Modeling of the Ink Printing System and Improving the Accuracy of Its Adjustment Based on the Obtained Three-Dimensional Imprints

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Abstract. A mathematical model of the ink printing system of the offset machine is developed, which reflects the processes of ink distributing and transfer in the circular and axial directions. The model takes into account the operation modes of the ink feeder subsystem and the oscillator cylinder and the functioning of all other ink printing system elements. The model reflects the process of ink distribution and movement by surfaces of rollers and cylinders in three coordinates, that is, in three-dimensional space. Based on the mathematical model and the functional scheme, a simulator of the ink printing system was constructed, which reproduces the process of imprints replication and allows changing the parameters of the oscillator cylinder operation modes and the ink feeder subsystem. Based on the balance of ink supply and the expense, the reliability of the developed model of the ink printing system was verified. The simulation results in three-dimensional images of the imprints for different axial stroke values of the oscillator cylinder. The influence of the oscillator cylinder operation mode on the uniformity of the ink thickness on the imprints is conducted. The ink relief's analysis for different axial stroke values of the oscillator cylinder is carried out. The advantages of mathematical representation of ink distribution and transfer processes in three-dimensional coordinates over two-dimensional models are substantiated. Based on the obtained ink thicknesses profiles in different zones of three-dimensional imprints, the need for more accurate adjustment of the ink printing system was established. And this can only be done based on information obtained from 3-D images of imprints.

Keywords: 3-D Images of Imprints, Ink Printing System, Ink Feeder Subsystem, Oscillator Cylinder, Printing Form, Ink Thickness.

1 Introduction

1.1 Formulation of the problem

The ink transfer at the output of the ink printing system is carried out only on the printing elements of the form, so on the form rollers are formed corresponding ink

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reliefs. To smooth the ink thickness on the surface of the form rollers are used oscillator rollers, which simultaneously with the rotational motion carry out an axial reciprocating movement. The effectiveness of ink rolling depends on the initial phase of the motion trajectory and the magnitude of the oscillator's axial stroke, as well as their number and location in the ink printing system [1]. Consequently, the quality of the printed products depends significantly on the parameters and topology of the ink printing system.

Increasing requirements for print quality are pushing printing machine manufacturers to improve their ink printing systems. The solution to this problem is possible only if the theoretical principles of analysis and synthesis of ink printing systems are further developed. The ink transfer from the ink fountain to the imprints is accompanied by the sequential imposition (formation) and separation (distribution) of ink at the contact points of the ink printing system elements [2]. The perturbations that occur in the ink printing systems from the action of the ink feeder subsystem, the oscillator cylinders and the printing form cause fluctuations in the ink thickness at the output of the ink printing system. From the size and uniformity of the ink thickness on the imprints directly depends on their quality. Therefore, determining the ink thickness layer at any point in the imprint is an important task.

1.2 Analysis of literary data and problem statement

The existing methods and means of determining the ink layer thickness on the imprints through optical density give only integral information about the ink thickness, so this problem can only be done by computer simulation. And this requires the development of mathematical models that must accurately describe the process of ink distribution and transfer, taking into account the operation modes of the ink fountain subsystem and oscillator cylinders.

The work [3] is devoted to the ink printing system research of different structures. A mathematical model with a discrete and continuous ink supply system has been developed. As a result of the simulation, it is established that the ink supply system, the parameters of the oscillator cylinder, filling the form with printing elements have a significant impact on the dynamic properties. It was found that with increasing the frequency of the ink supply, the time of the system to enter the operating mode decreases, and accordingly the costs of the ink decrease. In [4], the study results of an offset printing ink printing system dynamic properties are presented. Computer simulation investigated the influence of oscillator cylinders and printing form on the duration of the ink printing system set mode. It is established that in the absence of the axial stroke of the oscillator cylinders, the time of the transition process is inversely proportional to the density of the form's printing elements filling. Article [5] investigates the distribution of ink supplied from the ink feeder device to the printed imprints. It is established that part of the ink, which should come in zones with higher coefficients of the printing elements form's filling, is transferred to zones with the fewer coefficients of the printing elements form's filling. Therefore, the change in the ink thickness on the imprint due to the redistribution between the zones with different intensities of printing elements form's filling should be compensated by the input task.

In [6], to improve the properties of the ink printing system, the structural elements of the ink feeder device used in the offset printing machine were analyzed. A computer simulation and printing experiment were performed to test the dynamic features of the printing system. The research showed that the ink transfer from the inking feeder device to the printing imprints is affected by the rotation of the vibrator roller, the duration of its cycle and the plate cylinder gap. As the oscillation of the vibrator roller, the axial stroke of the oscillator cylinders and the plate cylinder gap cannot be eliminated in a sheet printing machine, therefore it is necessary to carry out a study of the imprint's quality taking into account the effect of these negative factors. In [7], a neural network model of an ink printing system was proposed, with the help of which a research of the distribution process and ink transfer from the input of the system to imprints was carried out. The neural model is built based on a three-layer perceptron of direct propagation, so it cannot take into account the circulation of back ink flows, nor does it take into account the action of the feeder device and the plate cylinder gap.

In all the publications discussed above, the average zonal values of the ink thicknesses within individual zones are used for research and analysis of the ink printing systems. Since the width of the ink supply zone in different offset machines is different and maybe several centimeters, and the length of the form is several tens of centimeters, the ink thickness on the imprint within one particular zone may vary significantly. Therefore, to research the process of ink transfer and the quality of imprints, it is necessary to develop mathematical models that would detail reflect printed imprints in three-dimensional space.

2 Materials and methods

2.1 The operation algorithm of the ink printing system

We will demonstrate the solution of this problem on the example of an ink printing system, the functional scheme of which is presented in Fig. 1. Unit 1 of the input zonal task is a set of regulators that can be driven by cam mechanisms or stepper motors. The number of such regulators corresponds to the number of zones for regulating the ink supply. Adjustment of the ink supply is made by changing the size of the gap between the fountain blade and the fountain roller. The composition of the ink feeder subsystem (block 2) in addition to the fountain cylinder also includes a ductor roller [8]. The fountain cylinder has a rotating motion, and the ductor roller in addition to the rotating one is also oscillating. The ductor roller transfers ink from the fountain cylinder obtained during its rotation in contact with the fountain cylinder and transmits it to the subsystem (block 3) during joint movement with the first distributing roller of this subsystem. The ink distributing and transfer subsystem includes a group of rollers with a rubber surface, which are driven in a friction-rotating manner in a circular direction. In this subsystem, ink during transferred from block 2 to block 4 is superimposed and splits at the contact points of the rollers, forming direct and reverse ink flows circulating in a circular direction. The subsystem of ink distributing and transfer in an axial direction (block 4) is implemented based on oscillator cylinders, which are driven by the main electric drive of the ink printing system. The oscillator cylinders simultaneously with the rotary motion carry out also an axial reciprocating movement. This subsystem makes it possible to adjust the initial phase and the amplitude of the axial movement of the oscillator cylinders. The oscillator cylinders in contact with the rollers of the ink distributing and accumulation subsystem (block 5) align an ink in the axial direction on the surface of the form rollers. The form rollers, in contact with the printing form (block 6), transfer the ink to the surface of the printing elements. The subsystem of ink transferring from printing form to paper (block 6) includes a form cylinder with a printing form fixed to its surface and an offset cylinder, which are rotated from the main drive of the ink printing system. The ink from the surface of the printing form is transmitted through the offset cylinder to the paper, forming the imprints. Since all the elements of the printing system have rotational motion, the part of ink that is transmitted from the ink feeder subsystem to the imprints will be rotated back to the ink fountain.

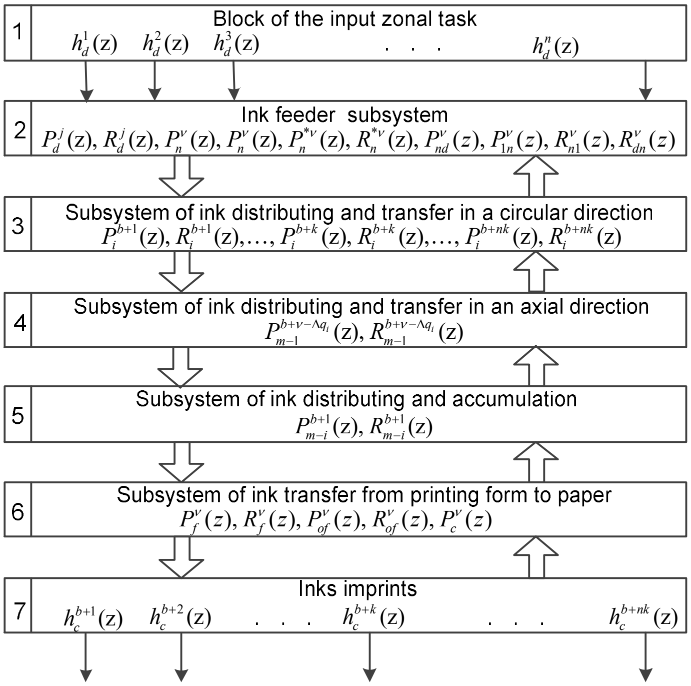


Fig. 1. Functional scheme of the ink printing system.

2.2 Mathematical model of the ink printing system with a three-dimensional reflection of imprints

When constructing the model, we accept the following assumptions: the diameters of the ink rollers and cylinders are different; the linear speeds of the rollers, the oscillator cylinder, plate cylinder with the form fixed to its surface and the offset cylinders are equal; the axial stroke value of the oscillator cylinder can be set arbitrarily; no-slip at the points of the ink printing system elements contact; the ink flow thickness supplied to the inlet of the ink printing system within a separate regulation zone is constant; the surfaces of the ink rollers, the oscillator cylinder, the plate and the offset cylinder are conditionally divided in a circular direction into *m* zones, which are additionally divided into *b* microflows within a separate *j*-th zone; the ink microflows thickness on the surface of the ink printing system elements as it moves between the points of their contacts is constant.

Based on works [9, 10] and the operation algorithm of the ink printing system, the functional scheme of which is presented in Fig. 1, we form a system of equations, which describes the process of ink circular and axial distribution and its transfer to the printing form and further through the offset cylinder on paper.

For the first microflow of the first zone:

$$x_n^{b+1}(z) = P_g^{b+1}(z)P_d^{b+1}(z)h_d^{b+1}(z) + l_{dn}^{b+1}(z);$$

$$h_{nd}^{b+1}(z) = P_n^{b+1}(z)x_1^{b+1}(z);\ \ l_d^{b+1}(z) = R_d^{b+1}(z)x_n^{b+1}(z);$$

$$l_{dn}^{b+1}(z) = R_n^{b+1}(z)P_g^{b+1}(z)h_{nd}^{b+1}(z) + (R_{dn}^{b+1}(z) + R_n^{b+1}(z)R_{n1}^{b+1}(z)P_p^{b+1}(z))l_{n1}^{b+1}(z);$$

$$h_{1n}^{b+1}(z) = (P_{1n}^{b+1}(z) + P_n^{*(b+1)}(z)P_{nd}^{b+1}(z)P_g^{b+1}(z))h_{nd}^{b+1}(z) + P_n^{*(b+1)}(z)P_p^{b+1}(z)l_{n1}^{b+1}(z);$$

$$x_1^{b+1}(z) = h_{1n}^{b+1}(z) + l_1^{b+1}(z);\ \ l_{n1}^{b+1}(z) = R_n^{*(b+1)}(z)x_1^{b+1}(z);$$

$$h_1^{b+1}(z) = P_1^{b+1}(z)x_1^{b+1}(z);\ \ x_2^{b+1}(z) = h_1^{b+1}(z) + l_2^{b+1}(z);$$

. . . .

$$h_{m-2}^{b+1}(z) = P_{m-2}^{b+1}(z)x_{m-2}^{b+1}(z);\ \ l_{m-3}^{b+1}(z) = R_{m-3}^{b+1}(z)x_{m-2}^{b+1}(z);$$

$$x_{m-1}^{b+1-\mathrm{g(z)}+\Delta \mathrm{g}_r(\mathrm{z})}(z) = h_{m-2}^{b+1}(z) + l_{m-1}^{b+1-\mathrm{g(z)}+\Delta \mathrm{g}_r(\mathrm{z})}(z);$$

$$h_{m-1}^{b+1-\mathrm{g(z)}+\Delta \mathrm{g}_p(\mathrm{z})}(z) = P_{m-1}^{b+1+\Delta \mathrm{g}_p(\mathrm{z})}(z)x_{m-1}^{b+1-\mathrm{g(z)}}(z);\ l_{m-2}^{b+1}(z) = R_{m-2}^{b+1}(z)x_{m-1}^{b+1}(z);$$

$$x_m^{b+1-\mathrm{g(z)}+\Delta \mathrm{g}_p(\mathrm{z})}(z) = h_{m-1}^{b+1-\mathrm{g(z)}+\Delta \mathrm{g}_p(\mathrm{z})}(z) + l_m^{b+1}(z);$$

$$h_m^{b+1}(z) = P_m^{b+1}(z)x_m^{b+1}(z);\ l_{m-1}^{b+1-\mathrm{g(z)}+\Delta \mathrm{g}_r(\mathrm{z})}(z) = R_{m-1}^{b+1+\Delta \mathrm{g}_r(\mathrm{z})}(z)x_m^{b+1-\mathrm{g(z)}}(z);$$

$$x_f^{b+1}(z) = h_m^{b+1}(z) + l_f^{b+1}(z);$$

$$h_f^{b+1}(z) = P_f^{b+1}(z)x_f^{b+1}(z);\ l_m^{b+1}(z) = R_m^{b+1}(z)x_f^{b+1}(z);$$

$$x_{of}^{b+1}(z) = h_f^{b+1}(z) + l_{of}^{b+1}(z);$$

$$h_{of}^{b+1}(z) = P_{of}^{b+1}(z)x_{of}^{b+1}(z);$$

$$x_c^{b+1}(z) = h_{of}^{b+1}(z);\ l_{of}^{b+1}(z) = R_{of}^{b+1}(z)x_c^{b+1}(z);$$

$$h_c^{b+1}(z) = P_c^{b+1}(z)x_c^{b+1}(z);$$

For *k* microflow of the first zone:

$$x_n^{b+k}(z) = P_g^{b+k}(z)P_d^{b+k}(z)h_d^{b+k}(z) + l_{dn}^{b+k}(z);$$

$$h_{nd}^{b+k}(z) = P_n^{b+k}(z)x_1^{b+k}(z);\ \ l_d^{b+k}(z) = R_d^{b+k}(z)x_n^{b+k}(z);$$

$$l_{dn}^{b+k}(z) = R_n^{b+k}(z)P_g^{b+k}(z)h_{nd}^{b+k}(z) + (R_{dn}^{b+k}(z) + R_n^{b+k}(z)R_{n1}^{b+k}(z)P_p^{b+k}(z))l_{n1}^{b+k}(z);$$

$$h_{1n}^{b+k}(z) = (P_{1n}^{b+k}(z) + P_n^{*(b+k)}(z)P_{nd}^{b+k}(z)P_g^{b+k}(z))h_{nd}^{b+k}(z) + P_n^{*(b+k)}(z)P_p^{b+k}(z)l_{n1}^{b+k}(z);$$

$$x_1^{b+k}(z) = h_{1n}^{b+k}(z) + l_1^{b+k}(z);\quad l_{n1}^{b+k}(z) = R_n^{*(b+k)}(z)x_1^{b+k}(z);$$

$$h_1^{b+k}(z) = P_1^{b+k}(z)x_1^{b+k}(z);\quad x_2^{b+k}(z) = h_1^{b+k}(z) + l_2^{b+k}(z);$$

. . . .

$$x_m^{b+k-g(z)+\Delta g_p(z)}(z) = h_{m-1}^{b+k-g(z)+\Delta g_p(z)}(z) + l_m^{b+k}(z);$$

$$h_m^{b+k}(z) = P_m^{b+k}(z)x_m^{b+k}(z);\ l_{m-1}^{b+k-g(z)+\Delta g_r(z)}(z) = R_{m-1}^{b+k+\Delta g_r(z)}(z)x_m^{b+k-g(z)}(z);$$

$$x_f^{b+k}(z) = h_m^{b+k}(z) + l_f^{b+k}(z);$$

$$h_f^{b+k}(z) = P_f^{b+k}(z)x_f^{b+k}(z);\quad l_m^{b+k}(z) = R_m^{b+k}(z)x_f^{b+k}(z);$$

$$x_{of}^{b+k}(z) = h_f^{b+k}(z) + l_{of}^{b+k}(z);$$

$$h_{of}^{b+k}(z) = P_{of}^{b+k}(z)x_{of}^{b+k}(z);$$

$$x_c^{b+k}(z) = h_{of}^{b+k}(z);\ l_{of}^{b+k}(z) = R_{of}^{b+k}(z)x_c^{b+k}(z);$$

$$h_c^{b+k}(z) = P_c^{b+k}(z)x_c^{b+k}(z);$$

For *k* microflow of *n* zone:

$$x_n^{b+nk}(z) = P_g^{b+nk}(z)P_d^{b+nk}(z)h_d^{b+nk}(z) + l_{dn}^{b+nk}(z);$$

$$h_{nd}^{b+nk}(z) = P_n^{b+nk}(z)x_1^{b+nk}(z);\quad l_d^{b+nk}(z) = R_d^{b+nk}(z)x_n^{b+nk}(z);$$

$$l_{dn}^{b+nk}(z) = R_n^{b+nk}(z)P_g^{b+nk}(z)h_{nd}^{b+nk}(z) + (R_{dn}^{b+nk}(z) + R_n^{b+nk}(z)R_{n1}^{b+nk}(z)P_p^{b+nk}(z))l_{n1}^{b+nk}(z);$$

$$h_{1n}^{b+nk}(z) = (P_{1n}^{b+nk}(z) + P_n^{*(b+nk)}(z)P_{nd}^{b+nk}(z)P_g^{b+nk}(z))h_{nd}^{b+nk}(z) + P_n^{*(b+nk)}(z)P_p^{b+nk}(z)l_{n1}^{b+nk}(z);$$

$$x_1^{b+nk}(z) = h_{1n}^{b+nk}(z) + l_1^{b+nk}(z);\quad l_{n1}^{b+nk}(z) = R_n^{*(b+nk)}(z)x_1^{b+nk}(z);$$

$$h_1^{b+nk}(z) = P_1^{b+nk}(z)x_1^{b+nk}(z);\quad x_2^{b+nk}(z) = h_1^{b+nk}(z) + l_2^{b+nk}(z);$$

. . . .

$$h_{m-2}^{b+nk}(z) = P_{m-2}^{b+nk}(z)x_{m-2}^{b+nk}(z);\quad l_{m-3}^{b+nk}(z) = R_{m-3}^{b+nk}(z)x_{m-2}^{b+nk}(z);$$

$$x_{m-1}^{b+nk-g(z)+\Delta g_r(z)}(z) = h_{m-2}^{b+nk}(z) + l_{m-1}^{b+nk-g(z)+\Delta g_r(z)}(z);$$

$$h_{m-1}^{b+nk-g(z)+\Delta g_p(z)}(z) = P_{m-1}^{b+nk+\Delta g_p(z)}(z)x_{m-1}^{b+nk-g(z)}(z);\ l_{m-2}^{b+nk}(z) = R_{m-2}^{b+nk}(z)x_{m-1}^{b+nk}(z);$$

$$x_m^{b+nk-g(z)+\Delta g_p(z)}(z) = h_{m-1}^{b+nk-g(z)+\Delta g_p(z)}(z) + l_m^{b+nk}(z);$$

$$h_m^{b+nk}(z) = P_m^{b+nk}(z)x_m^{b+nk}(z);\ l_{m-1}^{b+nk-g(z)+\Delta g_r(z)}(z) = R_{m-1}^{b+nk+\Delta g_r(z)}(z)x_m^{b+nk-g(z)}(z);$$

$$x_f^{b+nk}(z) = h_m^{b+nk}(z) + l_f^{b+nk}(z);$$

$$h_f^{b+nk}(z) = P_f^{b+nk}(z)x_f^{b+nk}(z);\quad l_m^{b+nk}(z) = R_m^{b+nk}(z)x_f^{b+nk}(z);$$

$$x_{of}^{b+nk}(z) = h_f^{b+nk}(z) + l_{of}^{b+nk}(z);$$

$$h_{of}^{b+nk}(z) = P_{of}^{b+nk}(z)x_{of}^{b+nk}(z);$$

$$x_c^{b+nk}(z) = h_{of}^{b+nk}(z);\ l_{of}^{b+nk}(z) = R_{of}^{b+nk}(z)x_c^{b+nk}(z);$$

$$h_c^{b+nk}(z) = P_c^{b+nk}(z)x_c^{b+nk}(z), \tag{1}$$

where $x_i^v(z), x_n^v(z), x_f^v(z), x_{of}^v(z), x_c^v(z)$ – z-image of the ink flow thickness at the contact points of the ink printing system elements (*i*=1, 2, 3,…, *m*) within the *v*-th microflow (ν=1, 2, 3,…, *nk*); $P_d^j(z)$, $R_d^j(z)$ – operators of ink transfer by fountain roller (*j* - number of ink supply zone); $P_n^\nu(z)$, $R_n^\nu(z)$ and $P*_n^\nu(z)$, $R*_n^\nu(z)$ – operators of ink transfer by ductor roller during contact with a fountain roller and the first distributing roller; $P_{nd}^\nu(z)$, $P_{1n}^\nu(z)$ i $R_{n1}^\nu(z)$, $R_{dn}^\nu(z)$ – operators of ink transfer by the ductor roller from the fountain roller to the distributing roller and in the opposite direction to the fountain roller; $P_i^\nu(z)$, $R_i^\nu(z)$ – operators of transferring the direct and reverse ink microflows by rollers in a circular direction; $P_f^\nu(z)$, $P_{of}^\nu(z)$, $R_f^\nu(z)$, $R_{of}^\nu(z)$ – operators of transferring the direct and reverse microflows by surfaces of the plate and offset cylinders; $P_c^\nu(z)$ – operator of transferring the ink microflows from an offset cylinder to paper; $h_d^j(z)$ – z-image of the ink thickness on the surface of the fountain roller at the exit of the gap between the fountain blade and the ductor within j-th zone of its supply; $h_c^\nu(z)$ – z-images of ink thicknesses transmitted to paper along the printing direction within the width of the *v*-th microflow; $P_{m-1}^{b+\nu+\Delta g_p(z)}(z)$, $R_{m-1}^{b+\nu+\Delta g_r(z)}(z)$ – operators of transfer the direct and reverse ink microflows by an oscillator cylinder in the axial direction; b – the number of microflows in a separate zone; $g(z)$ - movement of the oscillator cylinder in the axial direction; $\Delta g_r(z)$, $\Delta g_p(z)$ - movement of the direct and reverse ink microflows by an oscillator cylinder between its contact points with adjacent rollers.

3 Results of modeling

Based on the three-dimensional mathematical model (1) we build a simulator of the ink printing system in the Matlab Simulink software package. Sets in the simulator parameters of geometric sizes of the ink printing system elements through the corresponding transport delays of the ink transfer between the rollers and cylinders contact points; transmission coefficients of forward and reverse ink flows in a circular direction are 0,5; transmission coefficients on paper transfer – 0,7; the maximum axial stroke value of the oscillator cylinder $b_{os\max}$ is considered equal to the width of the ink supply zone.

For research, we develop a test form, which is shown in Fig. 2. Using the computer program "InkUnit" [11] determines the density of the form's zonal filling with printing elements. Using the technology proposed in [12], we determine the parameters of the input zonal task for different axial stroke value of the oscillator cylinder (table 1).

In determining the parameters of the input task, the average values of the form filling density with printing elements and the ink thickness in the respective zones of the imprint were used. In the simulation, the average values of the ink thicknesses error did not exceed 3%, which is significantly less than the allowable value of the predicted standard ISO 12647-1, i.e. 5%. Given that the area of one zone is large enough and can be tens of centimeters square, such accuracy is not a guarantee that individual parts of the image within the same zone or adjacent zones will not exceed the permissible limits.

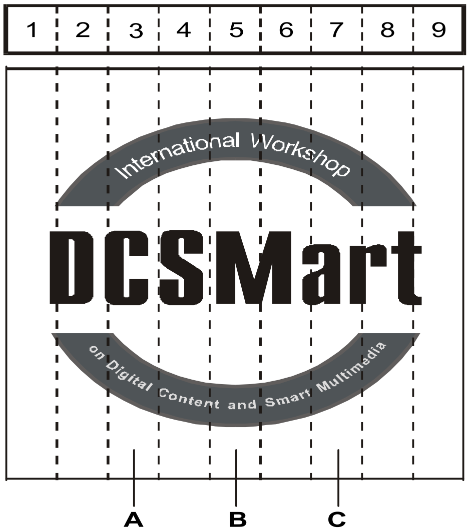


Fig. 2. Test form.

Table 1. Input task parameters for two modes of oscillator cylinder operation.

№ zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
k_z^j	0,0916	0,3215	0,3073	0,3144	0,2987	0,3006	0,2932	0,2261	0,0490
$0{,}1\,b_{os\,\max}$									
h_d^j, *μm*	9,1	30,8	30,0	28,8	27,9	28,4	27,9	22,0	6,9
$b_{os\,\max}$									
h_d^j, *μm*	15,0	22,4	27,6	28,8	27,9	27,7	25,2	19,3	15,2

Such assumptions can only be verified if 3-D imprints are obtained. In Fig. 3 presents a three-dimensional image of the imprints obtained as a result of modeling the ink printing system at the maximum axial stroke value of the oscillator cylinder.

Since one of the objects that generate significant technological perturbations to the ink transfer process is the oscillator cylinder, so we will investigate its effect on the accuracy of reproduction of imprints. To analyze the influence of the operation mode the oscillator cylinder on the ink transfer on the imprints, we derive the longitudinal profiles of the ink microflows at different axial stroke values of the oscillator cylinder (Fig. 4). The cross sections of the imprint's ink thickness obtained for positions A, B, and C of the printing form shown in Fig. 2.

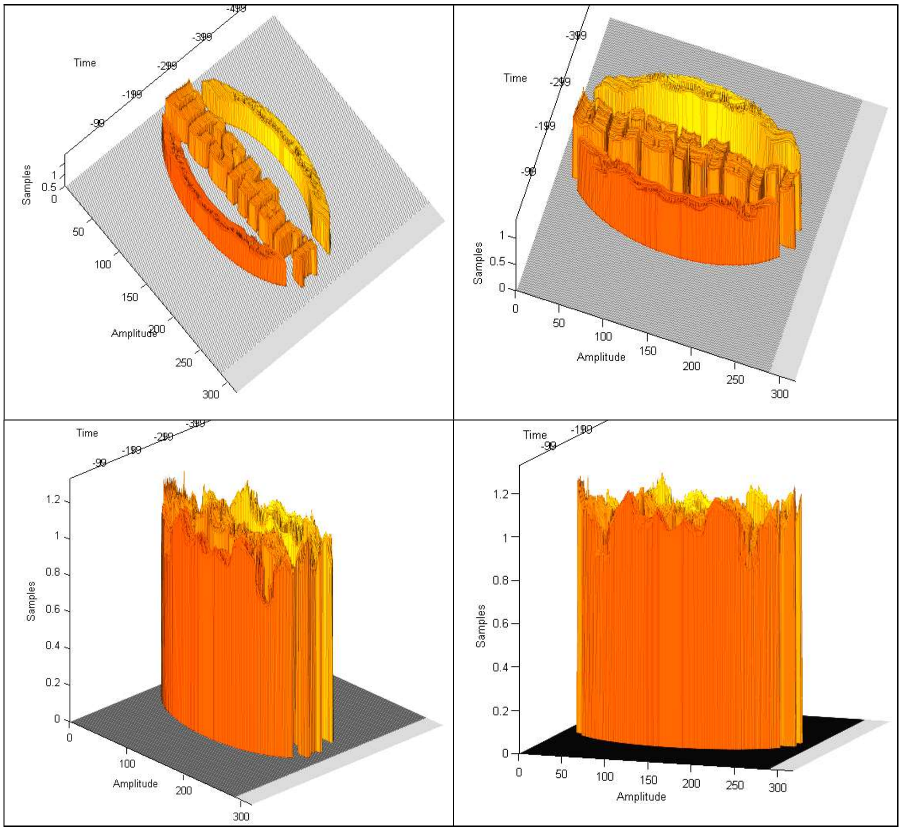
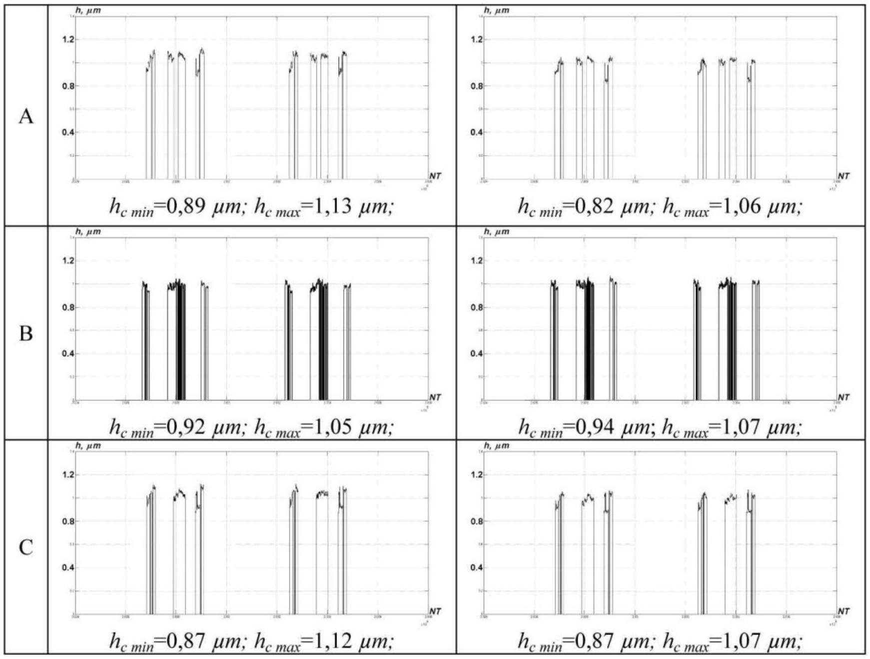


Fig. 3. Three-dimensional image of the imprint.

The profiles of the imprints intersections for the two variants of the axial stroke coincide. However, as can be seen from Fig. 4a, the deviation of the ink thickness in the middle zone of the imprint (position B) is in the range -8÷5% of the standard value ISO 12647-1. At the left edge of the imprint (position A), the deviation is from -11% to 13%. At the right edge of the imprint (position C) – from -13% to 12%. A similar character of the change in the ink thickness in the corresponding positions of different imprint zones is observed even with the maximum value of the axial stroke (Fig. 4b). The research confirmed that the magnitude of the axial stroke greatly affects the redistribution of ink flows at the output of the ink printing system both longitudinally and across the imprint. Therefore, this factor must be taken into account when setting up ink printing systems. As shown by the simulation results, the correction of the axial stroke value influence obtained based on the average values of the ink flows thicknesses in the zones, i.e. based on two-dimensional models, does not provide the required accuracy of the imprints.



a) b)

Fig. 4. Ink sections in different areas of three-dimensional imprint:
a) at the axial stroke value $0,1\,b_{os\,\max}$; b) at the axial stroke value $b_{os\,\max}$.

To correct this problem, it is necessary to improve the accuracy of the ink printing system adjustment, which can only be realized if the 3-D model is developed and applied.

4 Conclusions

The functional scheme of the ink printing system was constructed, which reflects the interaction of all components of the system. A mathematical model has been developed that takes into account the operation of each element ink printing system, describes in detail the process of discrete ink transfer from the fountain roller to the ink distributing subsystem and the operation modes of the oscillator cylinder, which performs axial displacement by sinusoidal law. The model reflects the process of ink distribution and movement by surfaces of rollers and cylinders in three-dimensional space. A simulator for the ink printing system was built. The influence of the axial stroke value of the oscillator cylinders on the uniformity of the imprint's ink thickness is simulated and researched.

Based on the analysis of obtained results, it was established that determining the parameters of the input task using a two-dimensional model of the ink printing system does not provide an acceptable by the standard ISO 12647-1 of imprints accuracy. In two-dimensional models, the influence of the oscillator cylinder operation mode was taken into account due to the corresponding change in the transmission coefficients of the forward and reverse ink flows in the axial direction. Therefore, in two-dimensional models, individual ink transfer zones are only displayed by their profile. Three-dimensional models make it possible to take into account not only the width of the supply zones and ink transportation to imprints but also to reproduce three-dimensional images of imprints that give complete information about the surface relief of the imprint. Therefore, three-dimensional models should be used for a more accurate set-up of ink printing systems.

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