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Back Corona in Fabrics

Abstract
This paper emphasises the practical aspect of the maximum surface potential of fabric. The phenomenon of back discharges (back corona) was described, and the possibility of generating these discharges on polymeric fabrics was practically confirmed. The results obtained showed that in the case of high volume-resistivity fabrics the back discharges may be the basic mechanism responsible for the limitation of the maximum value of the surface potential of fabrics placed on conducting surfaces. The limited application of Paschen's law for determining the surface's potential maximum value was also shown.

Key words: *fabrics, surface potential, electrical discharges, back corona.*

■ Introduction

An electrical charge which appears on the surface or in the volume of fibres, yarns, warp or weft or ultimately on the textile product itself, may be a source of the electric field in its structure [1] as well as in its neighbourhood [2]. Depending on the function the textiles fulfil, the effects associated with the appearance of a strong electric field may be considered as positive or negative. Among the positive effects we may mention the high filtering efficiency of the electret filters made of polymeric non-woven fabrics [3]. On the other hand, electrostatic 'gluing' (which is especially dangerous in the use of parachutes), electrostatically escalated dirtying, electrical discharges from clothing (which can cause serious damage to sensitive electronics [2]) or discharges from fabric containers (hazards associated with the likely ignition of flammable media) may be considered as negative effects, along with many others. Hazards caused by application of fabrics may also be associated with the fact that the discharges from the fabric surfaces may produce pulses supplying the object with energy of the order of many micro-joules, and thus generate electrical current pulses with an amplitude of the order of some amperes [2].

The energy W, released during the discharge from the surface of a non-conducting object (layer) depends on the total charge carried by the current pulse during the discharge, as well as on the geometry of the electrostatic material and the discharge system (the neighbourhood of grounded objects), determining the potential V of the surface the discharge is released from [4]. The value of energy released during the discharge may be determined [5] from the following general relation:

$$W \approx \frac{(V_A - V_B)Q}{2} \qquad (1)$$

where Q is the charge carried during the discharge, and V_A, V_B are average values of the surface potential before and after the discharge respectively. In the case of a fabric placed on the conducting and grounded surface, the relation (1) may be rewritten in the following form:

$$W \approx \frac{\varepsilon_0 \varepsilon S}{2d} V_A^{\,2} \qquad (2)$$

where ε_0 is the electrical permittivity of the free space (8.855×10^8 F/m), ε is the relative electrical permittivity of the fabric, d the fabric thickness, and S the total area of the surface the charge was released from during the discharge. The relation (2) was obtained for the plane-parallel geometry, and upon the assumption that there are no air gaps between the fabric and the grounded conducting surface which the fabric rests on. It was additionally assumed that the surface potential value after discharge V_B drops to zero after the discharge (total discharge). It can be demonstrated [6] that the fabric attracting force (to grounded, conducting objects), which is responsible for the 'gluing' effect, depends on the surface potential value in a similar way.

In any case, the intensity of the effects mentioned above depends on the value of the surface potential of the dielectric layer, such as the fabric placed on the conducting surface. Mechanisms limiting the maximum value of the surface potential have been studied for many years. One possible way to limit the surface potential of fabrics (e.g. floor coverings) applied in antistatic textile covering production is to introduce thin conducting fibres into their structure [7]. Strong and non-uniform electric fields generated by the charge created on their surface by tribo-electrification may lead to local partial discharges, neutralising the charge and finally the value of the surface potential. Another mechanism may be associated with so-called 'back ionisation' or the 'back corona' effect. [8 - 10].

■ Back discharge phenomenon

From the point of view of the electrical properties of an object, fabrics can be treated as non-uniform high-resistivity dielectric layers. Fabric's non-uniformity is associated with the structure of the threads (a kind of polymer fibre-air composite) as well as with the appearance of regularly distributed air channels in the fabric structure. The channels create a mesh of so-called weak points (in the sense of electrical strength) of the dielectric layer in a natural way. When one of sides of the fabric rests on a conducting surface, and the second one is covered by an electrical charge of appropriate density, electrical discharges may arise in the air channels mentioned above. Such discharges are called 'back discharges' or 'back corona' (the latter is used when the dielectric layer is permanently electrified by corona charging).

The phenomenon called 'back corona' was observed for the first time in high-resistivity powder layers in electrostatic precipitators [8]. These discharges led to a serious increase in the precipitator discharge current, as well as a visible decrease in its collecting efficiency. In the case of fabrics, we can expect the same phenomenon to occur when the electric field intensity in air channels (present in fabrics) surpassed the electrical strength of the air in the channel. This phenomenon would cause a decrease in the density of charge stored on the fabric surface, and simultaneously a maximum value of its surface potential. The phenomenon can only be observed in high resistivity fabrics, where the electrical charge (deposited during the electrification process) may be stored and collected up to a level enabling the generation of the strong electrical field (with the value necessary for electrical breakdown in the air channels).

In the first approximation, the maximum value of the surface potential of the fabric

Sample no.	Fabric thickness t,	Warp width,	Weft width,	Channel cross-section rectangle's side 1,	Channel cross-section rectangle's side 2,
	µm	µm	µm	µm	µm
1	600	1350-PP	1350-PP	45	90
2	600	1800-PP	1800-PP	150	400
3	500	1050-PP	825-PP	45	200
4	600	975-PA	600-PET	30	60
5	600	975-PA	600-PET	30	200

placed on a conducting surface may be determined from the relation:

$$V_A = E_{KR} d \qquad (3)$$

where E_{KR} is the electrical strength of the air, determined for the air gap of a thickness equal to the fabric thickness d (the air channel length is assumed to be equal to the fabric thickness). The E_{KR} value can be determined from Paschen's law, assuming a uniform distribution of the electrical field in the air channel. For the air temperature of 20 °C and for a product of pressure p and channel length d within the range 0.1 to 5×10^3 [hPa·m], Paschen's law may be written [12] in the form:

$$E_{KR} = 6{,}72\sqrt{\frac{p}{d}} + 24{,}4p \qquad (4)$$

where E_{KR} is in kV/cm, p in hPa and d in m. It should be emphasised that the potential value V_A in case of the sample resting on the conducting and grounded surface is equal to the fabric equivalent voltage U_Z.

A characteristic property of back discharges is associated with a sudden increase in discharge current value (for dielectric layers electrified by corona discharges) after surpassing the threshold field value (the field in air channels surpassing the E_{KR} value). In order to verify the stated hypothesis that the back discharges may limit the maximum value of the fabric surface's potential, the direct measurements of the surface potential and sample charging current (during their electrification by the corona method) were carried out on the samples of different polymeric fabrics.

Samples

The measurements were carried out on samples of plain fabrics made of different yarns. The yarns were made of polypropylene (PP), polyamide (PA) and polyethylenterephtalate (PET) fibres. The

yarns were free from any dyes or other additives. The geometrical data for all the measured fabrics are collected in Table 1.

The air channels in the fabric had approximately rectangular cross-section area, with dimensions the rectangle's sides 1 and 2 show in Table 1. Generally, the shape and structure of the air channels existing in a real fabric is much more complicated [9, 13] and their characteristic dimensions as well as distribution in space subordinate to a statistical distribution. The 'back discharges' phenomenon may be observed in high electrical resistivity layers only. Practically in the case of continuously charging the dielectric layer with high-stability corona discharges this phenomenon occurring only for a dielectric (fabric) volume resistivity higher then $\rho_V > 5 \times 10^8$ Ωm [10]. The low resistivity-limit value is determined by the accessible current densities during the corona charging process, as well as by the necessity of storage (by the electrified layer-fabric) charge with a high enough density to create electrical fields with values higher then E_{KR}.

The values of the half-decay time on fabric samples in the state 'as produced', measured by the field-window method [11], fell within the range of 4 to 10 s. This is why, prior to the measurements of the electrical properties, all the samples were submitted to a washing process. The process consisted of basic washing in water containing a surfactant, rinsing in water and finally rinsing in distilled water. The applied washing facilitated the removal of the textile finish. This was confirmed by measurements of the charge decay characteristics and volume resistivity. Appropriate investigations showed that the charge decay was lower than 10% after 1000 s of discharge time, and the resistivities of samples (no. 1 to 5), as measured in air at the temperature T = 22 ± 2 °C and with relative humidity h = 41 ± 2%, reached the level of $\rho_V = 2.4 \times 10^{14}$ - 1.7×10^{15} Ωm.

Measurement of the equivalent voltage

The equivalent voltage U_z was determined by application of the indirect method. The method based on the measurements of the electric field intensity in the air gap between the sample placed on a grounded metal sheet and a sensitive aperture of the field-meter (field-mill FM981-METRA). If the field meter body is at the ground potential, the U_z voltage may be determined from the relation:

$$U_Z = E\left(l + \frac{d}{\varepsilon}\right) \qquad (5)$$

where E – is the electric field intensity in the air gap l between the sample and the sensitive aperture of the field-meter, d is the sample thickness, and ε the electrical permittivity of the sample material. In the experimental set-up, the air gap thickness l fulfilled the relation $l \gg d$, and was maintained constantly at 10 mm. This allowed for the application of a simplified relation:

$$U_z = E \, l \qquad (6)$$

All the field measurements were carried out after a period of 15 seconds after the completion of the electrification process.

Air triode circuitry

A schematic picture of the applied circuit is shown in Figure 1. In the forming circuitry, the grid-corona electrode and the grid-sample distances were kept constant, and equalled 50 and 10 mm respectively. Three Ni-Cu strings in a star-shaped configuration were applied as the corona electrode; the diameter of the strings was 30 µm. The corona electrode was polarised with a constant dc voltage, equal to U_U = (+)8 kV. The grid voltage U_S was regulated within the range of 0 to 3 kV. The total surface of the sample subjected to the corona charging was
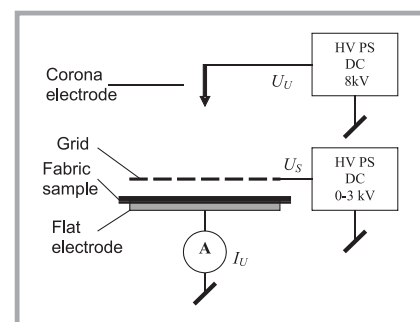

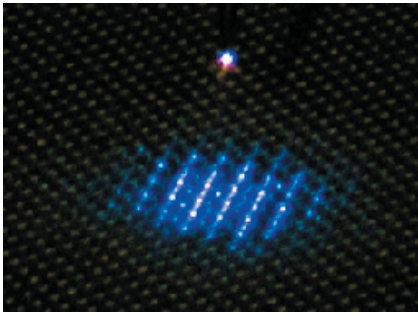*Figure 1. The air triode circuit for charging of fabric layer and measurements of corona discharge current.*

Figure 2. *Back corona phenomenon on a PP fabric (sample No 3) observed in a point-to-plane system, with a negative point, for average an current density of 5.7 µA/cm². The image was observed in air under normal conditions (pressure and temperature). The lighting point above the fabric surface represents the corona discharges near the point electrode.*

8.0×10^{-3} m². An A ammeter (type 219A electrometer) was used to measure the total discharge current I_U. The circuit was applied to electrify the fabric samples as well as to detect the back discharges. The occurrence of the back discharges led to a visible increase in the discharge current I_U value.

■ Results and discussion

The possibility of the back discharges occurring on high-resistivity polymeric fabrics was tested quantitatively in the simplified corona charging circuit, containing a point-plane electrode system only. A photograph illustrating the surface distribution of the discharge intensity is shown in Figure 2. It is apparent that the regularity of the discharge points which the glow light was emitted from is unambiguously determined by the distribution of the air channels in the fabric samples (the electrical 'weak points'). The air-triode system (shown in Figure 1) was used to determine the maximum value of the sample surface's potential. Two dependencies were measured in parallel: the sample equivalent voltage U_Z as a function of the grid voltage U_S and the dependence of the total discharge current I_U, flowing through the sample, as a function of the grid voltage. Examples of the characteristics mentioned, obtained for fabric No. 3 (Table 1) are shown in Figures 3a and 3b.

Similar dependencies were obtained for samples of all the fabrics mentioned in Table 1. A comparison of both kinds of dependencies required the selection of certain characteristic points. These were the maximum obtainable value of

the equivalent voltage (in the system with corona charging) U_{Zmax}, the 'knee' voltage U_{SS}, the grid voltage value as determined from the cross-section point of the tangents to the $U_Z(U_S)$ curve, before and after appearance of its saturation, and U_{SI} the grid voltage value, for which the sample charging current I_U increase is observed on the $I_U(U_S)$ dependency. All of the characteristic voltages mentioned above were collected in Table 2. The maximum values of the equivalent voltages U_{ZP}, calculated for all the samples on the basis of relation (4) are also shown in Table 2. The calculations were carried out upon the assumption that the air channel length was equal to the fabric thickness d.

The comparison of the results collected in Tables 1 and 2 indicated the following regularities:

- For low grid voltages U_S (before the 'knee' originating from the saturation effect, which is for $U_S < U_{SS}$), the equivalent voltage U_Z increases linearly with the increase of the grid voltage U_S – Figure 3a;
- The U_{Zmax} values observed are lower by about 100-200 V, in comparison to the estimated grid voltage U_{SS};
- In all samples, the determined values of the U_{SS} voltage are very close to the U_{SI} voltage values determined from the $I_U(U_S)$ dependencies (characteristic voltage value, for which the sudden increase in the value of the total discharge current I_U is observed), see Figures 3a and 3b.
- The U_{zmax} voltages measured for all the investigated fabrics were generally lower in comparison to the values determined from Paschen's equation.

The following mechanism is responsible for the observed regularities: increasing the equivalent voltage (or surface potential, when the sample is placed on the grounded and conducting surface) of the fabric leads to an increase in the electrical field intensity in the air channels (present in the fabrics). The process may develop until the field value (in the
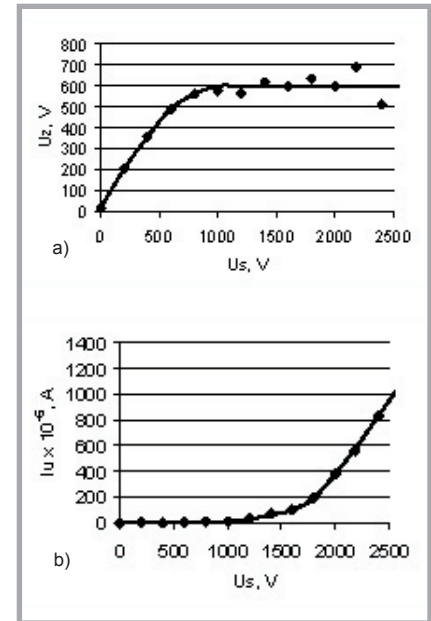

Figure 3. *Dependencies of the sample equivalent voltage U_Z – A, and the total current value I_U – B on the grid voltage U_S obtained for the sample No 3. Measurements carried out in air under the following conditions: temperature $T = 22 \pm 2$ °C, relative humidity $h = 41 \pm 2\%$.*

air channels) is equal to the air electrical strength E_{KR}; the discharges in air channels then start to appear, which finally leads to the observed saturation effect on $U_Z(U_S)$ curves (Figure 3.a). The appearance of the back discharges is confirmed by the visible increase in total discharge current I_U (for small current densities, Figure 3.b), or in the form of glow for higher densities of the discharge current (Figure 2).

■ Conclusion

The maximum value of the fabric surface's potential (or the equivalent voltage) is an important parameter characterising the electrostatic properties of non-conducting materials. The results obtained for perforated dielectric layers in the form of high volume-resistivity fabrics have shown that the back discharges may be the main mechanism determining and limiting the maximum value of the

Table 2. *Characteristic voltages on $I_U(U_S)$ and $U_Z(U_S)$ curves for fabric samples given in Table 1.*

Sample No	U_{Zmax} V	U_{SS} V	U_{SI} V	U_{ZP} V
1	1100	1300	1300	2020
2	550	700	700	2020
3	600	700	700	1720
4	420	450	500	2020
5	360	300	300	2020

surface's potential or equivalent voltage. It has also been demonstrated that the direct application of Paschen's law to the determination of the maximum value of the surface potential (or equivalent voltage) gives values which are higher in comparison to those measured. The problem of serious variation between the U_{Zmax} and U_{ZP} voltage values is under study. It has been suggested that the observed incompatibility may result from:

- the incorrectly determined average length of the air channels (assumed to be equal to the fabric thickness);
- phenomena occurring in the immediate neighbourhood of the discharge channel and associated with its direct contact with ionised air (such as the penetration of the channel space by the electrons and ions, resulting in a shortening of its equivalent length).

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