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Surface Roughness Optimization in Laser Beam Machining (LBM) by using Taguchi Method

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Abstract-*Laser Beam Cutting (LBM) is one of the most widely used manufacturing Field for generation of accurate and complex geometrical shapes on ferrous metal, non ferrous metal, stones, plastic and ceramics components with high dimensional accuracy. Fiber lasers are solid state laser technologies that offer a combination of high beam quality and a wavelength that is easily absorbed by metal surfaces. This work aims to evaluate the optimum laser cutting parameters for 0.5 mm thickness of EN10137-2 steel material sheets by using Fiber laser beam machine of 1000W Power as Focus of work is mainly on output response parameters Surface roughness SR. Results are analyzed using Analysis of Variance (ANOVA) technique. The effects of different input process parameters like laser power, Cutting Speed and gas pressure is studied on the output responses.*

Key Words: LBM, Taguchi, ANOVA, SR, S/N Ratio, L-9 orthogonal array, Optimization.

1.INTRODUCTION-

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications. Laser cutting works by directing the output of a high- power laser most commonly through optics. The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high- quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

Nowadays, production companies in high-wage countries face the challenge of meeting individual customer requirements and rapidly changing market demands while keeping costs low. Providing a reliable but efficient production leads to growing complexities in the production processes.

Production planning and scheduling requires a large amount of human information processing and decision making. In particular in the field of manufacturing process planning, decisions involve the consideration of the effect of multidimensional parameters on preselected criteria of the manufacturing process. For instance, one common problem is the choice of an appropriate machine parameter set those results in desirable process outputs (e.g. high output quality or minimal energy consumption). Due to a high dimensional domain space, the relationship between interdependent parameters and criteria is very difficult to achieve. In addition, they are very complex for the human mind to handle at a time. In order to handle these problems, process designers make use of modern computational approaches for modelling and simulating manufacturing processes.

The conventional techniques to perform several sets of simulation run on the process, whereas each individual simulation is characterized by a high dimensional set of parameters and several criteria. The problem is that revealing the whole process behaviour requires a very large number of time-consuming experiments. It is not feasible to run full numerical simulations throughout the whole parameter space at a reasonable computational cost. Because of that, experimental simulation runs are performed by appropriate Design of Experiment (DoE) techniques as well as other, experience-based procedures. Since simulations are based on discrete sets of process parameters, they can only cover partial aspects of the process and do not provide insights into the whole process.

The laser beams are widely used for cutting, drilling, marking, welding, sintering and heat treatment. It is normally used for applications, ranging from military weapons to medical instruments, Cutting, Welding, Aerospace, Aeronautical industry. Materials which are cut by LBM are Al alloy, wood, ceramic, rubber, plastic, Brass, Hardox-400, etc

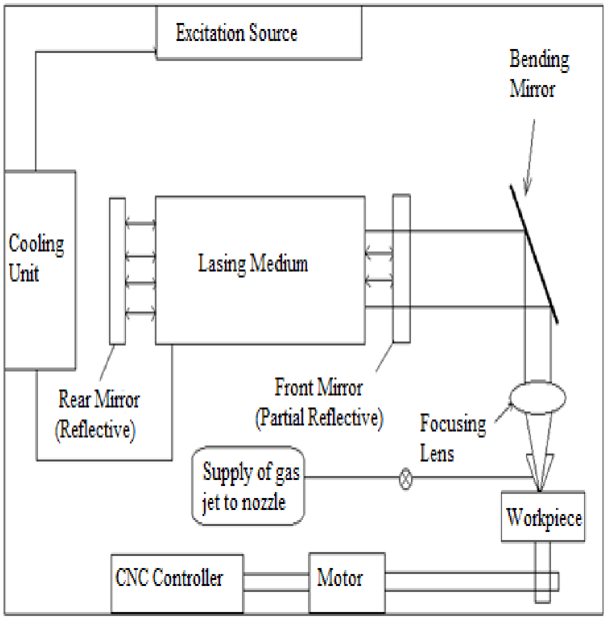


Fig. Laser Beam Machine Schematic diagram

2. EXPERIMENTATION-

The experiments have been conducted on the Fiber Laser Beam Machine model SIL10X5FL0020 of SIL expertise innovation excellence made in India which is available at Lane no. 7, Sub Plot No. 19 , Ramtekadi industrial area, Hadapsar, Pune in Machine Tool Lab. It is a 1000 W Fiber Laser fully integrated and with hardware, software and peripherals incorporated. It is a continuous mode laser beam machine having number of input parameters which could be varied i.e. laser power, frequency, feed rate, gas pressure, nozzle stand-off distance and type of gas used. Each parameter has its effect on the output parameters such as Material Removal Rate (MRR), Kerf Width (K_W) and Kerf Deviation (K_D). Laser Power, Frequency, Feed rate and Gas pressure were the parameters which were varied on machine for experimentation.

The ranges of the values of these parameters for the experimental work have been selected on the basis of some trial experiments for which certain quality factors are taken care. The effect of these parameters has been checked on output factors like MRR, Kerf Width and Kerf Deviation.

LBM has certain advantageous characteristics, which turns to achieve significant penetration into manufacturing industries.

- high precision
- small heat-affected zone
- low level of noise
- No need of special fixtures for the work piece
- No need of expensive or replaceable tools
- Low waste

2.1 Experimental Machine Selection

Fig Work piece / Part / Job &Machine Setup:

While cutting of material on laser beam machining some parameters constant like stand off distance, Gas type, Material, duty cycle, out height, cut frequency, laser off delay and work some input and output parameters like MRR, SR, Kerf Width and Kerf

Sr.No.	Parameters	Value/ Type
1	Stand-off distance	3 mm
2	Gas type	Gas
3	Material	EN10137(M.S)
4	Duty cycle	85%

3. SELECTION OF LEVELS

The basic criteria for selection of levels of factors for Laser Beam Machine of various mould steels is selected from technology guidelines of machine

Cutting Speed: 1000, 1100, 1200, 1300, 1400 mm/min

Laser Power: 800,850, 900, 950, 1000 Watt

Gas Pressure: 0.8, 0.9, 1.0, 1.1, 1.2 bar

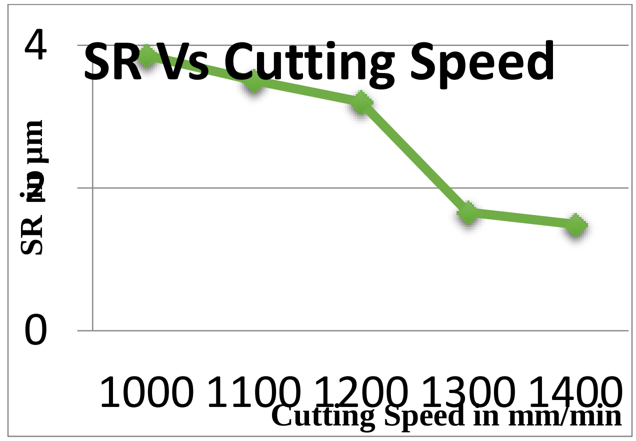
O-VAT for Cutting Speed

When cutting speed is increases interaction between Laser beam and material is decreases. That is Heat generation decreases which leads to minimum side burning.

The experimental condition used for cutting the 5 mm thick EN10137-2 is above given

Table summarizes the variation of surface roughness as a function of Laser Cutting Speed 1000, 1100, 1200,1300 and 1400 mm/min.

From Table As the Cutting Speed is increases 1000 to 1400 mm/min, the Surface Roughness is decreases from 3.86 to 1.49 μm.



Graph 4.1 O-VAT for

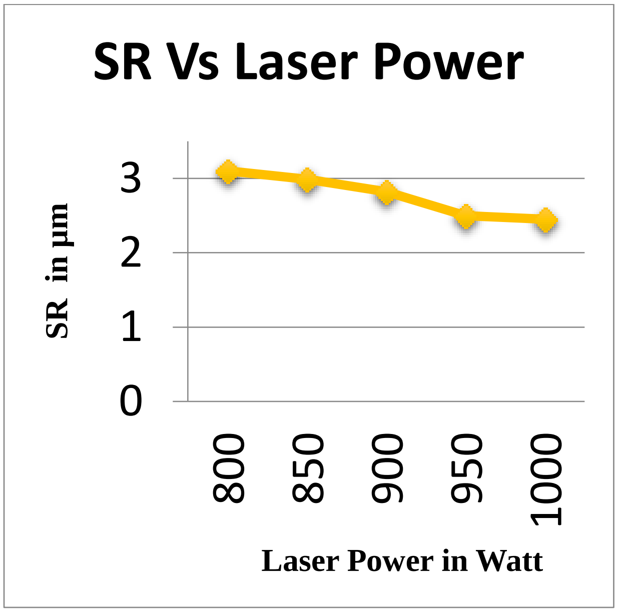
Cutting Speed Vs SR

From the above table it is observed that, the rate of change of Surface roughness is lower in the region of Laser Power is 0.9-1.1 bar hence this level of factor is selected

O-VAT for Laser Power

Sr. No	Cutting Speed	SR
1	1000	3.86
2	1100	3.51
3	1200	3.21
4	1300	1.66
5	1400	1.49

The experimental condition used for cutting the 5 mm thick EN10137-2 is above given summarizes the variation of surface roughness as a function of Laser Power 800,850, 900, 950 and 1000 Watt. Table As the Cutting Speed is increases 800 to 1000 Watt, the Surface Roughness is decreases from 3.10 to 2.45 μm



Graph O-VAT for Laser Power Vs SR

It is observed that, the rate of change of Surface roughness is lower in the region of Laser Power is 850-950 Watt hence this level of factor is selected.

O-VAT for Gas Pressure

Sr. No.	Laser Power	SR
1	800	3.10
2	850	2.99
3	900	2.82
4	950	2.50
5	1000	2.45

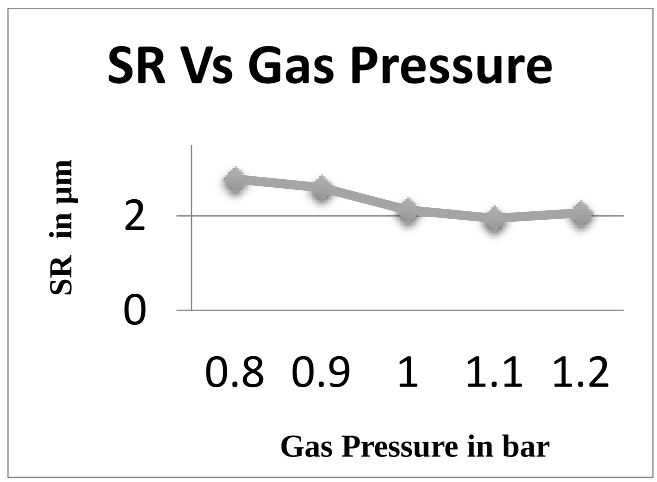
When the pressure of the cutting gas is too high, the influence on the cutting quality: the cutting surface is rough, and the slit is wide; at the same time, the cut section is partially melted, and a good cutting section cannot be formed.

When the pressure of the cutting gas is insufficient, the following effects will be affected on the cutting quality: the melting will occur during cutting, and the cutting speed cannot meet the production efficiency By increasing the Gas pressure, the Heat Generated by exothermic is increased which results in self burning of the cut surface and hence the increase in the surface roughness

Sr. No.	Gas Pressure	SR
1	0.8	2.78
2	0.9	2.60
3	1.0	2.12
4	1.1	1.95
5	1.2	2.06

The experimental condition used for cutting the 5 mm thick EN10137-2 is above given

Table 4.3, summarizes the variation of surface roughness as a function of Gas pressure 0.8 0.9, 1.0 1.1,1.2bar.



From the above table it is observed that, the rate of change of Surface roughness is lower in the region of Laser Power is 0.9-1.1 bar hence this level of factor is selected.

Sr. No	Level 1	Level 2	Level 3
Cutting Speed (mm/min)	1100	1200	1300
Laser Power (Watt)	850	900	950
Gas Pressure (bar)	0.9	1.0	1.1

Levels of Input Parameters

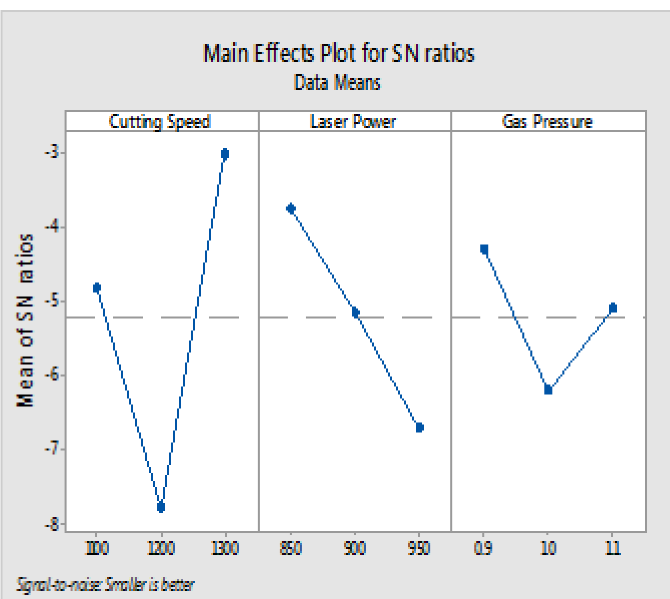
4. MODEL ANALYSIS FOR SR

Experiments	Inputs Factors			Output Responses	
Trial No.	**Cutting Speed**	**Laser Power**	**Gas Pressure**	**SR**	**SNRA**
1	1100	850	0.9	1.118	17.2014
2	1100	900	1.0	2.008	17.9514
3	1100	950	1.1	2.210	18.1718
4	1200	900	0.9	2.519	17.0458
5	1200	950	1.0	2.157	17.7285
6	1200	850	1.1	2.710	17.9662
7	1300	950	0.9	1.220	16.8046
8	1300	850	1.0	1.371	17.3169
9	1300	900	1.1	1.691	17.7172

SN Ratio MRR

Shows the L_9 orthogonal array with repeat measurement of responses for runs one to nine. Repeats of response measurement technique is used overcome the drawback of saturated design in MINITAB software. It also shows that the SN ratio for run one and ten are same as it is calculated for the repeats measurement. The SN ratio values are calculated with help of MINITAB 17 software.

Main Effects of SR



Graph Main effect plots for mean of SN ratio of SR

ANOVA Result

In ANOVA, the ratio between the variance of the cutting parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. If the F test value is greater than P test the cutting parameter is considered significant.

Relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test).

In ANOVA, the ratio between the variance of the cutting parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. If the F test value is greater than P test the cutting parameter is considered significant.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Cutting Speed	2	34.911	17.465	7.98	0.111	60.25
Laser Power	2	13.099	6.549	2.99	0.250	22.60
Gas Pressure	2	5.554	2.777	1.27	0.441	9.58
Error	2	4.375	21.88			7.55
Total	8	57.939				

relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test). anova table shows the result of the ANOVA analysis. The ANOVA analysis makes it possible to observe that the value of P is less than 0.5 in the three parametric sources. It is therefore clear that (1) the Cutting speed, (2) the Laser Power, (3) the Gas Pressure of the material have an influence on the EN10137-2 material. The last column of cumulative anova shows the percentage of each factor in the total variance that indicates the degree of impact on the outcome.

The table shows that the Cutting Speed 60.25%), the Laser Power (22.60%) and the Gas Pressure (9.85%) have a major influence on the Surface roughness.

Optimum level of parameters

Sr. No.	Parameter	Optimum Value
1	Cutting Speed (level 3)	1300
2	Laser Power (level 1)	850
4	Gas Pressure (level 1)	0.9

From Table observed that Optimum value of cutting speed is 1300 mm/min at level 3, Laser power is 850 Watt at level 1 and Gas pressure is 0.9 bar at alevel 1.

5. CONCLUSIONS

This study covers the observations about the Surface Roughness over the EN10137-2 Steel material by the process of Laser Beam Machine for the different input parameters to thoroughly study over the effect of \Laser beam machining process on the EN10137-2 Steel material. Throughout the experimentation I got some results as under.

The combination of laser cutting parameters i.e. cutting speed, laser power and gas pressure were planned by L9 Orthogonal Array Taguchi method , based on the results obtained and derived analysis the following can be concluded.

- The optimal solution obtained for SR based on the combination of laser cutting parameters and their levels is (i.e. cutting speed 1300 mm/min, laser power 850W and Gas pressure 0.9 bar).
- ANOVA results indicate that cutting speed plays prominent role in determining the surface roughness. The contribution of Cutting speed, Laser power and Gas pressure to the quality characteristics surface roughness Ra is 60.25%, 22.60% and 9.58% respectively.
- Cutting speed and Laser Power are the most significant parameters majorly affecting the surface roughness whereas the Gas Pressure is much smaller.
- The optimal cutting parameters are determined using Taguchi methods match with the experimental values by minimum errors i.e7.55% for SR
- Through the developed mathematical models, any experimental results of surface roughness with any combination of laser cutting parameters can be estimated.

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