Date of publication DEC-31, 2024, date of current version OCT-18, 2024.
www.computingonline.net / computing@computingonline.net

Print ISSN 1727-6209
Online ISSN 2312-5381
DOI 10.47839/ijc.23.4.3758

Information Technology of Thermodynamic Interaction of Laser Radiation Quality Upgrade while Drying Book Blocks

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ABSTRACT The article deals with the information technology of the structure and objects of thermodynamic interaction of book block drying processes. The article analyzes the literature on the selected research topic. It is found that to improve the quality of drying processes, convective-radiation drying with interruptions in irradiation of the spines of book blocks is a promising direction, which contributes to more intensive and faster moisture removal. A method for activating the drying processes of book blocks based on models of interaction 'glue - paper' with the use of infrared, ultraviolet, laser emitters is developed. The design of laser emitters for optimizing and intensifying the drying processes of book blocks is also developed by the authors and the necessary energy and spatial characteristics are substantiated. The paper presents the technical characteristics of the studied offset paper. The paper characterizes the images of the paper structure by thickness and, accordingly, the functions of laser beam power distribution when passing through the layers of paper sheets are obtained as a result of experiments.

KEYWORDS thermodynamics; laser emitters; offset paper; offset printing; structure; adhesive; drying quality; optical and thermodynamic interaction.

I. INTRODUCTION

In the printing industry, drying of semi-finished products is one of the final stages of manufacturing printed products, characterized by a significant time interval. The quality indicators of printed publications and their competitiveness depend on the methods, means and modes of drying, which are determined by the efficiency of thermodynamic process control. In the printing industry, various dryer designs are used for drying, the main ones being conveyor type. The most efficient is drying using infrared radiation sources, but they have the disadvantage of uneven distribution of the radiation field.

Many problems remain unresolved: inefficient control of drying processes and conveyor movement, imperfect models of thermodynamic interaction of the 'thermal field - object' components in drying processes. In conveyor dryers, entire book blocks are dried alongside the spines, which causes deformation. No dryers have been developed that are adapted for drying the spines of book blocks. The speed of the conveyors during drying is set manually by the operator depending on the final moisture content of the book blocks without information control, and is only occasionally measured by laboratory methods. To improve the quality of drying processes, convective-radiation drying with interruptions in irradiation of the spines of book blocks is a promising direction, which contributes to more intensive and faster moisture removal.

II. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

It was substantiated in works [3, 4] that the process of drying printing products is caused not only by purely physical processes of moisture removal, but is also associated with physical and chemical processes taking place in materials. During drying, the structural and mechanical properties of materials change, which is often accompanied by the appearance of various product deformations, such as warping, cracking of the adhesive layer, violation of the linear dimensions of bindings, etc.

In this regard, the drying mode of book blocks has to be chosen based not only on the optimal technical and economic performance of drying plants, but the technological properties of materials have also to be taken into account, which requires the construction of appropriate structural, parametric and dynamic models. These issues were highlighted in [5, 9, 14, 22, 23].

Drying is the process of removing moisture from a material as a result of dehydration of the material, or by polymerization or oxidation. This was substantiated in [1, 3, 4, 6]. In other words, drying of wet materials is not only a heat engineering process, but also a technological process that changes the technological properties of the material. Properly organized drying significantly improves these properties.

During the drying of a wet material of sufficient thickness, when moisture evaporates from its surface, its equilibrium in the middle of the material is disturbed and it begins to move from the center to the edges, a moisture content drop is observed in the material. This was described by the model of boundary thermodynamic energy exchange [2, 12, 21, 24, 25].

This paper considers the method of laser sensing of paper sheets with a photon beam with a variable power, which was substantiated in [7, 8, 10, 11, 13, 14, 17-20].

Papers [15, 16] presented the results of studies aimed at developing an a priori assessment of the quality of the printing process determining the quality of the output product and a model of logical inference determining the predictive indicators of the quality of the process of flat offset printing technique based on fuzzy sets.

III. THE PURPOSE OF THE ARTICLE

The purpose of this research is to develop information technology in order to improve the quality of thermodynamic interaction of laser radiation in the process of drying book blocks.

IV. SUMMARY OF THE MAIN RESEARCH MATERIAL

Offset printing paper is the most common type of paper for multi-circulation printing, including one of the most common for book publishing. It must have the appropriate mechanical strength of the surface, stability of linear dimensions during moistening and subsequent drying.

The fibers in the paper structure do not have one clearly defined direction. They are placed, intertwined and bonded together in the form of lines that are at different angles to each other depending on the degree of fiber orientation. This indicates that there is a relationship between fiber orientation and the mechanical properties of the paper.

The paper formed on the meshes of a paper machine has a longitudinal or machine arrangement of fibers, i.e., in the direction of the web movement. However, the sheets that are produced after cutting the roll on a roll-to-roll sheeting machine to length or width can have either a longitudinal or transverse fiber direction. The direction of the fibers in a sheet of paper must be taken into account, as paper folds better with the fibers than against them. In the longitudinal direction of the paper web, it has greater strength, stiffness, and elongates several times less than in the transverse direction [1, 2].

Since paper is a capillary-porous colloidal material by nature, it deforms when moistened, increasing its width and length. The fibers are predominantly oriented in the longitudinal direction and their size increases in diameter, not in length. In this regard, the deformation (change in the linear dimensions of the paper) during wetting and drying in the longitudinal direction of the fibers is less than in the transverse direction. The adhesive is applied to the surface of the paper sheet only in the longitudinal direction of the fibers, since transverse application of the adhesive will cause severe deformation. The depth of glue penetration into the spine of the block depends on the nature of the glue and the structure of the paper, and for offset paper it is 10-20 microns [3]. All this must be taken into account when performing bookbinding and binding processes.

Offset paper should have a high degree of whiteness and a uniform structure on both sides, be hydrophobic, with a high degree of adhesion, and have increased surface strength that does not break down. Paper is characterized by such important dimensional indicators as paper thickness and weight per square meter. The value of this indicator for book printing is in the range of 25-150 g/m^2.

Offset paper is practically not produced by domestic enterprises. Therefore, book and magazine paper weighing 70 g/m^2, 80 g/m^2 and 100 g/m^2 "Amber Graphic", Arctic Paper, Kostrzyn S.A., Kieszczyn na Odre, Poland, was chosen for the study (Table 1). This paper is used for printing multi-color publications with a long shelf life (books, magazines, newspapers, advertising and paper and white products, etc.).

Table 1. Technical characteristics of offset paper

Name, manufacturer	Weight per square meter, g/m^2	Stiffness, sm^3/g	Whiteness, %	Non transparency, %	Paper thickness, micrometer
"Amber Graphic", Arctic Paper, Kostrzyn S.A., Kieszczyn on the Oder, Poland.	70	160	143	90	89±4
"Amber Graphic", Arctic Paper, Kostrzyn S.A., Kieszczyn on the Oder, Poland.	80	160	143	92	99±4
"Amber Graphic", Arctic Paper, Kostrzyn S.A., Kieszczyn on the Oder, Poland.	100	160	143	93	120±4

Since the spines of book blocks consist of folded notebooks, which, due to the folding process, lead to the fact that laser drying is carried out both in the transverse and longitudinal direction of the fibers [4].

Optimization of book block drying processes. Drying of printed products in the process of printing and after binding is associated with the regulation of the speed of movement and its periodic stops in the areas of infrared radiation lamps, as well as with the control of heated air sources and high-frequency current generators [2, 5, 9, 22]. In conveyor dryers, it is necessary to regulate the speed of the conveyor of book block bundles, the value of which should be consistent with the temperature of the internal environment of the dryer, the initial and final humidity of the book blocks, their number and weight.

The problems of optimizing the drying processes of various printed products and designing the most efficient dryers have not yet been fully resolved. To solve problems of this class, it is necessary to determine the characteristics of the thermal field. It is formed by different types of thermal energy sources according to their physical and energy structure and radiation energy distribution (Fig. 1).

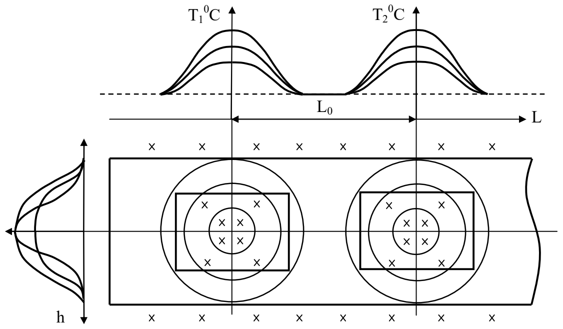

Figure 1. Distribution of the thermal field from lamp emitters on the surface of book blocks

It can be seen in Fig. 1 that T_1 ^{0}C and T_2^{0}C are temperatures of the thermal field, L is the distance between the emitters, and h is the density function of the laser beam intensity distribution in the plane R_2 .

This is the basis for building a model of the kinetics and dynamics of the drying processes of book blocks depending on their moisture content. According to the physical structure, let us distinguish the following types of heaters [6]: electric lamp emitters; infrared thermal (ceramic panels); infrared with electric heating (spiral gas-filled lamps, ceramics, panels); laser in a wide radiation range (1800÷380) Nm.

In such systems, the radiated heat field and its spatial structure are formed by reflectors and heat shields.

To determine the spatial and energy structure of the temperature field, it is necessary to build the following characteristics: the range of temperature control of the radiation source field; dependence of the field temperature on the temperature of the radiator surface; dependence of the temperature of the book block spines on the speed and energy of the radiator T=f(v,Td); dependence of the temperature change of the book block spines in the drying area on the cycle time; the spatial structure of the thermal energy distribution function; the spatial field T°(x,y,z) depending on the distribution of the radiation field. Besides, it is needed to build a graphical diagram of the relationship between the parameters of the book blocks, the thermal field and the productivity function (target) and to justify the use of laser emitters to intensify the drying process and increase productivity.

To build the spatial structure of the thermal field in the spine drying zone of book block spines, it is necessary to coordinate a number of characteristics of drying modes, i.e., to coordinate the dependence of rectifier power on voltage, conveyor speed, and the required temperature of the radiation source (Fig. 2). These two characteristics require the construction of the productivity dependence on the conveyor speed (ПР-VТР), while the required temperature of the thermal field in the product heating zone and drying time is consistent with the required value of the mode parameters.

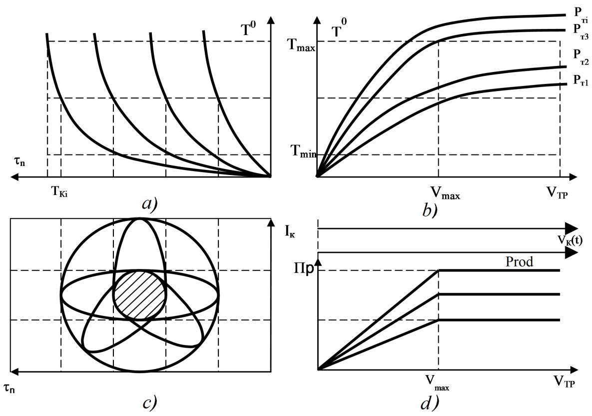

Figure 2. Graphical scheme for building an optimal thermal field

In accordance with this, a multi-criteria set is built that links the characteristics and factors that form them. This is the basis for building a control procedure based on the technological knowledge gained during the operation and testing of a conveyor-type dryer.

To increase the productivity of the drying process, it is necessary to use powerful lasers of different radiation ranges, that is, from infrared to ultraviolet due to the concentration of energy fluxes of rays [3, 5]. To do this, sections (Fig. 3) are formed from lasers of the same power (n = 8 pcs.), which are included in the structure of the temperature controller based on parallel or series connections.

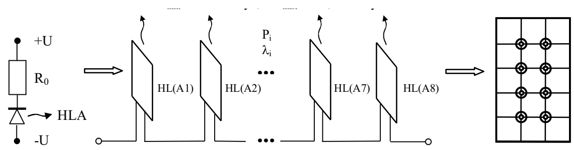

Figure 3. Structure of a laser section made of semiconductor lasers with a conical photon flux radiation pattern (Umax = 40V, Nmin = 40/5=8 pcs., Nmax = 40/4,5 ≈ 9 pcs.)

In accordance with the structure of the laser section, a matching scheme is built for both serial (Fig. 4, a) and parallel laser sections (Fig. 4, b).

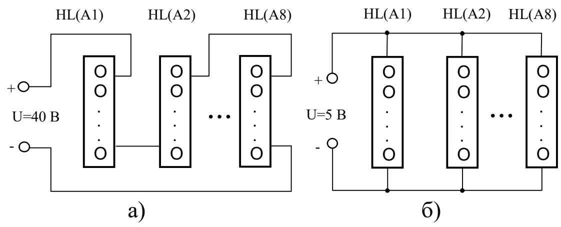

Figure 4. Laser section matching schemes a) serial U=4,5 V x8; b) parallel $I_{\min} = \sum_{i=1}^{8} I_i$

For the effective formation of the thermal field, laser sections of high-power lasers with a direct current in the range of (0.5÷5) A are used, which provide the conversion of electrical energy into optical energy with a conversion factor of $k_{OPT} = (0,5 \div 0,8) \times P_E$. The peculiarity of laser emitters is that each element is started at =2 V and minimum power $P_{\min}$. By adjusting $U = (2 \div 5)$ V, the optical power can be changed to the maximum value. Combined parallel-series connections are used to form laser sections that are consistent with the mains voltage. For a section of eight lasers with U = 40 V power supply, a series connection of the sections up to 240 V is required, i.e., six sections of U = 40 V in series, which enables direct connection to the temperature control system.

Here range of electric power laser is 25W or optical power direct radiation without focusing lenses = 0.5-1W.

Such a power supply section provides effective regulation of the power of the radiation thermal field, operational safety, and fits into the structure of a digital temperature controller.

The problems of controlling the average temperature in conveyor dryers and the speed of continuous movement of conveyors were partially solved in [1, 2, 7]. Rational methods and systems for regulating the position (positioning) of book blocks in repeatedly short-term modes of movement with the adaptation of regulators to these modes were substantiated.

V. RESULTS OF THE STUDY

To identify the structural features of the paper, we used the laser sensing method (a semiconductor laser with a cone beam). During laser sensing (Fig. 5), an image of the paper structure is formed due to the flow of photons passing through the test paper sheets. The image is characterized by micro clusters of paper density inhomogeneity. The distribution of the laser beam power density reflects in the projection the cluster structure of the paper sheets, which can be described by fuzzy sets [3-5]. The figures are the result of experimental studies conducted in the laboratory of laser technologies of the center for strategic research “Eco-bio-technical systems”.

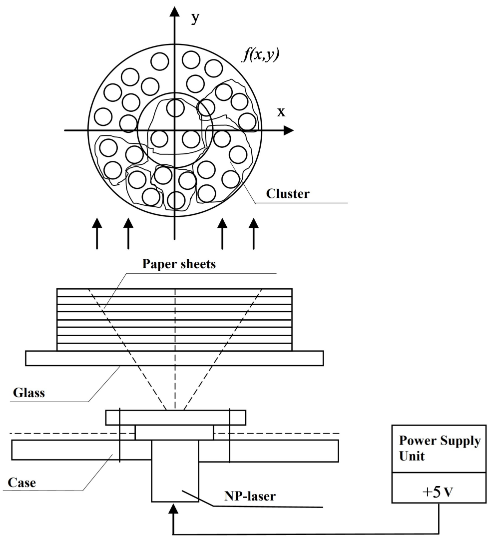

Figure 5. Laser sensing of paper sheets with a variable power photon beam flow

The graph (Fig. 6) shows the longitudinal (1), transverse (2), and oblique (3) distribution of densities of the volumetric structure of a sheet of paper. The images of the paper structure by thickness and, accordingly, the functions of the laser beam power distribution when passing through the layers of paper sheets are given.

Below are images (Fig.7-8) of the paper structure in terms of thickness and, accordingly, the laser beam power distribution function when passing through the layers of paper sheets, obtained as a result of the experiments.

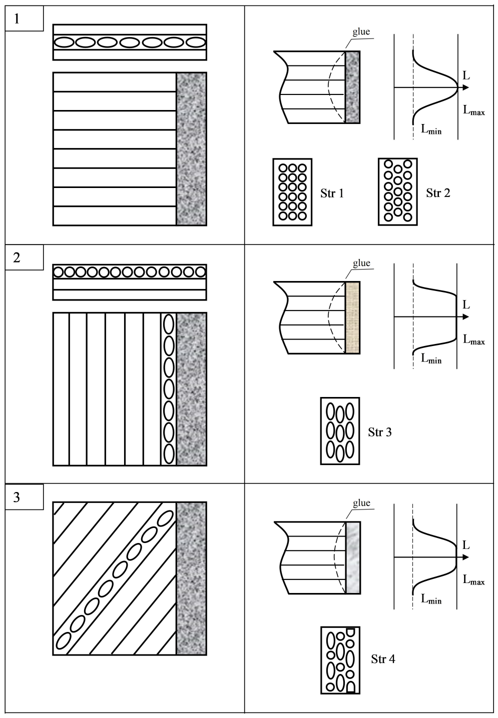

Figure 6. Penetration depth of the laser beam during the drying process of the glued joint with different paper structure

Table 2. The depth of penetration of the laser beam during the drying process when applying glue to a paper surface Paper type - "Amber Graphic", Arctic Paper, Kostrzyn S.A., Kieszczyn na Odre, Poland, paper density - 70 g/m2 at I=150 mA, 100mA, 50mA.

	Current, I / Color	Diameter of the adhesive joint D, mm		
		50 мA	**100 мA**	**150 мA**
Number of paper sheets, N=8 pcs.	White, W	21/41	21/42	21/43
	Blue, B	20/36	20/38	21/40
	Green, G	16/31	17/31	18/31
	Red, R	19/31	19/33	19/37
Number of paper sheets, N=16 pcs.	White, W	21/31	21/32	21/33
	Blue, B	20/38	20/39	20/40
	Green, G	15/27	16/27	17/27
	Red, R	17/19	18/19	18/19

Table 3. The depth of penetration of the laser beam during the drying process when applying glue to a paper surface Paper type - "Amber Graphic", Arctic Paper, Kostrzyn S.A., Kieszczyn na Odre, Poland, paper density - 80 g/m2 at I=150 mA, 100mA, 50mA.

	Current, I / Color	Diameter of the adhesive joint D, mm		
		50 мA	**100 мA**	**150 мA**
Number of paper sheets, N=8 pcs.	White, W	21/38	21/39	21/40
	Blue, B	20/41	20/46	20/50
	Green, G	17/34	17/34	18/35
	Red, R	18/25	19/28	19/31
Number of paper sheets, N=16 pcs.	White, W	18/27	19/31	20/33
	Blue, B	17/32	18/36	19/40
	Green, G	16/22	17/24	18/27
	Red, R	10/12	10/14	13/15

Table 4. The depth of penetration of the laser beam during the drying process when applying glue to a paper surface Paper type - "Amber Graphic", Arctic Paper, Kostrzyn S.A., Kieszczyn na Odre, Poland, paper density - 100 g/m2 at I=150 mA, 100mA, 50mA.

	Current, I / Color	Diameter of the adhesive joint D, mm		
		50 мА	**100 мА**	**150 мА**
Number of paper sheets, N=8 pcs.	White, W	21/31	21/35	21/38
	Blue, B	20/40	20/44	20/48
	Green, G	17/30	17/33	18/37
	Red, R	18/24	18/25	19/27
Number of paper sheets, N=16 pcs.	White, W	15/20	17/21	19/22
	Blue, B	17/20	18/23	20/26
	Green, G	11/22	13/23	16/24
	Red, R	14 sheets 10/15	14 sheets 12/16	15 sheets 12/14

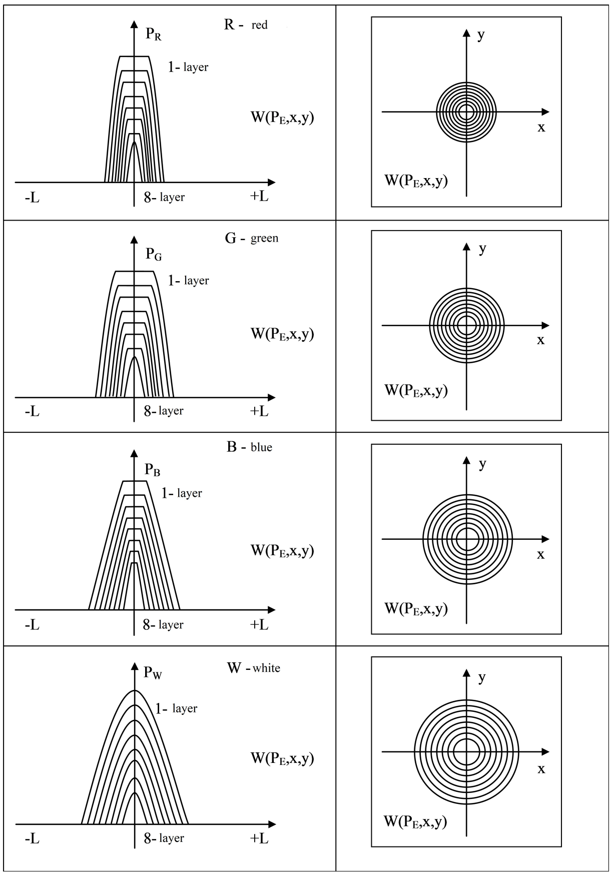

Figure 7. Laser color (RGBW) sensing of 8 sheets of paper and photos of the beams after passing through the paper medium

Nowadays, the development of modern technologies for the formation of book blocks has led to the emergence of new technologies for gluing book spines. This has made it possible to form books that do not require stitching and gluing, but the problem of drying book blocks at the final stage of book production has arisen. The drying of a book block is performed by a thermodynamic heat flow from a heat source using electrical radiation, which requires a long drying time.

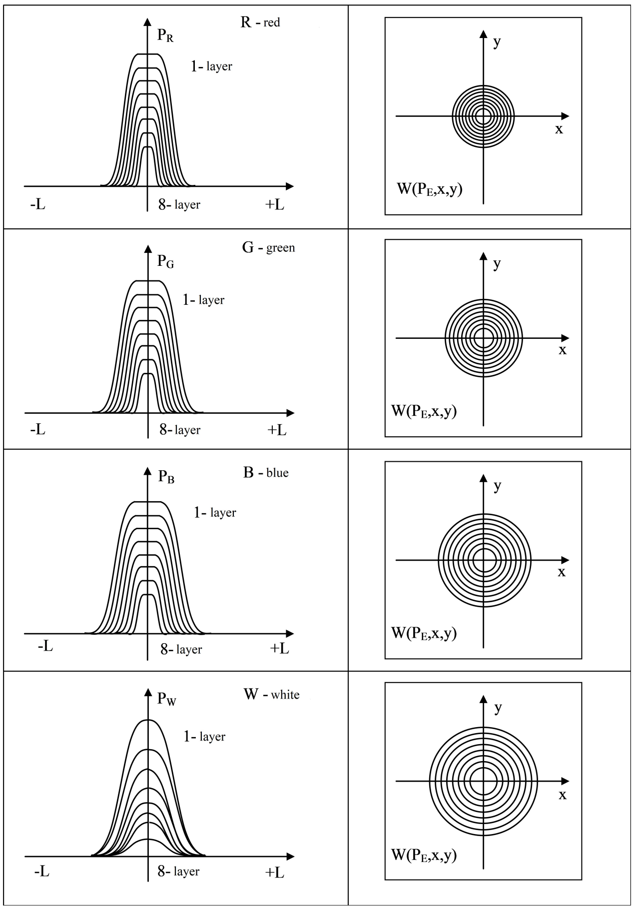

Figure 8. Structure of the laser beam cone power distribution function

The paper proposes a complex formation of the heat flow using thermal electric radiators (high-power lamps). The proposed method of integrated use of electric thermal emitters (infrared, white light bulbs) together with powerful laser radiation (powerful lasers in the red, white, and green range) made it possible to reduce the drying time and the glue polymerization by laser radiation and to improve the quality of the spine bonding strength. Semiconductor lasers with a power of [1-10] W were used to form emitter blocks that overlap the length of the book block. For each type of paper, the power of the laser array and the corresponding color of radiation are selected, which allows for optimal drying modes.

VI. CONCLUSIONS

In this paper, the method for simulation modeling of drying cycles for the temperature control system is substantiated, which is the basis for the development of a control system for the thermodynamic regime of the dryer.

The method for improving product quality based on the use of systems of coordination strategy for decision support using optimization procedures in the state space of the object is justified.

A structural model of the thermal field with a combination of laser and thermal emitters is built, which makes it possible to increase the efficiency of the drying process of book blocks.

The effectiveness of the use of a frequency-controlled asynchronous conveyor drive, which provides an appropriate thermal field mode according to the selected structure, is highlighted.

The use of laser emitters of thermal energy in the range of λ = (0.36÷1.8) micrometers is substantiated and schemes for their inclusion in the structure of a digital temperature controller are developed.

The components of the information technology for selecting and interval processing of data on the thermodynamic regime of the drying process of book blocks as a basis for control are defined and developed.

The information structure of the thermodynamic regime control system is determined and developed.

The use of interval estimation of data flows is substantiated.

An information technology for coordinating strategies for regulating the drying processes of book blocks is developed.

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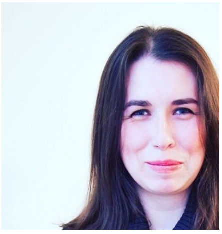

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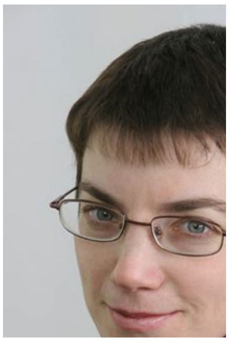

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