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Modeling and Analysis of Ink Distribution in the Ink Printing System of the Sequential-Parallel Structure

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Abstract. In the paper, a multi-zone signal graph is constructed that corresponds to the structure of the ink printing system and reflects the process of circulating the direct and reverse ink flows. A mathematical model of the ink printing system of a sequential-parallel structure with two oscillator cylinders was developed, which describes the process of ink distribution and its transfer by elements of the ink printing system from the ink feeder device to the imprints. The model details the mathematical description of the work mode of the oscillator cylinders and the ink feeder device. On the basis of the mathematical model and the signal graph, a simulator of the ink printing system is constructed in Matlab-Simulink environment. Checking the validity of the simulation model and, accordingly, the mathematical model is based on the balance of ink's supply and selection. Based on the models of the ink printing system components, information technology is developed which makes it possible to investigate the process of ink transfer at different work modes of the oscillator cylinders. The research and analysis of the effect by the change in the value of the axial stroke of each oscillator cylinders on the ink flow distribution on the imprints at various densities of form filling with the printing elements were carried out.

Key words: information technology; ink feeder device, mathematical model, oscillator cylinders, simulator.

INTRODUCTION

Offset printing is widely used in the advertising sphere for the production of fashion and souvenir products, as well as for the printing of labels, newspapers, magazines, etc. In offset printing machines, the quality of the image reproduction depends on the technologically needed ink thickness and its uniform application on the imprint. This process is provided by the ink printing systems of machines and to a large extent depends on the features of their design, adjustment and operation. The ink printing systems of offset printing machines consist of the following basic elements: an ink feeder device; an ink distributing group; plate and offset cylinders. Metal oscillator cylinders and elastic rollers of the ink distributing group distribute and transport the ink to the form rollers, which serve to ink's apply to the printing elements of the form. The offset cylinder transfers the ink from the printing elements of the form to the paper [1]. In order to align the ink relief arising on the form rollers after their contact with the form, the oscillator cylinders provide axial reciprocating motion [2]. This creates disturbance in the process of ink transfer and leads to a decrease in the uniformity of the ink thickness on the imprints. Solving this problem in order to improve the quality of printed product requires thorough research of the oscillator cylinders effect on the process of ink distribution and transfer in the ink printing system.

Through the integral action of oscillator cylinders on the process of ink transfer, it is practically impossible to investigate their impact on the quality of the printed product by experiment. Therefore, solving this problem is proposed by computer simulation of the ink printing system. In [3] a mathematical model was developed and the research results of the offset ink printing system dynamics were presented. But this mathematical model does not take into account the work mode of the oscillator cylinders. In [4] a mathematical model of the ink printing system was constructed taking into account the action of the oscillator cylinder. As a result of the simulation, it was established that the time of the transition process increases with decreasing the density of form filling with the printing elements. In [5] by computer simulation, the effect research of the oscillator cylinder on the ink flows distribution in the transverse direction of the imprints was carried out. In the publication [6], as a result of the simulation, it was established that through the axial motion of the oscillator cylinder, the ink thickness at the output of the ink printing system in zones with the high density of printing elements is reduced and redistributed in zones with a lower density. In [7], a method is proposed for calculating the amount of ink supply, which is based on computer identification of singular matrix elements and form data. However, from the material presented in the above-mentioned works, it is not clear whether the work mode of the vibrator roller, which carries out the ink transfer between the fountain roller and the ink distributing group, is taken into account. And accordingly, in due to lack of data on the ink supply and selection balance, it is not possible to determine if take into account the ink amount that is returned into the ink pan of the ink feeder device. This information is extremely important for determining the input distribution.

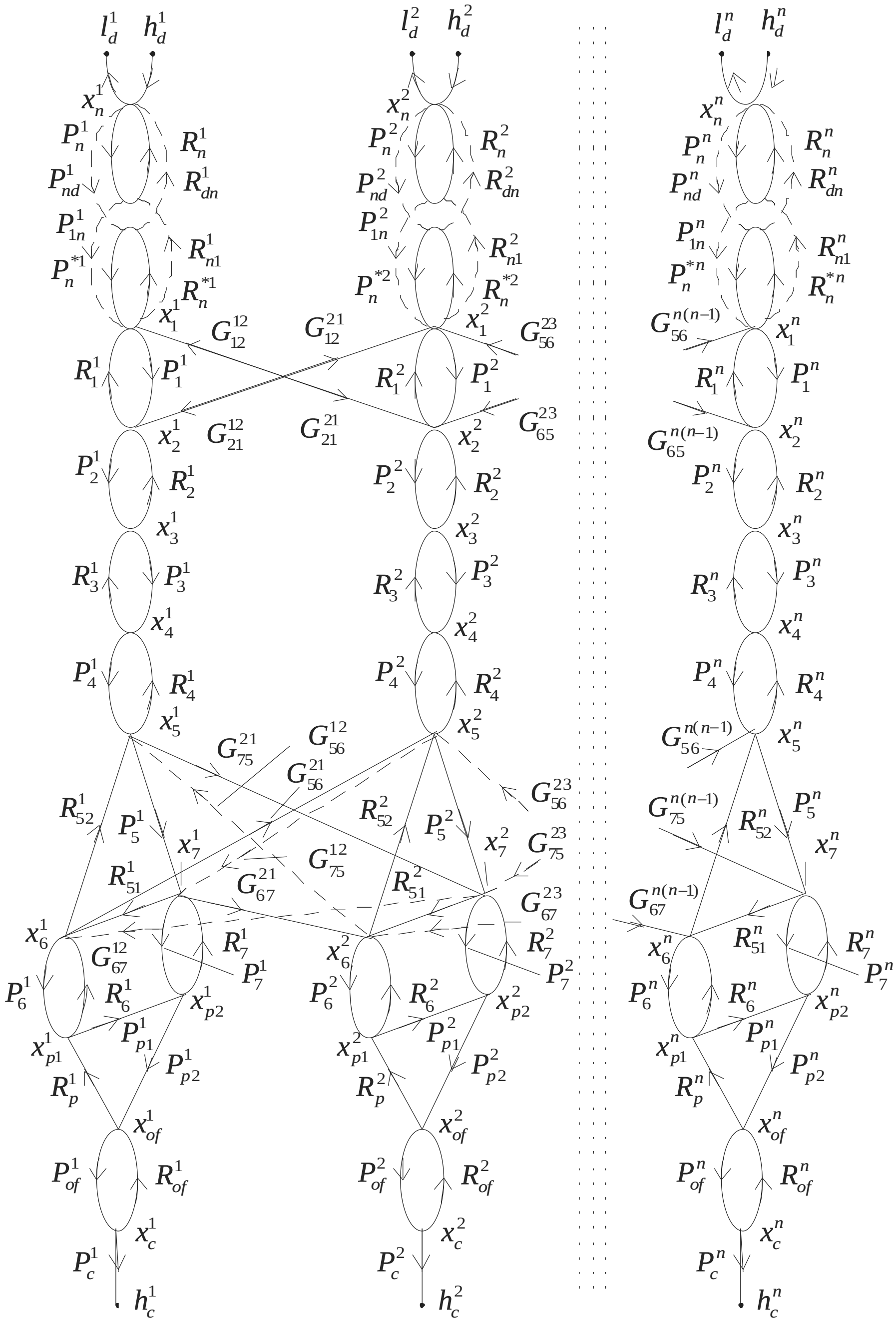

Fig. 1. Signal graph of the multi-zone ink printing system of the sequentially-parallel structure

MATERIAL AND METHODS

I Mathematical model of ink printing system: For the visibility of the representation of ink circular and axial distribution and transfer, we will construct a signal graph, which takes into account the work of all elements at the ink printing system of a sequential -parallel structure with two oscillator cylinders (Fig. 1). The thickness of the ink zonal supply is determined by the appropriate regulatory bodies by varying the size of the gap between the ductor knife and the cylinder. From the ductor cylinder with the help of a vibration roller, ink is transferred to the first roller of the ink distributing subsystem. The ink micro-streams are transmitted by a system of rollers and cylinders to the form rollers that come into contact with the printing form. The ink from the surface of the form's printing elements with the help of an offset plate is transferred to the paper creating at the same time printing imprints.

Input nodes of graph's each zone corresponds to the ink flows thickness, which is fed to the input of the ink system and returned to the ink pan, and the output nodes correspond to the ink thickness, which is transmitted to the paper. All other nodes of the graph correspond to the ink flow thickness within the j-th zone in the contact places of the ink printing system elements. The nodes are connected within each j-th zone by the branches correspond to the operators of direct and reverse ink flow in a circular direction what are taking into account the geometrical dimensions of the rollers and cylinders. The branches connecting the nodes of neighboring zones correspond to the operators of the direct and reverse ink flow in the axial direction. The constructed signal graph is convenient for developing a mathematical model and simulator of a corresponding ink printing system.

To compile the mathematical model we accept the following assumptions: the ink printing system is conventionally divided into zones from its entrance to the exit; the number of zones corresponds to the number of fountain keys; the widths of the zones are equal to each other; linear velocities of rollers and cylinders surfaces are equal; the diameters of rollers and cylinders have different sizes; time of ink transfer by the surface of rollers and cylinders on one millimeter is equal to one conditional unit; due to the ink flow circulation, part of it, applied to the input of each zone, returns to the ink pan. Based on the above-accepted assumptions and works [8, 9] in accordance with the graph (Fig. 1), we compile a system of equations, which reflects the process of ink flow distribution and transfer in the ***j***-th zone:

$$l_d^j(z) = R_d^j(z)x_n^j(z);$$

$$x_n^j(z) = P_d^j(z)h_d^j(z) + R_n^j(z)P_g^j(z)P_n^j(z)x_n^j(z) + [R_n^j(z)R_{n1}^j(z) + R_{dn}^j(z)R_n^{*j}(z)]x_1^j(z);$$

$$h_n^j(z) = [P_{1n}^j(z)P_n^j(z) + P_n^{*j}(z)P_{nd}^j(z)]x_n^j(z) + P_n^{*j}(z)P_r^j(z)R_n^{*j}(z)x_1^j(z);$$

$$x_1^j(z) = [P_{1n}^j(z)P_n^j(z) + P_n^{*j}(z)P_{nd}^j(z)]x_n^j(z) + P_n^{*j}(z)P_n^j(z)R_n^{*j}(z)x_1^j(z) + R_1^j(z)x_2^j(z) +$$
$$+G_{12}^{j(j-1)}(z)x_2^{j-1}(z) + G_{12}^{j(j+1)}(z)x_2^{j+1}(z);$$

$$h_1^j(z) = [P_r^j(z)a_1 + \overline{P}_r^j(z)]x_1^j(z);$$

$$l_n^j(z) = R_n^j(z)P_g^j(z)P_n^j(z)x_n^j(z) + [R_n^j(z)R_{n1}^j(z) + R_{dn}^j(z)R_n^{*j}(z)]x_1^j(z);$$

$$x_2^j(z) = P_1^j(z)x_1^j(z) + R_2^j(z)x_3^j(z) + G_{21}^{j(j-1)}(z)x_1^{j-1}(z) + G_{21}^{j(j+1)}(z)x_1^{j+1}(z);$$

$$h_2^j(z) = P_2^j(z)x_2^j(z); \quad l_1^j(z) = R_1^j(z)x_2^j(z);$$

$$x_3^j(z) = P_2^j(z)x_2^j(z) + R_3^j(z)x_4^j(z); \quad h_3^j(z) = P_3^j(z)x_3^j(z); \qquad l_2^j(z) = R_2^j(z)x_3^j(z);$$

$$x_4^j(z) = P_3^j(z)x_3^j(z) + R_4^j(z)x_5^j(z);$$

$$h_4^j(z) = P_4^j(z)x_4^j(z); \quad l_3^j(z) = R_3^j(z)x_4^j(z);$$

$$x_5^j(z) = P_4^j(z)x_4^j(z) + R_{52}^j(z)x_6^j(z) + G_{56}^{j(j-1)}(z)x_6^{j-1}(z) + G_{56}^{j(j+1)}(z)x_6^{j+1}(z);$$

$$h_5^j(z) = P_5^j(z)x_5^j(z); \quad l_4^j(z) = R_4^j(z)x_5^j(z);$$

$$x_6^j(z) = P_{51}^j(z)x_7^j(z) + R_6^j(z)x_{p1}^j(z) + G_{67}^{j(j-1)}(z)x_7^{j-1}(z) + G_{67}^{j(j+1)}(z)x_7^{j+1}(z);$$

$$h_6^j(z) = P_6^j(z)x_6^j(z); \quad l_{52}^j(z) = R_{52}^j(z)x_6^j(z);$$

$$x_7^j(z) = P_5^j(z)x_5^j(z) + R_7^j(z)x_{p2}^j(z) + G_{75}^{j(j-1)}(z)x_5^{j-1}(z) + G_{75}^{j(j+1)}(z)x_5^{j+1}(z);$$

$$h_7^j(z) = P_7^j(z)x_7^j(z); \quad l_{51}^j(z) = R_{51}^j(z)x_7^j(z);$$

$$x_{p1}^j(z) = P_6^j(z)x_6^j(z) + R_p^j(z)x_{of}^j(z);$$

$$h_{p1}^j(z) = P_{p1}^j(z)x_6^j(z); \quad l_6^j(z) = R_6^j(z)x_{p1}^j(z);$$

$$x_{p2}^j(z) = P_{p1}^j(z)x_{p1}^j(z) + P_7^j(z)x_7^j(z);$$

$$h_{p2}^j(z) = P_{p2}^j(z)x_{p2}^j(z); \qquad l_7^j(z) = R_7^j(z)x_{p2}^j(z);$$

$$x_{of}^{j}(z)=P_{p2}^{j}(z)x_{p2}^{j}(z)+R_{of}^{j}(z)x_{c}^{j}(z);$$
$$h_{of}^{j}(z)=P_{of}^{j}(z)x_{of}^{j}(z);\ \ l_{p}^{j}(z)=R_{p}^{j}(z)x_{of}^{j}(z);$$
$$x_{c}^{j}(z)=P_{of}^{j}(z)x_{of}^{j}(z);$$
$$h_{c}^{j}(z)=P_{c}^{j}(z)x_{c}^{j}(z);\quad l_{of}^{j}(z)=R_{of}^{j}(z)x_{c}^{j}(z), \tag{1}$$

where $j = 1, ..., n$ is number of zones for adjusting the ink supply; $x_i^j(z)$ is z-image of the ink flow thickness within a separate zone in the contact places of the printing ink system elements; $h_i^j(z)$, $l_i^j(z)$ is a z-image the thickness of the direct and reverse ink flows on the surfaces of rollers and cylinders; $h_d^j(z)$ is a z-image of the ink thickness applied to the input of the j-th zone of the ink printing system; $h_c^j(z)$ is a z-image of the ink thickness on the surface of the j-th zone of the imprint; $P_d^j(z)$, $R_d^j(z)$, $P_n^j(z)$, $R_n^j(z)$, $P_n^{*j}(z)$, $R_n^{*j}(z)$; $P_{nd}^j(z)$, $P_{1n}^j(z)$, $R_{n1}^j(z)$, $R_{dn}^j(z)$, $P_g(z)$, $P_r(z)$ is a operators of direct and reverse ink flow transfer by a ink feeder device [9]; $P_i^j(z)$, $R_i^j(z)$ are the operators of direct and reverse ink flow transfer within the j-th zone of rollers and cylinders surfaces; $P_c^j(z)$ is an operator of ink transfer from an offset cylinder to a paper; $G_{(i\pm1)i}^{j(j-1)}(z)$, $G_{(i\pm1)i}^{j(j+1)}(z)$ are the operators of ink flow transfer by oscillator cylinders in an axial direction between neighboring zones [8].

II Information technology for investigating the effect of the oscillator cylinders on the process of ink transfer: In this paper, to investigate the effect of oscillator cylinders on the process of ink transfer is proposed using information technology (Fig. 2). To implement such technology, a mathematical model of the ink printing system is required (block 1). On the basis of the model, the code of the program or simulator in the simulation environment (block 2) is developed, which takes into account the parameters and work modes of the all ink printing system components (blocks 2.1-2.4) and reproduces the processes occurring in such systems. In the simulation model introduces the parameters of the geometric dimensions of the ink printing system elements, the values of coefficients the ink transfer and the form's filling, parameters of the work mode of the ink feeder device and the oscillator cylinders. On the basis of the information on the printed form (block 3), the parameters of the input distribution (block 4) are determined. After running the model, the simulation of the ink transfer process is carried out, as a result of which we obtain the ink thickness in the j-th zones of the imprint (block 5). The obtained values are used to determine the summary ink thickness on the imprint (block 6). In blocks 8 and 7, the summary values of the ink thickness of the zonal supply and ink returned to the ink pan are determined. When the ink printing system is released to the set mode, the balance of ink supply and selection is checked (block 9) on the following condition:

$$\Delta=\sum_{j=1}^{n}h_{d}^{j}-(\sum_{j=1}^{n}h_{c}^{j}+\sum_{j=1}^{n}l_{d}^{j})\leq 0,01\sum_{j=1}^{n}h_{d}^{j}\,. \tag{2}$$

If the condition of block 9 is not satisfied, then the simulator (block 10) is corrected. When the condition is fulfilled, changing the parameters in the work mode of the oscillator cylinders (block 11), it is possible to conduct research and analysis of the effect of the given parameters on the process of ink distribution and transfer in ink printing systems.

RESULTS AND DISCUSSION

To investigate the effect of the oscillator cylinders on the ink flow distribution in the ink printing system, we set the model parameters of the 7-zone printing form and determinate the values of the ink thickness of the zonal supply. After adjusting the model of the ink feeder device, we simulate the printing process for different work modes of the oscillator cylinders. In this work are presented the fragments of the research results of the ink thickness distribution on the imprints at the exit of the ink printing system on the set mode for various form's filling coefficients with the printing elements k_z provided that the ink is fed into the middle zone.

In Fig. 3 shows the character of the zonal ink thickness distribution on the imprints when $k_z = 0.1$ for different axial stroke values ($b_{min} = 3$ mm and $b_{max} = 30$ mm): at action of the first oscillator cylinder (OC 1), which is in contact with the ink feeder device (Fig. 3, a); at action of the second oscillator cylinder (OC 2), which is in contact with the form rollers (Fig. 3, b); at the simultaneous action of two oscillator cylinders (OC 1 and OC 2) (Fig. 3, c). In Fig. 4 shows the results of the ink thickness distribution of the thickness obtained under similar conditions for $k_z = 1.0$.

Increasing the axial stroke value leads to a leveling of the ink thickness on the surface of the imprints. As can be seen from Fig. 3, a with increasing the axial stroke value from b_{min} to the maximum b_{max}, the ink thickness in the middle zone of the imprint obtained at the density of the printing elements $k_z = 0.1$ decreases from 0.644 μm to 0.259 μm, i.e. 2.5 times. A significant effect on the ink distribution has the density of form filling with the printing elements. So for $k_z = 1.0$, the ink thickness in the middle zone of the imprint when the axial stroke changes from the minimum to the maximum value decreases from 0.821 μm to 0.393 μm, that is, in this case, the ink thickness in the middle zone is greater than at $k_z = 0.1$ and with an increase of axial stroke value decreases by 2.1 times. In the process of modeling, the effect of the oscillator cylinders on the character of ink micro-streams distribution in the ink printing system was investigated.

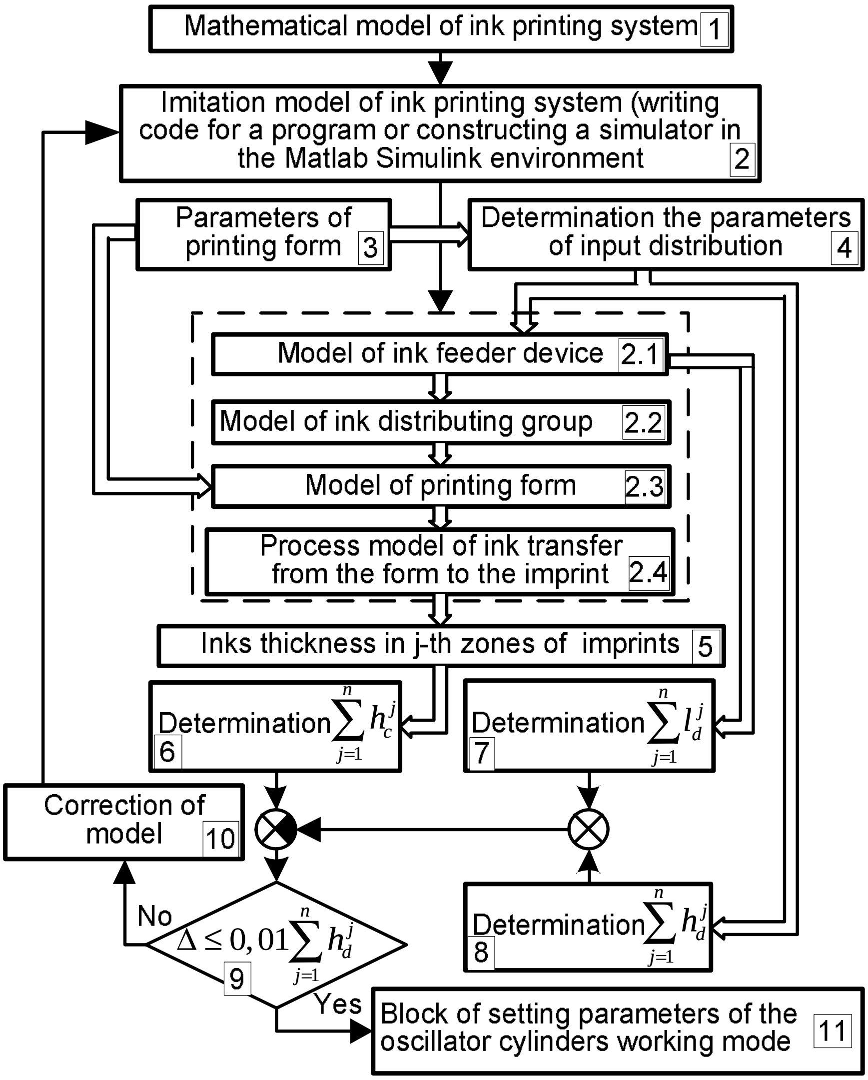

Fig. 2. Algorithm of information technology for investigating the effect of the oscillator cylinders on the process of ink transfer

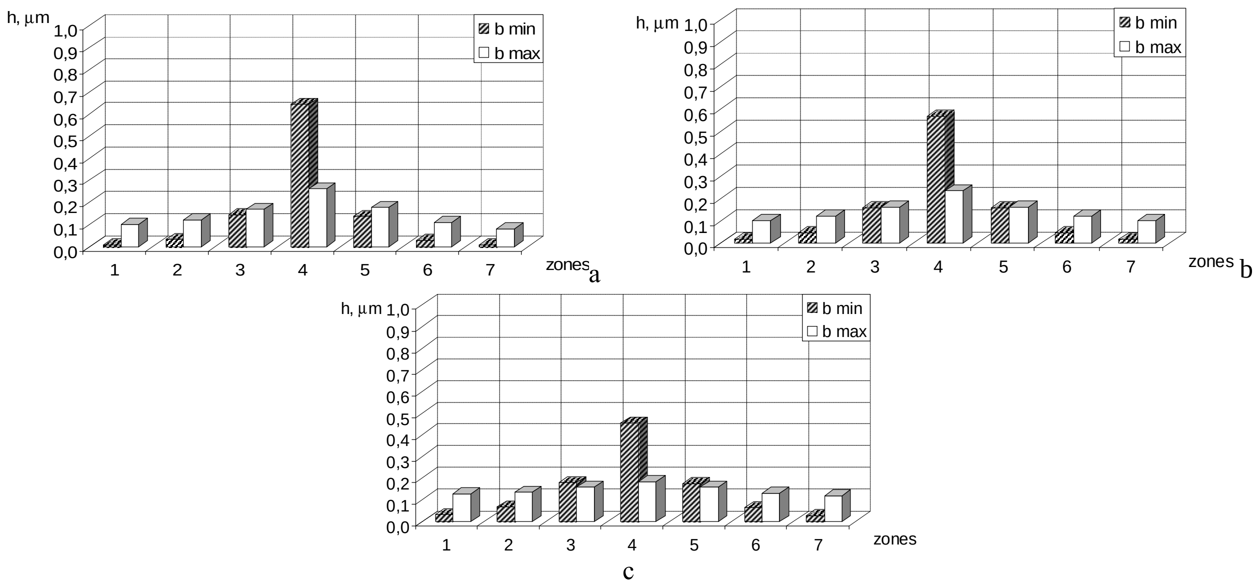

Fig. 3. The ink thickness on the imprints at k_z = 0,1 at the condition of action: a – OC 1; b – OC 2; c – OC 1 and OC 2

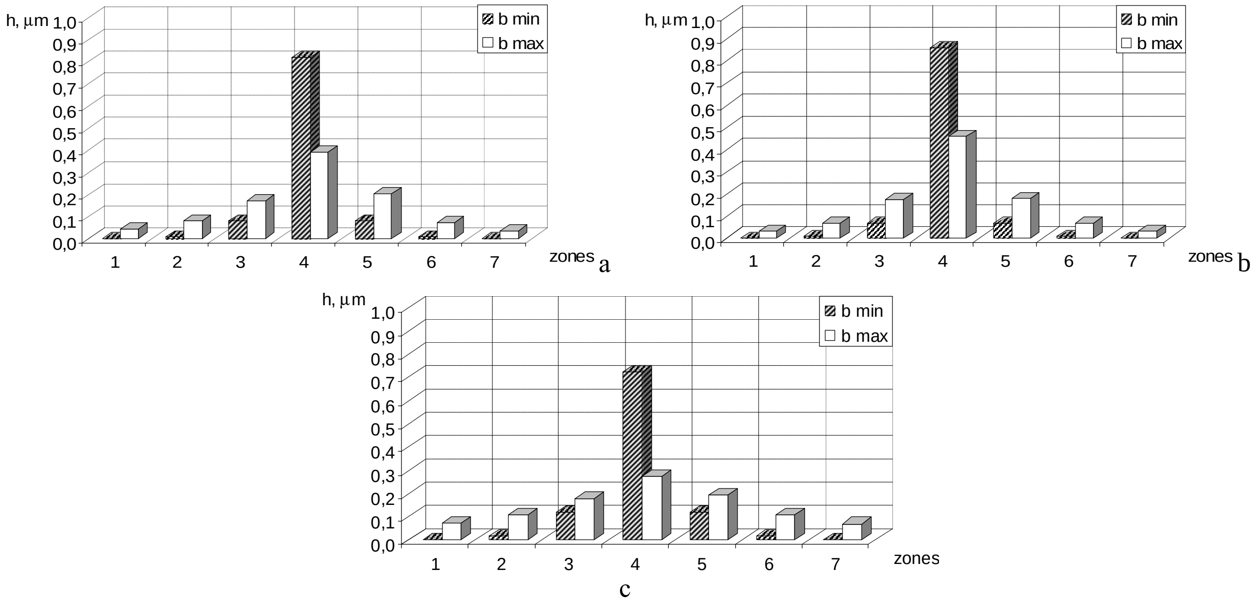

Fig. 4. The ink thickness on the imprints at k_z = 1,0 at the condition of action:
a – OC 1; b – OC 2; c – OC 1 and OC 2

CONCLUSIONS

1. The signal graph of the ink printing system was constructed, which reflects the circulation of direct and reverse ink flows between the ink feeder device and printing imprints.
2. A mathematical model is developed that describes the work mode of the oscillator cylinders, the ink feeder device and the ink flow distribution and transfer by the surfaces of all ink-printing system components.
3. On the basis of a multi-zonal graph and mathematical model, information technology for research and analyzing the working mode effect of the oscillator cylinders on the zonal ink flow distribution at the output of the system is developed.
4. By the research result, it was established that as the axial stroke of the oscillator cylinders increases, there is a tendency to ink equalize at the output, and in line with the increase in its redistribution in the axial direction. But this negatively affects the accuracy of debugging the ink feeder device.
5. It was established that the value of the ink axial distribution to a large extent also depends on the position of the oscillator cylinder in the structure of the ink printing system and the form's filling coefficient. The oscillator cylinders with a change of form's filling coefficient change their character of the effect on the ink distribution in the axial direction.
6. The results of the effect research of the oscillator cylinders on the ink redistribution can be used to correct the parameters of the input distribution.
7. The proposed method for constructing an ink printing system mathematical model of a sequential -parallel structure can be used to compose ink printing systems models of a more complex structure.

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