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Laser Marking Methods

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Abstract. **Different methods for laser marking are systematized and discussed in the paper. Today in the practice there are many different methods that could be used to realise high quality on the workpiece of various materials with various shapes. Some materials could be marked only by marking or engraving without special requirements and difficulty, while for other materials one can choose the concrete method about the kind of material, marking type, and the specific needs of the production process and the geometry of detail. This makes it necessary to know, to summarise and systematize in a database all methods for particular lasers and materials, in order to quickly and flexibly respond to the specific needs of each customer by the manufacturies on marking systems. The report studies the specific opportunities and fields of applications of different methods for marking with laser.**

Keywords: **laser marking, methods.**

I INTRODUCTION

In recent years the process of laser marking is used to perform automated reading of information plotted on a given part and written as alphanumeric or coded as bar and matrix codes of individual components or products [1, 2, 3, 4]. The marked parts and details containing coded information which can be read automatically enable them to be monitored during the manufactoring process and throughout the supply chain (fig. 1). It is ideal when looking for service parts and repairs or putting in a claim, as well as being able to contribute to accountability and ensuring guarantee.

In many branches of industry the method of „Direct Marking on the Product" (DPM) is used to allow identification of the final industrial product. Ordinarily, the usage of DPM is preferred over other methods such as labeling of products. However, the physical characteristics and makeup of the part can also result in marking issues for manufacturers.

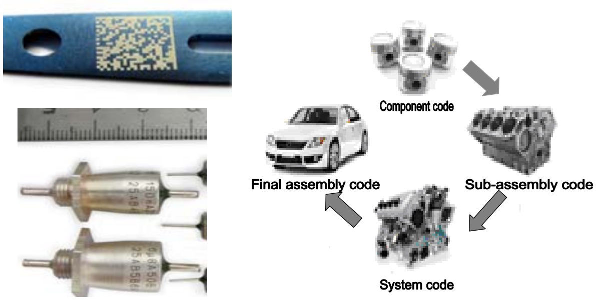

Fig. 1. Laser marking of parts with different codes

Today in automotive and aerospace industries, mechanical engineering, etc., the most common technologies used for DPM are laser marking, continuous ink jet printing, dot peening and electrochemical etching [5, 6]. When selecting one of these marking technologies it is necessary to focus on the type of material, the flexibility of the process, the financial cost, the process speed, the productivity and ability to automate the process of marking. In making a decision on the marking of some product except the choosing type of code and its content, it is also important to evaluate and select the best marking method – view table 1 and table 2.

TABLE 1

A COMPARISON BETWEEN THE DIFFERENT TECHNOLOGIES AND MATERIALS SUITABLE FOR MARKING

	Type of method	Ease of integration	Investment	Flexibility	Abrasion resistance	Mobility	Ternal or chemical stress
Electrochemical etching	contact	low	low	low	high	high	yes
Dot peening	contact	average	low	average	high	high	no
Continuous ink jet	non-contact	high	average	average	low	high	no
Laser	non-contact	high	high	high	high	low	yes

TABLE 2

A COMPARATIVE ANALYSIS BETWEEN MARKING TECHNOLOGIES BASED ON SEVERAL FACTORS

	Steel	Cu	Ti	Al	Fe	Mg	Ceramic	Glass	Plastic
Electrochemical etching	☻	☻	☻	☻	☻	☻			
Dot peening	☻	☻		☻	☻				☻
Continuous ink jet	☻	☻	☻	☻	☻	☻	☻	☻	☻
Laser	☻	☻	☻	☻	☻	☻	☻	☻	☻

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II LASER MARKING

The process of laser marking is one of the most widespread industrial applications of lasers. It can be implemented through different physical processes by interaction of laser beam with the substrate – fig. 2. Different types of lasers and optical delivery systems for transportations, focus locked, and deviation of the beam are used by laser marking systems to mark metals, ceramics, glass, plastics, leather, wood and other different kinds of materials. Laser marking is mostly in the form of an alphanumeric and 2D Data Matrix code affixed on the surface of the product, containing some information about the date of manufacture, serial number etc. [7, 8, 9, 10].

Fig. 2. Physical processes in laser marking on metals

Laser marking compared with traditional techniques for marking has not only a higher quality and flexibility of the process, but also it allows the introduction of automation and integration within production process. The main advantages of various types of laser techniques for marking are [2, 11]:

- durable process;
- non-contact technology;
- precise beam focusing;
- high speed machining;
- high contrast and quality of the treatment;
- high productivity and low operation cost;
- good accessibility, even if the surface is irregularly shaped;
- easy automation and integration in the manufacturing process;
- prompt localization of laser energy to the workpiece;
- high reproducibility;
- environmental technology.

Depending on the absorbed energy and the reaction time thermal processing is distinguished from cold treatment (UV).

Photons with high energy (UV) can realize the so-called "cold treatment", as well as they may cause some cuts in the material by breaking the chemical bonds within the organic material, or separate a given material in some parts, without having a thermal process in the treatment zone. Laser marking by "cold processing" is a specific process that implements material removal without causing any thermal effect of the areas around cuts, i.e., no thermal damage or heat deformation, etc. effect. For example, in the industrial electronics using an excimer laser a material may be removed by a thin layer deposited on a backing of semiconductor matter.

The thermal method is based on the absorption of electromagnetic energy of the laser radiation from the sample surface and its transformation into thermal energy. The temperature in the treatment zone is increased and it is possible to realize physical processes such as heating, melting, vaporization, etc. in the area of the marking. As a result of the interaction marking can be achieved by layers deposited on the base material as well as the surface. The thermal laser processing for marking is divided into two groups - laser marking and laser engraving:

Laser marking?

"Laser marking" means a marking or labeling of details and materials with a laser beam. In this respect, there are various processes of implementation, such as removing of substance, coloring, annealing, foaming, etc. Depending on the material and requirement for the quality, each of these procedures has its own advantages and disadvantages.

Laser engraving?

During laser engraving, the surface of the workpiece is melted and evaporated. Therefore, the laser beam removes the material. So the result obtained on the surface is the "engraving".

III TYPES OF LASER MARKING

There are several ways of the realization of laser marking on the surface of products: Raster Marking, Vector Marking and Marking using a Mask.

A. Raster Marking

The principle is similar to a dot matrix printer, with the particularity that here the working tool is the laser beam (fig. 3). The raster marking is primarily used in cases where it is necessary to affix mainly textual information at high speed. Rarely, it is used for drawing images (photos/logos), i.e., where there is no need for high quality and high volume of information.

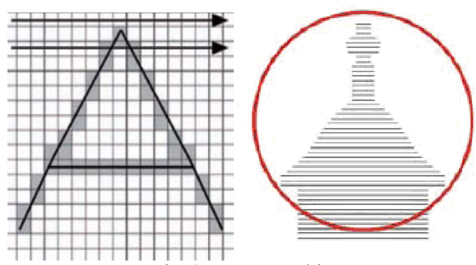

Fig. 3. Raster marking

B. Vector Marking

This is the most widespread method of laser marking. This is the most flexible method for marking with which various applications almost anywhere in the industry that require making of numerical codes, bar codes, 2D codes, logos and almost any other kind of a desirable marking can be realized. The beam is focused onto the workpiece via an optical system (lenses and mirrors), whose management is controlled by a sophisticated computer program. Using special software, a computer controls mirrors of the galvanometer. The marking is made by directing the beam in directions x and y onto the working area (fig. 4). The beam deflection method can transmit a high density of information. The position of the laser beam and its focus can be changed in order to implement exactly the preset image without distortions or deviations. In accordance to the needs of the user, the new image is started easily by the software and the passing to marking can take away only some seconds. The most commonly used lasers for this method are in continuous mode.

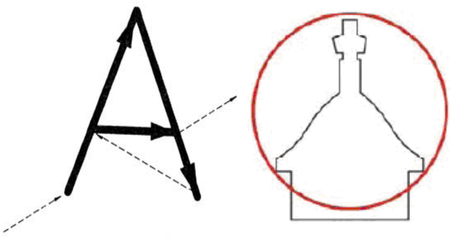

Fig. 4 Vector marking

Methods a) and b) can be implemented successfully as well as systems of plotter and such incorporating scanner fig. 5.

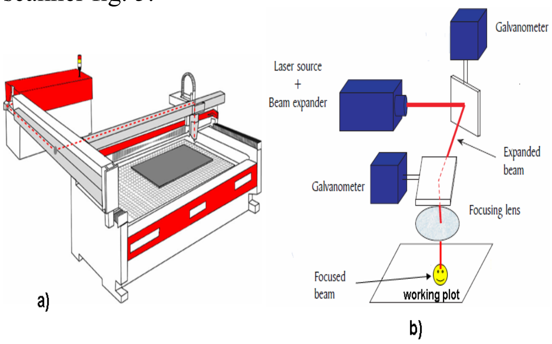

Fig.5. a) plotter system b) scanner system

A. Projection Marking Using a Mask

A laser beam passes through a mask (template). The beam is designed by an optical system on the working area – fig. 6. The method allows the mask to be used repeatedly, thereby the processing parameters are not changed. Receiving time of the image is very short because it works in pulsed mode of the laser. Disadvantage of the projection method is that for each new task a new mask has to be prepared, i.e., lacking flexibility; more time and resources to make new mask are necessary; time lost on another selection of appropriate technological parameters.

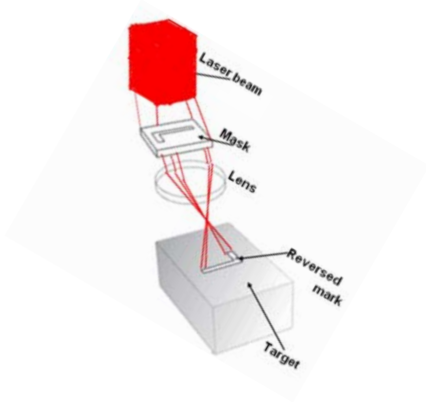

Fig. 6. Projection marking

Comparing the three marking types, it is concluded that:

• **marking speed:** the projection method for marking using mask is the highest-speed – per second up to several tens of marks. This is due to the fact that marking is made in pulse mode as the duration of laser pulses is within the range of microsecond μs to nanosecond ns. During the marking it is not necessary to stop the movement of the specimen.

• ***working area:*** A) and B) methods provide significantly bigger working area of the marking. By mask marking the marking area is very small because the diameter of beam spot is with limited sizes, as well as the energy per pulse on the mask is restricted, too.

• ***flexibility:*** for the projection method to produce each new mark a new mask is required. The production of a mask requires a lot of time. Therefore, the projection method is more suitable for manufacturing of large series without any change in the patterns. In beam deflected marking, the patterns are produced by software. Thus, it is highly flexible to change patterns.

• ***investment cost:*** investments for the realization of the methods A) and B) are higher, as the system for scanning and deflection of the beam is more expensive.

IV MARKING METHODS IN LASER MARKING TECHNOLOGIES

The marking processes include one or a combination of the following:

- forming a channel with a smallish depth into the material by evaporation;
- a modification of the surface by melting and a subsequent solidification;
- changing the colors in the material;
- physical modification of the layers piled on the material surface;
- etc.

REMOVING THE SURFACE LAYER

During the impact, the laser beam removes the coatings previously insisted onto the substrate (fig. 7). As a result, contrast is obtained between the substrate and the colors of the coating. Most often used materials to be plotted onto the surface are: special foils, films, laminates, anodized aluminum or coating of other metals.

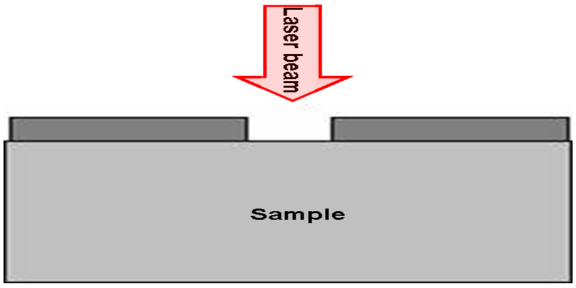

Fig. 7. A schema of removing the surface layer

LASER ENGRAVING

For implementation of laser engraving it is necessary for material to absorb a larger amount of energy in the zone of the processing than when implementing laser marking. Removal of material by evaporation occurs in the process. With this method, engraved channel is obtained in the specimen (fig. 8) similar to that which arises as a marking in the method of the electrochemical etching. The main advantage of this laser marking method is that it can be done at high speed. Although this method appears to be the most vigorous laser marking technique, it can not be seen coloring the treatment zone as a result of the interaction. Like laser etching, direct laser engraving can be easily determined by touch or low power microscope (10X) magnification. Laser engraving is not recommended for use on parts with thickness less than 2,5 mm.

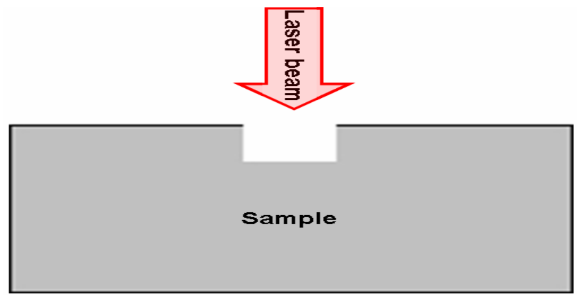

Fig. 8. A scheme of formation of a channel in the material under the action of laser radiation

LASER THERMAL BONDING

Laser thermal bonding is a process realized by an additional material which under the heat influence generated from laser impact is coupled with the base material (fig. 9). Fine glass powder or crushed metal oxides mixed with inorganic pigments or a liquid carrier (typically water) are primarily used as additive materials. The pigment can be applied by brush or sprayed directly onto the surface.

When using laser bonding, it is possible to transfer the coating to be implemented with a pad printer, a screen printer or a roller. For this process adhesive tape with plotting on the additional material is often used.

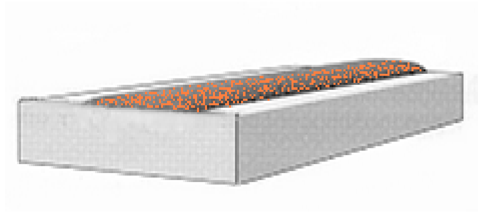

Fig.9. Material fused on a surface using the laser thermal bonding process

LASER SURFACE MODIFICATION

Laser surface modification by melting and diffusion is done by some material preliminarily deposited onto the surface (fig. 10). As a result of the impact a new alloy with other physical and mechanical properties (e.g. corrosion-resistant and rubbing (wear)) is generated. The coating materials can be applied with a brush or sprayed with an atomizer onto the surface, as the process is realized after the drying of the layer. Unmarked areas of the coating subsequently are washed with water or a special cleaning agent. The marking symbol may be located directly in the untreated surface or on the laser treatment area. The process is well done on the surfaces of carbon steel and aluminum alloys.

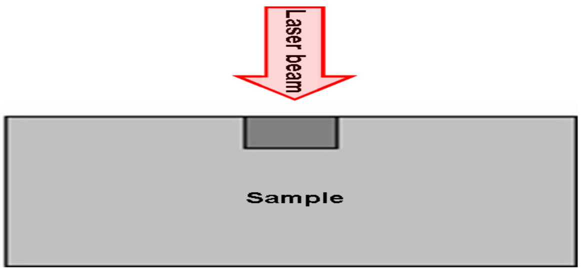

Fig. 10. A scheme of laser modifying the material

LASER INDUCED VAPOR DEPOSITION (LIVD)

Laser induced vapor deposition is a patent pending process that is used to apply for identification markings, heating and defrosting strips, antennas, circuitry, and sun shields of gauzy materials. This is achieved by vaporizing material from a marking zone under a transparent part using the heat generated from a laser. The gaseous vapors and droplets resulting from the heat make condense on the cooler surface to form a hard uniform coating that is applied in a prescribed pattern. The process is carried out under normal conditions without a need for high heat or seal gas. The marking materials (most metals) used to produce machine-readable symbols can be formulated to be read using optical readers and sensing devices like X-ray, thermal imaging, ultrasound, magneto-optic, radar, capacitance, or other similar sensing means.

The LIVD processes will provide another sure way to apply machine-readable marking to aerospace parts. Details of these advanced processes will be reported in updates to the future.

ANNEALING MARKING / LASER COLORING

Color laser marking is a special kind of laser etching for metals. The energy absorbed in the impact zone of the laser beam leads to a process of oxidation on the material surface.

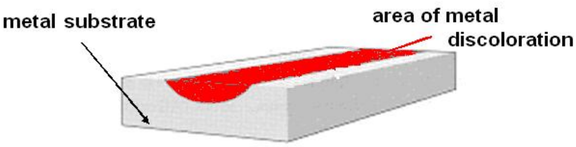

Fig.11. Marking of a surface using the laser coloration process

The process is used to change the color of metallic substrate material without burning, melting, or vaporizing the irradiated material. This is done using a laser beam with low power that moves slowly across the surface at a given speed as a result of which the marking area is changed (fig. 11). In this laser marking method a high-quality, high-contrast marking is obtained that does not destroy the surface of the specimen. A colored laser marking penetrates in deep surface roughness and allows the process to be implemented at levels of unevenness to 12,7 μm. Laser color marking causes less damage to the surface in comparison with other methods and does not lead to corrosion of the surface and therefore it can be used for the marking of some stainless steel. These effects can be minimized or eliminated by careful selection of the parameters of the laser marking. This method of marking cannot be removed by rubbing the surface with fingers and can be successfully seen at a magnification less than ten (10X).

LASER ETCHING

The method of laser etching is similar to that of the laser coloring excluding that energy absorbed by the surface is sufficient here to implement the process of melting in the work area. The advantage of using this technique is that the marking process can be implemented at high speed since it is not realized to a great depth in the preparation of the colored image. Excellent results can be obtained at the depths of penetration less than 25 μm. This technique, however, should not be used in some cases for metals because the cracks resulting from the cooling of the melt may be disseminated on surface of the basic material that can prove critical for a safe exploitation of certain details. These cracks can be extended into the material, by subjecting it to repeated cycles of heating/cooling. In such modes of operation of this method, the details to the marking are not preferable.

GAS ASSISTED LASER ETCH (GALE)

Laser marking that takes place in a normal environment often has no better contrast, i.e., the difference between the engraved mark and background of the substrate is not large. This often makes it necessary to increase the time for marking (impact) and also may result in the limitation of the various materials that can be marked. Laser etching (GALE) is a technique that uses an auxiliary gas, i.e., the marking is carried out in the presence of an appropriate gas environment, thereby improving the contrast and increasing readability. The mark is done at lower values of laser power, i.e., marking on the material is realized with minimal laser treatment. GALE method achieves this through the use of an auxiliary gas that reacts with the material under the laser impact. A mark is prepared which is a different color from the background – fig. 12. The auxiliary gases might be reductive, oxidizing or even inert, such as their choice being dependent upon the target material. Contrasting surface results were achieved through optimization of the parameters of the laser source, the gas and the material.

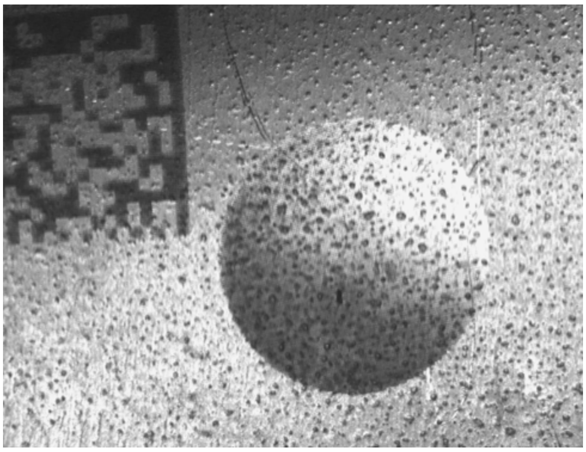

Fig. 12. View of gas auxiliary laser etch coating under magnification (Note that surface protrusions are left intact after marking) - Tests performed at the University of Tennessee Space Institute, B. H. Goethert Parkway, Tullahoma, TN 373888

V LASERS FOR THE MARKING PROCESS

Technological schema of a system for laser marking is shown in fig. 13.

In the process various types of lasers can be used in systems [12] – see table 3. The most popular laser sources that are used in the marking technological systems are: Nd:YAG lamp-pumped lasers, which produce a light in the near infrared area at a wavelength of 1064 nm [13], and CO_2 lasers - at the wavelength 10600 nm.

The wavelength of Nd:YAG lasers – 1064 nm is absorbed more easily by a vast range of materials.

CO_2 lasers are economically advantageous for marking on condition that their wavelengths are being absorbed by the treated materials.

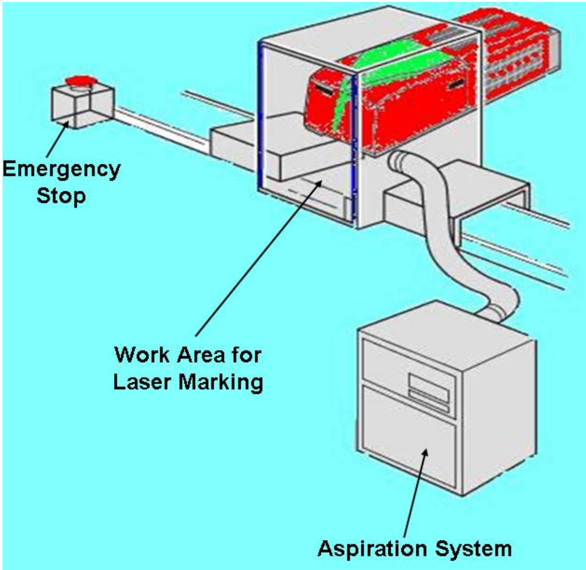

Fig. 13. A general view of the technological system for laser marking

TABLE 3

SOME LASER SOURCES USED IN THE TECHNOLOGICAL SYSTEMS FOR MARKING AND ENGRAVING

Type of laser	**Wavelength** λ, nm	**Power** *P*, W
CO_2	10600	10÷200 W 6J/pulse when marking
Nd:YAG	1060	25÷10 W, 0.20 J/pulse when marking
Doubled Nd:YAG	532	1-3 W
Eximer	175-483	max 2 J/pulse when marking
Fiber	1062-1064	10 – 20 W
Disc	1062-1064	20-70 W

Excimer lasers also are successfully used in the laser marking [14,15]. Among all types of lasers, they shall ensure the highest resolution of the mark. But, these types of lasers are rarely used due to the low productivity of the process and the very high cost of the laser equipment. Recently, diode-pumped fiber and disc lasers have appeared, which are also successfully used for the marking process. These lasers offer high beam quality, excellent stability of the frequency, and long maintenance intervals (typically every 12,000 to 15,000 hours without service).

For any particular application of laser marking many factors should be taken into account [16,17,18,19,20,21]:

- power density q_S;
- wavelength λ;
- time of impact t_{proc};
- material properties;
  - thermal conductivity k
  - specific heat capacity c
  - melting temperature T_m
  - vaporisation temperature T_v
  - reflectivity R / absorptivity A for the concrete material, wavelength and temperature.

Power density q_S is determined by the amount of power P generated by the laser divided by the area of focused beam.

$$q_S = \frac{4P}{\pi d^2}, \qquad P = P_p \, \tau \, v$$

where: P_p is pulsed power,
τ – duration of time,
ν – pulse frequency,
d – diameter of working spot.

Wavelength, beam divergence and quality of optics become important factors in determining how small a focused beam can be on the work surface.

$$d_0 = M^2 \frac{4\lambda}{\pi} \frac{f}{D}$$

where: f is the focal length,
D – beam diameter,
M^2 – a parameter defining the quality of the beam

(for fiber laser M^2 = 1.1, for disk laser - M^2 = 1.2, i.e., these lasers have almost perfect quality of radiation, for Nd:YAG laser – $M^2 = 1.5 \div 2$, for CO_2-lasers – $M^2 = 1.5 \div 2$, for diode lasers – $M^2 = 10 \div 20$).

The time of the impact of the laser beam on the material also has a significant influence on the quality of marking and the penetration depth (fig. 14).

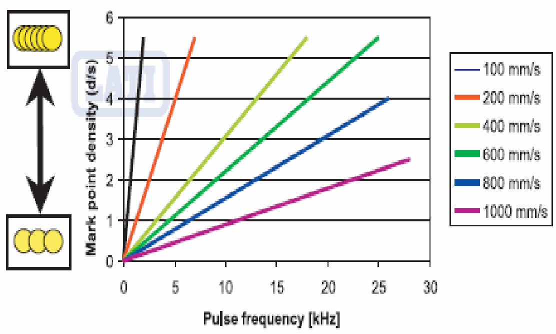

Fig. 14. Mark-point density vs. pulse rate at various beam velocities [22].

Sometimes, the pulse duration is a key factor when choosing a laser which can be used for carrying out a certain marking.

The reflectivity or absorptivity depends on the kind of the material, surface state (i.e. smooth or rugged, polish or oxidized), the wavelength of the laser radiation and the surface temperature. In general, metals absorb a larger percentage of the incident laser power of Nd:YAG lasers (λ = 1064 nm) than that of CO_2 laser (λ = 10600 nm). On the other hand, nonmetals such as wood, paper, leather, plastics, glass, etc. absorb the wavelength of the CO_2 lasers better. Some materials, such as silicon successfully absorbs energy from the both lasers. Laser marking is a complex technological process. For its implementation it is necessary to select the appropriate laser.

To evaluate the correct choice of a system for realizing a specific laser marking the following factors should be taken into account:

- a system for transportation of laser radiation;
- laser specification;
- system control and software;
- ergonomics - ease of operation;
- recommendations for the manufacturer;
- service guarantee and maintenance;
- the cost.

The laser specifications of different types of lasers are different. For CW lasers, the basic positions that should be required in a specification are: wavelength, average laser power, output power stability, quality factors of the beam and Q-switch mode (maximum pulse repetition rate, minimum pulse duration, laser peak power).

For pulsed lasers, the specifications should include: wavelength, average power of the laser, maximum peak power, maximum energy per pulse, pulse repetition rate, pulse duration, frequency stability, and quality of the beam.

There are many types of optical delivery systems. For mask marking processes, the systems can include: beam expander, homogeniser, CCD camera and monitor or/and microscope, and project lens. The project lens, together with the beam size entering it, determines how big a mark can be obtained per pulse. For beam deflected marking system, the system may include beam expander, CCD camera and monitor or/and microscope, scanner, fiber optics, and lens. The lens is very important in determining focused spot size, marking field, minimum marked-line width and power density on the workpiece.

The scanner together with the marking software determines the scanning speed.

Control systems and software for different laser marking systems are very different. The control system can involve feeding of the workpiece, control for switching the beam on/off, as well as interfaces for computers, laser source, stage, and protection/alarm systems. The marking software must be easy to introduce into the consumer system and provide convenient and easy interaction.

VI CONCLUSIONS

An increasing number of companies is interested in industrial applications of laser technology, primarily in mechanical engineering, automotive and electronics. More and more new products that were made using the laser as one of the most important tools in their production have appeared in the strongly competitive global market. Industrial laser applications, mainly for cutting, welding and marking are well established techniques.

Currently, among the different types of material processing that use laser, laser marking is one of those that found the highest prevalence. It provides a high quality of marking compared to traditional methods.

Nowadays, lasers are effective as tools for marking and engraving, as well as their application is predominate in marking of plastics, metals, alloys, silicon, ceramics. Laser technology meets the requirements for speed, quality, flexibility and price. Some of these qualities are impossible to implement with traditional technologies.

The need to process materials that have special characteristics as well as the implementation of the processes of marking in new fields of industry require the development and the production of new technological systems that will meet these requirements. The progress in the laser equipment and technology provides users with a wide range of new options for marking at a rapid pace. At present, several new lasers are under development; their appearance will result in lower investment and operating costs and will improve the quality of product marking. There are new green lasers being developed for marking special products such as silicon wafers, without damaging the base material, and lasers emitting in the blue and violet ranges of the electromagnetic waves, such that it would be possible to significantly reduce the amount of marking sign with their assistance. This leads to a continuous development in the sector of laser marking.

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