Mathematical modelling and description of friction and temperature phenomena in inking unit of the offset printing machine

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In this paper a proposition of mathematical formula of the temperature distribution caused by friction phenomena in the cylinder/cylinder contact in the inking unit of the offset printing machine is presented. In the inking unit there are pairs of wheeling inking rollers, one of which is made of steel and the second one has got a rubber layer outside. The steel roller besides the circular motion moves reciprocating along the cylinder pivot. The measurements made during the tests in the various research centres have shown that the inking rollers' temperature increases during the work of the offset printing machine. Some derivative heat equations are applied to the case study and are solved.

Keywords and phrases: friction, cylinder/cylinder contact, temperature, offset printing, inking unit, inking roller.

Introduction

During the printing process in the offset printing machine, temperature of the rollers in the inking unit and surrounding air increases gradually. This phenomena bases on the influence of the pressure between the steel and rubber coated rollers and influence of the reciprocating motion along the roller pivot. The phenomena of temperature variations in the inking unit of the printing machines, particularly the offset printing machines which are characterised by a complex inking unit, is inevitable. Even in the machines, in which the inking units (more precisely selected inking rollers) are thermostatted, the fluctuations of the temperature are considerable [1]. The main cause of temperature increase in the inking unit is the friction between the flexible and stiff axially oscillating rollers. Temperature variations affect the quality of prints. The temperature increase in the inking unit leads to changes of the rheological ink properties (especially viscosity), to the instability of emulsion of ink and dampening solution, to the deposition of dust on a rubber blanket and to increased demand for dampening solution [2], which eventually negatively affects quality of prints.

The result of friction on the contact surface between two rollers is the generated heat. We assume that the friction force is transformed into the heat energy. Practically, this means that two heat streams arise which are directed towards the inside of the bodies being in contact, and between which there is friction.

The aim of the study is to construct and solve a mathematical model of temperature effects in the inking unit that arise as a result of friction. Considered issue boils down to solving the heat conduction equations with appropriate boundary conditions. These conditions require mathematical modelling and description of friction phenomena.

The analysis of the input parameters impact on the characteristics of the inking unit and the surrounding was made.

Construction of the inking unit of the offset printing machine

The inking unit of an offset printing machine consists of three sections: the ink feeding section, rubbing section an forming section. The ink feeding section of the ink is composed of the ink fountain, the ink fountain roller and the vibrator roller (Fig. 1). The rubbing section consists of stiff rider rollers and elastic rollers, that are situated alternately. Ink form section contains the ink form cylinders with an elastic cover, which transmit ink to the printing elements on the printing form.

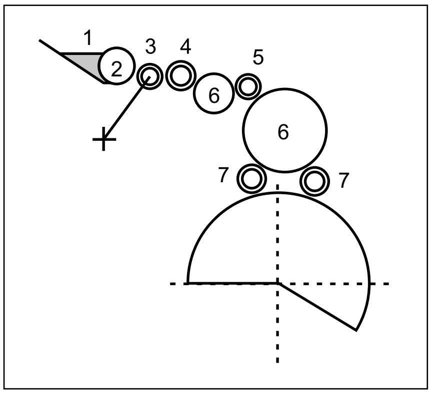

Fig. 1. Schema of the inking unit: 1 — ink fountain, 2 — ink fountain roller, 3 — vibrator roller, 4 and 6 — steel rollers, 5 — roller with flexible cover, 7 — ink form roller.

The inking unit's functions are:

- constant transfer of the ink film with uniform and stable thickness (1.5–2 mm) on printed form;
- steady regulation of ink transfer to the printing form;
- possibility of running while the machine is off (independent drive);
- high sensitivity to changes in the quantity of given ink;
- the minimal stabilization time after the adjustment and switching on the inking unit;
- minimum power consumption.

Solving the problem we focus on the rubbing section, especially on the pair of rollers: stiff rider roller which oscillates axially and ink form roller with an elastic cover. The stiff rollers are usually made of steel with polished surface or are covered with a layer of hard rilson, special nylon or other plastic material with high hardness and low surface-wear [3]. The reciprocating motion is in the range of 0 to 36 mm depending on the type of machinery and the performed work. In the printing machines for high quality printing the rider rollers, which moves reciprocating along roller axis, are cooled by coolant flowing inside the roller. Ink form rollers are covered with a suitable rubber, super-polyamide, and have various diameters.

Problem description and motivation

The measurements made during the tests in various research centres [1, 4, 5] have shown that the inking rollers' temperature increases. For example, in a newspaper rotary printing machine, while printing at 60 000 revolutions per hour, the temperature of the rollers has increased 30°C [3]. Researches also show that the temperature increases with the speed of the machine, the pressure between the rollers and the width of the contact zone. The temperature increase is also determined by the material from which the rollers are made and its' diameter.

Temperature change during the printing process affects the quality of prints in one edition due to the instable printing process. The temperature increase in the inking unit causes the heating of the printing machine unit, which is emitted through the ink and dampening solution and by the radiation and convection (drift). The heat gradually warms the machine and after about 4–5 hours the balance between produced and emitted heat is achieved [2]. Temperature fluctuations result in fluctuations of the measurable indicators of the prints quality (e.g. optical density) and varying their values within a single edition. Hence it is reasonable to model both friction and temperature rise in order to get better knowledge of the issue.

Due to the high real speed of the rotating rollers (one of them is cooled by liquid flowing inside the roller), the problem of the cylinder pairs is simplified and reduced to the problem of the cylinder with liquid coolant inside and the cylinder surrounding, which on the border with

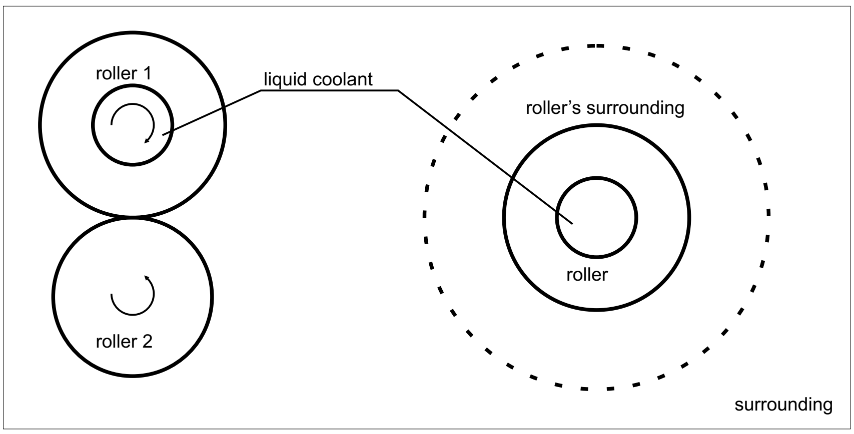

Fig. 2. The transition from the real issues to the model.

the surrounding reaches the temperature equal to the ambient (surrounding) temperature (Fig. 2).

Mathematical formulation of the problem

The source of heat are the circumferential sliding cylinders:

$$Q = (1-\eta) \cdot f(v_r) \cdot v_r \cdot P(t) \quad (1)$$

where: Q — density of the heat stream,
η — part of power which is lost (e.g. because of material consumption),
$f(v_r)$ — kinematic friction coefficient depending on relative velocity v_r of cylinders in contact,
$P(t)$ — contact pressure depending on the time .

In the case of axis symmetrical state of the cylinder temperature T_1 and the cylinder surrounding temperature T_2 the heat conduction equation for isotropic bodies in cooperation with cylindrical coordinates (R, φ, z) given in [6] will take the form as follows:

$$\frac{\partial^2 T_1(R,t)}{\partial R^2} + \frac{1}{R}\frac{\partial T_1(R,t)}{\partial R} = \frac{1}{a_1}\frac{\partial T_1(R,t)}{\partial t}, R_1 < R < R_2 \quad (2)$$

$$\frac{\partial^2 T_2(R,t)}{\partial R^2} + \frac{1}{R}\frac{\partial T_2(R,t)}{\partial R} = \frac{1}{a_2}\frac{\partial T_2(R,t)}{\partial t}, R_2 < R < R_3 \quad (3)$$

with the following boundary conditions:

- heat stream inside the cylinder on the border with cooling liquid equals to the product of multiplication of the heat transfer coefficient between the liquid and the cylinder and the cylinder temperature at this boundary minus the temperature of the cooling liquid:

$$\lambda_1 \frac{\partial T_1(R_1,t)}{\partial R} = \alpha_1^T [T_1(R_1,t) - T_0 h_1^T(t)] \quad (4)$$

- sum of heat flows at the border of the cylinder and the ambient directed to the inside and outside of the cylinder is equal to the heat resulting from friction:

$$\lambda_1 \frac{\partial T_1(R_2,t)}{\partial R} - \lambda_2 \frac{\partial T_2(R_2,t)}{\partial R} = (1-\eta) \cdot f(v_r) \cdot v_r \cdot P(t) \quad (5)$$

- cylinder's temperature on the border with the cylinder's surrounding is equal to the cylinder's surrounding temperature on this boundary:

$$T_1(R_2,t) = T_2(R_2,t) \quad (6)$$

- cylinder's surrounding temperature on the border with the ambient is equal to the ambient temperature:

$$T_2(R_3,t) = T_3 h_3^T(t) \quad (7)$$

and initial conditions:

- initial temperature of the cylinder is equal to the temperature of the coolant:

$$T_1(R,0) = T_0, R_1 < R < R_2 \quad (8)$$

- initial temperature of the cylinder's surrounding is equal to the ambient temperature:

$$T_2(R,0) = T_3, R_2 < R < R_3 \quad (9)$$

Above, the following signs:
T_1, T_2 — temperature of the cylinder and the cylinder's surrounding,
t — time,
R — distance from the axis of the cylinder,
a_1 — thermal diffusivity (l = 1, 2),
α_1^T — coefficient of heat transfer between the coolant and the material, which the cylinder is made from,
λ_1, λ_2 — thermal conductivity, respectively to the cylinder and the cylinder's surrounding (thermal conductivity),
$h_l(t)$ — dimensionless temperature of the inner (l = 1) and outer (l = 3),
T_0, T_3 — temperature of the coolant liquid and the ambient.

We have found the temperature in the system for large values of time t. We assume that $h_l^T(t) \to 1, T_l(R,t) \to T_l(R), l = 1, 2,$ for $t \to \infty$. The problem for the stationary temperature is reduced to solve the system of equations:

$$\frac{d^2 T_1(R)}{dR^2} + \frac{1}{R}\frac{dT_1(R)}{dR} = 0, R_1 < R < R_2 \quad (10)$$

$$\frac{d^2 T_2(R)}{dR^2} + \frac{1}{R}\frac{dT_2(R)}{dR} = 0, R_2 < R < R_3 \quad (11)$$

with the following boundary conditions:

$$\lambda_1 \frac{dT_1(R_1)}{dR} = \alpha_1^T [T_1(R_1) - T_0] \quad (12)$$

$$\lambda_1 \frac{dT_1(R_2)}{dR} - \lambda_2 \frac{dT_2(R_2)}{dR} = (1-\eta) \cdot f(v_r) \cdot v_r \cdot P \quad (13)$$

$$T_1(R_2) = T_2(R_2) \quad (14)$$

$$T_2(R_3) = T_3. \quad (15)$$

The general solution of equations (10) and (11) has the form:

$$T_1(R) = A_1 + A_2 \log R \quad (16)$$

$$T_2(R) = B_1 + B_2 \log R \quad (17)$$

Therefore we have to determine four unknowns. For this purpose, we will use four boundary conditions:

$$\lambda_1 \frac{A_2}{R_1} = \alpha_1^T [A_1 + A_2 \cdot \log R_1 - T_0] \quad (18)$$

$$\lambda_1 \frac{A_2}{R_2} - \lambda_2 \frac{B_2}{R_2} = Q \quad (19)$$

$$A_1 + A_2 \log R_2 = B_1 + B_2 \log R_2 \tag{20}$$

$$B_1 + B_2 \log R_3 = T_3 \tag{21}$$

where: $Q = (1 - \eta) \cdot f(v_r) \cdot v_r \cdot P$.

The final solution is written in the form:

$$T_1(R) = \frac{\left(T_3 + Q\frac{R_2}{\lambda_2}\log\frac{R_3}{R_2}\right)\left(\frac{1}{R_1\alpha_1^T} + \frac{1}{\lambda_1}\log\frac{R}{R_1}\right) + T_0\left(\frac{1}{\lambda_2}\log\frac{R_3}{R_2} - \frac{1}{\lambda_1}\log\frac{R}{R_2}\right)}{\frac{1}{R_1\alpha_1^T} + \frac{1}{\lambda_1}\log\frac{R_2}{R_1} + \frac{1}{\lambda_2}\log\frac{R_3}{R_2}} \tag{22}$$

$$T_2(R) = T_3 - \frac{\left(QR_2\left(\frac{1}{R_1\alpha_1^T} + \frac{1}{\lambda_1}\log\frac{R_2}{R_1}\right) + T_0 - T_3\right)\frac{1}{\lambda_2}\log\frac{R}{R_3}}{\frac{1}{R_1\alpha_1^T} + \frac{1}{\lambda_1}\log\frac{R_2}{R_1} + \frac{1}{\lambda_2}\log\frac{R_3}{R_2}}. \tag{23}$$

Summary

Work on the proposed model is still under development. In the work assumptions the cyclical character of ink transfer through the ink fountain roller that rotates a specific angle and the pendulum motion of vibrator roller were omitted. These mechanisms mean that the input is given as a discrete non-modulated signal and the output signal is in the analog format. This issue is described in [7].The dissertation is planned for the review of the research model in the production.

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