Determination of the Optical Density of Two-Parameter Tone Transfer for a Short Printing System of the Sixth Dimension

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Abstract

A sixth dimension mathematical model for a short printing system of parallel structure is designed, which makes it possible to determine different parameters of optical density for the corresponding test scales. Depending on the tone transmission interval and the optical density of the print, a mathematical model to calculate the thickness of the ink on the print was created. The simulation results are presented, the optical density parameters for different test scales are determined, their deviation from the linear tone transmission is specified. Studies have shown the nature of the effect of the ink thickness of the print surface on the optical density, which should be taken into consideration at tone transfer synthesis.

Keywords

Printing system, model, graph, scheme, ink thickness, imprint, tone transfer, optical density, characteristics, analysis, properties

1. Problem Statement

Reproduction of halftone images by printing means in offset printing is carried out by modulation of ink flows by a raster printing form which is provided by change of the relative area of printing elements. In most cases, conducting analysis and synthesizing raster tone transfer, the ink thickness on raster elements is considered to be constant, that is it does not vary with the tone transfer interval, and the synthesis itself is the synthesis of raster elements areas [1, 3, 4, 10]. To ensure a constant thickness of the ink on the imprint surface, automatic zone ink supply systems are used for a given circulation.

Short ink printing systems do not have mechanisms for zone adjustment of the ink supply, so they do not provide a uniform thickness of ink on the imprint surface, which limits their use for printing books and magazines [5, 9]. Since most patented short printing ink devices with anilox ink supply unit are not made of metal and only some of them are used in offset printing in particular in newspaper aggregates, so there is not enough experience in production exploitation, adjustment and synthesis of tone transmission [9]. The organization of half-tone image reproduction for a constant thickness of ink on the imprint, types of tone transmissions, tone reproduction schemes, and synthesis algorithms were covered in separate publications; they are well known about [1, 3, 9]. Since the traditional methods of synthesis of tone transfer are one-parameter, they cannot be directly applied to short printing systems in which the ink thickness at the tone transfer interval can be reduced to 30% [5, 6].

Solving the problem of high-quality synthesis and adjusting the transfer plan requires measuring the ink thickness on the imprint surface, which is inaccurate and complicated. Since, to ensure high-quality synthesis and correction of tone transfer, the ink thickness should be measured on the print

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surface, which is a separate task and has certain difficulties, that is why the task to determine optical density of the print depending on the amount of ink on the tone transfer range is relevant for this type of printing systems.

2. Literature Review

Ink machines with an anilox ink feeder are a new class of devices. Their analysis differs significantly from traditional objects and systems, because the processes within them are due to the circulation of direct and reverse ink flows, as well as the modulation of the raster printing plate. Conducted studies have shown that the ink thickness on the raster print depends on the interval of tone transfer and is from 20-30%, and in some cases even more, which affects the quality of book and magazine products and does not meet the standards of regulatory requirements to them [7, 8]. In publications [5, 6] models of raster inking elements of square to rhombic shape the characteristics of which are S-shaped curve, have been constructed. The maximum deviation from the linear is on gray tones and is equal to 25%. In publication [7] mathematical models are offered to describe the determination of the optical density of the ink layer on the printed material, provided that there is no relation between the maximum value of the optical density and the area of the raster elements, which restricts their application.

3. Presentation of the research main material

Provided that a mathematical model, describing a short printing system with an anilox ink input device, is known and describes such dependences as filling the raster elements with ink on the tone transfer interval, which in its turn is reproduced as an image on the plate having the form of a linear scale. Thus, in relative units, let us show a two-parameter description of the tone transfer on the surface of the imprint scale as following:

$$V = PH_{max}, \text{if } 0 \leq P \leq 1, H_{min} \leq H \leq H_{max}, \qquad (1)$$

where H- is an ink thickness for a set tone transfer interval on the surface of an imprint scale, H_{max}, H_{min} - maximum and minimum parameters of the ink thickness, P is the relative area of the raster scale that corresponds to the level of filling the scale with ink on the tone transfer interval.

Depending on the relative area of filling of the printing element, let's determine it on the basis of Yul-Nicholas formula, taking into account the demodulation line (derasterization) [1, 3, 14].

$$V = -n\, lg\left[V \cdot 10^{-D_{пл}/n} + (1-V) \cdot 10^{-D_{п}/n}\right], \qquad (2)$$

where $D_{п}/_{n}$- is the optical density of the full tone area obtained on the print from a short typewriter, Dп - the optical density of the paper, п is Yul-Nicholas index which depends on the linearity of the raster and can be within the limits $[1{,}3 \leq n \leq 3{,}0]$. To increase the accuracy of the calculation in production conditions, the specific value of this indicator can be expressed by expression (2), provided that the relative amount of paint is within the limits $[0 \leq V \leq 1]$.

If in expression (1) and (2) the degree of coverage is linearly changed within the given limits [0.1], it becomes possible to calculate as well as design parameters of an imprint optical density depending on tone transfer range at ink thickness change.

To solve the set problem and research, let's consider a short printing system of parallel structure of the 6th dimension with anilox ink supply device, the scheme is shown in Figure 1.

In the chamber *K*, the ink under pressure fills the small cells of the anilox (raster) cylinder *A* and on the sixth roller delivers a meaasured amount of ink, which is sequentially rolled out and rolled on by the third and the fourth rollers on the printing plate. The ink stream modulated by the raster printing form *Φ* is transmitted to the offset cylinder *O* and further to the substrate material. The part of the ink, which was not absorbed by the nonprinting elements, creates untreated ink flows on the rolling up rollers, which causes the circulation of reverse streams of ink that interact with the lines and partially returns back to the ink chamber.

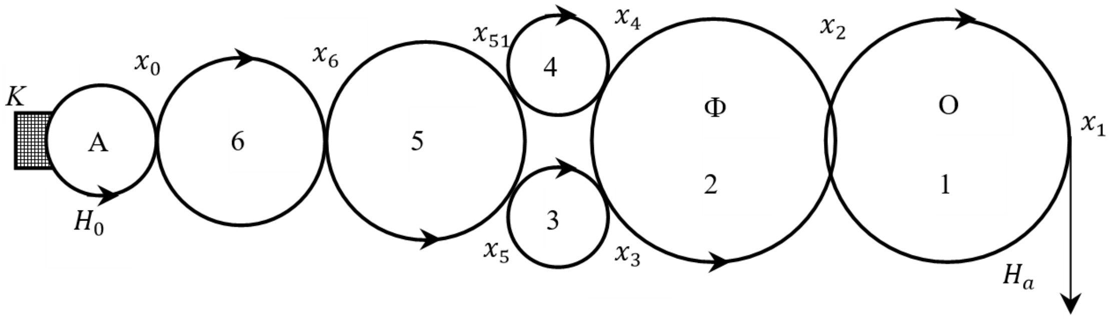

Figure 1: Scheme of a short printing system of parallel structure

The processes occurring in the printing system are complex, so to simplify the construction of the model we make the following assumptions: the established modes of operation are considered, the system input is supplied with a uniform thickness of ink flow, the raster printing form modulates ink flow, the printing system is a low-pass filter. Also we should take into consideration the selection of ink at the system input, as there are stable conditions of the printing process. Under the accepted assumptions on the basis of known corelations [5, 6, 11], and according to the scheme of Fig. 1 a system of mathematical dependences is constructed that corresponds to supply and consumption balance of ink streams if the following assumptions are observed

$$\begin{array}{ll} x_0 = H_0 + Y_6 x_6 & x_4 = \alpha_4 x_{51} + P_2 x_2 \\ l_0 = Y_0 x_0 & x_3 = \alpha_3 x_5 + P_{21} x_4 \\ x_6 = \alpha_6 x_0 + Y_5 x_{51} & x_2 = \alpha_2 x_3 + Y_1 x_1 \\ x_5 = \alpha_5 x_6 + P_3 x_3 & x_1 = \alpha_1 x_2 \\ x_{51} = \alpha_5 x_5 + P_4 x_4 & H_a = P_1 x_1 \quad , \end{array} \tag{3}$$

where x_i – is the average value of the thickness of the ink flow at the points of contact of the painted rollers, form and offset cylinders, H_0 - т is the thickness of the ink flow at the model input, H_a - is the amplitude value of the ink thickness at the system output (on the imprint), l_0- is the thickness of the flow that returns back to the ink chamber, α_i, H_i - is the transmission coefficients of forward and reverse flows of ink at the exit from the points of contact, P_{21}, P_2, P_3, P_4- are transmissions of modulated and untreated flows, P_1- is transmission of the model output.

$$P_{21} = \alpha_2 P; P_2 = \alpha_3 P;\ P_3 = 1 - \alpha_3 P;\ P_4 = 1 - \alpha_4 P;\ P_1 = \frac{B}{P} if 0 \leq P \leq 1 \tag{4}$$

where B – the ink transfer coefficient on the printed material from the offset cylinder.

If to change linearly the coefficient in expressions (3) and (4) in the limits $[0 \leq P \leq 1]$ for a given constant value of the ink flow thickness at the model input, thus, it is possible to determine the dependence of ink thickness at the output of the ink-printing system. To simplify the task, the method of simulation has been applied, for which, at first, according to the scheme of Fig. 1 and the system of equations (3) a graph of ink flows of the printing system, presented in Figure 2 has been created.

The vertices of the graph marked x_i correspond to the average value of the thickness of the ink streams at the points of contact of the forming cylinder with the offset and rolling group rollers. The arcs of the graph marked as α_i, Y_i correspond to the direct and reverse ink flows and depend on the transfer coefficient at the output of the contact points. Arrows on the arcs indicate the direction of flows. According to the graph, let’s determine the amplitude of the ink flow thickness at the input of the model by Maison formula [5,6].

$$H_a = \frac{\alpha_6\alpha_5\alpha_3\alpha_2\alpha_1 P_1(1 + \alpha_4 + P_4) + \alpha_6\alpha_5 Y_{51}\alpha_4 P_{21}\alpha_2\alpha_1 P_1}{\Delta_6} H_0, \tag{5}$$

where Δ_6 is the determinant of the graph which is cumbersome and therefore not given.

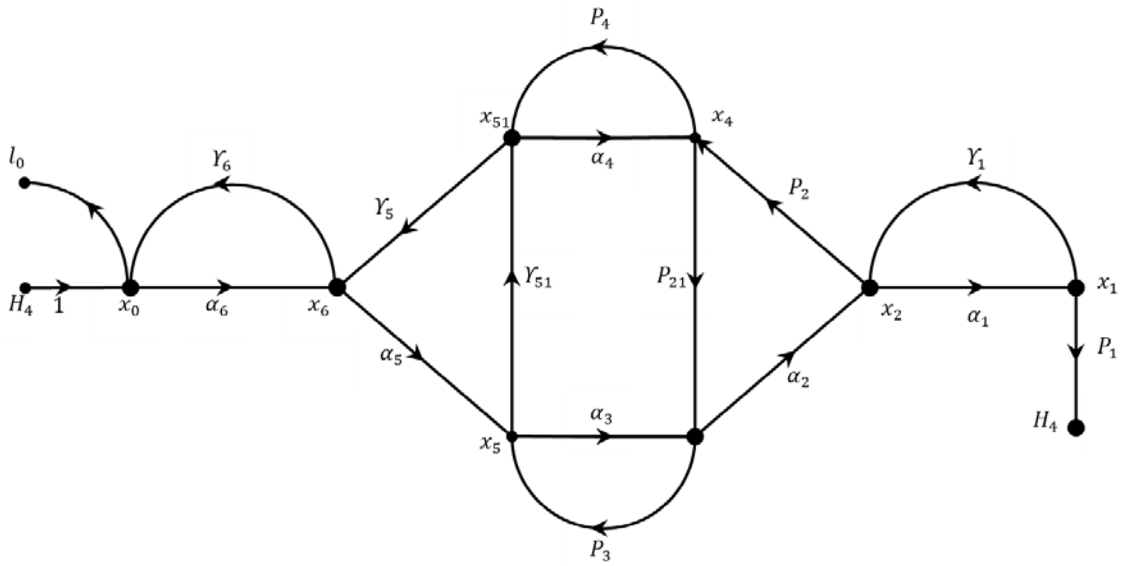

Figure 2: Graph of ink flows of the printing system

Using the nonlinear dependence (5) we determine the ink thickness on the surface of the imprint scale and depending on the parameters of the printing system by expression (1) we determine a two-parameter tone transfer - the amount of ink transferred on the surface of the imprint scale.

$$V = \frac{P[\alpha_6\alpha_5\alpha_3\alpha_2\alpha_1 P_1(1 + \alpha_4 + P_4) + \alpha_6\alpha_5\Upsilon_{51}\alpha_4 P_{21}\alpha_2\alpha_1 P_1]}{\Delta_6} H_0, \qquad (6)$$

Since we determine the optical tone transfer density for a short printing system by expression (2), taking into account the amount of ink on the surface of this scale. Using object-oriented programming implemented in the Matlab package: Simulink [2, 12, 13], we simplify the solution of this task. Based on expressions (1) - (6) and constructed graph, to calculate the ink thickness and optical density, a block diagram of a simulator model for a short printing system was developed, which is shown in Figure 3.

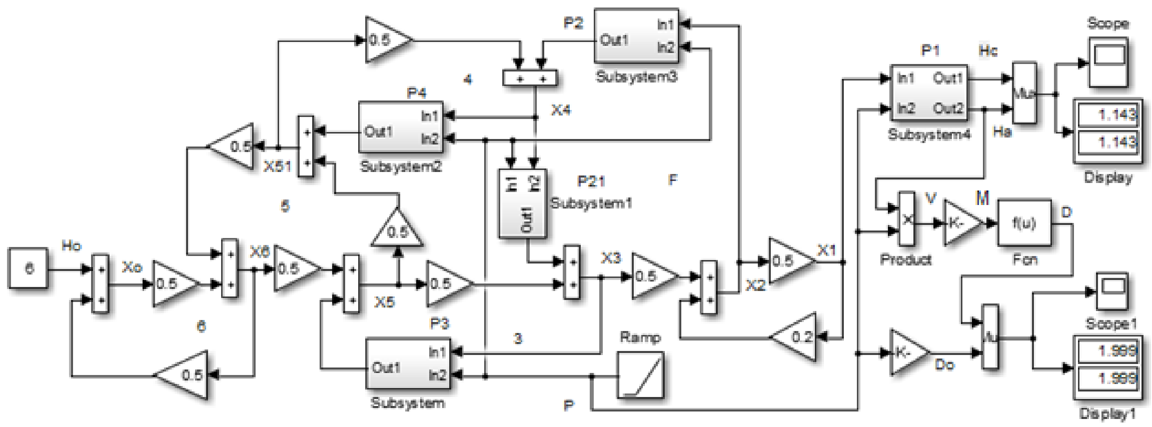

Figure 3: Block diagram of the model of a short printing system in Simulink

The summation blocks correspond to the graph nodes at the inputs of which direct and reverse ink flows are fed. Gain blocks correspond to the graph arcs, values of the transfer coefficients of the direct and reverse ink flows are set in their dialog boxes. The variable transfer coefficients of the modulated and unmanaged flows are implemented by the expressions (4) and are located in the Subsystem blocks. The thickness of the ink flow at the outlet is set by the *Constant* unit. At the output of the model, the amplitude value of the thickness H_a on the scale of the imprint is obtained. In the dialog box of *Fcn* mathematical functions block in accordance with expression (2) there is a program for calculating the optical density. At the bottom of the circuit there is the Ramp unit which generates a linear scale signal within $[0 \leq P \leq 1]$ limits, which is fed to the Subsystem inputs required to calculate the transfer according to the expression (4). Scope and Display blocks are used to visualize the results of simulation modeling.

The purpose of simulation was to calculate and plot optical density graphs for scales of different types and analyze their properties. The model was adjusted to the nominal parameters of the system ($\alpha_i = \Upsilon_i = 0{,}5$, $\Upsilon_1 = 0{,}7$, $\beta = 0{,}8$). In the Constant unit, the ink flow thickness at the input of the model $H_0 = 6_{\text{мкм}}$, are shown in Figure 4.

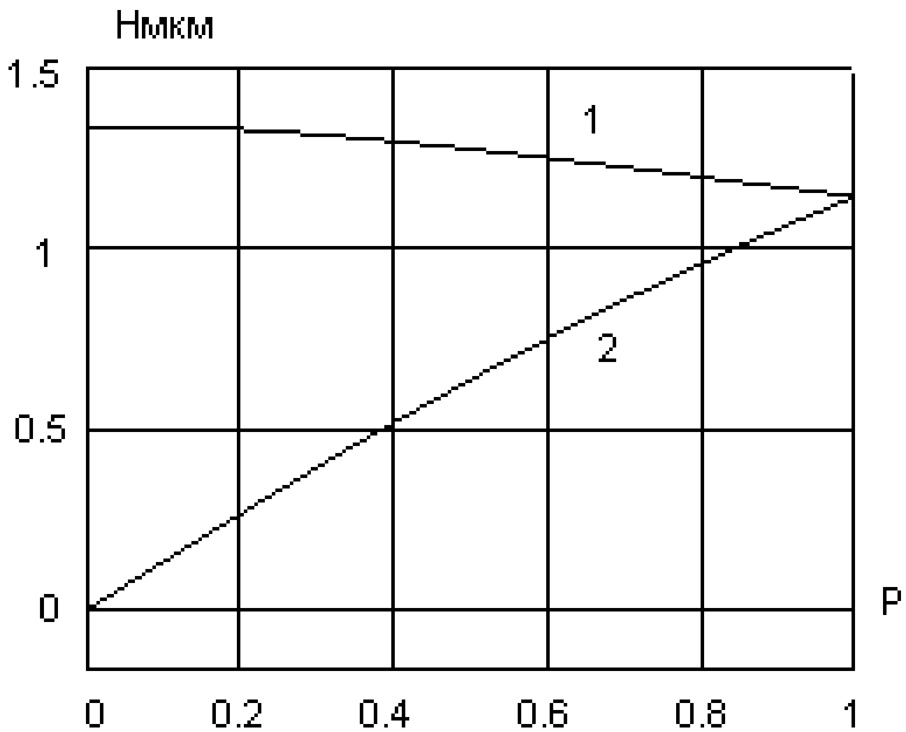

Figure 4: Dependence of ink thickness on the tone interval: 1 - absolute value, 2 - average value

At the beginning of the interval, the thickness of ink layer is 1,334 μm, it gradually decreases and at the end of the interval it is 1,143 μm. Therefore, the dependence of the ink thickness on the tone transfer interval is nonlinear. The average value of the ink thickness at the beginning of the range is zero, gradually it increases and at the end of the interval it is equal to 1.334 μm. The convergence of the absolute and average values of the ink thicknesses confirms the reliability of the developed model.

To determine the optical density in the *Fcn* mathematical functions block the value of the optical density of the die $D_d = 3{,}0$ and the value *n* = 3 have been set. For comparison, the maximum value of the optical density $D_0 = 2{,}0$ has been set in the Gain unit. The results of simulation modeling of optical density values depending on the tone transfer interval are shown in Figure 5.

For comparison, the figure shows a linear characteristic of the optical density, which is located at the top. Values of the optical density of a short printing system, the maximum value of which at the end of the interval is 2.0. and has the form of a concave curve. It makes it possible to evaluate the tone transfer properties for a short printing system, because the characteristic of the optical density is determined for a linear test raster scale. To do this, let's determine the deviation of the optical density from the linear one

$$E = \mathrm{D} - \mathrm{D}_0 \tag{7}$$

where D_0 is a linear characteristic.

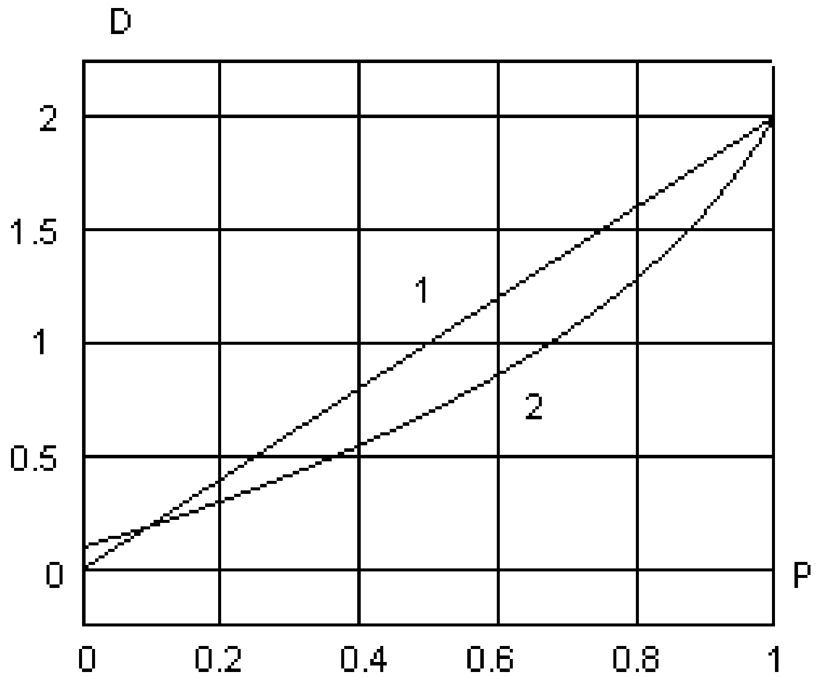

Figure 5: Characteristics of optical density on the tone transfer interval: 2 - printing system, 1 - linear optical density

As a result of modeling of the deviation of the optical density of the printing system from the linear, the graph, shown in Figure 6 was obtained.

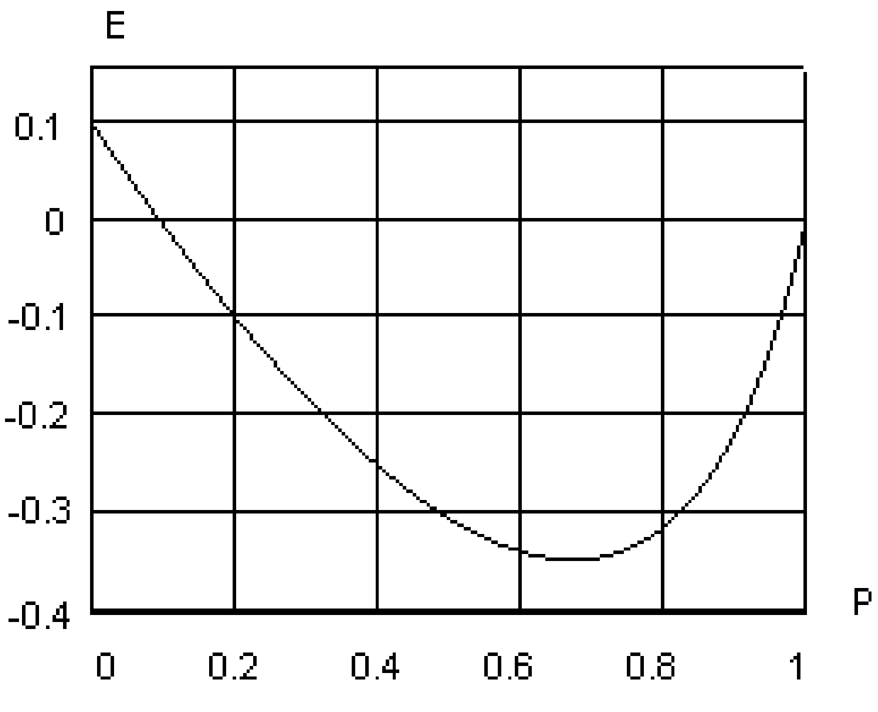

Figure 6: Deviation of optical density from linear density

The deviation of the optical density is a U-shaped curve. The maximum value of the deviation is in the middle of the tone interval and is equal to -0.4. On the basis of the standardization data, we obtain that the tolerance for the deviation of the optical density equals E = ± 0.15 [8]. Thus, the short printing system of the parallel structure of the fifth dimension does not ensure the quality of printed products, as a result of which the image is significantly brightened, so it is necessary to adjust the tone, which is the subject of further research.

4. Conclusions.

The constructed mathematical model takes into account the relative change in the amount of ink on the surface of a linear raster scale for a short printing system of parallel structure of the sixth dimension for a two-parameter description of tone reproduction, which expands its capabilities. To increase the accuracy of determining visual optical density of the image obtained on a short printing system, Yul-Nichols demodulation formula was modified, which accounts for the relative change in the ink amount.

The structural scheme of the simulator for calculation of ink thickness and optical density of the short printing system which gives the chance to define its properties has been developed. The results of simulation modeling in the form of graphs of dependence of ink thickness and characteristics of the optical density on the tone transfer interval have been presented and its properties have been determined.

The necessity to adjust the tone transfer was defined, because the value of the optical density of a short printing system is a nonlinear concave curve, the maximum deviation of this characteristic from the linear one is - 0.40, resulting in a significantly brighter image, thus, tone transfer requires adjusting. The results can be used to adjust the images at the stage of preparation for rasterization and production of printing plates.

5. References

[1] P. Fieguth, Statistical Image Processing and Multidimensional Modeling, Springer-Verlag New York, 2011.

[2] R. Gonzalez, R. Woods, Digital image processing, M. Techno- sphere, 2012.

[3] L. Phil, Improving of raster technological process at the stage of formation and linearization of printing elements, Lviv. 2014.

[4] M. Lutskiv, Digital printing technologies, Lviv; UAD. 2012.

[5] M. Lutskiv, P. Kurka, Model of painting raster elements of rhombic shape, Computer printing technology 34(2) (2015) 80-87.

[6] L. Burstein, A Matlab Primer for Technical Programming for Materials Science and Engineering, Woodhead Pub Ltd, 2020

[7] B. Eihab, M. Bashier, Practical Numerical and Scientific Computing with Matlab® and Python, CRC Press, 2020.

[8] P. Pashulia, Standardization, metrology, compliance, quality in printing, Lviv: UAP, 2011.

[9] O. Velichko, Y.Zorenko, V. Skiba, Reproduction of a tone gradient by means of reproduction VPC Kyiv University, 2011

[10] L. Krawczyk, Intentional Printing: Simple Techniques for Inspired Fabric Art, Interweave, 2014.

[11] I. Safonov, I. Kurilin, M. Rychagov, E. Tolstaya, Document Image Processing for Scanning and Printing, Springer International Publishing, 2019.

[12] A. Ferreira, N. Fantuzzi MATLAB Codes for Finite Element Analysis: Solids and Structures (Solid Mechanics and Its Applications (157), Band 157), Springer, 2020.

[13] L. Phil, Improving of raster technological process at the stage of formation and linearization of printing elements, Lviv. 2014.

[14] R. Rameshan, C. Arora, S. D. Roy, Computer Vision, Pattern Recognition, Image Processing, and Graphics, Springer Singapore, 2018.