REVIEWED ARTICLE

DOI: 10.15199/42.2022.4.2

PROFESSOR SVITLANA HAVENKO, Ph.D., D.Sc. / ORCID: 0000-0003-4973-5174
CENTRE OF PAPERMAKING AND PRINTING, ŁÓDŹ UNIVERSITY OF TECHNOLOGY
ASSISTANT PROFESSOR OLGA SAVCZENKO, Ph.D. / ORCID: 0000-0002-8706-7122
UKRAINIAN ACADEMY OF PRINTING, LVIV

STUDIES OF THE FACTORS AFFECTING THE PROCESS OF LASER MARKING OF CARDBOARD PACKAGING

BADANIE CZYNNIKÓW WPŁYWAJĄCYCH NA PROCES OZNAKOWANIA LASEROWEGO OPAKOWAŃ KARTONOWYCH

ABSTRACT: Studies of the carbon dioxide laser marking process on cardboard packaging are presented. Approbation of the technological process of marking was carried out at different power of the laser beam and the speed of its movement. The optimal marking mode is set (laser radiation power 12 W and speed 240 mm/s), which provides the smoothest and clearest line edges. With such modes of laser processing, only the surface layers of the cardboard are destroyed, but the internal structure remains intact. It has been confirmed that the quality of laser marking is affected by the characteristics of the material, in particular its morphological surface structure. On the basis of the system and technical analysis, the factors influencing the quality of laser marking were determined, which were grouped into three groups: characteristics of the laser beam; properties of the base material; conditions of interaction of laser radiation with the material.
Key words: laser marking, packaging, cardboard, microscopy, surface structure,quality

STRESZCZENIE: Przedstawiono badania procesu znakowania laserowego dwutlenku węgla na opakowaniach kartonowych. Dokonano aprobację procesu technologicznego znakowania przy różnej mocy wiązki laserowej i prędkości jej ruchu. Ustawiony jest optymalny tryb znakowania (moc promieniowania lasera 12 W i prędkość 240 mm/s), który zapewnia najgładsze i najdokładniejsze krawędzie linii. Przy takich trybach obróbki laserowej niszczone są tylko powierzchniowe warstwy tektury, ale struktura wewnętrzna pozostaje nienaruszona. Za pomocą badań mikroskopii elektronowej potwierdzono, że na jakość znakowania laserowego mają wpływ właściwości materiału, w szczególności jego morfologiczna struktura powierzchni. Na podstawie analizy systemowej i technicznej określono czynniki wpływające na jakość znakowania laserowego, które obejmują trzy grupy: charakterystyki wiązki laserowej; właściwości materiału bazowego, warunki oddziaływania promieniowania laserowego z materiałem.
Słowa kluczowe: znakowanie laserowe, opakowanie, karton, mikroskopia, struktury powierzchni, jakość

INTRODUCTION

The contemporary development of technology makes the producers obliged to create and introduce perfect quality control systems for the products, their identification and logistics. In connection with this situation, there is a need of multi-level marking of the manufactured products, with the aim to deliver the obligatory and optional information about production to the consumer. Nowadays, there are known different technologies for marking of the products. It includes, in particular, mechanical contact marking (extrusion or incision, cutting, perforation, engraving and use of stamp), thermal marking (melting and burning); thermo-transfer printing; digital printing (ink-jet) and electrochemical process. From among the mentioned above technologies, laser marking occupies the important place (carbon-dioxide laser or semiconductor laser). It is employed in many applications – for marking of the production date and expiration date (Best before...) of food products on their packaging, labelling of packaging for medicinal products, cosmetics, bar codes, symbols, logos, eco-signs, etc. [1-3].

The advantage of laser marking includes the rate of placing the information and the possibility of marking in hardly accessible sites and, also a lack of direct contact of mechanical impact on the products what prevents their damage. There are, however, the increased requirements concerning a high detail of the text, precise transmission of small letter types and images.

Physical principle of laser marking consists in the interaction between falling laser beam and the used packaging materials; it is dependent on three componential factors – values of reflected, absorbed and penetrating rays. The reflected and penetrating beam renders energy to the material to be marked. The absorption capacity is dependent on the length of the wave of the falling beam which determines its power. When the wavelength is decreased, the energy of laser irradiation is increased. The absorbed energy is used for vibration or electronic induction or for performance of photo-chemical reactions.

As affected by CO_2 laser irradiation in the IR area at spectrum of ca. 9.6 – 10.6 nm, being absorbed by a given material, its local heating up, melting or evaporation takes place at the site of passage of laser beam. The mentioned processes are based on untypical structural and stage transformations of a given material; they are generated as a result of extremely high rates of its heating and later cooling down under the conditions of laser irradiation.

The elements which play here the important role include: values of density, strength of laser irradiation, the possibility of saturation of surface layers with the environment elements, increase of the density of dislocation in the irradiation zone and other effects. Laser gas tube, in which the laser beam is indicated, is the main element of laser equipment.

Under the influence of strong laser irradiation, different physical and chemical processes occur in the employed materials; their nature and type are determined by temperature, time and rate of heating and cooling of material. The mentioned factors are dependent on energetic and geometric characteristics of the laser beam, properties of the processed material and geometric shape and weight (mass) of the product, technological scheme of its processing, etc. [4].

During laser marking of the products, the packaging materials absorb laser irradiation and transform it from the light energy into heat energy. The general scheme of CO_2 laser is given in Fig.1.

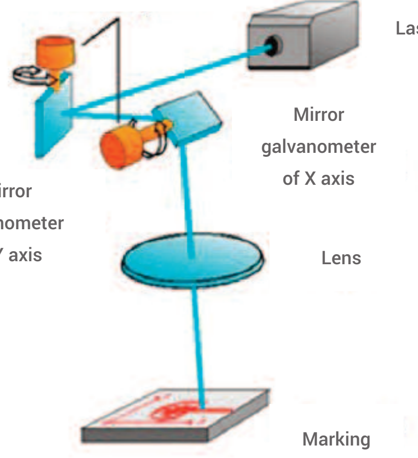


FIG.1. SCHEME OF MARKING WITH CO_2 LASER [5]

THE SUBJECT AND METHODS OF THE TESTS

The subject of the test covered the process of laser (CO_2) marking of cardboard packaging.

In the tests, Kromopak GC2 cardboard (producer: Mayr-Melnhof Karton, Slovenia) was used. It was produced from primary cellulose fibres (FBB) with the double chalked layer; the upper and lower layer was composed of chemical whitened cellulose and waste paper; the middle layer was mechanical mass; the composition was as follows: primary fibres – 60%, industrial waste paper – 30%, surface coating – 10%. Such cardboard is employed in packaging of cosmetics, medicinal products, personal hygiene products and foodstuffs. Technical characteristics of cardboard are given in Tab.1 [6].

Overprint on the cardboard was performed in offset sheet machine HEIDELBERG Speedmaster SM 74-5+L using Corona GA5015 ink (produced by Huber Group).

The experimental studies of laser marking process were carried out in machine of TS1390 model. The control panel of laser installation is equipped with monitor that displays the rate, power and time of work and volume of file; it also enables change of the processing parameters during the work. The driver facilitates work with the programmes: CorelDraw,

TAB.1. TECHNICAL PROPERTIES OF CARDBOARD (ACCORDING TO ISO 187)

density, ISO 536, g/m^2	350
Thickness, ISO 534, μm	572
Rigidity L+W 50 – longitudinal direction, N/m, DIN 53121	61.3
Rigidity L+W 50 – transverse direction, N/m, DIN 53121	27.2
Rigidity (L+W)/V(md x cd)	40.8
Whiteness, ISO 2470, %	87

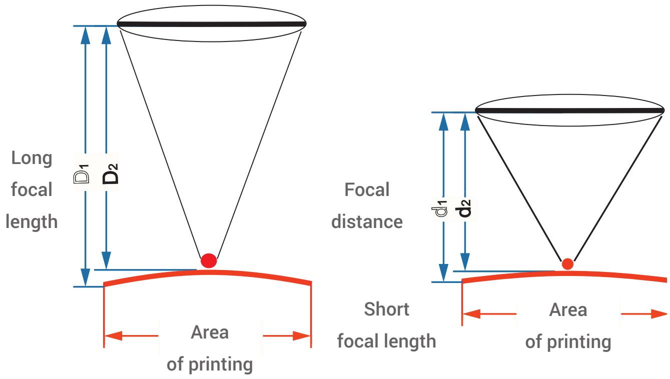
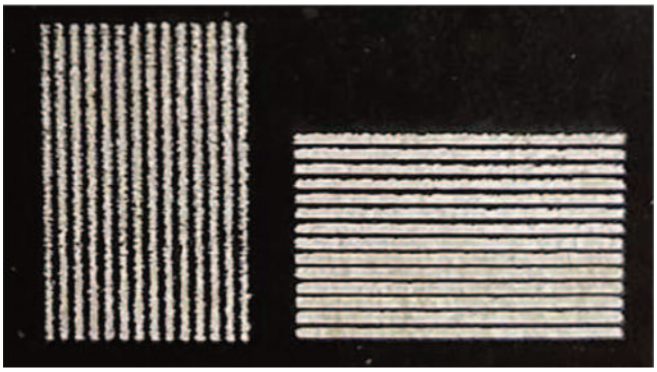


FIG.2. CALCULATION OF FOCAL LENGTH DURING LASER MARKING

AutoCad and LaserCut what ensures the effectiveness of work with the variable data (logo, bar codes, numbers, and different texts of marking and typing letters). The built-in memory allows the storage of files in laser machine and work without computer, causing the performance of the program from the memory of laser machine. The process of marking is fully automated.

Technological process of marking was conducted at the following parameters: power from 12 to 20 W and the rate of the beam motion during marking from 140 to 240 mm/s, marking step was equal to 0.635, width of the line of laser irradiation (laser seam) amounted to 0.05 – 3 mm; the frequency of laser irradiation impulses was 10 kHz. During laser marking of the packaging, the choice of focal length is the important parameter. The discussed technology allows the choice of the lens with large (Fig. 2a) and small (Fig. 2b) focal length. The larger focal distance means greater area of marking and larger focusing. The shorter focal length means smaller marking area and narrower sharpness.



a b

FIG.3. SAMPLE OF LINE OF LASER MARKING, THICKNESS OF 1 POINT IN LONGITUDINAL (A) AND TRANSVERSE (B) DIRECTION ON THE SURFACE OF CARDBOARD COPY, PRINTED WITH BLACK OFFSET INK

It is known that in order to ensure the reliable readout of bar codes, it is necessary to create the bars which will be in contrast, depending on the surface of material. To examine the coarseness of the cardboard surface without marking and in the areas of marking, the profiles were sampled in longitudinal and transverse direction. They were then evaluated on the grounds of curvature characteristic of material element according to standard DINO ENISO 13565-2. To these ends, the studies of the morphology of the surface of overprints were carried out. The studies utilized profilegraph MICRO MEASURE 3D the work of which is based upon the contactless method. Profilegraph has software, digital camera, allowing the magnification of the image of the surface of the tested sample; it enables also the visual choice of the site of measuring the roughness. The three-dimensional image is obtained as a result of multiple scanning of the surface.

The structure of the surface of the copies was examined in the light microscope BIOLAM at maximum magnification of the lens x 2500 and photography was made using a special adapter in digital camera Olympus E520 with the image resolution of 10 megapixels.

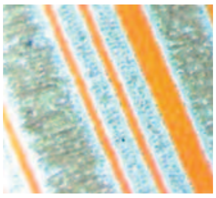
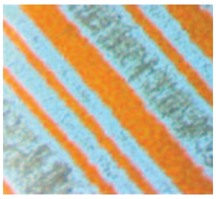
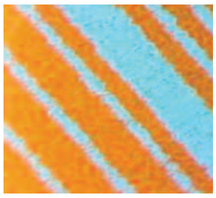
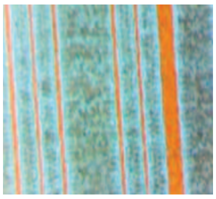
THE RESULTS OF THE STUDIES

The precision of mapping of bars and spaces which contain the indispensable coded information is the important parameter of the quality control of bar codes, determining the correctness of their verification. Quality indices, which are employed in evaluation of bar code lines, include as follows: width, density, sharpness, edge equality, etc.

All bar codes have linear parameters and their permitted deviations, specified in the standard. Bar code may be applied on different materials, so the quality of mapping the bars will be dependent on the character of their structure. The most possible deviations of geometric dimensions of bar code elements should be smaller than those admitted for the code [1, 7].

The possible shades of bar code colours are determined by the colour of internal structure of cardboard and its upper layer. The thinnest line of bar code corresponds to 1 module what

TAB.2.

Modes				
P (w)	V (mm/s)	Images generated by CO_2 laser	Photographs	Photographs
20	200			
17	200			
14	140			
12	200			
12	240			
14	240			

corresponds to 0.33 mm. Therefore, 1 mm-thick line contains 3 modules. The bar codes with the following combinations are well readable: blue on white, yellow and orange; green on white, yellow and orange, and brown on white, yellow and orange. We cannot read out red bar codes on light-green and light-brown colours, red on golden, blue and light-brown colours and orange colour on golden and yellow on white.

The task consisted in determination of technological modes of marking which were carried out at the stage of launching the earlier developed program; it should contain such modes as frequency of laser irradiation pulses; rate of the beam motion; width of laser irradiation line (laser seam); power of laser irradiation. The coordinates of marking are set in accordance with the arrangement of the future image.

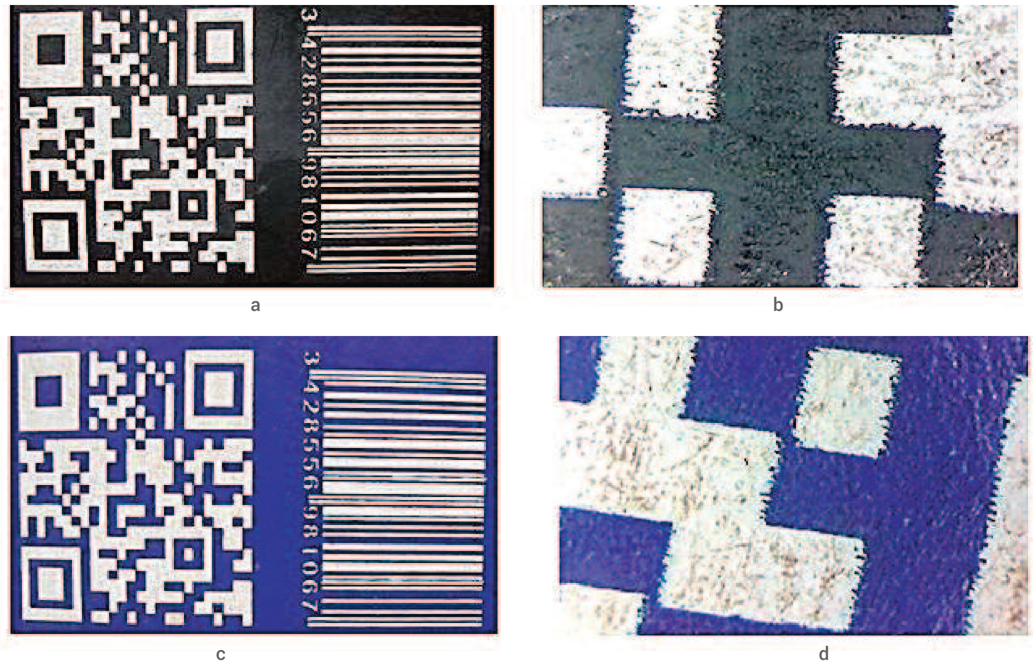


FIG.4. SAMPLES OF BAR CODES (A, C) AND THEIR MICRO-PHOTOGRAPHS (B, D X 100), GENERATED BY LASER MARKING ON THE SURFACE OF CARDBOARD AT MODES: POWER 12 W AND RATE 240 MM/S

To evaluate the quality of the seam of laser marking, 14 lines with thickness of 1 point were marked on black background, both in longitudinal (Fig. 3a) as well as in transverse (Fig. 3b) direction in relation to the axis of laser tube.

From the analysis of the discussed marking it is followed that the lines contain the irregularities (zigzags) in both directions; and in the case of longitudinal direction, they are somewhat greater. Small precision of the line when engraving thin elements in longitudinal direction results from the fact that laser has not time for reaching the full power. The results of the measurements of line edges show that the periods of oscillation in longitudinal and transverse direction are different.

FIG.5. EXAMPLE OF BAR CODE ON CARDBOARD GC-2 (MODES OF LASER MARKING: POWER P=14 W, RATE V=240 MM/S)

Due to above reasons, placing of packaging in transverse or longitudinal direction in relation to the axis of laser beam must be carried out with the consideration of the image character. The process of marking the bar codes QR and UAN-13 was tested on cardboard GC-2, printed on brown and orange background (Table 2).

As it is followed from analysis of bar codes, the smoothest and most equal edges of lies are ensured by the following modes of laser treatment – power of irradiation P=12W and rate V=240 mm/s where the surface layers of cardboard are destructed nut the internal structure remain intact. In connection with this fact, the following marking was performed on the cardboard materials, overprinted in black and blue colour, employing the following modes: power 12W and rate of marking 240 mm/s (Fig.4).

As a result of the tests it was confirmed that the colour of the surface of cardboard packaging had an effect on contrast and readability of marking. The contrast of codes is considerably greater on blue, black and brown background and smaller on yellow colour. The studies revealed that the presence of

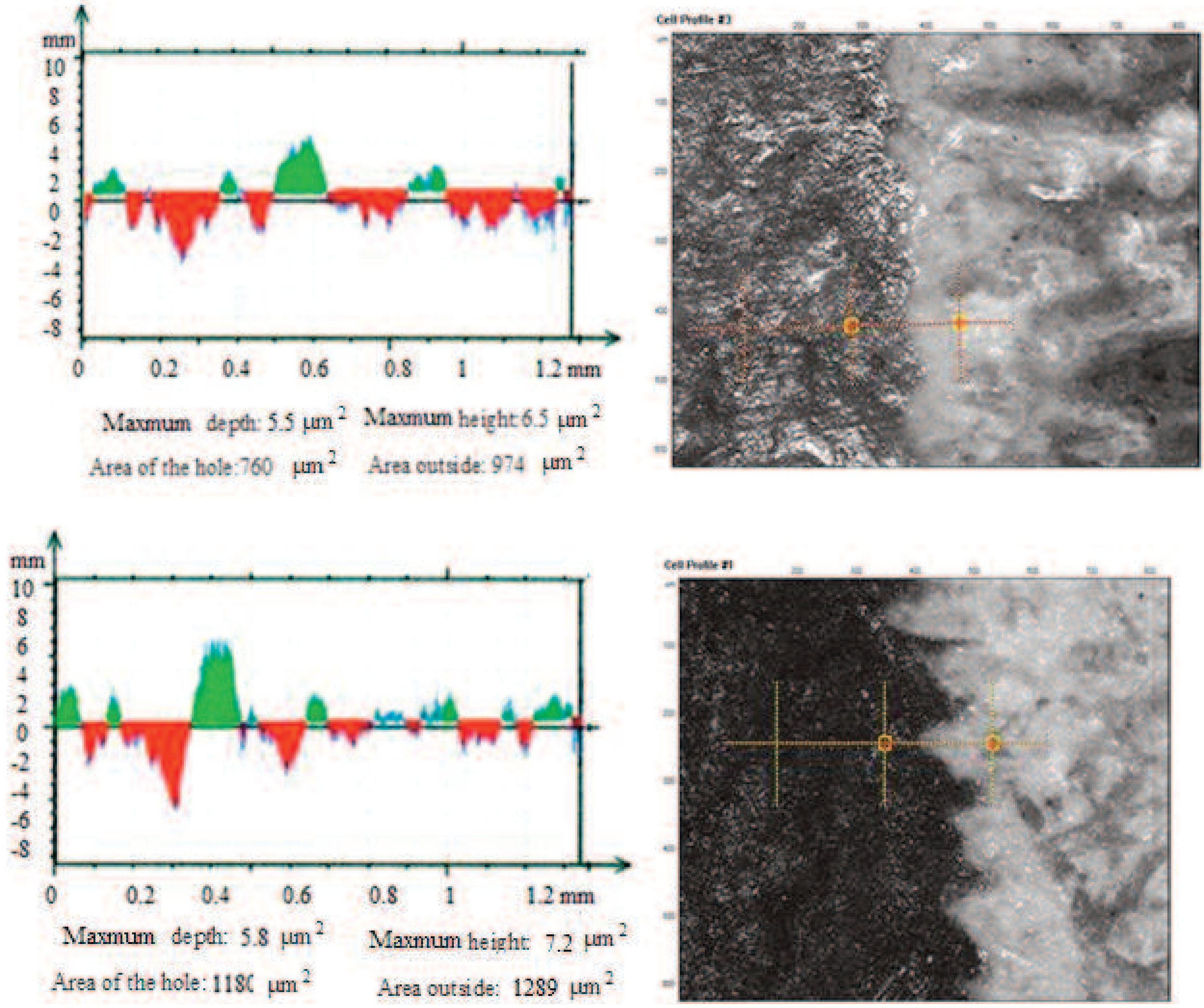


FIG.6. PROFILE OF THE AREA OF OVERPRINT (1A AND 1 B) AND TOPOGRAPHY OF SURFACE (2A AND 2 B) AT THE MODES OF LASER MARKING: A): P=12 W, V=240 MM/S; B): P=14 W, V=240 MM/S.

three-layer chalked layer on the surface of the cardboard has a positive impact on the quality of marking, increased the readability and precision of the images.

The increase of power up to 14W leads to deep removal of upper layer of ink and coating and destruction of internal structure of cardboard (Fig.5).

The quality of laser marking is affected by properties of a given material, and in particular, the structure of its surface, thermal conductivity, density, absorption capacity which is , in turn, dependent on the roughness of the surface, chemical composition of material, its temperature and presence of coating. In connection with this fact, the studies of the microstructure of cardboard surface were carried out before and after laser marking (Fig.6).

The analysis of the surface revealed the change in the roughness in the sites of laser marking. The mentioned change was also dependent on the modes of marking.

The analysis of profilegrams allowed determining the inequalities in the sites of laser marking. The results of the tests are given in Tab.2.

The examined surface of cardboard GC2-2 is characterized by the mean degree of the surface irregularity (-5.5 up to +6.5 μm) what is an evidence of uniform arrangement of structural elements of bleached and chemo-thermo-mechanical cellulose fibres and lack of large macro-irregularities. On the surface of the texture, however, we can observe partially thin, deep slots. The parameter of roughness, Ra, is equal to 0.426 μm. In the sites of laser marking, the mentioned roughness parameter (Ra)

TAB.2. MORPHOLOGICAL PARAMETERS OF OVERPRINT SURFACE

RA IS ROUGHNESS, RZ = MEAN DEPTH OF ROUGHNESS, SW = SURFACE OF CONVEXITY, SZ = SURFACE OF DEPRESSION

Cardboard GC2	Modes	Ra, µm	Rz, µm	Sw, µm^2	Sz, µm^2
Surface of overprint before laser marking	–	0.426	5.5	974	760
Surface after laser marking	P=12 Вт; V=240 mm/s	0.942	6.5	1289	1180
Surface after laser marking	P=14 Вт; V=240 mm/s	1.23	13.2	1476	2014

increases up to 0.942 µ; the surfaces of convexities Sw and depressions Sz are also increased respectively to 1289 µm^2 and 1180 µm^2 (at mode of marking – 12 W and rate 240 mm/s). In the case of laser beam amounting to 14 W, the surface Sw is equal to 1476 µm^2 and Sz increases to 2014 µm^2.

SUMMING UP

The analysis of the experimental studies revealed that the process of laser marking the bar codes includes many factors and many criteria. From the viewpoint of systemic analysis, the factors affecting the laser marking may be classified in three groups.

The first group of factors is composed directly by characteristics of the laser beam which generates a source of heat. The most important parameters of the laser beam during surface treatment are the length of the irradiation wavelength, shape and size of the focus of the “point” and character of the distribution of irradiation in the “focusing point”. Depending on the power used, the mode of continuous irradiation or pulsation is possible. The pulsation work considers energy, time of action, shape and frequency of pulses; in the conditions of scanning – amplitude, frequency and possibility of scanning. Polarization is classified into linear or circular type.

The second group of factors includes characteristics of the laser substrate material and, in particular, its surface structure, thermal conductivity, heat capacity, density, absorption capacity, which, in turn, is dependent on surface roughness,, chemical composition of a given material, its temperature and the presence of coating. Chemical composition of coating, its thickness and dispersion will have, of course, the impact on the absorption process and transmission of irradiation energy.

The third group of factors covers characteristics of the conditions of laser irradiation effect exerted on material: time of the impact, kinematics of a relative motion, temperature and chemical composition of the centre and angle of the beam falling on the material’s surface.

Therefore, to determine the formal relationships between the factors and parameters, the process of laser marking may be described using three-level model. It would contain the geometric parameters of codes on the higher level; the weight of the impact and effectiveness of the code readout (to facilitate verification) at the second level; the third level would contain the resistance to mechanical wearing and deformations of the image created by laser.

All the mentioned above factors have the direct or indirect impact on the quality of laser marking; therefore, they require further deepened studies.

LITERATURE

1. Havenko Svitlana, Svitlana Khadzhynova. 2015 Oznakowanie: technologia, wyposażenie, materiały. s. 206.: Łviv.
2. Henning, D., 2001. Scoring Big with Laser: Lasers and Packaging Technology, Flexible Packaging, 1, pp. 33-34.
3. Belosludtsev A., Buinovskis D. 2021.Significant increase of UV reflectivity of SiC galvanometer mirror scanners for the high-power laser applications // Optics & Laser Technology. – Volume 140, August 2021. DOI:10.1016/j.optlastec.2021.107027
4. Francesc Bravo, David Castells-Rufas, Sven Alexander Vogler, Jordi Carrabina.2020. Laser Inkless Eco-Printing on Paper and Cardboard / IEEE International Conference on Industrial Technology (ICIT). - February 2020. - Pp. 59-64. DOI:10.1109/ICIT45562.2020.9067267
5. CO_2 laser marking for the packaging industry. Електронний ресурс: https://elenlaser.com/blog/co2-laser-marking-packaging-industry.html (dostęp 30.11.2022 r.
6. Kromopakhttps://www.igepa.pl › _userfiles › products › IGP... PDF Kromopak. KARTON GC2 www.igepa.pl. Opis.
7. Alexander Stepanova, Esa Saukkonenb, Heidi Piilia. 2015. Possibilities of laser processing of paper materials.15th Nordic Laser Materials Processing Conference, Nolamp 15, 25-27 August 2015, Lappeenranta, Finland p.138-146.