Parametric optimization of CO_2 Laser beam machining Process of Spur Gears

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ABSTRACT

Laser cutting is one of the most widely used thermal energy based non-contact advance machining process which can be applied for almost whole range of materials. The kerf width, quality of the cut edges and the operating cost are affected by laser power, cutting speed, assist gas pressure, nozzle diameter and focus point position as well as the work-piece material. Gears are power transmission devices, are compact and help in transferring power with the minimum loss. They are used in different application like high speed marine engines, automobile etc. different material are used for fabrication of gear like metals, acrylic, composites and alloys etc. In this paper, first spur gears were designed by CREO 5.0 solid modeling software as per specified dimensions. After that, spur gears were cut by the CO_2 laser in less time with better accuracy and control unlike traditional machining methods. The material of gear, its thickness, and size were kept as constant. Standoff distances, laser power and cutting speed were taken as input parameters. To reduce the cost of experiments, L_9 Taguchi design of experiment was employed. The significance of the parameters on overall mean kerf width (KW) was analyzed using Minitab 19.0 software. It was found that laser power has dominant effect on kerf width.

Keywords: CO_2 laser cutting, Spur gears, laser power, standoff distance, cutting speed, kerf width

1- INTRODUCTION AND LITERATURE REVIEW

Laser, which is stands for Light Amplification by Stimulated Emission of radiation, is an electrical-optical device that produces coherent radiation. Simply put, a laser is a device that creates and amplifies a narrow, intense beam of coherent light. Nowadays, laser is widely applied in today's industry. Lasers are widely used in industry for cutting and boring metals and other materials, in medicine for surgery, and in communications, scientific research, and holography [1, 2]. The main advantages of laser beam machining are ease of automation for complex cutting patterns, absence of tool wear and breakage, ability to cut at shallow angles, and rapid cutting rates. As it is a noncontact process, energy transfer between the laser and the material occurs through radiation. No cutting forces are generated by the laser, so there is no mechanically induced material damage, no tool wear, and no machine vibration.

Laser cutting machines have significant contribution in many industrial applications. In the plastic industry, lasers are useful to cut and make engraving accurately and to make complex geometries. The effect of the CO_2 laser cutting parameters on the resulting cut surface quality for different plastics was reviewed as follows:

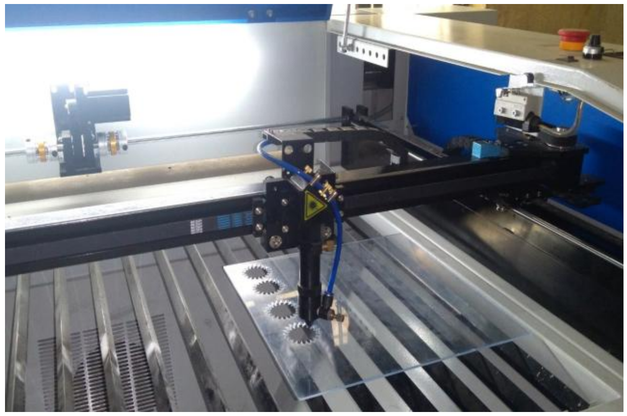


Figure 1. CO_2 laser cutting process of spur gear

Caiazzo et al. [3] have studied the laser cutting of three different polymeric plastics. It was found that cutting speeds have the most significant effect on the different aspects of the quality of the cutting edge. Choudhury and Shirley [4] have investigated the CO_2 laser cutting of three polymeric materials (PP), (PC) and Polymethyl-methacrylate (PMMA). They found that the cut quality in the case of PMMA is much better than in the case of PP and PC. It was found that the roughness is inversely proportional to the laser power, the cutting speed and the compressed air pressure. It was observed that PMMA has a smaller HAZ, followed by PC and PP. Davim et al. [5] have studied the cut quality of PMMA using a CO_2 laser. They found that the HAZ increases with the laser power and decreases with the cutting speed. Also, they found that the surface roughness increases with a decrease in laser power and an increase in cutting speed. Kurt et al. [6] have studied the effect of the CO_2 laser cutting process parameters on the dimensional accuracy and surface roughness of engineering plastics. It was found that the cutting speed and laser power must be regulated to obtain the desired dimensions and surface quality. Bahr et al. [7] have studied the laser cutting of plastic scintillator and light guide materials. It was found that a scintillator with thickness of up to 10 mm can be laser cut with a reflection factor of 80%.

Davim et al. [8] have studied the effect of process parameters (laser power and cutting speed) on the laser cut quality of polymeric materials with different thicknesses. It was found that the HAZ increases with the laser power and decreases with the cutting speed. Berrir and Birkett [9] have investigated cutting and drilling of Perspex. It was found that increasing the power, increases the depth of the cut, whereas, increasing cutting speed decreases the depth of the cut. Black [10] found that the pressure of the shielding gas (normally air) must be kept above 0.1 bar, to prevent vapour ignition. Zhou and Nuss [11] studied that laser cutting is faster and cleaner and reduces the time spent on post-operation work. Tagliaferri et al. [12] found that the thermal properties of the fibres and matrix are the principal factors which affect laser cut performance of fibrous composites. Groke and Emmelmann [13] have investigated the effect of laser cutting parameters on the quality of carbon fibre reinforced plastic. It was found that both the HAZ size and the KW decrease with increase in cutting speed and small energy inputs. Riveiro et al. [14] studied the effect of different process parameters such as the pulse frequency, the pulse energy, the duty cycle, and type, and pressure of the assist gas on the cut quality. It was found that proper selection of process parameters allowed good quality cuts to be obtained. Dillio et al [15] found that cracks were detected in plies with the fibre direction at 90° to the cutting direction.

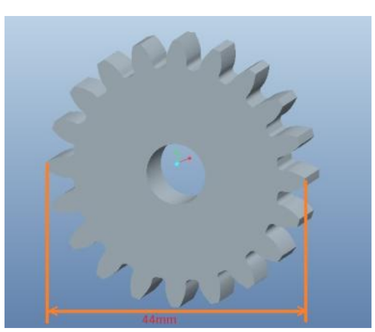
Voisey et al. [16] conducted Nd:YAG laser drilling experiments. It was found that MRR first increases and then decreases after a critical value with increasing power density for all metals. Lau et al. found that the MRR during laser machining of concretes shows increasing trend with both laser power and cutting speed. Ghany et al. [17] have observed the same variation of KW with cutting speed, power and type of gas and pressure as above in Nd:YAG laser cutting of austenitic stainless steel. They have also found that on increasing frequency the KW decreases. Karatas et al. [18] found that the KW reduces to minimum when the focus setting is kept on the workpiece surface for thin sheets and inside the workpiece for thicker sheets in hot rolled steel using CO2 laser. Thawari et al. [19] have performed Nd:YAG laser cutting experiment on 1 mm thick sheet of nickel-based superalloy It was found that on increasing the spot overlap, the KW increases. The shorter pulse duration yields lower taper kerf compared to a longer duration pulse. Borki et al. [20] investigated the laser surface transformation hardening of 4340 steel spur gears. Laser power, scanning speed, and rotation speed are used as input process parameters. The cumulative contribution of the three parameters in the hardened depth variation represents more than 80% with a clear predominance of laser power. Anghel et al. [21] conducted CO_2 laser cutting of miniature gears of stainless steel 304. Focal position was found to be the most significant parameter. Zhai el al. [22] developed a new modeling method using Scilab software. This method can more quickly and accurately produced the standard spur or modified spur gear. Nieszporek et al. [23] presented the principles of the technology of machining gears on universal CNC machine tools. The developed technology enabled the longitudinal modification of the tooth profile. In the present work, CO_2 laser cutting of spur gear made of acrylic was studied experimentally in terms of KW and MRR. This work will be quite directional in design and fabrication of spur gear with better accuracy and control using CO_2 laser.

2-EXPERIMENTAL PROCEDURE

First of all, Spur gears were designed in specified dimensions using ‘CREO 5.0’ solid modeling CAE software as shown in Figure 2 (A). Cutting Experiments using CO_2 laser were performed on Acrylic sheet of thickness 2.0-3.0 mm. The selection of process parameters and their range is shown in Table 1. After conducting experiments, the KW is measured by a digital vernier caliper with an accuracy of 0.01 mm. Eight different measurement points were taken and the average was considered as the mean KW for each cut sample of spur gear as shown in Figure 2 (BKW is dependent on the combined effects of laser power, cutting speed and standoff distance. The HAZ was detected using the high resolution digital camera. Some damage in the teeth profile of few spur gears was also observed (Figure 5).

Table 1: Process parameter and their range

Parameters	Levels		
	1	2	3
Laser power (W)	30	60	90
Cutting speed (mm/s)	10	15	20
Standoff distance (mm)	4	8	12



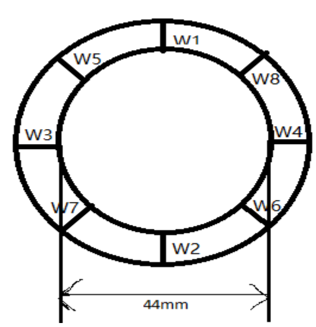


Figure 2: (A) 3D solid model of Spur gear designed in CREO 5.0 CAE Software (B) Determination of mean kerf width

3-RESULTS AND DISCUSSION

The S/N ratio for "smaller is better" target (KW) is calculated as follows:

$$\eta_i = -10 \log 10 (y_j^{\,2})\ldots\ldots\ldots(\mathrm{I})$$

where y_j is the value of the *i*th experimental response for *j*th quality characteristics.

With the help of above responses of S/N ratios, analysis was completed and graphs were plotted between mean KW and MRR for three laser process parameters (laser power, cutting speed and standoff distance) using Minitab 19.0 analytic software.

It is observed that the mean KW increases with laser power as shown in Figure 3. Increasing the laser power increases the amount of heat input to the substrate. Usually, power density criterion is used to account for the overall effects of power and beam spot diameter. The cutting speed has least significant effect on mean KW. The KW decreases with increase in cutting speed and after that at a point KW starts increases as shown in Figure 3.

The effect of stand-off distance appears less significant. The pattern of the mean KW appears quadratic across varying stand-off distance with reported minimum KW at 8 mm. The smallest beam spot area could be identified in this region. The reason for this quadratic relationship is because the power density increases with the inverse square of the mean spot diameter. The significance of each process parameters was calculated using Minitab software and ANOVA analysis. According to ANOVA results shown in Table 2, laser power is the most dominant and followed by standoff distance and cutting speed (the least influential) for KW. The contour plots for KW were also drawn between these three input parameters (Figures 4(A), (B)).

The change in metallurgical characteristics of laser machined workpiece is mainly governed by HAZ. This recast zone has entirely different property as compared to parent material. Therefore, aim is always to remove or minimize the recast layer. Some amount of damage to teeth profile and HAZ is observed in few cut samples of spur gear (Figure 5).

Table 2: Factor response table for KW used to determine the rank (percentage contribution) from each parameter

Levels	S/N response data (dB)		
	Laser power (W)	Cutting speed (mm/s)	Standoff distance (mm)
1	8.64	7.22	7.97
2	6.96	6.47	6.7
3	5.85	7.79	6.78
Delta	1.68	0.75	1.27
Rank	1	3	2

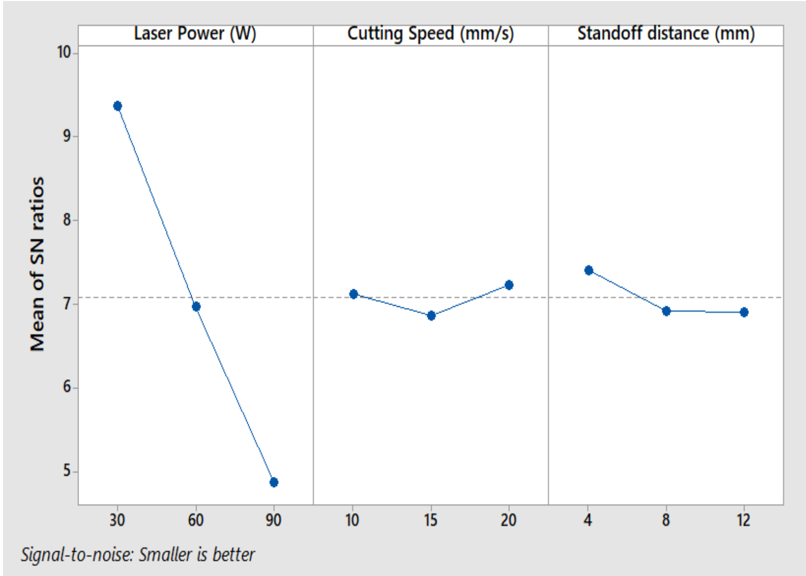
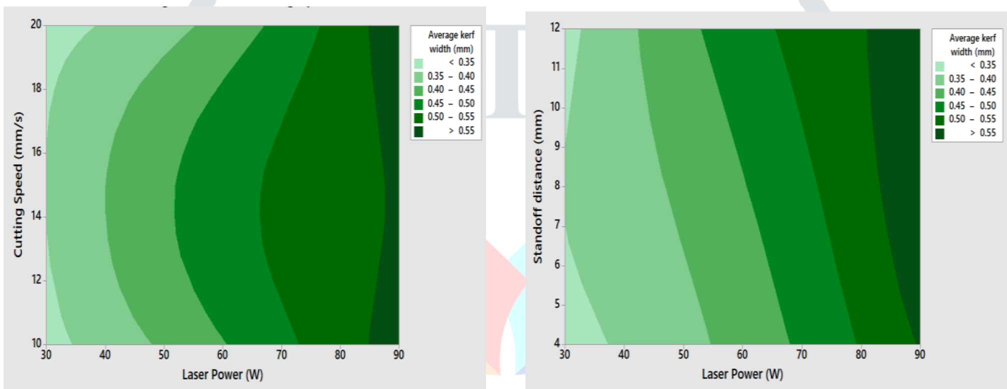


Figure 3: Main effect plots for S/N ratios for kerf width



4(A) 4(B)

Figure 4 (A) Contour plot of mean KW (A) for laser power and cutting speed (B) for laser power and standoff

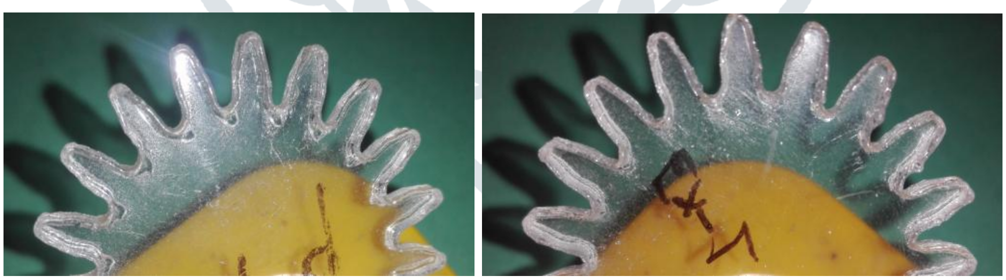


Figure 5. Teeth profile damage associated with HAZ in few laser cut samples of spur gear

4-CONCLUSIONS

Following conclusions have been drawn from the present work of CO_2 laser cutting of spur gear made of acrylic.

KW decreases with increase in laser power.

Initially KW decreases with increase in cutting speed and then starts increases with further increase in cutting speed.

KW decreases with increase in standoff distance.

From delta statistics, laser power is kept at rank 1 (most important) followed by standoff distance at rank 2 while cutting speed is kept at rank 3 (least important).

Optimum combination for minimum KW is at higher laser power (90 W), medium cutting speed (15 mm/s) and higher standoff distance (12 mm).

Some amount of damage to teeth profile and heat affected zone is observed in few cut samples of spur gear.

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