State of the Art in Elastomeric Rollers for Printing

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Abstract

This article gives an overview on elastomeric rollers used in printing (excluding fuser and foam rollers). The focus will be on rollers used for digital printing technologies, especially electrophotography and ink-jet. Properties needed for rollers for these printing technologies will be described as well as current technologies to meet these demands. A focus here is electrical conductivity. This includes methods to achieve conductivity in elastomers and dependence of conductivity on several important parameters as for example electric field, function of time, temperature, humidity, and contact force.

Finally some required properties for rollers for non-digital printing technologies as offset and gravure will be outlined and compared with those for digital printing. Such properties are for example swelling behavior, dynamic properties, and electrical conductivity.

Introduction

Elastomeric rollers play a key role in the majority of today's printing technologies. This holds for digital (electrophotography, ink-jet) as well as "traditional" printing technologies (offset, gravure, flexo).

Most ink-jet printers have one or more elastomeric rollers for a defined paper transport. Rollers with similar function are found in electrophotographic printers. Additionally, many electrophotographic printers have elastomeric rollers for the following functions: photoconductor charging, application of toner to the photoconductor (nonmagnetic monocomponent development [1]), biased electrostatic transfer from photoconductor to paper, intermediate transfer, and fusing rollers (fusing rollers will not be discussed here; refer for example to [2]).

Offset printing uses elastomeric rollers to apply ink and fountain solution to the print plate. In gravure printing an elastomeric roller presses paper against the print cylinder so that ink is transferred to paper.

Each application requires very special properties from the elastomeric rollers. This paper will give an overview on some of the important properties and some similarities and differences between digital and "traditional" systems will be discussed. Note that typically each roller works in a special environment with many interactions with several sub systems. An in-depth discussion is out of the scope of this paper. Such information can be found in the references.

Electrophotography

Charge Rollers

The first step in electrophotography is charging of the photoconductor. Traditionally, this is accomplished with a corona [1]. Since more than a decade we see a trend towards an elastomeric roller instead of a corona in the charging position, especially for cartridges. The roller is set with light pressure against the photoconductor and a high voltage is applied. The elastomeric nature of the roller avoids damaging the fragile surface of the photoconductor. The main advantage of a roller compared to a corona is reduced generation of unwanted ozone [3].

Major requirements for rollers in the charging position are no contamination or damaging of the photoconductor, resistance to ozone, and a well defined electrical conductivity (note that these three requirements hold for all types of rollers for electrophotography that are described in this article). The lower boundary for conductivity is dictated by the need of a sufficient current for charging, the upper by avoiding sparks at photoconductor pinholes.

Typical materials are Polyurethane, ECO, and EPDM. Hardness is in the range from about 20 to 50 Shore A [4] (Rubber hardness in Shore A is equivalent to durometer type A of ASTM D 2240).

Development Rollers

Development is the third step in electrophotography after exposure and charging. Development rollers are present in practically all commercial development systems. Typically only those for nonmagnetic monocomponent development have an elastomeric cover. Such a roller is loaded with dry toner particles and a uniform layer is formed by a doctor blade. At the same time toner particles are triboelectrically charged by friction with roller and doctor blade surface. As with a charging roller, the roller is set against the photoconductor with light pressure. In image areas toner particles are driven by the electric field towards the photoconductor, whereas they remain on the roller in non-image areas. See also [1,5,6] for more information about this development system.

In addition to the requirements for charging rollers, development rollers need a defined triboelectric interaction with toner particles, a defined surface roughness (this is important for the loading and doctoring step) and a better wear resistance (toner particles and doctoring are somehow abrasive). The lower boundary for conductivity is dictated by the build-up of an electric field in the nip which is in principal similar but not identical to a charging current.

Polyurethane is the typical material of choice for development rollers. Hardness is mostly in the range from 40 to 60 Shore A.

Intermediate Transfer Rollers

Toner is (typically electrostatically) transferred from photoconductor to an intermediate transfer roller and from there to paper. Potential advantages of such a roller over direct transfer to paper are an improved image quality due to better compliance to a rough paper surface and better registration. For example the NexPress 2100 works with such rollers [7]. However, nowadays more common for the function as an intermediate carrier are belts (e. g. Xerox DocuColor 2060 or [8]) with a trend towards seamless belts.

In addition to the requirements for charging rollers, intermediate transfer rollers have different requirements for electrical conductivity, special surface characteristics and wear resistance. The lower boundary for conductivity is dictated by getting a field high enough for a high efficiency electrostatic transfer, the upper by avoiding pre-nip breakdown [9]. Surface properties are delicate. Typically a toner particle that has come in contact with an elastomeric surface sticks there because of the high contact area due to the compliance of the elastomeric material to the shape of the toner particle [10]. Therefore a thin rigid layer on top of the elastic layer is used in order to avoid this sticking [10,11]. Obviously, this requires a balance in hardness and thickness of both layers in order to maintain compliance to the paper surface. Wear resistance here is even more important than for development rollers because of contact with abrasive paper.

For example Polyurethane is the material used in the NexPress 2100.

Transfer Rollers

Transfer is the fourth step in electrophotography and comes after development. Traditionally, a corona is used to charge the back side of paper so that an electric field is generated, which transfers charged toner particles from photoconductor to paper. Similar to charge rollers, transfer rollers have replaced many coronas in this position [12,13]. Important advantages of rollers compared to coronas are less ozone and a potentially simpler system.

Major requirements for transfer rollers are identical to intermediate transfer rollers with the exception of surface properties, which are here much easier.

Typical materials for transfer rollers are Polyurethane, ECO, and EPDM. Hardness is mostly in the range from 30 to 60 Shore A. Some EPDMs are used as sponge types in order to create a wide nip at low pressure.

Electrical Conductivity

General

All of the roller types described above require a defined electrical conductivity. The following section deals with some critical aspects of this important property.

Generally, it has been and to some extent still is a major challenge to produce elastomeric materials with a well defined electrical conductivity.

The traditional approach is to add a conductive filler, especially carbon black. When narrow specifications are required, as for example a volume resistivity ρ of 10^7 Ωcm plus/minus half an order of magnitude, results are often not satisfactory. The reasons for this are percolation and process variations. Figure 1 shows a typical percolation curve (bold line), namely volume resistivity ρ as a function of carbon black contents. Note the steep part of the curve. Typically the desired value for ρ is in the steep part. A qualitative explanation for the steep part is straightforward [20]. At low concentrations the conducting carbon black particles do not touch each other and ρ is close to the low conductivity elastomeric bulk material value. Even a substantial increase in carbon black contents leads to an only low increase in conductivity. At a critical level the carbon black particles form a conductive path through the material and ρ is close to the value of carbon black. Above this critical level even significantly more carbon black will lead to only low decrease in ρ. This percolation together with always remaining process variations makes it very hard to obtain the desired conductivity level in a reproducible manner.

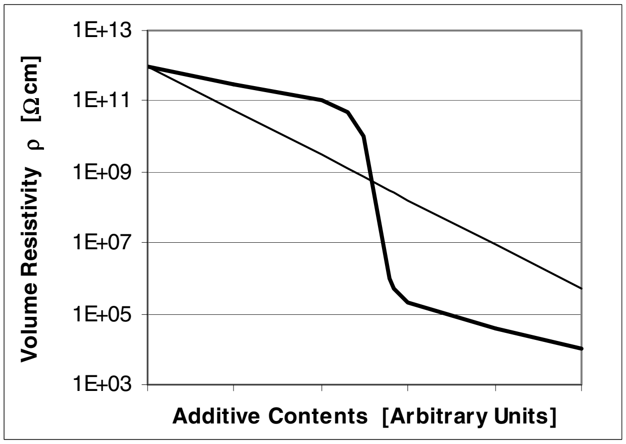

Figure 1. Schematically: volume resistivity ρ as a function of additive contents for carbon black (bold line) and salt (thin line).

An approach with ionic conductive materials has been much more successful for electrophotographic applications. Conductivity for most commercial elastomeric electrically conductive rollers is achieved with this method. Here a salt or another "ionic" material is added to the elastomer matrix [13,15].

Figure 1 schematically shows ρ as a function of salt contents (thin line). In first order the curve is a straight line in the log-log diagram and obviously much less steep than the percolation curve with carbon black. With the right combination of elastomeric material and additive, specifications as mentioned above are readily achievable.

However, there are also disadvantages with this approach. Conductivity tends to change rather strongly with changes in humidity (and temperature) and it is very hard to get ρ lower than about 5×10^5 Ωcm.

Measurement Results

At first sight, measurement of conductivity for elastomeric materials seems straightforward, but it turns out to be a rather complex subject with a substantial number of parameters that strongly influence the result. Substantial contributions to this issue can be found for example in [13,14,16,17]. Here we will highlight a few aspects and compare data for two elastomers: N (NBR with carbon black, hardness 50 Shore A) and P (Polyurethane with an ionic filler, 40 Shore A). Elastomer N contains a high amount of carbon black, so conductivity is high and in right third of the percolation curve of Figure 1.

Standard conditions for the following measurements are:

- ➢ Stainless steel electrodes
- ➢ Lower electrode larger than elastomer slab
- ➢ Upper electrode with diameter 2 cm
- ➢ Pressure 3.3 N/cm^2
- ➢ Sample thickness 6 mm
- ➢ DC Voltage: 10 V (elastomer N), 100 V (elastomer P)
- ➢ Current reading 10 seconds after applying the voltage
- ➢ Temperature 21°C and 50% relative humidity

Volume resistivity ρ is calculated from resistance R with contact area A and sample thickness d by

$$\rho = R\frac{A}{d}\,. \tag{1}$$

The following Figures 2 to 6 show the dependence of ρ as a function of important parameters for the two elastomers N and P. Results are normalized to the average volume resistivities of each material, which are $\rho = 6.2 \bullet 10^3$ Ωcm for elastomer N and $\rho = 3.2 \bullet 10^6$ Ωcm for elastomer P.

A comparison of elastomers N and P shows clearly better behavior of elastomer P. As discussed above, ionic conductivity works more consistently in elastomers than percolation. Obviously elastomer N is not suitable for an electrophotographic application. However, the properties are totally sufficient for example for antistatic applications.

Figure 2 shows the result of repetitive measurements over several weeks of elastomers N and P. Note the better consistency of elastomer P, which is in the range of ±10% at most and considered excellent for a semi-conductive elastomeric material.

Dependence on time is shown in Figure 3 (more precisely: time after applying voltage). The increase of ρ for elastomer P is readily explained by a depletion of ions. The authors do not have an explanation for the behavior of the carbon black filled elastomer N.

Figure 4 shows the influence of pressure P. The change of sample thickness d due to pressure P has been considered, though it is small in the shown range (less than about 0.2 mm for the softer elastomer P). Obviously ρ drops with increasing pressure. This can be explained by an insufficient contact between metal electrode and elastomer at low pressure.

Dependence on electric field is shown in Figure 5. The electric field was changed by applying different voltages to the elastomer sample. Elastomer P shows a higher conductivity at higher fields, which is to be expected due to increasing ion mobility with increasing field strength. As with time dependence, elastomer N shows a rather strange behavior, for which we do not have a good explanation.

Finally, Figure 6 shows the relation to environmental conditions. L, M, H stand for low, medium and high. Here L/L is a temperature of 4°C and 25% relative humidity, M/M 21°C/ 50% (standard), and H/H 35°C/ 75%. Note the opposite behavior of the two elastomers. Elastomer N shows increasing resistivity with increasing temperature. Part of an explanation could be the semi conductive nature of the carbon black. Note however, that opposite behavior is observed for pressure rollers for gravure printing (for details see [20]). Materials for this application are in the steep part of the percolation curve of Figure 1. In any case, conductivity for materials filled with carbon black is mostly independent from humidity (not shown here). For elastomer P we have ionic conductivity, which increases with increasing humidity and increasing temperature.

The results presented here clearly prove the need of a complete definition of measurements parameters. Note that the standard conditions chosen for our measurements are typically in a range where the curves are rather flat. For example we use a pressure of 3.3 N/cm^2. A small change in pressure in this range has practically no effect on measured volume resistance. Obviously this is an important factor for consistent results.

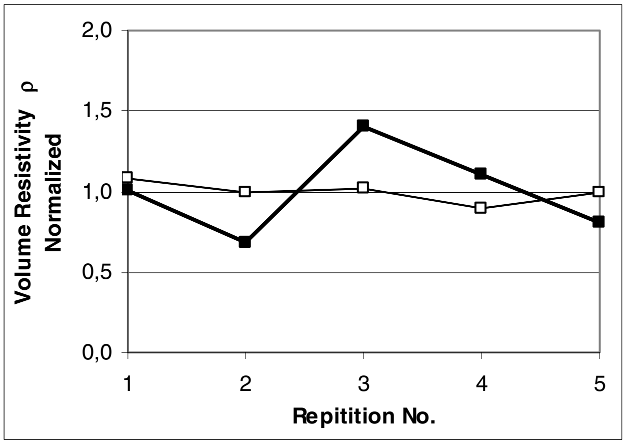

Figure 2. Consistency of volume resistivity ρ for elastomer N (thick line, NBR with carbon black) and elastomer P (thin line, Polyurethane with ionic filler).

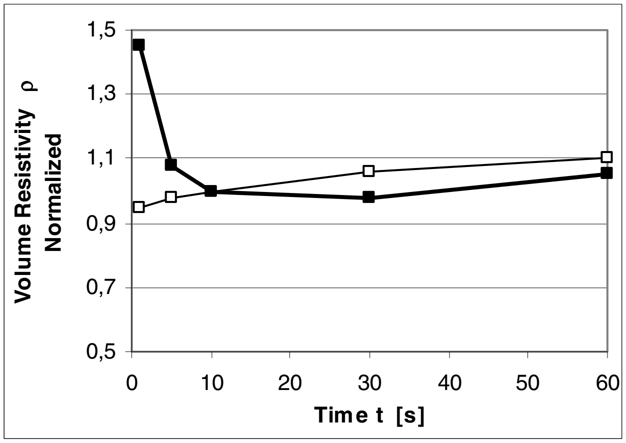

Figure 3. Volume resistivity ρ as a function of time t after applying voltage.

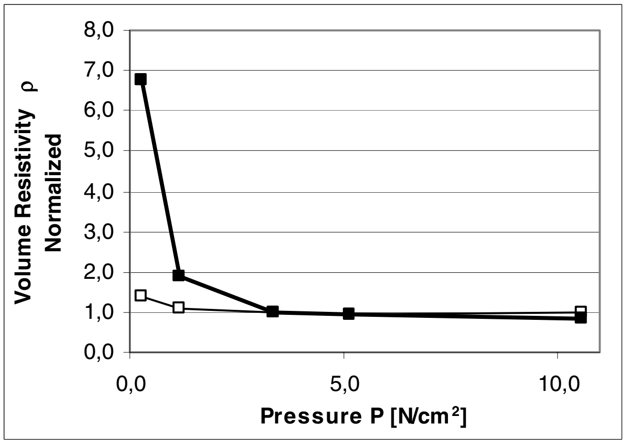

Figure 4. Volume resistivity ρ as a function of contact pressure P.

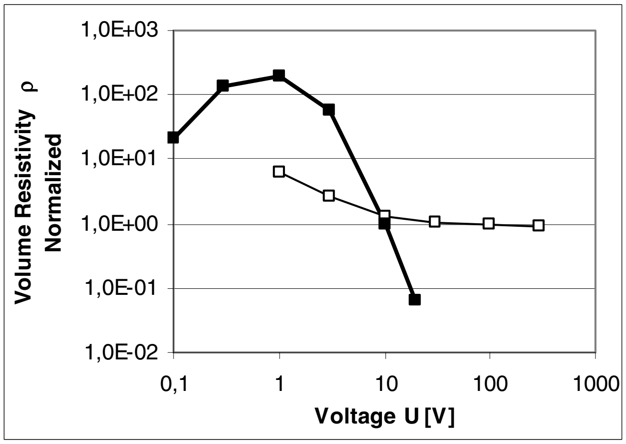

Figure 5. Volume resistivity ρ as a function of electric field.

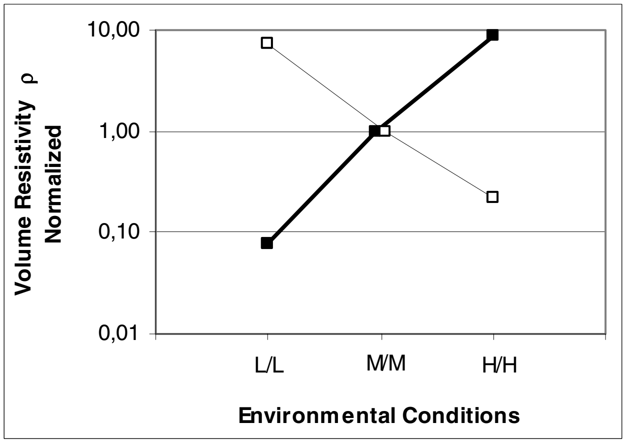

Figure 6. Volume resistivity ρ as a function of environmental conditions.

Ink-Jet

Typically elastomeric rollers for ink jet printers are used for paper transport. The elastomeric roller presses the paper against a hard roller surface and moves it through the machine, especially passing the ink-jet head.

Major requirements for elastomeric rollers for ink-jet paper transport are high friction to paper, good mechanical precision, and resistance against the ink. A high friction between elastomer and paper surface is required in order to achieve a precise paper transport, which again is very important for precise paper positioning under the ink-jet print head for accurate dot placement and thus high image quality. Mechanical precision (diameter, cylindricity, runout) becomes increasingly important with increasing roller size. Ink can soak through the paper and lead to swelling or shrinking of the elastomeric cover.

Very common for this application are EPDM-type rubbers.

Non-Digital Printing Technologies

Offset Printing - Inking Rollers

Here we have to distinguish between rollers for sheet fed and web offset [18]. The main difference is speed. Speed for sheet fed offset goes up to about 3 m/s, whereas web offset gets up to 15 m/s or higher. This high speed offers additional challenges, which will be discussed further below.

In principal an offset inking unit transports high viscosity ink from a reservoir to the print plate. In many cases 4 elastomeric inking rollers are in contact with the print plate and deliver a uniform ink film with a thickness of a few microns. There are several additional rollers between the reservoir and these delivery rollers. In this roller train a roller with an elastomeric cover is followed by a roller with a rigid surface.

Major requirements for inking rollers are good ink transport and minimal swelling behavior. These are to some degree contradicting requirements, as a transport of an ink film does require an interaction or more precisely a wetting of the roller surface, whereas minimal swelling or shrinking is best achieved with minimal interaction.

For rollers in the field, the interaction between ink and elastomeric material is typically the most important factor limiting roller life. The hardness range of the elastomeric materials is in the range between 20 and 40 Shore A and most materials contain a substantial amount of a plasticizer, which is liquid at room temperature of 21°C. Basically, there are two opposing interactions between elastomeric material and ink. Either the elastomer shrinks (volume decrease) in contact with the ink or it swells (volume increase). Swelling mostly happens when ink migrates into the elastomer. Shrinking is mostly related to plasticizer being solvable in the ink and transported out of the elastomer.

Common rubber materials for inking rollers depend highly on the type of used ink. For example for conventional inks NBR is often used, whereas EPDM is often the material of choice for UV curing inks.

All this holds for all types of offset printing. Fast running web offset additionally requires good dynamic properties of the elastomer [19]. The high speed generates many nip transitions per second. During each nip transition the rubber is compressed and heat is generated. The heat causes an enlargement of the roller diameter, which increases force in the nip, as typically the rollers are set with a constant engagement. An increased force leads to more heat generation and so on. As a worst case, the heat can degrade the rubber leading to a destruction of the roller and potentially damages to the printing machine. In order to avoid this, the roller elastomers need good dynamic properties. This means that only a small amount of the mechanic energy that is put into the rubber during a nip transition is converted to heat. In first order these are materials with a high rebound resilience, but a better characterization uses modulus (real and imaginary part) and tan(δ) as a function of temperature, frequency, and load [19].

Offset Printing - Dampening Rollers

Basically the dampening unit is similar to the inking unit. Differences are the transported medium (a mixture of water and Isopropanol) and the uniformity of the delivered film. Here dampening units are less demanding than inking units. Therefore they are less complicated than inking units and mostly with a lower number of rollers.

Everything that has been described for inking rollers holds for dampening rollers. Only media are different. NBR is the type of elastomer most widely used for this position.

Gravure Printing - Pressure Rollers

In gravure printing pressure rollers press paper against the print cylinder in order to transfer ink from the grooves onto paper [18,20]. This requires high pressures with line loads in the range of about 10 to 30 N/mm. Speeds in gravure printing are about as fast as in web offset, which is up to 15 m/s and higher.

Inks in gravure printing commonly use toluene as a solvent. Even though there is typically no direct contact between ink and roller, the solvent loaded environment as well as seeping through paper dictates a substantial resistance of the elastomer against toluene.

There are two different types of pressure rollers and related transfer systems. Conventional systems use high pressure in the range of 30 N/mm and the roller has no electrical conductivity. Modern systems work with semi-conducting elastomers in the range of 10^6 to 10^7 Ωcm. A (nip effective) voltage in the order of 800 V is applied to the pressure roller in order to form an electric field between pressure roller and print cylinder surface. This electric field will move the ink a bit out of the grooves (migration of a dielectric in a non-uniform electric field) and thus improves ink transfer to paper. Such systems achieve good transfer quality with line loads in the range of 12 N/mm, even with moderately rough paper. The lower line load reduces problems with bending of the steel roller core, especially for wide roller types of up to about 4.2 m length and additionally enables higher speeds.

Major requirements for all types of pressure rollers for gravure printing are good mechanical durability including high abrasion resistance (paper is abrasive, especially at high line loads), resistance against toluene, and good dynamic properties (same issue as with inking rollers for web offset, see above).

ECO is the rubber type, which is most widely used for this application. Hardness is typically in the range of 90 Shore A.

A well defined electrical conductivity is required for the electrostatically assisted systems. Conductivity of the elastomer has to be high enough to lead to a sufficient field for transfer in the nip. In gravure printing it is essential that conductivity and voltage stay below a threshold for electrical sparks. Due to the toluene solvent of the ink, there is a high danger for fire. A substantial number of print shops has suffered from this effect.

As with non-conductive pressure rollers, ECO is the rubber type which is most widely used for this application and hardness is also in the range of 90 Shore A. The required conductivity range is achieved with carbon black. Due to the percolation described above, it is always a challenge to achieve the right resistivity. Newer developments work with polyurethane with ionic additives.

Conclusions

A comparison of the properties needed for digital printing technologies (electrophotography, ink-jet) with those for conventional printing (offset, gravure) shows only few common items. Each printing technology has its specific demands, which determine the key properties of the elastomeric rollers. On a high level, these are:

- electrophotography: electrical conductivity
- ink-jet: friction to paper
- offset: media resistance
- gravure: durability.

Having stressed the differences, it is worth noting the properties that elastomeric rollers for different printing technologies usually have in common:

- well defined hardness
- well defined geometry
- long life
- abrasion resistance.

The final conclusion is that elastomeric rollers for different printing technologies have a number of similar as well as a number of different requirements for each technology. The demands can be met with a huge number of different elastomeric materials with an ongoing effort to improve existing materials as well as developing new compounds.

References

[1] L. B. Schein, Electrophotography and Development Physics (Laplacian Press, San Jose, 1992)

[2] G. Goldmann (Editor), The World of Printing (Océ, 2002)

[3] M. Kadonaga et. al., A Study of Non-Uniform Charging by Charging Roller with DC Voltage, Proc. NIP 13, pg. 55 (1997)

[4] ISO 868

[5] A. Shinozaki, F. Takeda, T. Totohashi, The Influence of Electric Characteristics of Development Roller Used in Non-Magnetic Single Component and Contact Development, Proc. NIP 6, pg. 55 (1990)

[6] M. Hosoyo, M. Saito, “Theory of Nonmagnetic Contact Development” J. Imaging. Sci. and Technol. 37, pg. 223 (1993).

[7] A. Chowdry, Digital Color Printing and the NexPress Approach, Proc. NIP 17, pg. 267 (2001)

[8] T. Mizuno, J. Hanna, Characteristics of Intermediate Transfer Process, Proc. NIP 18, pg. 49 (2002)

[9] T. Tombs, Electrostatic Toner Transfer to an Intermediate: Results from a Continuum Model, Proc. NIP 14, pg. 440 (1998)

[10] M. C. Enzenyilimba et. al. , US Pat No. 5968656

[11] D. Herrick, B. Patterson, B. Tan, Reinforced Elastomer Roller for Toner Transfer, Proc. NIP 18, pg. 53 (2002)

[12] M. C. Zaretsky, “Performance of an Electrically Biased Transfer Roller in a Kodak ColorEdgeTM CD Copier” J. Imaging. Sci. and Technol. 37, pg. 187 (1993).

[13] C. Matteliano, The Expanding Role of Semi-Conductive Polyurethane in Electro-Photographic Systems, Proc. NIP 17, pg. 71 (2001)

[14] C. Matteliano, Semi-Conductive Polyurethane in EP Systems, Proc. NIP 18, pg. 112 (2002)

[15] J. W. Lovette, Novel Polyurethane Materials for Use in Digital Imaging Equipment, Proc. NIP 20, pg. 132 (2004)

[16] ASTM D257 – 1999, Standard Test Methods for DC Resistance or Conductance of Insulating Materials

[17] I. Chen, M-K. Tse, Electrical Characterization of Semi-Insulating Devices, Proc. NIP 15, pg. 486 (1999)

[18] H. Kipphan (Editor), Handbook of Print Media (Springer, 2001)

[19] J. Weinert, Viscoelastic Rollers and their Environment, Boettcher Publication, available on request

[20] J. Weinert, Electrically Conductive Rubber Covered Impression Rollers in Roto Gravure Printing, Boettcher Publication, available on request

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