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Electrostatic charging of material webs in gravure printing presses

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ABSTRACT

This paper deals with the electrostatic charging of material webs in production machines. Measurements were made with a special measurement setup inside a gravure printing press and the results were analyzed and interpreted. In order to gather as much information as possible, the electric field strength of a free-spanning web was monitored at different positions inside the machine and under different production conditions. The measurement results confirmed theoretical principles and practical experience, such as the fact that the type of material, printing inks, coatings, machine speed, web tension, printing process and corona pretreatment have a significant effect on the level and polarity of the electrostatic charging. During the series of experiments, peak field strengths of up to 300 kV/m resulting from the charge on the web were measured and changes in the sign were detected within a very short period of time.

1. Introduction and background

During the production and processing of web materials, a wide range of problems can be observed in practice, which can often be traced back to electrostatic charging phenomena. Printers and flexible film manufacturers, for example, are affected by these problems because the material can become dangerously charged as it is transported through the production machine by guide rollers, rubber rollers, and systems such as electrostatic printing assist (ESA) or corona pretreatment systems. These highly charged material webs not only cause seemingly harmless quality problems, but in the case of discharge, serious personal risks, or ignition hazards with enormous consequential damage – as numerous fires, explosions and accidents in the past have shown – can be caused. For this reason, the industry always tries to avoid electrostatic charges or, if this is not possible, to reduce them by controlled discharging. An exception to this is the use of static electricity in utility applications, for example to simplify the manufacturing process.

To better understand and control static electricity in production machines, it must be detected quantitatively. This is done by measuring the strength of the electric field, which always depends on the level of electrostatic charge and the distance to the object being measured.

Initial measurements of the electric field strength on material webs in production machines by W. Schubert using an Electric Field Meter (EFM) have already shown that the results of laboratory tests do not or only slightly correspond to the real situation on printing presses and that these measurement results are also difficult to explain and to reproduce [1]. This is because moisture in the ambient air, pollution, or other contaminants can deposit on the surface of the webs and thus alter the actual electrostatic behavior of the material. These mostly invisible impurities can be located right next to each other on the material surface, resulting in the formation of "charged islands" with only a small distance between each other on the material web. A sign change of the electrical surface potential is therefore quite possible due to the local change between donor and acceptor [2]. Fig. 1 shows an example of this kind based on a visualized representation of a real charge distribution from a test experiment.

In this paper, therefore, further measurements and investigations are carried out on different types of material and at various positions within a gravure printing press under production conditions at a manufacturer of flexible packaging. The results are analyzed and interpreted.

2. Electric field measurement overview

In this work, measurements were carried out on free-spanning material webs, so an EFM with a wide measuring range was used. From the detected electric field strength and the distance to the measured object, the potential difference to the material web can be determined [3].

In general, however, it should be noted that in such measurements the charges on the front and back of the material web are added up during detection. In the case of so-called double-layer charging (bi-

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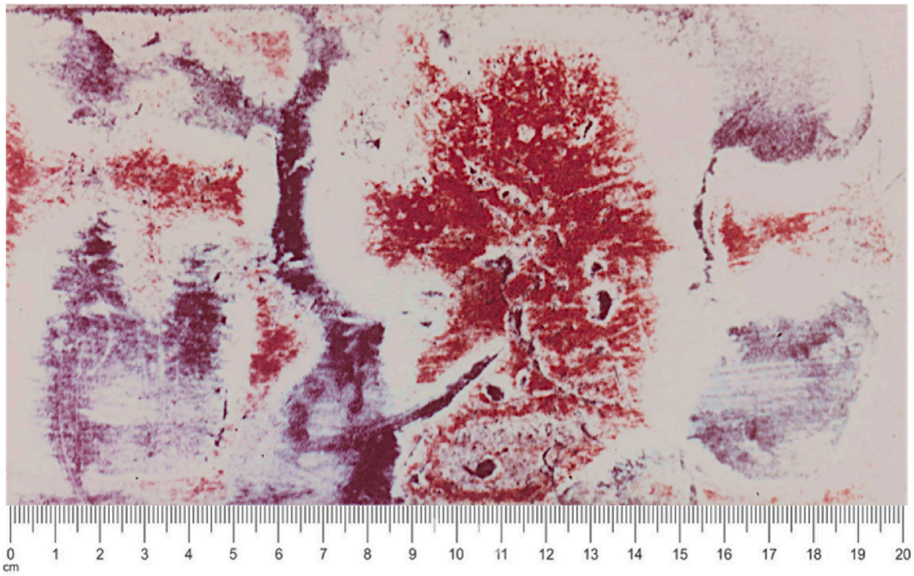

Fig. 1. Example of a visualized real charge distribution on an insulator surface. Blue areas are negatively charges, red areas are positively charged [2]. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

charge), it is possible that no or only low field strengths are measured despite very high static charges. The reason for this is that charges of opposite polarity on the front and back of the material web generate an electric field inside the film that appears neutral from the outside [4]. However, such double-layer charges can lead to disruptions in production or to dangerous discharge phenomena because very large amounts of charge can accumulate, resulting in high surface charge densities that can lead to propagating brush discharges in the event of a short circuit [5].

Composite film materials with electrically conductive layers present a further problem in measuring static electricity when these layers are in contact with the grounded conductive roller. Also, in this case, the field lines are directed to the ground potential and not outward to the electric field meter.

Field strength measurements should always be made in a homogeneous electric field so that the measured values are not falsified by field distortions caused by grounded components. Such disturbances in the form of field distortion can also be caused by the grounded electric field meter itself. When an electric field approaches the device, it causes a much denser field strength directly at the sensor head. This erroneously results in higher electric field strengths and thus to less accurate measured values. At least a more homogeneous electric field can be generated by homogenization on one side using a conductive and grounded plate [2].

It should also be noted that an electric field meter can only detect an average value over a certain area, which means that locally small "charge islands" with a high surface charge density may not be detected [4].

2.1. Measurement setup

The Eltex EMF 57 electric field meter with a variable measuring

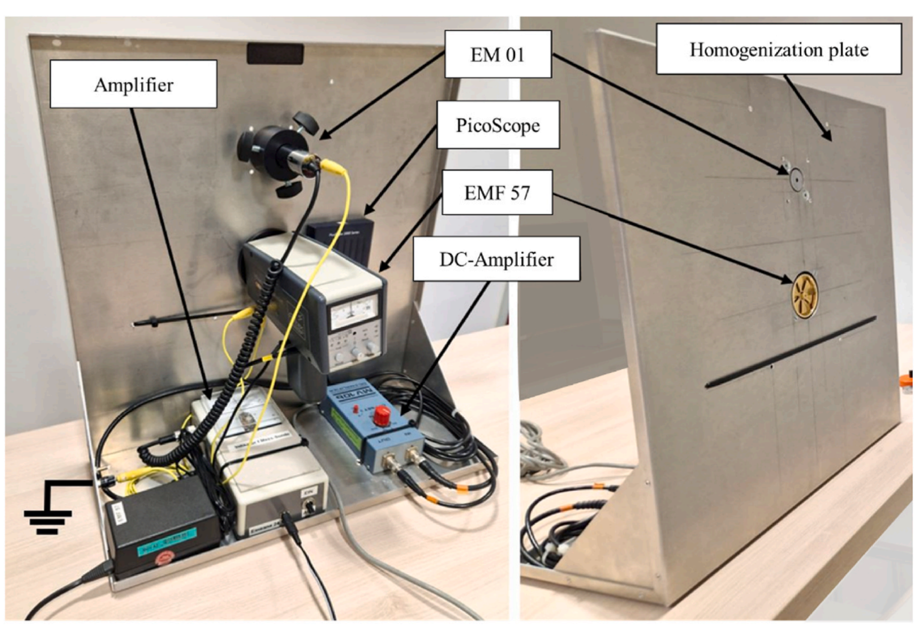

Fig. 2. Measurement setup with all components for detecting the electric field strength of moving material webs in production machines.

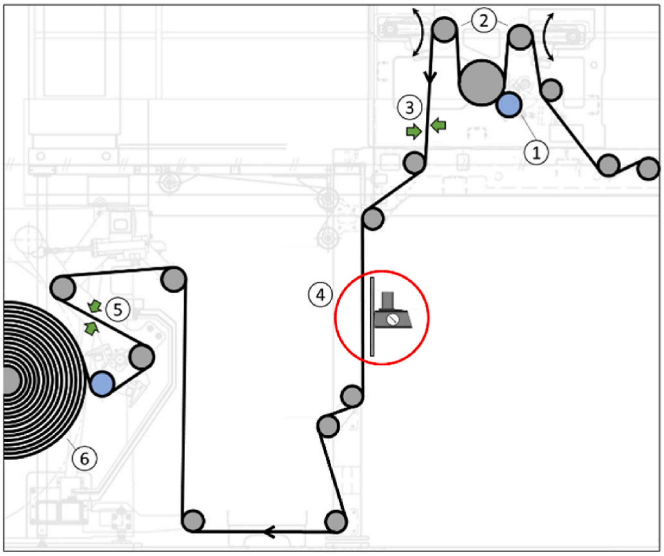

Fig. 3. Position of the setup for measuring the electric field strength of moving material webs in the area after the draw group und before the rewinder; 1: Nip roller, 2: Dancer rollers, 3: Passive ionizers, 4: Measurement setup, 5: Active ionizers, 6: Rewinder.

range of ±2 kV/m up to ±200 kV/m and an additional field meter (Eltex EM 01) with a radioactive probe were used for the measurement of material webs at speeds of several hundred meters per minute. This probe is intended to be used to verify the readings, because the electric field meter is specified with a time resolution of only 0.1 s. The radioactive probe, on the other hand, allows a theoretical measurement frequency of several kHz. However, the measurement accuracy of such radioactive-based probes is considered to be rather low [6]. Both measuring devices were mounted flush in a conductive and grounded homogenization plate and connected to an oscilloscope (Picoscope 2204A). The signal of the EM 01 probe has been inverted in the diagrams for better visibility.

The entire setup shown in Fig. 2 was then arranged inside the machine in such a way that the EMF 57 first reached the material web and then the radioactive probe. The reason for this is that the radiation emitted by the EM 01 has an ionizing effect and thus already discharges the material at this point. For optimal positioning, tripods were provided to allow the measurement setup to be placed stepless in terms of height and inclination within the rotogravure printing press.

2.2. Measurements in a web-fed rotogravure press

The following series of tests took place on a Bobst RS 6003 10-color gravure printing press with inline lamination. For the first measurements, the setup was positioned on a free-spanning web between the draw group and the rewinder (see Fig. 3). Because solvent-based inks are used on this production line, the discharge electrodes required for explosion protection could not be removed for testing purposes. The material web in the production machine was a film laminate consisting of 20 μm polypropylene, reverse print, laminating adhesive, 35 μm polypropylene and partial cold seal coating.

The measurement was made on the cold seal side at a distance of 50 mm from the web. Approximately 800 mm in front of the measuring point, there are metal guide rollers and the already mentioned draw group, which is used to control the web tension for a good production run. The draw group consists of a conductive nip roller (rubber roller) and two dancer rollers, followed by passive ionizers on both sides. Therefore, relatively low electric field strengths were detected at this point.

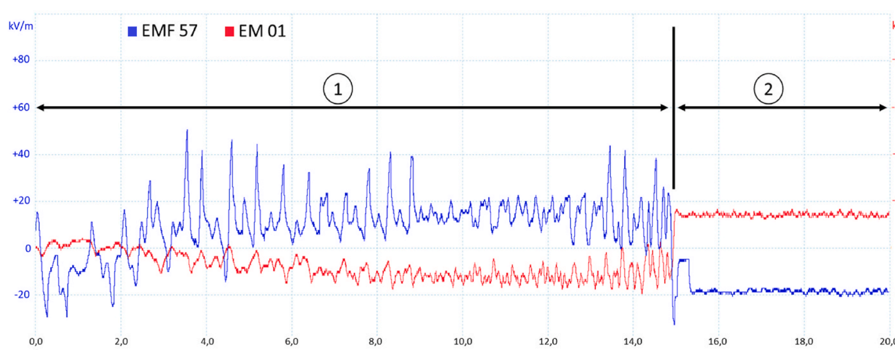

Fig. 4. Measured values of the electric field strength of the material web during machine startup and after moving down the impression rollers for printing.

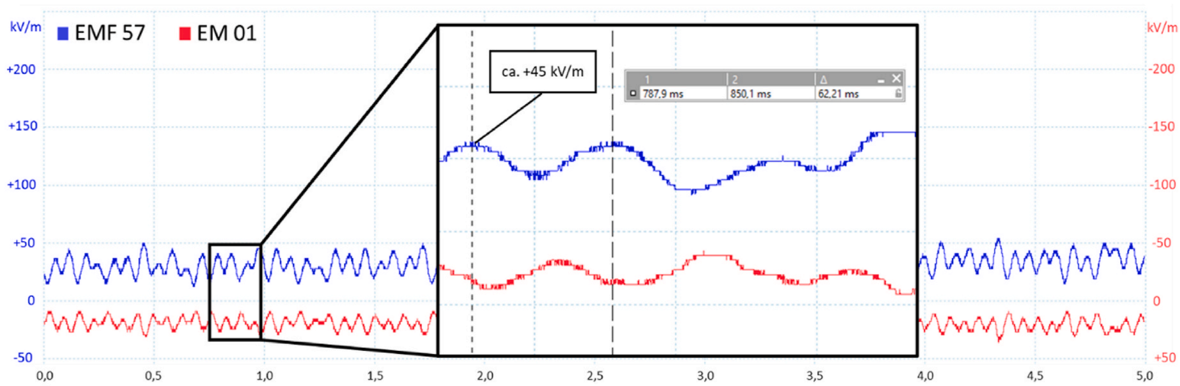

Fig. 5. Measured values of the electric field strength of the material web during normal production conditions with constant process parameters.

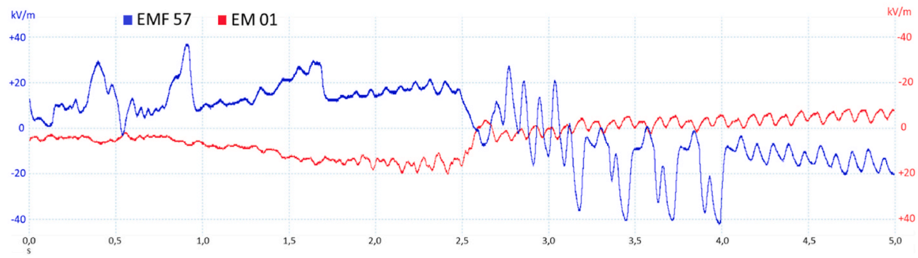

Fig. 6. Measured values of the electric field strength of the material web during the braking process of the machine.

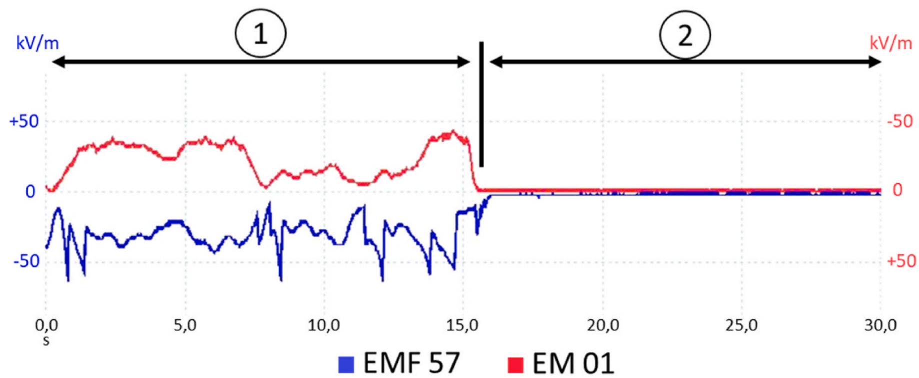

Fig. 7. Measured values of the electric field strength of the material web during change from a fully non-conducting film to a material with a conductive grounded layer.

Section 1 in Fig. 4 shows the electric field during machine startup and adjustment of the gravure printing press. Strongly fluctuating field strengths of up to 50 kV/m were observed. This is due to the very high fluctuation in web tension, resulting in increased contact pressure and increased friction between the material web and the various rollers. From time $t = 15$ s, the impression rollers were lowered, resulting in a more constant web tension and a smoothed charge curve with opposite sign of the electric field strength. At this time, there was a constant web speed of 30 m/min.

In the packaging industry, cold seal coatings are often used to seal heat-sensitive products without heat impact. This coating was applied using the gravure printing process. When the printing units were switched on, the printed material, partially coated with cold seal, reached the measurement setup after a short time. From this point on, the sign changed again and an oscillating electric field strength in the range of $+20$ kV/m to $+50$ kV/m was observed at a web speed of 450 m/min (see Fig. 5). The period duration of about 60 ms is due to the circumference of the metal guide roller with a diameter of 140 mm located in front of the measuring point.

During the braking process of the machine, which can be seen in Fig. 6, higher electric field strength fluctuations were again observed within short time intervals due to the increasing friction caused by the differential velocities between the material web and the guide rollers. Likewise, with decreasing web speed, a renewed temporary sign change of the polarity took place again, whereby clear analogies between acceleration and deceleration of the material web could be determined.

In web-fed rotogravure printing presses, it is common for the new material web to be taped edge to edge to the old material web when the substrate is changed and thus threaded through the machine. In the printing and packaging industry, this part of the web where the old and the new material touch each other is called the splice. The measurement result in Fig. 7 shows that on insulating substrates (section 1), the electric field strength due to electrostatic charging can be easily detected with the electric field meters, while after passing the splice and thus the rapid material change to a metallized lamination film (section 2), the detected signal drops to 0 kV/m. This confirms the assumption of the theory that material webs with grounded conductive layers show no or only very low electric field strength to the outside, because the electric field lines are mainly inside the film directed to the grounded layer and thus cannot be detected by the electric field meter.

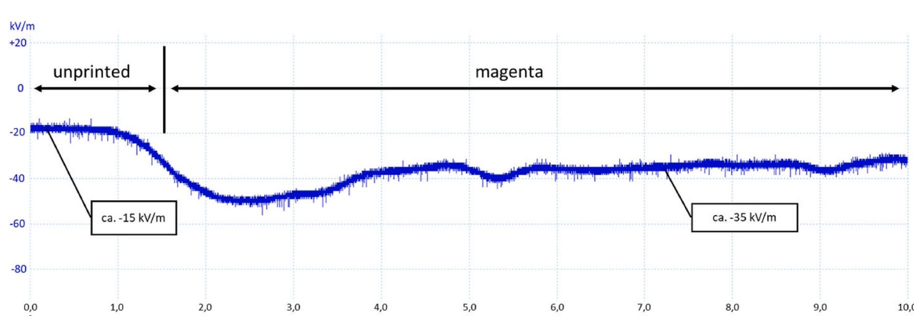

Fig. 8. Impact of different gravure printing inks on the level of electrostatic charge of a material web at constant production conditions when changing from unprinted material to material printed with magenta ($v = 30$ m/min).

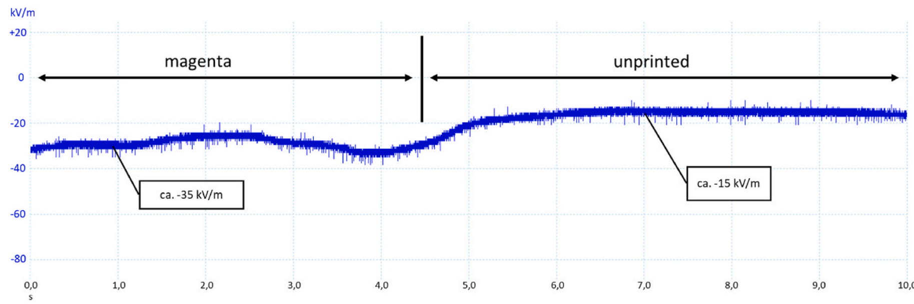

Fig. 9. Impact of different gravure printing inks on the level of electrostatic charge of a material web at constant production conditions when changing from material printed with magenta to unprinted material (v = 30 m/min).

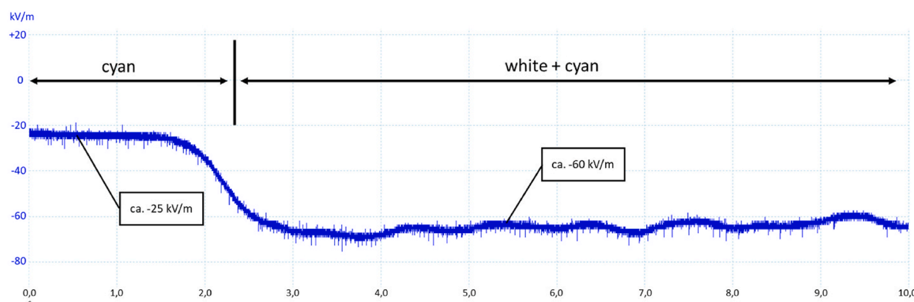

Fig. 10. Impact of different gravure printing inks on the level of electrostatic charge of a material web at constant production conditions when changing from material printed with cyan to material printed with white + cyan (v = 30 m/min). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

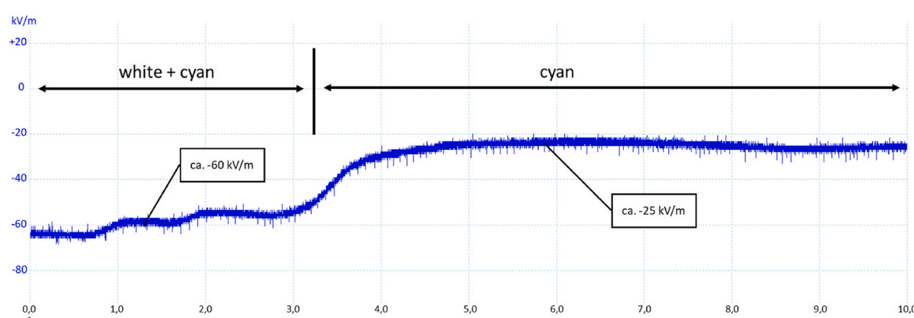

Fig. 11. Impact of different gravure printing inks on the level of electrostatic charge of a material web at constant production conditions when changing from material printed with white + cyan to material printed with cyan (v = 30 m/min). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

From the previous results, it was evident that the radioactive EM 01 probe did not provide any additional increase in information. The charge peaks that occurred for a short period of time were also detected by the EMF 57, which provided a significantly better time resolution than expected. At a web speed of 450 m/min, the curve of the electric field was clearly reproduced by both instruments. Due to the easier handling and positioning of the measurement setup, the EM 01 was not used for further measurements.

In the next series of measurements, the effect of printing inks applied to the substrate over the whole surface on the electric field strength in the area before rewinding was investigated. The measurements were taken at a constant speed of 30 m/min. The substrate was a polypropylene monofilm with a thickness of 35 μm. It was printed with cyan, magenta, and white inks alternately and in various combinations.

The following charts (Figs. 8–11) show that the printing inks have a significant impact on the level of electrostatic charging of web materials. Reproducible results for the electric field strength could be determined for each ink within a short period of time using the same measurement setup and under stable environmental conditions. The different levels of electrostatic charging can very probably be attributed to the components of the gravure printing ink, in particular its color pigments [7]. These can vary greatly from one dye to another.

In these measurements, the highest charges were detected especially when printing with white solid inks, suggesting a low conductivity of the gravure ink or a high surface resistivity of the printed substrate. Titanium dioxide is often used in white gravure printing inks to achieve an optimum degree of whiteness. Titanium dioxide has a very high permittivity of $\varepsilon_r = 111$ and can therefore be permanently charged by external influences such as an ESA or by high temperatures in the drying sections through the formation of electrets [1].

During a later production run, the measurement device was installed at the first possible point after the unwinder (see Fig. 12). After unwinding, the material web passed through a switched-off corona pretreatment system with nip roller and then over a dancer roller, which is used to compensate web tension fluctuations. The web then passes through the unused printing unit and the inactive dryer section before

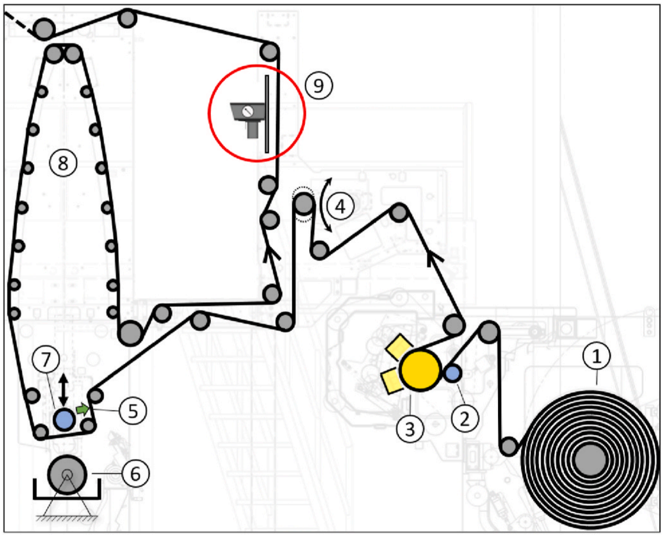

Fig. 12. Position of the setup for measuring the electric field strength of moving material webs in the area after the unwinder; 1: Unwinder, 2: Nip roller, 3: Corona pretreatment system, 4: Dancer roller, 5: Active ionizer, 6: Rotogravure cylinder, 7: Impression roller, 8: Dryer section, 9: Measurement setup.

passing through a few guide rollers and entering the measuring unit. Because no ink has been applied in this first printing unit, the substrate has no contact with the impression roller, which would otherwise be pressed against the gravure cylinder below during an active printing process. In front of the printing unit is an active discharge bar arranged on one side of the material.

At the time of this measurement, a PET was being processed that had already been corona pretreated in the previous film extrusion with a material thickness of only 12 μm. Because of the high electric field strength and because of the positioning possibilities, the distance between the homogenization plate and the web was increased to 100 mm from that moment. Section 1 in Fig. 13 shows the machine start up to the infeed speed (v = 30 m/min). Similar to the first measurement, increased electric charge fluctuations in the range of +20 kV/m to −110 kV/m were observed within a few seconds. The high web tension fluctuation could be noticed due to the very strongly moving dancer roller. In section 2 of Fig. 13 at about t = 35 s, the material web was further accelerated to production speed (v = 270 m/min), which resulted in the electric field strength reaching peaks greater than −120 kV/m. In relation to the measuring distance of 100 mm, this means that at some times an electrical surface potential of approximately 12 kV was present at a temperature of 27 °C and a relative humidity of 37 %.

In the final measurement, the effect of a corona pretreatment on the electrostatic charge of a polypropylene film with a thickness of 35 μm was investigated in more detail by running up the machine with the corona pretreatment on and then off. In this case, measurements were also taken at the first possible position after the unwinder (Fig. 12). Here, however, the material was printed in the first printing unit without ESA with black text and contour. The substrate is pressed with a defined force by the impression roller (shown in blue in Fig. 12) against the gravure cylinder below and then transported through the dryer section, where the ink dries due to the increased temperature.

This measurement experiment showed very high electric field strengths for both polarities. While a negative charge of the material web was observed during the active corona pretreatment (see Fig. 14), a charge of approximately the same amount but positive (see Fig. 15) was detected in the deactivated state at the same web speed. In section 1 of Fig. 15, a slightly negative electric field strength was initially detected. This was due to the fact that pre-treated material initially passed the measurement device during the startup. After a short distance, the sign then changed to the positive direction already mentioned (section 2).

3. Summary and conclusion

The aim of this work was to carry out further investigations into the electrostatic charging of material webs under production conditions and thus to gather more information regarding the formation and possible hazard potentials. The measurement results from the rotogravure printing press confirmed that charge peaks and sudden polarity changes can occur within a very short time, especially during acceleration and

Fig. 13. Measured values of the electric field strength of the material web during machine startup and acceleration in the area after the unwinder.

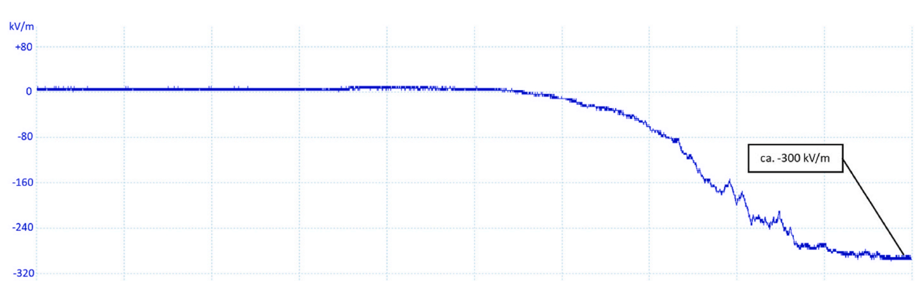

Fig. 14. Measured values of the electric field strength of the material web during acceleration with the corona pre-treatment system switched on.

Fig. 15. Measured values of the electric field strength of the material web during acceleration with the corona pre-treatment system switched off.

deceleration, due to the high fluctuations in web tension. It has also become clear that the level of electrostatic charging is strongly dependent on the type of coating and the web speed. As expected from the theoretical considerations, no measurement values could be detected for films with conductive grounded layers. Relatively high electric field strengths were measured, especially in the area after the unwinder. The sign of the electric field strength was dependent on the effect of the corona pretreatment system. It can be concluded from this that additional active or passive discharge bars should be installed in the area after the unwinders and also after the corona pretreatment systems in order to achieve the best possible discharge of the material and to avoid ignition hazards due to electrostatic charging.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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