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ANALYSIS OF DIGITAL TECHNOLOGIES IN PLATE-MAKING PROCESSES OF GRAVURE PRINTING

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Abstract. *The evolution of gravure printing plate manufacturing methods is examined, from traditional electromechanical techniques to high-precision laser technologies of direct laser engraving. A study was conducted on the influence of halftone cell parameters on the ink-carrying capacity of printing plates manufactured by laser engraving.*

Keywords: *digital technologies, plate-making processes, gravure printing forms, gravure printing, laser engraving, quality indicators.*

Introduction

The modern development of the printing industry is characterized by the intensive implementation of digital technologies that significantly transform traditional production processes. These changes are particularly noticeable in the plate-making processes of gravure printing, which remains one of the leading methods for producing high-quality products in large print runs, especially in the packaging industry, the production of security documents, and decorative materials. High requirements for image reproduction quality, printing process stability, and economic efficiency necessitate the improvement of printing plate manufacturing technologies.

Traditional methods of gravure plate preparation, based on electromechanical engraving or chemical etching, have a number of limitations related to the accuracy of reproducing fine details, the complexity of controlling halftone cell parameters, and a significant dependence on the human factor. In this regard, digital technologies, in particular laser engraving, automated control systems, and digital image processing, open new opportunities for improving the quality and efficiency of plate-making processes.

The relevance of this study is determined by the need for a systematic analysis of modern digital solutions in the field of gravure plate manufacturing, assessment of their impact on the qualitative and technological indicators of the process, as well as identification of prospects for further industry development. Despite the considerable number of scientific works devoted to certain aspects of the digitalization of printing production, the issue of the comprehensive impact of digital technologies on the plate-making processes of gravure printing requires further research.

Research Aim and Objectives

The aim of the study is a comprehensive analysis of modern digital technologies used in the plate-making processes of gravure printing, with the determination of their impact on the quality of printing plate production, the stability of the printing process, and the efficiency of printing production.

To achieve this aim, the following objectives must be accomplished:

– to analyze the current state and development trends of plate-making processes in gravure printing;

– to characterize the operating principles and technological capabilities of digital systems, in particular laser engraving and automated process control;

– to assess the impact of digital technologies on the parameters of halftone cell formation (ink-carrying capacity);

– to determine the advantages and limitations of implementing digital technologies in gravure plate-making processes.

The formulated aim and objectives define the logic of the research and are aimed at a comprehensive disclosure of the specific features of applying digital technologies in the plate-making processes of gravure printing.

Main Part

Implementation of Digital Technologies in Gravure Plate-Making Processes

Pixel-by-pixel image recording on a gravure printing cylinder can be performed by three methods: electromechanical, electro-optical (laser), and electron-beam techniques. The technology of gravure plate production by removing material from the printing elements through electromechanical engraving became widespread in 1964 after the German company Hell developed the electronic opto-mechanical device known as the helioklischograph. Electromechanical engraving (EME) is characterized by a reduced number of process stages, operational stability, high productivity, lower material consumption, and improved working conditions. At the same time, it requires expensive and sophisticated equipment, high precision, accurate cylinder geometry, and an improved quality of the copper coating. Since 1977, models of electromechanical engraving systems have been produced, differing in the number of simultaneously operating engraving heads, the number of cylinders processed at the same time, engraving speed, scanning parameters, screen ruling capabilities, and other technical characteristics [1-5].

The increase in computer performance and their widespread adoption in the 1980s made it possible to fully realize the advantages of electromechanical engraving. Beginning in 1985, digital electronic engraving devices controlled directly by computer signals were introduced. This contributed to the development of computer-to-plate (CtP) technologies. The operating speed of the first helioklischographs reached 3,500 cells per second. Later, the standard speed for a long period was considered to be 4,000 cells per second (4 kHz). In 1998, systems with an engraving frequency of 8 kHz were introduced, followed later by 10 kHz systems developed by Hell.

In the first installation created in 1977 by Crosfield, engraving with a CO_2 laser was carried out on a layer of epoxy resin applied to a printing cylinder with pre-etched cells of identical depth. After printing, the epoxy resin was removed from the cylinder cells, allowing the cylinder to be reused multiple times. Along with high production speed, these forms demonstrated high run durability of up to 3 million impressions [6].

In 1995, MAN Roland Druckmaschinen AG developed a process for obtaining gravure forms by direct laser engraving inside the printing press itself – the computer-to-press (CtPress) technology. The engraved cells of a ceramic or steel cylinder are filled with polymer, after which the cylinder is installed in the printing machine. A laser evaporates the polymer and forms the printing elements directly on the cylinder surface.

At the beginning of the 1990s, the so-called indirect laser engraving method was implemented by Spectron Schepers-Ohio. This method was based on a combination of laser imaging and chemical etching processes. Laser exposure was carried out on a light-sensitive or thermal-sensitive layer to obtain a mask resistant to the etching solution. In 1995, the Digital system was introduced, based on digital laser exposure of gravure cylinders. Laser imaging was performed on a cylinder coated with a special polymer layer, followed by chemical etching. An important advantage of this technology was the possibility of using the same copper-plated cylinders as in electromechanical engraving. Its limitation was the inability to produce cells of variable depth. In the same year, MDC Max Daetwyler presented the automatic engraving system LaserStar, designed for direct laser engraving of a zinc layer applied to a printing cylinder.

Alongside these technologies, further developments continued in the field of direct laser engraving of copper-plated gravure cylinders. In 1998, Hell introduced a process for laser engraving electrolytic copper alloy cylinders [6]. The first photopolymer gravure plate, Nylograv, intended to replace copper-coated cylinders, was launched in 1985 by BASF.

Laser Technologies for Gravure Plate Manufacturing

Modern CtP Systems and Materials for Printing Plate Production

Ukrainian printing enterprises operate under new market conditions; as a result, print runs are decreasing, product quality requirements are increasing, and the number of printing colors is expanding. New concepts such as print-on-demand and personalized printing have emerged [7-9].

The possibility of processing textual and illustrative materials in digital form has led to the development of several new technological directions in printing plate production, particularly the computer-to-plate (CtP) technology. The essence of this technology lies in recording the image directly onto the printing plate, bypassing the stage of producing and assembling screened film positives, which significantly simplifies and reduces the cost of the technological cycle. The purpose of developing and implementing new technologies is to shorten the production cycle, reduce labor intensity, and save costs related to equipment and consumable materials [7–9, 11].

The operating principle of a CtP device differs little from that of conventional imagesetters: a laser beam forms the image on the printing plate fixed on the inner or outer side of a drum [6]. CtP technologies used in various sectors of the printing industry, including newspapers, books, packaging products, magazines, and catalogs, make it possible to widely implement digital production systems.

The application of CtP technology has a number of advantages [6, 7]:

– reduction of the production cycle due to the elimination of film exposure, film processing, and intermediate plate-making stages;

– generation of additional profit through increased efficiency and reduced overall production costs. For short print runs, direct plate exposure, despite somewhat higher plate costs, may be more economical than traditional methods, primarily because there is no need to produce film positives. CtP also eliminates the need for certain equipment such as contact frames and film assembly systems. Production space requirements and energy consumption are reduced;

– reduction of prepress preparation time;

– decrease in the number of personnel required in prepress operations;

– lower prepress costs due to the absence of films and processing chemicals;

– reduction of waste sheets and, consequently, savings in ink, washing solutions, and related materials;

– CtP is a more accurate process. Each plate is the first original “copy” produced from the same digital data set. As a result, sharper halftone dots, more precise registration, more accurate reproduction of the full tonal range, and lower dot gain are achieved, while simultaneously accelerating make-ready and press setup operations;

– elimination of mounting errors. Since film assembly is absent in direct plate exposure, problems associated with inaccurate or faulty film mounting are removed;

– the technology is environmentally friendly due to the absence of film-processing chemicals;

– along with improved print quality, the technological cycle time is reduced, and the system allows publications to remain open until the last moment for placement of advertising materials.

At the same time, CtP systems also have certain disadvantages:

– relatively high cost of the systems, requiring substantial investment;

– difficulties with producing large-format proof prints;

– increased qualification requirements for the operator;

– use of expensive specialized plates and consumable materials.

Main Types of Lasers Used in CtP Systems

All plates used in CtP systems, with the exception of inkjet technology or electrophotography, are sensitive to a specific spectral region and to the wavelength of a particular laser source. Therefore, the following types of lasers are currently used in CtP systems [6, 7, 10]:

– Argon-ion (Argon) – blue visible laser with a wavelength of 488 nm;

– Helium-neon (He-Ne) – visible laser with wavelength of 633 nm;

– Carbon dioxide (CO_2) – gas infrared laser with a wavelength of 10,600 nm;

– Red Laser Diode (RLD) – low-power red visible laser with a wavelength of 670 nm;

– High-Power Laser Diode (HPLD) – infrared laser with a wavelength of 830 nm used for thermal exposure;

– Nd:YAG – high-power infrared laser for thermal exposure with a wavelength of 1064 nm;

– Frequency-doubled Nd:YAG – green visible laser with a wavelength of 532 nm.

In most CtP systems, argon-ion and helium-neon gas lasers, as well as low-power red and infrared diode lasers, are commonly used. However, thermal-sensitive plates are becoming increasingly widespread, requiring higher-energy imaging devices. Therefore, sufficiently powerful infrared laser diodes are used for imaging such plates. Radiation sources in external drum systems are infrared lasers with emission wavelengths around 1100 nm. Some types of thermal-sensitive plates also require the use of argon-ion lasers.

Nd:YAG lasers with radiation wavelengths of 1064 nm and 532 nm are also used in plate-making production. These are solid-state lasers based on neodymium-doped yttrium aluminum garnet, widely used in industrial applications, with power outputs ranging from several milliwatts to several hundred watts. By using nonlinear optical elements, radiation with doubled frequency and a wavelength of 532 nm can be obtained. Such lasers have increased power levels and are employed in CtP devices manufactured by a number of companies [6, 7, 10].

Laser radiation sources also differ in service life. The operating lifetime of an argon laser is approximately 6-9 months, Nd:YAG lasers 9-15 months, red laser diodes 12-24 months, and high-power laser diodes 24-36 months.

Study of the Influence of Halftone Image Parameters on the Cell Volume of Gravure Printing Plates

To develop new compositions for manufacturing gravure printing plates intended for product marking, testing of the main classes of polymer materials was carried out. The research was conducted taking into account the following parameters: compatibility and the possibility of introducing carbon black into the polymer composition (up to 10%); the possibility of high-quality coating of the composition onto a polymer base; absence, after curing, of cracks, cavities, irregularities, flow marks, and other mechanical defects on the polymer surface; suitability of the polymer material for mechanical processing (grinding and polishing); sensitivity to laser radiation with a wavelength of 1.06 μm; the possibility of obtaining high reproductive-graphic and printing-technical characteristics; resistance to gravure ink solvents (alcohol, toluene, gasoline); high physical and mechanical properties (print run durability); optimal deformation properties promoting gradual wear of the plate rather than chipping or fracture; resistance to thermomechanical degradation; and the presence of a positive gradient of the main mechanical properties determining wear resistance.

Based on the working hypothesis and the conducted analysis, a material was developed for the production of gravure printing plates by direct laser engraving. The composition included: bis/4-(1-hydroxyethyl)phenyl/ether methacrylic acid system; a mixture of oligoester acrylate and oligoethylene glycol maleinate in a ratio of 3:2; epoxy resin ED-20; maleic anhydride; butadiene-nitrile rubber; benzoyl peroxide; dicumyl peroxide; carbon black; phenol-formaldehyde resin; and polystyrene.

The function of the screen ruling in gravure printing differs fundamentally from its purpose in letterpress or offset printing. In gravure printing, the screen creates a grid on the printing plate that serves as a support for the doctor blade. In addition, the support lines formed by the screen create isolated cells separated from one another, which are filled with ink and prevent its spreading. Practice shows that square screen patterns provide the best results for preserving the system of screen lines, which is an important condition for the operational durability of printing plates.

The direction of cell arrangement on the surface of the screened image relative to the generatrix of the gravure form determines the screen angle. From the viewpoint of the doctor blade's mechanical operation, it is more advisable to position the screen lines not parallel to its edges, but at an angle (45° and 60°); in our studies, an angle of 45° was used (Fig. 1). With regard to filling the cells with ink, these angles offer advantages because the cells are gradually filled through their side walls. Such an arrangement of screen lines, and accordingly of doctor blade supports on the printing plate, ensures a more stable printing process. Otherwise, the plate wears rapidly and defects are formed.

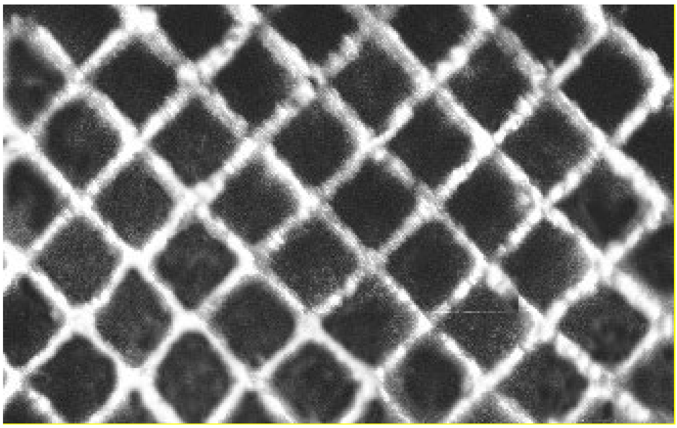

Figure 1 – Diagram of halftone elements manufactured using an Nd:YAG laser, λ = 1.06 μm (near-infrared range)

Since plate engraving is carried out using a laser, this provides the possibility, unlike traditional methods of gravure plate production, to define in the image preparation software the screen ruling, halftone cell pitch, and screen angle, as well as the parameters of the screened image cells (cell depth, inclination angle of the side walls, and the ratio between cells and bridges), which influence their volume and the ink-carrying capacity of the plate.

All parameters of engraving the image elements affect the cell volume and, accordingly, the amount of ink used for printing the product. Therefore, an important characteristic of gravure printing plates is their ink-carrying capacity, which is determined by the volume of ink per unit area of the plate and is measured in cm³/m².

This indicator characterizes the amount of ink transferred from the printing plate to the substrate. It depends on the volume of a single cell and the number of cells per unit area of the plate. These characteristics, in turn, depend on the screen ruling, cell depth, inclination angle of the side walls, and the ratio between cells and bridges.

Depending on the nature of the image and the intended purpose of the printing plate, screens with different rulings are used. For product marking, screens with a ruling of 40-50 lines/cm are applied; for standard magazine production, 60-70 lines/cm; and for high-quality editions, 70 lines/cm and higher.

The screen ruling determines the screen pitch (40 lines/cm – 250 μm, 50 lines/cm – 200 μm, 60 lines/cm – 167 μm, 70 lines/cm – 143 μm, 80 lines/cm – 125 μm, 100 lines/cm – 100 μm). As the screen ruling increases, the screen pitch decreases. With an increase in screen ruling and the same ratio between bridges and cells, the size of the halftone cell and its volume decrease.

Table 1 presents the cell volume and, accordingly, the ink-carrying capacity of the plate for a depth of 30 μm at a cell-to-bridge ratio of 1:2 for Materials 1 and 2.

Table 1 – Cell Volume Values of Polymer Printing Plates for Materials 1 and 2

Screen Ruling, lines/cm	Cell Volume, cm^3		Ink-Carrying Capacity, cm^3/m^2	
	Material 1	Material 2	Material 1	Material 2
40	$8,14\times10^{-7}$	$7,94\times10^{-7}$	13,02	12,70
50	$5,05\times10^{-7}$	$4,89\times10^{-7}$	12,63	12,23
60	$3,84\times10^{-7}$	$3,35\times10^{-7}$	12,49	12,02
70	$2,53\times10^{-7}$	$2,41\times10^{-7}$	12,35	11,80
80	$1,91\times10^{-7}$	$1,81\times10^{-7}$	12,22	11,59
100	$1,22\times10^{-7}$	$1,14\times10^{-7}$	12,21	11,43

The depth of the halftone image cells largely determines their volume and is therefore a very important parameter. At an engraving depth of 60 μm, difficulties in ink transfer may arise due to the capillary effect. If the engraving depth is insufficient, the amount of ink transferred to the printed substrate decreases. In laser engraving of polymer gravure printing plates, an engraving depth of up to 60 μm can be achieved depending on the nature of the image.

An increase in engraving depth, while all other parameters remain unchanged, linearly increases the cell volume and the ink-carrying capacity of the plate (table 2).

Table 2 – Values of Cell Volume and Ink-Carrying Capacity of Printing Plates for Materials 1 and 2

Лініатура растра, лін/см (1:2)	Діапазон зміни глиб. ком., мкм	Cell Volume, cm^3		Ink-Carrying Capacity, cm^3/m^2	
		Material 1	Material 2	Material 1	Material 2
40	5 ÷ 60	1,41÷15,27	2,24÷24,43	1,39÷14,68	2,28÷23,49
50	5 ÷ 60	0,88÷9,31	2,26÷23,277	0,87÷8,85	2,19÷22,13
60	5 ÷ 60	0,62÷6,320	2,21÷21,30	0,61÷5,94	2,16÷21,31
70	5 ÷ 60	0,45÷4,50	2,28÷22,02	0,44÷4,19	2,15÷20,49
80	5 ÷ 60	0,36÷3,35	2,21÷21,41	0,35÷3,08	2,14÷19,70
100	5 ÷ 60	0,26÷2,07	2,2÷20,7	0,27÷1,86	2,13÷18,64

The ratio between cells and bridges is an important parameter that influences cell volume, print quality, and the mechanical durability of the plate. The bridge width affects the ability of the engraved surface to transfer ink. If the bridge width is large, during printing the ink droplets must move across a bridge area that contains no ink. As a result, image non-uniformity occurs, and the screen structure may become visible.

The area occupied by the screen lines is, in fact, an area that absorbs a certain part of the image itself. Accordingly, the wider the bridge of the halftone cell, the larger the portion of the reproduced image that disappears, and therefore the printed image is reproduced with certain losses. However, these losses are almost invisible without special instruments. This occurs because the screen lines are extremely narrow (at cell-to-bridge ratios greater than 1:2), making them imperceptible to the naked eye. In addition, the gaps caused by the screen lines are compensated on the print by the printing ink itself.

The relatively low-viscosity gravure ink, when transferred from the plate to the substrate, partially spreads over the surface and thus covers the screen lines. As a result, in deep shadow areas of the image, where ink is concentrated in large quantities, the screen lines cannot be observed on the print even under magnification. Only in areas where the amount of ink is small (midtones and highlights) can the gaps caused by the screen lines be seen through a magnifier. Moreover, these screen lines are not sharp and regular because of the spreading of ink from adjacent cells across the substrate surface.

Considering image losses caused by screen lines, when selecting the screen ruling and the ratio between cells and bridges, image quality requirements must be taken into account. For example, lower-quality illustrations may be printed using screens with fewer lines, whereas higher-quality artistic reproductions require screens with a greater number of lines. Thus, it can be concluded that the minimum width of the screen line is optimal for carrying out the printing process.

However, the screen line carries a mechanical load. To provide it with the required mechanical strength, it is necessary to ensure the minimum possible bridge width. Therefore, screens with different ratios of transparent to non-transparent elements are used within the range from 1:1 to 1:9. Screen lines are least noticeable on prints when screens with a ratio of 1:5 are used, but such screens can only be applied on low-speed printing presses. For rotary sheet-fed presses, screens with ratios of 1:4 and 1:3.5 are used. For rotary web presses, a ratio of 1:3 is commonly applied. As printing speed increases, wider screen lines must be created on the plate in order to improve run durability. Therefore, studies were conducted on plates with cell-to-bridge ratios of 1:2, 1:3, 1:4, 1:5, and 1:6.

Calculations for a square screen indicate that with different screen rulings but the same ratio between bridges and cells, the area occupied by the cells, expressed as a percentage, remains constant, while the cell volume depends only on the cell depth and the inclination angle of the cell walls. At the same screen ruling, reducing the ratio between bridges and cells decreases the size of the halftone cell. This makes it possible to calculate the cell volume and the ink-carrying capacity of the plate depending on the bridge-to-cell ratio, taking into account the cell depth and the inclination angle of the side wall for Materials 1 and 2 (Figs. 5.2, 5.3, 5.4, 5.5).

For example, the cell volume at a cell depth of 40 μm and a screen ruling of 40 lines/cm for Material 1, with a cell-to-bridge ratio ranging from 1:2 to 1:6, lies within the range from 10.63×10^{-7} cm³ to 17.97×10^{-7} cm³ (ink-carrying capacity from 17 to 28.76 cm³/m²). For Material 2, the corresponding values range from 10.3×10^{-7} cm³ to 17.57×10^{-7} cm³ (ink-carrying capacity from 16.5 to 28.1 cm³/m²). Thus, by changing the ratio between cells and bridges, it is possible to obtain cells of the required volume and, accordingly, the necessary amount of ink on the plate and on the print.

For optimal ink transfer and release of ink from the cell to the printed substrate, steeper side walls are preferable, corresponding to the maximum inclination angle of the cell side faces. The inclination angle of the halftone cell depends on the engraving mode.

Experimental studies of the engraving process for Materials 1 and 2 established that the maximum inclination angle of the side faces is 80° for Material 1 and 78° for Material 2. At these inclination values, the cells of Materials 1 and 2 have the shape of a truncated pyramid. Changes in the inclination angle of the cell side faces affect both the cell volume and the ink-carrying capacity of the plate.

For example, for a cell depth of 40 μm, a screen ruling of 40 lines/cm, and a cell-to-bridge ratio of 1:2, the cell volume for Material 1 changes within the side-wall angle range from 27° to 80°, from 4.35×10^{-7} cm³ to 10.63×10^{-7} cm³ (ink-carrying capacity from 6.96 to 17 cm³/m²). For Material 2, within the side-wall angle range from 25° to 78°, the cell volume changes from 3.75×10^{-7} cm³ to 10.3×10^{-7} cm³ (ink-carrying capacity from 6 to 16.5 cm³/m²).

Thus, by changing the angle of the side walls while maintaining the same screen ruling and engraving depth, it is possible to purposefully vary the cell volume.

Conclusions

As a result of the conducted analysis, it has been established that digital technologies play a key role in the modernization of gravure plate-making processes. Their implementation ensures a significant increase in image reproduction accuracy, stability of printing plate quality, and overall production efficiency.

It has been proven that the application of computerized data preparation systems, automated engraving, and digital parameter control makes it possible to reduce the number of technological operations, minimize the influence of the human factor, and decrease the consumption of time and resources.

For the production of gravure printing plates by laser engraving using infrared solid-state Nd:YAG lasers ($\lambda = 1.064$ μm), carbon-black-filled polymer materials based on rolivsan compositions were developed.

The possibility of influencing cell volume and the ink-carrying capacity of the plate by changing the characteristics of halftone image cells has been demonstrated. Such characteristics include screen pitch, the ratio between cells and bridges, cell depth, bottom width, and the angle of the side walls, which makes it possible to obtain high-quality marking results.

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