

Theory and Measurement of Overdrive in Friction-Driven Systems

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Abstract

Friction-driven roller systems are prevalent in non-impact printing, from initial paper-feed to image fixing. As an aid in design, a non-linear finite element model has been developed to predict surface strains and overdrive of elastomer-coated rollers in friction-driven systems. Data from experiments designed to measure overdrive are in good agreement with model predictions, showing overdrive to be an increasing function of nip engagement influenced by elastomer thickness.

Introduction

In commercial electrophotographic copiers and printers, roll fusing, media handling, and toner transfer are tech-nologies 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 is influenced by the amount of surface indentation, the Poisson ratio of the elastomer, and surface friction.[1] When the elastomers are incompressible, as is the case discussed in this work, the perimeter of the compliant roller in the deformed state is always greater than in the undeformed state. The extent of surface strain 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. With a method to predict surface speeds of friction-driven systems, the sensitivity to such noises can be anticipated.

Theory

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 ε is the circumferential strain of the compliant roller in the contact area of the nip, assuming small strains.[2,3] 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 ω_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

$$S_r = r\,\omega_r = S \tag{3}$$

where r is the radius of the rigid roller and ω_r is its angular speed.

A definition of overdrive requires the two rollers forming the pressure nip be assigned driver and driven, respectively. For this work, the compliant roller is driving the rigid 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, the compliant roller overdrives the rigid roller to a speed higher than that if the driver were non-deformable. Overdrive, therefore, is defined as

$$Overdrive = S_r / S_c = (1 + \varepsilon) \tag{4}$$

A measure of angular speed ratio is a direct measure of overdrive

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

Finite Element Analysis

A two-dimensional, plane strain model[4] was developed using the finite element code ABAQUS.[5] A cross-sectional slice of the rolling contact between two rollers forming a pressure nip is modeled with elastomers assumed to be incompressible. The materials are not considered hyper-elastic[6] 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. For various deformable roller structures over a series of surface indentation, the circumferential strain of the deformable roller in the pressure nip is extracted from which overdrive is calculated.

Measurement Details

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 for comparisons to the theoretical predictions from the finite element model. Initial values of engagement between rollers are know to an accuracy of +/- 10 µm and changes of engagement are measured with linear voltage displace-ment transducers and are known to a higher accuracy +/- 1 µm. Shaft encoders are mounted to the axel 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.

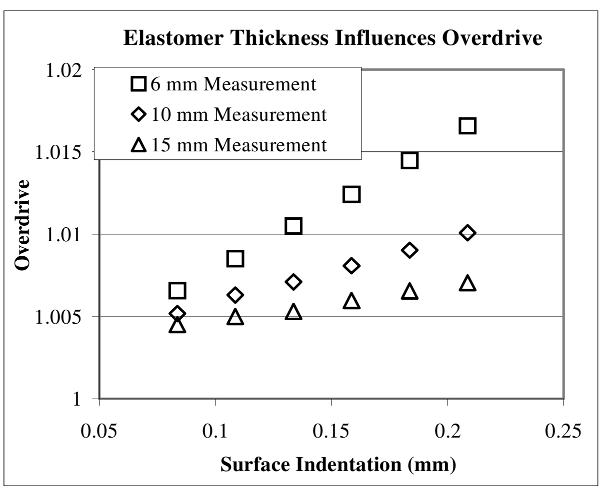

Figure 1. Measured overdrive over a series of engagements for three elastomer-coated structures

Results

Figure 1 shows overdrive extracted from measurements of angular speed ratio of a rigid (driven) to a compliant (driver) roller plotted against engagement. Three different compliant rollers were tested, identical in outer diameter but differing in thickness of elastomer: 6, 10, and 15 mm. At a given engagement, a thin elastomer-coated roller overdrives the rigid roller more than a thick elastomer-coated roller. Since overdrive is determined by surface strain, the thin elastomer suffers higher strain at a given engagement than a thick elastomer. As a function of engagement, overdrive more rapidly increases with decreasing elastomer thickness; in other words, the sensitivity to engagement is higher with the thinner elastomer.

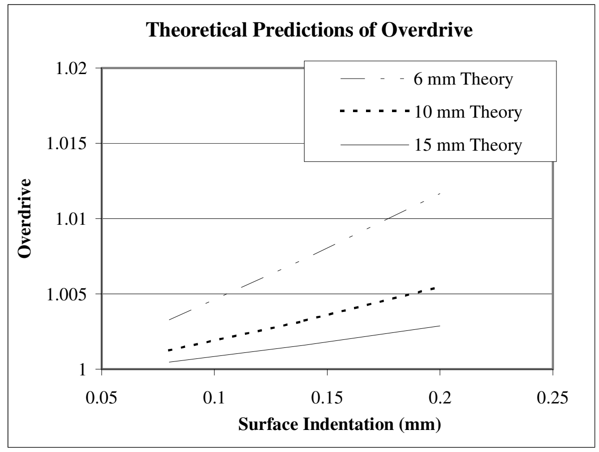

Figure 2. Theoretical overdrive over a series of engagements for three elastomer-coated structures.

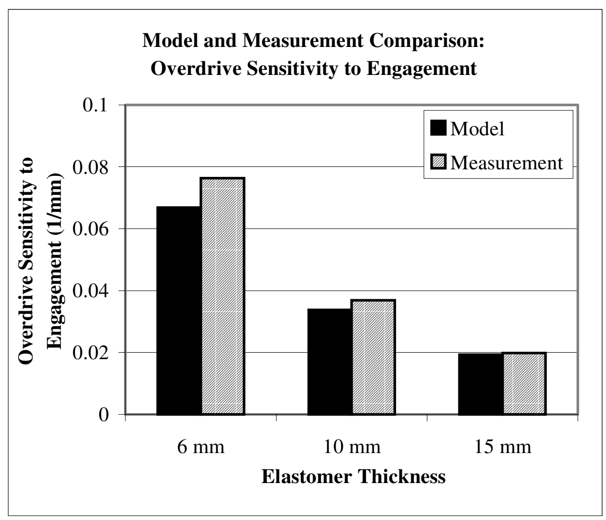

Figure 3. Comparison of modeled and measured overdrive sensitivity to engagement.

Figure 2 shows the theoretical predictions of overdrive for the rollers described by Figure 1. The theoretical trends are consistent with the measured trends. However, the magnitude of overdrive is slightly underpredicted by less than 1% for all cases. 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 1 agree with theoretical values with no more than a 15% discrepancy.

Conclusion

An investigation into the mechanics of overdrive has been presented. Overdrive and overdrive sensitivity to engagement with elastomer-coated rollers depends on coating thickness, a trend predicted by the model and confirmed with measurement. The finite element model proved valid by experiment serves as an invaluable tool for predicting the behavior of elastomeric rollers in friction-driven nips.

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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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