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A visualization tool for paper compression in a rolling nip

Emanuele Zeni[1,2], *Cecilia Rydefalk*[3] *and Li Yang*[3]

[1] School of Electrical Engineering and Computer Science, Royal Instititute of Technology (KTH), Stockholm, Sweden

[2] Department of Information and Communication Engineering, Università di Trento, Trento, Italy

[3] Department of Pulp, Paper, and Packaging, RISE - Research Institutes of Sweden, Stockholm, Sweden

E-mails: zeni@kth.se; cecilia.rydefalk@ri.se; li.yang@ri.se

Short abstract

Rolling nip consisting of two rotational cylinders is an essential element of a conventional printing device, flexography, gravure, and offset. Running at a speed up to ten(s) of meters per second, material behaviour inside a printing nip is not only complex but also hard to be accessed or studied. Quantitative knowledge on the materials behaviours has been shallow. We have thus proposed to use scientific visualisation technology to bring clear details of the dynamic processes inside the nip. As an example, dynamic behaviour of a model material (like a paperboard) has been studied and demonstrated.

Keywords: printing dynamics, viscoelasticity, graphic representation, scientific visualisation

1. Introduction and background

Rolling nip consisting of two rotational cylinders is an essential element of a conventional printing device, e.g., flexography, gravure, and offset. These cylinders are often called print cylinder and compression cylinder, respectively. The surface of the print cylinder is either covered by a print plate or engraved in case of gravure. When entering the nip, a paperboard undergoes compressive deformation governed by soled nip pressure. Texts and graphics are created by transferring inks from the print plate onto the paperboard surface with the help of mechanical contacts / compressions between the printing plate, the ink, and the paperboard.

Packaging printing is complex and multidisciplinary. With a modern printing press running at a printing speed up to ten(s) of meters per second, the duration time that the substrate is compressed in the nip is very brief, e.g., in a few or even a fraction of milliseconds. On the other hand, the materials involved in the compression process, print plate made of either polymer or rubber, foam materials, and paper substrate etc, are very often viscoelastic. Their responses to the nip compression depend not only on the nip geometry, but also on their mutual interactions between these materials, and even printing speed. Thus, experimental studies have been very difficult and rare. Apart from qualitative knowledge accumulated in the field, there are a lot of unknowns about what is happening inside the nip.

Simulation and visualization may fill the knowledge gap. There are two major types of visualization techniques: scientific visualization and information visualization. Scientific visualization provides graphical representations of numerical data that help qualitative and quantitative analysis (Hansen and Johnson, 2004). It has found applications in a broad scientific research and industrial applications, e.g., fluid-flow simulations, molecular dynamics, digital pathology, material sciences, astronomy, space missions, and many medical topics. There is plenty of visualization software available on the market, from general purpose numeric programs MATLAB and IDL to more specialized and powerful ones provided by VTK and ParaView software, OpenGL för graphics programming, and OpenSceneGraph, a higher-level programming library built on top of OpenGL, etc. (BU TechWeb, n.d.). However, to our best knowledge, there has been no work reported on printing related topics.

The goal of this project is to introduce and demonstrate the usefulness of scientific visualisation in printing related applications. In the present study to visualize the dynamic interactions involved in printing nip, based on a physical model and simulation.

2. Methods

Rather than a genuine printing situation, we limit our study to compression dynamics of a paper board which is known as being viscoelastic. The rolling nip is formed by two rigid cylinders, like the case of hard calendering.

2.1 Physics model of compression dynamics

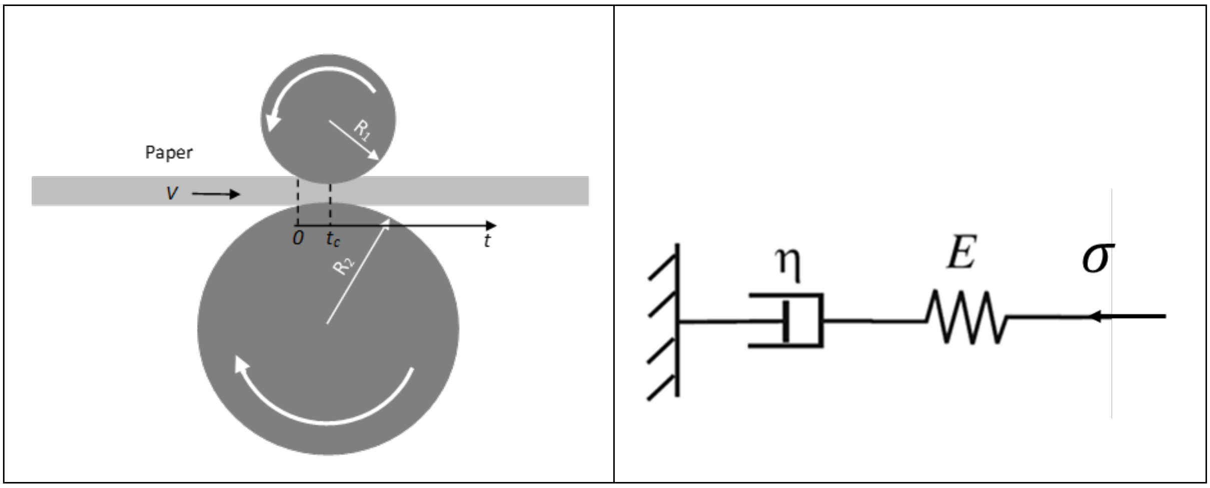

Figure 1: Illustration of the rolling nip between two rigid cylinders (left), t_c is the time duration from entering the nip to reaching the nip center; and the material model of the paper (right)

In the rolling nip shown in Figure 1 (left), the paper is subjected to compressive stress of the nip. To simulate the viscoelastic response of paper in creep and relaxation experiments spring and dashpot elements are frequently used (Roylance, 2001; Sperling, 1992). Similar treatment has been applied in fast compression situation like printing or calendaring (Litvinov and Farnood, 2010; Yang, 2020). Figure 1 (right) depicts the material model of the paper, known as Maxwell model, in which the string and the dashpot is connected in series. The mathematical expression for the model is (Yang, 2020),

$$\sigma(t) = 2\frac{\eta \cdot \Phi}{D_0}t + 2\frac{\eta \cdot \Phi}{D_0}\left(t_c + \frac{\eta}{E}\right)\left[exp\left(-\frac{E}{\eta}t\right) - 1\right] \quad [1]$$

where E and η stand for the elastic and viscos modulus, respectively, while σ for the correspondent stress. The quantity Φ is dependent of the nip geometry and the printing speed, as given below

$$\Phi = \frac{V^2}{2}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad [2]$$

Hence, for a given nip geometry, R_1 and R_2, the nip pressure can be determined by the following parameters, E, η, and V, or the elastic and viscos modulus of the material and the print speed, respectively. The pressure data with respect to the material properties and print settings are generated by employing these equations.

2.2 Visualisation of the dynamic compression

The visual representation has been built following a very specific process derived from Munzner's work (Munzner, 2009) using a high-level, general-purpose programming language, Python. The user interface is shown in Figure 2. By sliding the bar(s), one can change the input parameters of the simulation and visualisation, e.g., the print speed, the viscos and elastic modules of the paper substrate.

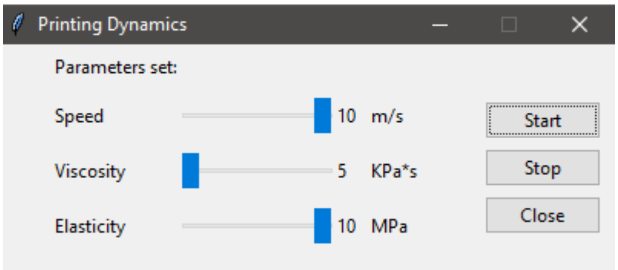

Figure 2: The user interface of the visualisation tool

3. Results and discussion

Figure 3 shows six or three pairs of examples of pressure distributions in the nips. The two circular disks with the arrow are the printing rollers where the arrow shows the direction of rotation. The ratio of the cylinders' radius is 1:2. The blue rectangle represents the substrate or paper in the present case. The pressure distribution inside the nip is represented by colour code, blue for low pressure and red for high pressure, as denoted by the vertical pressure-scale bar on the right. The input parameters of the three pairs of the simulations, e.g., the elastic and viscos components and the printing speed are listed in Table 1. For an easy reading, the parameters that are different are highlighted in the table.

Table 1: Material properties and printing speed used in the six simulation cases; the highlighted areas are the parameters different in each pair

Case	Elastic component E (MPa)	Viscos component η (KPa·s)	Speed V (m/s)
1	7	12	5
2	7	198	5
3	7	198	1
4	7	198	10
5	3	198	5
6	10	198	5

In the first two cases, the model materials have the same elastic modulus but different viscos modulus. These model materials were compressed in the same speed. As seen from the images, the pressure was low at the position of entering or exiting the nip. The nip pressure became higher when approaching the nip center denoted by the dashed lines. There are some obvious differences between the images. First, the maximal pressure in the left image is lower than that in the right. Second, the pressure distribution in the left image is much more asymmetric with respect to the nip geometry i.e., the major part lies towards the nip entrance side. Third, the model material didn't recover its full thickness when exiting the nip in the left image.

The second pair of the simulation (cases 3 and 4) illustrates the influence of the elastic component on the nip pressure. As seen from the images, when the elastic increased from 3 MPa to 10 MPa, the nip pressure was drastically increased.

The third pair of the simulation (cases 5 and 6) demonstrate the influence of the printing speed. As seen from the images, at V = 1 m/s only the positions in the vicinity of the nip center gain somewhat yellow tone while at V = 10 m/s, the width of the yellow band is significantly extended and the yellow tone more saturated. This indicates that for the same material and the same nip geometry, the nip pressure increased with the increasing printing speed.

These observations can be attributed to the viscoelastic nature of the model materials as earlier reported (Yang, 2020).

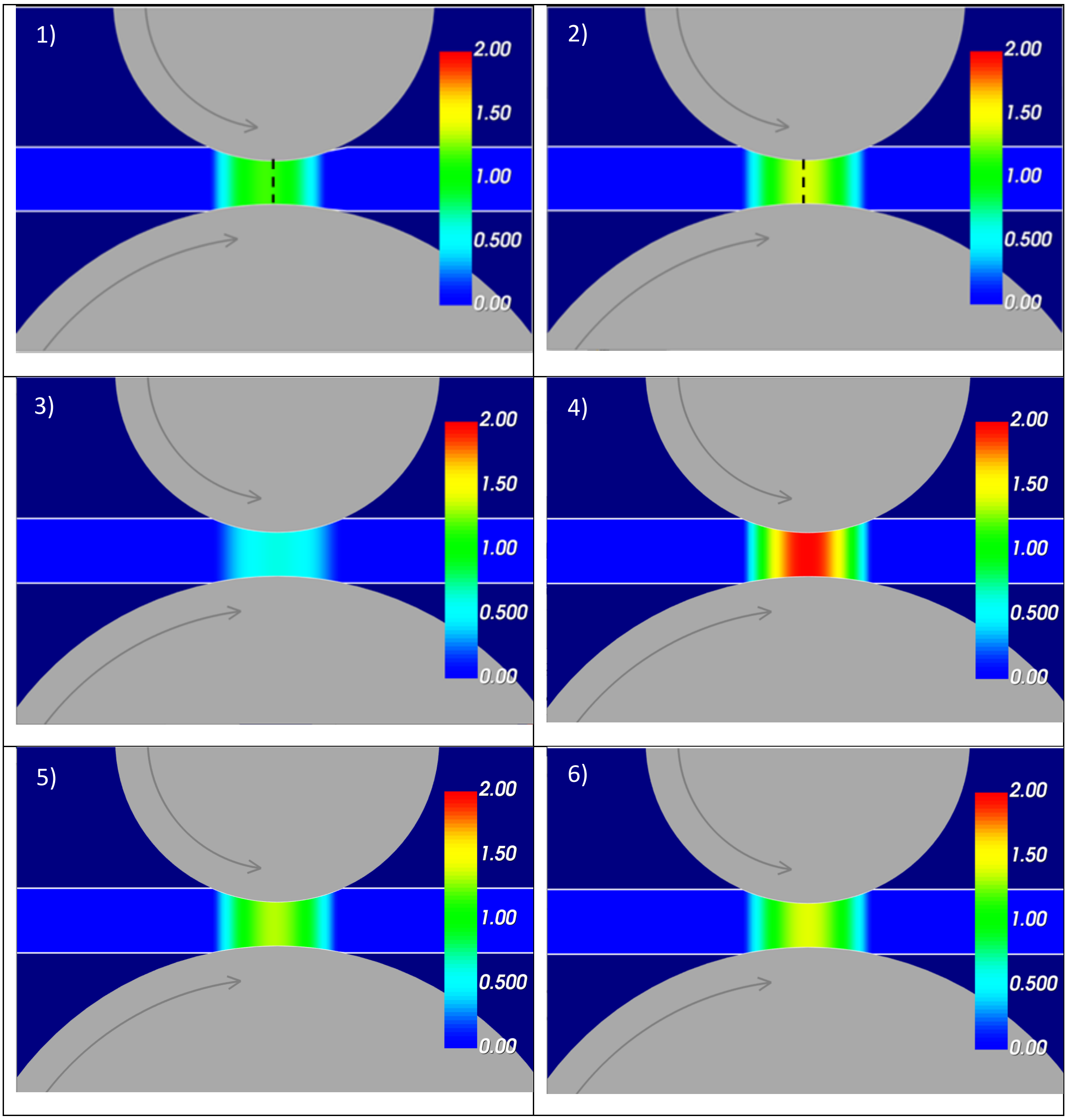

Figure 3: Three pairs of examples of nip pressure distribution; the material properties and the printing speed used in the simulations are given in Table 1, the dashed lines in images 1 and 2 stand for the position of the nip center

4. Conclusion remarks

Compression process in a printing nip is complex and highly dynamic. For an easy understanding of paper's response towards the compression from a rolling nip, a visualisation tool for the dynamic compression has been developed. This can be utilized to promote understanding and communication about complex dynamic processes. For instance, the impacts of the viscoelastic properties of the material as well as printing speed can be easily captured / perceived from the colour coded zone in the nip.

In the present work Maxwell model was used because of its simplicity. In this material model, a few assumptions were made as listed below.

The paper is a linear viscoelastic material, whose mechanical properties (both elastic and viscos components) remain constant during the compression, or independent of compression rate. For a paper material, its elastic modulus gradually increases with the increasing strain-rate as the mass density increases.

The compression is modest or within the elastic range of the paper, namely neither fibre nor its network structure is damaged during the compression.

The material distribution is uniform in x–y plane and in the thickness (z) direction. Variations of the paper structure can be ignored in the model.

With these assumptions in mind, the material model is probably most applicable to a paper having a single-ply fibre structure. For paper of multiply structure having different mass densities and viscoelastic properties or the densification effect is no negligible, a non-linear material model has to be considered which is beyond the scope of this work. Even though a simplified material model was used in the simulation, here Maxwell model, the concept of using visualisation as an aid for understanding and research is rather general. Extension of this framework to a more complex material model is more straight forward.

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