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# QUALITY PREDICTION MODEL FOR THE MANUFACTURING PROCESS OF FLEXOGRAPHIC PRINTING PLATES

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*Ensuring high quality of flexographic printing plates is critically important for efficient and stable reproduction of images and texts in high-speed printing process. Modern requirements for the plate accuracy, their physical and mechanical properties, relief geometry and compatibility with various materials make it necessary to implement intelligent information systems capable of predicting the result even at the stage of production preparation. The proposed model is based on the integration of physical and mechanical, optical-raster and geometric parameters of the plate into a single integral quality indicator, which allows quantitatively assessing the plate condition and determining its suitability for stable reproduction. To verify the model adequacy, two typical situations are simulated: a reference plate, all parameters of which are within technological standards, and a defective plate with deviations of key parameters. The results demonstrate that the proposed fuzzy-multi-criteria model efficiently distinguishes reference and defective plates, providing an accurate quality assessment and prediction of possible deviations. This approach allows one to reduce production risks, optimize the technological process of plate manufacturing, and integrate the principles of smart manufacturing into the printing industry, providing automated quality control in Computer-to-Plate (CtP) and IIoT monitoring systems.*

***Keywords:*** *flexographic printing plate, process quality, model, fuzzy multi-criteria analysis.*

**Problem setting.** In modern conditions of manufacturing process digitalization, publishing and printing industry places increases demands on the stability of printed product quality, especially in the plate manufacturing for high-speed reproduction of images and texts. Traditional methods of the plate quality control involve checking after the completion of the manufacturing process, which makes it impossible to detect defects in a timely manner and causes material losses. In the case of large-scale printing process, the lack of even a single plate can lead to the rework of the entire batch. This reduces the manufacturing efficiency and makes it difficult to meet the established deadlines for fulfilling the orders.

In view of this, it is relevant to develop a model that allows predicting the printing plate quality before the printing process, based on the analysis of technological process parameters. This approach ensures a reduction in production risks, stabilization of the plate manufacturing process and an increase in the overall level of technological control. The integration of machine learning and modelling elements into information management systems makes it possible to implement the principles of smart manufacturing in the publishing and printing area.

**Analysis of recent research and publications.** The issue of quality assurance in printing production has been presented in the works of a number of researchers. The author of the work [1] formulates the theoretical foundations of quality management at all stages of the printing cycle, focusing on the need to move to quantitative assessment of parameters. The monograph [2] considers the technological aspects of flexographic printing process, in particular, factors affecting the quality of printing plates during their manufacturing. The study [3] shows that the physical and mechanical properties of flexographic printing plates, in particular hardness, elasticity and surface structure, are decisive factors in print quality and tone stability. The publication [4] presents an adaptive prediction model that uses neuro-fuzzy systems to optimize technological printing modes. This work confirms the efficiency of integrating intelligent algorithms that can learn from experimental data and predict the quality under conditions of variations in technological parameters. In the scientific literature, approaches to predicting the quality of flexo plates based on machine learning and big data analysis are actively developing. For example, in [5] it is shown that machine learning methods are effectively used to assess the flexographic printing quality. Linear regression algorithms, decision trees and the Random Forest method are implemented to predict dot gain as a characteristic of print quality. The highest prediction accuracy – 93,02% – is achieved using Random Forest. The approach allows one to analyse data quickly and make informed conclusions about print quality.

These studies demonstrate the active development of approaches to predicting the quality of flexoplates, which contributes to improving the efficiency and quality of flexographic printing process.

**The aim of the article** is to develop a model for predicting the quality of the flexographic printing plate manufacturing process based on the control of quality parameters.

**Research methods.** The overall quality indicator of a flexographic printing plate is determined as a weight sum of partial coefficients:

$$Q_{plate} = \frac{\sum_{i=1}^{n} w_i \cdot K_i}{\sum_{i=1}^{n} w_i}, \tag{1}$$

where $w_i$ is the weight coefficient of the significance of the $i$-th parameter, $n$ is the number of parameters.

The sum of the parameter weights is normalized to 1, i.e.:

$$\sum_{i=1}^{n} w_i = 1. \tag{2}$$

The scale for interpreting the quality indicator of the printing plate manufacturing process is presented in Table 1.

Table 1

**Scale of quality indicator interpretation**

| Value $Q_{plate}$ | Interpreting the plate condition |
|---|---|
| ≥ 0,85 | Excellent – the plate meets all requirements, ready to print |
| 0,70–0,84 | Acceptable – permissible deviations, the plate is suitable for short runs |
| 0,50–0,69 | Marginal – the plate requires technological adjustment |
| < 050 | Defective – the plate is defective |

**Presentation of the main research material**. The analysis of publications and practical recommendations on the technological process of photopolymer printing plate manufacturing allows one to form factors that present the quality of their manufacturing. Quality factors and their controlled indicators are shown in Table 1. The quality of the manufactured flexographic plate is assessed by three integral components:

$$Q = f(F, O, G), \quad (3)$$

where *F* is a group of physical and mechanical indicators; *O* is a group of optical raster reproduction indicators; *G* is a group of geometric indicators.

Table 2

**Quality factors and their controlled indicators [6-12]**

| № | Quality factor | Controlled indicator | Typical range/ assessment criterion |
|---|---|---|---|
| 1 | Plate thickness ($x_1$) | Total thickness of the photopolymer plate | 1,14 ± 0,02 mm, 1,70 mm, 2,84 mm (depending on the plate type) |
| 2 | Relief height ($x_2$) | The difference between the top and the base of the relief | 0,018 – 0,028 inch ≈ 460–710 μm |
| 3 | Polymer hardness ($x_3$) | Hardness index (Shore A) | 63° A – 75° A |
| 4 | Surface roughness and topography ($x_4$) | Average roughness Ra, surface uniformity | Ra ≈ 0,2 – 0,5 μm, without micro-cracks |
| 5 | Raster dot shape and integrity ($y_1$) | Geometry (flat, conical, rounded), edge clarity, lack of erosion | Symmetrical shape, without undercuts or chipping |
| 6 | Minimum reproducible dot ($y_2$) | The smallest stably formed raster element (%) | 1–3 % (2400 dpi), < 1 % (4000 dpi) |
| 7 | Dot size accuracy (Plate Dot Gain) ($y_3$) | Deviation of the dot area on a plate from a digital standard | Δ ≤ 2–4 % (digital), Δ ≤ 5–7 % (analogue) |
| 8 | Angle of relief wall inclination ($z_1$) | Angle between the base and the side walls of the dot | 60° – 75° (depending on the technology) |
| 9 | Dimensional stability ($z_2$) | Linear dimensional changes after drying or cooling | Δ ≤ 0.2 – 0.6 % |

Group $F$ includes items 1-4 of Table 2.

Group $O$ includes items 5-7, representing the quality of exposure, washing and polymerization.

Group $G$ includes items 8-9.

These parameters form the input control before installing the photopolymer printing plate in the flexographic press and represent its suitability for stable reproduction.

Fig. 1 shows a logical model of quality formation in the manufacturing process of flexographic printing plates.

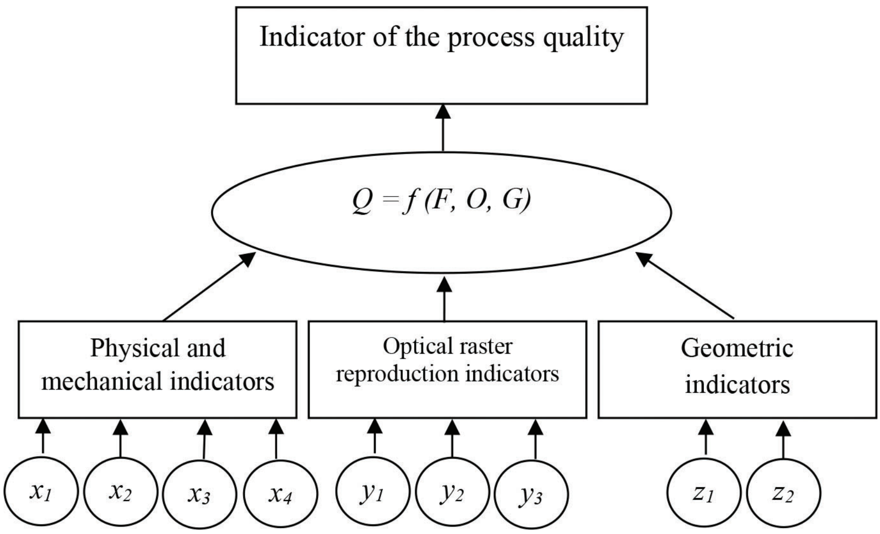


Fig. 1. Model of logical quality formation of the technological process of flexographic plate manufacturing

For our model, the parameter weights are formed (Table 3):

Table 3

**Groups of printing plate parameters and their weights**

| Group | Parameter | Weight ($w_i$) |
|---|---|---|
| Physical and mechanical indicators | Plate thickness | 0,07 |
| | Relief depth | 0.12 |
| | Hardness (Shore A) | 0.08 |
| | Surface roughness | 0,08 |
| Optical raster reproduction indicators | Dot geometry | 0.18 |
| | Minimum reproducible dot | 0,12 |
| | Dot distortion on a plate (dot gain) | 0,10 |
| Geometric indicators | Relief wall angle | 0,13 |
| | Dimensional stability | 0,12 |

To verify the model adequacy, two typical situations are simulated:
A (reference plate) – all parameters within the standard range;
B (defective plate) – understated thickness, small relief depth, high roughness, etc.
The results of the calculations are presented in Table 4.

Table 4

**Results of fuzzy analysis of the flexographic printing plate quality**

| № | Factor | $K_i$, A | $K_i$, B | Weight, $w_i$ | $w_i \times K_i$ (A) | $w_i \times K_i$ (B) |
|---|---|---|---|---|---|---|
| 1 | Thickness, mm | 0,95 | 0,35 | 0,07 | 0,0665 | 0,0245 |
| 2 | Relief depth, inch | 0,97 | 0,30 | 0,12 | 0,1164 | 0,0360 |
| 3 | Hardness (Shore A) | 0,92 | 0,40 | 0,08 | 0,0736 | 0,0320 |
| 4 | Surface roughness Ra, µm | 0,90 | 0,45 | 0,08 | 0,0720 | 0,0360 |
| 5 | Dot geometry | 0,96 | 0,55 | 0,18 | 0,1728 | 0,0990 |
| 6 | Minimum reproducible dot, % | 0,93 | 0,42 | 0,12 | 0,1116 | 0,0504 |
| 7 | Plate dot gain, % | 0,92 | 0,50 | 0,10 | 0,0920 | 0,0500 |
| 8 | Wall angle, ° | 0,88 | 0,35 | 0,13 | 0,1144 | 0,0455 |
| 9 | Dimensional stability, % | 0,90 | 0,25 | 0,12 | 0,1080 | 0,0300 |
| Q | | | | 1,00 | 0,8378 | 0,2103 |

The results obtained show that the proposed fuzzy multi-criteria model allows quantitatively assessing the quality of a flexographic plate, taking into account the fuzzy boundaries between the states of the parameters. For the reference plate, $Q_{plate}$ = 0,838 is obtained, which corresponds to the Acceptable/Excellent level. For the defective plate, $Q_{plate}$ = 0,210, which indicates a significant deviation from technological standards and the need for re-manufacturing.

The model can be used as a basis for automated quality control of printing plates in systems such as Computer-to-Plate (CtP) or IIoT-monitoring.

**Conclusions.** Thus, the developed fuzzy multi-criteria model for predicting the quality of flexographic printing plates provides the integration of physical-mechanical, optical raster and geometric parameters into a single integral indicator $Q_{plate}$, which allows quantitatively assessing the plate suitability for stable reproduction at the stage of production preparation. The modelling shows that the reference plate reaches $Q_{plate}$ = 0,838, while the defective plate has $Q_{plate}$ = 0,210, which indicates significant deviations from technological standards. This approach allows one to reduce production losses, increase the accuracy and stability of the plate manufacturing process, as well as integrate automated quality control into CtP and IIoT monitoring systems, ensuring the efficient implementation of the smart manufacturing principles in the printing process. The use of the model contributes to increasing the prediction accuracy, optimizing the technological process and making informed decisions regarding control and adjustment of production parameters.

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# МОДЕЛЬ ПРОГНОЗУВАННЯ ЯКОСТІ ПРОЦЕСУ ВИРОБНИЦТВА ФЛЕКСОГРАФІЧНИХ ДРУКАРСЬКИХ ФОРМ

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*Забезпечення високої якості флексографічних друкарських форм є критично важливим для ефективного та стабільного відтворення зображень і текстів у високошвидкісному друку. Сучасні вимоги до точності форм, їх фізико-механічних властивостей, геометрії рельєфу та сумісності з різними матеріалами роблять необхідним впровадження інтелектуальних інформаційних систем, здатних прогнозувати результат ще на етапі підготовки виробництва. Запропонована модель ґрунтується на інтеграції фізико-механічних, оптично-растрових та геометричних параметрів форми у єдиний інтегральний показник якості, що дозволяє* *кількісно оцінювати стан форми та визначати її придатність до стабільного тиражування. Для перевірки адекватності моделі проведено моделювання двох типових ситуацій: еталонної форми, усі параметри якої знаходяться в межах технологічних норм, та дефектної форми з відхиленнями ключових параметрів. Результати демонструють, що запропонована нечітко-мультикритеріальна модель ефективно відрізняє еталонні та дефектні форми, забезпечуючи точну оцінку якості та прогнозування можливих відхилень. Такий підхід дозволяє знизити виробничі ризики, оптимізувати технологічний процес виготовлення форм та інтегрувати принципи розумного виробництва у поліграфічну галузь, забезпечуючи автоматизований контроль якості у системах Computer-to-Plate (CtP) та IIoT-моніторингу.*

***Ключові слова:*** *флексографічна друкарська форма, якість процесу, модель, нечіткий мультикритеральний аналіз.*

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