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Abstract. The article provides a comparison of the main valuation techniques for a regulated parameter of printability of the offset paper by current standards GOST 24356 and ISO 3783: 2006. The results of development and implementation of a complex test scale for management and control the quality of printed production are represented. The estimation scale is introduced. It includes normalized parameters of print optical density, print uniformity, picking out speed, the value of dot gain, print contrast with the added criteria of minimizing microtexts, a paper slip, resolution threshold and effusing ability of paper surface. The results of analysis allow directionally form surface properties of the substrate to facilitate achieving the required quality of the printed image parameters, i. e. optical density of a print at a predetermined level not less than 1.3, the print uniformity with minimal deviation of dot gain about the order of 10 per cents.

1. Introduction

Offset paper has several features, i. e. anisotropy sheet structure, complex composite and chemical compound. Overview the modern technologies on studying of multiscale structure of the printing paper in [1] showed the importance and urgency of this issue.

Forecasting and management of properties of printing paper is now receiving more attention. Paper printability is studying by J. Aspler, A. Mackay, D. V. Dunayev, V. N. Leontiev, P. V. Lukanin. J. Aspler in the works [2, 3] connected the quality of prints and paper, has shown that the structure of its surface significantly affects the print image parameters. A. Mackay has studied the correlation between print quality and test results according to standard methods using proofing devices. He showed that data correlation of the actual print close to the threshold value determined for the laboratory tests that indicated an indirect relation [4]. D. V. Dunayev, V. N. Leontiev, P. V. Lukanin [5, 6] during studying papermaking technology for printing have introduced the concept of "the cloud" as a parameter of paper characterizing its irregularity of structure and properties, but their researches haven't embraced the joint effect of composition and the quality of printed image.

Questions on quantitative evaluation of size of the filler and its distribution in paper using SEM-techniques are discussed in [7]. Despite the results achieved, to control the quality of offset paper need to know exactly how its properties change by the composition. The papermaking process involves many factors, i. e. temperature, concentration of the compound at the inlet / outlet flow, feed rate of the mixture, the amount and type of additives that can cardinally change the properties of the final material. On the other hand, paper requirements include such parameters as breaking length, opacity, whiteness, Kobb test, tightness, breaking strength with special demand of picking strength that characterizes the printability of paper.

2. Experimental setup

Comparison of estimation techniques of the main regulating parameter of printing properties of the offset paper the picking out speed in accordance with GOST 24356 [8] and ISO 3783: 2006 [9] shows the differences in method of its determining. For example, according to GOST 24356 regulated thickness of specimen on form is 4.3 micron, and by ISO 3783: 2006 is given 8.0 ±0.5 microns. Printing pressure is recommended about 650 N / m2 in accordance with GOST 24356, and 350 N/m^2 by ISO 3783: 2006. There is a difference in normalizable value of picking strength (i. e. according to GOST 24356 it is 2.2 m/s, and according to ISO 3783: 2006 it is 4.0 m/s). Also, there is a discrepancy in number of experiments. All above leads to difficulties in comparing the properties of printed paper by regulated parameters and the need of more detailed studying the printing paper properties, including by used in printing industry scale control methods for forecasting paper behavior during the printing process and the management its quality.

It should be noted that most of standardized parameters characterize the strength of printing paper but not its behavior in the printing process. Interaction with ink is described with a very limited number of parameters determination of which is carried out by indirect methods. It caused the developing of a complex test scale. The main difference between a complex test scale and the scales used in printing industry is its high resolution, which allows showing changes in printed image from the paper furnish. A number of additional graphic elements is also introduced in it and allow determining the machine and cross direction of paper sheet formation and the front side of the grid. The main purpose of this work is to develop a method of quality management of the printed image with taking into account the composition of the offset paper compound. To solve this aim it is necessary to work out a set of criteria to estimate and control the quality of outputs, carry out tests on selected criteria, develop recommendations for quality managing of printing paper.

3. Material and methods

A proofing machine Korex and laboratory proofing device IGT have been taken for the process equipment. Printing was performed under standard conditions. The test samples have been taken with a mixed stack of paper of varying composition to obtain prints with the image of a complex test scale, which made it possible to evaluate such print image parameters, as the absolute optical density of a print, print uniformity, dot gain value, print contrast, microtext, paper slip, resolution and effusing ability of paper surface. In addition, we evaluated the surface resistance to picking by the ISO 3783: 2006. The minimum number of replicates was 10 prints for each paper type determined by its compositional structure.

The main problem in the evaluation of the experimental data was the large amount of data (more than 400 types of paper and about 15 criteria for each). Therefore, to predict the behavior of paper in printing process and decision management the technology of complex quantitative quality estimation was applied. Algorithm of solution includes two main stages, i. e. the estimation of separate parameters and properties, and complex assessment of quality overall. Evaluation object property reduces to determining the location of a separate property on a scale. The analysis is performed on the basis of calculating the geometric mean of expert evaluation:

$$D = \left(\prod_{u=1}^{p} d_u^{\delta_u} \right)^{\frac{1}{\sum_{u=1}^{p} \delta_u}}, \tag{1}$$

where δ_u – statistical weight (importance) u-criterion.

In (1) d_u – private desirability function for each of the parameters calculated by the formula:

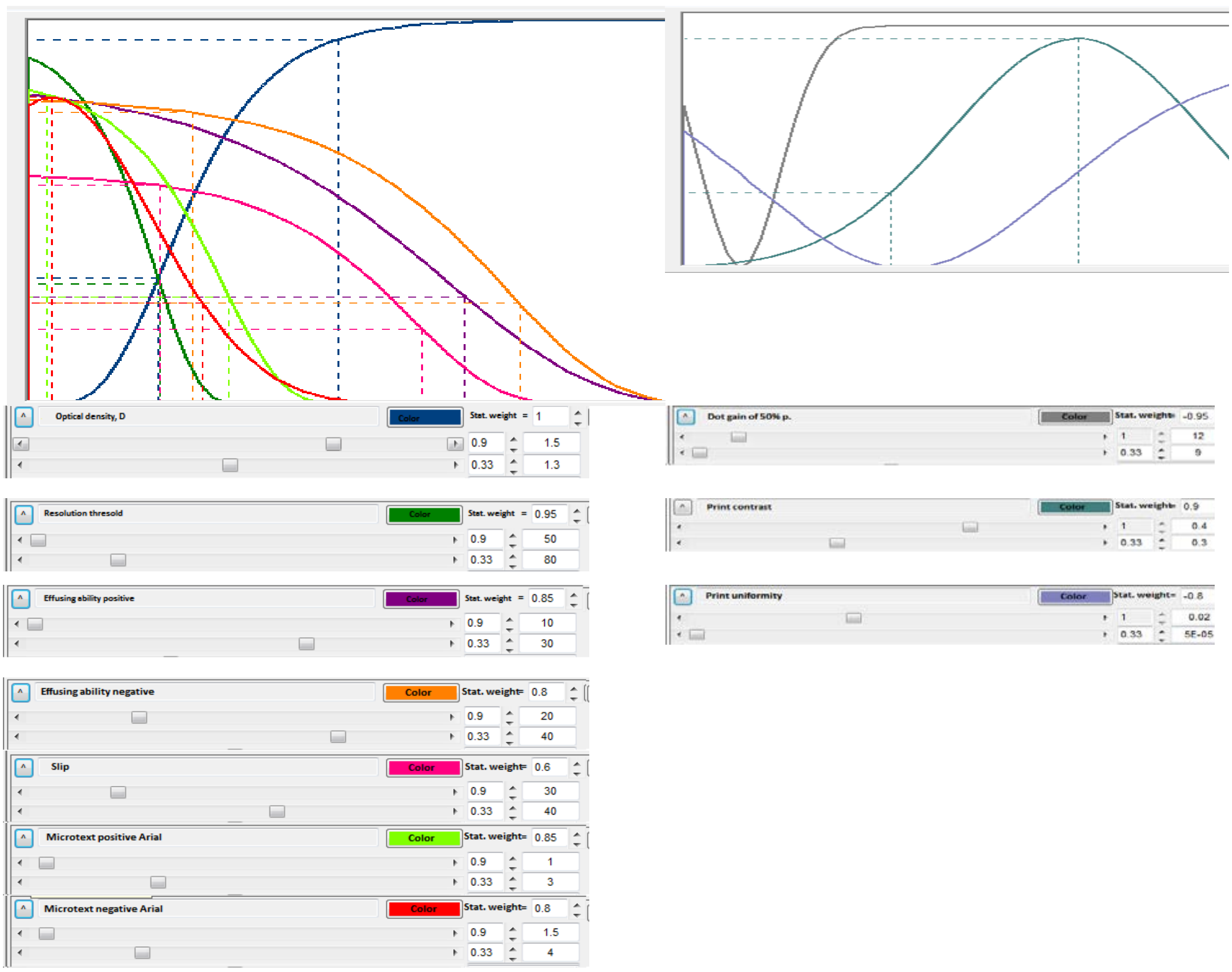
$$d_u = \exp\left[-\exp\left(-y'_u\right)\right].$$

where y'_u – coded parameter value.

As the rating scale the normalized parameter values of optical density of a print, print uniformity, surface resistance to picking, the value of dot gain, print contrast, and also added the criteria of minimizing microtext, the value of paper slip, resolution and effusing ability of paper surface have been taken.

The results of tests carried out by us have shown that the limited values not always fit into the recommended limits for print contrast index, calculated by Schirmer index K_{Sh}, and corresponded with the worst characteristics of paper printability. Therefore, it was decided to bring the indicator to the intervals within a scale experimental data, K_{Sh} = 0.3÷0.5, and the best value was on the point of 0.4.

Processing of the experimental data with the calculation of desirability private functions and the generalized quality criterion have been carried out using software tools of program FUZZY developed in BSTU. Screen copies on assign the desirability private functions curves of offset paper are shown in Figure 1.



a b

Figure 1. Shape of desirability private functions curves: a – function type – sigmoid; b – function type – Gauss.

The value of dot gain is normalized by ISO 12647-2 [10]. Practice shows that for the production of paper with improved printing properties it should be limited the allowable range of dot gain for the 50% raster field to 12%. For negative microtexts and effusing ability in comparison with the positive ones the weight have been reduced on 0.05 as they are used relatively rare.

4. Experimental results

To evaluate the paper printing properties a complex test scale has been developed (Table 1) [11, 12], and the basic requirement was a frequency of no less than 300 lpi, which guaranteed a minimum size of microdots on the level of 5 micron that matches to the thickness of paper sheet fibers.

Table 1. Desirability scale for quality parameters of the offset paper.

Parameter Name	**Values on a scale of desirability metrics**				
	Discard	*Satisfactory*	*Good*	*Very Good*	*Perfect*
Optical Density, D	менее 1.1	1.1	1.3	1.5	более 1.5
Printing Contrast, K_{Sh}	менее 0.25	0.25	0.3–0.5	0.35–0.45	0.4
Print Uniformity, D	более ±0.1	±0.1	±0.02	±0.001	0
Dot Gain of 50% p., %	более ±15	±15	±12	±9	0
Resolution threshold, μ	более 100	100	80	50	менее 50
Microtext, pt.:					
– positive	более 3.5	3.5	3.0	1.0	менее 1.0
– negative	более 5.0	5.0	4.0	1.5	менее 1.5
Effusing ability, μ:					
– positive	более 40	40	30	10	менее 10
– negative	более 50	50	40	20	менее 20
Slip, μ	более 50	50	40	30	менее 30

The values of parameters were normalized with the recommendations of various normative documents. The statistical weight for a set of standardized parameters was on the level of 0.9, and for non-standardized – 0.65.

For example, for the optical density of a print according to the technological instructions for printing of Institute of printing for the offset paper the standardized value for the black ink is 1.2 D, and by the requirements of ISO 12647-2 it is 1.0 D, and according to recommendations of X-Rite company the optical density for uncoated paper is 1.55 D for black ink.

Therefore, the minimum acceptable value of optical density was taken on 1.1 D based on the range of variation of the experimental data of 0.95÷1.6 D, and to assess perfect metric the optical density must be greater than 1.5 D.

The results of approbation on Goznak "Paper mill" of Borisov (Byelorussia) with optimized composite structure are shown in Tables 2 and 3.

Analysis of experimental data in Tables 2 and 3 shows that the management of a composite compound of the paper by the use of fuzzy sets and generalized desirability functions for processing the results of approbation suggested the increase not only the physical and mechanical properties of the offset paper but its printing properties for all quality parameters of the printed image.

In particular, increasing ink sensitivity to the surface by the surface sizing, increase the homogeneity of the surface as a result of changes in the composition be the fiber filler leads to increase of printing uniformity and optical density, minimizing microtexts, reduces dot gain and slip.

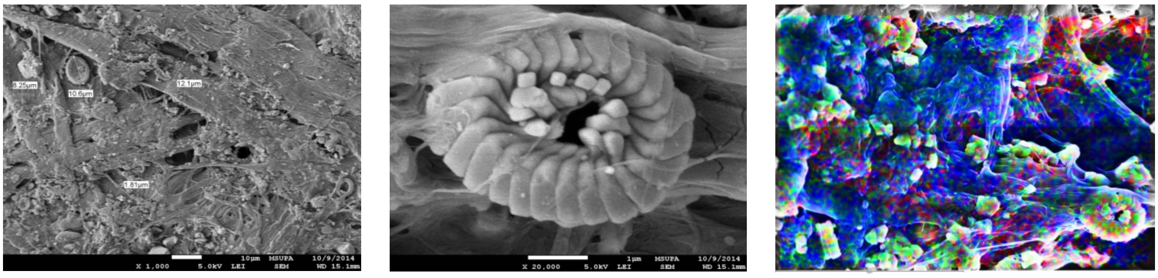
SEM-image of the sample paper layer surface under the magnification of $1000^{\times}$ is shown in Figure 2*a*. In the sample the formation of modified inorganic filler obtained by the technology of Goznak "Paper mill", containing $CaCO_3$, is revealed (Figure 2*b*).

Table 2. Physical and mechanical properties of the offset paper obtained in an industry.

Parameter Name	**Offset Paper (control)**	**Paper With Optimized Composite Structure**
Fracture Strength, n. d. f.	149	264
Breaking length, m		
– in machine direction	6700	6900
– in a transverse direction	3900	4000
Resistance to tearing, mN	630	640
Kobb test, g/m^2	18	18
Smoothness, s	50	67
Linear deformation, mm	2.9	2.8
Sizing degree, mm	2.0	2.0
Ash content, %	6.2	9.7

Table 3. Paper printing properties obtained in an industry.

Parameter Name			**Offset Paper (control)**	**Paper With Optimized Composite Structure**
Optical density of print, D			1.17	1.45
Uniformity Print, D			±0.0924	±0.0531
Microtext, pt.	Negative	Arial	2.0	1.9
		Times	2.5	2.0
		Script	4.0	2.5
	Positive	Arial	1.4	0.9
		Times	1.7	0.9
		Script	2.5	1.7
Paper resolution threshold, μ			80	50
Effusing ability, μ			30	10
Printing Contrast K_{Sh}			0.324	0.350
Slip, μ			60	40
Dot Gain of 50% p., %			+12.8	+10.8



a b c

Figure 2. SEM-images of the structure of the paper (a) and the filler (b) overlaid with EDS map the distribution of elements (c).

It is clearly visible forming the grid of paper sheet from fibers, microfibrils and filler particles on Figure 2*a*. Figure 2*c* shows the distribution map of the elemental composition of a paper sheet with carbon C by blue, oxygen O by red and Calcium Ca by green.

5. Results and discussion

Printing uniformity according to the recommendations of the Institute of printing for black ink needs to be no more than ±0.1 D. The experiment carried out with the paper surface sizing has showed that printing uniformity does not exceed the level of ±0.05 D. Therefore, as a criterion for this parameter the average value is taken ±0.02 D. Parameter should show function with two-sided contingencies with a minimum at 0. For the rest parameters the logistic sigmoid with 0.33-0.9 terms in corresponding percentages are used as a membership function, which are evaluated as "good" and "very good".

To determine the criteria by which parameters of paper printability change the decision tree is modeled by the data set processing in the JMP program for each of identified by the scale parameters. The example of the decision tree for the optical density is shown in Figure 3.

Detailed analysis is shown in an example for the surface sizing of the offset paper by compositions based on various types of starches with additives recommended by manufacturers of chemicals for the pulp and paper industry to improve paper printability.

Parameter of optical density of a print obtained on the offset paper with surface sizing is greatly affected by the concentration and type of the starch composition (Figure 3).

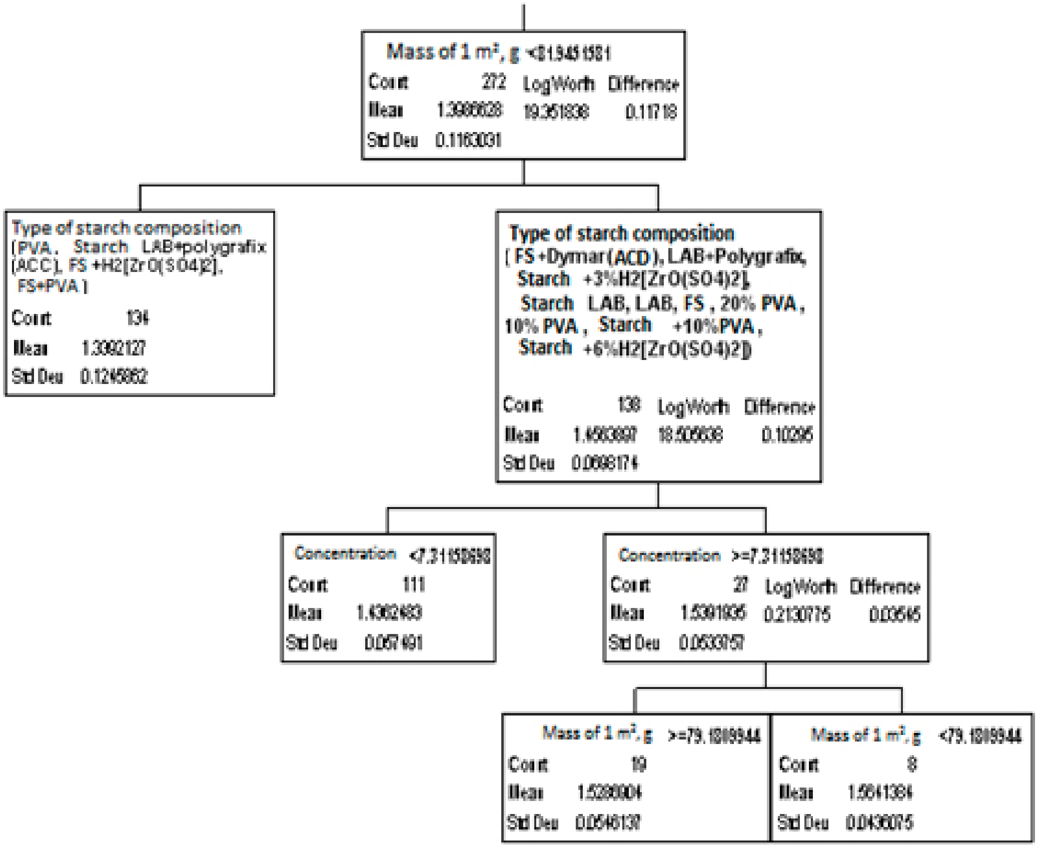


Figure 3. Example of decision tree in JMP.

For maximum of optical density it is necessary to have mass of 1 m^2 not exceed to 80 g. Further analysis showed that to improve the resolution and effusing ability of the paper surface it is necessary to change the type of starch composition and starch expiry speed. Slip parameter also has the greatest effect by the type of starch composition and its concentration.

In order to increase the reproducibility of fonts by parameter of microtext it is prefered to vary the type of the starch composition, starch flow discharge and its velocity. To reduce dot gain value it is needed to modify the starch digestion temperature, the concentration and its discharge velocity. Printing Contrast is within optimal limits when changing the type of composition and starch concentration. For the parameter of printing uniformity it is important to change all the dependent factors.

It was found that in the aggregate for the offset paper with its surface sizing parameters vary from changes in type of the composition for surface sizing, discharge velocity and starch concentration.

Overall analysis of SEM-images showed a significant increase in the uniformity of the paper sheet due to a more equal distribution of the filler particles in the structure of a sheet and its retention by fibrils and microfibrils of cellulose fibers, changes in its shape and dispersion.

In general, quantity of filler particles distributed over the surface in the relative atomic units is low and assists to increase of the smoothness, resolution and effusing ability of the paper surface, reduces the amount of dot gain.

6. Conclusion and summary

Correlation of quality parameters of the printed image with the condition parameters of the technology in papermaking process by complex test scale is shown in the work. This allowed predicting and directionally controlling final printing paper properties in order to improve the uniformity of paper sheet structure, change the resolution and effusing ability, which is particularly important for special types of paper.

The use of fuzzy sets, linguistic variables, membership functions and formulas for calculation the complex quality criterion of image reduces the dimension of the problem for the analysis of printing paper properties.

From the viewpoint of reproducibility fonts improve by microtext parameter, increase of prints saturation by enhancement of ink sensitivity with the compositions for surface sizing, rise of paper structure uniformity, its smoothness and ash content due to the introduction of the compositions with modified fillers that higher the natural paper whiteness, the most important criteria for predicting and quality control of the printed image are revealed.

The results of the analysis allow directionally improve surface properties to give a paper with improved quality of the printed image, i. e. optical density at a given level of not less than 1.3 D, print uniformity with minimal deviation $\sim 10^{-5}$, dot gain for offset paper at a level of coated paper about 10%, microtext reproducibility, resolution and effusing ability and minimum slip. This procedure can be applied not only to paper, but, for example, and to ink, the blanket and the plate.

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