PROCESS OPTIMIZATION OF CO_2 LASER DRILLING ON C65 (SPRING STEEL)

Siddhant R. Gade[1]*, Dr. K. H. Inamdar [2]

1PG Student, Department of Mechanical Engineering, Walchand College of Engineering, Sangli- 416415

2Associate Professor, Department of Mechanical Engineering, Walchand College of Engineering, Sangli- 416415, India

Abstract: *Now a day's non-conventional process findings are coming into picture because of their low efficiency and economy. Laser drilling is a process has been used in non-conventional industries like aerospace, power, electronic,and related marine applications etc. There are input parameters such as laser power, gas pressure, scanning speed etc. that affect the quality of laser drilled hole like circularity, heat affected zone (HAZ), taper, spatter loss etc. This paper is focusing on research work and results in laser drilling based on Taguchi based experiment. We have to know how a perfect hole characterized .This paper, gives the information regarding the parameters available, range specifications.*

Keywords: ***Non-Conventional, CO_2 Laser drilling, Paper***

1. INTRODUCTION

1.1 Brief introduction laser drilling

Manufacturing is the process through which transformation of material takes place into goods to satisfy human needs [1]. In the engineering field, it is found to be, a machining is an important area. It is noticed that, there is need to use advanced technologies in the production process to fulfill today's challenges. Laser machining is the advanced machining process belongs to family of machining and laser- based machine tools can be considered as an advanced machining process. Now a day's, laser-based machining processes are referred as non-conventional machining process.

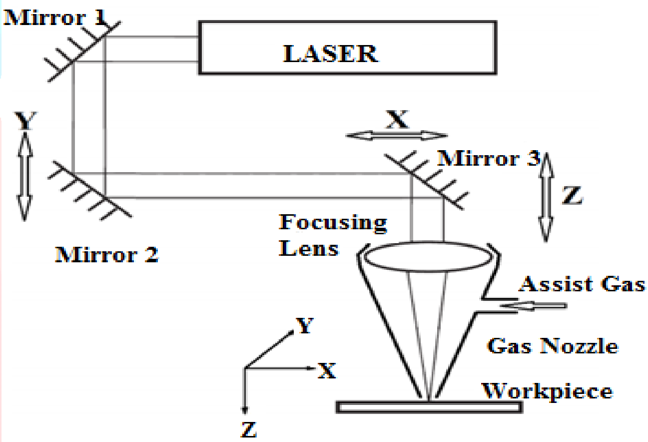

Figure 1.1: Laser Drilling Process

An American scientist Charles Hard Townes and two Soviet scientists are Alexander Mikhailovich Prokhorov and Nikolai Gennediyevich Basov gave the basic concept of laser [2]. Now a day's laser based machining processes have been widely used for different applications like drilling, cutting, forming etc. If the component is going to be used in a precise device, variation among holes such as taper, roundness etc. must be within certain limits. Laser Drilling is the one of application where the heat of laser beam is used to melt and evaporate the required area of the material. For industry application like in aerospace, power, electronic and sheet metal forming Laser drilling has become an integral part.

The Quality of end product is determined by assessment of geometric features of laser drilled holes such as circularity at the entrance, exit ,and taper of hole as well as heat affected zone (HAZ) and spatter loss after laser process [3]. It is possible to control the laser beam precisely by an arrangement of optical setting, so that it is possible to get desired hole features with high accuracy and less defects.. Vaporization and melt ejection are the two mechanisms through which material removed from the workpiece during drilling [4]. Laser drilling is not restricted by the hardness, strength, and brittleness of materials. CO2 laser drilling has become one of the important factors in advanced machine field for its high speed, no tool loss, low cost [5].

1.2 Parameters of laser system

Focal length laser, position of nozzle with respect to material that is distance between them, assist gases, laser wavelength, peak power of laser, pulse width, number of pulses, properties of material, environmental conditions etc. the parameters of laser system affects the quality laser drilled hole [1,3], some of them are discussed below.

Laser wavelength

The spot diameter of laser is depends on the wavelength of laser to be produced, short wavelength with same quality of laser beam can produce spot diameter of small size and vice versa. As spot diameter small the intensity of laser is high and vice versa. Also shorter wavelength lasers have better energy coupling with workpiece and less absorption by plasma [2, 3].

Peak power of laser

The quality of drilled holes increases as power density and peak power of laser beam increases. This is due to ablation process. However it is found that vaporization dominated drilling is slower than molten ejection [3].

Pulse width

Pulse width is known as pulse duration. Short pulse length gives good quality of hole thus there is much more interest having pulse length ranges from a fraction of a microsecond that is 1 x 10^{-6} micro-second to 1 x 10^{-15}femto-second range [3].

Assist gas

Numbers of process gases are used to assist the laser drilling process, and are reactive or inert. In CO2 laser drilling, CO2 gas is used as exited gas to produce laser light but not to assist laser process. Oxygen or nitrogen or air as reactive assist gases commonly used [3].

1.3 Types of laser drilling

According to diameter, depth and required accuracy of hole to be produced, there are three main types of laser drilling processes.

Direct drilling

The hole is produced in a single shot of laser pulse; this limits the maximum achievable length in workpiece. Also with direct drilling possibility of taper in hole considerably increases [3].

Percussion drilling

In this type, at fixed location a number of laser pulses are applied on workpiece and each pulse removes the small amount of material. This enables operator to produce hole with considerable depth. But it has limitation; hole with large diameter is not possible [3, 12].

Trepanning drilling

In this process, firstly a hole is quickly pierced to drill the hole into the material, then laser is moved around the desired path of hole. This method is good for large diameter but has slower rate than other two processes [3, 6].

2.LITERATURE REVIEW

Literature review is required to gain precise knowledge about laser drilling process and its analysis. Before going to research directly, it is required to do literature review gives the data related to how much research has been done and where the research gap would available. Drilling of materials like stainless steel and titanium alloys is difficult due to work hardening and rubbing of tools against the hardened zone causing rapid tool wear [7, 8]. Laser drilling is an alternative way for micro-drilling. Since there is no contact between tool and the work materials, the problem of chatter and vibration during machining can be eliminated [9].

2.1 Geometry of hole

During manufacturing of circular hole, circularity of hole at entrance and exit are the important attributes as well as taper of hole which greatly influence the quality of drilled hole. To produce the parts from range of one to tens of thousands holes per piece as micro-hole drilling process, Sandip Kumar Bhuyan studied and developed the use of visible and UV sources with correct wavelength and pulse duration. Process having maximum L/D ratio and minimum circulate error gives the best drilling he concluded [10]. Bharatish et al. [11] represents the work on CO2 laser drilling of alumina ceramics. They used orthogonal array experimentation and response surface methodology to find out effect of laser parameters on the quality of drilled holes such as Circularity of drilled hole at the entry and exit, heat affected zone and taper in alumina ceramics. Finally they concluded that, both entrance and exit circularities were significantly influenced by hole diameter and laser power, heat affected zone was influenced by frequency and Taper was also significantly influenced by laser power.

The percussion drilling process, on the basis of repeatability characteristic of produced drilled holes for same fixed parameters investigated by G.K.L. Ng and L. Li [12]. They drilled total 665 holes for 19 set of parameters that is 35 holes for each set. They found that circularity of drilled holes ranges from 0.94 to 0.87 and is correlated with repeatability. Finally they concluded higher peak power and shorter pulse width gives better repeatability of hole geometry. Also Melt ejection and spatter formation contribute to the poor repeatability of the process they concluded. Hussein et al. [13] did the Laser Hole Drilling of Stainless Steel 321H and Steel 33 using 3D CO2 Laser CNC Machine. Firstly they carried out simulation work on COMSOL 3.5A software, for this they took two cases with or without use of assists gases through nozzle to obtain optimum result for temperature distribution. After this they plotted the graph for same two cases, one is between power and diameter of hole, second plot between exposure time and power and lastly they analyses the result. Then they carriedout two experimental works with or without assists gases and analyses the result. They found that, as power increases hole diameter increases and quality of hole is increase when assist gas is used. Lastly they compare the experimental with simulated work.

2.2 Heat affected zone (HAZ) and spatter deposition

A heat-affected zone (HAZ) is the portion of the base metal that does not melt during cutting but whose microstructure and mechanical properties were altered by the heat. With the use of femto-second fiber laser micro holes were fabricated by Huan

Huang et al. [15] in both transparent (glasses) and non-transparent materials (metals and tissues). Optical microscope and scanning electron microscopy (SEM) were used to characterise and evaluate hole shape and morphology. They found complete absence of visible cracks or thermal damage was observed around the edges of the drilled in both hard and soft tissues. Increased efficiency of the laser beam due to the highly absorptive property of the coating resulted in increased vaporization and reduced molten material. The effect of process parameters on spatter deposition was investigated by Low et al. [16].

Tsay et al. [17] investigated the fatigue crack growth behaviour in 304 stainless steels annealed by a CO2 laser. The notch is produced in laser annealed zone (LAZ) which is perpendicular to LAZ. They showed residual tensile stress obtained around the center of LAZ and the residual stress field changes gradually from tensile into compressive stress with increasing the distance away from the centreline of LAZ. Experimental result shows that laser-annealed specimen tested under low thermal conductivity had a higher resistance to fatigue crack growth in the region preceding the LAZ after introducing a notch perpendicular to the LAZ. The result showed that residual compressive stresses closes the crack and tensile stress do not allow crack to propagate ahead of tip.

2.3 Optimization techniques

Choudhury et al [20] did the laser trepan drilling on Acrylonitrile butadiene styrene (ABS) and Polymethylmethacrylate (PMMA) polymer material. Polymeric material having 5mm thickness with laser power, assist gas pressure, cutting speed and standoff distance were four input parameters chosen for different 2mm, 4mm and 6mm diameter of hole. L9 orthogonal array for different 4 factors and 3 levels for each factor were used to perform experiment. From ANOVA analysis, they found that the optimum levels of 4 process variables were different for different hole size and material. Also they found that for ABS polymer circularity of hole at entrance more than that of exit while for PMMA it was opposite. Taguchi's design of experiment (DoE) technique was used by S. Bandyopadhyay et al. [21] to study the effects of the laser process variables on the quality of the drilled holes and to obtain optimum processing conditions. For laser cutting of Kevlar-49 using CO2 laser, Taweel et al. [22] have proposed a Taguchi method. Implementation of Taguchi method helps to systematically analyze the effect of each parameter on quality of laser drilled hole such as taper, kerf width and dross height. However DoE method is used for optimization of single response; therefore there is need to go for other methods. Grey relation analysis along with DoE suggested by Tosun [23].

3.MATERIAL SPECIFICATIONS

3.1Material Selection and Input Parameters Level

Material selected for dissertation work is as per the application of CO_2 laser drilling process, this process is widely used in electrical, aerospace and automobile industries for drilling holes. These industries make extensive use of CO_2 lasers with powers up to several kilowatts.

(a) Chemical Composition of Material

Chemical composition of material of Spring Steel is as shown in Table 3.1.

Table 3.1: Chemical Composition of Spring Steel (C65)

Element	C	Mn	Si	S	P
Percent (%)	0.60-0.69	0.6-0.90	0.35 max	0.35 max	0.35max

(b) Properties

i These steels are generally low-alloy Manganese, medium-carbon steel or high-carbon steel with a very high yield strength.

ii This allows objects made of spring steel to return to their original shape despite significant deflection or twisting

(c) Applications

Spring Steel nozzles are generally laser drilled for different nozzle operations.

Figure 3.1: Spring Steel Nozzle

i General piano wire (also known as music wire) such as ASTM A228(0.80–0.95% carbon), spring clamps, antennas, springs, and vehicle coil springs, leaf springs.

ii Spring steel is also commonly used in the manufacture of metal swords both historically and for stage combat due to its resistance to bending, snapping or shattering

iii Tubular spring steel is used in the landing gear of some small aircraft due to its ability to absorb the impact of landing

iv Spring steel is one of the most popular materials used in the fabrication of lockpick due to its pliability and resilience.

v Spring Steel used in the manufacture of springs, prominently in automotive and industrial suspension applications.

4.TRIAL EXPERIMENT

Trial experiments were carried out to get overview of range of process parameters and their significance. Based on the literature review, parameters and their levels selected for trial experimentation are as shown in Table 4.3. Experiments were performed on CO_2 laser drilling machine Yawei HLB-1530 series and for programming CNC-CAD 10.59 software was used to perform drilling operations on laser machine. Trial experiments were taken on spring steel of 4mm thickness and laser beam having 127mm focal length and various beam diameters. For all experiments there was a sensor which keeps 1mm constant distance between sheet and nozzle of laser head.

Before doing experiments, firstly it is required to draw a profile having required shape in AutoCAD software. Then this drawing needs to feed into CNC-CAD 10.591 software where programming is done for particular profile to get the path for laser beam. In programming input parameters such as laser power, scanning speed and gas pressure were defined. After this, the program of CNC-CAD 10.591 was required to feed into Autonest 10.591 software that operates the laser machine. According to input parameters, operator of Autonest software can set the size of sheet and choose the number of profiles that are going to make.

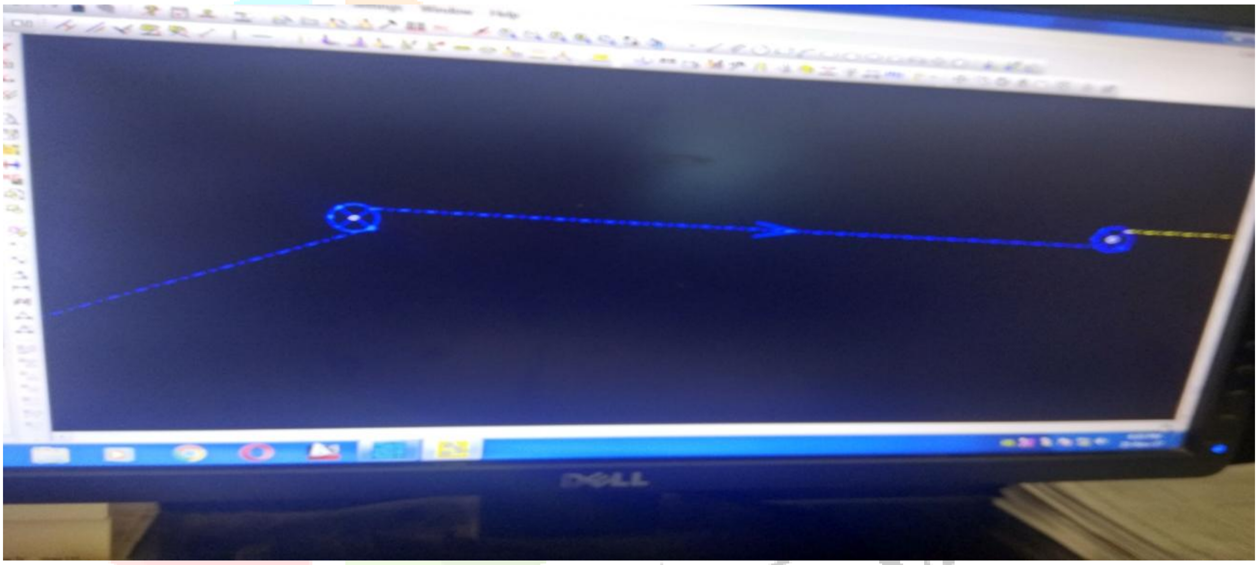

Figure 4.1: Autonest 10.591 Software

Table 4.3 shows the process parameters and their levels selected for trial experimentation of Spring Steel. The values and their range are mainly depends on material properties. Three input process parameters namely laser power, scanning speed and gas pressure selected and their three levels for each parameter were selected for experimentation purpose. For no spatter influence on the quality between two holes 10mm pitch distance were kept.

Figure 4.2: Laser Drilling action on C65

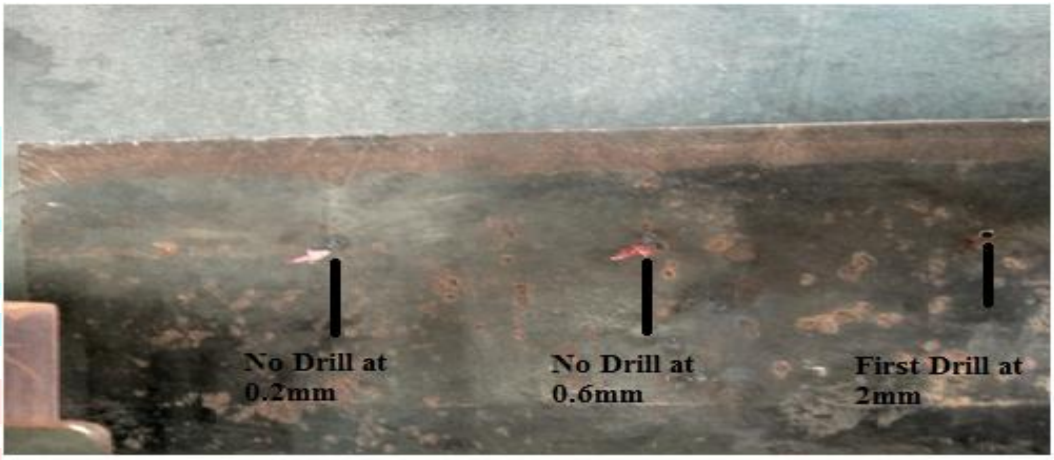

Figure 4.3: Drilling action on C65

Figure 4.4: Different hole geometry

Every hole diameters is checked 5-6 times and average of that readings is taken into account.This is done with the help of dinocapture USB cam available at our college.The process parameters values were noted down while performing laser drilling at different beam diameters.The constant parameters was the nozzle clearance it was 1 mm for all trial experiments and the other three input parameters can varied through machine

Table 4.1: Trail Experiment

Expt. No.	**Beam Diameter(mm)**	**Nozzle Clearance (mm)**	**Laser power (Kw)**	**Scanning Speed (mm/min)**	**Gas Pressure (bar)**

1	0.2	1	-	-	-
2	0.6	1	-	-	-
3	2	1	1400	195	0.6
4	6	1	1600	185	0.7
5	8	1	1700	177	0.9
6	10	1	1800	170	1.5

Table 4.2: Results

Expt. No.	**Beam Diameter(mm)**	**Whether hole is drilled or not**
1	0.2	No
2	0.6	No
3	2	Yes
4	6	Yes
5	8	Yes(Good)
6	10	Yes

4.1 Measurement of Responses

The each trial is carried out to get the accurate response values and then average value of the responses for each trial is taken for analysis. The responses are circularity at entrance and exit measured using following equation (4.1) and (4.2) respectively as [10],

Cent = Dmin / Dmax…………(4.1)

Cext = Dmin / Dmax.............(4.2)

Here, Dmax is the required diameter of hole and Dmin is available diameter of hole at entrance after experiment and similarly dmax and dmin are required and available diameter after experiment at exit respectively. Considering _t‘ is the thickness of material, the taper angle was calculated by Equation (4.3), where Dent and Dext are diameter at entrance and exit of hole respectively [10],

Taper Angle (θ) = $\tan^{-1}$((Dent — Dext) / 2t)……….. (4.3)

4.2 Validation of results

The Hole Quality is validated, whether it is good or bad by measuring the hole geometry such as entrance and exit diameters of hole and hence calculating the taper angle of hole the Entrance and Exit diameters are measured Dinocapture USB Interface 2.0 and Verneir caliper, six readings of the entrance and exit diameters were taken.

Figure 4.5:Dinocapture USB Interface 2.0

Figure 4.6: Dinocapture measurements of drilled hole

Table 4.3: Validation of Results

Expt. No.	Beam Diameter(mm)	Entrance Circularity(mm)	Exit Circularity(mm)	Taper angle(Degree)
1	0.2	-	-	-
2	0.6	-	-	-
3	2	2.77	2.63	1.0025
4	6	6.64	6.46	1.2889
5	8	8.40	8.33	0.5490
6	10	10.71	10.23	3.4336

5. RESULTS AND DISCUSSION

Out of the six experiments, drilling action was only seen in hole diameters 2mm and above below which there was no drilling at all. The results were then tabulated in the form of entrance, exit diameters and hole taper. Validation of results is done by calculating the taper angle of hole by using the entrance and exit diameters. Nearer the values of measured circularity diameters of given hole, more the accuracy of hole achieved and lower the taper angle of hole then the quality of hole is good. By observations, the lowest taper angle and the nearer diameters of drilled hole were observed at 8mm hole diameter at laser power of 1700waat, scanning speed of 177mm/min , gas pressure of 0.9bar .The measured entrance diameter of 8mm drilled hole was 8.40mm and the exit diameter was 8.33mm and the taper angle found to be was 0.549^0 which was lowest amongst all drilled hole taper angles.at higher peak powers formation of craters were found(1800 waat).

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