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Multi-objective Optimization of Laser Beam Machining Process Parameters

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Abstract

Laser beam machining (LBM) is one of the most widely used thermal energy based non-contact type advance machining process. In recent years, researchers have explored a number of ways to improve the LBM process performance by analyzing different factors that affect the quality characteristics of LBM process such as kerf width, kerf taper, surface finish etc. It is revealed from the literature that process performance of the LBM process can be improved considerably by appropriate selection of laser beam process parameters. However, researchers had mostly employed statistical methods such as Taguchi, Response Surface Methodology (RSM), Grey Relation Analysis (GRA), Principal Component Analysis (PCA) etc. for optimization of the LBM process. Although these methods are applied for multi-objective optimization, these are based on weights approach and provide single optimum solution. Hence, in this work an attempt is made for multi-objective optimization of LBM process using posteriori approach known as non-dominated sorting genetic algorithm (NSGA) in which the set of non-dominated optimum solutions is obtained. This provides the ready reference to process planner to choose appropriate set of optimum solutions as per requirement. For this work the experiments are carried out on the CO_2 laser machine to cut 3 mm thick plate of material stainless steel AISI 321. The process parameters considered are assist gas pressure, cutting speed, laser power, and pulse frequency. The quality performance measures are in terms of kerf width, kerf taper and surface roughness.

Keywords: Laser beam machining, multi-objective optimization, non-dominated sorting genetic algorithm (NSGA).

1. Introduction

Laser beam machining, being a non-contact process, does not involve any mechanical cutting forces and tool wear. Laser beam machining is a thermal energy based cutting process, which is executed by moving a focused laser beam on the surface of the work-piece with appropriate scanning speed. Asist gas is supplied through a nozzle with pressure to remove the molten metal. Laser beam machining of sheet metals has always been a major research area for getting the improves quality of cut which depend on several factors such as laser type, laser power, pressure of assist gas, cutting speed, sheet material composition and its thickness, and mode of operation of laser beam (Continuous or Pulsed mode). The capability of the laser cutting mainly depends on the optical and thermal properties rather than mechanical properties of the material to be cut. The materials which exhibit high degree of hardness or brittleness and passing through favorable thermal and optical properties such as low reflectivity, low thermal conductivity and diffusivity are well suited for laser cutting process. To achieve acceptable level of kerf quality characteristics, it is necessary to choose optimum combination of input process parameters. Various researchers had applied statistical methods such as Response surface method (Ghosal and Manna 2012; Sharma and Yadava, 2008; Dubey and Yadava, 2007), Taguchi method (Dubey and Yadava,2011; Sharma and Yadava, 2011; Sharma et al., 2010; Rao and Yadava, 2009) and principal component analysis (Dubey and Yadava, 2007).It is thus revealed from the literature that the researchers had mostly employed statistical methods such as Taguchi, response surface methodology (RSM), grey relation analysis (GRA), principal component analysis (PCA) etc. for optimization of the LBM process. Although these methods are applied for multi-objective optimization, these are based on weights approach and provide single optimum solution.

Hence, in this work an attempt is made for multi-objective optimization of LBM process using posteriori approach known as non-dominated sorting genetic algorithm (NSGA) in which the set of non-dominated optimum solutions is obtained. This provides the ready reference to process planner to choose appropriate set of optimum solutions as per timely requirement.

2. Experimental Design and Data Collection

Four process parameters namely assist gas pressure, cutting speed, laser power, and pulse frequency are considered for experimentation. Table 1 shows coded values of process variables.

Table 1: Coded values of process variables.

Variable	Parameters	LEVELS				
		-2	**-1**	**0**	**1**	**2**
X_1	Gas pressure (bar)	4	6	8	10	12
X_2	Cutting speed (mm/min)	2500	3000	3500	4000	4500
X_3	Laser power (watt)	2400	2600	2800	3000	3200
X_4	Pulse frequency (Hz)	6000	7000	8000	9000	10000

The experimental set up used for data collection is as given below: Machine type/make: Tru Laser 3030; Workpiece specification: Stainless steel (AISI 321) plate 3 mm thick; Gas type: Nitrogen, Focal length: 7.50”; Nozzle diameter: 1.4 mm.

An experiment is designed with 2^k (where, k = number of variables, in this study k =4) factorial with central composite-second order ratable design is used. This consists of number of corner points =16, number of axial points=8, and a centre point at zero level =4. However, for 8 experiments, the parameter combination could not result into complete cutting. Hence, 20 experiments are presented in Table 2.

Table 2: Design of experiment.

Expt. No.	X_1	X_2	X_3	X_4	**Kerf width (mm)**	**Taper angle (°)**	**Surface roughness (μm)**
1	-1	-1	-1	-1	0.242	2.333	2.919
2	1	-1	-1	-1	0.275	2.800	2.154
3	-1	1	-1	-1	0.330	2.383	2.880
4	1	1	-1	-1	0.270	2.583	2.117
5	-1	-1	1	-1	0.267	2.667	2.698
6	1	-1	1	-1	0.325	2.167	1.918
7	-1	1	1	-1	0.279	2.833	2.878
8	-1	-1	-1	1	0.219	2.883	3.454
9	1	-1	-1	1	0.208	3.133	2.134
10	-1	-1	1	1	0.293	2.433	3.422
11	1	-1	1	1	0.271	2.833	2.845
12	2	0	0	0	0.239	2.667	2.613
13	0	-2	0	0	0.237	2.600	2.807
14	0	0	2	0	0.250	2.767	2.400
15	0	0	0	-2	0.230	3.750	2.663
16	0	0	0	2	0.229	4.150	3.267
17	0	0	0	0	0.237	2.467	2.706
18	0	0	0	0	0.264	3.250	2.546
19	0	0	0	0	0.246	1.833	2.593
20	0	0	0	0	0.215	1.833	2.408

To study the effect of process parameters on performance measures i.e. kerf width (*KW*), kerf taper (*KT*) and surface roughness (SR), a second-order polynomial response is fitted into the following equations:

$$KW = 0.2404 - 0.026229x_1 + 0.005998x_2 - 0.00256x_3 - 0.00268x_4 - 0.03221x_1x_2 - 0.00188x_1x_3 \\ - 0.01691x_1x_4 - 0.02784x_2x_3 + 0.010909x_2x_4 + 0.006609x_3x_4 + 0.01522x_1^2 + 0.004573x_2^2 + 0.006x_3^2 \\ - 0.00151x_4^2 \quad (1)$$

$$KT = 2.345 + 0.1852x_1 + 0.097x_2 + 0.0727x_3 + 0.1323x_4 + 0.092x_1x_2 - 0.0536x_1x_3 + 0.1015x_1x_4 + 0.1878x_2x_3 - 0.0160x_2x_4 - 0.0400x_3x_4 - 0.044x_1^2 + 0.0801x_2^2 + 0.0364x_3^2 - 0.3848x_4^2 \quad (2)$$

$$SR = 2.56325 - 0.33373x_1 + 0.012022x_2 + 0.178522x_3 + 0.165968x_4 + 0.089038x_1x_2 + 0.113453x_1x_3 - 0.036522x_1x_4 + 0.143288x_2x_3 - 0.09733x_2x_4 - 0.149484x_3x_4 + 0.164333x_1^2 + 0.051988x_2^2 - 0.145044x_3^2 + 0.092953x_4^2 \quad (3)$$

3. Multi-objective Optimization of Laser Beam Machining Process Parameters Using NSGA

The multi-objective optimization of LBM process is carried out considering objective 1 as to minimize the kerf width given by Eq. (1) and objective 2 as to minimize kerf taper given by Eq. (2) subjected to the constraint on surface roughness given by Eq. (3) so as to ensure that the surface roughness should not exceed 2.3 µm. Following steps of NSGA are applied:

Step 1: Population initialization: Initialize the population based on the problem range and constraint.

Step 2: Non-dominated sorting: Sorting process based on non domination criteria of the population that has been initialized.

Step 3: Crowding distance: Once the sorting is complete, the crowding distance value is assign front wise. The individuals in population are selected based on rank and crowding distance.

Step 4: Selection: The selection of individuals is carried out using a tournament selection with crowded-comparison operator.

Step 5: Genetic Operators: These are crossover and mutation as in case of genetic algorithm

Step 6: Recombination and selection: Offspring population and current generation population are combined and the individuals of the next generation are set by selection. The new generation is filled by each front subsequently until the population size exceeds the current population size.

In this work a penalty parameter less constraint handling technique is used as described below.

$$F(x) = \begin{cases} f(x), & if\ x\, is\ feasible \\ f_{max} + \sum_{j=1}^{j} \langle g_j(x) \rangle + \sum_{K=1}^{K} |h_k(x)|, & otherwise \end{cases} \quad (4)$$

Where, $f(x)$ is the value of objective function corresponding to feasible a solution, f_{max} is the objective function value of the worst feasible solution in the population, $g_j(x)$,$h_k(x)$ are the inequality and equality constraints respectively.

After several trial runs, the following parameters of NSGA are selected for the present case study: Population size (N) = 60; Cross-over probability (pc) = 0.8; Mutation probability (pm) = 0.1. Table 3 presents set of nominated solutions obtained by using NSGA. Fig. 1 shows Pareto front.

Table 3: Set of Pareto optimal solutions.

X_1	X_2	X_3	X_4	KW	KT	SR
8.317	3754.599	2635.257	7782.736	0.257	2.326	2.227874
8.316	3802.591	2643.561	8124.738	0.257	2.382	2.238603
8.716	3778.331	2640.607	7951.941	0.250	2.393	2.176293
9.201	3835.568	2643.228	7948.681	0.245	2.462	2.13377
11.236	3865.076	2652.473	8305.75	0.220	2.812	2.158388
10.770	3897.890	2652.694	8457.095	0.218	2.870	2.133879
11.085	3907.656	2660.518	8532.83	0.213	2.963	2.184675
11.041	3843.659	2651.845	8667.815	0.212	3.032	2.146718
10.830	3895.155	2657.049	8750.842	0.210	3.100	2.165292
11.295	3885.178	2660.465	8718.589	0.207	3.122	2.206171
11.274	3872.598	2661.609	8839.571	0.203	3.225	2.216398
11.317	3907.855	2660.434	8846.35	0.202	3.252	2.219846
11.114	3902.004	2657.601	8956.146	0.201	3.335	2.202186
11.114	3902.492	2657.601	8956.146	0.201	3.335	2.202231
10.864	3886.522	2660.176	9078.758	0.201	3.428	2.212693
11.398	3917.133	2660.789	9059.624	0.195	3.491	2.250486
11.384	3921.322	2661.847	9109.072	0.193	3.548	2.26011
11.217	3917.437	2662.487	9188.376	0.193	3.619	2.259737
11.374	3914.538	2658.032	9221.145	0.191	3.679	2.257611
11.380	3918.977	2661.393	9285.927	0.188	3.766	2.282988
11.433	3926.789	2661.335	9329.58	0.186	3.835	2.294812

4. Conclusions

In the present work, multi-objective optimization aspects of laser beam machining process parameters are considered using NSGA. The two objectives considered are: minimization of kerf width and minimization of kerf taper subjected to the constraints on surface finish. Although various traditional and non-traditional methods have been employed so far by earlier researchers for multi-objective optimization of laser beam machining process, they converted the multi-objective problem into single objective problem by assigning weights to the different objectives. However, such approach does not provide a dense spread of the Pareto points. Also, the process engineer needs to have a comprehensive knowledge regarding the preference factor of each objective. To overcome this drawback of a priori approach, a posterior approach namely NSGA is used in this work.

The non-dominated solutions obtained in this work for laser beam machining process provide a ready reference to the process engineer. It is also observed from Table 3 that, although the ranges of the process parameters are very wide, the effective range to achieve minimum kerf width, minimum kerf taper and desired surface finish is 8.316 to 11.433 bar for gas pressure, 3754.6 to 3826.78 mm/min for cutting speed, 2635.25 to 2662.48 watt for laser power and 7782.73 to 9329.58 Hz for frequency.

References

[1] Amit Sharma & Vinod Yadava (2011). Modelling and optimization of cut quality during pulsed Nd:YAG laser cutting of thin Al-alloy sheet for straight profile. *Optics and Laser Technology 44 (2012) 159-168.*

[2] Amit Sharma, Vinod Yadava & Raghavendra Rao (2010). Optimization of kerf quality characteristics during Nd: YAG laser cutting of nickel based superalloy sheet for straight and curved cut profiles. *Optics and Lasers in Engineering 48 (2010) 915-925.*

[3] Arindam Ghosal & Alakesh Manna (2012). Response surface method based optimization of ytterbium fiber laser parameter during machining of Al/Al2O3-MMC. *Optics and Laser Technology 46 (2013) 67-76***.**

[4] Arun Kumar Pandey & Avanish Kumar Dubey (2011).Taguchi based fuzzy logic optimization of multiple quality characteristics in laser cutting of Duralumin sheet. *Optics and Laser in Engineering 50 (2012) 328-335.*

[5] Arun Kumar Pandey & Avanish Kumar Dubey (2011).Taguchi based fuzzy logic optimization of multiple quality characteristics in laser cutting of Duralumin sheet. Optics and Laser in Engineering 50 (2012) 328-335.

[6] Avanish Kumar Dubey, Vinod Yadava (2007). Optimization of kerf quality during pulsed laser cutting of aluminium alloy sheet. *Journal of Materials Processing Technology 204 (2008) 412-418.*

[7] Avanish Kumar Dubey, Vinod Yadava (2007). Multi-objective optimization of Nd:YAG laser cutting of nickel-based super alloy sheet using orthogonal array with principal component analysis. *Optics and Lasers in Engineering 46 (2008) 124-132.*

[8] Avanish Kumar Dubey, Vinod Yadava (2007). Multi-objective optimization of laser beam cutting process. *Optics and Laser Technology 40 (2008) 562-570.*

[9] Raghavendra Rao & Vinod Yadava (2009). Multi-objective optimization of Nd:YAG laser cutting of thin superalloy sheet using grey relational analysis with entropy measurement. *Optics and Laser Technology 41 (2009) 922-930.*