A Review on Laser Marking Process for Different Materials

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Abstract— this paper describes a variety of fundamental research of laser marking of different materials which the authors have recently performed. Product laser marking is one of the most common industrial applications of lasers. The laser marking systems using different lasers and optical delivery systems may be used to mark an almost endless list of materials including metals, plastics, ceramics, glass, woodland leather as well as painted surfaces and photographic emulsions. In this review the research and progress in laser marking of different materials are critically reviewed from different perspectives. Basically many types of industrial lasers like, carbon dioxide (CO2) laser and neodymium-doped yttrium aluminium garnet (Nd: YAG) laser, fiber laser, semiconductor laser which are used for laser marking process. Some important laser processing parameters and their effects on MRR and surface roughness are discussed. This paper deals with the review of papers by authors.

Key words: Laser Marking, Process Parameters, Optimization, Full Factorial Design (FFD)

I. INTRODUCTION

The laser is one of the most widespread technical inventions of the last century. There are two basic methods for laser marking: they are mask marking and beam deflected marking.

In mask marking, a stencil of the desired mark is projected onto the work piece. The picture of the mask on the object is made using a lens. Extremely short impulse of light energy is directed on the work piece. Therefore, employed in the mask marking are often the pulsed lasers such as pulsed TEA CO2 laser, excimer laser, and pulsed Nd-YAG laser.

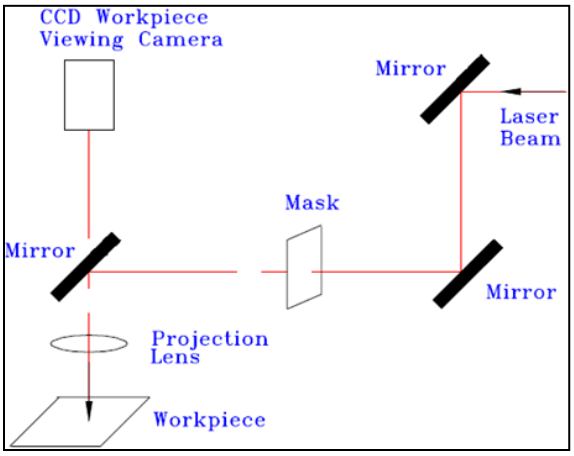

Fig. 1: Optical Diagram of a Simple Mask Marking System

In the beam deflected method, the laser is directed via two galvanometer mirrors and a lens system to the object to be marked. Using special software, a computer controls the galvanometer mirrors. The marking is made by directing the beam in directions x and y.

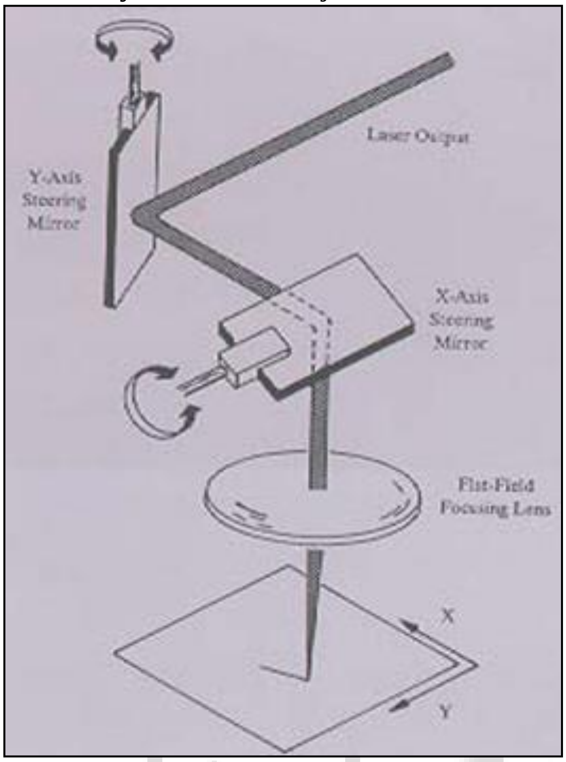

Fig. 2: Schematic Diagram of Beam Deflected Marking

Fig. 3 shows the mark depth and width as a function of pulse frequency. It is clear that the mark depth increases with increase in the pulse frequency when the pulse frequency is below 3 kHz. Contrarily, if the pulse frequency is above 3 kHz, the mark depth decreases with increase in the pulse frequency. It is also seen that the mark width hardly depends on the pulse frequency.

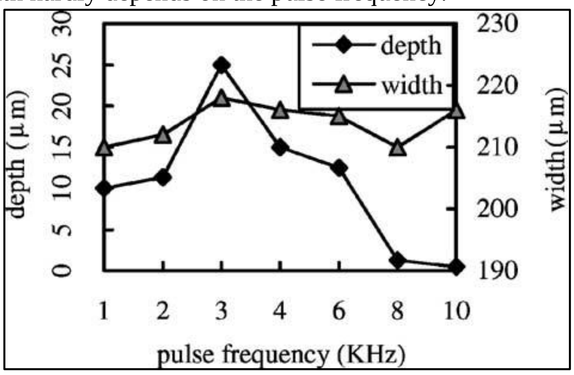

Fig. 3: Mark depth and width as functions of pulse frequency

II. LITERATURE REVIEW

J. Qi, K.L. Wang, Y.M. Zhu [1] studied on the influence of the pulse frequency of the laser beam on the mark depth, width and mark contrast. A Q-switched Nd: YAG laser was used in the laser marking process of stainless steel. The mark contrast is the ratio of the apparent brightness between the mark and unmarked areas which shows the clearance degree of the mark. An optical microscope, scanning electron microscope and surface profile instrument were used to measure the effects of pulse frequency on the mark depth and width.

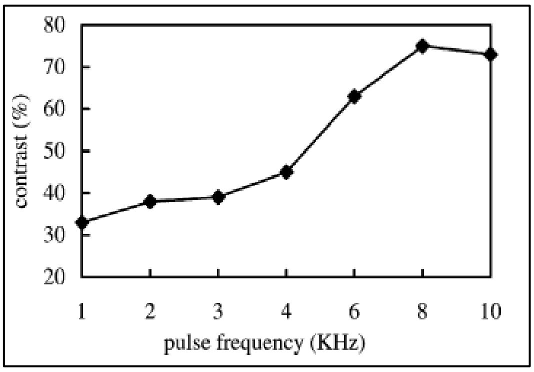

Fig. 4: Mark Contrast as a Function of Pulse Frequency

An image-analysis system with a frame-grabber card and a charged-couple-device (CCD) was used to measure mark contrast. Fig. 4 shows mark contrast as a function of pulse frequency. As can be seen from this figure, the mark contrast increases with increase in the pulse frequency when pulse frequency is below 8 kHz. Contrarily, when the pulse frequency increases to above 8 kHz, the mark contrast decreases. This is because vaporization of material is significant and very little material has been oxidized at low pulse frequency, while the main process is oxidization of materials at high pulse frequency. Oxidization of materials improves mark contrast.

Also they have investigated that the pulse frequency of a Q-switched Nd: YAG laser has a significant effect on the mark quality. There is maximum mark depth when the pulse frequency is about 3 kHz, while the mark width remains almost constant at different pulse frequency. With the increase in pulse frequency, evaporation of material decreases, whilst at the same time oxidization is more significant, which leads to the improvement of mark contrast. The highest mark contrast was obtained when the pulse frequency of the laser was about 8 kHz.

T.W. Ng, S.C. Yeo [2] has studied on the CIE colour difference formula was applied to evaluate four types of material surfaces; anodized aluminium, stainless steel, poly-butylenes tetra-phthalate (PBT), and phenol formaldehyde, marked using a Nd: YAG laser, and viewed under three common modes of illumination; tungsten, Fluorescent and daylight at different speeds. The colour difference values were based on the spectral reflectance readings obtained from a spectrophotometer. The plots of colour difference value against laser marking speed revealed different trends for the materials and illumination modes applied.

Fig. 5 describes the case for anodized aluminium. The curves for the deferent illuminates were roughly of the same magnitude but tended to exhibit a wavy trend. Hence, it was difficult to ascertain the presence of particular optimal marking speeds wherein the colour deference was maximal.

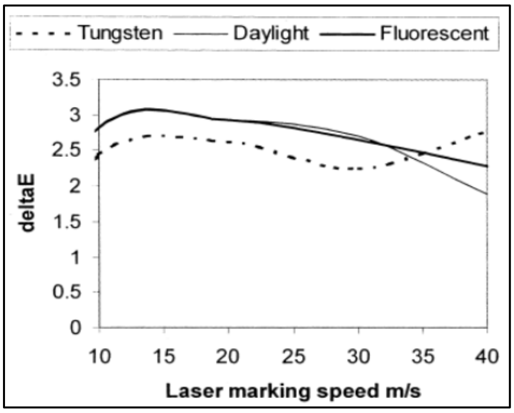

Fig. 5: Colour deference values obtained at deferent marking speeds and types of illumination for anodized aluminium.

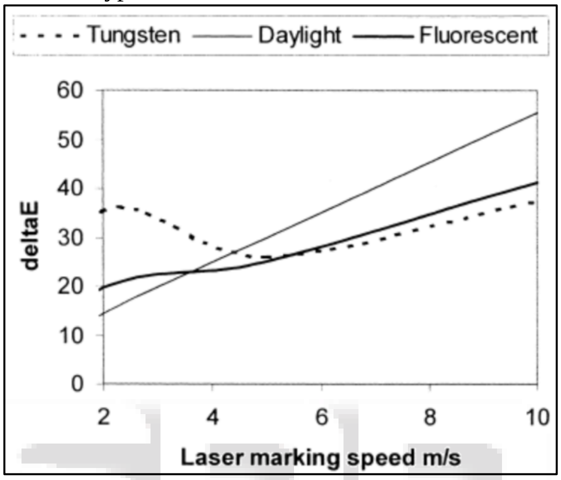

Fig. 6: Colour Deference Values Obtained At Deferent Marking Speeds and Types of Illumination for Stainless Steel

Fig. 6 shows the results obtained for stainless steel. In the case of daylight and fluorescent illumination, increasing colour deference with marking speed trend was uncovered. While this might appear to be favourable in a sense that faster marking throughputs could be implemented, there was a possibility that marking speeds beyond 10 m/s might produce uneven lines.

F. Agalianos, S. Patelis, P. Kyratsis, E. Maravelakis, E. Vasarmidis, A. Antoniadis [3] has been investigated industrial application of laser engraving of influence of the process parameters on machined surface quality. Laser engraving technology removes material layer by layer and thickness of layer is usually in the range of few microns. The aim of the present work is to investigate the influence of process parameter on surface quality when machined by laser engraving. The examined parameters like pulse frequency, beam speed, layer thickness. The surface quality was determined by surface roughness for every set of parameters. Experimental results on Al7075 material showed that the surface roughness depends on the frequency and the scan speed used. Based on the experimental work of the present paper in laser engraving of Al7075 using a Q-switched Yb:YAG fiber laser, it can be summarized that the surface roughness strongly depends on the frequency and the scan speed used. In addition it was proven that the resulted roughness depends less by the layer thickness. When considering all the experimental data of the current experimental plan, the best surface roughness was achieved when using a frequency of 20kHz, a scan speed in the range of 600- 700mm/s and a layer thickness of 4 and 6μm.

Sefika Kasman [4] has been investigated impact of parameters on the process response, a taguchi orthogonal analysis for laser engraving. Laser engraving is the most effective technique in the machining of hard materials has a complex geometry. The present study investigates the machinability of hard metal produced with powder metallurgy and puts forward a new approach to the relating to the laser engraving of P/M metals. The main objective of this study is to determine the impact of laser engraving process on powder metallurgy cold work tool steel: Vanadis 10. For this purpose, three process parameters like effective scan speed, frequency and laser effective power on the surface roughness and engraving depth. The taguchi and linear regression were used in the analysis. The experiments were accordance with an L9 orthogonal array based on S/N ratio for surface roughness and engraving depth. It was found that scan speed has statistically significant effect on both surface roughness and engraving depth. The scan speed appeared to be the main effective parameter for the two performance characteristics. The experimental results showed that increasing scan speed decreases both Ra and D. To minimize Ra, the scan speed should be selected at a high level (800 mm/s), whereas to maximize D, the scan speed should be selected at a low level (200 mm/s).Furthermore a mathematical model for surface roughness and engraving was established and estimated using regression.

Lyubomir Kostadimov Lazov, Nikolay Angelov Petrov [5] covers the results of several numerical experiments carried out with specific software working under MATLAB for marking of tool steel and electronic elements in their study. CuBr and Nd YAG lasers were used in this study. The use of numeric methods and simulations helps in the proper determination of the border zones and operation modes for different laser technological methods or processing of materials. They contribute also to the clarification of complicated issues associated with the thermo-chemical reactions, phase transitions, and outbreak of substance in liquid and evaporated from the zone of the laser impact. These preliminary experiments result in sparing of funds and time, which is of great importance for companies intending to introduce different laser methods in their industrial production process. Simulations with 3 different durations of pulse of laser radiation were achieved. Numerical calculations were performed with values (for laser sources and technological parameters) based on real experiments.

Hyuk-Jin Kang, Hyung-JungKim, Ji-SeokKim, Woon-YongChoi, Won ShikChu,Sung- hoonAhn [6] have studied that, the laser marking process is applied to the fabrication of light guide panels as the new fabrication process. In order to obtain a light guide panel which has high luminance and uniformity, four principal parameters such as power, scanning speed, ratio of line gap, and number of line were selected.

This system enables a designer to understand the tendency of optical performance according to variation of each factor before conducting complicated optical analysis which demands high cost and expert knowledge. Effective factors for making LGP by laser and DOE for obtaining improved levels for the factors were investigated as follows:

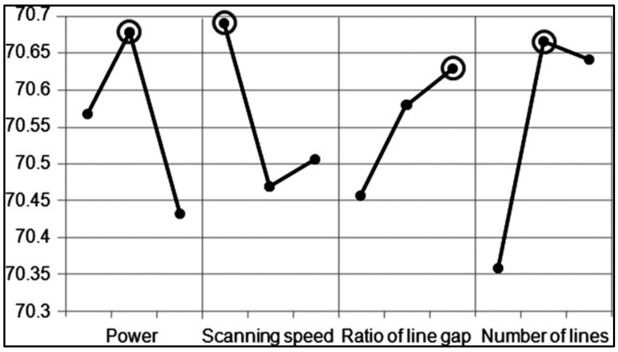

Fig. 7: Main Effect Plot for Average SN Ratio for High Luminance

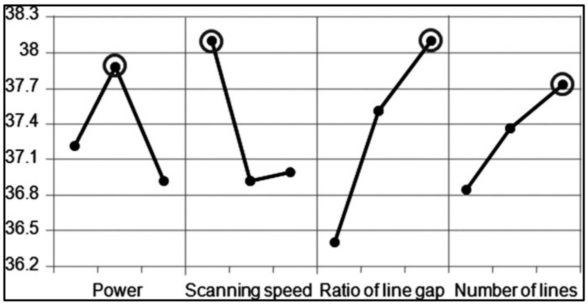

Fig. 8: Main Effect Plot for Average SN Ratio for High Uniformity

1) Four factors namely, power, scanning speed, gap between pattern lines, and number of lines were selected, and levels were decided accordingly.
2) 40 W, 30 mm/s, and 100:50 ratio provided the highest luminance (with 85 lines) and the highest uniformity (with 90 lines).
3) The number of lines had the greatest effect on luminance, and the ratio of line gap had the greatest effect on uniformity.
4) By Taguchi method, optimized levels of each parameter were found, and luminance of 3523cd/cm2 and uniformity of 92% were achieved using the laser machined BLU.

C. Leone, S. Genna, G. Caprino , I. De Iorio [7] has been investigated AISI 304 stainless steel marking by a Q-switched diode pumped Nd: YAG laser. The aim was to determine the correlation occurring between working parameters like pulse frequency, beam scanning speed, and current intensity and resulting mark visibility. To characterize mark feature, its width and roughness were estimated and analyses optical and scanning electron microscopy coupled with energy were dispersive X-ray technique were carried out. Laser marking tests were carried out on AISI 304 steel, using a Q-switched diode pumped Nd: YAG laser, in order to determine the best working parameters to obtain a given visibility. From the results obtained, the main conclusions are as follows:

1) Within the range of process parameters employed, mark width is only moderately affected by operating conditions
2) Mark contrast is affected by both surface roughness and oxidation, with the former probably prevailing at low contrast, and the latter at high contrast;
3) If the aim is obtaining good mark visibility, relatively low frequencies and average powers should be used;

4) The best mark visibility achievable is strictly dependent on the operating features of the particular laser system used.

Janez Diaci, Drago Bracun, Ales Gorkic, Janez Mozina [8] has presented a novel method for rapid and flexible laser marking and engraving of tilted, curved and freeform work-piece surfaces. The method is based on integrating a three-dimensional (3D) laser measurement system into a 3D laser marking system. The same laser source and optics for measurement and processing with a minimum of additional hardware components were used. A novel method is presented that allows rapid and flexible laser marking and engraving of tilted, curved and freeform work- piece surfaces.

The described method assumes tight integration of 3D measurement to laser manufacturing process. It has the advantage of rapid and accurate determination of the position and orientation of the surface relative to the marking system and interactive positioning of the mark. Existing 3D marking systems offer no suitable software tools to facilitate these tasks.

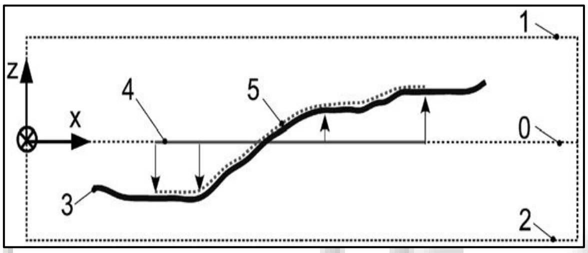

Fig. 9: 3D trajectory (5) of the processing beam focus is calculated by projecting a 2D mark (4) on the measured surface (3) along the z-axis.

An implementation is described where a digital camera is integrated into a 3D laser marking system in such a way that it is possible to measure the 3D shape of the work-piece surface just before processing. The measurement phase takes typically less than 10 seconds. Custom software has been developed which allows 3D surface measurement, placement of the laser mark onto the measured surface and process control. Examples are presented which demonstrate the advantages of the novel 3D system with respect to the existing industrial 2D and 3D systems. This paper has discussed key issues concerning an implementation of the method and presents typical examples of markings and engravings, which demonstrate the advantages of the method with respect to the existing industrial 2D and 3D laser marking and engraving methods. The method can also be applied to flexible laser structuring and micro processing of curved surfaces.

Ming-Fei Chen, Wen-Tse Hsiao, Wei-Lun Huang, Chun-Wei Hu, Yu-Pin Chen [9] has investigated According to the experimental results, the laser coding method does not cause damage to the bottom of the eggshell and the heat affect zone (HAZ) does not influence the egg theca. . In order to measure the dimension and the quality of the marking results, the scanning electron microscope (SEM) is used to measure the surface and cross-section of the eggshell. The depth of the marking results is approximately fourth of the eggshell thickness. The investigation principally uses the CO2 laser marking system to code on the eggshell. The Arabic number has been successfully marked on the surface of eggshell in this paper. The results provide that an increasing number of shots are influential to the dimensions of marked holes.

S. Rusu, A. Buzaianu, D.G. Galusca1, L. Ionel, D. Ursescu [10] proposes a study of the Influences of such radiation processing on an Aluminium alloy, a vastly used material base within several industry fields. For the novelty impact, femtolaser marking has been carried out, besides the standard commercial nanosecond engraving. All marks have been analysed using profilometry, overhead and cross section SEM microscopy, respectively EDAX measurements.

In the case of the nanosecond laser marks, due to the fact that the melt resulted from the laser beam scanning presents a very good stability and resistance to oxidation, high temperatures are reached only on the sample surface and for a depth which does not affect the functionality of the potential part. Mainly, the microstructure is not influenced, except for the superficial oxidation of certain elements. The marking depth obtained by employing laser treatment grows along with the laser beam power (for the same dimensions of the laser spot); the quality of the mark depends on the diameter of the laser spot, but also on the scanning speed. If the laser power exceeds 350W, obvious irregularities occur. The conclusion regarding processing is that a mean scanning speed of 10 mm/s and a 300-400 W laser beam can lead to a uniform mark, with a good texture and without massive oxide deposits. For femtosecond laser engraving, there is a completely different morphology, with a more continuous marking profile, of a more constant depth and with a well-defined outline. In the marked areas, re-crystallization areas are absent, except small amorphous oxide fragments. A detailed analysis of the molten area has indicated an in-depth penetration of the laser beam, with a clear separation into melting and ultra-fast solidification areas. The molten areas copy the geometry of the laser spot and maintain the sequential character and rapid solidification property of the beam scanning upon the alloy surface. In conclusion, despite the proven fact that femtosecond laser marking is superior from the microscopic imaging qualitative point of view, the proven benefits do not tip the scales in its favour, because of the technological costs and sheer applicable dimensions of the apparatus itself.

III. Conclusion

Many researchers have worked on different type of materials with various types of laser. Researchers have used varieties of design of experiment (DOE) technique like as full factorial design, Taguchi method, Box-Behnken design and Response surface methodology and different types of techniques for optimization like GLA technique, Grey relational technique, anova analysis. Some studies conducted on various behaviours like effect of process parameters on different types of material like AISI 304 steel, C45 steel, wood, moso bamboo, Al 7075 and output parameters like MRR, surface roughness, depth, kerf width, and contrast.

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