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TESTING OF PERSONAL PROTECTIVE EQUIPMENT AGAINST THE THERMAL HAZARDS OF ELECTRIC ARCS

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ABSTRACT

Electric fault arcs occurring with short-circuits in electric installations are enormous sources of power. Particularly heat and radiation is converted. There are very high risks for persons especially in case of direct exposure, e.g. during live working. Personal protective equipment (PPE) can essentially contribute to increase the personal safety.

Necessary base for the assessment of PPE and their selection for practical use are reproducible product tests. The PPE have to be tested for proving resistance as well as protection effect against electric fault arcs. The paper gives information on systematic tests of PPE against the thermal hazards of arc flash. A suitable test set-up was found. Base is the set-up of the box test method of protective clothing (IEC/EN 61482-1-2) that is modified for testing of other components of PPE (gloves, visors, helmets), too. Besides of arc resistance the protective effect is evaluated by means of calorimetric measurement (direct exposure and transmitted incident energy). General conclusions are drawn on how to test and how to standardize tests.

Index Terms - Electic power installations, arc flash protection, live working, personal protection equipment, testing

1. INTRODUCTION

Electric fault arcs represent a high risk for people working at or in the vicinity of electric power installations. There is a particular risk due to the thermal effects of these arcs in case of live working when being exposed directly. In addition to the electric power system protection devices, personal protective equipment (PPE) is necessary for preventing injuries. Essential components of PPE are flame-retardant protective clothing, gloves, helmets and visors.

PPE must meet two requirements regarding arc flash risks: arc resistance as well as arc protection. In the past considerations and tests were only focussed on flame resistance and proving PPE to do not aggravate the arc consequences. To be flame retardant, is a very important base for PPE but not sufficient. PPE components such as textiles of garment and clothing, gloves and visors must also limit the incident energy to a non-dangerous degree.

Research work has been focussed, among others, to create materials with high heat attenuation (high arc thermal performance value ATPV [1]) and develop test methods for proving arc thermal protection as well resistance. In the following the progress in the second point regarding testing is considered.

In addition to the ATPV test [1] providing a material property, the box test method was developed to prove if requirements of certain protection classes representing different protection levels are met by textile material, garments and clothing [2]. Measurement of the incident energy is included in the test procedure for assessing the heat flux as a criterion and one result of testing.

A number of research activities were necessary to introduce this test method. One key aspect of the box test method is the reproducibility of the test to assure the validity despite of the stochastic nature of arc processes and the limited number of arc shots within a test.

In the following, this box test method is described. Causes are given regarding parameters set-up, test steps and assessment. The box test is subject of the standard IEC 61482-1-2. The test set-up and procedure are modified to cover also the needs regarding the testing of protective gloves and combinations of helmet and visors. Covering as much as possible practical arc exposure conditions, the test shall simulate worst case heat transfer conditions, with making, for this, an abstraction from special geometrical and constructional installation sites, working positions etc. The tests are drafted to certificating single products but may also be the base for complex testing of PPE component combinations as used in practice.

2. BOX TEST METHOD

In the box test arc resistance and protection are assessed for two different protection classes. An electric arc is fired in a 400 V AC test circuit, burning between two vertically arranged electrodes which are surrounded by a special test box.

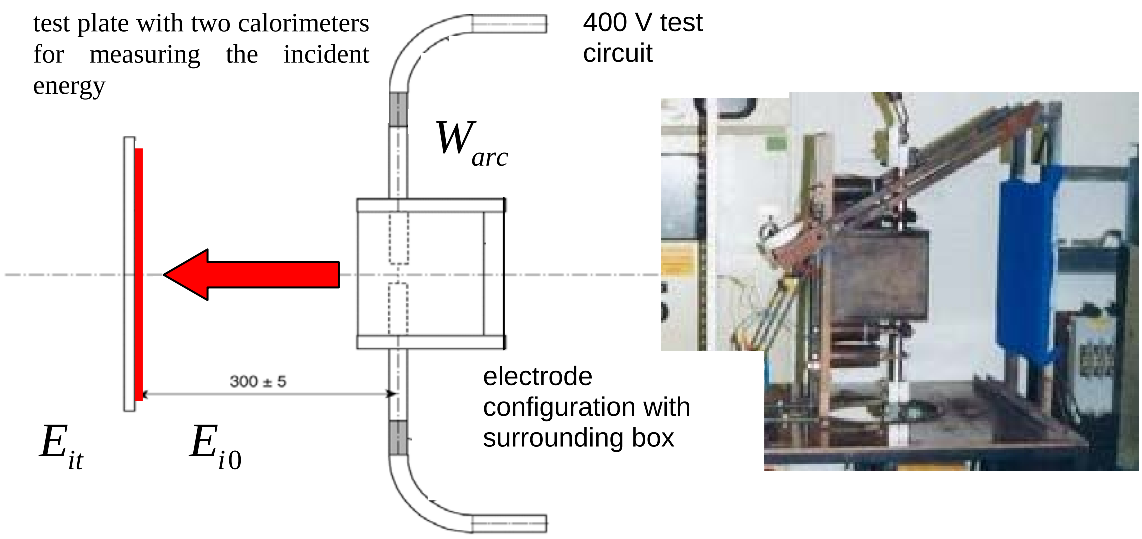

Figure 1: Box test set-up for textile material testing of protective clothing

The electrode spacing is 30 mm. The test parameters of both protection classes are summarized in Tab. 1.

Table 1: Test parameters and conditions

	class 1	class 2	tolerance
test current	4 kA	7 kA	+/- 5 %
test voltage	400 V AC, 50 Hz		+/- 5 %
arcing time	0.5 s		+/- 5 %
electrodes	aluminium (top) copper (bottom)		
electrode gap	30 mm		+/- 1 mm
distance a	300 mm		+/- 5 mm

The test box set up (see Fig. 1) is introduced to meet typical high risk conditions and particularly to cover actual arc exposure conditions in low-voltage systems, e.g. service entrance boxes, cable distribution cabinets, distribution substations or comparable installations where the electric arc is directed to the front of a worker at the height of his breastbone. Under these test conditions the incident energy of the electric arc will be higher than in other working positions.

In the tests a free-burning high-current arc of defined input power P_{LB} and duration t_p is reproducibly fired in an electric test circuit with the test voltage U_p and test current I_p. The arc is ignited by means of a fuse wire by switching-on the voltage and, after the burning interval t_p of 500 ms, switched-off by circuit breaker. During the arc duration the electrical arc energy $W_{el} = W_{arc}$ is converted in the arc flash.

The arc burning volume is limited by the test box surrounding the arc. Radial, the box is open to only one side, a directing effect of arc heat radiation and flux results (without box a diffuse spread to all direction would appear). A test plate, panel or mannequin is placed in this direction, carrying the test samples. There also the calorimeters are located for measuring the incident energy E_i. In case of direct arc expose (without test sample) the calorimeters measure the maximum heat (total heat) E_{io}. When being covered by the test sample, the calorimeters indicate the incident energy transmitted E_{it}.

The protection classes are characterized by different levels of the electric arc energy, and the incident energy resulting. Tab. 2 gives an overview. The incident energy is the exposure level resulting at a distance a = 300 mm to the perpendicular arc axis.

Table 2: Statistically confirmed exposure values

	W_{arc} in kJ		E_{io} in kJ/m²	
	Mean value	± 2*s	Mean value	± 2*s
Class 1	158	±34	135	±56
Class 2	318	±44	423	±78

2*s – double standard deviation

The characterizing electric and calorimetric parameters are recorded or calculated by transient analyzer. Recorded electric parameters are the arc current, arc voltage and arc power. The calorimetric parameters primarily analyzed are, based on the time curves of calorimeters temperature rises dT(t), the maximum values dT_{max} (delta peak temperatures) and the related time points t_{max} (time to delta peak temperature). By means of these parameters the incident energies are determined and the assessment by overlaying with the Stoll criterion for the onset of second degree skin burns is made.

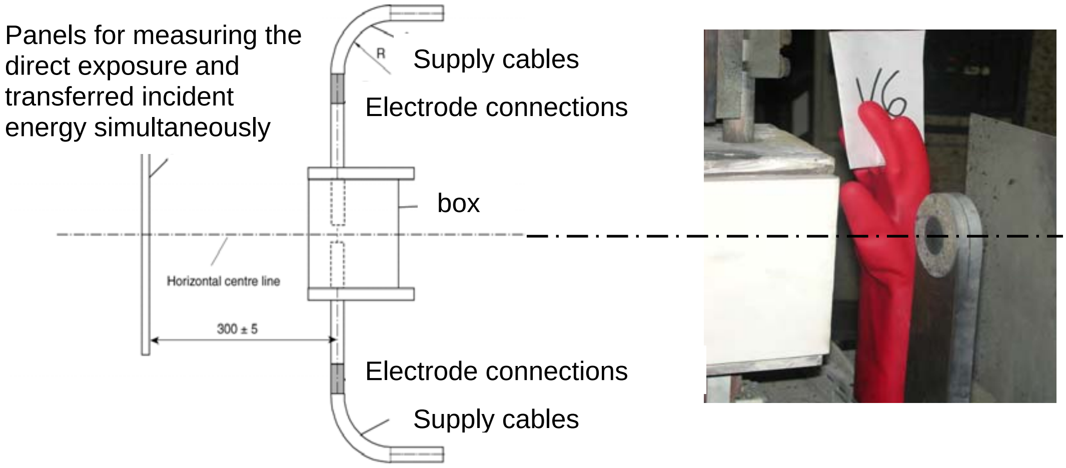

Figure 2: Box test set-up for glove testing with glove panels equipped by calorimeters

Figure 3: Test set-up with test head developed for visor testing and equipped by 6 calorimeters measuring the transferred incident energy in the eye, mouth/nose, ear and chin region

The incident energy E_i transmitting the area A is proportional to the temperature rise dT_{max}

$$E_i = \frac{m \cdot C_P}{A} \, dT_{max}$$

Using the actual mass m and specific heat values c_p of a copper calorimeter plate it is

$$E_i = 5{,}54 \cdot \frac{dT_{max}}{°C} \cdot \frac{kJ}{m^2} = 0{,}132 \frac{dT_{max}}{°C} \cdot \frac{cal}{cm^2}$$

The calorimetric quantities are assessed by the so-called Stoll criterion. The Stoll curve [3] is the criterion of the onset of second degree burning of human skin.

Generally test series have to be carried out taking into account the stochastic nature of the electric and thermodynamic arc processes.

The conditions of the box test allow to take into account, additionally to those of radiation and convection, the thermal arc consequences which may result from the amplifying effect of installation back and side walls. Metal splashes and hot metal particles, due to melting electrode material, affecting the PPE tested are also simulated in the tests.

3. TESTING OF DIFFERENT PPE COMPONENTS

3.1. Textile material and protective clothing

For protective clothing, the standardized procedure with the box test according to [1] is available to carry out such tests. The method has being used for certification in Europe for a couple of years. Fig. 1 shows the principle of testing and the set-up of the box test method for textile material and protective clothing. For product assessment and certificating material and garment/clothing tests are distinguished. The material box test method is used to measure and find material response to an arc exposure when tested in a flat configuration. A quantitative measurement of the arc thermal performance is made by means of the energy transmitted through the material.

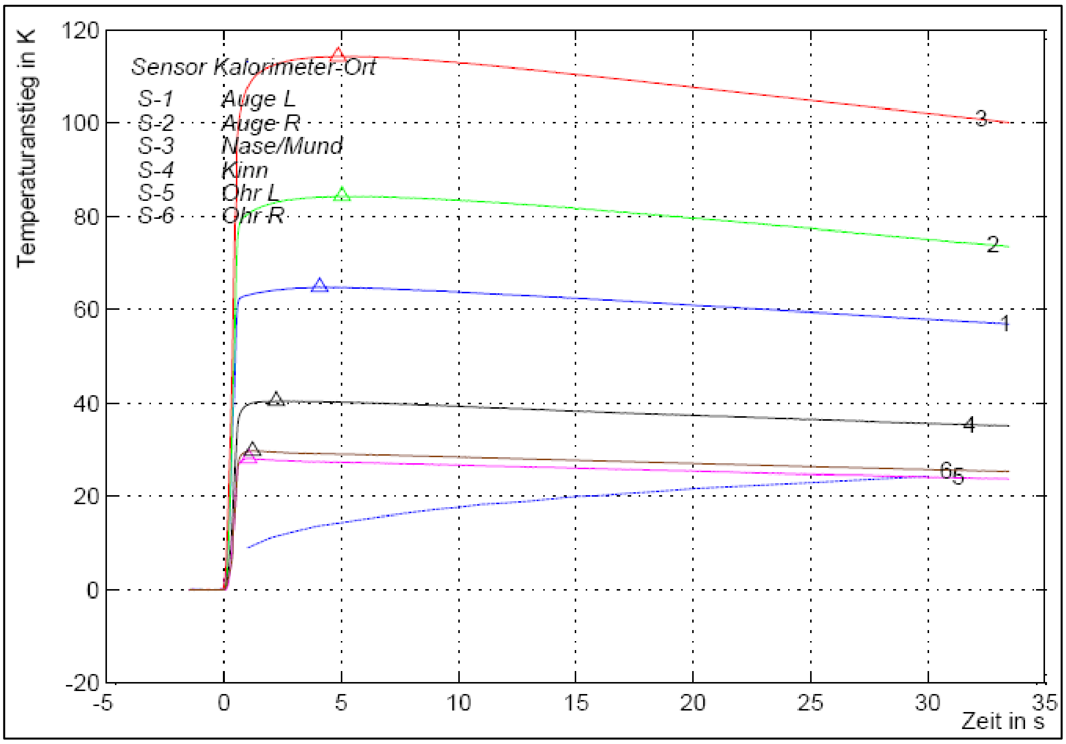

Figure 4: Test head calorimeter temperature rise curves for a direct exposure test under box test class 2 conditions (example)

The garment box test method is used to test the function of the protective clothing after an arc exposure including all the garment findings, sewing tread, fastenings and other accessories, no heat flux will be measured.

The tests are assessed by means of the criteria of Tab. 3.

Table 3: Test acceptance criteria

Parameter	Criterion
Burning time	≤ 5 s
Melting	No melting through to the inner side
Hole formation	No hole bigger than max. 5 mm in every direction (in the innermost layer)
Heat flux	All eight value pairs ($E_{it} - t_{max}$) of the two calorimeters for a 4 tests series are below corresponding STOLL limit

Final result of testing is the categorization to the protection classes (prove of passing test class conditions), meaning the test prove if protection class 1 or 2 according to the corresponding test class conditions are achieved. The test is considered as passed, if all of the criteria according to Table 3 are met. Within one test, four arc shots are made under unchanged conditions.

In case of garment testing the materials of the garment must have passed successfully the material box test and the garment must fulfil the criteria burning time, melting and hole formation also according to Table 3.. After exposure fasteners shall be functional. Accessories shall have no negative influence to the results of the burning time, melting and hole formation. The incident energy is not measured because of the influence of the design of the garment (e.g. pockets, flaps etc).

3.2. Testing gloves and visor/helmet combinations

For other components of PPE, such as protective gloves, helmets, face shields or visors etc. so far there have not yet been standard requirements for this protection and proving by tests.

The box test has been investigated and modified with the aim to enable tests of protective gloves and helmet-visor combinations as well. Fig. 2 and 3 show the modified test set-ups. In general test series as well as tests on couple of very different PPE and types experiences in using the developed methods were made. An example of incident energy values as test results measured in case of calorimeter direct exposure by using the test head for visor testing is shown in Fig. 4. The incident energy values are used for assessing the risk of second degree skin burns in the face area (behind the visor) being one of the essential criteria for passing the test as well.

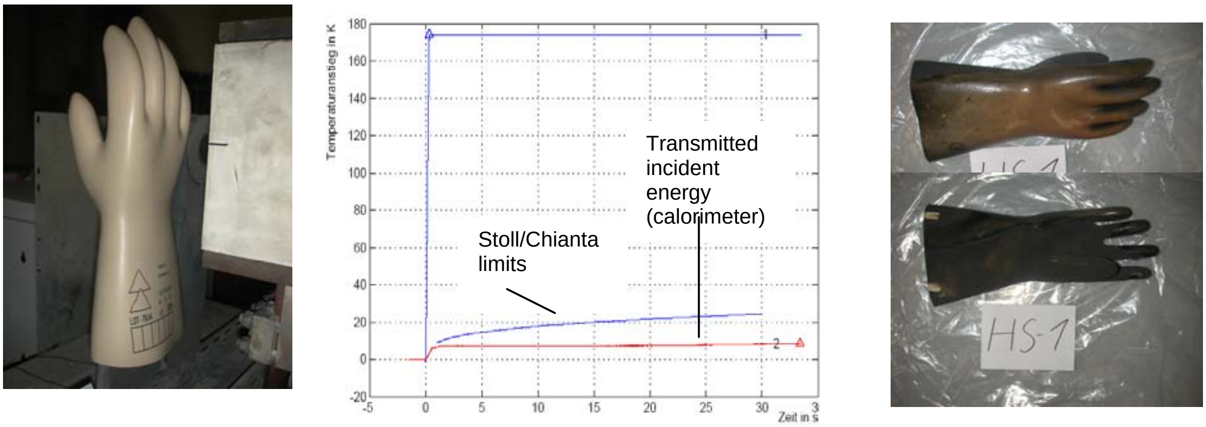

Figure 5: Result of a voltage class 1latex glove under arc test class 3 conditions (test passed)

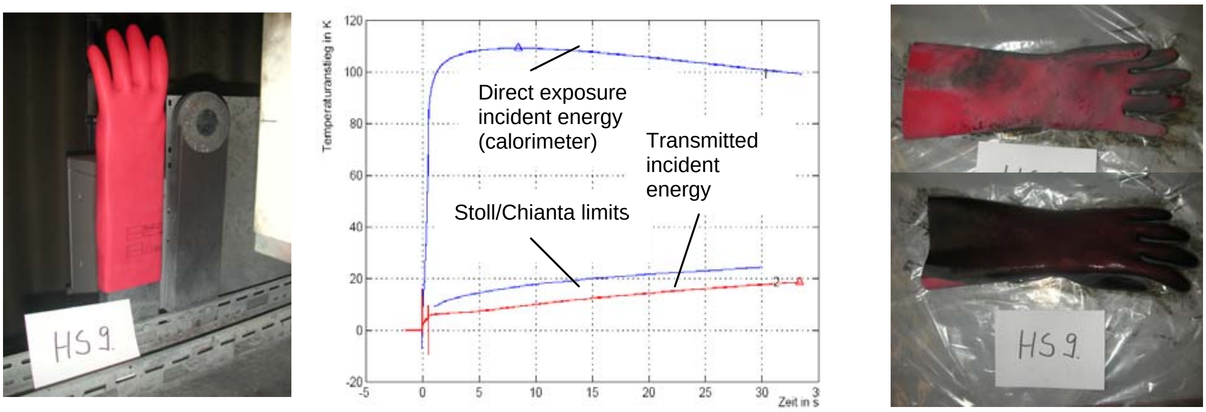

Figure 6: Test of voltage class 0 latex glove with textile inliner under arc test class 2 conditions (test passed)

In glove testing two sensor panels are used in parallel. On test panel carries the test sample and the calorimeter of this panel measures the transmitted incident energy. The other one is not covered, so the calorimeter measures in each shot the direct exposure incident energy at the same time [4].

For testing gloves also investigations are carried out for introducing an additional protection class 3 characterizing a higher level of arc exposure. This level is reached by reducing the distance of the panels (sample, calorimeters) to the arc to a = 150 mm with the lower arc energy level of Tab. 2. This protection class is interesting because of the closer distance of hands or gloves, respectively, in practical working activities (compared to body and face of persons). Test examples are shown in the Fig. 5 and 6.

For testing visors a test head with several calorimeters (at maximum 6 ones) for measuring the transmitted incident energy (for assessing skin burns behind the visor) is used. The calorimeters are measuring the heat exposures at different face regions. The closest position (to the arc axis) has got the calorimeter in the mouth/noze region. It should be placed in a distance of 300 mm, centred to the arc axis horizontally and vertically, for comparison reasons. The statistical values of the box test for clothing can be applied. The calorimeters in the eyes region are at a wider distance to the arc because of the head form. Very important is also the chin calorimeter indicating the heat in the lower part of the head. The calorimeters in the positions of the ear are of secondary importance because of a generally lower exposure, so at least 4 calorimeters (mouth, chin, eyes) shall be used in certificating.

The test configuration shown in Fig. 3 is suitable for assessing the visor behaviour and effects in the standard wearing position because of mounting the visors on the helmets. Worst case testing of the helmet arc resistance is not possible with this configuration. For this the helmet should be centred to the arc axis also horizontally in separate tests.

4. GUARANTEEING QUALITY AND REPRODUCIBILITY OF TESTING

The experiences in using the box test method confirm the tests to be very close to practice as well as reproducible.

Essential factors influencing testing are the ambient test conditions (indoor/outdoor, temperature, humidity, wind etc.), the initial test conditions and the box conditions. Frequent calibration checks of the test arrangements and parameters are necessary .

The test apparatus setting has to be checked for each test. Values recorded should be the arc current, arc duration, arc energy, and arc voltage. In addition, the ambient temperature and relative humidity shall be recorded. Influence of wind or air convection flow during testing shall be prevented.

Calorimeters must be calibrated and checked to verify proper operation.

Calibration oscillograms of the prospective test current adjusted and the test voltage proving the test conditions shall be recorded at least for each test series with unchanged test parameters. When testing textiles, clothing, helmets and visors, reference tests without samples shall be carried out with measuring the direct exposure incident energy $E_{\mathbf{io}}$ before testing and after a test series. In the direct exposure shot before the test series, the direct exposure incident energy should be greater than the long term mean value (Table 2). In testing gloves this control parameter is available in each arc shot..

For each of the tests the arc energy values shall be determined. The arc energy and direct exposure incident energy characterizing the according test class are the relevant parameters for assessing the tests on how far the test conditions cover the needs resulting from risk assessment regarding the real fault conditions. The arc energy and incident energy to be expected in a real fault case at a certain fault location (plant, network) has to be compared with the arc energy levels of the class tested and passed.

5. SUMMARY AND CONCLUSIONS

Electric arcs are a potential risk for people and plant. Particularly the protection against electric fault arcs is of largest importance for human injury while working in, at or in the vicinity to electric power installations. An essential contribution to this protection can be made by PPE. PPE must be tested under practically relevant and reproducible conditions.

With the box test a test method for analyzing arc resistance and protecting effect of PPE has been developed. The test procedure includes measuring of the heat flux.

This box method is very well reproducible, near to practice and relatively favourable in price. It has being used for certifications.

The box test allows the classification of material and PPE products regarding the protection against the thermal hazards of electric arcs; two protection classes are defined. The classes are characterised by the level of electric arc energy. Quality assurance of testing as well as the estimation of practical hazards covered by the according test or class must be based on the electric arc energy and the direct exposure incident energy. Both risk assessment and classification have to be made by means of these arc energy parameters.

The modifications investigated confirm the suitability of the method for testing different PPE products such as gloves and visors, too, and build the base for according standardizations.

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