

Multi Response Optimization of Laser Micro Marking Process: A Grey- Fuzzy Approach

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Abstract. The selection of optimal parametric combination for efficient machining has always become a challenging issue for the manufacturing researcher. The optimal parametric combination always provides a better machining which improves the productivity, product quality and subsequently reduces the production cost and time. The paper presents the hybrid approach of Grey relational analysis and Fuzzy logic to obtain the optimal parametric combination for better laser beam micro marking on the Gallium Nitride (GaN) work material. The response surface methodology has been implemented for design of experiment considering three parameters with their five levels. The parameter such as current, frequency and scanning speed has been considered and the mark width, mark depth and mark intensity has been considered as the process response.

1. Introduction

The laser marking is the method of producing a mark on the surface of the work material. It is considered to be an efficient marking process as compared to traditional marking process. It produces clean and rapid marking onto the work material [1]. The demand of laser marking is increasing rapidly due to its diversified application. The product traceability and its identification is one of the important applications of laser marking [2]. The fuzzy logic was first introduced in 1965 by Lotfi A. Zadeh [3]. Fuzzy logic technique deals with the information which is uncertain. The hybrid approach of Grey based fuzzy shows the great improvement in the manufacturing process [4-5].

The improper selection of process parameters always shows the negative effect on the machining process [6]. The Grey based fuzzy logic when implemented for process parameter optimization of CNC milling shows a significant improvement in the process [7]. The Grey based Fuzzy logic technique is suitable for all the machining process. The hybrid aspect of Grey-Fuzzy provides good and understandable results [8]. The hybrid approach of Grey-Fuzzy logic technique combined with RSM design of experiment can be effectively used for process parameter optimization in EDM to achieve the minimum aspect of surface integrity [9].

The Grey-Fuzzy decision system can be used to solve the discrete multi-attributes decision problem in the manufacturing firms for process improvement [10]. The Grey- Fuzzy logic technique improves the grey-fuzzy reasoning grade and provides fewer uncertainties in the output as compared to grey relational analysis technique [11]. The paper presents the selection of optimal process parametric combination for laser beam micro marking process in order to obtain the effective marking on the Gallium Nitride (GaN) work material.



2. Experimental Planning and Methodology

The experiment was conducted on Laser Machine (Nd-YAG, Diode pumped). The parameter such as current, frequency and scanning speed with their five levels are considered for designing the experiment using Response surface methodology. As per the design the experiment has been conducted and responses such as mark width, mark depth and mark intensity are calculated.

Table 1. Parameters and their levels

Parameters	Unit	Levels				
		L1	L2	L3	L4	L5
Current	A	18	18.5	19	19.5	20
Pulse frequency	Hz	4000	4200	4400	4600	4800
Scanning speed	mm/s	5	7	9	11	13

The mark width and mark depth are evaluated using precision microscope and the image taken from the microscope has been processed through image processing in Matlab to calculate the mark intensity. As per the design of experiment twenty set of experiments has been conducted. The Gallium Nitride which is considered to be a difficult-to-cut material due to high hardness has been used as the work material. Table 1 shows the parameter and their levels.

3. Optimization using Grey-Fuzzy logic Technique

The Grey relational analysis soft-tool can be used to handle those data which is having a multiple response characteristics. The Grey system forms the basis for the Grey relational analysis where some part of information is provided and some part of information is unknown. Usually this situation is termed as grey i.e. neither white nor black. The Grey relational analysis involves following steps [12].

3.1. Normalization

The Normalization is the process of converting the experimental data set into the range between 0 to 1. The process response such as mark width, mark depth and mark intensity has been normalized. The response which is higher the better type was normalized using the equation 1 and the response of lower the better type was normalized using equation 2. Table 2 shows the experimental results and its normalized value.

$$m_{ij} = (x_{ij} - \min(x_{ij})) / (\max(x_{ij}) - \min(x_{ij})) \quad (1)$$

$$m_{ij} = (\max(x_{ij}) - x_{ij}) / (\max(x_{ij}) - \min(x_{ij})) \quad (2)$$

where m_{ij} is normalized value of x_{ij} for response j ($j = 1, 2, 3, \dots, n$) of experiment i ($i = 1, 2, 3, \dots, m$).

3.2. Grey relational coefficient

The grey relational coefficient determines the closeness between x_{ij} to x_{0j} . Higher the grey relational coefficient depicts x_{ij} is closer to x_{0j} . Table 3 shows the Grey relational coefficient values. The Grey relational coefficient is calculated as follows

$$\gamma(x_{0j}, x_{ij}) = (\Delta_{\min} + \xi \Delta_{\max}) / (\Delta_{ij} + \xi \Delta_{\max}) \quad (3)$$

The distinguish coefficient is taken as 0.5. Further the Grey relational coefficient has been used in Fuzzy logic in order to evaluate Grey-fuzzy relational grade (GFRG).

3.3. Fuzzy logic

In this research work Fuzzy logic is coupled with the Grey relational analysis. The experimental data are normalized in order to avoid unit influence for mark width, mark depth and mark analysis. Fuzzy logic consists of fuzzification and defuzzification. The fuzzification is the method for converting the input data into linguistic variable. The linguistic variable is assigned as high, medium and low. The fuzzy inference system is based on IF-THEN rules. The defuzzification converts the output data in terms of numerical form. Fig 1, 2& 3 shows the membership function for input and output and Fuzzy rules respectively.

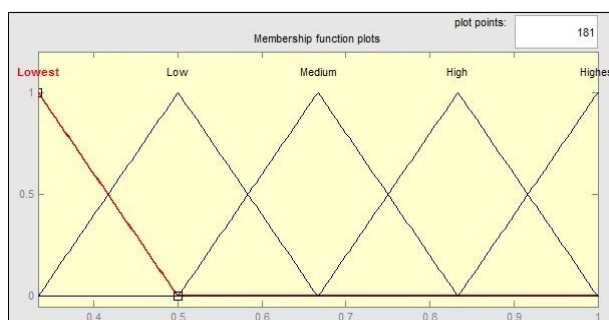
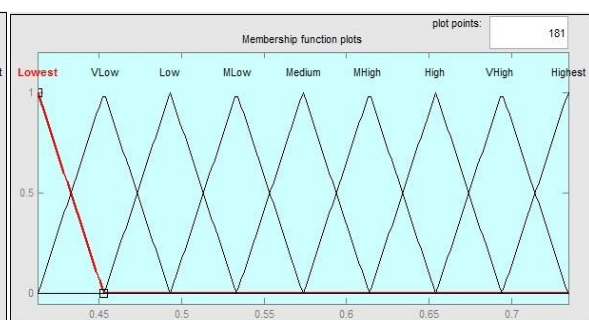
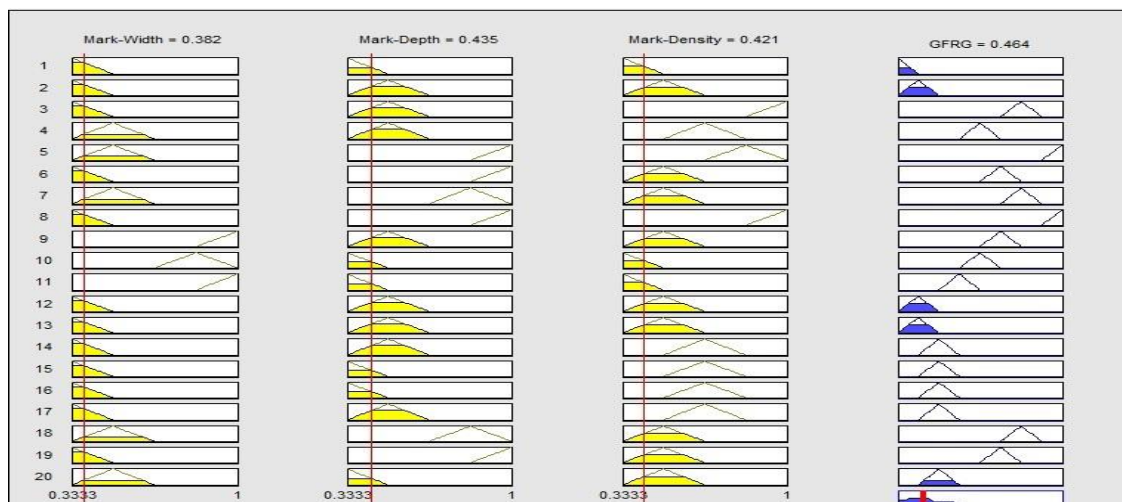
Table 2. Experimental data and its normalized values

Parametric combination				Experimental results			Normalized value		
Expt. No	Current (A)	Frequency (Hz)	Scanning Speed (mm/sec)	Mark width (μm)	Mark Depth (μm)	Mark Intensity	Mark width (μm)	Mark depth (μm)	Mark Intensity (μm)
1	18.5	4200	7	143.90	55.94	0.255	0.1916	0.3499	0.3117
2	19.0	4400	9	141.97	62.93	0.325	0.242	0.4403	0.5951
3	19.0	4000	9	149.14	89.11	0.425	0.0554	0.7789	1
4	19.0	4400	9	134.40	69.58	0.377	0.4388	0.5263	0.8057
5	19.0	4800	9	134.01	103.92	0.391	0.4489	0.9704	0.8623
6	20.0	4400	9	149.53	106.21	0.311	0.0454	1	0.5385
7	19.0	4400	5	130.91	99.29	0.321	0.5295	0.9105	0.5789
8	19.5	4200	11	148.56	102.33	0.411	0.0705	0.9498	0.9433
9	18.5	4600	7	115.78	73.04	0.301	0.923	0.5711	0.498
10	18.5	4600	11	117.91	56.86	0.281	0.8676	0.3618	0.417
11	18.0	4400	9	112.82	28.88	0.178	1	0	0
12	19.5	4600	11	151.27	74.98	0.303	0	0.5961	0.5061
13	19.0	4400	9	143.66	63.73	0.326	0.1979	0.4507	0.5992
14	19.0	4400	13	136.73	63.30	0.343	0.3783	0.4451	0.668
15	19.0	4400	9	144.88	57.94	0.355	0.1663	0.3758	0.7166
16	19.0	4400	9	140.41	53.63	0.353	0.2824	0.3201	0.7085
17	19.0	4400	9	138.86	71.25	0.343	0.3227	0.5479	0.668
18	19.5	4600	7	127.38	98.76	0.312	0.6212	0.9037	0.5425
19	19.5	4200	7	149.72	104.02	0.324	0.0403	0.9717	0.5911
20	18.5	4200	11	131.86	61.59	0.306	0.5048	0.423	0.5182

Table 3. Grey relational coefficient

Sl No	Mark width (μm)	Mark depth (μm)	Mark Intensity
1	0.4347	0.4208	0.3821
2	0.4718	0.5525	0.3975
3	0.6934	1	0.3461
4	0.5135	0.7201	0.4712
5	0.9441	0.7841	0.4757
6	1	0.52	0.3437
7	0.8482	0.5428	0.5152
8	0.9088	0.8981	0.3498
9	0.5383	0.499	0.8666
10	0.4393	0.4617	0.7906

11	0.3333	0.3333	1
12	0.5532	0.5031	0.3333
13	0.4765	0.5551	0.384
14	0.474	0.601	0.4458
15	0.4448	0.6382	0.3749
16	0.4238	0.6317	0.4106
17	0.5252	0.601	0.4247
18	0.8385	0.5222	0.569
19	0.9464	0.5501	0.3425
20	0.4643	0.5093	0.5024

**Fig. 1** Membership function for input coefficient**Fig. 2** Membership function for GFRG**Fig. 3** Fuzzy rule viewer**Table 4.** Grey- Fuzzy relational grade

Sl No	Mark width (μm)	Mark depth (μm)	Mark Intensity (μm)	Grey-Fuzzy relational grade (GFRG)	Rank
1	0.4347	0.4208	0.3821	0.464	19
2	0.4718	0.5525	0.3975	0.501	17
3	0.6934	1	0.3461	0.574	9
4	0.5135	0.7201	0.4712	0.553	10
5	0.9441	0.7841	0.4757	0.721	1
6	1	0.52	0.3437	0.614	6
7	0.8482	0.5428	0.5152	0.654	3

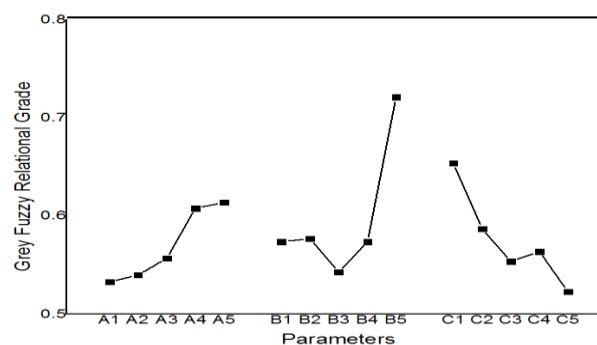
8	0.9088	0.8981	0.3498	0.719	2
9	0.5383	0.499	0.8666	0.614	7
10	0.4393	0.4617	0.7906	0.574	8
11	0.3333	0.3333	1	0.533	11
12	0.5532	0.5031	0.3333	0.454	20
13	0.4765	0.5551	0.384	0.499	18
14	0.474	0.601	0.4458	0.523	12
15	0.4448	0.6382	0.3749	0.51	16
16	0.4238	0.6317	0.4106	0.52	13
17	0.5252	0.601	0.4247	0.516	14
18	0.8385	0.5222	0.569	0.654	4
19	0.9464	0.5501	0.3425	0.617	5
20	0.4643	0.5093	0.5024	0.511	15

Table 5. Response table for GFRG

Levels	Current (Amp)	Frequency (Hz)	Scanning Speed (mm/sec)
1	0.533	0.574	0.654
2	0.540	0.577	0.587
3	0.557	0.543	0.554
4	0.608	0.574	0.564
5	0.614	0.721	0.523

Table 6. ANOVA for GFRG

Source	DF	SS	MS	F	P	%
Regression	3	0.1060	0.0353	58.16	0.000	19.46
Linear	3	0.1060	0.0353	58.16	0.000	19.46
Current (Amp)	1	0.0759	0.0714	117.51	0.000	39.31
Frequency (Hz)	1	0.0014	0.0108	17.91	0.001	5.99
Scanning speed (mm/sec)	1	0.0286	0.0286	47.20	0.000	15.79
Residual error	16	0.0097	0.0006			
Total	19	0.1158				

**Fig 4.** Response plot for GFRG

The Grey relational coefficient value is processed through the Fuzzy logic technique and the Grey-Fuzzy relational grade has been calculated. The Fuzzy IF-THEN rule has been utilized for the same and the defuzzification has been done in order to convert the linguistic variable into numerical value. Table 4 shows the Grey-Fuzzy relational grade (GFRG).

4. Results and Discussion

The Grey relational coefficient is used to determine the GFRG. The ranking of GFRG has been done. The parametric combination having the highest value of GFRG represents the strong correlation with the reference sequence. Table 5 shows the response table for GFRG. The response table has been made considering the different levels at which the marking is performed. The maximum value of each level has been used to select the optimal values. Fig 4 shows the response plot for GFRG. The table reveals that the optimal parametric combination for minimum mark width, maximum mark depth and maximum mark intensity are 20Amp/ 4800 Hz/ 5 mm/sec. The ANOVA for GFRG is shown in table 6 in order to validate the optimum levels obtained. The p value in the ANOVA table is less than 0.05 which depicts that the obtained GFRG is significant. Further the percentage contribution of each parameters on the response has been calculated in order to observe the most significant parameter. The current is the most contributing factor having the highest percentage followed by scanning speed and frequency.

5. Conclusion

The paper discusses the Fuzzy based Grey relational optimization for optimizing multi-criteria performance. RSM based design of experiment has been adopted and the micro marking has been performed in the Gallium Nitride (GaN) work material. The grey relational coefficient is used for evaluating Grey-Fuzzy relational grade and the ranking of GFRG has been done. The optimal parametric combination obtained is 20Amp/ 4800 Hz/ 5 mm/sec. Further the ANOVA for GFRG has been performed in order to validate the GFRG values. The percentage contribution of each parameter on the response has been obtained. The obtained results may be utilised for laser beam micro marking of Gallium Nitride (GaN).

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