Multiple Response Optimization in Drilling Using Taguchi and Grey Relational Analysis

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Abstract : This paper presents a new approach for the optimization of drilling parameters on drilling EN-8 Carbon steel with multiple responses based on L9 orthogonal array with grey relational analysis. As EN-8 steel plates findings many applications such as Shaft, axle, gears and fasteners due to their strength to weight ratio. Experiments are conducted on EN-8 steel plate. Drilling tests are carried out using HSS twist drills of (8,10,12) mm diameter under dry condition. In this study, drilling parameters namely cutting speed, feed and drill diameter are optimized with the considerations of multi responses such as torque and thrust. A grey relational grade is obtained from the grey analysis. Based on the grey relational grade, optimum levels of parameters have been identified and significant contribution of parameters is determined by ANOVA. Experimental results have shown that the responses in drilling process can be improved effectively through the new approach.

IndexTerms - **Drilling, EN-8Carbonsteel, Orthogonalarray, Greyrelational analysis & ANOVA.**

I. INTRODUCTION

Drilling is one of the most complex machining processes .The chief characteristic that distinguishes it from other machining operations. It is the combined cutting and extrusion of metal at the chisel edge in the centre of the drill . A drill bit is to cut a hole of circular cross-section in solid materials. The drill bit is usually a rotary cutting tool, often multi-point. The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute. The high-thrust force caused by the feeding motion first extrudes metal under the chisel edge. Then it tends to shear under the action of a negative rake angle tool.

1.1 Material Used

EN8 is an unalloyed medium carbon steel which is used in applications where better properties than mild steel are required but where the costs do not justify the purchase of a steel alloy. EN8 can be heat treated to provide a good surface hardness and moderate wear resistance by flame or induction hardening processes.

1.2 Cutting Tool (High Speed Steel)

It is often used in power-saw blades and drill bits. It can withstand higher temperatures without losing its temper (hardness).

II. LITERATURE REVIEW

J Paulo davim et al. (2002) [1] A study of the influence of cutting parameters and cutting time on drilling metal matrix composites. A plan of experiments, based on the techniques of Taguchi, was performed on controlled machining with cutting conditions prefixed in workpieces. The objective was to establish correlation between cutting velocity, feed rate and cutting time with the evaluator the tool wear, the specific cuing pressure and the holes surface roughness. These correlations were obtained by multiple linear regression. Finally, confirmation tests were performed to make a comparison between the experimental results foreseen.

C.C. Tsao et al. (2004) [2] The approach is based on Taguchi's method and the analysis of variance (ANOVA). An ultrasonic C-Scan to examine the delamination of carbon fiber-reinforced plastic (CFRP) laminate is used in this paper. The experimental results indicate that the feed rate and the drill diameter are recognized to make the most significant contribution to the overall performance. The objective was to establish a correlation between feed rate, spindle speed and drill diameter with the induced delamination in a CFRP laminate.

M. Balajia et al. (2016) [3] The present work deals with the effect of cutting parameters namely cutting speed, feed rate and helix angle on the tool life. The experiments were performed on drilling of AISI304 steel with carbide drill bits. Design of experiments was prepared according to Taguchi orthogonal array of L8 and experiments were performed with two levels of the cutting parameters. The effects of cutting parameters were analyzed by evaluating the amplitude of drill bit vibration and surface roughness.

Ramo´n Quiza Sardin˜as et al. (2006) [4] Machining of composite materials is an important and current topic in modern researches on manufacturing processes. Two mutually conflicting objectives are optimized: material removal rate, which represents the productivity; and delamination factor, which characterizes the superficial quality. A micro-genetic algorithm was implemented to carry out the optimization process.

III. DESIGN OF EXPERIMENTS & METHODOLOGY

3.1 Taguchi Approach

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance " for the experiment with " optimum settings " of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

3.2 Selection of orthogonal array

A major step in the DOE process is the selection of orthogonal array based on number of factors and number of levels for each factor. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. The degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters [13-14]. In present work three factors and four level were considered. Therefore degrees of freedom were calculated as shown below.

1. Number of factors =3
2. Numbers of levels = 4
3. Degrees of freedom of each factor = 4-1=3
4. Total degrees of freedom = Sum of the degrees of freedoms of all factors.

= 3+3+3=9

i) Minimum numbers of experiments to be conducted = 9+1= 10.

Based on the required minimum number of experiments the nearest orthogonal array fulfilling the condition is L16.

IV. EXPERIMENTAL DETAILS

The experiments were conducted on EN8 steel material for different cutting speeds, feed rates and diameter of drill bit combinations. The cutting speeds considered are 71 rpm, 112 rpm and 180 rpm. Feed rate considered are 0.13 mm/rev, 0.21 mm/rev and 0.33 mm/rev. Diameter of drill bit considered are 8mm, 10mm and 12mm. Experimental set-up is as shown in the

Fig1: RADIAL DRILLING MACHINE

4.1 MACHINE SPECIFICATIONS

Drilling capacity ---- 40MM
Radius ---- 1125
No of Speeds ---- 8
Range of Speed ---- 71-1800 RPM
Power ---- 415/3HP

Material & Drill Bits

Fig.2: EN - 8

Fig.3: Drill Bits (8mm 10mm 12mm)

Table 1: Input parameters and their levels

Control factors (unit)	Level 1	Level 2	Level 3
Spindle speed (rpm)	71	112	180
Feed rate (mm/min)	0.13	0.21	0.33
Drill dia (mm)	8	10	12

Taguchi method is a powerful tool in quality Optimization makes use of a special design of orthogonal array (OA) to examine the number of experiments used to design the orthogonal array for 3 factors and 3 levels of drilling parameters.

Minimum experiments = [(L-1) X p] +1

= [(3-1) X 3] +1

= 7 ≈ L9

Table 2: TAGUCHI'S Design of Experiments

Experiment NO	Speed	Feed	Drill Diameter
1	71	0.13	8
2	112	0.33	8
3	180	0.21	8
4	71	0.21	10
5	112	0.13	10
6	180	0.33	10
7	71	0.33	12
8	112	0.21	12
9	180	0.13	12

V. EXPERIMENTAL PROCEDURE

The Taguchi relation are now analysed with Taguchi in Minitab software

5.1 Minitab Software

Minitab is a statistics package. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab began as a light version of MNITAB, a statistical analysis program by NIST. Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College. Pennsylvania, with subsidiaries in Coventry, England, Paris, France and Sydney, Australia Today, Minitab is often used in conjunction with the implementation of Six sigma, CMMI and other statistics-based process improvement methods.

5.2 Selection of Orthogonal Array

To select an appropriate orthogonal array for conducting the experiments, the degrees of freedom are to be computed. The same is given below:

Degrees of Freedom: 1 for Mean Value, and

8= (2x4), two each for the remaining factors

Total Degrees of Freedom: 9

The most suitable orthogonal array for experimentation is L9 array as shown in Table 4.3[5]. Therefore, a total nine experiments are to be carried out.

5.3 Analysis of the Signal-to-Noise Ratio

Analysis of the experimental results uses a signal to noise ratio to aid in the determination of the best process designs. The Taguchi technique is a effective layout of experiment device for acquiring the facts in a managed way and to investigate the influence of method variable over a few precise variable that's unknown feature of these procedure variables and for the layout of excessive best structures. Taguchi creates a preferred orthogonal array to accommodate the impact of numerous elements on the goal cost and defines the plan of experiment. The experimental results are analyzed using evaluation of variance to observe the affect of parameters. sign-to-noise ratio for smaller is the higher characteristics given by using Taguchi which may be calculated as logarithmic transformation of the loss function, is given as[16] :

$$S/N = -10 \times l(\frac{\sum(Y^2)}{n})$$

Table 3: Orthogonal Array (OA) L9 (Coded)

Experiment No	Control Factors		
	1	2	3
1	1	1	1
2	2	3	1
3	3	2	1
4	1	2	2
5	2	1	2
6	3	3	2
7	1	3	3
8	2	2	3
9	3	1	3

Table 4: Orthogonal Array (OA) L9 (Un-coded)

Experiment No	Control Factors		
	Speed rpm	Feed mm/min	Drill Dia mm
1	71	0.13	8
2	112	0.33	8
3	180	0.21	8
4	71	0.21	10
5	112	0.13	10
6	180	0.33	10
7	71	0.33	12
8	112	0.21	12
9	180	0.13	12

Experiment no	Speed RPM	Feed Mm/min	Drill Dia mm	Torque Kg/m	Thrust kgf
1	71	0.13	8	15	39
2	112	0.33	8	17	34
3	180	0.21	8	26	38
4	71	0.21	10	61	45
5	112	0.13	10	36	29
6	180	0.33	10	79	43
7	71	0.33	12	98	48
8	112	0.21	12	64	29
9	180	0.13	12	37	20

After conducting experiments on EN8 steel material for different cutting speeds, feed rates and diameter of drill bit combinations. The cutting speeds considered are 71 rpm, 112 rpm and 180 rpm. Feed rate considered are 0.13 mm/rev, 0.21 mm/rev and 0.33 mm/rev. Diameter of drill bit considered are 8mm, 10mm and 12mm.Values are to be noted using Dynamometer while doing experiment.

VI. RESULTS & DISCUSSIONS

6.1 Grey Relational Anaylsis

The algorithm of grey relational analysis coupled with principal analysis to determine the optimal combinations of the cutting parameters for rough cutting process in high-speed drilling operation is described step by step as follow:
(1) Convert the experimental data into S/N values.
(2) Normalize the S/N ratio.
(3) Calculate the corresponding grey relational coefficients.
(4) Calculate the grey relational grade using principal component analysis.
(5) Select the optimal levels of cutting parameters.
(6) Conduct confirmation experiments.

6.2 Optimal combination of the cutting parameters

The performance characteristics obtained from the experimental results are initially converted into S/N ratio to search for a desirable result with the best performance and the smallest variance.
The experimental results are substituted into Equation 1 to calculate the S/N ratios of surface roughness and metal removal rate shown in Table 4.

$$S/N=-10\log 1/n\sum yi^2$$

Table 5: S/N ratio for Torque and Thrust

Experiment no	Speed RPM	Feed mm	Drill Dia mm	Torque Kg/m	Thrust Kgf	SNRA1 Torque	SNRA1 Thrust
1	71	0.13	8	15	39	-23.5218	-31.8213
2	112	0.33	8	17	34	-24.6090	-30.6296
3	180	0.21	8	26	38	-28.2995	-31.5957
4	71	0.21	10	61	45	-35.7066	-33.0643
5	112	0.13	10	36	29	-31.1261	-29.2480
6	180	0.33	10	79	43	-37.9525	-32.6694
7	71	0.33	12	98	48	-39.8245	-33.6248
8	112	0.21	12	64	29	-36.1236	-29.2480
9	180	0.13	12	37	20	-31.3640	-26.0206

All the original sequences of S/N ratio in Table 3 are then substituted into Equation 2 to be normalized. The outcomes result is shown in Table 4 and denoted as Zi and Zj for reference sequence and comparability sequence respectively. In order to objectively the relative importance for each performance characteristic in grey relational analysis, principal component analysis is specially introduced here to determine the corresponding weighting values for each performance characteristic. The elements of the array for multiple performance characteristics listed in Table 5 represent the grey relational coefficient of each performance characteristic

$$Z^*ij(k) = zij(k) - \min zij(k)/\max zij(k) - \min zij(k)$$

Table 6: Normalized values of S/N Ratio for Torque and Thrust

Experiment-no	torque	thurst
1	1.000	0.321
2	0.976	0.500
3	0.867	0.357
4	0.446	0.107
5	0.747	0.679
6	0.229	0.179
7	0.000	0.000
8	0.410	0.679
9	0.735	1.000

Table 7: Grey Relational Coefficients for Torque and Thrust

Experiment- no	grey relational coefficient		grey relational grade
	torque	thrust	
1	1.000	0.712	0.424
2	0.954	0.727	0.500
3	0.790	0.614	0.438
4	0.474	0.417	0.359
5	0.664	0.636	0.609
6	0.393	0.386	0.378
7	0.333	0.333	0.333
8	0.459	0.534	0.609
9	0.654	0.827	1.000

The response table of Taguchi method is employed here to calculate the average grey relational grade for each cutting parameter level. It is done by sorting the grey relational grades corresponding to levels of the cutting parameter in each column of the orthogonal array, and taking an average on those with the same level. Using the same method, calculations are performed for each cutting parameter level and the response table is constructed as shown in Table 6. Basically, the larger the grey relational grade is the better the corresponding multiple performance characteristic. From the response table for the grey relational grades shown in Table 05, the best combination of the cutting parameters is the set with spindle low speed, high feed rate and middle depth of cut.

Table 8: Optimum Level for Drilling Parameter

	Factors	1	2	3
A	Speed	-3.318	-6.699	-5.558
B	Feed Rate	-6.601	-4.050	-4.009
C	Drill Dia	-5.550	-4.720	-5.902

6.3 Analysis of Variance

ANOVA was used to determine the design parameters significantly influencing the mass loss (response). Analysis of variance(ANOVA) results of mass loss were shown in Table-5. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of TABLE-5 shows the percentage of contribution of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained, that Load was the most significant parameter having the highest statistical contribution (83.73%) on the sliding wear followed by Speed(6.97%) and Distance (4.69%). Contribution for each source parameter is calculated as follows ;

$$\%\ Contribution = \frac{Seq\ SS\ of\ each\ parameter}{Total\ of\ each\ parameter} \times 100$$

source	df	seq ss	adj ss	adj ms	f	p	%contribution
speed	2	16.859	16.859	8.429	0.65	0.606	27.98871088
feed	2	11.379	11.379	5.69	0.44	0.695	18.89101021
drill dia	2	6.102	6.102	3.051	0.24	0.809	10.1303229
residual error	2	25.893	25.893	12.946			42.98663568
total	8	60.235					100

Predicting the optimum performance

Optimum level for each factor (Speed,Feed and Drill Dia) was obtained from Main effects plot shown Fig-3. Main effects plot shows that Mean S/N ratio is decreasing with increase in the levels. Optimum parameters obtained are listed in Table-9.

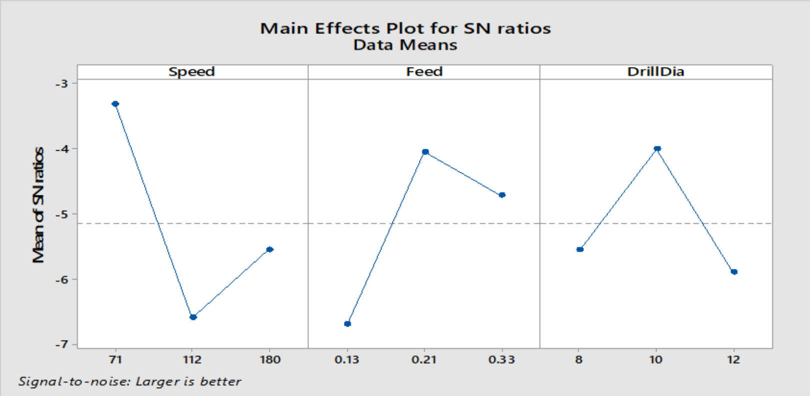

Table 10: Optimum Factors based on Main effects plot

S.No	Factor	Level	Value of corresponding optimum level
1	Speed,	1	71
2	Feed	2	0.21
3	Drill Dia	2	10

VII. CONCLUSION

This study has presented the application of Taguchi method for minimizing Torque and maximum thrust. The following conclusions can be drawn from the experimental and predicted results.

1. Optimum parameters for drilling EN-8 Material were obtained i.e Speed=71rpm, Feed = 0.21mm/min, Drill Dia = 10mm
2. ANOVA results for achieving Speed has high contribution with 27.98% followed by Feed 18.89% and Drill Dia 10.13% and Residual error 42.98%
3. Predicted S/N Ratio obtained as 2.769 at optimum parameters.

VIII. REFERENCES

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