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Management the paper printing properties by methods of factor analysis

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Abstract. The article deals with the actual problem of managing the paper printing properties using factor analysis methods. The analysis of the stone debris method allowed us to prove the combination of data in three ways: the interaction of the ink with the paper surface, which controls the optical density of the print, the value of dot gain; structural properties of the surface, which determine the effusing ability of the paper, printing slip; features of the distribution of the ink layer, which change the parameters of the prints resolution, font resolution threshold, print contrast. The identified factors allowed to simplify the task of rational decision making. As a result of the analysis of a set of technological parameters, i.e. the composition by fiber, filling, surface treatment and mass sizing, production of paper within the improved printing properties was achieved. Changes have been made in the technology of producing uncoated printing paper under the conditions of IUE "Paper Mill" Goznak. The analysis of the quality of management was carried out on the basis of the integral method and made up 92%.
Keywords - paper, printing properties, factor analysis, quality

1. Introduction

Managing the quality of pulp and paper products is invariably a hot topic of scientific research due to the complexity of the system that forms it. There are many approaches for solving the problem. Russian and foreign researchers consider the problem, both in the complex, and in relation to very narrow aspects. In [1], it is proposed to define paper as a biopolymer and composite material and analyze the deformation properties from the standpoint of the theory of deformation of elastic-elastic bodies. As a result, control and prediction of properties of final materials is achieved. In works [2, 3], a systematic approach to the analysis of the printing properties of paper is proposed. It provides for an estimation the quality of experimental samples based on the parameters of the printed image. The author notes a close correlation between the technological parameters of the paper making process and the print result. In [4], a high degree of correlation between the properties of paper and the quality of prints was also shown, and a model for ink film fixing a on a paper is proposed. In [5], the problem of controlling the quality of uncoated paper is considered, but the control procedure involves a single process related to the drying part of the paper machine, and the final properties are considered as a set of constraints. At the same time, the properties complex refers to standardized parameters of paper quality in accordance with GOST 9094 [6] and does not affect its behavior in the printing process. In a similar way, the process of controlling the properties of the thermomechanical pulp

(TMP) based on the quality of the raw material (wood chips) and the parameters of the pulp refining in the refiner of papermaking machine is given in [7]. In [8], a factor analysis was proposed to estimate a quality of TMP due to seasonal changes in wood supply. As a result, two main factors are identified from the set of parameters that need to be analyzed and changed during the production of TMP (consumption of bleaching agents, energy consumption for grinding). The experience of using factor analysis in the production of TMP allows to apply it to the problem of managing the paper printing properties. It should be based on a set of parameters obtained as a result of printing paper samples, the most significant of which include the optical density of the print, the paper surface resolution obtained by the scale control methods.

2. Problem statement

There are many ways of product quality control. For example, the paper [9] discusses the questions of management theory proposed by such experts as W. Edward Deming, Joseph M. Juran, Philip B. Crosby, Armand V. Feigenbaum, and others. All of them appoint on end-to-end quality management from the positions of consumer and producer, which suppose the output of products according to customer requirements and the work of enterprises aimed on meeting these requirements. According to the Japanese expert Kaouru Ishikawa [10], the most significant factor is the ability to correlate customer requirements and the economic expediency of the achieved quality level from side of manufacturer. The Russian school relies on strict production planning and work in accordance with technological regulations and other technical regulatory documents [11, 12]. This significantly reduces the flexibility of the management process of the final product properties, because it requires changes in existing documentation. Due to these factors, in order to speed up the quality management process, it is necessary to reduce the number of objective factors by combining them into groups and develop on their basis a system of control actions that will allow to efficiently correct the current documentation, process, and to obtain products with a given set of properties in accordance with possible customer requirements.

3. Theory

Factor analysis is a universal tool for finding hidden dependencies in a large sample of experimental data [13]. It allows you to concentrate the source information, expressing a large number of considered features through a smaller number of more capacious internal characteristics of the phenomenon, which are off direct measure.

Suggest that the structure of parameters includes a common random factor, deterministic (non-random) factor loadings and random deviations that act only on factors, and are independent both between themselves and with a common factor. Thus, it is assumed that the correlations between parameters occur only under the influence of some general factor, which, therefore, makes point to consider as an index. In this case, factor loadings are considered as unknown parameters to be estimated. In this regard, factor analysis allows to combine data into groups that will be uniquely controlled by the initial parameters. In [14], the structure of correlations that results in difficult subordinate groups of properties of the process of manufacturing printing paper is shown. The structure provides for the control of printing properties in nine main parameters: print optical density, paper surface resolution, effusing ability in negative and positive display, paper slip, font resolution threshold in positive and negative style, dot gain of 50% raster dot, printing contrast K_{Sh}. It is required to check the redundancy of the model on the basis of the entire array of data obtained during the experiment of changing paper composition. The methods of factor analysis are quite diverse. In this paper, the principal component method was applied. The evaluation was made in a JMP environment. The results of the calculation of the correlation matrix are presented in Table. I.

Table 1. Correlation matrix

		Print optical density	**Paper surface resolution**	**Effusing ability**		**Paper slip**	**Font resolution threshold**		**Dot gain**	**Printing contrast**
				positive	**negative**		**positive**	**negative**		
Print optical density		1.0000	-0.4948	-0.5514	-0.6711	-0.5695	-0.0405	0.0121	0.3223	0.6233
Paper surface resolution		-0.4948	1.0000	0.5695	0.1956	0.2273	0.7789	0.7372	0.3425	-0.8724
Effusing ability	posi-tive	-0.5514	0.5695	1.0000	0.5821	0.5520	0.3313	0.2263	0.1822	-0.5933
	nega-	-0.6711	0.1956	0.5821	1.0000	0.7508	-0.1905	-0.2268	-0.2488	-0.3205

		Print optical density	**Paper surface resolution**	**Effusing ability**		**Paper slip**	**Font resolution threshold**		**Dot gain**	**Printing contrast**
				positive	**negative**		**positive**	**negative**		
	tive									
Paper slip		-0.5695	0.2273	0.5520	0.7508	1.0000	-0.1661	-0.2385	-0.1896	-0.3203
Font resolution threshold	posi-tive	-0.0405	0.7789	0.3313	-0.1905	-0.1661	1.0000	0.9617	0.5749	-0.6677
	nega-tive	0.0121	0.7372	0.2263	-0.2268	-0.2385	0.9617	1.0000	0.5969	-0.6003
Dot gain		0.3223	0.3425	0.1822	-0.2488	-0.1896	0.5749	0.5969	1.0000	-0.1886
Printing contrast		0.6233	-0.8724	-0.5933	-0.3205	-0.3203	-0.6677	-0.6003	-0.1886	1.0000

Data in table show that the closest values have parameters of font resolution threshold in a positive and negative display, i.e. they can be combined into one parameter. Effusing ability and paper slip, resolution, optical density and printing contrast are also clearly linked. Nevertheless, it is difficult to isolate strictly determined factors, therefore, the “stone scree” screening criterion is chosen (Fig. 1).

Number of criterion	Characteristic constant	Percentage	Final percentage
1	4.1088	45.654	45.654
2	3.0148	33.498	79.152
3	0.8136	9.040	88.192
4	0.3199	3.554	91.746
5	0.2606	2.895	94.641
6	0.2379	2.644	97.285
7	0.1211	1.345	98.630
8	0.0965	1.072	99.702
9	0.0269	0.298	100.000

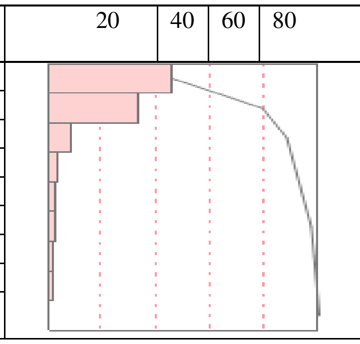

Figure 1. Graph-based mapping on criterion “Stone scree”

The figure shows that it can be determined the number of three factors, since after three components there is a “smooth subsidence of stone scree”, their values are “factorial scree”.

The orthogonal rotation of the three factors according to the criterion of Varimax made it possible to distinguish groups of factors, according to three characteristics, determining the interaction of the ink with the paper surface, the structural properties of the surface, and features of the distribution of the ink layer. Each group of factors corresponds to only one of the nine analyzed parameters of printing properties. The result of the calculation of the factor structure obtained from the matrix of the main factors is presented in tab. II. Here the factors of the distribution of the ink layer, such as paper surface resolution, the font resolution threshold (positive and negative), the contrast of printing, can be attributed to the factors F1. The factors F2 - the structural properties of the surface - determine the effusing ability of the paper surface (positive and negative) and the paper slip. Factors F3 - the interaction of ink with paper surface correspond to the parameters of print optical density, dot gain.

The cluster analysis allowed us to confirm the minimum number of criteria grouping a set of parameters of paper printing properties.

Table 2. Factor structure

Parameter	Factors		
	F1	F2	F3
Print optical density	-0.36	-0.66	0.56
Paper surface resolution	0.91	0.30	0.03
Effusing ability positive	0.39	0.78	0.18
Effusing ability negative	-0.05	0.89	-0.20
Paper slip	-0.07	0.89	-0.10
Font resolution threshold positive	0.91	-0.11	0.32
Font resolution threshold negative	0.89	-0.19	0.33
Dot gain	0.37	-0.06	0.86
Printing contrast	-0.86	-0.40	0.14

Fig. 2 shows the result of a grouping of print optical density parameters, resolution and effusing ability. Since data overlap did not occur, it can be argued that these parameters will be the main and decisive for the complex printing properties.

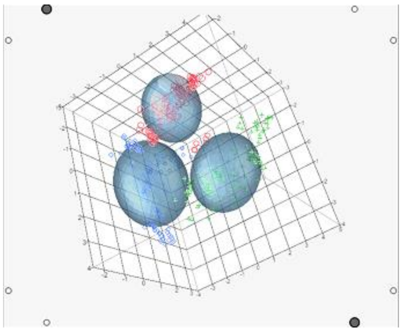

Figure 2. Data scatter and centers of clustering by three clusters

As a result, the hypothesis of a three-factor description of the printing properties complex can be considered to be proven. The main factors can be considered as features of the distribution of the ink layerincluding resolution, structural surface properties (effusing ability) and the interaction of ink with the paper surface, which is determined by the optical density of the print.

4. Experimental results

The main factors that control the printing properties of the paper are the technological parameters of the introduction of the fibrous component, filler, mass sizing and surface treatment. The complex of these factors allows to manage not only the properties, but also the type of paper. In the technology of uncoated papermaking, various types of pulp and waste paper are used as the fibrous component. The filler can be chalk, microcalcite, talc, etc., with or without a modifying treatment. Mass sizing, as well as surface treatment, is produced by compositions of adhesives with different concentrations. Changing technological regimes contributes to the regulation of surface properties, mass. Then the target control structure will have the form shown in Fig. 3a In fig. 3a, the following keys are introduced: B1 - fibrous component, B2 – mass sizing, B3 - surface treatment, B4 - filling; P1 – P9 - single indicators of paper printing properties, respectively, print optical density, resolution, positive and negative effusing ability, paper slip, positive and negative font resolution threshold, dot gain, print contrast. Such a complex of multiple connections requires a simplified management structure. Therefore, on the basis of the factor analysis, the control factors of printing properties were reduced to three: F1 - features of the distribution of the ink layer, F2 - structural surface properties, F3 - interaction of ink with paper surface (Fig. 3b).

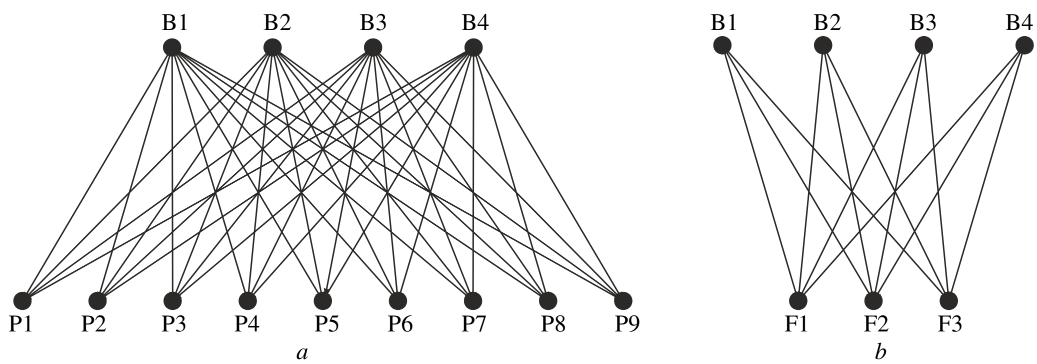

Figure 3. Sheme of managing factors of printing properties:
a – before transformation; *b* – after transformation

In order to study the effect of the fibrous component on the paper printing properties for offset printing with a mass of 1 m^2 80 g, an experiment was carried out in laboratory conditions. In the course of the experiment, the parameters of the refining of cellulose and its content in the ratio of softwood / hardwood / waste paper were varied. At the same time, all other parameters of filling, mass sizing and surface treatment were modeled according to the technology used at IUE “Paper Mill” Goznak (Borisov, Republic of Belarus).

Similarly, the variation of mass sizing parameters was carried out by changing the rate and the type of components. In the study of surface treatment factor, the modification and concentration of the compositions were changed. Filling factors included the type, modification and content of the filler. The study of the influence of joint factors filling – mass sizing and filling – surface treatment showed the absence of their influence on each other. At the same time, there is a connection between the type of fiber and the filling and surface treatment with mass sizing. These additional links complicate the system and require their accounting to control printed properties.

As in each of the three factors of the printing process there are several parameters, in order to bring the system to a single type, it was need to combine according to the complex quantitative quality estimation [15]. During the calculation of the generalized quality criterion, the levels of marks "satisfactory" and higher are taken. The final values of the generalized quality criterion for factors of printing properties, depending on the technological parameters of paper manufacturing are presented in Tab. 3.

Table 3. Values of the generalized quality criterion

Factors of printing properties	Fibrous component B1	Mass sizing B2	Surface treatment B3	Filling B4
F1	0.208	0.400	0.752	0.646
F2	0.684	0.574	0.134	0.652
F3	0.804	0.740	0.811	0.802

Analysis of tab. III allows to identify the degree of influence the technological factors on the printing properties. As a result, to control the factors of interaction of the ink in the paper surface, it is necessary to take into account all the parameters of the technological process of its manufacture. Structural properties are controlled to a greater extent by the parameters of grinding and the type of fiber, the content of the filler and the amount of sizing substances in the mass. The characteristics of the distribution of the ink layer are more influenced by the type of surface treatment and filler modification.

5. Discussion results

The analysis of the data of paper printing properties obtained by a complex scale using the methods of factor analysis allows us to make recommendations on changing the composition in order to achieve maximum indicators of the quality of a printed image. As a result, the optimal parameters of the fibrous composition were selected (for the introduction of hardwood pulp in the amount of 50%, two-step grinding and reduction of the degree of grinding are required); mass sizing is determined by its quantitative content, since it affects the depth of penetration; surface treatment changes the printing properties depending on mass concentration and the type of working dispersion; during filling, the optimum content of the filler is achieved by the final ash content of 10% –12% and the parameters of the modifying treatment. Tab. IV shows the results of testing the printing properties for all quality parameters on printing properties of paper obtained in laboratory conditions.

Table 4. Printing properties of uncoated paper, produced in laboratory conditions

Parameter		**Sample, obtained by standard technology**	**Paper, obtained by optimized parameters of its manufacturing**
Print optical density, D		1.35	1.89
Font resolution threshold, p.	negative	3.0	2.5
	positive	2.0	2.0
Paper surface resolution, μ		80	60
Effusing ability, μ	negative	60	40
	positive	50	30
Printing contrast K_{Sh}		0.32	0.35
Paper slip, μ		50	40
Dot gain 50% screen. Δ, %		+16.8	+14.1

From tab. IV one can see that paper produced according to optimized parameters of manufacturing technology has improved printing properties. In order to estimate the quality of management, the achieved parameters were compared in accordance with the qualimetric estimation on the scale of desirability [15].

To assess the quality of management, an integral method was used, which implies a generalized estimation of the quality prognostication based on the assessment of the quality prognostication according to particular criteria:

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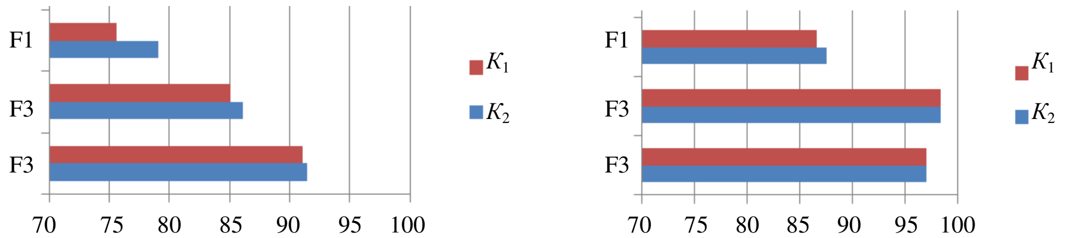
$$K_1 = \left| X - I \right| \quad \text{and} \quad K_2 = \left| \ln X / I \right|,$$

where X – prognosticated value of parameter; I – real value of parameter.

Preliminary results showed low reliability of the results on the factor of interaction of the ink with the surface F3. This was due to a large variation in the achieved values, as well as laboratory conditions for papermaking. Therefore, in order to increase the confidence level of the prognostication, changes were made to the desirability scale (for the level "good", the value of optical density was changed from 1.3 to 1.45 D, the maximum value was entered as 2.0 D and above; the value of printing contrast became minor and changed from 0.4 to 0.35; permissible dot gain of 50% of the screen was increased from 12% to 14.5%; the Font resolution threshold was not change (3 points), and the technological modes of filling were also changed. Fig. 4a shows the initial estimates for indicators K_1 and K_2; 4b are given the refined results.



a b

Figure 4. Results of assessment of printing properties of uncoated printing paper in accordancy with the quality of criteria of prognostication: a – initial; b – refined

From fig. 4 it is shown that there was a significant improvement in the quality management (by 10%), which on average gave an acceptable value of the confidence level of the result of 92%.

6. Conclusions and summary

The approbation of the results obtained in industrial conditions made it possible to make changes to the parameters of paper manufacturing technology operating at IUE "Paper Mil" Goznak and to develop a new process procedure. The achieved values are given in average with a sample size of 500 prints out of 10,000 (Tab. V).

Table 5. Printing properties of uncoated paper, produced in industry conditions

Parameter		Control sample obtained in accordance with Standard	Paper, obtained by optimized parameters of its manufacturing
Print optical density, D		1.45 ±0.10	1.65 ±0.05
Font resolution	2.0 ±0.3	1.4 ±0.30	1.4 ±0.3
threshold, p.	1.5 ±0.2	0.9 ±0.10	0.9 ±0.1
Paper surface resolution, μ		50 ±5.0	30 ±5.0
Effusing ability, μ	40 ±5.0	20 ±5.0	20 ±5.0
	30 ±10	10 ±5.0	10 ±5.0
Printing contrast K_{Sh}		0.38 ±0.05	0.35 ±0.,03
Paper slip, μ		40 ±5.0	30 ±5.0
Dot gain 50% screen. Δ, %		+11.4 ±2.4	+7.8 ±1.8

The data in tab. V show the effectiveness of the developed control system for printing properties based on factor analysis, followed by combining the parameters on a scale of desirability. It should be noted that on the basis of the generalized indicators selected as a result of the factor analysis, it is possible to obtain paper with target properties. That is, to set the properties of paper, aimed at improving the properties of the surface, changing the distribution of ink over the surface, improving the interaction of ink with the surface. Changing the product mix of printed paper types to be produced will increase consumer interest in paper products.

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