International Journal of Mechanical Sciences 88 (2014) 82–92

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

journal homepage: www.elsevier.com/locate/ijmecsci

Feeding in rolling contact of layered printing cylinders

Joonas Sorvari [a,*], Markku Parola [b]

[a] LUT Savo Sustainable Technologies, Varkaus Unit and Department of Mathematics and Physics, Lappeenranta University of Technology, P.O. Box 20, 53851 Lappeenranta, Finland
[b] VTT Technical Research Centre of Finland, P.O. Box 1000, 02044 VTT, Finland

ARTICLE INFO

Article history:
Received 27 December 2013
Received in revised form
23 May 2014
Accepted 28 July 2014
Available online 12 August 2014

Keywords:
Nip
Rubber blanket
Feeding
Rolling creep
Printing

ABSTRACT

Many web handling processes involve nips through which the web passes. Due to contact deformations, the speed at which the nip cylinders feed the web may differ from the peripheral speed of the cylinders. This paper examines in detail the feeding phenomenon in the case of layered cylinders. In particular, we focus on offset printing cylinders which are covered by a thin rubbery layer. We begin our analysis by considering existing limiting solutions of thin layered cylinders undergoing small strains, and thereafter study the large deformation rolling contact problem using the finite element method. It turns out that the feeding tendency of layered cylinders is dominated by the compressibility of the layer. However, feeding characteristics of layered cylinders are not constant but rather depend on the applied indentation: an increase in indentation may even alter the feeding tendency of the cylinders. The results also indicate that the feeding type affects web strain. Consequently, we conclude that in order to attain better web handling, the feeding characteristics of the cylinders should be known.

1. Introduction

In offset printing, ink is transferred to paper in a nip. The nip consists of rubber-covered printing cylinders and a paper web. Although the primary function of the rubber printing blankets is to transfer ink to the surface of the paper web, they also have a strong impact on the mechanical response of the paper web in two ways. Firstly, printing nips induce variations in the web tension which have been linked to web breaks, decreasing productivity [1]. Secondly, printing nips can degrade the structure of the paper web. In the case of coated paper, the cohesive forces between the blanket and the paper can cause delamination [2]. Thus, printing nips have a central role in the overall success of printing. Poor control of printing cylinders and a lack of understanding of nip mechanics can lead to runnability problems and deterioration in the quality of the printed product.

Nip mechanics have already been extensively studied in various areas of the papermaking industry, most notably in calendering and winding [3–5]. However, this is not the case with printing. In fact, in a recent publication by Uesaka [6], the printing nip is referred to as a “black box” for the industry, as only recently have serious mechanistic studies been published. Perhaps the most extensive study of the nip mechanics in printing is that of Wiberg [7], who studied the deformation of paper in a single offset printing nip with the aid of finite element modeling. Though Wibergs work offers an in-depth look into printing nip mechanics, it does not address the feeding characteristics of printing blankets. In web tension formation, it is important to understand how printing cylinders feed or drive the web through the nip to an open draw. In addition, uneven feeding across the width of the cylinders can cause lateral movement of the web, which in turn can cause the formation of wrinkles. In the context of this paper, feeding is to be understood as the tendency of nip cylinders to change the speed of the transported media. In the field of contact mechanics, the phenomenon where bodies in rolling contact have different peripheral speeds is known as rolling creep or creepage [8].

The phenomenon of rolling creep has long been recognized. Parish [9] was the first to point out rolling creep in the case of covered rollers. In the experiments performed by Parish, it was found that a rubber-covered roller always has a lower peripheral speed than a rigid roller, whether or not the covered roller is doing the driving or is driven. The peripheral speed difference was found to increase with load and decrease with rolling speed. By measuring the extension of the covered surface, Parish was able to conclude that the observed rolling creep was mainly due to the extension of the surface. He attributed the effect of the rolling speed on the speed difference to imperfect elastic properties.

The work of Parish was soon followed by that of Miller [10], who studied the effect of indentation on both nip load and rolling creep. Unlike the results of Parish, Millers experimental results demonstrated a case where the covered roller had a higher

* Corresponding author. Tel.: +358 504397712.
E-mail addresses: joonas.sorvari@lut.fi (J. Sorvari), markku.parola@vtt.fi (M. Parola).

http://dx.doi.org/10.1016/j.ijmecsci.2014.07.008
0020-7403/

peripheral speed than the rigid roller. The effect of indentation depth on the rolling creep was found to be dependent on the cover material. According to Miller, this was due to differences in compressibility between cover materials. Indeed, this was later confirmed to some extent by Miller [11], whose numerical analysis showed that tangential surface strain at the contact area depends on the cover compressibility. Highly compressible material exhibited compressive straining, while incompressible material showed extensional straining. Moreover, the effect of loading was found to have less impact on highly compressible material compared to incompressible material, for which the surface strain strongly increased as the roller loading was increased. Most strikingly, his results showed that for some materials, the sign of the tangential surface strain can change as a result of changes in roller loading. This implies that the feeding properties of covered rollers may change due to loading conditions.

The latter study of Miller was based on the work of Hannah [12], who first solved the two-dimensional problem of indentation of a layered elastic half space by a rigid cylinder. Thereafter, the indentation issue has been addressed by Meijers [13], Bentall and Johnson [14], and Alblas and Kuipers [15]. In all these papers, asymptotic solutions are derived and the effect of compressibility on nip conditions is evaluated. However, only Bentall and Johnson discuss rolling creep. They defined rolling creep explicitly and demonstrated that it depends on the compressibility and thickness of the cover material. The approximate solution technique of Bentall and Johnson was later extended to a tractive rolling case by Nowell and Hills [16], who discussed the effect of tangential force on rolling creep.

The rolling contact problem between covered rollers and media in the nip has been studied by Soon and Li [17,18], who provided a solution to the problem in a series form. Their results fore mostly showed that the tail force or downstream media tension has an effect on rolling creep. More recently, Stack et al. [19] employed a nonlinear large-deformation finite element method to study the media transport problem. Once again, the effect of compressibility on rolling creep was demonstrated. It was observed that incompressible cover materials have a tendency to increase the speed of the transported media, whereas highly compressible materials have a tendency to decrease the speed of the media. The effect of media tension on rolling creep was found to be significant only for soft cover material.

The literature on rolling creep of layered cylinders is extensive but scattered. This reflects the non-uniform naming of the phenomenon: rolling creep [14], apparent slip [9] and undrive/overdrive phenomena [19], to cite a few examples. The aim of this study is to form a uniform and sound survey of feeding properties of layered cylinders. In addition, we study how the feeding type affects nip conditions and web strain. The application focus is on printing; however, results presented herein may also be applied to other application areas, namely to cases where the nip width is larger than the thickness of the cover. The examination starts from theoretical considerations and arrives at clear conclusions supported both theoretically and numerically. Throughout this study, we focus on plane strain rolling contact problems.

2. Feeding characteristics of printing blankets

The offset printing nip, which is illustrated in Fig. 1, consists of a paper web and steel-based printing cylinders covered with a thin printing blanket. The thickness of the blanket is approximately 2 mm. The printing blanket is a laminate structure composed of different material layers. The outermost layer of the printing blanket is known as the surface layer, as it contacts the paper surface. The primary task of the surface layer is to transfer an image from the printing plate to the paper surface as sharply as possible. The surface layer is made of solid rubber. The carcass refers to the structure of the blanket beneath the surface layer. In modern printing blankets, the carcass consists of various fabric plies and a compressible layer. The fabric plies are made of strong woven fabric, and the compressible layer is made of rubber containing microspheres or voids.

The feeding characteristics of a printing blanket can be studied in a specially designed rolling contact experiment [20]. The experimental setup comprises a rigid roller acting as the driver and a blanket cylinder driven by friction from the contact, see Fig. 2. In the experiment, angular velocities of both cylinders are measured. The feeding type can then be classified according to delta value

$$\delta = \frac{\omega_r - \omega_b}{\omega_r}, \tag{1}$$

where ω_b and ω_r are the angular velocity of the blanket and the rigid cylinder, respectively. Depending on the sign of the delta value, the blanket can be classified as positive if $\delta > 0$ or negative if $\delta < 0$. The absolute value of delta indicates how strong the feeding tendency is. If the absolute value is negligible, the printing blanket can be classified as neutral. When the radii of the cylinders are equal in size, the delta value is a measure of the difference in peripheral surface speeds. In rolling contact mechanics, this measure is known as the rolling creep ratio [8]. A positive delta value indicates that the blanket cylinder rotates more slowly than the rigid one, and in the case of a negative delta value, the situation is the reverse. If a printer makes the decision about the choice of one blanket over another in light of the delta value, it is important to understand the physics of the feeding experiment in detail. The following set of questions thus arises:

- What causes the difference in surface speeds?
- What is the difference between a negative and a positive blanket?
- How do the nip conditions differ between a negative and a positive blanket?
- What is the influence of loading upon feeding?

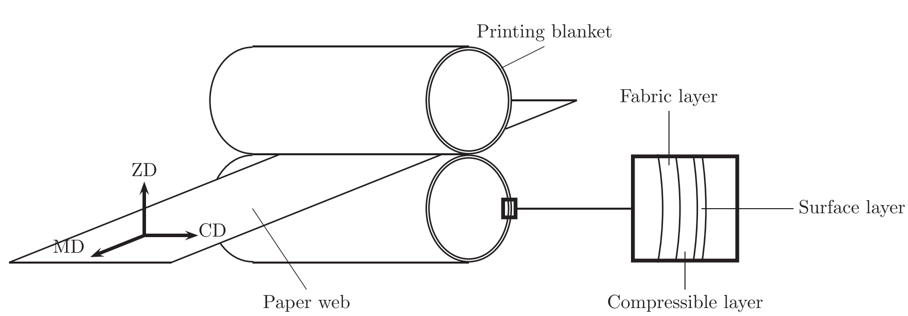

Fig. 1. Schematic illustration of a printing nip and principal material directions of machine made paper. MD refers to machine direction, CD refers to cross direction and ZD refers to *z*-direction.