Analysis of pressure force between two cylinders

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Cylinders are very important elements in an offset printing machine because after being supplied with ink they transfer a printing image on paper. A type of setting as regards the stress between cylinders affects quality of printouts as well as rate of wear and tear of operating materials and machine's elements. It is of great importance to provide for accurate calculation of stress force between two cylinders because this allows for setting an adequate contact zone width and cylinders indentation. In the printing unit of the offset machine there occurs contact between a metal cylinder and cylinder with fixed rubber blanket. The said blanket is composed of some layers, where one of them is a compressible layer. Therefore, the problem is not of trivial nature, as the blanket is made of a non-linear material.

Keywords and phrases: contact problem, offset, blanket cylinder, rubber blanket.

Introduction

Offset printing is based on two main assumptions: flat printing plate and presence of a blanket cylinder in the printing unit, where the cylinder transfers ink from plate cylinder to paper. First, ink and a dampening solution (in offset with dampening) are put on the printing plate with printing and non-printing areas which is fixed on the plate cylinder. Then, a printing image is transported onto the blanket cylinder coated with rubber blanket and, subsequently, the image is printed on paper pressed to the blanket cylinder by the impression cylinder.

In the printing unit there are 3 cylinders: a plate cylinder, a blanket cylinder and an impression cylinder. It is very important to ensure that an adequate stress is set between the cylinders.

The stress affects quality of printouts and as well as rate of wear and tear of operating materials and machine's elements.

Printing unit construction

In a single color offset printing machine the printing unit is composed of a plate cylinder, a blanket cylinder and an impression cylinder (Fig. 1). A sheet-fed offset machine includes a number of such moduluses which are inter-connected by the conveying mechanisms. A multi-color offset printing machine construction can involve another solution, which is less frequently used and the idea of which consists in that one common impression cylinder remains in contact with more than one contacting plate cylinder. Usually, this is a five-cylinder printing unit (one impression cylinder, two blanket cylinders and two plate cylinders). There is also another possible configuration where two blanket cylinders remain in mutual contact and the sheet is running between them, which is referred to as the so called blanket-to-blanket system. Each of the said blanket cylinders is in contact with a separate plate cylinder. Another configuration regarding the printing unit consists in the blanket cylinder contacting with two plate cylinders [1, 3].

All of these cylinders have to be in mutual contact to provide for ink transfer. A place where they are in contact is called a contact zone (contact area, nip). For proper quality of print-outs it is necessary to set up an adequate contact zone width. All of the printing unit cylinders mesh with each other through gear wheels [2].

Plate cylinder

On the plate cylinder there is fixed a printing plate which transfers ink image onto the blanket cylinder.

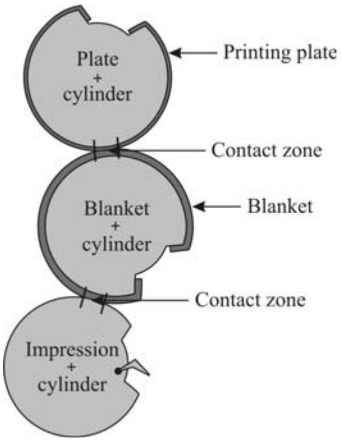

Fig. 1. Scheme of printing unit where contact zones between cylinders are selected.

Depending on the type of a machine under the printing plate the underlay sheets may be placed which are used to set up an adequate surface pressure between the plate and the blanket. From its top the plate cylinder remains in contact with the ink form rollers and the dampening form roller, whereas from its bottom — with the blanket cylinder.

Usually, the plate cylinder is composed of two bearer rings (also called cylinder bearers) placed on each of the ends of the cylinder. They are made of hardened metal. In most machines, during printing the plate cylinder's bearer rings remain in contact with the blanket cylinder's bearer rings. Between the said bearer rings there is the cylinder's working part which is separated from the bearer rings with a channel. The surface of this working part is located slightly lower than the surface of the rings, which means that the radius of the working part is smaller than the radius of the bearer rings. This makes up the so called undercut in relation to the bearer rings [3, 2].

The circumference of the bearer rings is closed. In turn, in the working part there is a channel which takes about 20% of the circumference length. In this place there are clamping bars aimed at fixing the printing form to the cylinder as well as the screws aimed at adjusting the printing form accordingly [2, 3].

Blanket cylinder

Similarly to the plate cylinder, the blanket cylinder with the fixed rubber blanket (sometimes with underlay sheets) is composed of bearer rings, channels, working part showing some undercut in relation to the bearer rings. The depth of the said undercut in the blanket cylinder is bigger than the one in the plate cylinder because the rubber blanket is thicker than the printing plate. The blanket cylinder also includes a channel parallel to the cylinder's axis where there are rollers aimed at fixing and stretching the rubber blanket [3].

The objective of the rubber blanket fixed on the working part of the blanket cylinder is to transfer a printing image onto the sheet with possibly smallest strain. Elasticity of the said rubber blanket compensates all inequalities of the sheet and the printing plate. While pressing the blanket its stress will increase. Depending on speed of the stress increase the blankets can be divided into soft, semi-hard and hard. Selection of an adequate rubber blanket is of great importance because it makes up the last stage of transferring a printing image onto the sheet [1, 3].

There are two types of blankets: compressible and incompressible (conventional). This division is because of way of blanket strain during its compression. The conventional blanket (Fig. 2a), which is used only in older machinery, comprises the rubber being a printing surface and fabrics located beneath accordingly. In turn, as regards the compressible blanket (Fig. 2 b) there is a compressible layer between fabrics which shows qualities of sponge [1, 3].

As regards the production of blanket, the first stage consists in producing the skeleton made of fabrics connected to each other with caoutchouc-based glue which is damp-proof and resistant against some selective chemicals. In case of a compressible blanket, it is additionally equipped with an internal compressible layer made of cork or synthetic rubber. On its top, there is a superficial film made of synthetic rubber which, during the printing process, remains in contact with the printing plate and with the sheet [3].

The three-layer blankets are made of three fabric layers and have thickness within 1,63–1,78 mm. The four-layer blankets are made of four fabric layers and have thickness within 1,91–2,03 mm. Toleration for thickness is ±0,013 mm. At present, when fabrics are of better quality and a compressible layer is involved, the blankets do not need to include three or four fabric layers. However, the previous names have been maintained in force [3].

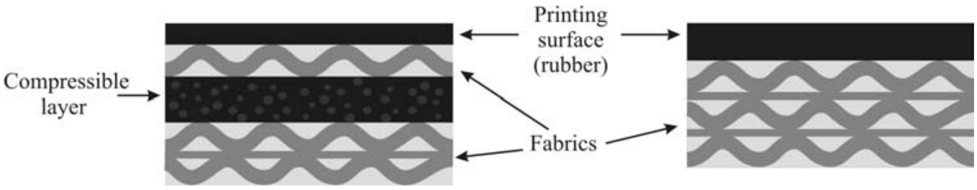

Fig. 2. Scheme of compressible blanket (on the left) and conventional blanket (on the right) [based on [3]].

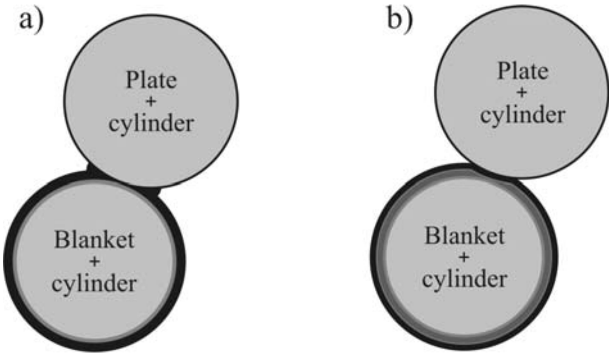

Fig. 3. Contact between the plate cylinder and the blanket one coated with a) incompressible (conventional) blanket and b) compressible blanket [based on [3]].

The compressible layer in the blanket may have open or closed microcanaliculi and micropores. Disadvantage of blankets including a compressible layer with open microcanaliculi is a long time of return to their original thickness after being pressed. Therefore, they are not used in modern machines with high speed of printing. The blankets including a compressible layer with closed microcanaliculi show faster return to their original thickness after being pressed and they are more fault--tolerant and resistant to chemicals [2].

Previously, natural rubber was used to make the superficial layer. Unfortunately, it failed to be resistant to chemicals, such as dissolvents and lubricants. Nowadays, the blanket's superficial layer is made of synthetic rubber enriched with additives that increase resistance of the blanket's surface, and with softeners and plasticizers that increase elasticity. The additives are selected in such a manner which allows for matching the blanket with the ink and with the solvent. A vulcanizing agent, like sulphur, is added with the aim to link transversely the rubber molecules in the vulcanisation procedure. Usually, Buna-N rubber or, rarely, neoprene is used as a synthetic rubber [3].

The compression ratio for conventional blankets by Panak [1] is 5–7% — such a percent figure can be taken into account while compressing without a risk of bulges. A strain of conventional blanket by Ciupalski [2] is less than 4%, and a strain of compressible blanket is more than 4%. The compressible blanket better compensates inequalities, if any, while being in contact with the printing plate and with the sheet. Additionally, it makes the printing dots sharper, provides for better register alignment and smaller strain of paper sheet [1–3].

A maximum indentation depth of blanket by Ciupalski [2] should be 0,06 mm, although for some materials it should be only 0,03 mm. The size of indentation depends on materials of which the blanket has been made, on stretch force of the blanket coated on the blanket cylinder and on pressure between the cylinders in the printing unit [1, 2].

Impression cylinder

It is possible for the diameter of the impression cylinder to be identical to the diameter of the plate cylinder's bearer rings and blanket cylinder's bearer rings, or it can be twice bigger. The impression cylinder has a channel as well, which is provided with the sucker and gripper system. The double-sized impression cylinder includes two channels with the sucker and gripper system. In contrast to the other cylinders of the printing unit, the impression cylinder shows an insignificant undercut of the bearer rings. This means that the bearer rings are of smaller diameters than the working part of the impression cylinder [2, 3].

As regards the offset printing machine there are two types of mechanism to change a distance between the axis of the impression cylinder and the blanket cylinder. First of the mechanisms consists in moving the impression cylinder towards the blanket cylinder — this solution is rarely used because of the impression cylinder being very heavy. The other mechanism, more often used, consists in moving the blanket cylinder closely to and from the impression cylinder and the plate cylinder [3, 2].

Computation of force pushing the cylinders to each other

As appears from the previously presented analysis of knowledge, a printing machine includes mutually contacting cylinders. Simultaneously, it can be seen that they are significantly important elements of the offset machine.

In the contact zone there arise stresses. According to the previously presented information, the blanket material is of non-linear nature [9] and, therefore, there is no possibility to apply the linear Hook's law. It is worth noting [12] that the non-linear relationship between the load and the extension was emphasized by, for instance, Leibniz G.W. (1690), Bernoulli J. (1694), Bulfinger G.B. (1729). In the printing sector, as referred to for instance by [11], the non-linear approximation was used for the first time by Tir K. W. [9] (1952). The non-linear relationship was also analysed by [11], Czechman J. I. [8].

In printing technical literature [6, 9], the following non-linear relationship is assumed between stress σ and strain ε (relative strain):

$$\sigma = E\varepsilon^n \tag{1}$$

where E — conditional elastic modulus (for $n = 1$ it is Young's modulus), n — coefficient which shows different non-dimenssional values for different materials. As regards stresses which occur in blankiet with thickness δ (Fig. 4) the following equation has been assumed:

$$\sigma = E\left(\frac{\lambda}{\delta}\right)^n \tag{2}$$

where λ/δ — strain of blankiet in the radius direction.

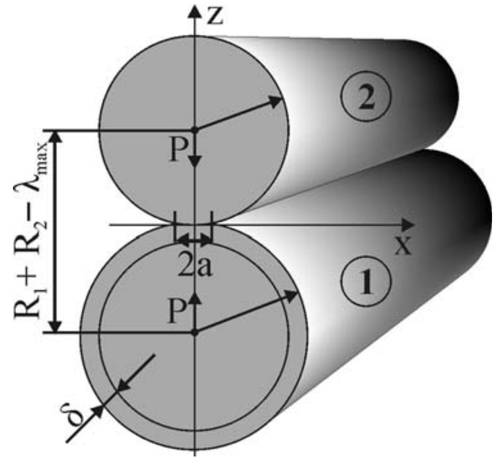

Fig. 4. Contact between two rollers.

The constants of the material *E*, *n* characterise the stress--strain curve of considered material. They can be determined for example according to equation (1) based on two experimental researches:

$$\sigma = E\varepsilon_1^n, \qquad \sigma = E\varepsilon_2^n \tag{3}$$

First there have to be computed *n* given by equation:

$$n = \frac{\ln(\sigma_2/\sigma_1)}{\ln(\varepsilon_2/\varepsilon_1)} \tag{4}$$

And then *E* can be computed according to equation:

$$E = \frac{\sigma_1}{\varepsilon_1^n} = \frac{\sigma_2}{\varepsilon_2^n} \tag{5}$$

Some of the scientists [9] assume coefficient $n = 1/m$ instead of coefficient *n*:

$$\sigma^m = E_0\frac{\lambda}{\delta} \tag{6}$$

By taking into account the strain [8] in the equation (2), we arrive at the stress relationship in the contact zone:

$$\sigma(x) = E\left(\frac{\lambda_{\max}}{\delta}\right)^n\left(1 - \frac{x^2}{a^2}\right)^n = \sigma_{\max}\left(1 - \frac{x^2}{a^2}\right)^n \tag{7}$$

where (fig. 4) $\sigma_{\max} = E\left(\frac{\lambda_{\max}}{\delta}\right)^n$, $a = \sqrt{\frac{2R_1R_2}{R_1+R_2}\lambda_{\max}}$, *a* — half of the contact zone width, R_1, R_2 — radius accordingly of upper roller and lower roller, λ_{max} — maximum strain of cylinders or their indentation.

The equation (7) gives a possibility to compute a force cunterbalancing the force P per unit of length of the cylinder:

$$\begin{aligned} \mathrm{P} &= 2\int_0^a \sigma(x)dx = 2\sigma_{\max}\int_0^a \left(1 - \frac{x^2}{a^2}\right)^n dx = \\ &= 2\sigma_{\max}\frac{a\sqrt{\pi}\Gamma(n+1)}{2\Gamma(n+3/2)} = 2a\sigma_{\max}\Psi(n) \end{aligned} \tag{8}$$

where the function $\Psi(n)$ has been expressed in an in analytic form [13]:

$$\Psi(n) = \frac{\sqrt{\pi}\Gamma(n+1)}{2\Gamma(n+3/2)}. \tag{9}$$

where $\Gamma(x)$ — Gamma function. In turn, in the case $n = 1/m$ the following function has been obtained:

$$\Psi(m) = \frac{\sqrt{\pi}\Gamma(1/m+1)}{2\Gamma(1/m+3/2)}. \tag{10}$$

The so obtained equations (9) and (10) are met in neither technical nor scientific literature connected with printing. Previously, some scientists [5–11] obtained asymptotic representations of the said functions. Accordingly, in the paper [6], by way of expanding in series the integrand (8) the function $\Psi(m)$ was presented as follow:

$$\begin{aligned} \Psi(m) &= 1 - \frac{1}{3m} + \frac{1-m}{10m^2} - \frac{(1-m)(1-2m)}{42m^3} + \\ &+ \frac{(1-m)(1-2m)(1-3m)}{216m^4} \end{aligned} \tag{11}$$

Unfortunately the above presentation proved to have errors.

The book [9] includes an equation which is only a certain approximation:

$$\Psi(m) = \frac{4}{3}\frac{m}{m+1} \tag{12}$$

The book by the same author [9] includes the corrected equation which was obtained with the Simpson's method aimed at integral computing:

$$\Psi(n) = \frac{1}{12}\left(1 + 2\left(\frac{3}{4}\right)^n + 4\left(\frac{15}{16}\right)^n + 4\left(\frac{7}{16}\right)^n\right). \tag{13}$$

For power *n* the equation (11) takes the form:

$$\begin{aligned} \Psi(n) &= 1 - \frac{n}{3} + \frac{n(n-1)}{10} - \frac{n(n-1)(n-2)}{42} + \\ &+ \frac{n(n-1)(n-2)(n-3)}{216} \end{aligned} \tag{14}$$

Figure 5 shows functions $\Psi(n)$ and $\Psi(m)$ along with their approximations. The analysis of graphs proves that as regards function $\Psi(n)$ the approximation (14) is correct for values $n < 4$, and approximation (13) — for values $n > 0, 6$. As regards the function $\Psi(m)$ the approximation (11) is correct for $m > 0, 2$. The equation (12) is right only for value $m = 1$. In conclusion, with the aim to derive the functions $\Psi(n)$ and $\Psi(m)$, the most appropriate equations are (9) and (10).

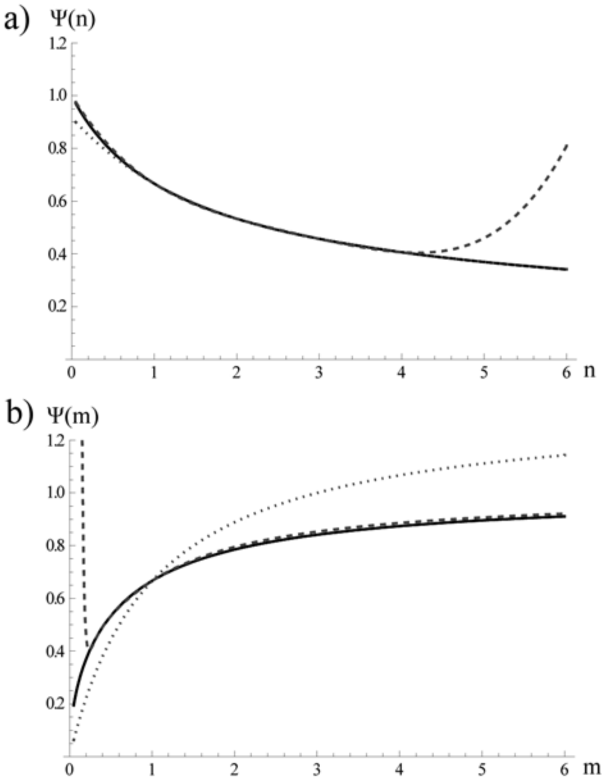

Fig. 5. Dependence of the function Ψ(*n*) on parameter *n* (a) and function Ψ(*m*) on parameter *m* (b). Continuous curves — equations (9), (10); dashed curves — equations (14), (11); dotted curves — equations (12), (13).

Conclusion

The paper includes an equation that determines dependence of the cylinders pressure force P on the cylinders strain λ_{max} and on the contact zone width *a* which is expressed based on radiuses of the contacting cylinders. The obtained equation for P is accurate for the adopted nonlinear model of material for any *n*. The adopted in this paper model of material is limited only for exponential relation between stress and strain. The so obtained equation allows for setting the contact zone width (printing nip) between the cylinders correctly. It brings about obtaining better quality of the printouts.

In the future we plan to make a verification of constants for concrete blankets, which are on polish market. We will use machine for tensile and compression made by Zwick/Roell company. We try to make similar condition to technological process conditions.

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