

Study of CO₂ Laser Parameters for Generating Slot with Multi Pass Using DOE Approach

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ABSTRACT: The micromachining can be employed by using laser as a source for evaporation of material. The control of power and traverse speed of head are main parameters at the autofocus distance from workpiece to laser head. The present work deals with imparting laser beam on passing laser beam on straight line for multipass to observe material removal and the depth of cut obtained by the experimentation is used for statistical analysis to develop the predictive model. The predictive model developed for acrylic material found with fair closeness with experimental depth of cut obtained.

KEYWORDS: CO₂ laser, slot, multi pass, micro machining, DOE

I. INTRODUCTION

Laser beam cutting (LBC) process has a wide range of applications in different manufacturing processes in industry due to its advantages of high cut quality and cost effectiveness through mass- production rate[1]. Micro machining using laser is the most common industrial application now a day in manufacturing, the basic process of laser machining is the use of a focused light beam to generate highly localized heating that melts the material. The molten material is subsequently blown away by a gas jet. Controlled, local laser heating can also be used to modify surface layers and textures of materials. One of the potential advantages with laser machining is that the cutting is a contamination-free, near-zero force operation, thereby eliminating the relatively high force loads and contamination potential common with traditional machining methods [2]. High intensity laser beam can be directed to a narrow region in order to instantly evaporate material with very narrow heat affected zone. This ability to cut instantly with extremely narrow laser beam distinguishes it from other cutting methods. The key to success in precision cut by laser depends on many factors such as laser characteristics, material properties of the specimen, and manufacturing parameters [3]. In precision manufacturing the quality of the cut is often measured based on the shape of the groove and amount of material removal. Therefore, better understanding of the process and role of various parameters are essential for investigation [4-5].

There have been numerous investigations on laser applications. Some investigated states of stresses in fracture, chemical compositions and properties, and heat transfer on different types of materials such as metals, composites, ceramics, and metallic glasses. Others studied heat treatment effects on the material by laser irradiation. Considerable researches have been done with heat transfer models on the effects of laser characteristics and material properties for the quality of laser processes. Laser drilling is an important industrial process to produce various sizes of holes for critical applications, such as cooling holes in turbine components. In micro-hole drilling via laser ablation, it is important to control material removal rate (MRR), ablation depth, and aspect ratio. Important process parameters include laser pulse duration, energy, peak power, the material properties [6]. The entrance circularity increased with increase in laser power but it decreased with increase in hole diameter. Exit circularity increased with increase in both laser power and hole diameter. HAZ thickness decreased with increase in pulse frequency at constant laser power. Taper decreased with increase in laser power at constant pulse frequency [7]. The contour dimensions of the drilling

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

hole are significantly affected by laser power and inclination angle [8]. At a given thickness, the MRR increases with an increase of laser parameters, i.e., pulse width, pulse frequency, and peak power. The effects of pulse width and pulse frequency are more prominent than those of peak power in enhancing the MRR. As the thickness of workpiece increases the MRR also increases [9]. It is found that increasing the laser power intensity enhances the kerf width size and this is more pronounced with reducing cutting speed. It was reported that a small variation in laser power results in a large variation in the kerf size. And also the influence of cutting speed was less than that corresponding to the laser power. Also, observed that by using defocused laser beam, which in retrain reduces the laser power density, would increase the kerf width size [10]. Increasing laser power and energy coupling factor increase the kerf width size and also any increase in the cutting speed reduces the kerf width. It was found that the laser power has a highly significant effect on the kerf size [11]. The current experimentations are on the base of study the shape of generated hole by CO₂ laser micromachining and the slot generated by using multi pass technique as well as the change in the shape with change in the input CO₂ laser parameters.

II. EXPERIMENTAL PROCEDURE

The experiments are performed on the MERCURY Laser Pro CO₂ laser machine 25 watt capacity and pure acrylic specimen with 6 mm thickness is selected. Here acrylic material is preferred due to the absorptivity of laser beam energy is unity [12]. Laser cutting on acrylic material is non toxic process and due to its transferencey generated cavity can be easily measured in the optical measurement system with higher accuracy. The thickness of acrylic material is selected by using try end error method in such a way that the generated cavity by minimum and the maximum level of the parameters should easily accommodated in the material. CO₂ laser machine works with interfacing software. In the CO₂ laser machine the input parameters are power and speed of laser head. On the control console power and speed are in the percentage form (i.e. 20% power = 5 watt power), the maximum travelling speed of laser head is 42 IPS (inch per second, i.e. 10% speed = 4.2 inch per second). The experiments are performed at the focus distance of 50 mm. The machine setup used in present work is CO₂ laser machine which removes the materials by two mode vector mode and raster mode. Vector mode gives the line cut or curvature cutting ware as the raster cutting cuts the cavity on the material.

The design of experiments (DOE) method is followed for deciding the numbers of experiments run. The numbers of parameters are three or less than three the full factorial method is suitable for the optimization [13-14]. For generating slot input parameters are power (p), laser head speed (s) and numbers of overlapping lines (n_l).

III. EXPERIMENTATION FOR GENERATING SLOT GEOMETRY

The selection of cutting parameters are on the bases of try end error method in such a way that the generated slot should be in the range of specimen size of 6 mm and DOE by the full factorial method have suggested the sets of experiments as mention in table no.I.

Table I : Sets of Parameters for Experimentation

Sr.No	Power (p) (%)	Speed (s) (%)	Numbers of overlapping lines (n _l)
1	-1	1	0
2	-1	-1	1
3	1	-1	0
4	-1	0	0
5	1	1	0
6	0	0	1
7	1	0	-1
8	0	1	1
9	0	-1	-1
10	-1	-1	0

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

11	0	-1	1
12	0	1	-1
13	0	-1	0
14	1	0	1
15	0	0	-1
16	1	0	0
17	1	-1	-1
18	-1	-1	-1
19	-1	0	1
20	-1	0	-1
21	1	-1	1
22	0	0	0
23	0	1	0
24	1	1	-1
25	-1	1	1
26	-1	1	-1
27	1	1	1

By doing the autofocus and selecting the parameters which gives the cutting limited to the specimen thickness the 60, 40, and 20 numbers of overlapping lines are engraved on the particular specimen as shown in fig1. with varying the power 90%, 60%, and 30%. With the combinations of speed 70%, 40%, and 10%. The experiments are performed as per run order suggested by the statistical software.



Fig. 1 Specimen 30×15×6 mm³ size

The numbers of overlapping lines are placed on the one layer of interfacing software file as shown in fig.2

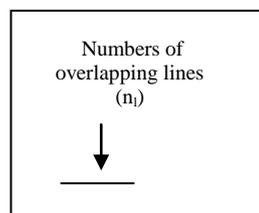


Fig. 2 Overlapping lines in interfacing software

By using the various power levels, numbers of overlapping lines and various head travelling speed the generated slot on the acrylic material specimen is as shown in fig.3.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015



Fig. 1 Machined specimen in CO₂ laser machine by overlapping of lines

The width of slot can be measured on the microscope interfacing with the computer with the software and the measurements can be taken using this interfacing software in the precision of 0.1 micron. The measurement interface is as shown in fig.4.

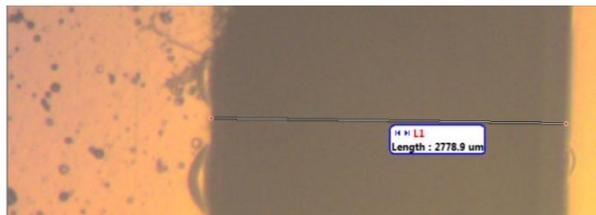


Fig. 4 Measurement of width of slot in computer interface of microscope

For measurements of slot depth all the specimens are arranged on the flatbed scanner with scale as shown in fig.5 indirect light is blow on the specimens to highlight the slot clearly that can be easily scan in the scanner.



Fig. 5 Scanning of specimen on flat bed scanner

The option of high resolution is selected for getting the scanning image that can be further processed through cad drafting package. In CAD package the a scale is developed by using the scanned steel rule as the reference. All the groves are measured by mapping the groove length with the generated scale as shown in fig.6.

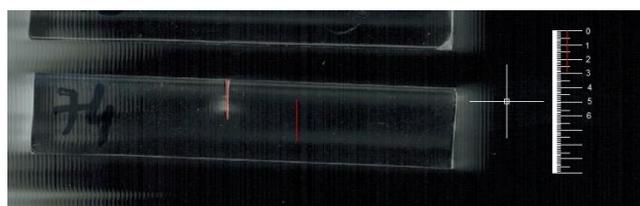


Fig. 6 Measurement of slot by mapping of line in cad software

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

The width of groove measured from the microscope and the depth of groove measured from the cad package are mansion in the following table no II.

Table II : Measured Value of Width and Depth of Slot

Sr. No	Power (p) (%)	Seed (s) (%)	No.of Overlapp ing lines(n_1)	Width (w) (mm)	Depth (t_g) (mm)
1	30	70	40	0.383	0.60
2	30	10	60	0.538	0.89
3	90	10	40	0.742	3.58
4	30	40	40	0.383	0.57
5	90	70	40	0.587	2.21
6	60	40	60	0.547	1.41
7	90	40	20	0.566	1.64
8	60	70	60	0.558	1.80
9	60	10	20	0.611	2.05
10	30	10	40	0.507	0.95
11	60	10	60	0.679	2.54
12	60	70	20	0.489	1.11
13	60	10	40	0.653	2.70
14	90	40	60	0.612	2.23
15	60	40	20	0.522	1.06
16	90	40	40	0.574	2.18
17	90	10	20	0.728	2.95
18	30	10	20	0.484	0.85
19	30	40	60	0.387	0.62
20	30	40	20	0.342	0.46
21	90	10	60	0.808	4.03
22	60	40	40	0.548	1.35
23	60	70	40	0.510	1.40
24	90	70	20	0.445	1.97
25	30	70	60	0.398	0.57
26	30	70	20	0.358	0.59
27	90	70	60	0.622	2.12

IV. DEVELOPING PREDICTIVE MODEL FOR SLOT WIDTH AND SLOT DEPTH

The measured values of slot width and slot depth are submitted in the statistical software work sheet and performed the statistical analysis in the statistical software for finding out the predictive equations of the response values individually and calculating the analysis of variance (ANOVA). The following tables III to VIII shows the parameter tables of regression in the analytical software.

Table III : General Linear Model : Width (w) Versus Power (p), Speed (s), Numbers of Overlapping Lines (n_1)

Factor	Type	Levels	Values
p	Fixed	3	30, 60, 90
s	Fixed	3	10, 40, 70
n_1	Fixed	3	20, 40, 60

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Table IV : Analysis of Variance for Width(w), Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
p	2	0.212381	0.212381	0.106190	117.15	0.000
s	2	0.132871	0.132871	0.066436	73.29	0.000
n ₁	2	0.020386	0.020386	0.010193	11.24	0.001
Error	20	0.018129	0.018129	0.000906		
Total	26	0.383767				

Table V : Regression Analysis : Width (w) Versus Power (p), Speed (s), Numbers of Overlapping Lines (n₁)

Predictor	Coef	SE Coef	T	P
Constant	0.36507	0.03664	9.96	0.000
p	0.0035259	0.0003779	9.33	0.000
s	-0.002592	0.0003779	-6.86	0.000
n ₁	0.0016778	0.0005668	2.96	0.007

S = 0.0480985, R-Sq = 86.1%, R-Sq (adj) = 84.3%

Table VI : General Linear Model : Slot Depth (t_g), Versus Power (p), Speed (s), Numbers of Overlapping Lines (n₁)

Factor	Type	Levels	Values
p	Fixed	3	30, 60, 90
s	Fixed	3	10, 40, 70
n ₁	Fixed	3	20, 40, 60

Table VII : Analysis of Variance for Width, Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
p	2	15.7607	15.7607	7.8803	80.85	0.000
s	2	5.5123	5.5123	2.7561	28.28	0.000
n ₁	2	0.7811	0.7811	0.3905	4.01	0.034
Error	20	1.9494	1.9494	0.0975		
Total	26	24.0035				

Table VIII : Regression Analysis : Slot depth (t_g), versus Power (p), Speed (s), numbers of overlapping lines (n₁)

Predictor	Coef	SE Coef	T	P
Constant	-0.0093	0.3138	-0.03	0.997
p	0.03113	0.003237	9.62	0.000
s	-0.01513	0.003237	-4.67	0.000
n ₁	0.009806	0.004856	2.02	0.055

S = 0.412007, R-Sq = 83.7%, R-Sq (adj) = 81.6%

The regression analysis gives the P value in acceptable limits so models are acceptable. The regression analysis gives the mathematical equation of the output parameters like width of slot and the depth of slot in the form of the input variables power, speed and numbers of overlapping lines. The individual equation of width of slots and the depth of slots are as mention below.

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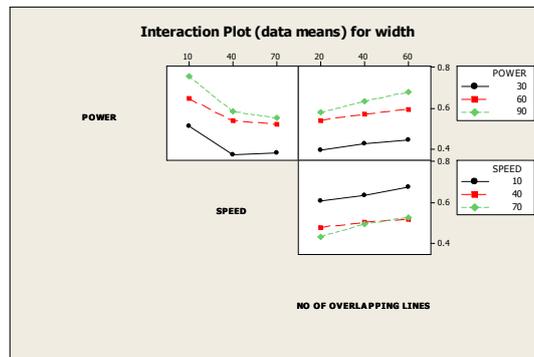
Vol. 4, Issue 8, August 2015

$$\text{Width (w)} = 0.365 + 0.00353 p - 0.00259 s + 0.00168 n_1$$

$$\text{Depth (t}_p\text{)} = -0.009 + 0.0311 p - 0.0151 s + 0.00981 n_1$$

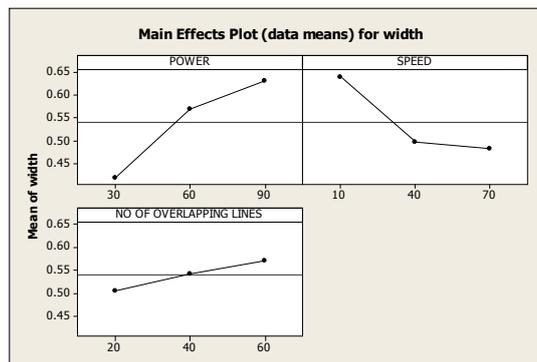
V. RESULTS AND DISCUSSION

From the output parameters the combine graph of slot width verses power, speed and numbers of overlapping lines are generated as graph no 5. The graph indicates that as the laser speed is increase the width of slot is decrease with constant power level because as the speed of laser head is increase the interaction time between laser spot and the material is decrease so due to less time of interaction less amount of material is evaporated. Similarly as the numbers of overlapping lines are increase the width of slot is increase with particular power levels. Here as the numbers of overlapping lines are increase then the numbers of laser passes over the material is also increase so width is increase due to expansion of heat effected zone at the edges.



Graph 5 Width of slot verses speed and numbers of overlapping lines with particular power levels

Graph 6 shows the mean data of width verses power, speed and numbers of overlapping lines. It shows that as power is increase the width of slot is increase, as the speed of laser head is increase the width of slot is decrease and as the numbers of overlapping lines are increase the width of slot is increase.



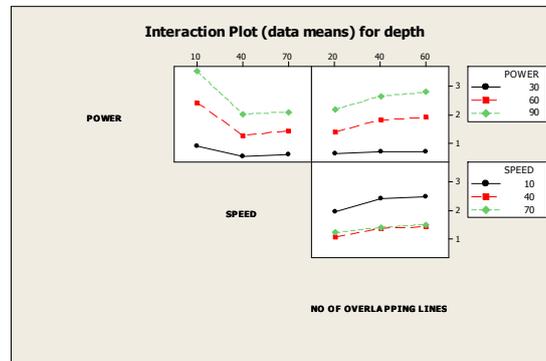
Graph 6. Slot width verses power, speed and no. of overlapping lines (mean data)

Similar to slot width the depth of slot is measured and the graph is generated slot depth verses speed and numbers of overlapping lines as shown in graph 7. It shows that as the speed of laser head is increase the depth of slot is decrease with the particular power level. The behavior of increasing the speed verses slot depth may be curvature instead of linear. Also the increments in numbers of overlapping lines results in to increase in depth of the slot for particular power levels.

International Journal of Innovative Research in Science, Engineering and Technology

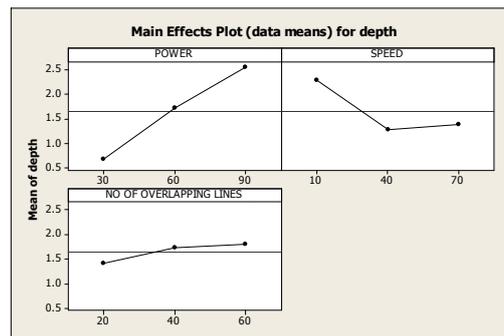
(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015



Graph 7 Depth of slot verses speed and numbers of overlapping lines with particular power levels

Graph 8 is the combination of slot depth verses power, speed and numbers of overlapping lines. It indicates as power is increase the slot depth is increase, as the laser cutting head speed is increase the slot depth is decrease and as the numbers of overlapping lines are increase the slot depth is increase



Graph 8. Slot depth verses power, speed and numbers of overlapping lines (mean data)

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