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Application of Taguchi Method to Optimize Drilling Parameters

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Abstract: *In the cut-throat technologies, Mechanical system development includes many disciplines for design, development and enhancement of the end product. Machining processes is one of the disciplines used to remove unwanted part from the desired one. Milling, turning, drilling, grinding, shaping, boring etc. are some of the machining processes out of which drilling contributes maximum percentage while developing mechanical parts. These operations are characterized in terms of cutting speed, feed rate, cutting time, thrust force, torque, MRR etc. to obtain desired results. Hence there is need of optimizing these parameters by using a proper technique or method to get quality and productivity which are equally important in analysis of any process. Taguchi methods are widely used for design of experiments and analysis of experimental data for the optimization of processing conditions. In this paper, a comprehensive and in-depth review on optimization of drilling parameters using Taguchi method is carried out.*

Keywords: *Drilling, MRR, ANOVA, Taguchi Method.*

I. Introduction

Drilling is one of the most common and complex industrial machining process used to make and enlarge circular holes in almost all mechanical parts. Drilling contributes nearly 40% of all the metal removal operations in aerospace and automobile industries. Since drilling is a continuous machining process, it is done with the help of multi-point cutting tools called drills or drill bits. Various cutting tools are available for drilling but the most common is the twist drill. Drilling is a material removal process; it directly affects the quality and productivity. Quality refers to product characteristics. Hence these characteristics are measured in terms of major performance responses such as surface roughness, MRR and thrust force.

Material removal rate (MRR) is the primary response variable affecting productivity. It depends on input parameters and the machine during drilling so the primary objective of optimization analysis during drilling operation is to optimize input parameters. Also MRR plays a major role in achieving good surface roughness. [2]

In drilling parameter optimization, the primary objective is to optimize input parameters such as tool geometry, spindle speed, feed rate, drill diameter etc. Optimization of these parameters means reducing the value of surface roughness by improving material removal rate. This will improve hole quality (roundness, cylindricality and hole diameter). To obtain such quality holes large data relating to input parameters is collected through statistical method as experimenting on every parameter will be tedious and time consuming job. Statistical methods help in collecting the data related to all parameters in an orderly manner and help in predicting exact response for multiple inputs. One of such statistical tools is Taguchi Method based on design of experiments that helps in optimizing parameters and the cost of optimization. Followed to Taguchi method, ANOVA is another mathematical tool used to identify the effect of individual parameters on performance response. Collectively Design of Experiment, Taguchi method and ANOVA are the powerful tools that can be used to improve any machining process by selecting appropriate parameters for desired output. [4]

II. Literature Review

Rahul Bhole, R.S. Shelke [1], have considered the input parameters namely spindle speed, drilled hole depth and feed rate. Prediction were analyzed with actual data by conducting drilling experiments using the L_9 orthogonal array on VMC drilling machine on material AISI 316L block using HSS twist drills and the measured results were analyzed by Minitab 16. Analysis of variance is used to determine most significant control factors affecting the surface roughness & MRR from Taguchi S/N ratio Analysis. Vignesh V. Sasikumar R. [2], have performed the work to optimize process parameters such as cutting speed, feed & drill diameter to obtain minimum surface roughness (Ra). Drilling experiments were conducted on a radial drilling machine using L_9 orthogonal array. Analysis of Variance (ANOVA) was used to determine the most significant control factors affecting surface roughness by selecting cutting speed, feed rate & drill diameter. The results obtained showed that drill diameter was the most significant factor for surface roughness.

Table 1: Parameters and their Levels [2]

FACTORS	LEVEL-1	LEVEL-2	LEVEL-3
Cutting Speed (RPM)	1200	1350	1500
Feed (mm/rev)	200	250	300
Drill Diameters (mm)	8	8	8

M. Sundeep, M Sudhahar [3], have studied experimentally the behavior of Austenitic Stainless Steel (AISI 316) using L_9 orthogonal array design of experiment of Taguchi methodology. The main objective of this study was to identify lowest thrust force and more Material Removal Rate (MRR) through experimental analysis by using process parameters like spindle speed, feed rate and drill diameter which are influenced by surface roughness & MRR. The final results showed that more material removal rate occur at cutting speed 1250 rpm and feed rate 0.02mm using 8mm drill bit tool. Good surface finish was obtained at 0.016 feed rate and cutting speed of 1250 rpm using 6mm drill bit tool.

Table 2: S/N Ratio for MRR [3]

Level	Cutting Speed	Feed Rate	Drill Diameter
1	51.5221	53.2240	50.9117
2	55.6042	55.7227	55.9095
3	59.4810	55.6606	59.7861
Delta	7.9589	4.4366	8.8743
Rank	2	3	1

P. Singh and K. Bhambri [4], made the report on optimizing drilling parameters for AISI D3 Steel using Abrasive assisted drilling using HSS drill. The experiment included supply of silicon carbide abrasive having grain size 1200µm mesh size through abrasive slurry.

Table 3: S/N Ratio Calculation [2]

TRIAL NO.	SPEED (RPM)	FEED (mm/rev)	DRILL DIA. (mm)	SURFACE ROUGHNESS		S/N RATIO
1	1200	200	8	1.63	1.65	1.2311
2	1200	250	8	2.20	2.22	1.2311
3	1200	300	8	2.36	2.37	0.6156
4	1350	200	8	1.85	1.86	0.8807
5	1350	250	8	2.40	2.42	0.8807
6	1350	300	8	2.22	2.25	0.4404
7	1500	200	8	2.32	2.35	0.2085
8	1500	250	8	2.64	2.63	0.2085
9	1500	300	8	3.63	3.67	0.1229

The slurry concentration was in between 15-30% by weight. Abrasive slurry performs the function of coolant as well as increases the surface finish, MRR. The experiments were performed on 3-axis HAAS TM1 Vertical Milling Machine with HSS drill bit of diameter 10mm having two flutes. Three control factors were decided viz. spindle speed, feed rate and slurry concentration and have been analyzed using Taguchi L9 array, tables of which are given below,

Table4: Control Factors and their Units [4]

Factors	Levels	Level 1	Level 2	Level 3
Spindle Speed (A)	3	400	500	600
Feed Rate (B)	3	30	50	80
% Slurry (C)	3	15%	25%	35%

Upon analysis it was concluded that in case of surface finish, 25% slurry concentration and a feed rate 30mm/min with spindle speed of 600rpm found to be optimized parameters. With the same percentage of slurry and spindle speed, feed rate obtained was 80mm/min for MRR. [4]

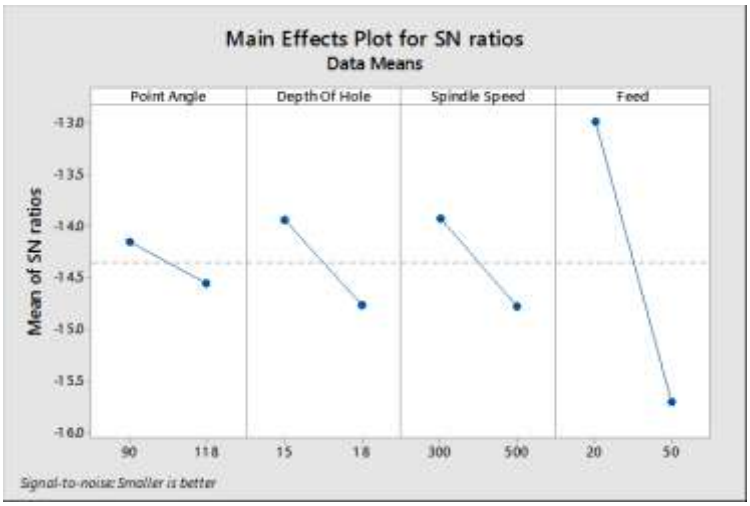
Nisha Tamta, R.S. Jadoun [5], have adapted the Taguchi Method for parametric optimization of drilling machining process for surface roughness (Ra) on Aluminum Alloy 6082 material. The drilling operation was performed on CNC machine and the tool used was HSS. Spindle speed, feed rate & drilling depth are the

process parameters, analysed using L_9 orthogonal array to conduct experiments. The effect of drilling parameters on material was concluded using S/N ratio and Analysis of Variance (ANOVA). The optimum parameter combination for these experiments to minimize surface roughness was obtained at spindle speed 3000 rpm, 15mm/min, feed rate with 9 mm drilling depth.

Table 5: L9 Orthogonal Array

Sr. No.	Spindle Speed (RPM)	Feed (mm/min)	Slurry Concen. (%)
1	400	30	15
2	400	50	25
3	400	80	35
4	500	30	35
5	500	50	15
6	500	80	25
7	600	30	25
8	600	50	35
9	600	80	15

Yogendra Tyagi, V Chaturvedi [6], performed CNC drilling operation on mild steel with HSS drill bit tool. The signal-to-noise ratio was applied to find optimum process parameter. L_9 orthogonal array and ANOVA are applied to study the performance characteristics of machining parameter (spindle speed, feed & hole depth) with consideration of surface finish as well as material removal rate (MRR). The results obtained were give the value of 0.5mm/min at 1500rpm with depth of cut 3mm for MRR. K. Sharma, A. Jatav [7], have proposed study on performance characteristics of AISI304 Stainless Steel during CNC drilling process. The factors considered were spindle speed, feed rate and point angle which affect performance parameters such as surface roughness and ovality in drilling process. The study was carried for multi-objective optimization of drilling process parameters using Taguchi method. The experiments were conducted based on Taguchi L_{16} orthogonal array by taking point angle, drill diameter, feed rate and spindle speed at two levels. The conclusion includes that for better or minimum surface roughness the feed need to be kept low along with the spindle speed and depth of hole and the ovality increases with increase in depth of hole, spindle speed and feed, and for minimum ovality point angle should be high.



Graph 1: Main Effect Plot on Surface Roughness [7]

III. Taguchi Design

3.1. Robust Design:

The application of Taguchi methods lead to superior performer designs known as robust designs- an *engineering methodology for improving productivity during research and development so that high quality products can be produced quickly and low costs.* The end result in robust design is that has minimum sensitivity to variations in uncontrollable factors. In the design of any new system, any activity can be called a Robust Design, if it causes the system, i) To have longer life (higher reliability) ii) To be more consistent from use to

use, iii) To be more consistent from product to product, iv) To perform consistently as temperature and other conditions change. The idea behind robust design is to improve the quality of a product by minimizing the effects of variation without eliminating the causes (since they are too difficult too expensive to control). (Phadke, 1989)

3.2. Design of Experiments (DoE):

Design of experiment is a powerful approach to improve product design or process performance where it can be used to reduce cycle time required to develop new product or processes. Design of experiment is a test or series of tests that the input variable (parameter) of a process is change so that observation and identifying corresponding changes in the output response can be verify. The result of process is analyze to find the optimum value or parameters that have a most significant effect to the process. [8]

3.3. Taguchi Method:

Dr. Ginichi Taguchi introduced an optimization method that helped in making calculations of experiments easier and rapid. It was originally made to make the improvement in the quality of goods that were being made in Japan. This technique helped in introducing a method that only requires a specific set of experiments to find the effectiveness on the response parameters. It is widely used in engineering design and can be applied to many aspects such as optimization, experimental design, sensitivity analysis, parameter estimation, model prediction etc. The distinct idea of Taguchi's robust design is that designing for the simultaneous modeling of both mean and variability.

For fractionated factorial design, Taguchi method uses Orthogonal Array (OA) which represents the data structure and the matrix that it shows contains the data for the experiments. The OA uses combination of number of rows and columns which shows the number of runs during experiment. The column of OA represents the experimental parameters to be optimized and the rows represent the individual trials (combinations of levels). [8]

Traditionally, data from the experiments is used to analyze the mean response. However, in Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristics and the term 'noise' represents the undesirable value (external factors affecting the performance of process) i.e. standard deviation (S.D.) for the output characteristics. Therefore S/N ration is the ration of mean to the S.D.

Depending on the criterion for the quality characteristics to be optimized, different S/N ratios can be selected:

- Smaller-the-better
- Larger-the-better
- Nominal-the -better
- Smaller-the-better

S/N = -10Log (mean square of the responses)

$= -10\text{Log}_{10} [(\sum y_i^2/n)]$

Larger-the-better

S/N = -10Log_{10} (mean of square of the inverse of the response)

$= -10\text{Log}_{10} [(1/n)*(1/\sum y_i^2)]$

Table 6: L9 Standard Orthogonal Array

Parameter/ Level				
Experiment No.	**A**	**B**	**C**	**D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Nominal-the-better

S/N = 10Log_{10} [square of the mean (y^2)/variance (s^2)]

Where n = number of measurements in trial/run, $y_i = i^{th}$ measured value in run/row, i = 1, 2, 3...

Thus S/N ratios in Taguchi method are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

3.4. Analysis of Variance (ANOVA):

The Analysis of Variance (ANOVA) is another powerful and common statistical approach in the social sciences. It is the application to identify the effect of individual factors. In statistics, ANOVA is a collection of statistical data models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. In its simplest form ANOVA gives a statistical test of whether the means of several groups are all equal, and therefore generalizes.

IV. Conclusion

Following conclusions can be drawn from the extensive literature review on drilling process:

1. There are many significant parameters which affect the process performance while drilling that need to be optimized.
2. To optimize those parameters (which are large in numbers), Taguchi method gives the best possible solutions from the set of many sequential experiments based on machining conditions.
3. The important performance characteristics such as tool life, cutting force, surface roughness and overall productivity can be improved by Taguchi method.
4. In case of drilling surface roughness is affected by cutting speed, feed rate, depth of cut, cutting time, tool geometry. Effects on surface roughness by other parameters are identified by statistical approach called ANOVA.
5. Most of the time cutting speed and feed rate are the affecting parameters on surface roughness and productivity.

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