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OPTIMISATION OF SHEET METAL CUTTING PARAMETERS OF LASER BEAM MACHINE

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ABSTRACT

This paper is about optimization of sheet metal cutting parameter of Laser Beam Machining (LBM) process parameters on surface roughness while machining Stainless Steel (SS 304). Laser Beam Machining (LBM) is a non conventional process in which material removal takes place through melting and vaporization of metal when the laser beam comes in contact with the metal surface. There are so many process parameters which affect the quality of machined surface cut by LBM. But, the laser power, cutting speed, assist gas pressure, nozzle distance, focal length, pulse frequency and pulse width are most important. However, the important performance measures in LBM are Surface Roughness (SR), Material Removal Rate (MRR), kerf width and Heat Affected Zone (HAZ). Experiments are carried out using L_9 Orthogonal array by varying laser power, cutting speed and assist gas pressure for stainless steel SS 304 material.

Keywords: Laser, Process parameters, Optimization, Software Minitab18.

I. INTRODUCTION

Laser is a coherent and amplified beam of electro- magnetic radiation. The key element in making a practical laser is the light amplification achieved by stimulated emission due to the incident photons of high energy. A laser comprises three principal components, namely, a gain medium, a device for exciting the gain medium (amplifying state), and optical delivery /feedback system. For example, in CO2 laser, a gain or laser medium CO2, an optical resonator or cavity with two mirror (one is fully reflective and another partial reflective) and, an energizing or pumping source that supplies energy to the gain medium to activate CO2 into amplifying state. Additional provisions of cooling the mirrors, guiding the beam and manipulating the target are also important. The laser medium may be a solid (e.g. Nd: YAG or neodymium doped yttrium– aluminium– garnet), liquid (dye) or gas (e.g. CO2, He, Ne).

Laser light differs from ordinary light because it has the photons of same frequency, wavelength and phase. Thus, unlike ordinary light laser beams are highly directional, have high power density and better focusing characteristics. These unique characteristics of laser beam are useful in processing of materials. Among different type of lasers, Nd:YAG and CO2 are most widely used for LBM application. CO2 lasers have wavelength of 10.6 m in infrared region. It has high average beam power, better efficiency and good beam quality. It is suitable for fine cutting of sheet metal at high speed.

Figure No. 1: Laser Machine

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3D Laser Cutting Machine Specification:
X-3,000mm Y-1,500mm Z-400mm A-360 B± 135^0

Axis Speed

- X, Y 100m/min Z 50m/min (combined 140 m/min)
- A, B 540^0/s (1.5 rev per second)
- Laser source CO2 4000W
- Cutting thickness M.S-200mm,S.S.-12 mm,Al-8mm

II. OBJECTIVE

The objective of experimentation is to find out the measured surface roughness value and S/N Ratio.

III. LITERATURE REVIEW

J. Wang, (2000) has been worked on an experimental analysis and optimization of CO_2lasercutting process for metallic coated sheet steels. An experimental analysis of the CO_2 laser cutting process for metallic coated sheet steels, i.e. 0.55, 0.8 and 1.0 mm GALVABOND, has been presented. It has been shown that these materials can be cut at high cutting rate of up to 5,000 mm/min while the cut quality is superior to that with low cutting speed recommended in an early study. The difficult nature in processing this kind of materials is attributed to their anomalous behavior when subjected to laser light by virtue of the high light reflectivity and thermal conductivity of the coatings as well as the difference in the physical properties between the coating and the substrate. Plausible trends of the percentage of energy used in cutting with respect to the process parameters have been analyzed. It has shown that the energy efficiency ranges from as low as 5% to about 24% under the test conditions.

Siti Lydia Binti Rahim, (2007) has been Analysis and optimization of process parameters involved in laser beam machining of stainless steel (6mm and 8mm thickness). This machine uses a laser sensor for flexible referencing by non-contact scanning, after the measurement of fixed points. The control calculates the position of the item relative to the machine itself. Internal translation and rotation by the control system insures that the machine co-ordinates correspond with those of the plate. The laser sensor is particularly useful for picking up on or locating of pre punched references and datum points. The Fanuc 16LB CNC control is one of the most advanced systems available this guarantees perfect reproduction of programmed contours even on sharp edges or acute angles at high speed. Most finishes can be laser marked with names, part numbers, serial numbers or logos the marking is clear, burr free and permanent and the process causes no mechanical deformation of the work piece and uneven or inaccessible surfaces are observed.

Jun Li and G K Anantha Suresh, Journal of Micromechanics and Micro-Engineering (2010) has been worked on A quality study on the exciter laser micromachining of electro-thermal-compliant micro devices we attempted laser machining in water. A silicon sample was cut in both air and water to compare the performances. The feed rate was 200 /xm s^1, the frequency 100 Hz and the discharge voltage 20 KV. During the laser cutting in the water, we put the sample in the water so that there was a water layer of 3 mm above the sample. From figure 10, we can see that the material removal is lower than the case of the cut in the air, but there is no debris either in the cut edge or on the surface of the sample. Laser cutting of silicon in water gives a much better finish than in the air, but takes a longer time to cut. Thus, there is a trade-off between machining quality and the time taken to machine. This conclusion is consistent with the observations made by Krussing et al (1999) who attempted laser cutting of NdFeB and MnZn ferrites in the water ambient.

Daniel Teixidora, et al (2012) has been worked on Optimization of process parameters for pulsed laser milling of micro-channels on AISI H13 tool steel surface finishing and dimensional features of micro-channels have been investigated in laser milling process of hardened AISI H13 tool steel. 3D plots are used to illustrate the trends of the effects of the process parameters and a method using multi-criteria ranking and selection of parameters is presented to find the best combinations for different quality criteria. Experimental models based on quadratic regression are developed for surface roughness and width and depth errors. Furthermore, an evolutionary computational approach is applied to the decision-making problem in micro-machining parameters. Finally, an analysis of optimal solutions that form the Pareto front in objective function space is provided in decision variable space. The analysis indicates that the control parameter level ranges should be wider to obtain results close to the optimum.

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NatasaNaprstkova, StanislavDubsky (2012) had worked on Optimization of settingparameters of Laser Cutting Machine. After the analysis of the production costs of usually manufactured components, selecting the most suitable manufacturing operations to search for savings and mapping of the cutting parameters of the laser cutting machine has been selected. For optimization of the performance parameters of the machines platino on the following steps and have been designed: determine the shape of the experimental sample for testing to match the machine parameters, specifying for which quality and thickness the parameters will be optimized, selection of a suitable stock for tests; technological preparation of production representative articles; design of experiment methodology; choice of the number of pieces needed to optimize the parameters; performance of the experiments according to the methodology and their evaluation. The solution to the given task was to find reserves in the use of laser cutting machines Platino. Series of experiments were performed in which the cutting parameters have been optimized for most grades of the processed materials and thicknesses.

IV. EXPERIMENTAL SET-UP

Work Material:
Grade 304 is the standard "18/8" stainless; it is the most versatile and most widely used stainless steel, available in a wider range of products, forms and finishes than any other. It has excellent forming and welding characteristics.

Typical Chemical Composition of SS 304:

Table No. 4.1: Chemical Composition of SS 304

Grade 304	%Max	%Min
C	0.08	-
Mn	2.0	-
Si	0.75	-
P	0.045	-
S	0.030	-
Cr	20.0	18.0
Ni	10.5	-
N	0.10	-

Mechanical Properties:

Table No. 4.2: Mechanical Properties of SS 304

Tensile Strength(MPa) min	515
Yield Strength proof 0.2% (MPa) min	205
Elongation (% in 50mm)min	40
Rockwell B(HRB)max	92
Rockwell Brienell (HB)max	201

Parameter:

Input Factors:-
1) Laser Power (watt): It is the rate at which energy is emitted from lasers. The unit is Watt.
2) Cutting Speed (mm/min): It is a travel of a point on the cutting edge relative to the surface of cut in unit time in the process accomplishing the primary cutting motion. It is expressed in mm/min.
3) Gas Pressure (mm): Pressure is the expression of force exerted on a surface per unit area. Unit is bar.

Parameters to be optimized,

List of Parameters	Description
Laser Power	SS 3800Watt
Cutting Speed	SS 2600 mm/min
Type and Pressure of Assist Gas	SS(Nitrogen-15bar)
Material Thickness	SS (0.5-12 mm)

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Mode of Operation	SS(CW)
Cutting Angle	$0^0,2^0,4^0$
Nozzle Gap	1mm – 3mm

This research is carried out through three main stages, which are:
First, literature reviews on fundamentals of Laser Beam Cutting (LBC) Taguchi method is conducted. This review is to know the principles of laser cutting process, the parameters that influence the quality of laser cut.

Second, a new method is proposed in order to obtain the optimum cutting parameters. The proposed method, which is based on the Variable Weight assignment, is applied to overcome the limitation of existing Grey-

Taguchi algorithm.
Lastly, the proposed Variable Weight Grey-Taguchi algorithm on CO2 laser beam cutting for acrylic sheet was conducted. Design of Experiment by Taguchi method was used in designing the experiments. Control and noise factors are considered in the experiments as suggested by previous research. Finally, experiments are conducted to verify the performances of the proposed new method.

V. DESIGN OF EXPERIMENTS

Introduction to Taguchi Method:
Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases. In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a design of orthogonal arrays to study the entire parameter space with small number of experiments only. Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests to analyze variation using an appropriately chosen signal-to-noise ratio (S/N). There are 3 Signal-to-Noise ratios of common interest for optimization of static problems.

(1) SMALLER-THE-BETTER:

$$\eta = S/N = -10 \log (1/n \sum_{i=1}^{n} y^2)$$

(2) LARGER-THE-BETTER:

$$\eta = S/N = -10 \log (1/n \sum_{i=1}^{n} 1/y^{2k})$$

(3) NOMINAL-THE-BEST

$$\eta = S/N = 10 \log (y^2/s^2)$$

Where, η - Signal to Noise(S/N) Ratio, Yi-ith observed value of the response, n - no. of observations in a trial, y - average of observed values (responses). Regardless of category of the performance characteristics, the higher S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the highest S/N value.

Selection of Orthogonal Array:
If there is an experiment having 3 factors which have three values, then total number of experiment is 27. Then results of all experiment will give 100 accurate results. In comparison to above method the Taguchi orthogonal array make list of nine experiments in a particular order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments reduced to 9 instead of 27 with almost same accuracy.

Table No. 5.1: Layout for Experimental Design according to L9 Array

Expt.No.	X1	X2	X3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2

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5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Pilot Experiment:
In the pilot experiment for the study of surface roughness of SS 304,the relationships of Laser power, Cutting speed, Gas pressure versus thickness, keeping all other remaining parameters constants is observed. The thickness versus Laser power, Cutting speed, Gas pressure. The variation in surface roughness shows linear with Laser power, Cutting speed, Gas pressure.

Table 5.2: Layout for Experimental Design according to L9 Array

Sr. No.	Laser Power (watt)	Cutting Speed (mm/min)	Gas pressure (mm)
1	2400	1600	13
2	2400	1700	14
3	2400	1800	15
4	2500	1600	14
5	2500	1700	15
6	2500	1800	13
7	2600	1600	15
8	2600	1700	13
9	2600	1800	14

Figure No.5.1: Surface Roughness Tester (SJ410)

Each combination of experiments will be repeated three times to acquire a more accurate result in this process.

VI. ANALYSIS OF RESULTS AND DISCUSSION

Surface roughness SS 304 of 4,6 and 8 mm thickness:

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Table 6.1: Levels to the Variable as Applicable to Laser Beam Machine

Parameters	Levels		
	1	2	3
Laser Power (watt)	2400	2500	2600
Cutting Speed (mm/min)	1600	1700	1800
Gas pressure (bar)	13	14	15
Code	1	2	3

The tests were conducted with the aim of relating the influence of Laser Power, Cutting Speed, Gas Pressure with the number of thickness. On conducting the experiments as per orthogonal array, the results for the input parameters were obtained.

Table No 6.1:S/N ratio, Main Effect plot and Response Table for SS304:
A) Table 6.2: S/N Ratio for Surface roughness (4mm):

Sr. No.	Laser Power (watt)	Cutting Speed (mm/min)	Gas pressure (mm)	Ra	S/N Ratio	MEAN
1	2400	1600	13	1.757	7.458	1.757
2	2400	1700	14	1.001	6.158	1.001
3	2400	1800	15	1.239	6.677	1.239
4	2500	1600	14	1.096	6.584	1.096
5	2500	1700	15	1.268	7.436	1.268
6	2500	1800	13	1.643	6.188	1.643
7	2600	1600	15	1.884	8.293	1.288
8	2600	1700	13	1.288	7.694	1.884
9	2600	1800	14	1.114	5.493	1.114

A) Table 6.2: S/N Ratio for Surface roughness (4mm):

Sr. No.	Laser Power (watt)	Cutting Speed (mm/min)	Gas pressure (mm)	Ra	S/N Ratio	MEAN
1	2400	1600	13	1.757	7.458	1.757
2	2400	1700	14	1.001	6.158	1.001
3	2400	1800	15	1.239	6.677	1.239
4	2500	1600	14	1.096	6.584	1.096
5	2500	1700	15	1.268	7.436	1.268
6	2500	1800	13	1.643	6.188	1.643
7	2600	1600	15	1.884	8.293	1.288
8	2600	1700	13	1.288	7.694	1.884
9	2600	1800	14	1.114	5.493	1.114

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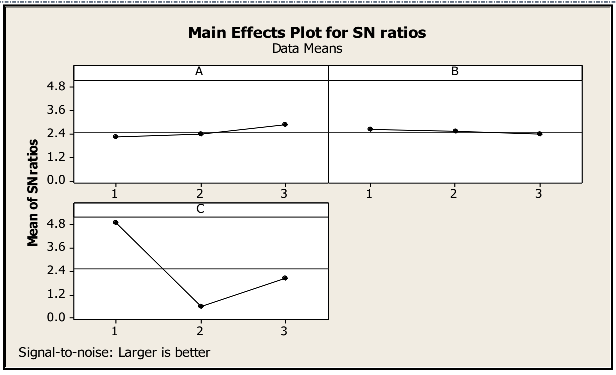


Graph 6.1: Main Effects plot for SN Ratio (4mm)

Table 6.3: Response Table Signal Noise Ratio (4mm):

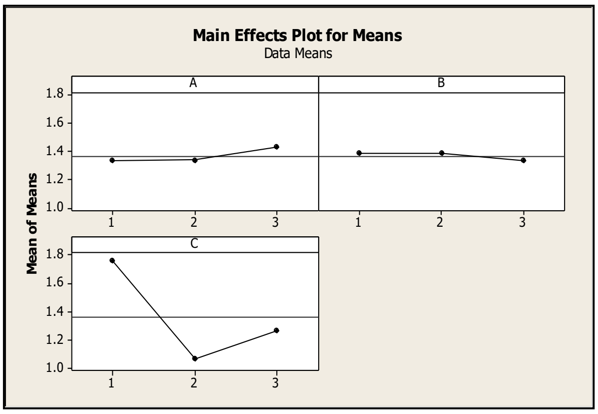
Level	A	B	C
1	2.2552	2.63	4.9033
2	2.3904	2.5242	0.5809
3	2.8792	2.3706	2.0407
Delta	0.624	0.2594	4.3224
Rank	2	3	1

Main Effect Plot for SS304 (4mm):

The graph show the change of ratio when setting of the control parameter was changed from one level to another.

Table 6.4: Response Table for Mean (4mm):

Level	A	B	C
1	1.332	1.38	1.761
2	1.336	1.384	1.07
3	1.429	1.332	1.265
Delta	0.096	0.052	0.691
Rank	2	3	1



Graph 6.2: Main Effects plot for Surface Roughness (4mm)

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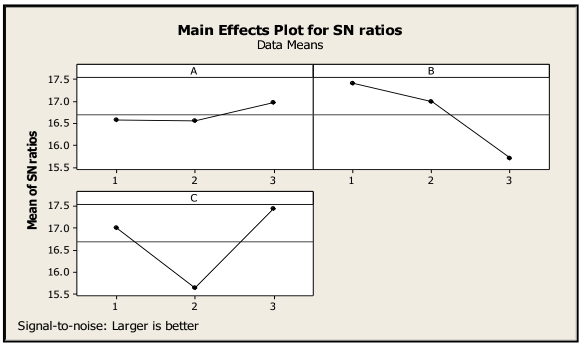
B) Table 6.5: S/N Ratio for Surface roughness (6mm):

Sr. No.	Laser Power (watt)	Cutting Speed (mm/min)	Gas pressure (mm)	Ra	S/N Ratio	MEAN
1	2400	1600	13	1.663	7.458	7.458
2	2400	1700	14	1.333	6.158	6.158
3	2400	1800	15	1.043	6.677	6.677
4	2500	1600	14	1.253	6.584	6.584
5	2500	1700	15	1.667	7.436	7.436
6	2500	1800	13	1.089	6.188	6.188
7	2600	1600	15	1.744	8.293	8.293
8	2600	1700	13	1.374	7.694	7.694
9	2600	1800	14	1.112	5.493	5.493



Graph 6.3: Main Effects plot for SN Ratio (6mm)

Table 6.6: Response Table Signal Noise Ratio (6mm):

Level	A	B	C
1	16.58	17.4	17
2	16.54	16.98	15.65
3	16.96	15.71	17.43
Delta	0.42	1.69	1.78
Rank	3	2	1

Main Effect Plot for SS304 (6mm):

The graph show the change of ratio when setting of the control parameter was changed from one level to another.

Table 6.7: Response Table for Mean (6mm):

Level	A	B	C
1	6.764	7.445	7.113
2	6.736	7.096	6.078
3	7.16	6.119	7.469
Delta	0.424	1.326	1.39
Rank	3	2	1

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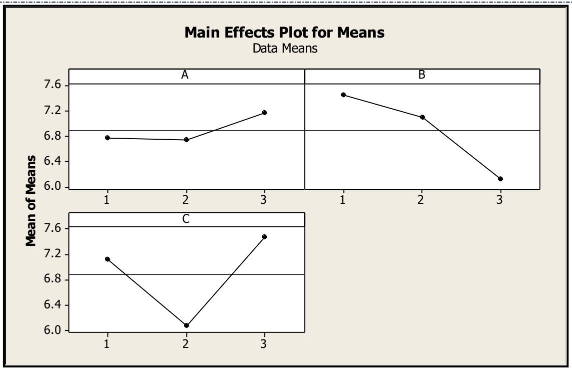
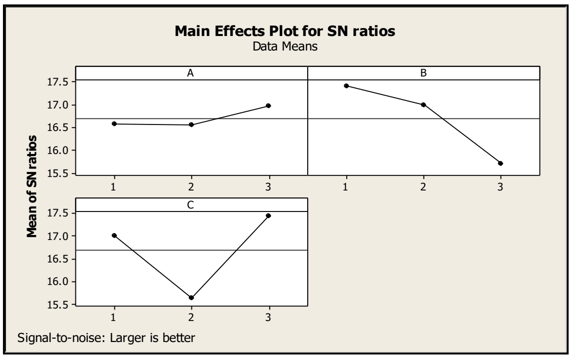


Graph 6.4: Main Effects plot for Surface Roughness (6mm)

C) Table 6.8: S/N Ratio for Surface roughness (8mm):

Sr. No.	Laser Power (watt)	Cutting Speed (mm/min)	Gas pressure (mm)	Ra	S/N Ratio	MEAN
1	2400	1600	13	1.746	7.458	7.458
2	2400	1700	14	2.409	6.158	6.158
3	2400	1800	15	1.88	6.677	6.677
4	2500	1600	14	1.981	6.584	6.584
5	2500	1700	15	1.789	7.436	7.436
6	2500	1800	13	1.887	6.188	6.188
7	2600	1600	15	2.839	8.293	8.293
8	2600	1700	13	1.647	7.694	7.694
9	2600	1800	14	1.588	5.493	5.493



Graph 6.5: Main Effects plot for SN Ratio (8mm)

Table 6.9: Response Table Signal Noise Ratio (8mm):

Level	A	B	C
1	16.58	17.4	17
2	16.54	16.98	15.65
3	16.96	15.71	17.43
Delta	0.42	1.69	1.78
Rank	3	2	1

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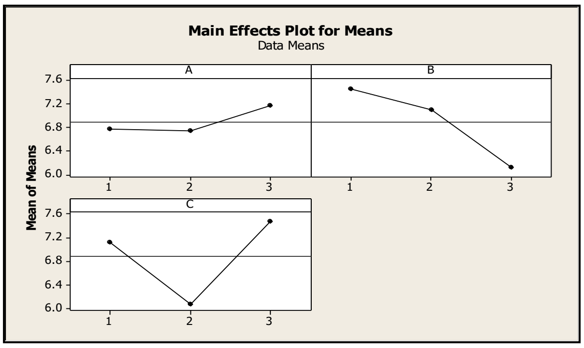
Main Effect Plot for SS304 (8mm):

The graph show the change of ratio when setting of the control parameter was changed from one level to another.

Table 6.10: Response Table for Mean (8mm):

Level	A	B	C
1	6.764	7.445	7.113
2	6.736	7.096	6.078
3	7.16	6.119	7.469
Delta	0.424	1.326	1.39
Rank	3	2	1



Graph 6.6: Main Effects plot for Surface Roughness (8mm)

VII. CONCLUSION

In this project, performing the experiment on Laser Beam Machine, we are able to find the optimum machining parameter which affects the surface finish of the work piece. And also the effects of machining parameters on S-N ratio i.e. signal to noise ratio.

In this experiment, Taguchi method was applied for the multiple performance characteristics of cutting operations. Analysis of various process parameters and on the basis of experimental results, analysis of variance (ANOVA) and S/N Ratio.

The following conclusions can be drawn for effective machining of Stainless steel (SS 304) by LBM process as follows:

Assist gas pressure is the most significant factor for SR during LBM. Meanwhile Laser power and Cutting speed are sub significant in influencing. Laser power is the most significant factor for thickness during LBM. Meanwhile Assist gas pressure and Cutting speed are sub significant in influencing. It is also shown that the performance characteristics of the cutting operations, such as the surface roughness are greatly enhanced by using this method.

VIII. FUTURE SCOPE

The present work can be extended to optimize the other laser parameters such as standoff distance and nozzle diameter etc. on kerf dimensions. And also similar work can be utilized for Nd: YAG laser cutting process parameter optimization.

- Experimentation can be carried out on different material with different input parameters combinations.
- Mixed optimization can be also done.
- The different methodology of analysis and also for optimization can be used

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