in electric and food domain.

The use of certain categories of equipment to protect against electric shock is determined by the material manufacturing recipe, based on components that provide the specific characteristics of the mixture (e.g. insulating rubber designed for normal environments, is not resistant to mineral oils and other oil products).

Other categories of equipment designed to protect against electric shock can also be used in oil environments, for example in the case of insulating rubber, based on components that provide the specific characteristics, can be resistant to mineral oils and petroleum products.

The monitoring, diagnosis and evaluation of the behavior of the protective features of the electrical insulating covers of the protective equipment against electric shock has been carried out since commissioning until 10 years in use.

Also, with the provision of new protective equipment by the manufacturers, were carried out the monitoring, diagnosis and evaluation of protection characteristics of the insulating material, made on the basis of different recipes, which determine different behaviors of the technical characteristics and safety in use.
New protective equipment has been tested and evaluated, initially conditioned on immersion in water, according to the test methods set out in the standards.

During the monitoring of electrical insulating covers of equipment against electric shock, the following elements were analyzed: the existence of the component elements, the technical status (mechanical, thermal, electrical, chemical damage), the electrical insulating protection characteristic, as well as the existence and durability of the marking.

Given that some visual test may be subjective by their nature, new witnesses were retained for the purpose of comparing the results.

In case of explosion hazard, the use of insulating materials for developing explosion-proof equipment raises higher issues due to the microclimate conditions which may influence decisively their quality, with regard to the insulation’s degradation, thus leading to a higher risk for the electrical equipment to break down and to generate possible failures and/or explosions [8].

4. Results and discussions

The study was carried out on specimens of new and used protective equipment in the specific activities of manufacturing industries and services specific to the electric and food domain.

Both visual examinations and destructive tests were performed to verify the dielectric characteristics and the performance level achieved by the material recipe established at the various manufacturers.

It was followed for four years, the behaviour of technical and protective characteristics of new protective equipment intended for use in normal and with oil environments, the samples of insulated material were stored and not sold in parallel with new specimens made by the same manufacturer at the time of the research study.

It was followed for a period of ten years, the behavior of the technical and protective characteristics of new protective equipment intended for use in normal and with oil environments, the behavior of dielectric characteristics, from three manufacturers, each one using own recipes and different components.

Electrical insulating matting are classified in accordance with the requirements of SR EN 61111: 2010 as follows: by an electrical class (Class 0, Class 1, Class 2, Class 3, Class 4) and, where applicable, by adding the suffix “C” in the electric class, meaning resistant to very low temperature. The Electrical insulating mattings were tested in accordance with the requirements of standard SR EN 61111: 2010 [10,11,13].

Figure 2 a and b shows the leakage current values for 4 batches of electrical insulating mats from three manufacturers and having different insulating rubber compound recipes. From the tests performed, the basic elements of the composition of the rubber compound influence the insulating properties of the dielectric and mechanical resistance; some of the mats (recipe 1K) not pass the tests for safety.

![Figure 2](image)

**Figure 2.** a Leakage current - new electrical insulating mattings; b - Leakage current - new electrical insulating mattings – details for recipe 1 E, 2 IK, 3A.
Analyzing the leakage current values for the electrical insulating mat - recipe 1K, it was found that the manufacturing technology was not respected.

Figure 3 shows the values of the leakage current for one batch of 10 electrical insulating mattings from the same manufacturer, tested before and after four years of storage.

From the performed tests, the recipe established by the manufacturer, regardless of the date of the manufacturing, in the conditions of storage in dust-free environments, guarantees the preservation of the dielectric characteristics even if the product has not been used [2,3]. The composition of the mixture established by the manufacturers, without modification of the recipe and manufacturing process, influences the dielectric characteristic and the mechanical resistance, validated be safety tests on electrical insulating matting (recipe 1E, recipe 2K and recipe 3A).

Figure 4 shows the values of leakage current for a batch of 4 electric insulating mattings having 10 m in length, in use for 10 years (electrical power station).

The test voltage for this batch of electrical insulating matting in use for 10 years (in electrical power station), was 20 kV, for electric class 2, tested under normal environmental conditions. The recipe for these electrical insulating mattings is 3A. It was found that after 10 years of use the protection characteristics were not altered. In the case of the electrical insulating mat 3, the high leakage currents were due to the mechanical stress generated by the workers’ traffic in the control room of the power station.

Figure 4. Leakage current - electrical insulating matting in use for 10 years.
Tests were carried out on other batches of electrical insulating mattings in use, following the behavior of electrical insulating mat in wear, contact with oils, dust, water and mold. It has been found that, over time, the insulating material loses its electrically insulating properties due to wear, contact with oils, dust, etc., the recorded results show the increase in leakage current due to the inappropriate use and maintenance of these products.

In this respect, manufacturers of electrical insulating rubber equipment must ensure that, when placed on the market for use, compliance with the applicable safety and health requirements, they must fully respect the declared, related to recipe (technical, functional, constructive and safety characteristics) related to thickness and color, including manufacturing technology [2, 3].

The study also analyzed the behavior of hand tools used by workers for five years, which fall under the category of electrically insulating tools for live working with rated voltage up to 1000V ac and 1500 V dc, equipment manufactured and designed not to endanger the user or the electrical installations, if they are properly used.

The test voltage was 10 kV, in accordance with the methods specified in SR EN 60900: 2010, for testing of new types of new various categories insulating hand tools (keys, pliers, screwdrivers, hex keys, and extension keys).

From the tests made, it resulted that the insulating material covers influences the dielectric characteristics and the mechanical resistance, the new tested insulating hand tools passing the safety tests.

Figure 5 shows the leakage current values for 6 sets of 10 new insulating hand tools. Verification of the dielectric characteristics was performed after the hand tools were mechanically tested, immersed in water and at extreme temperatures.

![Figure 5. Leakage currents - new insulating hand tools.](image)

The insulating sheath of hand tools must have two layers of insulating material with different colors, the insulating inner sheath being a rigid sheath with very high insulating characteristics, and the outer sheath, that protects the inner sheath, to absorb the mechanical shock, improving ease of use.

If the outer sheath is damage, the insulating hand tools must be replaced (out of use), a situation that occurs in the case of long time use.

Figure 6 shows the leakage current values for 6 sets of 10 insulating hand tools. Tool sets 1, 2, 3 and 4 were used in maintenance and set 5 and 6 in electrical industry.

From 40 samples used in the manufacturing industry, 5 samples punctured the insulation (not recorded in the chart). From batch 2, only one tool has been approved for use. Also, analyzing together with users, the biggest values of leakage currents for a series of tools, were found that the tools have been subjected to repeated mechanical shocks.
To validate the results, a batch of new tools was subjected to the mechanical shocks described by the users and verified that the materials of the insulating coatings maintain their dielectric characteristics.

![Leakage Current Values](image)

**Figure 6.** Leakage current values for 6 sets of 10 insulating hand tools in use.

The protective equipment must be tested by the user, both for safety status, in order to identify the defects by visual inspection (e.g. missing pieces, cracks, pinches, burrs, foreign inclusions, etc.) and the technical status, mainly related to their maintenance.

According to the provisions of Romanian legislation and technical regulations, protective equipment must be tested before use, commissioning, periodically in use and after repairs or alterations / upgrades [1, 3, 7].

It is recommended that the dielectric characteristics of the protective equipment to be tested once a year and, as the case may be, whenever it is found, after visual examination, that the insulating material of the equipment is not reliable.

The study presents the results of the research on the behavior over time of the protective characteristics for insulating material or insulating rubber of new and used work equipment, in order to determine the types and the periodicity of the safety tests, There are no explicit provisions at national level regarding the period during which these tests to be carried out.

5. Conclusions

By ensuring a safety and health level for workers, in order to prevent the risks of injury and professional disease, an objective underlined by the general objectives of the EUROPA 2020 Strategy, the research study aims to develop a verification methodology of electrical insulating, taking into account that during use, the electrical insulating equipment is subjected to various factors generated by the way of use, maintenance, storage and the working environment, which can alter the protection characteristics against electric shock.

Regular testing of protective equipment used in electrical installations is a mandatory safety requirement in order to guarantee and certify the fulfillment of the WE safety characteristics for workers both for sectors underlined by this study (electrical and food sector) and for national economy sectors.

This requirement must be ensured by the WE manufacturers used in the electrical installations, in order to notify the periodicity of carrying out the safety tests in the User Manual / Technical Instructions of the WE.
The results of periodic test are an important information in the management of occupational risks, in order to select and acquire effective equipment with high performance, long duration and to establish the most appropriate technical diagnostic and inspection/control of the safety level for protective equipment.

References
[1] Antonov A et al. 2014 Environmental Engineering and Management Journal 13(6) 1361-1354.
[2] Buićă G, Dobra R, Păsăulescu D and Tătar A IOP Conference Series: Materials Science and Engineering 133 1.
[3] Buićă G 2010 Contributions of diagnostic methods of safety and health at work in electrical installations PhD Thesis, Universitas, Petroşani 70 – 149
[4] INCIDPM 2013 Guide for the application of GD No.1146/2006 regarding the minimum safety and health requirements for the use of work equipment by workers (in Romanian) National Institute of Research and Development for Occupational Safety http://www.inpm.ro/files/publicatii/2013-05.01-ghid-t.pdf
[5] INCIDPM 2014 Risk management within professional equipment maintenance activities to prevent work accidents and occupational diseases - a prerequisite for increasing the competitiveness of employers on the market, research study.
[6] Kurihara, Satoshi, et al. 2003 Construction of remote monitoring system for separative measurement of leakage current of outdoor insulators, Properties and Applications of Dielectric Materials Proceedings of the 7th International Conference IEEE 1
[7] Law no. 319/2006 on the safe and healthy at work.
[8] Pascaulescu V M, Vlasin N I et. Al. 2016 Considerations on impact resistance tests for electrical equipment used in explosive atmospheres Proceedings of the 16th International Multidisciplinary Scientific Geoconference SGEM 2016, Section Science and Technologies in Geology, Exploration and Mining II 181-188
[9] RERA Order no. 23/2011 for the approval of the Technical Norm for establishing the requirements for the execution of live working in electrical installations, code NTE 010/11/00, http://www.anre.ro/ro/energie-electrica/legislatie/norme-tehnice/normative-tehnice-energetice-requirements.
[10] SR EN 60060-1: 2011 High-voltage test techniques. Part 1: General definitions and test.
[11] SR EN 60060-2: 2011 High-voltage test techniques – Part 2: Measuring systems.
[12] SR EN 60900:2005 Live working. Hand tools for use up to 1000V a.c and 1500V d.c.
[13] SR EN 61111:2010 Live working. Electrical insulating matting.
[14] SR ISO 2230:2008 Rubber products. Guidelines for storage.