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MODELING OF WEB OFFSET PRINTING PROCESSES

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The relevance of the work is contained in the automation of the printing process management, which allows achieving an increase in printing speeds. This problem is especially relevant for web offset printing, which expresses the most progressive trends in the development of printing equipment and technology. The aim of the article is to determine the mechanism of forming a structural-mathematical model of control objects related to the movement of the paper tape of the offset printing process. In web offset printing presses, the synchronous drive of the paper feeding cylinders is provided by continuous gear transmission. Due to the mechanical flexibility of the transmission, the system is prone to torsional oscillations, which are excited by many phenomena. Fluctuations in gear transmission affect the printing quality. The excitation frequencies or orders on the printing press lead to errors with the corresponding orders on the printed sheets. Using a mechanical model of a printing press, it is possible to simulate the effect of excitation on the system and thus make a prediction of the change in the actuation using the sheet tracking algorithm. By compensating the excitation (feedback control), the torsional vibrations of the machine can be suppressed and, thus, the printing quality can be ensured. This is shown both from simulations and taking into account measured data. In this way, the impact of mechanical or control-related changes in the design of the printing press can be predicted, ultimately saving time and money in machine development and production.

Keywords*: printing, offset, optimization, circulation, quality, automation, technological process.*

Introduction. The statement of the problem stems from the modern need for comprehensive automation of the printing process. Still, its solution is based on previous scientific works on the study of physical and chemical phenomena in printing processes, on the study of the dynamics of individual devices of rotary web printing machines, on the development of automatic control methods and automation techniques for the printing process.

The analysis of the most common printing methods currently used shows that the offset flatbed printing method has been developing at the highest rate over the past 10-15 years compared to other printing methods. This is due to the technical and economic advantages of the method and its better visual capabilities. This type of printing can now reproduce almost any original with high-quality printing. In the next 10 years, the domestic printing industry is expected to significantly increase the share of offset printing for book, magazine and newspaper products.

A web press is a multi-axis system that supports, transports, and manages elastic material through a continuous flexible strip called a “web”, such as plastic, film, tape, foil, etc. Roll-to-roll printing machines are widely used for film processing, newspaper printing, wallpaper printing, etc., enabling mass production at high speed and low cost.

Printing quality is ensured by controlling variables such as web transport speed, web tension, web density, etc. The required spatial positioning of the paper web is achieved by precise angular synchronization of the print cylinders. The accurate angular synchronization, i.e., the control of the drive, depends on the transportation conditions, web tension, web material properties, and machine installation features, such as web speed, roller size, and span length between rollers. Drive control uses web tension and web speed control to reduce drive errors.

The traditional analogue drive control approach cannot perform satisfactorily [1-3]. Since higher printing speeds and higher printing accuracy are required in modern printing plants, a new control method must be developed to solve communication problems, time delay, and nonlinear problems [4]. Many studies have been conducted to build dynamic mathematical models of the printing web passing through the sections of printing machines.

Whitworth and Harrison proposed a dynamic model for predicting changes in span tension, which formed the basis for almost all subsequent work on span tension dynamics [5]. Lynch et al. developed an online nonlinear tension monitor for web machines [6]. Some web tension monitoring methods were proposed by Fletcher [7], Lee, Kang, and Shin [8], and Kang, Lee, Shin, and Kim [9]. Pagilla et al. proposed a dynamic model for paper web production lines and developed a decentralised feedback controller to control web speed and tension [10]. This improved the efficiency of web tension control compared to the existing decentralised proportional-integral strategy. In the unwinding process, it was proposed to use the method of dynamic tension compensation [11]. Considering the existence of imperfect rollers, a web tension and speed control algorithm was suggested by Branca, Pagilla, and Reid [12], which could predict periodic fluctuations in web tension and speed and help control the system dynamics. Moreover, a mechanical model was built for the plastic film system and a model-based transverse directional controller was proposed to improve the system’s dynamic and static performance [13].

Kok et al. applied a robust control and linear parameter variation (LPV) strategy to control the tension and velocity of elastic materials [14]. Abjadi proposed a sliding mode feedback linearization method for a multi-motor web unwinding system and a robust nonlinear tracking controller [15]. Benlatres introduced multiparameter controllers with one or two degrees of freedom (DOF) to improve tracking performance and interference protection [16]. However, register control is not directly studied in these works.

For multi-axis printed systems, it is necessary to develop a longitudinal feedback control strategy to reduce the actuation error with high accuracy [17]. Pagilla and Knittel presented an overview of longitudinal control technology [18]. To avoid complicated mathematical equations, Xin and Hoang used a position and image sensor to measure the longitudinal displacement and implemented fuzzy logic for feedback longitudinal control [18].

In recent years, more and more paper web guiding systems have been driven by electric linear shafts instead of traditional mechanical shafts. In hybrid web printing systems that combine gravure and inkjet printing, mathematical modelling of the drive was obtained in Kang and Baumann [17]. Mathematical models of the machine-directed (MD) register and cross-direction register and control methods were proposed in Kang, Lee, and Shin,. [18].

In parallel with the growing role of management, automation of the printer's functions in the printing process control operations is developing rapidly. This problem is especially relevant for web offset printing, which expresses the most progressive trends in developing printing equipment and technology.

Materials and methods. In solving the tasks, we used methods of frequency analysis, the apparatus of the theory of ordinary differential equations, operational calculus, and numerical methods of analysing the dynamics of continuous and discrete systems using modern computer mathematics packages (MatCAD, Simulink, Maple). The dynamic and frequency analysis of automated belt tension control systems was performed using an ideal role. For this purpose, the equations of a stationary printed web were used based on the method of frozen transfer functions.

Results and discussion. The physical and mathematical foundations of the movement of tensioned tape material have been considered in several studies related to both the tape conveying systems of roll-to-roll rotary printing machines and other technical devices. The results of these studies can be used to some extent for mathematical modelling of the belt system.

When studying the interaction between a belt and a conductor, two issues are considered: the conditions for contact transmission of traction force from the leading conductor to the belt and the effect of a tensioned belt on the driven conductor, considering its dynamics. Papers [7-12] show that the transmission of tractive force from the conductor to the tape is carried out through the friction force arising in two prominent cases: when pressure is applied in the contact zone of a pair of conducting cylinders and when the radial component of the tension force is applied when a tape covers the shaft. A specific arc of contact between the tape and the conductor is required (Fig. 1).

In the absence of slippage, there is a resting arc on the side of the running branch in which the belt speed is equal to the rate of the conductor. In the remaining part of the contact arc, the ribbon speed gradually increases to the point of its convergence; at the same time, the deformation of the ribbon and its tension increase. In [6], the general case of rotational and translational motion of a driven conductor under the influence of a moving tensioned tape and experiencing resistance created by dry and viscous friction forces was studied in detail. From this general case, with appropriate assumptions, we can move on to the special cases of the movement of the guide and floating rollers of the belt system.

The roll from which the belt is unwound can also be considered as a special case of a belt guide, taking into account some features:

1) the roll is the outermost element of the belt system;

2) during the unwinding process, both driving and braking torques can be applied to the roll, as well as a disturbing moment due to the imperfect shape of the roll;

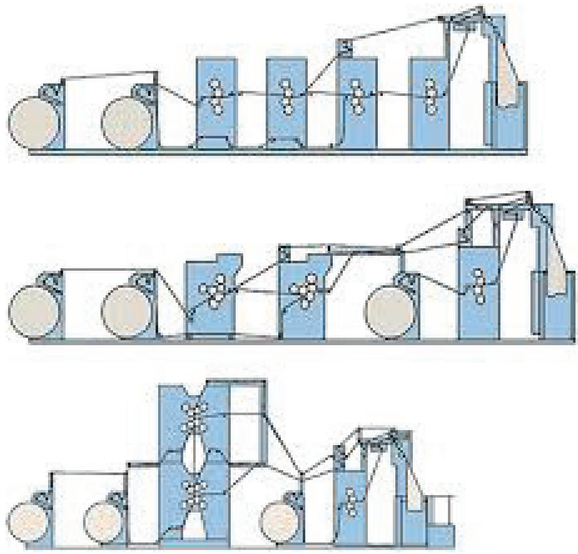

Fig. 1. Conductor belt system for offset printing

3) The bale's radius and moment of inertia change significantly during the unwinding process.

The latter circumstance gives grounds to apply the theory of motion of bodies of variable mass by I.V. Meshchersky to the study of the roll dynamics. Meshchersky. An important feature of the physical and mechanical process occurring in a tape conveying system is the deformation of the paper tape as it moves through the driving and driven elements.

There is information about similar studies in other fields of technology and abroad [15]. A number of papers [1, 4, 5] derived the equation of the section of the moving paper tape in a roll rotary printing machine, taking into account the effect of typical operational disturbances (change in inlet tension, rearrangement of the register roller, change in phase and speed of the working cylinder); the connection between successive sections of the belt conveying system was studied, and the influence of driven guide rollers on the deformation processes was shown.

The papers [9, 12] generally consider paper as an elastic-plastic medium. The inelastic Poynting-Thomson model and other models are used to describe the behaviour of the paper web mathematically. However, it is necessary to expressly agree on the conditions for the manifestation of rheological properties in a moving paper belt:

– the deformation of the ribbon is determined by the conditions of its replacement (origin - consumption); if these conditions are unchanged, the ribbon may show relaxation, but not the aftereffect - creep;
– the relaxation phenomena do not have time to manifest themselves in any noticeable way due to the short period the ribbon is in the printing machine; therefore, the ribbon section should be considered as an elastic body (with the introduction of a correction dynamic coefficient).

The mathematical description of a roll under the influence of periodic forces and a floating roller (shock absorber) designed to smooth out oscillations is the basis for the design of a tape feeder. The main character of the oscillatory processes occurring in the belt feeder is determined by the roll-tape system, which is characterized by its oscillation frequency and a rather low degree of damping. Oscillations may occur in this system even in the case of an ideal roll shape.

The development of automatic control methods for the printing process was mainly based on the automation of local operations and facilities, and only recently has there been a turn towards the creation of integrated automated control systems. Microprocessor technology should become the hardware basis for these systems. Issues related to developing a general strategy and structure for managing the printing process have not been studied. The principle of optimal management is the scientific basis for developing this coinage strategy.

The belt system of a printing press is understood to be a system formed by a belt and conductors that come into contact or interaction with it. A tape of continuous material (paper, film, etc.) can be divided into separate sections limited by conductors in contact with the tape. A conductor in the general case is a body (roller or cylinder) in contact with the tape that rotates and moves in some way. Private tape conductors are rolls of material (feed and take-up), floating, guide and register rollers, tape carrier pairs, including printed ones. A specific feature of the printing machine's SPP is the concurrent processing of the ribbon in successive printing, folding, cutting and other sections. Therefore, the quality of the operations performed on the ribbon - impressions, folds and cuts - is the most essential characteristic of the SPP, and the stability of the state parameters - tension, longitudinal and transverse coordinates of movement, and speed - significantly affects the quality of processing.

For mathematical modelling of the SPP, it is necessary, firstly, to identify its structure. Fig. 2 shows the structural diagram of a typical SPP, divided into three sections: a tape feeder, a device for guiding the tape through printed sections, and a tape ejector.

It is equipped with a sheet receiving device PU (Fig. 2, c), which contains a real RU device, a cylinder, a set of rollers and tape conveyors that form an overlap of cut sheets and place them in the stack. The sheet receiving devices are aggregated with other machine modules according to the diagram to the right of the folding and cutting machine; the arrow and dotted line show the direction of the belt movement when producing sheet products.

To perform the full range of technological operations, the belt must be tensioned while moving in the machine. In addition, to expand the technological capabilities of the machine, and the tension must be constant. The simplest belt tension regulator is also shown in Fig. 2.

As mentioned above, to be able to control the belt in its movement and perform the entire range of technological operations, it must be tensioned. At the same time, the tape deformation values must be maintained within certain limits, which are determined by the specified quality parameters of printed products. One of the most important quality parameters is the accuracy of ink mixing on the print, or ink drive.

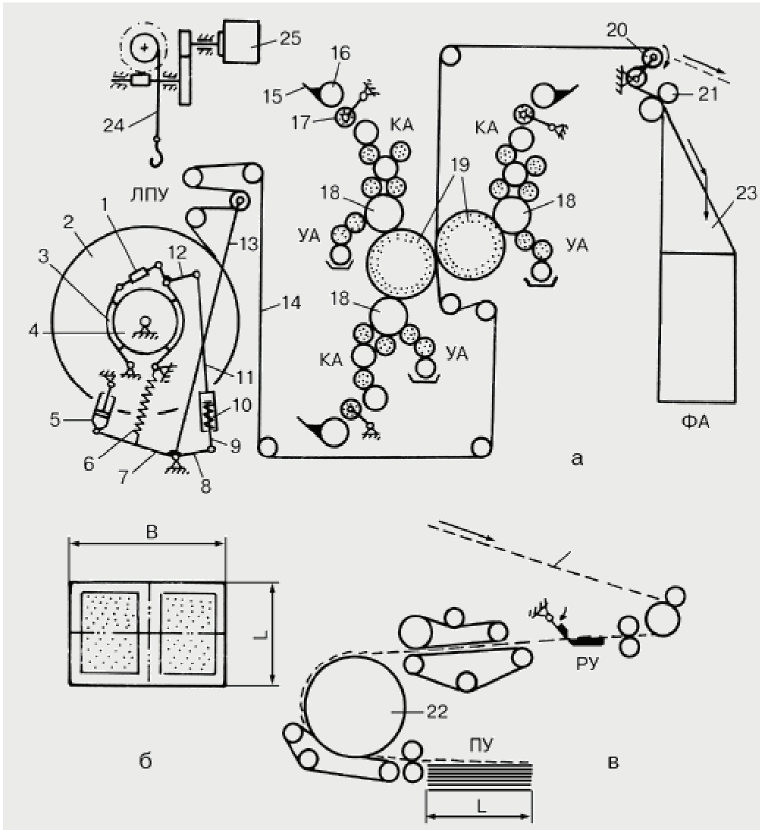

Fig. 2. Block diagram of a belt conveyor system

It is most strongly influenced by the ribbon feeder and drive of the printing presses, deviations in cylinder diameters and tire thickness from the nominal values, as well as deviations in the operating modes of the ink and wetting units. In gravure printing machines, the dryer is a decisive disturbing factor. Variations of the ribbon thickness and its elastic modulus from the nominal values also affect the ink drive. Of course, the inaccuracy of the mould manufacturing and its installation on the cylinders also negatively contribute to the total ink misalignment. Thus, ink misalignment in sectional roll-to-roll machines results from inaccurate manufacturing and operation of machine mechanisms, deviations of printed materials and process parameters from nominal values. This leads to variable deformations of the ribbon as it moves from one printing section to another and the corresponding ink failure.

To facilitate the understanding of the nature of this relationship, let's consider a separate machine with marks M (0, 1, 2, ..., Fig. 3) on the mold cylinder. Suppose that there is a rigid axis Ot, which moves the cylinders without slipping when they rotate. The Ot axis itself is also marked with the corresponding M labels, i.e., labels 0, 1, 2, 3, ... Since the Ot axis is non-deformable, when the initial marks O on the axis and on the cylinder are combined, in the future, when the cylinders rotate, the corresponding marks of the molding cylinder and the rigid axis in the contact zone will always coincide exactly. Now let's take an unmentioned tape L, apply the same marks M' on it, corresponding to the marks M on the cylinder and the rigid axis, and align the starting points O.

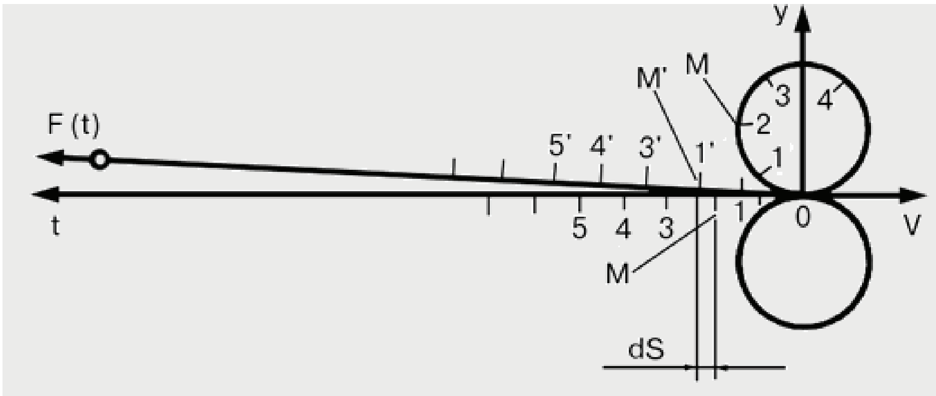

Fig. 3. Scheme of the printing machine

Having mentally prepared such a system, let's set the cylinders in motion with a constant speed vp and simultaneously change the tension of the ribbon according to a certain law F(t), where t is the current time. In this case, the belt will be deformed. Let us denote by εt the value of the current relative deformation of the belt just before entering the contact zone of the cylinders.

In this work, we calculated the changes in Fn(t), S2-1(t), M12(t) for the POG-9O rotary roll machine operating in two-colour printing mode.

Theoretical calculations were performed for four types of papers:

– Printing paper No. 2 (60 g/m2, E6 = 4763 MPa, δ = 0.085 mm).
– Book and magazine paper (60 g/m2, E6 = 6751 MPa, δ = 0.073 mm).
– Illustrative (80 g/m2, E6 = 7362 MPa, δ = 0.100 mm).
– Documentary (70 g/m2, = 7719 MPa, δ = 0.086 mm).

The change in belt tension during sudden acceleration is similar, but the maximum amplitude is about 1.5 N.

In the case of a sudden application of N to the system, the change in belt tension occurs according to the dependence. As shown by the numerical expansion of the constant coefficients included in the calculation formula, the values of C and E are equal to each other in absolute value (C = 6.08 *10-3, E = - 6.056 *10-3), so the first two terms in this formula make up an exponential dependence (1-e), which approaches unity at t -> ∞. In addition, the exponential law of change in belt tension is superimposed on the harmonic law with the vibration frequency v=y. At the amplitude of external action N = 20 H, the belt tension is set at a new level Fl = 10 N, since the equilibrium state in the "roll - shock absorber" system is determined by the equality 2Fl = N.

With a sudden change in the set point voltage in the circuit of the regulator U3, the change in belt tension is harmonic with the oscillation frequency y = y. The maximum amplitude of the change is 0.45 H.

Under harmonic external influences, the graphs of changes in belt tension are sinusoidal curves with non-decaying amplitudes and a frequency of oscillations equal to the frequency of external disturbances y =ω. The maximum amplitude of the change in belt tension is as follows: when N is acted upon, Fl max = 7.1 H, when a is changed, Fl max = 9 H, when U3 is changed, Fl max = 0.5 H.

It has been established that changes in the stiffness of the shafting and the type of paper used have little effect on changes in the amplitudes of belt tension. As can be seen from the obtained graphs, the largest amplitudes of changes in belt tension occur when the system is subjected to external actions of air pressure in the pneumatic system and acceleration.

When the acceleration is suddenly changed, the tension decreases by 2.5N and returns to the initial level over time. The short period in the study was very long, and various processes can occur in a real machine during this time. However, according to the assumptions made, we considered an ideal system, i.e., we did not consider friction forces. Yet, as a result of solving the characteristic equation, we obtained the torsional vibration damping coefficients. In a real machine, the damping coefficients are an order of magnitude greater than the ones obtained, and the transient time will also be shorter.

With a harmonic change in acceleration, the nature of the change in belt tension is similar to the harmonic action of N2. To identify the maximum amplitudes of the change in ribbon tension on the "roll - first printing machine" wiring section, total graphs were constructed and it was found that the maximum amplitude is about 15N. In the case of assigning the amplitude of external action, it is (11 - 67) N.

Similarly, variable belt tension between the printing machines will create moments from the resistance forces in the first and second printing machines M1 and M2. In this case, the electric motor will work out any changes in the technological load without straining its output shaft's constant speed. However, from the point of view of a real machine, this conclusion is untenable. The change in tape tension from perimeter resistance forces in the second printing machine can be written as presented in [3], since this work investigated the influence of the components that determine the magnitude and nature of the change in the external action Fl.

Let one try to answer the question: if the law εt of the change in the relative elongation of the ribbon immediately before entering the contact zone is known, how will the marks M' on the ribbon shift relative to the marks M on the t-axis at the moment when the marks M pass through the printing contact zone and coincide with the corresponding marks M on the mould cylinder. Thus, we will answer the question about the misalignment of the previously "printed" marks M' on the unstressed ribbon and the newly printed marks M from the cylinder under variable tension F (t).

The reduction, transformation of other coordinate systems consists in their parallel transfer. Now we know the displacement of each paint relative to the common base marks M' (which may not actually be printed beforehand, it is enough to imagine that they are printed).

In Fig. 4 shows graphs of the square of the modulus of the frequency response in a dimensionless form. They make it possible to find the ink dispersion that is not driven about the first ink by the spectral density of the relative elongation of the tape at the output of the tape feeder.

The quality of the tape feeder is assessed by comparing the calculated dispersion of ink drift with its factor permissible value DF. If Di < DF, it can be assumed that the tape feeder works normally. If Di> DF, then a thorough diagnosis of the device components is required to identify the cause of unacceptable deviations in the belt tension and eliminate it, or it needs to be modernized.

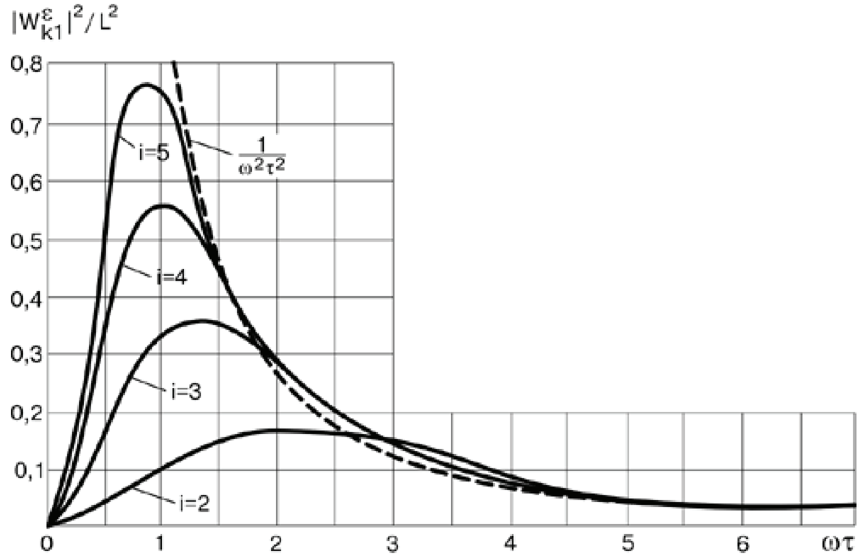

Fig. 4. Graphs of the square of the modulus of the normalized frequency characteristics of the disturbance channel - input relative tape elongation before the first printed section - non-drive between the i-th and the first ink. **Source**: developed by the authors

The formulas and graphs show that when the phase of the second PA cylinders changes abruptly by a certain amount, the misalignment between the third and second inks disappears. Random fluctuations in the ribbon path between the printed sections occur as a result of transverse vibrations of the ribbon in the intersectional area due to the runout of the guide rollers (if any in this area), sticking of the ribbon to the offset cylinders at the outlet of the four-cylinder duplex printing press. In this case, the trajectories of the ribbon dots deviate from the shortest straight line path and the value of L becomes a random variable L(t).

The presence of backlash in the movable joints of the drive of the printed sections and torsional vibrations in it lead to a change in the phase state of the cylinders relative to each other during their rotation.

The existing misalignment between inks can be eliminated in three ways

– by changing the parameter L with the help of a drive roller;
– changing the parameter φ0 by relative phase shift of the second inkjet cylinders relative to the first inkjet cylinders;
– changing the input belt tension (changing the parameter σ1).

The optimization of the printing process means the selection of such control influences at which the printing quality criterion receives an extreme value. The extreme quality criterion corresponds to the maximum of the printing quality indicators (saturation/contrast) or the minimum of distortions (pure colours, changes in the area of raster elements, changes in colour tone, etc.)

In the optimization process, the optimal ratio in the supply of the main working agents (paper, inks, wetting solution) is achieved provided that their physical and chemical properties (tension and humidity of the paper tape, ink viscosity, pH of the wetting solution) are stabilized. It is assumed that the change in process conditions (speed, pressure, atmospheric conditions, properties of ink and moisture-carrying surfaces, etc.) occurs within such limits that it is possible to restore the optimal printing mode by appropriately changing the material balance.

An important task of optimizing the printing process is to obtain the minimum contact time in the printing pair, which determines the maximum paper ribbon feed rate with stable transfer of the colourful image. However, the maximum printing speed is currently limited not by the ink splitting mechanism but by the design features of the printing press. Therefore, the realistically achievable print speed is the limit for feeding paper into the contact zone. The technologically required pressure value also corresponds to this speed.

Controllable factors of material balance that can optimize the offset printing process are: a) ink and wetting solution supply – when printing with each ink; b) supply of offset triad inks and black ink – when printing in multicolour.

Conclusions. A generalized model of the web offset printing process is proposed that reflects the movement of the main material flows (paper, ink, wetting solution); the influence of the field of factors (settings, perturbation control) on the process field (technological parameters); the formation of the final result in the form of a set of product quality indicators (combination and overlay of inks, position of fold and cut lines).

Based on the analysis of the functional model, a general strategy for managing the printing process is formulated, including programming; programmed and programmable control; stabilization of circulation printing; optimization of process control. The criteria for the optimal implementation of the management strategy, both for individual stages and the process as a whole, are determined. The structural principle of distributed control of the printing process through parallel channels (technological operations) and levels of control is substantiated.

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МОДЕЛЮВАННЯ ПРОЦЕСІВ РУЛОННОГО ОФСЕТНОГО ДРУКУ

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Актуальність роботи полягає в автоматизації управління процесом друку, що дозволяє досягти збільшення швидкостей отримання відбитків. Особливо актуальна ця проблема для рулонного офсетного друку, який виражає найпрогресивніші тенденції розвитку поліграфічної техніки та технології. Постановка проблеми випливає з сучасної потреби комплексної автоматизації друкарського процесу, однак її рішення сповивається на попередніх наукових роботах по дослідженню фізико-хімічних явищ в процесах друку, по вивченню динаміки окремих пристроїв рулонних ротаційних друкарських машин, з розробки методів автоматичного управління і техніки автоматизації друкованого процесу. Мета статті визначення механізму формування структурно-математичної моделі об'єктів керування, пов'язаних з рухом паперової стрічки при офсетному друку. У рулонних офсетних друкарських машинах синхронний привід циліндрів подачі паперу забезпечується безперервною зубчастою передачею. Завдяки механічній *гнучкості трансмісії система схильна до крутильних коливань, які збуджуються багатьма явищами. Ці коливання впливають на якість друку. Збудження які відбуваються на друкарському верстаті призводять до появи помилок на друкованих аркушах. Використовуючи механічну модель друкарського верстата, можна змоделювати вплив збудження на систему і таким чином зробити прогноз зміни в спрацьовуванні за допомогою алгоритму відстеження аркушів. Завдяки компенсації збудження (керування зворотним зв'язком) можна пригнічувати крутильні коливання машини і, таким чином, забезпечувати якість друку. У роботі це показано як при моделюванні, так і з урахуванням виміряних даних. Таким чином можна передбачити вплив механічних або пов'язаних із керуванням змін у конструкції друкарського верстата, що зрештою заощадить час і гроші на розробку та виробництво машин.*

***Ключові слова**: друк, офсет, оптимізація, тираж, якість, автоматизація, технологічний процес.*

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