Ryszard Kacprzyk

Study of Electric Fields in Fabric Surroundings

Institute of Electrical Engineering Fundamentals
Wrocław University of Technology
Wyb. Wyspiańskiego 27, 50-370 Wrocław, Poland,
E-mail: ryszard.kacprzyk@pwr.wroc.pl

Abstract
In this paper, research into potential distributions acquired during the tribo-electrification of fabrics is presented. It was shown that fabrics with non-uniform field distributions, including those made of natural fibres, can generate strong alternating fields in dynamic conditions, exceeding a level of 10^4 V/m. The conclusion made was that a comparison of the strength of electric fields occurring in the surroundings of fabrics made of natural fibres as well as those produced from any other sources may help in the rational assessment of the harmful effect of static and slow-alternating electric fields on the human body.

Key words: *fabrics, electrostatics, electric field.*

Introduction

The static electrification phenomenon is employed in numerous technological processes [1, 2], which may be the reason for the numerous serious problems and failures [2, 3]. The disadvantageous phenomena associated with static electrification also occur in textile technologies. The introduction of synthetic fibre technology into the textile industry is one of the most important reasons for the increased interest in the problem of static electrification. Thermoplastics (polypropylene, polyesters, polyamides, etc.), widely employed as starting materials, are characterised by a very high volume resistivity. A significant increase in the resistivity of the fibres of the material in comparison with the majority of fibres from natural origins leads, on the one hand, to their easy electrification and the occurrence of an electric charge, and on the other to the long-lasting storage of this charge. The problem above is illustrated in ***Table 1*** by the values of the volume resistivity of conventional materials from the polysaccharide group, like wood, cotton, paper and other polymers, currently commonly used in the textile industry.

The ability of an object made of material with a relative electrical permittivity ε and volume resistivity ρ_V to store electric charge can be roughly assessed by the so-called Maxwell time constant τ_M:

$$\tau_M = \varepsilon_0 \, \varepsilon \, \rho_V \quad (1)$$

where $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m is the electric permittivity of a vacuum.

From the data collected in ***Table 1***, it follows that in the case of polymers, the storage time of the electric charge exceeds the boundary value of 10^{-3} s i.e., which is assumed to be secure in terms of static electricity [4]. The electrification and storage of electric charge in an object like a fabric leads to the occurrence of an electric field in its surroundings. The electric field developed may interact with other objects, and its strength may exceed the electric strength of air, which, in consequence, may lead to electrostatic discharges (ESD). The existence of these strong electric fields in the surroundings of a fabric may result in numerous harmful effects. In the range of low values of the electric field intensity, the surface may show an excessive tendency to get dirty and “stick to” guarded components, whereas at higher values electrostatic discharges (ESD) may occur. The uncontrolled ESD discharge can, on the one hand, reduce the comfort of using a product (clothes, upholstery and carpets) and on the other lead to serious losses, especially in an environment ‘saturated’ with electronic devices.

Another field where strong static and slow-alternating electric fields play an important role is the problem of endangering a human being. It is commonly recognised that a strong electric field may have a harmful impact on the health condition, which has its reflection in regulations legally binding in Poland [5]. Some doubts concerning the direct influence of strong low frequency electric fields on the human body may arise from the commonly accepted Maxwell equations and from knowledge of the electrical proper-

Table 1. *Electrical properties of selected solid materials.*

Material	Volume resistivity ρ_V, Ωm	Maxwell time constant, s
wood, paper, cotton	$10^6 – 10^{10}$	$10^{-4} – 10^{-1}$
polypropylene	$10^{16} – 10^{18}$	$10^5 – 10^7$
polyester	$10^{15} – 10^{16}$	$10^4 – 10^5$
polyamide	$10^{13} – 10^{15}$	$10^2 – 10^4$

ties of the 'material' forming the subtle structure of a human being. The doubts mentioned are also deepened by the wide range of permissible/boundary values of static and slow-alternating fields included in the legal regulations of numerous countries.

One of the most frequent electrification processes both in the technological and human environment is trybo-electrification. This is a process which is common and permanent. The commonness of the process means that it also appears in the case of contact and friction between a fabric/fibre and human skin. The employment of fabrics made of natural material/fibres by humans for several thousand years proves the commonly accepted statement about their positive influence on the health and condition of human beings, not to mention the comfort which is given to the skin. The results of measurements of the strength of an electric field generated by the charge developed in the process of fabrics rubbing may be a source of valuable information about the nature of the fabrics and the harmfulness of static and low frequency fields existing in the contemporary human environment, irrespective of the origin of the fields.

The remarks above concerning the effect of strong electric fields on a living organism relate to the situation when the object- organism is coupled with the source of the field by an ambient considered as an ideal dielectric, i.e. air. The last remark means that the maximum value of the electric field intensity that can act on the object is restricted by the electrical strength of air (ca. 3 MV/m)

Transformation of fields in dynamic systems

The properties of fabrics, especially because of their occurrence in the close vicinity of humans, have been the subject of investigations for many years. In the context of the direct dangers that exist for a human body subjected to the impact of strong electric fields, an interesting issue seems to be the assessment of the amplitude and frequency of the oscillation of the electric field intensity in the close vicinity of human skin when it is covered by a fabric capable of storing the electric charge.

Taking into account the electrical properties of consecutive layers of an epidermis,

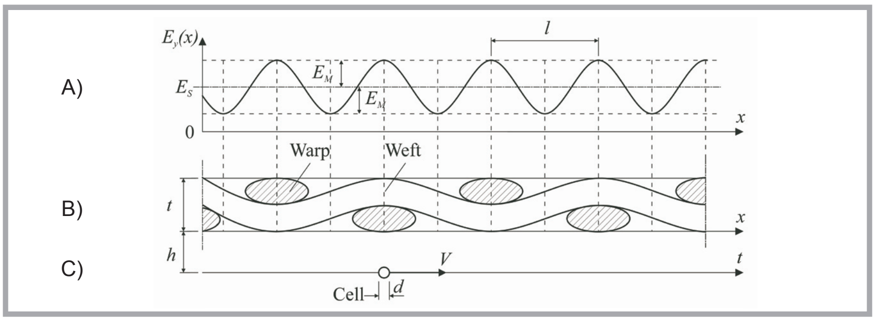

Figure 1. *Electric field acting on a skin cell during their mutual displacement. A) Distribution of the normal component of the electric field $E_y(x)$; B) cross section of the fabric (along the weft); C) a skin cell moving with velocity v in the x direction relative to the fabric surface.*

we can assume that the potential effect of strong low frequency electric fields, connected with the movement of free charge and associated energy absorption, may occur in the living cells of the granule-cell layer (*Stratum granulosum*) of the epidermis, which has a dimension of the order of 10 μm [6].

The surface of skin, including the cells in the granular layer, may be subjected to the impact of an electric field generated by arbitrary outer sources. When the source of the electric field is a fabric which shows regular oscillation of the potential and electric field along the weft or warp, the problem can be illustrated by the diagram shown in ***Figure 1***.

If the largest dimension *d* of the conducting epidermis cell fulfills the relationship:

$$d << l \qquad (2)$$

where *l* is the distance between weft or wrap threads, then the cell may be considered as a 'point' whose coordinate *'x'* may change with the mutual displacement of the cell (point) and the source of the field (fabric). In the case presented in ***Figure 1***, the run of the normal component of the strength of the electric field acting on a conductive surface may be roughly approximated by a sinusoidal distribution.

$$E_y(x) = E_s + \frac{1}{2} E_M \sin\left(2\pi \frac{x}{l}\right) \qquad (3)$$

where E_s is the static component, E_M the amplitude of the alternate component, and *l* is the step of the weft/wrap.

The relative movement of the fabric and the selected point of the skin - cell surface can be described by the shift *x* occurring, for instance, along the weft. In the case of periodic movements, the displacement *x* has, in a typical condition, a near sinusoidal character. Roughly assuming that the movement is rectilinear with a constant velocity *v*, implying $x=vt$, dependence (3) can then be expressed as:

$$E_y(t) = E_s + \frac{1}{2} E_M \sin \omega t \qquad (4)$$

where:

$$\omega = 2\pi \frac{v}{l} = 2\pi f \qquad (5)$$

This change in the time of (linearly) displacement *x* leads to the transformation of the static field existing in the fabric surroundings (***Figure 1.A***) into an alternating field at the point of the cell location. Dependence (4) highlights that in actual fact at the point of the cell location, which moves in relation to the fabric surface with velocity *v*, besides the static field there is also an alternate field changing at a frequency established by dependence (5). A comparison of the sizes of cells encountered in the granular layer of an epidermis and the step of the weft/wrap shows that they can be considered as 'points'. Taking into account the natural movement of a sleeve relative to the surface of an arm during a walk, and assuming that v = 10 mm/sec and l = 0.2 mm (typical of a shirt fabric), we will obtain the frequency f = 50 Hz for the basic harmonic of the alternating field.

The considerations above show that in the case of a fabric made of a homogenous yarn which is electrically charged, the skin (and its cells) in contact with the fabric is, in dynamic conditions, subjected to the action of alternating electric fields with a frequency comparable to that in industrial conditions.

If we consider a periodic distribution of the charge (electric field, potential)

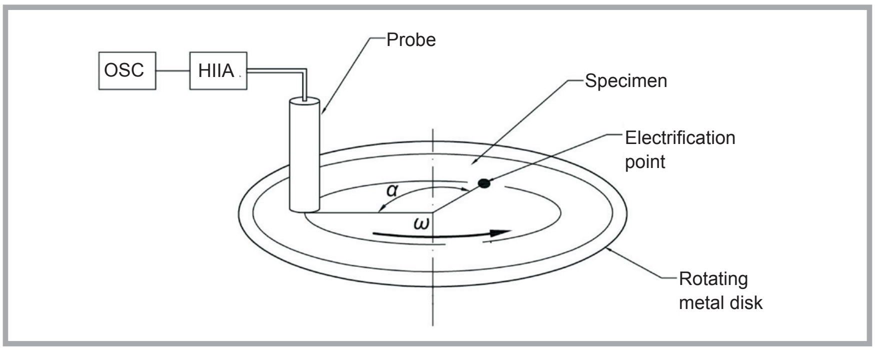

Figure 2. *Measurement set-up for testing the potential distribution in the surface of a fabric in conditions of permanent electrification by friction. OSC – oscilloscope, HIIA – high input impedance amplifier.*

in the fabric and the conditions of relative movement – the velocity/frequency of the shifts and their amplitude (step), then we should take into account the occurrence of hazards originating from the electric fields in the frequency range from 1 Hz to 1000 Hz.

Measurements of the potential distribution in the surface of fabrics

In the measurements of potential distributions, potential (induction) probes are usually used [7]. The probes, which enable the observation of the regularity of the potential distribution in the surface of a fabric, must have an appropriate resolution in the observation plane and should be located as close as possible to the surface of the object tested [8]. The local potential value of the object is determined on the basis of measurements (direct method) or observations (compensation method) of the electric charge induced on the sensitive surface of the probe. Because of the averaging property of the probe (Gauss law), its diameter should be as small as possible or at least comparable with the dimension of the detail of the object being tested. In the last case the resulting (obtained) potential distributions may strongly differ from the real ones (the potential distribution will be 'smoothened'), and the results obtained should be treated rather as a tendency than a real distribution. It is worth emphasising that because of the "smoothening" effect (introduced by the induction probes), the values of the local electrical field intensity (determined by the differentiation of potential distributions) will be lower than those appearing in reality. Usually, the probe position may be set and determined with better accuracy than the probe resolution. That is why the potential distributions (one dimensional) are presented with a higher density of measurement points from the probe resolution [9]. It should also be noted that measurements of the potential distribution (2D - surface distributions) with a resolution comparable with the warp/weft diameter (and fabric thickness) do not consider the 3D structure of the object, and the approaching of the fabric by the probe may change the local potential value (in any case i.e. applying the direct or compensation measurement method) [10]. Summarising, the potential distributions experimentally determined should be treated as a very rough approximation of the real state.

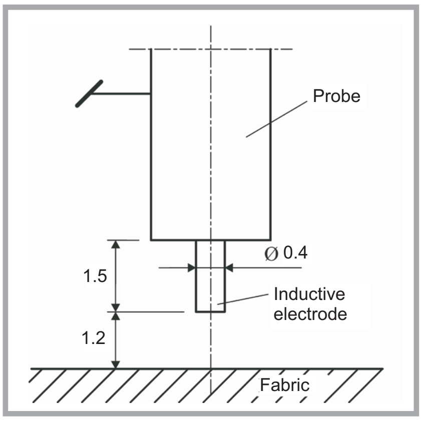

Figure 3. *Probe for measurement of the potential distribution, dimensions in mm.*

In the case of fabrics with an anticipated short time of charge relaxation (for example, fabrics made of natural fibres), measurement of the potential distribution can be carried out only in dynamic conditions. In the measurement, we used a common inductive probe equipped with a high input impedance amplifier (HIIA). The inductive electrode of the probe (its sensitive surface) "observed" the sample surface after the delay time, counted from the moment of stopping the electrification. The delay time was controlled by the rotational speed of the disc and by the angular position of the point of electrification (relative to the probe location) – angle α. A scheme of the measurement set-up is shown in ***Figure 2***.

A sample of the fabric tested was fastened on one of its sides to a conducting and grounded metal disc with a diameter of 120 mm, which rotated at a speed of ω = 2000 - 2800 r.p.m. Measurement of the potential distribution was performed with the use of a probe equipped with an inductive electrode of 0.40 mm diameter. The electrode was placed at a distance of 0.8 ± 0.2 mm above the surface of the rotating fabric sample and at a distance of r = 50 mm from the axis of the disc. The voltage signal from the inductive electrode of the sample controlled the preamplifier (impedance transformer - HIIA) placed in the probe housing. After its amplification, the signal was introduced into the input of a Tektronix TDS 100 2B memory oscilloscope. A scheme of the probe is shown in ***Figure 3***. The arrangement of the measurement system ensured the probe resolution at a level of 1.2 – 1.5 mm. Measurements of the potential were carried out 20 ms (delay time) after charging the sample by friction. The scaling of the potential measurement path was made by the method of field source substitution. In place of the disc with the fabric, a calibration disc was introduced containing flat electrodes firmly connected to a source of constant voltage with a known value. The measurement of the probe output voltage (with the oscilloscope) at a set value of the voltage of the calibration disc enabled the scaling of the entire

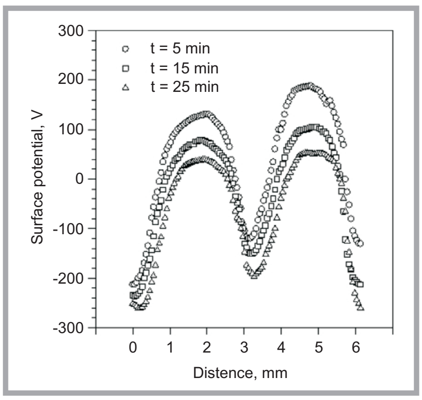

Figure 4. *Potential distribution in the vicinity of a PP-PA fabric placed on a guarded surface after tribo-electrisation (three-time friction with a PE foam under a pressure of ca 30 kPa along the weft or wrap direction). The measurements were carried out in air at T = 21 °C and h = 30% [9].*

measurement path of the voltage. Electrification by friction was carried out by exerting a small pressure (ca. 2.0 ± 0.6 kPa) on the surface of the fabric using a fingertip. The linear velocity of the mutual movement of the fabric and the fingertip ranged from 10 to 15 m/s. The measurements and conditioning of the samples were carried out in air at temperature T = 23 ± 1 °C and relative humidity h = 47 ± 3%.

Results of measurements and discussion

Potential and electric field distributions in the vicinity of the surface of a fabric made of synthetic fibres

Previous, direct measurements of potential distributions confirmed that in synthetic fabrics exposed to contact and/or friction, the spatial and surface periodicity of oscillations of the potential and electric field can be observed [9]. The periodicity of the field is determined by the structure of the fabric, especially by the diameter of the yarn it was made of.

A typical potential distribution along the warp of a fabric made of synthetic yarns of PP-PA (weft and wrap, respectively) without finishing and showing good insulating properties, (i.e. high value of time constant τ_M), obtained in static conditions is shown in ***Figure 4***.

Assuming the lack of any boundary effects (especially the multi-pole nature of the electric field source characteristic for an electrified fabric), the E_y value of the electric field intensity (normal component) at the gap made between the fabric and the grounded object (human body) may be roughly estimated from the equation:

$$E_y \cong \frac{\varepsilon U}{t + \varepsilon l} \qquad (6)$$

where U is the local value of the potential, t the average thickness of the fabric, ε the resulting value of the electric permittivity of the fabric, and l is the thickness of the air gap.

Assuming the values ε = 1.5 (the rather low value of ε results from the fact that the fabric is a kind of 'composite' of a solid dielectric-air), t = 0.6 mm and l = 1.0 mm, we can get for voltages like the ones in ***Figure 4*** values of the electric field E_y at a level of 10^5 V/m.

The value E_x of the tangent component of the field can be determined, under the same assumptions, from the dependence:

$$E_x \cong -\frac{dU}{dx} \qquad (7)$$

The differentiation of the potential distribution from ***Figure 4*** gives E_x values which do not exceed 10^6 V/m i.e. the value close to the electric strength of air.

In the case of fabrics with a long relaxation time, τ_M, fields with this value of strength may be maintained for a period of several tens of minute or even more, at least in the surface of a clean fabric.

Potential distributions of fabrics made of natural fibres

Due to the anticipated short relaxation time of the charge in the fabrics made of natural fibres, measurements were made in dynamic conditions using the measurement set-up described in section 3. The results of the measurements of the potential distribution obtained for a cotton fabric electrified by a fingertip are shown in ***Figure 5***.

Rough estimations of the electric field intensity based on dependence (6) for a sample of cotton fabric with a thickness of t = 500 μm, l = 1.0 mm and electric permittivity ε ≅ 1.6 give values of E_y at a level of 10^5 V/m.

The diagram presented in ***Figure 5*** shows the potential distribution in the surface of a fabric measured along the perimeter of a circle with a radius of r = 50 mm (equal to the distance between the probe and disc axis). The period of the analysis (period of complete rotation of the disc) ranged from 20 to 25 ms. Similar time diagrams were observed in the case of a cotton fabric electrified by the friction of a polypropylene unwoven fabric.

The character of the diagram was similar in the case of a wool fabric, but the peak values of voltages measured exceeded the level of 1500 V during electrification by rubbing with skin and 6800 V during rubbing with a polypropylene unwoven fabric. The values of the E_y component estimated from dependence (6) for t = 1800 μm and the value of electric permittivity ε ≅ 1.2 were $E_y = 6.0 \times 10^5$ V/m and $E_y = 2.7 \times 10^6$ V/m, respectively. Higher values of voltages resulted from the significantly longer relaxation time of wool, τ_{MW}, in comparison with the relaxation time of cotton τ_{MB} (the values of τ_M were determined in the following conditions: T = 23 ± 1 °C and relative humidity h = 61 ± 3%, and for electrification by rubbing with polypropylene - τ_{MW} = 25 ± 5 s & τ_{MB} = 15 ± 5 ms, respectively). A strong correlation of the peak values of measured voltages and relaxation times with the 'material' coming in contact with the surface of the fabric was found. The results depended on the properties of the skin of the person carrying out the tests. The values of voltages presented above, measured in dynamic conditions, show that in the case of fabrics made of natural fibres, the values of the electric field intensity (estimated on the basis of dependences (6) and (7)) occurring in their surroundings may also achieve a similar level to those typical of synthetic fabrics, i.e. 10^5 to10^6 V/m.

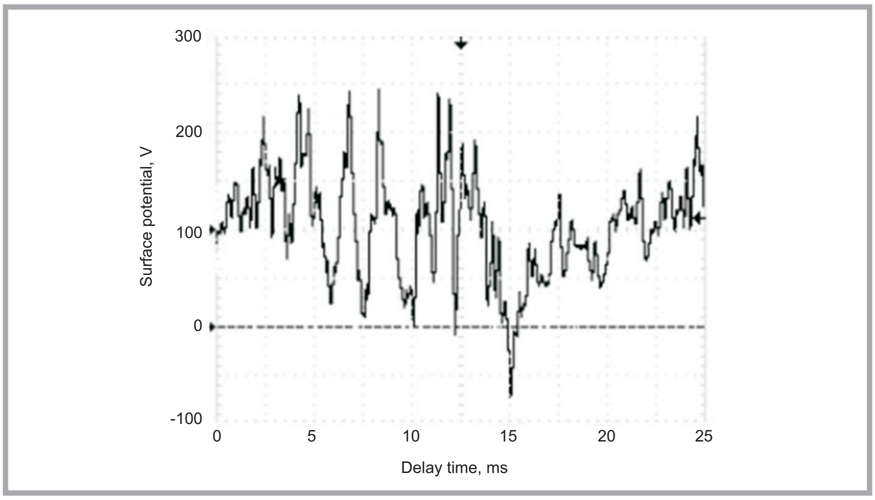

Figure 5. *Potential distributions in a cotton fabric (jeans) measured 20 ms after the moment of being touching by a fingertip (pressure ca 2.0±0.6 kPa). Measurement conditions: T=23±1 °C, h = 47 ± 3%.*

Table 2. *Values of the strength of electric fields occurring in the human environment*

Item	Source of field	Strength of field, E, V/m	Type of field
1	The earth's electric field	$10^2 – 10^3$	macro, static
2	The field in the vicinity of components made of plastic (including fabrics)	$10^2 – 10^5$	macro, static
3	Fields in the range of a fabric structure	$10^2 – 10^6$	micro, static/alternate
4	Storm cloud discharges	$10^4 – 3×10^6$	macro, static slow-alternating
5	Fields under the high voltage transmission lines (50 Hz)	$<10^4$	macro, alternate
6	Permissible values of electric field intensity in the range of 0-50 Hz [5]	10^3 10^4 (temporary)	macro, static slow-alternating

Static and low frequency electric fields in the human environment

Characteristic values of the strength of static and low frequency electric fields occurring in the human environment, as well as boundary and permissible values in terms of legal regulations [5] are collected in ***Table 2***. Due to the fact that the instruments used to measure the strength of the electric field indicate average values, the values presented in ***Table 2*** are for larger (macro) and smaller (micro) areas, starting from $1×10^{-5}$ m^2.

The values of electric field intensity estimated for selected fabrics on the basis of the measurement results mentioned above (items 2 and 3 in the ***Table 2***) show that they may approach a level limited by the electric strength of air. If we consider the effects occurring during the exploitation of the fabrics: 1) conversion of the static electric field into an alternating one (the effect was discussed in section 2) and, 2) permanent electrification by contact friction, we would be able to show that the alternating fields generated in the fabric's surroundings may significantly (1-2 orders of magnitude) exceed the permissible values, given in ***Table 2*** and item 6.

Conclusions

The results of the measurements and the considerations presented above lead to the following conclusions:

- electrification by friction of the surface of a fabric with high resistivity leads to charge distribution in the fabric surface and, in consequence, the generation of an electric field with an intensity approaching the level of $10^4 – 10^6$ V/m;
- the charge distribution may have a periodical character, changing along with the periodicity of the structure of the fabric;
- in dynamic conditions, i.e. the permanent electrification of a fabric (by friction), a field with a strength as mentioned above may occur even in the case of fabrics made of natural fibres (cotton), approaching values comparable with the electrical strength of air (wool);
- mutual movement between a fabric and objects smaller than the step of the warp/weft (a living cell of an epidermis) results in a conversion of the static electric field acting on the objects into an alternating one. The frequency of the basic harmonic of the field may range from 1 to 1000 Hz;
- the intensity of an electric field generated by the charge developed on a fabric (including fabrics made of natural fibres) may exceed, by two orders of magnitude, standard values of alternating fields currently considered as the boundary values in terms of hazard.

The many years of experience of using fabrics made of natural fibres (used in the closest vicinity of the human body) do not show any negative effect of fabrics on the health and condition of the human being. The detailed conclusions mentioned above allow us to formulate the following general conclusion:

Strong static and low frequency electric fields do not seem to have an important and direct effect on the health and condition of the human body, as is commonly assumed. The maximum values of the permissible strength of static electric fields and the fields of industrial frequency included in common standards seem to be questionable in terms of the boundary values assumed.

It seems that extensive studies in the subject of the generation of static and alternating electric fields in fabrics made of natural fibres (employed by mankind since the dawn of time) in dynamic conditions (permanent electrification, charge decay and conversion of a static electric field into an alternating one) would enable an objective assessment of their influence on human health, as well as in the context of low frequency alternating fields generated by other sources (like high voltage transmission lines, etc.).

Acknowledgment

The work was carried out within the Statutory Grant.

References

1. *Gajewski A.; Electrostatic Processes and Technologies (in Polish) Procesy i technologie elektrostatyczne. PWN, Warszawa-Kraków, 2000.*
2. *Cross J.; Electrostatics, Principles, Problems and Applications, Adam Hilger, Bristol, 1987.*
3. *Luttigens G., Glor M.; Understanding and Controlling Static Electricity. Expert-Verlag, Ehningen bei Boblingen, 1989.*
4. *PN-92 E-05201, Ochrona przed elektrycznością statyczną. Metody oceny zagrożeń wywołanych elektryzacją materiałów dielektrycznych stałych.*
5. *Rozporządzenie Ministra Środowiska z dn. 30 października 2003, w sprawie dopuszczalnych poziomów pól elektromagnetycznych w środowisku oraz sposobów sprawdzania dotrzymania tych poziomów. Dz. U. z dn. 14 listopada, 2003.*
6. *http://www.ncbi.nlm.nih.gov/pubmed/19429281*
7. *Taylor D. M., Secker P. E.; Industrial Electrostatics: Fundamentals and Measurements. Research Studies Press Ltd. N.Y. 1994.*
8. *Haynen H. T. M.; Potential Probe Measurement Analysis and Charge Distribution Determination. J. Electrostatics, v.2 (1976) p. 203-222.*
9. *Kacprzyk R., Łowkis B.; High Gradient Fabrics, Proc. 11th Int. Symposium on Electrets (ISE 11) 1-3 Oct. 2002, Novotel Hotel, Glen Waverley, Melbourne, Australia, pp. 302-305.*
10. *Kacprzyk R.; Measuring of Electrical Potential of Constant Charge Objects. Proc. of the 7th Conf. of the French Society of Electrostatics. 30 August, Montpellier, France. 2010 pp. 261-266.*

Received 29.04.2010 Reviewed 23.08.2010