International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 03 | Mar 2019 www.irjet.net p-ISSN: 2395-0072

Effect and Optimization of Laser Beam Machining Parameters using Taguchi and GRA Method: A Review

R.S. Barge[1], R.R. Kadam[2], R.V. Ugade[3], S.B. Sagade[4], A.K. Chandgude[5], M.N. Karad[6]

[1,2,3,4,5,6]*School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi (D), Pune*

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Abstract - Laser *cutting is one of the widely used non-contact type and thermal based non-conventional machining process. Due to its increasing use and demand lots of researches had been carried out in last few years. The main aim of these researches is to optimize the process parameters of the laser beam machining process. Laser beam machining is a process in which the quality of the output machined component depends upon various input parameters. Considering this an attempt has made in this paper after referring various research works to explain in detail about the relation between the input parameters and output quality and the effect on the output quality parameters by changing the input parameters. This paper will provide an idea about the range of input parameters required for obtaining the desired quality at the output. The quality of the material after the laser cutting is very important. Major development require in LBM is improvement in surface quality by reducing the spreading of heat affected zone and increasing the accuracy in particularly micromachining. Any improvement in this area will have a very great importance in the field of machining and manufacturing. Laser machining is a very complex thermal process and numerous techniques and methods are developed to optimize the process parameters of the LBM. Therefore, it is the aim of this paper to help you in proper understanding of various parameters.*

1. INTRODUCTION

Manufacturing industry is becoming more quality oriented and time conscious with the advancement in global economy. So it becomes essential to use non-conventional machining processes such as Laser Machining, Electric Discharge Machining, Chemical Machining, Abrasive Water Jet Machining etc. Laser beam machining produces an intense light beam, which quickly heats up the work piece and melts the material of work piece. The assist gas help removes the molten metal from the cut kerfs and also to cool and protect the focusing lens. Due to its narrow kerfs width, high accuracy of cutting, intricate shape, higher production rate, hard to cut material proves laser beam machining a good choice for industrial application. There are various parameters for LBM process to be selected and optimize to achieve desired response. For processing parameters various researchers have chosen input parameters like cutting speed, laser power, assist gas pressure, nozzle diameter, stand of Distance, varying thickness of work piece, focus length and focal point etc. to determine output parameters such as kerfs width, surface roughness, taper angle, heat affected zone, material removal rate, dross height, dross inclusion, and operating cost etc. Since there are multiple parameters, they require fine setting of these parameters to get better result of LBM.

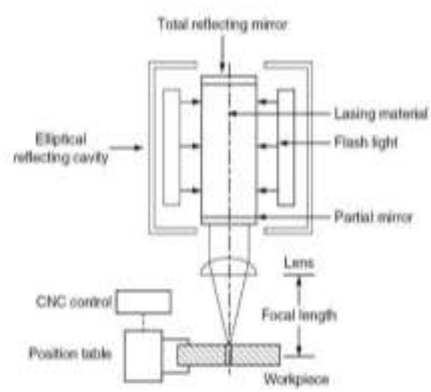

Fig - 1: Schematic diagram of Laser Beam Machine

- When some amount of metal which is not completely vaporised, then some amount may get stacked to the work piece itself or it may get stick to the work piece in form of small buds. Therefore, it is needed to remove these during the process itself, when they are soft enough. Therefore, we take assist gas which blows off these metals materials from machining spot.

- Relation between diameter of spot and wavelength is given as

$$d_f = \frac{2 * f * \lambda}{\Pi * d}$$

$d_f = dia\ of\ focused\ spot$, f= focal length of lens, λ= wavelength, d= beam diameter (unfocused). (all dimensions are in mm).

To get a desired quality of cut on a particular material lots of iterations has to be performed and if the material changes then again all iterations has to be repeated for that new material. To get the desired quality at output it is very much important to find relations between input parameters and output parameters.

Input parameters are wavelength, power intensity, spot size, continuous wave or pulse laser power, focal position, process gas pressure, nozzle diameter, stand-off distance, cutting speed.

Output parameters are kerf width, cut edge squareness, inner side slope of kerf, heat affected zone extent, dross appearance, surface roughness(striations) which depends upon wavelength and the depth of cut.

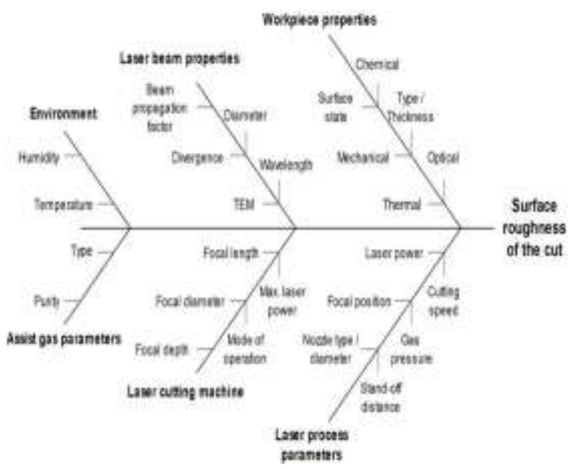

Fig - 2: Cause and effect diagram

Types of evaluations

1) Macroscopic evaluation
   a. Kerf width
   b. Dross appearance
   c. Kerf taper
2) Microscopic evaluation
   a. Surface roughness
   b. Heat affected zone (HAZ)

Different methods available for the modeling of laser cutting parameters are:

1) Analytical method
2) Multiple regression method
3) Fuzzy expert system
4) Artificial neutral networks.

OVERVIEW OF TAGUCHI METHOD

Taguchi method is a Robust Experimental Design Strategy which uses the integration of two basic concepts: Signal-to-Noise Ratio (SNR) and Design of Experiments using Orthogonal Array (OA). OA will give a set of systematic and well-balanced minimum number of experiments and Signal-to-Noise ratios (S/N) work as objective functions to optimize the parameters which we have considered in the orthogonal array and this whole will help in data analysis and help to predict the optimum condition of our process which is to be optimized.

Signal to Noise (S/N) Ratios:

Signal-to-noise ratio determines the robustness of a process or product or system.

There are two steps to solve this design optimization problem which is as follows:

a) Maximizing the S/N ratio

b) Adjusting the mean on desired target using a control factor.

Dr. Taguchi has defined number of different S/N ratios for this purpose, but out of them there are three most important which are widely used. These are

(I) Smaller the better

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

This S/N ratio is usually chosen for all those undesirable characteristics like "defects, surface roughness" etc. for which the ideal value should be zero or when an ideal value is finite or when the maximum or minimum value is known, then the difference between measured value and ideal value should be as small as possible.

(II) Larger -the –better

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

This case is similar to smaller-the-better case as here; only change is reciprocal of measured data and then taking the S/N ratio as we take in the smaller the better case. This case is generally used where we want increase in the value of certain characteristic or parameter which we are studying at the output. For example, we want to increase the surface finish of the machined component at the output but this is achieved by minimizing surface roughness. So we see the how smaller-the better and larger-the-better are interlinked.

(III) Nominal –the –best

$$\eta = S/N = 10 log \left(\frac{\bar{y}^2}{s^2}\right)$$

This case is used when a specified value is MOST desired at the output i.e. neither a larger nor a smaller value is desirable.

where y_i is the i-th observed value of the quality characteristic (response), n is the number of observations in an experiment, $\bar{y}$ is the average of observed values (response) and s is the variance.

The SN ratio is expressed in decibel (dB) unit. A higher the value of SN ratio implies a lower value of quality loss and hence a better quality of product.

Steps Involved in Taguchi Method

a. Identify the main function in the experiment and its side effects.

b. Identify the noise factors, testing condition and quality characteristics related to the experiment.

c. Identify the objective function which is to be optimized.

d. Identify the control factors in the experiment and their different levels.

e. Then select a suitable Orthogonal Array (OR) and construct the Matrix.

f. Then conduct the Matrix experiment.

g. Examine the data obtained; find out the optimum control factor levels by speculation and its performance.

h. Conduct the experiment for the verification of the optimum value we obtained.

Grey relational analysis

The grey relational analysis (GRA) is based on grey system theory. It represents an effective and powerful tool for the analysis and optimization of processes or systems which are characterized by multiple performance characteristics.

To use the GRA method, there are three basic steps: (1) data preprocessing, (2) calculating the grey relational coefficients and (3) calculating the overall grey relational grade (GRG).

Gray relational grade is calculated by using the weighting coefficient for the responses (performance characteristics). Once the GRG has been calculated, then the following analysis has to be performed:

(i) Analysis of variance (ANOVA)- To find out which parameters and their interactions significantly affect the multiple performance characteristics by using these calculated GRG values
(ii) Selecting the optimal combination of parameter levels so as to find higher GRG
(iii) Then conduct the confirmation experiment trial to verify the optimal combination of parameter levels.

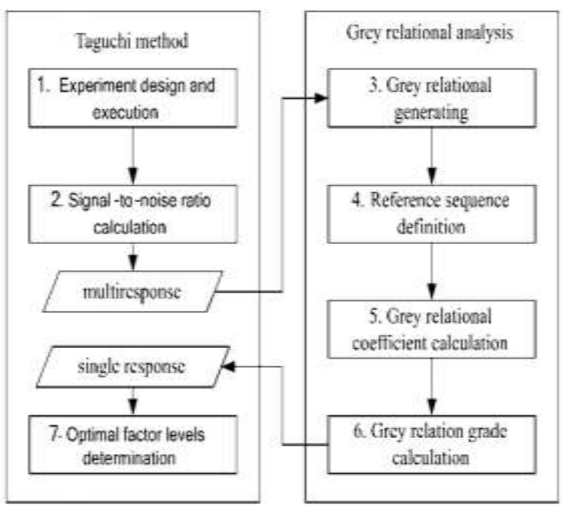

Fig - 3: Various Steps involved in process

Table - 1: Cutting speed Parameter List

Material	Thickness (mm)	500W	1000W	1500W	2000W	3000W	4000W
		The best cutting speed (m/min)	The best cutting speed (m/min)	The best cutting speed (m/min)	The best cutting speed (m/min)	The best cutting speed (m/min)	The best cutting speed (m/min)

Carbon steel (O_2)	1	10	14	20	24	30	35
	2	4.5	7	9	12	18	24
	3	2.1	3.3	3.5	3.8	4	6
	4	1.5	2.2	3	3.1	3.5	5
	5	0.1	1.8	2.5	2.7	3	4
	6	0.9	1.5	2	2.1	2.5	2.5
	8		1	1.5	1.5	1.9	1.9
	10		0.8	1.2	1.3	1.3	1.3
	12			0.8	0.9	1.2	1.2
	16				0.6	0.8	0.8
	20					0.7	0.7
	22						
	24						
Stainless steel (air)	1	9	14	20	25	30	35
	2	3	5	8	13	20	24
	3	1	3	4	5.4	11	13
	4		1.5	3	3.3	8	11
	5		1	1.5	2.4	5	7.5
	6			1	1.3	3	5
	8				1	1.7	3.5
	10					1	2
	12					0.6	1.5
	14						1
	16						0.6
Copper plate	1	4.8	9	18	25	28	30
	2	0.6	3	6	8	15	17
	3		0.6	1.8	2.4	3.6	12
	4			0.6	0.9	1.5	8
	5				0.8	3.2	5
	6				0.6	2.2	3
Aluminum plate	1	4.8	9	18	21	24	27
	2	1	3.6	7	9	14	17
	3		1	2	6	8.5	12
	4			1	3.2	5	8

	5				1.5	3.5	5.2
	6				0.6	2.2	3
	8					1	1.5
	10						0.5

2. LITERATURE REVIEW

A literature review of the recently published research work on Optimization of LBM process parameters is carried out to understand the research issues involved and is presented here,

P.T. Pajak, A.K.M. De silva, D.K. Harrison and J.A. McGeough [1] has made efforts to improve various laser parameters and to limit its drawback. It emphasis on application of novel, short and ultra-short pulsed lasers. One of the important directions is to improve the LBM surface integrity by limiting the Heat Affected Zone and increasing the machining accuracy mainly in micromachining. Shorter pulses of order 10-15 is used which minimizes the heat conduction and tends to maximize the ablation. Also shorter wavelength is absorbed to a greater extend by the material.

Chirag Patel, Sandip Chaudhary and Parth Panchal [2] has studied the effect of various process parameters such as input power, feed rate and gas pressure up to 3 levels for each parameter by using laser beam on stainless steel for determining the quality of machined surface during each level. Full Factorial Design is being used for implementing the design of experiments. The various effect of the process parameters on response have been displays by means of main effect plots developed by using ANOVA analysis. After Design of experiment using Full Factorial method, the further analysis was carried out by using Analysis of variance (ANOVA) method and optimization was carried out by Response surface methodology.

Milos Madic, DusanPetkovic and Miroslav Radovanovic [3] worked on 3mm thick AISI 304 stainless steel in order to optimize different laser cut quality characteristic such as the drag line, depth of separation and burr height. For optimization Grey Rational Analysis was used. Laser Nitrogen cutting was performed on a 2.2KW CO2 laser cutting system. This cutting experiment was conducted according to Taguchi's L27 Experimental Design. Laser Power, cutting speed, Assist Gas pressure and Focus position were the four cutting parameters considered for multi-objective optimization. The results which were obtained indicated that optimized and non-optimized laser cutting conditions produced different cut quality characteristics. The study found that the effect of Laser Power, assist gas pressure and cutting speed are not significant; however, its interaction effects with focus position are statistically significant. At last they derived at a conclusion that the optimal combination of laser cutting parameters is:

Laser power, P=1.8KW
Cutting speed, V= 3m/min
Assist gas pressure=9bar
Focus position, f = -2.5mm

Milos J. Madic and Miroslav R Radovanovic [4] worked on AISI 304 stainless steel and identified the robust condition for minimization of Heat Affected Zone(HAZ) and burr height in CO2 laser cutting. The experiment was carried out on the basis of standard L27 Taguchi's orthogonal array in which four laser cutting parameters such as laser power, cutting speed, assist gas pressure and focal position were arranged at three level. The best combination of parameters was found out by Analysis of means, analysis of variance and two-way interaction plots. The result indicated that the focus position is most significant parameter affecting the Heat Affected Zone (HAZ) and burr height whereas effect of assist gas pressure can be neglected. They presented Taguchi optimization methodology for minimization of width of HAZ and burr height. Sheet thickness was also considered to be one of the main process parameter having a greater impact on complex thermos-chemical processes which take place in a material during the cutting process and must be considered when selecting other process parameters values.

RudramuniKhed and N.K. Kamble [5] worked on Aluminum alloy 8011 to study the effect of laser power, cutting speed and assisting gas pressure on surface roughness and kerf width. They found Aluminum alloy 8011 difficult to cut because of its reflectivity. For the experiment 3mm thick sheet of Aluminum alloy 8011 was used as assisting gas. They used response surface methodology to create design of experiment design of experiment plan and this was further analyzed by regression method. It was found that at higher speed, lower power and gas pressure – minimum surface roughness and kerf width can be obtained. The result so obtained indicated that the cutting speed, power and gas pressure have major effect on kerf width and surface roughness. The Response surface model fits the experimental data of surface roughness well with coefficient of correlation nearing 93.73%, R-sq. (adjusted) – 90.25% and R-sq. (predicted)- 82.27% with insignificant lack of fit. However experimental data of kerf width well with coefficient of correlation nearing 91.77%, R-sq.(adjusted)- 82.25% and R-sq.(predicted) 76.95% with insignificant lack of fit. Minimum surface roughness can be achieved by operating at lower values of speed and gas pressure at any value of power. Operating at minimum values of speed and gas pressure can help achieve minimum kerf width. Aped and power has contribution of 42.7% and 38.6% on kerf width. The results so obtained indicated that minimum surface roughness and kerf width of 2.63µm and 0.1706mm by operating at 1.1273 m/min speed, 1060.6061 W power and 12bar gas pressure and overall desirability of 0.9511 was obtained.

Peter Sugar, Martin Necpal and Jana Sugarova [6] has given the relation between process parameter and machined surface quality characteristics. The experiment was studied on a five axis highly dynamic laser precision machining Centre Lasertec 80 shape quipped the pulsed ytterbium fiber laser and CNC system Seimens 840D.The Taguchi experimental design approach was used to measure the influence of pulse frequency and energy, laser scanning speed and step size on machined surface roughness. Step size was having significant influence on machined surface roughness both in case of hatching as well as cross-hatching scanning strategies was step size. Also minimum surface roughness was reached in hatching with following combination of process parameters –

Pulse Frequency – 80KHz
Pulse Energy – 0.8mJ
Scanning Speed – 1.0 m/s
Step Size - 15µm

Maximum value of roughness was reached when combination of process parameters was –
Pulse Frequency – 60KHz
Pulse Energy – 0.8mJ
Scanning Speed – 2.2 m/s
Step Size - 5µm

Experimental Design was based on Taguchi L9 array.
In cross-hatching, the minimum surface roughness was reached with following combination of parameters –
Pulse Frequency – 60KHz
Pulse Energy – 0.53mJ
Scanning Speed – 1.6 m/s
Step Size - 15µm

Maximum value of roughness was found at –
Pulse Frequency – 80KHz
Pulse Energy – 1.06mJ
Scanning Speed – 1.6 m/s
Step Size - 5µm

S Manjoth, R. Keshavamurthy and G S Pradeep Kumar [7] worked on laser beam machining of In-situ synthesized Al7075-TiB2 metal matrix composite. They studied the influence and optimization of laser machining process parameters on volumetric material removal rate, surface roughness and dimensional accuracy of composite. For design experimental trails Taguchi's L9 orthogonal array was used. They too standoff distance (SOD) (0.3-0.5mm), gas pressure (0.5-0.7 bar) and cutting speed (1000-1200 m/hr.) were considered at three different levels as variable input parameters whereas nozzle diameter and power were maintained constant with air as assisting gas. By generating the main effects plot for signal noise ratio (S/N ratio) for surface roughness various optimized value of process parameter for surface roughness, volumetric material removal rate (VMRR) and dimensional accuracy were calculated. This was also done using Minitab software (version 16). Significant standoff distance (SOD), cutting speed and gas pressure on volumetric material removal rate (VMRR0, surface roughness and dimensional error were calculated using analysis of variance (ANOVA) method.

Result so obtained concluded that for surface roughness, cutting speed (56.38%) is most significant parameter followed by standoff distance (41.03%) and gas pressure (2.6%).

For Dimensional error, standoff distance (53.34%) is most significant parameter followed by cutting speed (34.12%) and gas pressure (12.53%).

For Volumetric material removal rate (VMRR), gas pressure (42.52%) is most significant parameter followed by cutting speed (33.6%) and standoff distance (24.06%).

Dr. S.V.S.S. Srinivasa Raju, K. Srinivas, M. Venkata Ramana [8] worked on Mild Steel E350 grade to select the best technology for cutting this material by using Laser Cutting and Plasma Cutting machines. Since these are non-contact and non-conventional machining process. They studied the effect of laser and plasma cutting process by choosing gas pressure, laser power and cutting speed as input parameters, surface roughness, taper kerfs and heat affected zone as output parameters. They used Taguchi method for optimization of edge surface roughness, taper, kerf in laser cutting and plasma cutting of Mild Steel E350 material, using oxygen as assist gas. The experiment was designed according to Taguchi L27 orthogonal array with three different levels for each input parameter. For interpretation, Analysis of Variance (ANOVA) was conducted and optimum parameter was selected on the basis of signal to noise ratio which confirms the experiment results. The conclusion was drawn as:

The cutting speed and power are the most significant parameters effecting the taper, surface roughness and kerf as compared to gas pressure which is much smaller.

It was observed that the gas pressure should be in intermediate level and the cutting speed and power should be kept in low level.

Sahil Panu, Girish Dutt Gautam, Kaushal Pratap Singh and Gavendra Norkey [9] worked on the effect of process parameters such as frequency, cutting speed and duty cycle on surface roughness (Ra) for mild steel material in laser cutting. For better understanding of interaction between process parameters L-27 orthogonal array was selected for full factorial design. The values of surface roughness for mild steel were calculated using model equations and Box-Behnken design of Response Surface Methodology (RSM) was used for parametric analysis. It was concluded that the dimensions of Ra for mild steel are directly proportional to the duty cycle and frequency and inversely proportional to cutting speed can be observed with the help of model equation. For mild steel the best value for the surface roughness (6.37μm) can be obtained at high cutting speed (1200 mm/min) value and low duty cycle value (60%).

Vipul K Shah, Mr. Hardik J Patel, Dr. Dhaval M Patel [10] worked on mild steel using Laser beam machining for cutting operation. Two assistant gas pressures are being used. The main aim of concept was to improve cut quality and kerf width. Oxygen and nitrogen are two gases with pressure of around 1 bar & 15 bar respectively with the power of about 1100 watt. The three major contribution for increasing the cut quality are by oxygen, nitrogen & power combination. In this compared single assist gas laser, higher cutting speed was achieved by fiber laser with two assist gas pressures. Oxygen has found to be having most significant effect on surface roughness and kerf width. Because of exothermic reaction burning effect is caused on surface and it increases kerf width & surface roughness. Higher the power, higher the material removal rate so increase in kerf width and surface roughness. Nitrogen effect on kerf width is, kerf width decreases effectively. The reason being MRR depends on gas pressures.

Sandeep Kumar Singh, Ajay Kumar Maurya [11] have focused more upon quality of cut being important factor in LBM. The assistant gas used is CO_2. The input parameters such as power, speed & scanning speed are considered. Power is 1-10 KW & 0.2mm diameter of beam is taken. Many works have been carried out on MS grade. However, on Kevlar it has not yet discussed much. The aim of the concept is to reduce time & cost of machining.

Dubey A.K, and Yadava V [12] In this the cutting process is carried out & two kerf qualities, kerf deviation & width have been optimized by using Taguchi quality loss function. The material taken was aluminum alloy sheet (0.9mm thick). The ND-YAG laser beam cutting was used. Cut quality is achieved to a greater extent although the cutting was found difficult.

Koji Hirano and Remy Fabbro [13] used inert gas (+n2) laser cutting. the material was steel. they used 8 KW as power & was focused onto 3mm thick low carbon steel. the beam diameter was taken to be 1-7mm. the pressure of gas was 2.5 bar.

Cutting speed was varied from 1- 6metre per minute. in this they observed melt dynamics in which central flow is stable and side region remains unstable. This observed instability, is explained by combination of thermal instability of melting process & hydrodynamic instabilities due to surface tension.

MadicMiloc and Radovanovic Miroslav [14] studied the application of Taguchi method for the optimization of laser cutting parameters and found that Taguchi method helps to find optimal parameters setting without getting much affected by noise factors. Noise factors are the external conditions or manufacturing imperfections which are unwanted and difficult to control or very expensive to control. They studied that Taguchi method is mostly used for optimization of ND: YAG laser oxygen cutting of various materials. They conclude that the Application of Taguchi method is limited for the optimization of characteristics heat affected zone, burr inclusions and material removal rate.

B. Chatterjee, K.k. Mandal, A.S. Kuar and S. Mitra [15] performed experiments of micro-drilling on 0.2mm thick copper sheet by using Nd:YVO4 laser having maximum power 12w. In this, they study the effect of parameters like laser beam power, pulse frequency, scanning speed and number of passes on the HAZ. Then they use ANOVA and confirmation test to optimize the HAZ width. During the experiment 800μm diameter hole was made on the reflective copper sheet. The lowest value of width of HAZ is obtained at laser beam power of 8.4 w, pulse frequencies, of 9 KHz, scanning speed of 0.6 mm/sec and number of passes of 5.

D.J. Kotadiya and D.H. Pandya [16] performed the parametric analysis of laser machining by using response surface method on SS-304 material. In this they optimized Laser power, cutting speed and gas pressure according to surface roughness at output. Optimum value of surface roughness and input parameters is obtained using the Design of experiments (DOE), ANOVA, Reference surface methodology (RSM) approaches. Laser machine uses 10.6 μm wavelength of CO2 laser with nominal power output of 2500 w at pulse mode. Focal length of the lens was 127mm, nozzle diameter was 2.0mm, stand of distance was 4mm, and material used is 5mm thick stainless steel-304 as a work piece. They found laser power is more significant than cutting speed and gas pressure. Optimized value of parameters was found to be 1.46w power, gas pressure of 0.70 bars, and cutting speed was 2.00m/min for minimum surface roughness of 2.18179 μm.

3. CONCLUSIONS

We have concluded the following things after going through all the research work mentioned below as follows:

- Shorter pulse of order of 10^ (-15) s enable to minimize the heat conduction through the material and maximize ablation.
- Shorter wavelengths (less than 300nm) are absorbed to a greater extent by the material rather than shorter wavelength. It was observed that shorter wavelengths are unable to produce smaller features.
- Laser intensity or power density can be varied by the pulse length and focused laser spot diameter.
- The surface reflectivity mainly depends on the surface roughness and laser wavelengths. Longer the wavelength, higher the reflectivity becomes and hence smaller the absorption.
- Temperature also influences reflection and absorption of wavelength. Higher the temperature of the material, higher the absorption occurs.
- But the main factor which affects the absorption or reflection is the wavelength.
- The effect of parameters on the cut quality is in the order:
- Oxygen gas pressure > nitrogen gas pressure > laser power
- Oxygen has measure effect as the oxygen pressure increases, the value of kerf width and surface roughness increases because oxygen participate in exothermic reactions with mild steel.
- Increase in laser power increases the surface roughness and kerf width because of more material removal.
- With the increase in Nitrogen pressure, there is slight decrease in surface roughness and effective decrease in value of kerf width.
- Compare to Taguchi method, GRA method is simpler due to the weighing factor for different quality requirement.
- Depending upon the material to be cut the focal point can be located as on the work piece surface, in the work piece and under the work piece.
- The HAZ width increases with increase in laser power. This is because with more heat input, more melting of metal and vaporization of top surface. Due to this excess power, the HAZ width is more around the drilled region.

- With the increase in pulse frequency HAZ decreases. This is because the duration of heat input is decreased and hence most of the heat is utilized for material removal and therefore less chance of HAZ formation. But if the pulse frequency further increases then there is excess heating of top surface compared to heat conduction which tends to formation of HAZ.
- With the increase in scanning speed, HAZ width initially increases slowly but after a particular value of scanning speed HAZ decreases. This is because in initial stage the input power is more and after a particular value heat input became insufficient as the duration of pulse decreases due to further increase in scanning speed and hence HAZ formation reduces.
- With the increase in the number of passes the HAZ width increases and then again decreases uniformly with further increase in number of passes. This is because with increase in number of passes duration of heat input increases rapidly hence the excess heat may not be conducted so fast. But with further increase of number of passes, it will not affect more as the heat will pass away through the hole.
- Pure oxygen – rapid oxidation & exothermic reactions causing better process efficiency.
- Pulse energy – In drilling longer holes with longer pulses causes enlargement of holes at entrance so peak power should be obtained by increasing the pulse energy while keeping the pulse duration constant.
- Inert gases are preferred for better quality of cut such as argon & helium.
- Gas pressure also alters the quality of cut & rate of machining.
- Beam power intensity – it tells us how intensely can we apply power on work piece, how deep can we go with intensity and how fast we can cut.
- Reflectivity – higher the reflectivity of work piece, lower will be the efficiency of machining. As most of laser energy will get reflected instead of getting absorbed and getting work done.
- The factors like reflectivity, specific heat, thermal conductivity & latent heat should be low in magnitude so as to improve process efficiency.

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