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INDIRECT INK TRANSFER FOR OFFSET PRINTING, TAKING INTO ACCOUNT THE ROUGHNESS OF THE OFFSET PRINTING PLATE SURFACE

Eldar ALIYEV[1], Isa KHALILOV[2], Shabnam ISMAILOVA[3*]

[1,2,3]Department of Mechatronics and Machine Design, Azerbaijan Technical University
Baku, Azerbaijan

E-mail: elab57@mail.ru[1] , khalilov@aztu.edu.az[2], shebinem.ismayilova@aztu.edu.az[3]*

Abstract: This article is devoted to the study of the influence of the surface roughness of an offset printing plate on the form-decal contact and deckle-printed material. Taking into account the deepening of micro protrusions of the surface roughness of the printing plate into the body of the deckle, which lead to additional displacements and deformation of the deckle, the amount of ink on the surface of the form is determined. The separation and transition of the paint layer in the contact zone has been studied. It has been established that the ink layer located in the free space of the roughness of the surface of the printing plate is also involved in the transfer of ink. The proposed method of indirect ink transfer in offset printing allows you to determine more accurate values of consumables in the design of printing processes, also predict the quality of printed prints, determine the runtime of printing plates, and correctly configure the printing machine before the printing process.

Key words: *offset printing, contact area, roughness, deckle, ink transfer*

Introduction. To obtain prints in any number of copies in the printing process, the printing ink is transferred from the ink apparatus to the printing plate and from the form to the printed material [1-3]. The printing apparatus is one of the main components of the printing machine. It serves to transfer a certain amount of ink from the printing elements of the form to the printed material at sufficient specific pressure and to guide the printed material through the printing zone.

The actions of printing devices are associated with the type of printing form and the type of printed material [1,2].

The transfer of information from the printed form to the material can occur directly or indirectly [2]. Indirect ink transfers during offset printing is carried out in two stages. The ink layer located on the printing form comes into contact with the rubber-cloth plate (with the decal) of the offset cylinder. In this case, part of the layer remains on the surface of the plate. After that, the ink transfers to the printed material when the offset cylinder plate comes into contact with it, where the adhesive forces that act between the printing ink and the printing plate as well as the blanket of the offset cylinder and the printed material are always less than the cohesive forces acting in the printing ink [3]. The above makes the necessary separation of ink into layers possible.

It has been established that with an increase in the specific printing pressure of ink-absorbing materials, the ink transfer coefficient and the amount of ink transferred increase to a maximum value [2].

In [4, 5], the frictional interaction of a two-layer elastic body and a rough indenter was studied, which corresponds to the phenomena occurring in the printed contact zone. The research results show that the contact of a rough body with an elastic one leads to additional displacements. These displacements, which are determined by the deepening of the micro roughness of the surface roughness, affect the values of the deformation of the elastic body.

Based on the foregoing, it can be concluded that when studying a printed pair, it is necessary to take into account the roughness of a more rigid surface, i.e., the surface roughness of the printing plate. This, in turn, will make it possible to obtain more accurate values of the specific pressure, as well as the ink transfer coefficient and the amount of ink transferred, which determine the quality of prints and the runtime of the printing plate.

The study of the influence of the geometric parameters of the printing pair, therefore, the micro-geometry of the printing plate surface on the ink transfer coefficient and the amount of ink transferred, as well as on the quality of the prints is a very topical task.

The purpose of this article is to investigate the indirect transition of ink in offset printing, taking into account the roughness of the printing plate surface.

In order to achieve the goal, the following tasks were set:

- To determine the scheme of ink layer separation, also the interaction of elastic deckle and printing plate, taking into account the roughness of the surface of the printing plate. To determine theoretically the influence of printing plate surface roughness on ink quantity and on ink layer separation and transfer;
- to choose a method of estimation of ink quantity and ink layer separation taking into account micro geometry of printing plate surface.

Literature review and problem statement. In work [2], ink separations in the areas of printing form - offset plate and offset plate - printed material were studied. For this purpose, a scheme for ink separation is proposed and the amount of ink transferred from the printing plate to the deckle and from the deckle to the printed material is determined. For ink transfer, the Reynolds equation was derived based on the theory of elastohydrodynamic lubrication, and a model of the relationship between roller parameters, speed, pressure, and ink thickness in the ink roller gap was established using Hertz's contact theory [6]. The influence of speed, pressure and roller size on the thickness of the ink in the gaps of the ink rollers was analyzed. In addition, the ink transfer model was modified to take into account ink retention in the gaps of the ink rollers. The effect of print speed on ink performance was analyzed using a computer simulation method.

An ink apparatus [7] was used to study the effect of adding and evaporating a stabilized alcohol solution and a thin-film emulsion of offset inks on emulsion transfer. It has been found that by introducing a certain non-absorbent substrate in a single pass between the rollers, emulsion transfer can be achieved. By expressing the behavior as a function of the ratio of the emulsion component to the inks, it became possible to study the effect on the optical properties of the final thin layer in the form of a print.

Numerical simulations were used to evaluate the applicability and limitations of optical micro-roughness measurement for coated paper and ink [8]. Experimental results are presented for a number of inks on substrates of different macro-roughness.

The evaluation of a series of commercial raw, semi-matte and glossy coated papers for multi-color sheet offset printing is presented [9]. This research is aimed at better understanding the mutual influence of the free energy of the surface, the roughness of the paper surface and the fountain solution on the print spotting that occurs in full-format printing conditions.

The results of studies of the relationship between the properties of paper and the optical density or color coverage of printed paper have shown that the basic density increases with an increase in the amount of ink before the basic density reaches saturation [10].

The uniformity of water absorption and the structure of the coating on pilot-coated paper with different types and dosages of dispersants have been studied [11]. It was found that most of the samples with uneven water-moisture absorption and uneven reflectance to burn-in tended to have more severe printing problems related to surface moisture/water.

The effect of paper surface properties, including surface free energy, smoothness and gloss of some standard papers used in lithography, on ink transfer was analyzed by comparing the colorimetric values defined by ISO 12647-2:2013 [12]. Determination of the amount of ink transfer, optical density, mottling and difference in color of prints was performed to evaluate the interaction of paper with inks. The results showed that the amount of ink used to obtain a standardized print varies for different types of paper (even within the same ISO classification).

The mechanism of formation of serious bulk-type defects in a system with reverse offset printing operating at high speed was discussed [13]. A mathematical formula is proposed describing the temperature distribution in the ink block of an offset printing machine caused by the phenomenon of friction between cylinders that remain in contact [14].

It has been established that with an increase in the surface roughness of the printing plate, the value of the relative gear ratio α for elastic decals decreases, which contributes to the transfer of ink [15]. One of the most important criteria for print quality is the control of the point gain level. A CtP calibration method used for the manufacture of a printing plate is proposed, which calibrates the point gain in accordance with the recommendations of ISO 12647-2:2013 completely automatically in parallel with printing [16].

The printing mechanism and performance of the high-precision depth-shift printed circuit technology has been investigated from the point of view of the main printing parameters through experimental and theoretical analysis [17]. The ink transfer mechanism is theoretically analyzed for different solvent content using Surface Evolver. The calculation results are compared with the experimental results.

It has been established that within the standardization of the offset printing process, one of the most important tasks is the correct choice of the components of the printing system, taking into account the peculiarities of their interaction and behavior during the printing process [18]. For this purpose, a software product has been developed to calculate the ink transfer to the printed material between the contacting cylindrical surfaces of a sheet-fed offset printer with deformation boundaries.

In offset printing, a process of transfer of a viscous incompressible liquid (ink) is observed [19]. Simulation of the ink flow between rotating cylinders with subsequent crushing of the ink film is carried out using finite difference methods.

It has been established that differences in the values of viscosity, stickiness and fluidity of inks affect such parameters as adhesion, transferability and print stability [20].

Special experimental tests of coatings and industrial printing were carried out, designed to obtain fundamental knowledge about the violation of the adhesion of paints on coated paper [21].

Theoretically, the ink transfer to the printing plate was studied taking into account the surface roughness of the printing plate [22]. However, the paper does not consider and does not compare theoretical data with experimental ones.

Based on the analysis of published scientific papers, the following conclusions can be drawn about the state of the problem of ink transfer and the interaction of an elastic deckle with a printing plate in offset printing:

In studies (except work 22), the assessment of the amount of ink and the separation of the ink layer, as well as the interaction between the elastic deckle and the printing plate, were determined without taking into account the surface roughness of the printing plate.

Influence of mold surface (7) roughness on the amount and transfer of paint.

To study the influence of the surface roughness of the printing plate on the separation of ink in an indirect printing method, the scheme (Figure 1), which is proposed in work [22], is considered.

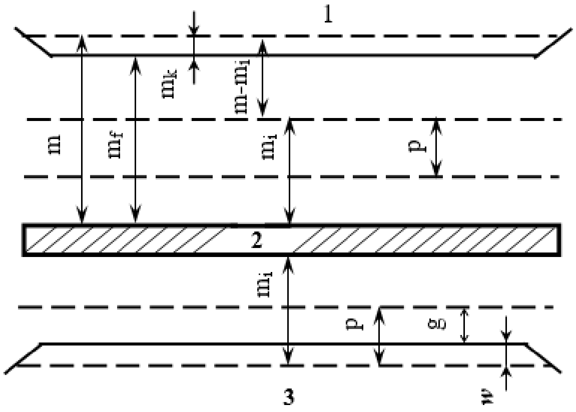

Fig 1. Scheme of separation of the ink layer with an indirect printing method

The diagram (Figure 1) shows the following designations:

1 - printing form; 2 - offset rubber-fabric plate; 3 - paper; m is the amount of ink on the printing plate before printing; $m_f -$ is the amount of ink lying freely on the surface of the printing plate, without regard to roughness; $m_k -$ is the amount of ink that is in the free space of the surface roughness of the printing plate. $p -$the amount of ink transferred to the printed material; mi is the amount of ink on the blanket of the offset cylinder before transferring to the printed material; g is the amount of ink lying freely on the material; w is the amount of ink absorbed by the printed material during the printing process. Given the parameters m_f and m_k the amount of ink m on the printing plate before printing is defined as follows.

$$m = m_f + m_k \tag{1}$$

According to this scheme (Figure 1), ink separations in two contact zones were studied: printing plate - offset plate and offset plate - printed material. Therefore, two ink layer separation coefficients are defined for them.

First zone: printing plate - offset plate (deckle)

$$v = \frac{m_i}{(m_f + m_k) - m_i} \tag{2}$$

second zone: offset plate - printed material

$$v_i = \frac{p}{(m_i - p)} \tag{3}$$

The transfer of ink from the printing plate to the rubber fabric plate (to the deckle) corresponds in principle to printing on non-absorbent material.

The ink transfers from the printing plate to the blanket cylinder plate (deckle) has been found to be.

$$m_i = \alpha(m_f + m_k)\left(1 - e^{-\alpha^2 (m_f + m_k)^2}\right) \tag{4}$$

Transferring ink from the offset plate (from the deckle) to the printed material

$$p = \left(1 - e^{-\alpha_i^2 m_i^2}\right)\left[(1 - \alpha_i) w_{\max}\left(1 - e^{-\frac{m_2}{w_{\max}}}\right) + \alpha_i m_i\right] \tag{5}$$

Where w_{max}- the maximum possible amount of paint, g/m^2;
α, α_i – separation coefficients of the paint layer.

$$\alpha = \frac{g}{(m_f + m_k) - w}; \alpha_i = \frac{g}{m_i - w} \tag{6}$$

The amount of ink in the free space of the surface roughness of the printing plate in the contact strip can be determined by the formula

$$m_k = \rho V_k \tag{7}$$

where ρ is the ink specific gravity, V_k is the volume of ink in the free space of the surface roughness of the printing plate.

To determine the amount of ink on the printing plate in the contact strip, taking into account the micro geometry of the surface of the printing plate, we use the contact scheme of the printing pair (Figure 2) proposed by the authors [23].

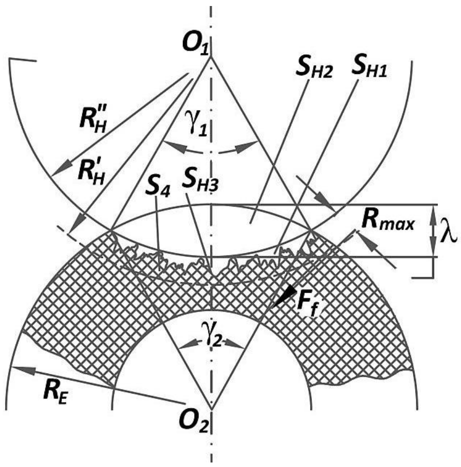

Fig 2. Scheme of contact of the printed pair, taking into account the roughness of the surface of the printing plate

According to this scheme, the volume of free space of the roughness of the printing plate in the contact strip is determined as

$$V_k = S_4 \cdot l \tag{8}$$

Or

$$V_k = \frac{\pi R'_H L}{180°} \gamma_1 \left[\frac{R_{\max}(2R'_H - R_{\max})}{2R'_H} - R_a \right] \tag{9}$$

Where $S_4 -$ is the free space area of the surface roughness of the printing plate in the contact strip; $L -$ is the contact length along the generatrix of the contacting cylinders; R'_H – the radius of the plate cylinder, taking into account the thickness and roughness of the surface of the printing plate; $\gamma_1 -$ the central angle of the sector of the contact zone; $R_{\max}$ – is the maximum height of micro roughness of the surface of the printing plate; R_a – is the arithmetic mean height of microroughness of the surface of the printing plate.

Taking into account formula (9), formula (7) can be written as:

$$m_k = \frac{\rho \pi R'_H L}{180°} \gamma_1 \left[\frac{R_{\max}(2R'_H - R_{\max})}{2R'_H} - R_a \right] \tag{10}$$

Taking into account (10), formulas (1), (2), (4) and (6) can be written in the following forms:

$$m = m_f + \frac{\rho\pi R'_H L}{180^\circ}\gamma_1\left[\frac{R_{\max}\left(2R'_H - R_{\max}\right)}{2R'_H} - R_a\right] \tag{11}$$

$$v = \frac{m_i}{(m_f - m_i) + \frac{\rho\pi R'_H L}{180^\circ}\gamma_1\left[\frac{R_{\max}\left(2R'_H - R_{\max}\right)}{2R'_H} - R_a\right]} \tag{12}$$

$$m_i = \alpha\left\{m_f + \frac{\rho\pi R'_H L}{180^\circ}\gamma_1\left[\frac{R_{\max}\left(2R'_H - R_{\max}\right)}{2R'_H} - R_a\right]\right\}\times\left(1 - e^{-\alpha^2\left\{m_f + \frac{\rho\pi R'_H L}{180^\circ}\gamma_1\left[\frac{R_{\max}\left(2R'_H - R_{\max}\right)}{2R'_H} - R_a\right]\right\}^2}\right) \tag{13}$$

$$\alpha = \frac{g}{(m_f - w) + \frac{\rho\pi R'_H L}{180^\circ}\gamma_1\left[\frac{R_{\max}\left(2R'_H - R_{\max}\right)}{2R'_H} - R_a\right]} \tag{14}$$

As can be seen from the above formulas, the amount of ink on the printing plate in the contact strip before printing, the separation factor of the ink layer and the transfer of ink from the printing plate to the deckle depend both on the radius of the plate cylinder, the length of the contact, as well as on the angle of contact arc wrapping and the parameters of the micro geometry of the surface of the printing plate.

The presented formulas are valid for plates, and the surface of the printing plate is filled with 100 percent ink. In this case, the filling factor of the form by printing elements is equal to one (k=1), i.e. the nominal surface area as a whole is the printing element. It is known that k is the coefficient of filling the form with printing elements for line images and text k = 0.13-0.15; for raster k = 0.4-0.6; for the plate k = 1 [24]. Taking into account k - the coefficient of filling the form with printing elements, we write the formula (11) in the following form:

$$m = k\left\{m_f + \frac{\rho\pi R'_H L}{180^\circ}\gamma_1\left[\frac{R_{\max}\left(2R'_H - R_{\max}\right)}{2R'_H} - R_a\right]\right\} \tag{15}$$

Also taking into account the fact that the number of contact strips that can be located on the nominal surface area of the printing plate $k_1 = B/b$, where B is the width of the nominal area of the printing plate and b is the width of the contact strip, we write the formula (15) for the nominal area of the printing plate in the following form:

$$M = kk\left\{m_f + \frac{\rho\pi R'_H L}{180^\circ}\gamma_1\left[\frac{R_{\max}\left(2R'_H - R_{\max}\right)}{2R'_H} - R_a\right]\right\} \tag{16}$$

Method for assessing the indirect transfer of ink in offset printing, taking into account the surface roughness of the printing plate

To conduct research and make calculations, an offset printing machine Rapida KBA 105 was chosen, which has the following parameters of a printed pair: $R_E = 14{,}68sm, R_H = 14{,}94sm$ are the radii of the elastic and rigid shafts, respectively. Thickness of deckle brand CONTI-AIR-3,1mm; thickness of the metal printing plate of PRO-V brand from Fujifilm company $\delta_F = 3{,}1mm, R_{\max} = 2{,}19mkm, R_a = 0{,}317mkm -$ parameters of the surface roughness of the printing plate, determined from the profilogram taken by the profilometer mod. 130.

Table 1. Examples of calculating the amount of ink transferred to the printing plate

№	Experimentally determined weight of the printing plate without applying ink	Roughness parameters mkm		Estimated weight of the printing plate with ink applied, excluding roughness	Estimated weight of the printing plate with ink applied, taking into account the roughness	Experimentally determined weight of the printing plate with ink application	Difference between values
	M, g	R_a	R_{max}	$M_{1,}g$	$M_{2,}\ g$	$M_{f,}$g	$M_f - M_{1,}g$
1	610	0,317	22,19	615,7	640,1	627,3	11,6
2	607	0,466	22,9	612,7	644,9	638,5	25,8
3	604	0,351	22,72	609,7	636,1	630,4	20,7
4	602	0,414	22,18	607,7	627,7	618,9	11,2
5	599	0,396	22,5	604,7	628,5	619,1	14,4

The amount of ink transferred to the printing plate is determined gravimetrically by calculating the difference between the masses of the printing plate before and after the ink is rolled onto the surface of the printing plate. For this, a sample printer and an analytical electronic balance of the KERN FTB 3Ko.1 model were used. When determining the amount of paint by calculation, the experimental data given in [25] were used as the layer thickness. The calculation results and experimental data are shown in Table 1. The given data show that with an increase in the surface roughness of the printing plate, the amount of ink on the printing plate increases. Based on the results of the research, it can be concluded that the surface roughness of the printing plate really affects the amount of ink transferred to the surface of the printing plate.

Results and discussion. As a result of the research the influence of micro geometry of the printing plate surface on the amount of ink on the printing plate before printing on ink layer separation coefficients and ink transfer from the printing plate to the deckle was established. To investigate the effect of micro geometry on the above parameters, the deepening of micro-roughness of the printing plate surface into the body of the deckle, which leads to additional displacements and deformations of the deckle among other things, is taken into account.

The difference between the values confirms that the surface roughness of the printing plate significantly affects the amount of ink transferred to the surface of the printing plate. The results of experimental studies and their comparison with calculated data show that with an increase in the surface roughness of the printing plate, the amount of ink transferred to the surface of the printing plate before printing increases.

Considering the purpose of the deckle, also the deepening of micro protrusions of the surface roughness of the printing plate into the body of the deckle, it can be said that in the zone of printed contact, the ink layer, located in the free space of the surface roughness of the printing plate, also participates in the transfer and division of ink.

The advantages of this study in comparison with analogues are the following: knowing the parameters of the printing pair and the micro geometry of the surface of the printing plate, it is possible to determine the amount of ink on the printing plate before printing, the separation coefficients of the ink layer and the transfer of ink from the printing plate to the deckle.

The proposed calculation method allows you to determine the amount of ink consumption, predict the quality of printed prints and the runtime of printing forms, as well as correctly set up the printing machine before the printing process.

Conclusions.

1. It has been found that the amount of ink transferred to the surface of the printing plate before printing is largely dependent on the surface roughness of the printing plate.

2. Theoretically determined that with increasing surface roughness of the printing plate, the amount of ink transferred to the surface of the printing plate increases. The results obtained by calculation are confirmed experimentally.

3. It has been established that the deepening of micro protrusions of the surface roughness of the printing plate into the deckle body leads to additional displacements and deformation of the deckle, which perceives part of the ink layer of the roughness of the surface of the printing plate located in the free space.

4. The results of the research show that the proposed methodology for the indirect transition of ink in offset printing differs from existing methods and allows you to determine more accurate values of consumables in the design of printing processes.

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