Testing a nano-barcode marking technology for identification and protection of the mechanical products

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Abstract. The article presents a technology for application and identification of nano-barcodes on the surface of industrial products. The essence of this process is to modify the surface of metallic materials by exposure to pulsed laser radiation. As a result of such exposure, the modified surface contains small labels, allowing storing encoded information directly on the machine part, bypassing intermediate carriers. The laser-applied labels are formed using software and encode informative data. The encoding of the input information ensures the uniqueness of the applied nano-barcodes. The proposed technology allows us to apply such unique labels on the materials surface for accounting and identification of industrial products. The proposed marking technology allows us to place a significant amount of information in a small area. Special software has been developed for decoding the information from the applied nano-barcode developed. Studies have been performed that have been conducted to determine the thickness of the marked symbols formed on the materials surfaces and the reliability of the applied symbols. There are also recommendations on the usage of the technology given for direct labeling of materials with the application of information with high recording density for various industries.

1. Introduction
The paper proposes a methodology for applying marking symbols directly on the machine parts and assemblies. As a result of exposure to the material surface of pulsed laser radiation, surface modification occurs, leading to the formation of the specified marking symbols. The presented technology makes it possible to obtain contrasting, readable images of bar codes directly on the surface of products by controlling the main parameters of the laser marking complex.

Considerable attention globally is paid to modern technologies for applying marking by a pulsed laser due to surface modification of materials [1-3]. Large and important volumes of information are conveniently stored and transmitted through barcode and binary coding.

The appearance of barcodes made it possible to use the mechanical engineering product labeling and its identification for the logistic accounting and the creation of the control databases. Currently, the following are the most used among all developed two-dimensional multiple and matrix barcodes: PDF417, Aztec Code, Data Matrix, QR Code, Maxi Code (Figure 1). However, the existing methods of the marking metal products are mainly based on the labeling of different intermediate carriers - labels, tags, packaging.
Figure 1. Types of the two-dimensional matrix barcodes

Usage of the two-dimensional matrix barcodes applied directly onto the surface of the finished products by means of laser radiation provides to the final marked product its identity and makes it more protected from counterfeiting. Application of two-dimensional high-density barcodes directly on the product’s surface allows us to solve another important problem – to place the necessary information on the product, containing a wide range of the product’s characteristics such as conditions of its manufacture process and operation [4].

However, until now, the direct bar coding technology of the mechanical products using marking lasers has not been widely used. This is due to the fact that if it is necessary to place a sufficiently large amount of information into the typical barcode (more than 1000 characters), the overall dimensions of the two-dimensional matrix barcodes increase noticeably, which do not allow them to be used for products with small dimensions.

How does the pulsed laser radiation modify the surface of metallic material and how is it possible to insert so big amount of data in one small-sized label? Figure 2 demonstrates how the modified metal surface looks like after just one single pulse of laser radiation being applied. There are two spots from two pulses on the surface of stainless steel, being done with some distance to study the modifying process. As one can see on the microstructure photograph the pulse imprint has a circular shape with a border of the fusion line and an area of the heat-affected zone around the print itself.

So, during the laser surface treatment, there is a short-term (tens of nanoseconds) melting and a very thin contrast oxide films are being formed [5]. Using contrast oxides films, it is possible to create the marking symbols by modifying the metal material surface.
2. Materials and Methods

By creating a matrix image of contrasting laser imprints on metal surface, a two-dimensional matrix code with an increased information capacity was developed to provide a more efficient product protection system. This type of code contains an ultra-high density information data, which can be recorded directly on the product by the pulsed laser on metal and other surfaces [6, 7]. To fulfill the requirements to a nano-barcode (NBC), a fundamentally new type of the code graphic design was developed (Figure 3), which reflects all its functions (ultra-density, multi-purposed, a possibility of using laser marking technology and the ability to be read relatively easily, including with existing modern gadgets). The labeling was applied to a stainless steel surface. NBC design has its own system of the support and alignment elements (an inner square and rectangles around the perimeter of the frame).

The design feature of the developed nano-barcode is the ability to control the size of the inner square (Figure 3) depending on the amount of information recorded in the code, as well as the formation of the visually readable text records and drawings in the inner square, including company logos. To increase the degree of protection for nano-barcodes, text records and images in the inner square can be multicolored for different types of metals.

Figure 3. General view of the nano-barcode (NBC).
The stability and reproducibility of the color characteristics of the resulting marking symbols can be achieved by determining the technological parameters of the laser marking process depending on the thermo-physical parameters of the marked material.

The applied nano-barcode ensures its uniqueness by encoding the input information using a random number generator, which excludes the possibility of reading the recorded text without knowing the individual encoding key. The proposed marking technology provides the placement of a large amount of the necessary information on a small product area and successful recognition of the applied nano-barcode by an original special reader device with much higher resolution compared to existing standard barcode scanners with their original software for the decryption. The original scanning reader constructs a structural diagram of the registered NBC image and provides high-density code recognition. An effectiveness of determining the laser prints coordinates of the image code structure by means of this scanner ensures a very high percentage of confidence.

The digital image of the high-density code after the recognition is loaded into a special decoding program. Figure 4 presents the general view of the decoding program work field. This field of the program presents the area where the code image is located. There is an animation zoom mode, which can be selected for a clearer perception of the working field of the program. The range zoom is from 100 to 1000% by the initial linear dimensions of the original image. When image zoom is selected with the scale of 1000%, the code’s image fills the entire working area of the window program [6].

![Image of the nano-barcode in the scale zoom of 1000%](image)

**Figure 4.** Picture of the nano-barcode in the scale zoom of 1000%.

To ensure the readability of the created images a criterion is proposed for assessing the contrast of colored characters, obtained on a metal surface and based on an assessment of the oxides film thickness.

3. **Results and Discussion**

The contrast oxide films provide the quality and readability of the NDC images. Figure 5 shows the results of the electronic microscopy used to determine film thickness and structure.

The image in gallium ions (Figure 5) allows us to observe a finely dispersed quasi-amorphous oxide film under the platinum film, a finely crystalline gas-saturated layer and then the zone of recrystallized coarse-grained metal below the surface begins. The obtained results allow us to conclude that during the laser marking formation process of the oxide structures, a quasi-amorphous nanostructured layer appears on the treated surface, which also finds confirmation in research by other scientists [8, 9].
Specialized software was created to perform the process of encoding digital information in the form of an ultra-compressed nano-barcode [10]. This software allows us to do the following operations:
- receive files or create your own files with any digital information to be encoded;
- make an information encoding using a code conversion table to obtain a code message;
- perform a compression after encoding information;
- add a redundant information for the recovery in the case of its loss;
- do a complete or partial encryption of the information (depending on the functional purpose of NBC).

![Diagram of the surface layer film structure](image)

**Figure 5.** The surface layer film structure

The described encryption can be carried out using cryptographic algorithms in two stages. The first one performs the encryption at the byte level using the formation of a polyalphabetic byte cipher with a different shift value for each byte of the information, the second stage at the bit level based on the AES symmetric bit encryption algorithm [11].

In a contrast to the existing two-dimensional codes (such as QR Code and Data Matrix), it is proposed to use the symmetric and asymmetric file encryption for a nano-barcode to protect the code data from an unauthorized access. The NBC encryption uses a unique multi-level security system comparable to the modern cryptographic encryption algorithms such as RSA or AES.

An important additional component of the created coding program also is the ability to control the inner square size of the nano-barcode depending on the information amount recorded in the code, as well as the formation of the visually readable text entries and drawings in the inner square, including such ones as company logos.

The data encoding software for NBC creation allows us to reduce the nano-barcode size over a wide range, depending on its information capacity. When comparing codes with the same information capacity (Figures 6, 7), the size of the nano-barcode is noticeably smaller: with a capacity for 10 000 characters the size of NBC is about 37x37 mm, while the size of the QR code exceeded 2000x2000 mm. This fact proves again the ultrahigh recording density of the nano-barcode. In addition, a special mobile application has been created that runs on the Android OS, which allows us to read and decode information using cameras of modern smart phones.
4. Conclusion

An approved process for implementation of application and identification of a new generation of nano-barcodes on an industrial scale will create real prerequisites for a sharp reduction in counterfeit products not only in Russia but also abroad. The proposed marking technology due to its specificity makes it possible almost completely to eliminate fakes and generate a nano-barcode with a large amount of the input information on the product itself. This allows, if it is necessary, to have a complete picture of the technical and operational products characteristics, including the preparation for an expert opinion in case of emergency failure or the product breaking down.

This technology also can be used in any industrial complex for marking with the purpose of accounting and control during production: in aviation and automotive industries, heavy and energy engineering for marking and identification of parts, motors and other equipment; in jewelry industry for protection, labeling and identification of art objects.

Laser marking technology of nano-bar code application can be used with a wide range of metal materials; process modes for obtaining high-quality images have been developed. There are also developments for further recommendations when marking non-metallic materials such as polymers. A promising direction of research is the expansion of the materials and process modes base into surface treatment of materials, capable of accepting markings with the images of nano-barcodes.

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