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Experimental Analysis of Material Removal Rate in Drilling of 41Cr4 by a Taguchi's Approach

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Abstract
In manufacturing industries the largest amount of money spent on drills. Therefore, from the viewpoint of cost and productivity, modeling and optimization of drilling processes parameter are extremely important for the manufacturing industry this paper presents a detailed model for drilling process parameter. The detailed structure includes in the model, are three parameters such as such as Spindle Speed, feed and depth of cut on material removal rate in drilling of 41 Cr 4 material using HSS spiral drill .We an effect of this three parameters on material removal rate .The detailed mathematical model is simulated by Minitab14 and simulation results fit experiment data very well

In this investigation, an effective approach based on Taguchi method, analysis of variance (ANOVA), multivariable linear regression (MVLR), has been developed to determine the optimum conditions leading to higher MRR. Experiments were conducted by varying Spindle Speed, feed and depth of cut using L9 orthogonal array of Taguchi method. The present work aims at optimizing process parameters to achieve high MMR.

Experimental results from the orthogonal array were used as the training data for the MVLR model to map the relationship between process parameters and MMR the experiment was conducted on drilling machine. From the investigation It concludes that speed is most influencing parameter followed by feed and depth of cut on MRR

Keywords: ANOVA, Drilling, 41 Cr 4, MVLR analysis, MMR

I. Introduction

The largest amount of money spent on any one class of cutting tools is spent on drills. Therefore, from the viewpoint of cost and productivity, modeling and optimization of drilling processes are extremely important for the manufacturing industry [1] Quality plays a major role in today's manufacturing market. From Customer's viewpoint quality is very important because the quality of product affects the degree of satisfaction of the consumer during usage of the product. It also improves the goodwill of the company for that purpose along with computerized numerical control (CNC) machines that are capable of achieving high accuracy and very low processing time [2] The quality of the surface plays a very important role in the performance of dry drilling because a good quality drilled surface surely improves fatigue strength, corrosion resistance and creep life. Surface roughness also effects on some functional attributes of parts, such as, contact causing surface friction, wearing, light reflection, ability of distributing and also holding a lubricant, load bearing capacity, coating and resisting fatigue. As we know in actual machining, there are many factors which affect the surface roughness i.e. cutting conditions, tool variables and work piece variables. Cutting conditions include speed, feed and depth of cut and also tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle etc. and work piece variable include hardness of material and mechanical properties. It is very difficult to take all the parameters that control the surface roughness for a particular manufacturing process. Drilling is a cutting process that uses a drill bit to cut or enlarge a hole of circular cross-section in solid materials. The drill bit is a rotary cutting tool, often multipoint. The bit is pressed against the work piece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work piece, cutting off chips from the hole as it is drilled.

Figure No: 1.1 Experimental setup

In a drilling operation, it is very difficult to select the cutting parameters to achieve the high MRR. Material removal processes are shaping operations, the common feature of which is removal of material from a starting work part so the remaining part has the desired shape Material removed from the surface of the work part by means of sharp cutting tools. Examples are turning, milling, drilling, etc some terms and definitions in machining there is relative motion between the work piece and the cutting tool.
Primary motion: Cutting motion (defined by cutting speed)

Secondary motion: Feed motion (defined by the feed rate) Depth of cut (defines the amount of plunging of the tool into the work piece)

This study would help the operator to select the cutting parameters. The work material used for the present study is 41Cr 4Its tensile strength is (620-850) Mpa. 41Cr4 Materials have been widely used in automotive driving elements. Although is more expensive 41Cr4 [3] it is more preferable in terms of material properties. This paper is about experimentally investigating and optimizing the machining parameters for MRR in CNC drilling by taguchi method. Taguchi's orthogonal arrays are highly fractional designs, used to estimate main effects using few experimental runs only. These designs are not only applicable for two level factorial Experiments [4], but also can investigate main effects when factors have more than two levels. Designs are also available to investigate main effects for some mixed level experiments where the factors included do not have the same number of levels. For example, a four-level full factorial design with five factors requires 1024 runs while the Taguchi orthogonal array reduces the required number of runs to 16 only. The Taguchi method has been widely used in engineering analysis and is a powerful tool to design a high quality system. Moreover, the Taguchi method employs a special design of orthogonal array to investigate the effects of the entire machining parameters through the small number of experiments. Recently, the Taguchi method has been widely employed in several industrial fields, and research works By applying the Taguchi technique, the time required for experimental investigations can be significantly reduced, as it is effective in the investigation of the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence.

II. Experimental details

In this study, the settings of drilling parameters were determined by using taguchi experimental design method. Orthogonal arrays of taguchi, the Signal – to– Noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis are employed to analyze the effect of the drilling parameters on material removal rate (MRR) In order to reduce time and cost, experiments are carried out using L9 orthogonal array. For the purpose of observing the degree of influence of the cutting conditions in drilling process three factors (cutting speed, feed and drill diameter), each at three levels are taken into account as shown in Table 2.1.

Table No 2.1 Process Parameters and their levels

Parameters	Levels I	Levels II	Levels III
Spindle Speed(rpm)	1000	1500	2000
Feed rate (mm/min)	0.15	0.20	0.25
Depth of cut (mm)	3	5	7

2.1 Experimental set up
2.1.1 Work piece material

In this study, 41Cr4 steel was selected as the work piece material. The material was purchased as Bar of 25Ø x 150 mm with the following specifications: (UTS = 902.83 N/mmm2, BHN = 278.55 and Chemical composition of 0.4%C, 0.25 S [2].

Drilling tests are performed on DECKEL MAHO-DMC 835V (continues speed up to 14000rpm and 14kw spindle power) CNC machining center using HSS spiral type drill bits. To guarantee the initial conditions of each test, a new drill tool is used in each experiment. The work piece is of 41Cr4 Material the experimental setup is shown figure No: 2.1

Figure No: 2.1 Experimental setup

The DX 150 is a CNC Chucker ideally suited for small disc-type components.
Its monoblock structure permits highly dynamic parameters.

Table No 2.2: L9 orthogonal array

Trial no	Spindle Speed (rev/min)	Feed rate (mm/min)	Depth of cut (mm)
1	1000	0.15	3
2	1000	0.20	5
3	1000	0.25	7
4	1500	0.15	5
5	1500	0.20	7
6	1500	0.25	3
7	2000	0.15	7
8	2000	0.20	3
9	2000	0.25	5

The spindle has super precision angular contact bearings in front and rear this construction gives very high precision and stiffness in both axial and radial directions. The assembly of the spindle is carried out in a controlled, dust free environment. The bearings are grease lubricated for life.CNC Part program are created for machining the work piece on CNC. With the help of CNC Program I have done operation on my entire sample as per L9 orthogonal array from following table No: 2.2

The Material removal rate in drilling of 41Cr4 Disc plate has been calculated by using the standard relation and the results entered Table No 3.1

Theoretical

MRR= (π/4*D2*f*N) mm3/min-------- (1)

Where
MRR=Material removal rate
D=diameter of the drill bit in mm
F=feed in mm/min
N=spindle speed in rev/min

Experimental

MRR= ***((****Initial wt of work piece* ***(****gms****))-(****final wt of work piece (gms****))) / ((****density in gms****)*(****Maching time (min****)))*** ---------------- (2)

III. Analysis of experimental results and discussion

Table No: 3.1: Summary Report for Different trials Conducted during Experimentation

Trial no	Spindle Speed (rev/min)	Feed rate (mm/min)	Depth of cut (mm)	MRR mm^3/min
1	1000	0.15	3	10000.00
2	1000	0.20	5	13125.00
3	1000	0.25	7	14013.16
4	1500	0.15	5	16000.00
5	1500	0.20	7	17025.00
6	1500	0.25	3	26850.00
7	2000	0.15	7	18991.07
8	2000	0.20	3	30825.00
9	2000	0.25	5	33250.00

a) S/N Ratio Analysis-

In the Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or larger is better (LB). Larger is better S/N ratio used here. Larger -the-better quality characteristic was implemented and introduced in this study.

For the for larger the better characteristic

S/N = -10 log10 (MSD)

Where MSD= Mean Squared Division

MSD = $(1/Y_1^2 + 2/Y_2^2 + 3/Y_3^2 + \ldots\ldots)/n$

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and MSD is the target value of the result. The level of a factor with the highest S/N ratio was the optimum level for responses measured. Table No 3.3 and Figure 3.1 depict the factor effect on material removal rate. The larger the signal to noise ratio the more favorable is the effect of the input variable on the output

Table No: 3.2 Estimated Model Coefficients for SN ratios

Term	Coef	SECoef	T	P
Constant	20008.8	184.8	108.246	0
N REV/MI 1000	-7629.4	261.4	-29.186	0.001
N REV/MI 1500	-50	261.4	-0.193	0.865
f mm/rev 0.15	-5011.8	261.4	-19.172	0.003
f mm/rev 0.20	316	261.4	1.21	0.35
t mm 3	2549.5	261.4	9.753	0.01
t mm 5	782.9	261.4	2.995	0.096

Summary of Model
S = 554.5 R-Sq = 99.9% R-Sq (adj) = 99.6%

Table No: 3.3 Response for Signal to Noise Ratios Larger is better

Level	N REV/MIN	f mm/rev	t mm
1	81.76	83.22	86.12
2	85.76	85.59	85.63
3	88.59	87.32	84.37
Delta	6.83	4.1	1.74
Rank	1	2	3

From the Table 3.2 and Figure 3.1 it is clear that, the optimum value levels for higher MRR are at speed (2000), feed (0.25), and depth of cut (5). Also, for material removal rate, from it can be seen that, the most significant factor is spindle speed (A), followed by feed rate (B) and Depth of cut (C).

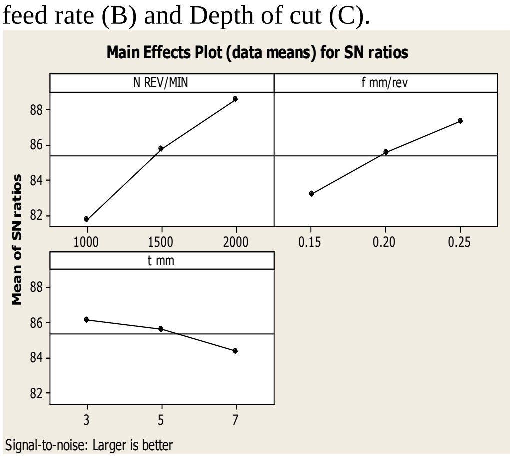

Figure No: 3.1 Effect of process parameters on S/N Ratio

b) Analysis of Variance (ANOVA):
Analysis of variance is a standard statistical technique to interpret experimental results. It is extensively used to detect differences in average performance of groups of items under investigation. It breaks down the variation in the experimental result into accountable sources and thus finds the parameters whose contribution to total variation is significant. Thus analysis of variance is used to study the relative influences of multiple variables, and their significance The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 14 specially used for design of experiment applications. In order to find out statistical Significance of various factors like speed (A), feed (B), and depth of cut (C), and their interactions on MRR, analysis of variance (ANOVA) is performed on experimental data. Table 3.4 shows the result of the ANOVA with the MRR. The last column of the table indicates p-value for the individual control factors.

Table No: 3.4 Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
N REV/MIN	2	351573615	351573615	175786808	571.65	0.002
F MM/REV	2	141799266	141799266	70899633	230.56	0.004
T MM	2	54653471	54653471	27326735	88.86	0.011
Residual Error	2	615019	615019	307509		
Total	8	548641370				

It is known that smaller the p-value, greater the significance of the factor. The ANOVA table for S/N ratio (Table 3.6) indicate that, the speed (s=2000), feed (f= 0.25) and depth of cut (doc=5) in this order, are significant control factors effecting MRR. It means, the speed is the most significant factor and the depth of cut. Has less influence on the performance output.

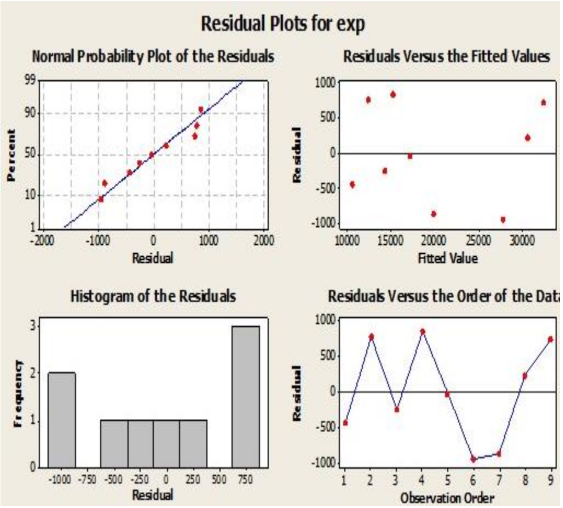

Figure 3.2: Residual Plots for MRR

C) Regression Analysis

The Spindle speed, feed rate and depth of cut are considered in the development of mathematical models for metal removal rate. The correlation between the considered drilling parameters for drilling conditions on 41Cr4 is obtained by linear regression. The linear polynomial models are developed using commercially available Minitab 14 software for various drilling parameters and are listed as below:

The regression equation is

Y = - 15017 + 15.3 N REV/MIN + 97074 f mm/rev - 1470 t mm -------------------------------- (3)

Where

N = Spindle speed, B = Feed rate (mm/rev), C = Depth of cut (mm).

Sample Calculation

As per my trail take trail no 8 readings for sample Calculation

Put this values in equation 3

Yopt = - 15017+15.3*2000+97074*0.25-1470*5

Yopt = 32501.5 (predicted by regression)

The predicated and experimental values are shown in table 3.5

Table No: 3.5 Predicated and experimental values

Optimum Experimental value of Ra	Optimum Predicted Value	S/N Ratio
33250	32501	90.4358

D) Analysis of S/N ratio

In the taguchi method, the term signal represents the desirable value (mean) for the output characteristic and the term noise represents the undesirable value (deviation, SD) for the output characteristic. Therefore the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of the characteristic Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N).

These S/N ratios are derived from the quadratic loss function and three of them (Equ. (4)– (6)) are considered to be standard and widely applicable.

$S/N=10\log Y^2/S^2$ -------------------- (4)

$S/N=-10\log (1/n\sum 1/y^2)$ --------------------- (5)

$S/N=-\log 1/n (\sum 1/y^2)$ --------------------- (6)

Where y, is the average of observed data, S^2 is the Variance of y, n is the number of observations and y is the observed data. Using the above-presented data with the selected above formula for calculating S/N, the Taguchi experiment results are summarized in Table 3.6 and presented in Fig.3.1. Which are obtained by means of MINITAB 14 statistical software. It can be noticed form the S/N responses that Spindle speed is the most important factor affecting metal removal rate is the most important factor affecting the accuracy. Response for Signal to Noise Ratios Larger is better.

Table No: 3.6 Responses table for S/N ratio

Level	N REV/MIN	f mm/rev	t mm
1	81.76	83.22	86.12
2	85.76	85.59	85.63
3	88.59	87.32	84.37
Delta	6.83	4.1	1.74
Rank	1	2	3

E) Analysis of variance (ANOVA)

The analysis of variance (ANOVA) establishes the relative significance of factors in terms of their percentage contribution to the response (Phadke, 1989; Ross, 1996) The ANOVA is also needed for estimating the variance of error for the effects and the confidence interval of the prediction error. The analysis is performed on S/N ratios to obtain the percentage contribution of each of the factors.DoF: Degree of freedom, SS: Sum of squares, %c: Percent contribution, #: 95% confidence interval

IV. CONCLUSIONS

This study has discussed an application of taguchi method for investigating the effects of drilling parameters on material removal rate in drilling of 41Cr4. From the analysis of results in the drilling process using conceptual Signal-to-Noise(S/N) ratio approach, regression analysis, analysis of variance(ANOVA) the following can be concluded from the present study:

- Statistically designed experiments based on taguchi method are performed using L9 orthogonal array to analyze the effect of drilling parameters on material removal rate.
- Linear regression equations are developed to predict the values of material removal rate and the predicted values are compared with measured values.
- Through ANOVA, it is found that the Spindle speed is important process parameters to material removal rate.
- Thus it is essential to employ suitable combination of Spindle speed and feed so as to reduce the variations.
- Optimum parametric level for higher MMR

Table No: 4.1 Optimum parametric level for higher MMR

Spindle Speed (rev/min)	2000
Feed rate (mm/min)	0.25
Depth of cut (mm)	5

Further study could consider more factors (drill properties [point angle, helix angle, flute number, types of drills] and run out of drill, thrust force, toques etc.) in the research to see how these factors would affect the hole quality.

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REFERENCES

[1] B. Y. Lee, H. S. Liu, Y.S. Tarng "*Modelling and optimization of Drilling process*", Journal of Materials Processing Technology 74(1998) 149 1571

[2] M. Nalbant*, H. Go¨ kkaya, G. Sur "*Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning*" Materials and Design 28 (2007) 1379–1385 www.sciecncedirct.com Received 21 July 2005; accepted 6 January 2006

[3] S. C. Eze1, C. O. Izelu2, B. U. Oreko3, B. A. Edward4" *Experimental Study of Induced Vibration and Work Surface Roughness in the Turning of 41Cr4 Alloy Steel using Response Surface Methodology*", International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 12, December 2013

[4] E. Kilickap "*Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite*" 2010 Elsevier Ltd. 37 (2010) 6116–6122

[5] S.A. Jalali, W.J. Kolarik, Tool life and machinability models for drilling steels, Int. J. Mach. Tools Manuf. 31 (3) (1991) 273–282.

[6] Chen W C, Tsao CC. Cutting performance of different coated twist drills. J Mater Process Technol. (1999) 88 : 203-207

[7] Chryssolouris G, Guillot M.,"*A comparison of statistical and AI approaches to the selection of process parameters in intelligent machining*", ASME J Eng Ind 1990; 112:122–31.

[8] Chua MS, Rahman M, Wong YS, Loh HT."*Determination of optimal cutting conditions using design of experiments and optimization techniques*", Int J Mach Tools Manuf 1993; 33(2): 297–305.

[9] Yang H, Tarng YS," *Design optimization of cutting parameters for turning operations based on the Taguchi method*", J Mater Process Technol 1998; 84:122–9.

[10] Paulo davim.J,"*Study of metal-matrix composites based on the Taguchi techniques*", Journal of material processing technology 132 (2003) 250- 254