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Research and Development in the Field of Special Protective Clothing; Requirements for Selected Methods and Products

Abstract
Clothes with antistatic properties are demanded in many fields of the industry. This is generally achieved by integrating highly-conductive fibres of different structures. Antistatic functionality is assessed by applying standardised test methods. The ongoing development of antistatic materials and clothes, as well as updating the requirements, requires a permanent adaptation of the examination basis. The aim is a comprehensive and practice-oriented assessment of antistatic characteristics. This paper describes selected research results from ***the Saxon Textile Research Institute*** *(STFI) in the field of textile electrostatics. As well as methods for the antistatic assessment of fabrics, a method for classifying fully antistatic clothes is introduced. Another field of the STFI's research comprises the development of test & assessment methods for protective clothing against the thermal risks of an electrical arc. Fundamentals, test equipments and normative integration are represented.*

Key words: *protective clothing, antistatic behaviour, conductive fibres, thermal risk, electrical arc, electrostatics, garment test, electrostatically dissipative clothing.*

Introduction

For some years the European textile and clothing industry has been characterised by an important structural change, which has also influenced the market segment of protective textiles and still requires continuous product innovations, customer- and end user-oriented developments, as well as the consideration of the state-of–the-art experiences for personal protection. The development of novel test and evaluation standards, especially for complex risks, is becoming one of the key factors of these multifunctional high-tech garments.

The test and assessment of the electrostatic properties of textiles and clothes has a long tradition. In the 1950s research was deepened by the introduction and processing of synthetic fibrous materials, and examining the resulting technological problems caused by electrostatic chargeability.

In the 1970s the comfort and quality--characteristic 'antistatics' gained acceptance in clothes and resulted in far-reaching activities in the development of suitable test procedures with corresponding measuring techniques.

Requirements by the industry that suitable protective clothing be worn in electrostatically sensitive areas were also a motivating factor. Flammable atmospheres (danger of explosion) or working areas for handling with electrostatically-sensitive devices and equipment are sensitive areas where this is relevant.

Furthermore, the research field of electrostatics has been characterised by the development of new, innovative types of protective clothing and materials. As electrostatic phenomena were investigated in increasing detail, so more effective measuring techniques were developed and designed.

A system of standards, regulations and guidelines are presently available for assessing different practice conditions and functional principles. The increasing level of knowledge, technological progress, strict safety regulations and the development of electrostatically highly sensitive devices and equipment forces has led to the permanent revision and customisation of test methods and equipment engineering. Phenomena which received hardly any attention are now increasingly found at the centre of research.

Test methods must be able to objectively include important electrostatic effects, characteristic quantities and parameters to allow a practical and relevant interpretation of the results, as well as to guarantee safe and reproducible handling.

The Saxon Textile Research Institute (STFI) has long carried out research into the development of new test methods concerned with protective clothing as well as improving those hitherto used.

In this paper, **we present our experience concerned with the three following test methods developed by us:** STFI Induction Decay Method, test method to determine the body potential and charge transfer by weaving electrostatically dissipative protective clothing against the thermal risks of an electrical arc.

The electrostatically dissipative characteristic is an often required parameter for protective clothing. The assessment is carried out by means of standardised test procedures. The technological progress, the new development of materials and the rise in the level of safety requirements force manufacturers to continually develop the standards. This concerns especially inhomogeneous materials.

This also leads to the development of novel test methods. Besides the assessment of materials for garments, the practice-oriented testing of the antistatic behaviour of entire clothing systems is becoming ever more important.

The development of test methods for protective clothing against the thermal risks of an electrical arc is a new field of research. Electrical arc accidents during maintenance activities under live working conditions rarely happen. However, statistics demonstrate that the risk is permanent, and the injuries which can occur are very harmful and sometimes fatall. Therefore the use of suitable protective clothing tested under near-real life conditions is very important.

STFI Induction Decay Method (EN 1149-3:2004, method 2)

The quality of the electrostatic dissipative characteristics of protective clothing is a requirement which is often regulated industry-wide. Beginning with the prevention of general uncritical charging effects, the requirements apply up to the highly effective and absolutely safe avoidance of electrostatic discharges (ignition risks in explosive atmosphere, prevention of destruction of electronic devices).

The classic and widespread test method for assessing the antistatic characteristics is the determination of surface resistivity in accordance with the standards (EN 1149-1, EN 61340-5-1) [1, 2].

However, due to the measuring principle, this method is only applicable to surface conductive materials. For textiles with core-conductive fibres, resistive test methods are not applicable for determining the antistatic functionality. We developed the so-called STFI Induction Decay Method particularly to examine such materials, using the suitable testing instrument ICM 1. By means of a probe, the decay characteristics of the charged sample (charging by induction) are investigated. Both the shielding factor and the different decay times are evaluated. With this contactless test method, different textiles (e.g. fabrics, warp-knitted fabrics, weft-knitted fabrics, non-woven, laminate) with and without antistatic components, can be tested and electrostatic assessed independently of their structure. The antistatic assessment of paper and foils is an additional possibility.

The STFI Induction Decay Method is included and described in detail in standard EN 1149-3:2004 as test method 2 [3]. The following explanations show further development possibilities. These are the focus of the STFI's current research work.

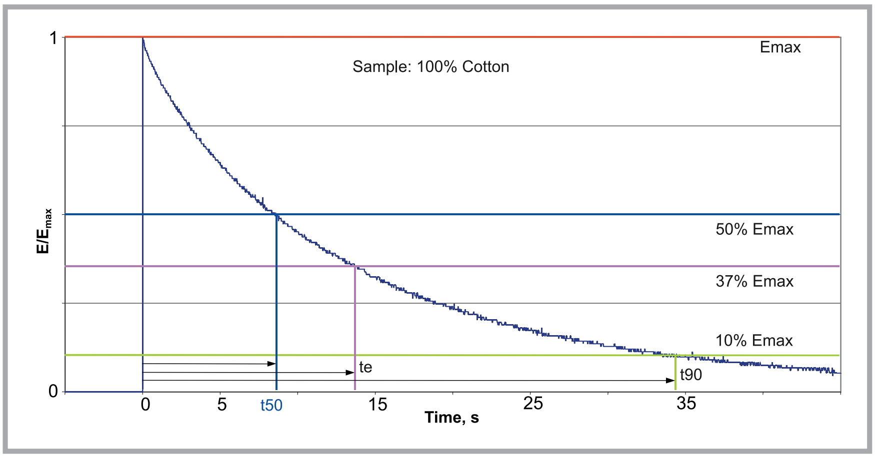

***Figure 1.** Typical diagram of a homogeneous fabric material by means of the STFI Induction Decay Method; Charge decay according to EN 1149-3, method 2.*

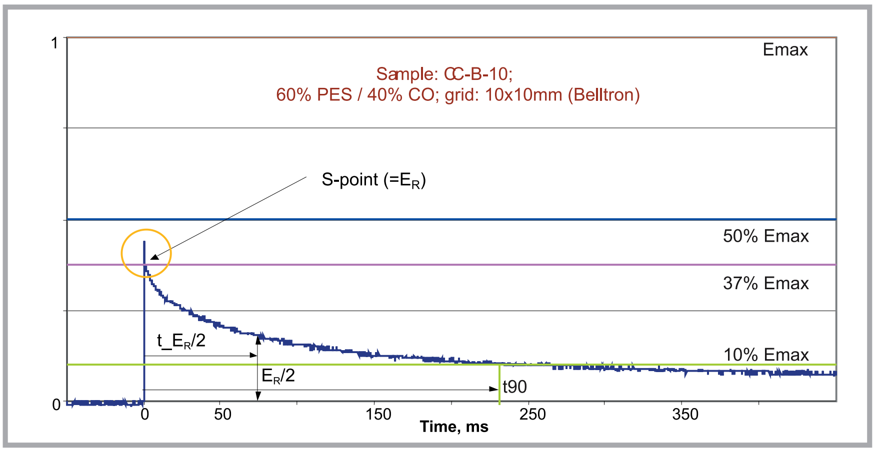

***Figure 2.** Typical diagram of an inhomogeneous (heterogeneous) fabric material with coreconductive fibers by means of the STFI Induction Decay Method; Charge decay according to EN 1149-3, method 2.*

The existence and the effectiveness of all kinds of conductive threads, filaments and fibres is detectable. The dynamics of discharge is clearly measurable, in fabrics, nonwoven, laminates, multilayer, foils and paper, among others.

According to EN 1149-3:2004, only the so-called shielding factor S and the half decay time t_{50} is assessed. The following explanations show that the resistance of the high conductive component and the fabric component can be calculated approximately.

The discharge time dependence of a homogeneous material follows the equation:

$$E = E_{\max} e^{\frac{-t}{RC}}$$

and after conversion;

$$R = \frac{t}{C \ln \frac{E_{\max}}{E}} \qquad (1)$$

with:

- E_{max} - electric field strength with no test specimen present (initial field strength)
- E - electric field strength as a function of time
- C - capacitance of the measuring device
- R - resistance
- t - time

If the decay time reaches the half-decay time (t_{50}), then $E = E_{max}/2$. At a known surface resistance (EN 1149-1), the capacitance of the measuring device is determinable according to the equation (1).

The course of the curve in the measuring diagram in Figure 2 is characteristic of an inhomogeneous sample with a compound of high conductivity. A sample (basic fabric PES/Cotton) was used with an antistatic Belltron-grid (Belltron is a highly conductive fibre in a sandwich structure/similar core matrix structure). The carbon core of the Belltron fibre has a considerably higher conductivity in comparison with the basic fabric, and is able to accelerate the charge decay considerably. This is obvious in the smaller curve amplitude in contrast to Figure 1.

Due to the two different conductivity components of the tested sample in Figure 2, a superposition of the discharge curve is given, that is, a superposition of

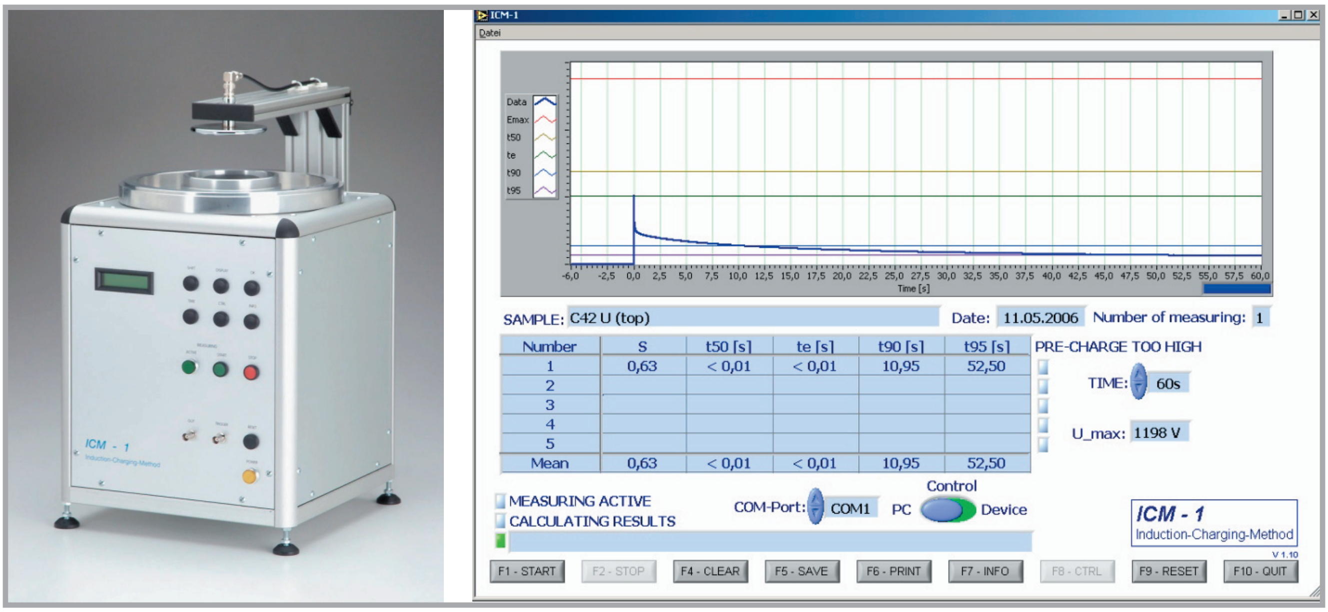

Figure 3. *Test instrument ICM-1 and registration software (developed by STFI); physical basis: STFI Induction Decay Method (EN 1149-3, method 2).*

the shares of fast and slow charge decay. The point E_R is the exact area for the transition of fast discharge by the fibre (Belltron) into slow discharge (PES/Cotton-based fabric). E_R is reached for carbon fibres after about 1.5 ms.

The resistance of the basic fabric (PES/Cotton) for the tested CC-B-10 sample according to Figure 2 is also determinable according to equation (1). E_R is used for E_{max}. A fabric resistance of about 0.9 x10^{10} Ω results from the example. By means of the ring electrode (EN according to 1149-1), a surface resistance was determined in the area of 3×10^{10} Ω.

Considering the normal spread of the measurements, the order of the magnitude for the fabric resistance can be determined arithmetically .

The resistance R_i of the high conductive fibre component can be assessed with the following equation.

$$R_i = \frac{t}{C \ln \dfrac{E_{\max} - E_R}{E_P - E_R}} \qquad (2)$$

where:

E_P - field strength at the maximum peak

t - rise time of the initial voltage (approx. 50 µs)

For Figure 2, R_i =1.7 x10^6 Ω; E_P = E_R than $R_i < 10^6$ Ω. The slow measuring dynamic (great response time) of the measuring instrument limits the value of R_i.

E_R/E_{max} is called 'field penetration', and depends on the distribution or grid density of the conductive fibres within a fabric. When the grid density is high, i.e. the spacing between conductive fibres is small, then $E_R/E_{max} \rightarrow 0$ and the value. The relation $S = 1 - E_R/E_{max}$ is called the 'electrostatic shielding value'.

Figure 3 shows the corresponding instrument and a typical diagram of an inhomogeneous (heterogeneous) fabric material with core-conductive fibres.

The S value also correlates with other charging/discharging methods. By means of tribocharging, different typical fabric samples (with sample diameters of c. 30 cm) were charged, isolated and then earthed. The surface potential was measured before and after earthing. The recording was carried out with a high-speed recorder. Due to the relatively slow measuring dynamic (great response time) of the EMF 58 field meter (Eltex, Ger-

Table 1. *Overview and comparison charging/discharging charging by induction and tribocharging.*

Fabric	Antistatic	EN 1149-3, method 2 STFI Induction Decay Method					Rubbing with PA-nonwoven	Shielding effect in analogy to the S value
		S	t50	te	t90	t95	Surface potential isolarthed -kV / -kV	(Note1)
SCF, 100% PES	RESISTAT, 5 x 5	0.95	<0.01	<0.01	<0.01	<0.01	-5.1 / <-0.2	0.96
SCG, PES / CO	RESISTAT, 5 x 5	0.86	<0.01	<0.01	0.04	0.29	-5.0 / <-0.2	0.96
SSG, PES / CO	BEKINOX, 5 x 5	0.86	<0.01	<0.01	0.03	0.19	-2.5 / <-0.2	0.92
HCG, 100% PES	MEGANA, 5 x 5	0.75	<0.01	<0.01	>30	>30	-4.5 / -1.6	0.65
CCF, 100% PES	NEGASTAT, 2.5 x 2.5	0.90	<0.01	<0.01	<0.01	>30	-4.8 / -0.7	0.86
CCG, 100% PES	NEGASTAT, 5 x 5	0.65	<0.01	<0.01	>60	>60	-9.0 / -2.6	0.71
PCG, PES / CO	no	0.00	12.82	20.16	>60	>60	>-15 / -15 ... -1	0.00
PEG, 100% PES	no	0.00	>60	>60	>60	>60	>-15 / >-15	0.00

Note 1. *Calculation: 1-[(surface potential by earthing)-(isolated surface potential)].*

many) which we used, the exact surface potential after earthing was not so readily measurable. A faster field meter should be used (as in the case of the STFI Induction Decay Method).

Table 1 shows an overview of the results. Deviations to the S value also result in the scattering of the tribo-charging. Furthermore, corona discharges appear, particularly at high surface potentials. Nevertheless the correlation is good.

The described correlation is being further investigated in current national STFI research projects.

Test method to determine the body potential and the charge transfer by earing electrostatically dissipative protective clothing [4]

Introduction

Protective clothing can be electrostatically charged by wearing (for example, when walking, in sliding across and rising a seat, through the removal of outer garments, when rubbing on the garment layers, by induction in a field of charged subjects).

The level of charging can be incendiary in the case of a rapid discharge. Generally, however, it does not cause a risk of explosion in dangerous areas, if the person is grounded by dissipative shoes and suitable floors.

In areas where the risk of explosion is prevalent, the wearing of electrostatically dissipative protective clothing is required.

The electrostatic dissipation of protective clothing is primarily determined by the dissipation of the materials from which the garment are manufactured. The testing and assessment of the materials are given according to EN 1149-1 (suitable for electrostatically homogeneous materials) or to EN 1149-3 (also suitable for electrostatically inhomogenous materials).

In addition, the electrostatic behaviour of the protective clothing is determined by the guarantee of the continuity of the dissipation across seams and by design elements. In the following test method, this will be applied for the testing and assessment of the electrostatically dissipative behaviour of complete protective clothing under test conditions simulating everyday practice on a human.

Scope

It is the purpose of the test method to determine the ignition risk of protective clothing made from dissipative materials, due to possible dangerous electrostatic charging of the wearer or the garment.

Principle

The test set-up is schematically shown in Figure 4. A male human (the operator) is clothed in a specified undergarment and the protective clothing tested as the outer garment. The outer garment is rendered highly tribo-electric, charged by rubbing by a tester with selected textile material on the back of the operator.

The body potential, which is caused by the generated charge on the clothing, is measured by means of an electrostatic voltage meter. A specified earthed probe (ball electrode) is brought near the charged area of the garment to measure the possible charge transfer in the type of spark- or brush discharges, via a rapid storage oscilloscope. The electrostatic ignition risk is evaluated based on the degree of charge transfer.

Procedure

Normal conditions - Person earthed

Under normal, required operating conditions within explosion-prone areas, the person is grounded by means of dissipative footwear. The test person, dressed in a special undergarment and in the testing outer garment, stands on a metal plate which lies on an insolating footstool. The footstool stands on a grounded metal plate. The metal plate can be connected via a switch (S_W) through a resistor of $R = 10^9\ \Omega$ to the metal plate (simulating dissipative footwear). No further earthed subjects (within a minimum distance of 1 m) are placed near the person.

The charging of the person is carried out with a closed switch. A third person (insulated to earth) rubs a package of the rubbing material 10 times strongly and fast (for total period of c. 5 s) along the back of the test person. The dimension (rubbing area) of the packages amounts to about 30×10 cm.

Before starting the triboelectric charging, the initial value of the body potential will be measured, which should be c. 0 V. Likewise, the surface potential of the outer garment is controlled, especially on the back, by means of an influence-E-field meter. The initial value must be less than 200 V. If needed, the garments are to be discharged by means of a static neutraliser.

With the beginning of the triboelectric charging, the time-related data of the body potential is recorded via a static voltmeter by means of a recording device. Immediately after the 10 friction cycles, the surface potential of the outer garment is monitored and recorded at a

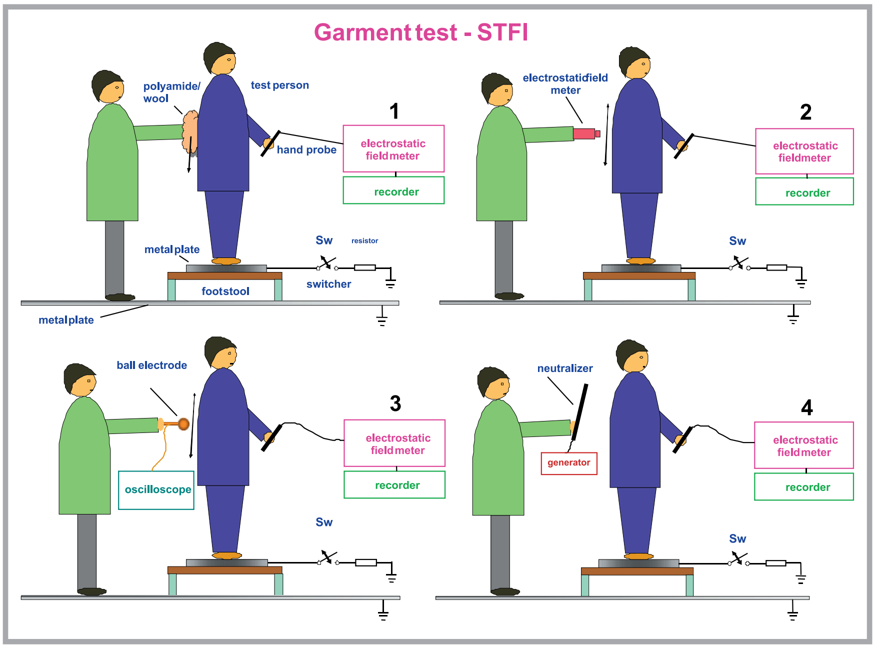

Figure 4. *STFI Charge transfer garment test;* S_W *– switch.*

minimum of 3 different places on the rubbed back areas.

Immediately after the triboelectric charging and the rapid monitoring of the surface potential, the ball electrode is brought close to the rubbed back and other places of the outer garment. By means of the oscilloscope, we observe whether charge transfer can be measured through air distances. Direct contact of the ball with the garment surface is to be avoided. The ball is repeatedly brought close to the areas, paying particular attention to exposed places such as distant folds or places with accessories (logos, reflective stripes, buttons, zips).

If an ignition event cannot be recorded within the duration of one minute, the test is finished.

The testing procedure is repeated 10 times altogether. Before beginning a new test, the outer garment should be discharged by the neutraliser if necessary.

Worst case conditions - person not grounded

Under practical working conditions, it can happen in extreme cases that no sufficient grounding of the person is ensured. An orienting examination of the electrostatic behaviour of the protective clothing under such worst-case conditions is possible, if the switch S_W is opened before beginning the test.

The test is further carried out according to the method given above.

Calculation and expression of results

Based on the time-related charge transfer visualised by the dependence $U = f(t)$, and measured with an oscilloscope, the transferred charge Q in [nC] will be calculated by integration.

$$Q = \int I * dt = \frac{1}{R_S} \int U * dt \qquad (3)$$

where:
U - in V,
t - in ns,
R_S - shunt resistor of the ball electrode in Ω.

For the assessment of the electrostatic ignition risk, the highest single value Q of the measured charge transfer is used.

Based on the time-related body potential diagrams registered by recorder, the mean value from the 10 highest voltage peaks is calculated.

Based on the surface potential at the triboelectric charged garment, measured by an influence-E-field meter, the mean value from the 10 highest single values is calculated.

Protective clothing against the thermal risks of an electrical arc – Requirements for development, testing and evaluation

Electrical arc accidents during maintenance activities under live working conditions happen rarely, although statistics demonstrate that the risk is constant, and the injuries which can occur may be very harmful and sometimes fatal. The use of a suitable protective clothing tested under conditions approximating real-life is thus very important.

Following the key aspect of the Directive 89/686/EEC to protect the wearer with the Personal Protective Equipment (PPE), an evaluation based on simplified parameters seems to be insufficient. Therefore this paper describes the testing and evaluation phases of protective clothing against the thermal risk of an electrical arc, based on a practice-oriented test standard.

Although there are different ways of exposing textile fabrics and garments to an electrical arc, the paper demonstrates in brief the imperative to define objective test parameters for reproducible testing and an appropriate evaluation of the protection effect. Safety-relevant parameters for the fabric and design requirements for the whole garment are given.

A practically-oriented method for testing textile material and garments is presented by introducing the test set-up and procedure development of the European Box-Test-Standard TS 50354 [5]. When testing according to this standard, the radiant and convective heat effects of electric arcs are considered, as well as the consequences of metal splash and vapour wich always accompany real arcing faults. By extending the test procedure of TS 50354, measurement and evaluation of the incident energy transmitting the sample is carried out, in addition to the visual assessment of the material or garment heat response (after-flame, hole formation, melting through, dripping, etc). The heat flux measurement by calorimeters simulating the human skin's behaviour allows the objective assessment of the protection level by comparing the measured incident energy with the Stoll criterion describing the onset of second-degree skin burns.

Figure 5 shows details of the test device for fabrics (method 1). The rear of the test plate shows the two calorimeters according to EN 367 with thermocouples of the T type. This allows the measurement of the heat flux through the material, and an assessment of the burning risks (in comparison to the Stoll curve for second-degree skin burns). Figure 6 shows the instrumented mannequin for the test of ready-made garments (method 2).

The test standard was developed in co-operation with the Saxon Textile Re-

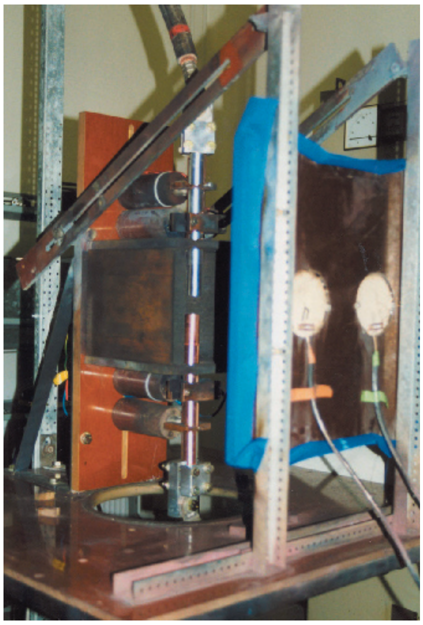

Figure 5. *Set of the electrodes with test plate, calorimeters (Method 1).*

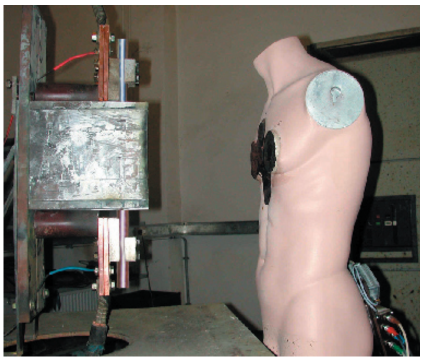

Figure 6. *Test mannequin with calorimeters in the chest area (Method 2).*

search Institute Chemnitz (STFI) and the Technische Universität Ilmenau.

Summary

The STFI Induction Decay Method was critically discussed, and the possible directions of development for the STFI's investigations were indicated.

A special test method for examining antistatic behaviour was developed by STFI. The electrostatic hazard level (e.g. charge transfer) is assessed by a test with dressed and charged protective clothing.

The paper also deals with the research and development for the Box Test Standard, an international standard for testing and evaluating the protection effect of textiles against the thermal risks of an electrical arc. Such accidents can occur during work on electrical power supply equipment under live-working conditions, and confront the worker with extreme temperatures up to 10,000°C, flame exposures, radiant heat and splashes of molten metal. Based on cooperation with the TU Ilmenau department's electrical power supply, a practically-oriented test and evaluation standard was developed for the European standard ENV 50354. The standard allows the test of textile fabrics as well as emtire garments in the given protection classes.

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