# Reinforced Elastomer Roller for Toner Transfer

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## Abstract

In commercial electrophotographic copiers and printers, roll fusing, media handling, and toner transfer are technologies that incorporate friction drive with elastomer-coated rollers. When two rollers form a pressure nip and at least one roller is deformable, the surface strain of the deformed roller defines the length of the nip contact area and the speed of the frictionally driven roller. To insure high levels of performance from sub-systems that utilize friction drive, it is important to maintain consistent surface speeds of rollers forming a nip, under a variety of external noises, such as manufacturer tolerances, lack of roller parallelism, media thickness, media tension, and variable toner stack heights. These noises cause variations in surface strains and subsequently surface speeds, adversely impacting image quality, for example, image-to-page registration, color registration, and fusing nip dwell times.

For an application that utilizes friction drive for toner transfer, an intermediate image-holding roller has been designed to conform radially with little change in shape circumferentially. The presence of a reinforcing layer just below the surface of an elastomer-coated roller enables sufficient nip contact area for electrostatic toner transfer with minimized drive variations due to external noises. The geometry and material properties of the composite roller is optimized with finite element analysis (FEA). Data from overdrive measurements confirm a reduction in speed variation, and results from a toner transfer experiment show suitable performance for high quality color printing.

## Introduction

The quality of dry toner images achieved with compliant intermediate transfer systems is higher than that found in traditional direct-to-paper transfer and non-compliant, intermediate transfer systems.[1-3] Electrophotographic color-printing has begun incorporating compliant intermediate transfer as the size of toner particles shrinks and the variety of receivers at customers' request grows, examples include the HP-Indigo UltraStream and the NexPress 2100. The benefits of using a compliant, intermediate transfer component in electrophotography, in the form of an elastomer-coated roller or belt accepting the toner image from a photoconductor and passing it to a receiver, are best described by Tombs.[4,5] A properly chosen elastomer can provide the key properties for toner transfer: nip width, electrical conductivity, and micro-compliance (compliance on a microscopic scale).

The surface speed of a conformable roller or belt in a friction-driven system, however, can be highly susceptible to noises typical of an electrophotographic printing process: variable toner stack heights, variable paper properties, and manufacturing tolerances. The surface strain and, subsequently, the surface speed of an elastomer-coated structure driven in a pressure nip are influenced by the amount of surface indentation, the material properties of the elastomer, and surface friction.[6] Any noise in these factors that define the surface strain will in turn cause speed variations. Maintaining not only consistent surface speed but also uniform surface speed along the length of the nip are critical for minimizing distortions in the transferred image and insuring well-registered images: color-to-color, image-to-page, and front-side to back-side in duplex printing.

To prevent possible image distortion and registration errors in a friction-driven transfer system while maintaining all the transfer benefits that compliance offers, reduced surface strain variations with respect to external noises can be achieved by reinforcing the surface of an elastomer-coated transfer roller. A prototype roller has been designed, with the aid of finite element analysis to optimize the reinforcing material and overall roller geometry, and tested to demonstrate reduced speed variations and desirable image quality. Selected details of the design, manufacturing, and testing follow.

## Theory of Overdrive

When a rotating roller having a compliant elastomeric coating forms a pressure nip with a counter-rotating rigid roller using friction drive between the rollers, the surface speed of the compliant roller within the nip is given by

$$S = S_c (1 + \varepsilon) \tag{1}$$

where $S_c$ is the surface speed of the compliant roller far from the nip and $\varepsilon$ is the circumferential strain of the compliant roller in the contact area of the nip, assuming small strains.[7,8] The surface speed of the compliant roller far from the nip is given by

$$S_c = R\,\omega_c \tag{2}$$

where R is the radius of the compliant roller and $\omega_c$ is its angular speed. Due to its non-deformable nature, the surface speed of the rigid roller far from the nip is equal to its surface speed in the nip

$$S_r = r\,\omega_r = S \qquad (3)$$

where r is the radius of the rigid roller and $\omega_r$ is its angular speed.

In the friction-drive system described in this work, a rigid roller drives a compliant roller. The amount of surface indentation is determined from the engagement of the two rollers: the distance the rollers axes are moved towards one another from the initial distance at which the roller surfaces just touch. For any given engagement and the resulting circumferential strain of the compliant roller, the rigid roller overdrives the compliant roller to a speed higher than that if the driven roller were non-deformable. Overdrive, therefore, is defined as

$$Overdrive = S_r / S_c = (1 + \varepsilon) \qquad (4)$$

Angular speed ratio is a direct measure of overdrive

$$Angular\ Speed\ Ratio = \omega_r / \omega_c = (R / r)(1 + \varepsilon) \qquad (5)$$

For incompressible elastomers, the surface strain and the resulting overdrive always increases with engagement. Overdrive sensitivity to engagement noises is defined as the slope of a graph of overdrive versus engagement. Controlling the extent that the strain changes with engagement is a means to reduce overdrive sensitivity.

## Model-Predicted Overdrive

A two-dimensional, plane strain model[9] was developed using the finite element code ABAQUS.[10] A cross-sectional slice of the contact between two rollers forming a pressure nip is modeled with elastomers assumed to be incompressible. The materials are not considered hyperelastic[11] since only small magnitudes of strain are investigated. Property definitions include Young's modulus, Poisson ratio, surface friction, and any initial drag for the roller system. Non-deformable rollers are modeled as rigid bodies; deformable elastomer-coated rollers are modeled as 2D-solids. From the model, the circumferential strain of the deformable roller over a series of surface indentations is extracted, from which overdrive and its sensitivity to engagement are calculated. The model has demonstrated good correlation with measurements on elastomer-coated rollers.[12]

Figure 1 shows a plot of model-predicted overdrive as a function of engagement for a 6 mm polyurethane coated roller and a similar structure with a seamless, metal reinforcing belt, 0.1 mm thick, located 1 mm below the surface of the roller. The polyurethane for both structures is assumed to have a Young's modulus of 3.45 MPa and Poisson ratio of 0.495. The metal stiffening layer is assumed to have a Young's modulus of 100 GPa. This material was chosen to reinforce the surface because of its high hoop strength and, therefore, smaller changes in circumferential strain with engagement. The dramatic reduction in slope for the latter structure illustrates the predicted effectiveness of the metal layer as a surface-reinforcing material.

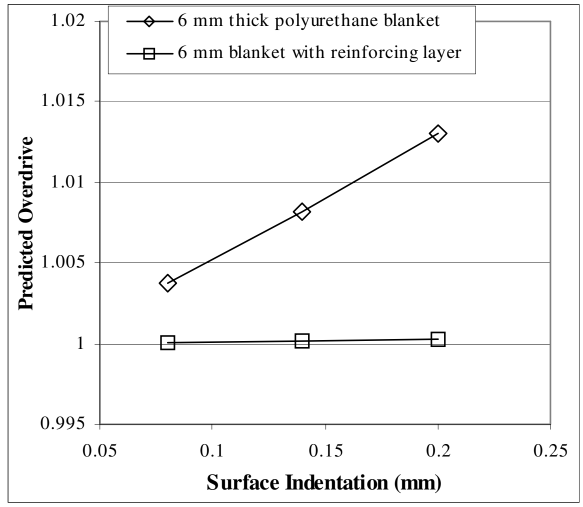


*Figure 1. Theoretical overdrive over a series of engagements for an elastomer-coated and a reinforced, elastomer-coated roller.*

The properties of the reinforcing layer and its location within the elastomer were explored with the FEA model.[13] Reduction in overdrive sensitivity is asymptotical with respect to the layer's thickness and modulus, with no further advantage achieved for reinforcing layers beyond a certain stiffness. In addition, the reinforcing layer becomes less effective with increasing distance from the surface of the elastomer. For a 6 mm elastomer, the optimal reinforcing location is no more than 1 mm below the surface with a reinforcing material of modulus at or above 80 GPa and thickness at or above 0.025 mm.

## Manufacturing Details

Prototype elastomer-coated and reinforced, elastomer-coated intermediate transfer rollers, with predicted overdrive behavior as described above, were produced for use in experimentation. A polyurethane[14,15] with the best electrical and mechanical properties for toner transfer was cast onto an aluminum cylinder and ground to a thickness of approximately 5 mm. A seamless nickel tube, 0.1 mm thick and Young's modulus of 100 GPa, was separately coated with 1 mm of the polyurethane. The elastomer-coated nickel tube was carefully press-fit onto the 5 mm elastomer-coated aluminum cylinder. The control roller for the overdrive and transfer experiments was 6 mm of polyurethane cast and ground onto an aluminum cylinder with no reinforcing layer. Both rollers also had a top coat of a thin toner-release layer.[16]

## Overdrive Results

A test apparatus in which the engagement between two rollers is controlled and in which one roller is motorized to frictionally drive another yields measures of overdrive. Initial values of engagement between rollers are know to an accuracy of +/- 10 µm and changes of engagement are measured with linear voltage displacement transducers and are known to a higher accuracy: +/- 1 µm. Shaft encoders are mounted to the axis of each roller with one revolution of a shaft encoder corresponding to 50,000 counts. The drive roller is typically rotating at a speed of 33 rpm. After a designated amount of time, the data from the shaft encoders are recorded. The ratio of the encoder counts collected during the measurement time interval is the angular speed ratio of the rollers at a given level of engagement. The angular speed ratio is measured for a series of engagements, from which overdrive sensitivity to engagement is determined.

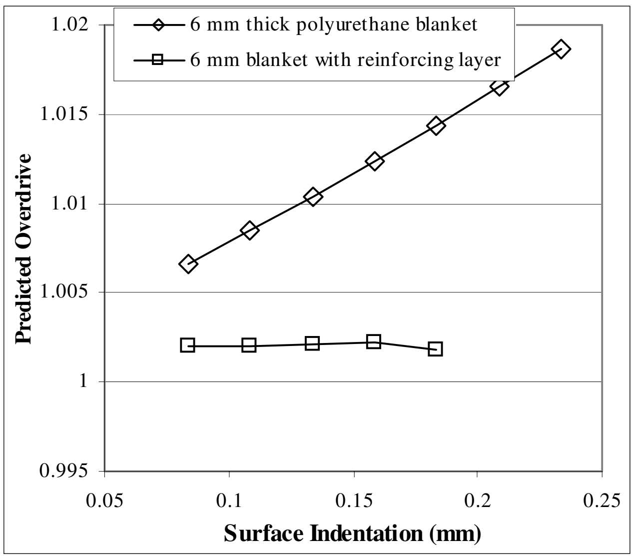


*Figure 2. Measured overdrive over a series of engagements for an elastomer-coated and a reinforced, elastomer-coated roller.*

Figure 2 shows overdrive extracted from measurements of angular speed ratio of a rigid (driver) roller to a compliant (driven) roller plotted against engagement for a 6 mm elastomer-coated and a reinforced, elastomer-coated roller. At a given engagement, in close agreement with the behavior predicted by the FEA model, the rigid roller overdrives the elastomer-coated roller more than a reinforced, elastomer-coated roller since the nickel layer restricts the extent of the circumferential strain. As a function of engagement, overdrive shows no increase with increasing engagement for the reinforced structure.

Figure 3 shows the comparison of model predicted overdrive sensitivity to engagement (slope of overdrive versus engagement) to the measured sensitivities. Measured sensitivities obtained from a linear fit to the data from Figure 6 agree well with theoretical values having no more than a 15% discrepancy.

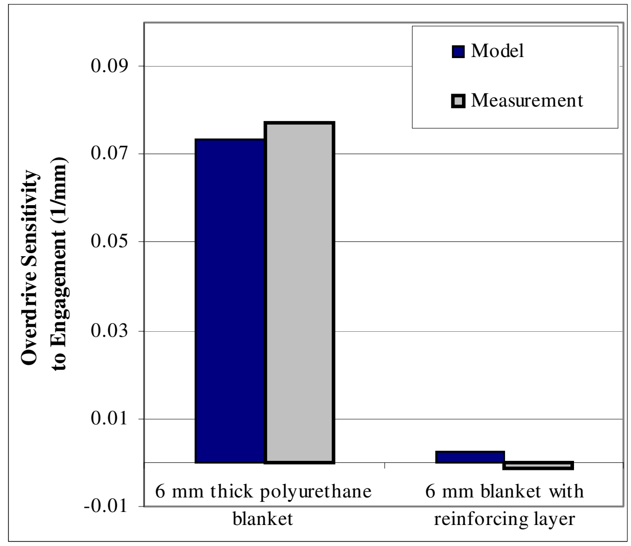


*Figure 3. Comparison of modeled and measured overdrive sensitivity to engagement.*

## Toner Transfer Results

A suitable intermediate transfer roller must have adequate radial conformance to achieve the proper transfer nip, electrical resistivity to provide the best rate of electric field build up in that nip, and surface compliance to transfer polydisperse toner stacks to rough and structured receivers. Tests were carried out on off-line fixtures and in print engines to assess the transfer characteristics and performance of the 6 mm reinforced, elastomer-coated roller.

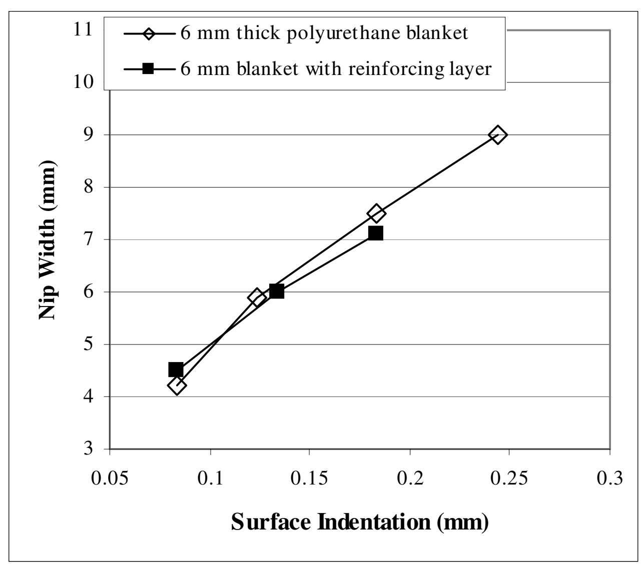


*Figure 4. Measured nip width over a series of engagements for an elastomer-coated and a reinforced, elastomer-coated roller.*

Figure 4 shows the nip width (the circumferential nip contact length) for the elastomer-coated and the reinforced, elastomer-coated rollers, as measured against a rigid roller over a series of engagements. Although the reinforced roller has increased hoop strength insuring small circumferential strain compared to an ordinary elastomer roller, the reinforced roller is still capable of achieving the same range of nip width. However, this nip range does require a higher applied load. The reinforced, elastomer roller causes a reaction force almost three times the elastomer-coated roller at a given engagement. Fortunately, this difference in reaction force has not shown any impact on performance characteristics in the electrophotographic test machine.

The electrical resistivity of the polyurethane was designed to provide both low pre-nip electric fields, preventing premature toner transfer and therefore minimizing dot and character scatter, and high in-nip electric fields to maximize the transfer efficiency of the highest laydown of toner, referred to as Dmax. The image quality achieved with the reinforced, elastomer-coated roller confirmed, through low toner scatter on the receiver and high Dmax transfer efficiency (see Table 1), that the electrical resistivity for the outer layer of polyurethane was optimal.

**Table 1. Transfer performance metrics.**

| | | Mottle Index* | | Dmax Transfer Effiiciency | |
|---|---|---|---|---|---|
| Receiver | Roughness Level | Elastomer Only | Reinforced Elastomer | Elastomer Only | Reinforced Elastomer |
| Smooth Gloss | 10 | 288 | 303 | 96% | 94% |
| Rough Linen | 300 | 300 | 299 | NA | NA |
| Textured Cover | 425 | 600 | 635 | NA | NA |

*Standard deviation ± 40 units; viewing threshold about 50 - 75 units.

Compliant intermediate rollers and belts enable transfer of toner to rough and structured receivers by allowing intimate contact of toner to paper, thus reducing or eliminating undesirable air gaps which typically impede toner transfer. A reinforced, elastomer-coated roller raises the concern that the surface conformance will be compromised. To circumvent this issue, the location of the reinforcing layer was chosen just below the surface of the elastomer to insure microcompliance. In order to determine the sufficiency of the microcompliance, the reinforced, elastomer-coated roller was used in tests of toner transfer to receivers of three different roughness levels. In Table 1, the "Smooth Gloss" receiver is the least rough, while the "Textured Cover" receiver is the most rough, with relative roughness level listed. A wide-area uniformity metric, as measured by the Tobias MTI Mottle Tester, was used to capture the quality of transfer to the different receivers. When compared to the elastomer-coated roller with no reinforcement, the reinforced roller proves to have comparable mottle indices for the variety of receivers.

## Conclusion

A reinforced, elastomer-coated roller, with overdrive sensitivity to engagement predicted to be well reduced when compared to a similar structure without reinforcement, has been designed, tested, and found to meet all performance goals. This reinforced structure maintains consistent and uniform surface speed without sacrificing its ideal transfer properties, such as nip width and surface conformance. When used as an intermediate transfer roller in a multi-color electrophotographic printer, it promises high quality color images through reduced registration error and image distortions during transfer, under a variety of external noises, such as manufacturer tolerances, lack of roller parallelism, media thickness, media tension, and variable toner stack heights.

## Acknowledgements

The authors would like to acknowledge Craig Cody for preparing the structures used in this study and Earl Gomes and Dean Smith for their assistance in experimentation.

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## Biography

Diane Herrick obtained her PhD in physics from the University of Rochester in 1996. Upon completion of her degree, she joined the Eastman Kodak Company Office Imaging Division to pursue research in electrophotography. As of February 1999, NexPress Solutions LLC was formed from a joint venture between Kodak and Heidelberg. Her current research interests at NexPress include electrostatic transfer of dry toners and nip mechanics of elastomeric structures.

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