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Effect of Process Parameters on Thrust Force during Drilling Operation

Vishal[1], Pardeep Kumar [2]

[1,2] *Modern Institute of Engineering and Technology, Kurukshetra (Haryana), India*

Abstract

In this study, drilling tests of high speed steel were carried out with three different types of drills under dry cutting conditions. The effects of the machining parameters such as cutting speed, feed rate, varying diameter of drill on the thrust force were determined with the Taguchi experimental design. Drilling parameters were optimized in terms of cutting forces (thrust force). Furthermore, an analysis of variance (ANOVA) was conducted to obtain the degree of the effect of the parameters. The most influential control factors for the cutting forces were found to be the feed rate. According to the experimental results, the thrust force increased significantly as the feed rate increased. On the other hand, the influences of the drill-bit diameter were quite low.

Keywords: : Taguchi, ANOVA, Drilling, Thrust

1. Introduction

Metal cutting operations such as turning, milling and drilling are widely used in manufacturing to produce a variety of mechanical components [1]. Drilling is especially important because it accounts for a large portion of overall machining operations. In addition, drilling problems may result in costly production waste because many drilling operations are usually among the final steps in fabricating a part. Even though the machine tool industry in India has made tremendous progress, the metal cutting industries continue to suffer from a major drawback of not utilizing the machines at their full potential. A major cause of such a situation is thought to be the failure to run the machine tools at their optimum operating conditions. This problem has attracted the attention of researchers and engineers for a very long time [2-3]. Unfortunately, however, the impact of research in this area does not seem to have reached a large majority of manufacturing engineers in India with the result that the process parameters continue to be set solely on the basis of handbook values and /or manufacturer's recommendations and /or worker's experience. Numerous researchers have been carried out research in this area. Some of researchers are briefly explained such as: ogawa et al. (1997) conducted experimental work which involved drilling of a glass fiber reinforced plastic (GFRP) with a cemented carbide drill. The authors concluded that the thrust force is drastically reduced when the hole is predrilled to 0.4 mm or above. Mathew et al. (1999) studied the influence of using a trepanning tool on thrust force and torque when drilling

GFRP. The investigation showed that the performance of the trepanning tool was superior to the conventional twist drill. Kilicap (2010) investigated the influence of the cutting parameters such as cutting speed, feed rate, and point angle on delamination produced while drilling a GFRP composite. The analysis of experimental results is carried out using Taguchi's orthogonal array and analysis of variance. The various levels of cutting parameters and point angles are determined by using ANOVA. The experiments revealed that feed rate and cutting speed were the most influential factors on the delamination. In this present study an attempt has been made to determine the effect of process parameters on thrust force. The principle of drilling process as shown in figure 1. Drilling process consists of producing holes in solid work pieces by rotary and axial movement of the drill or the work piece. It allows a cylindrical hole to be created in a block of material using a drill, which is subjected to a rotational movement around the axis and a feed motion along the axis.

The drill is subjected to an axial thrust force and a twisting couple or torque when in operation. Fig. 1& 2)

The axial thrust force in kg-f can be estimated with the following formula:

$$F = C_2 d f^{0.7}$$

Where,

C_2 = a constant, whose value is governed by drilling conditions

C_2 = 84.7 for carbon steel and 60.5 for cast iron

D = drilling diameter (mm)

F = feed rate (mm/rev)

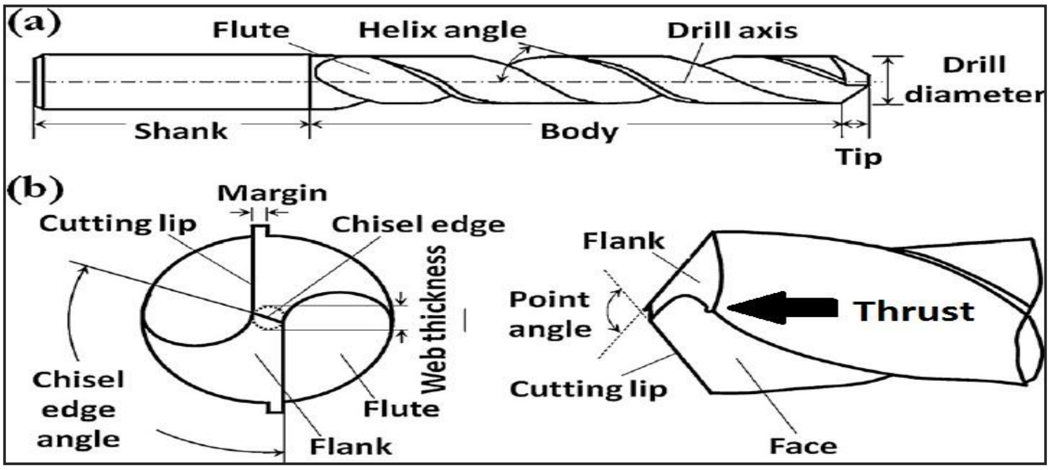

Figure 1: Thrust force on a drill

2. Experimental Procedure

In this work, BM-35 steel (including mass fractions: C (0.85-0.95), Si (≤0.40) Mn (≤0.40) Cr (3.75-4.50) Ni (≤0.40) Mo (4.75-5.25)) is used for drilling operation. Three different diameter drill bits made up of carbide are used for conduction the experiments. A scientific approach for planning of experiments was used in order to conduct the experiment most effectively. Design of Experiments using Taguchi technique was taken as the basis for carrying out experiment so that the appropriate data is collected which may be analyzed to obtain valid conclusions. The design of experiments was employed in order to fulfill the following requirements:

- To get the data uniformly distributed over the whole range of controllable factors to be investigated
- To reduce the total number of experiments
- To establish a relationship between different input variables and the output accurately in the selected range of experimentation The experimental set up is shown in Figure 3.8.

2.1 Selection of Process Parameters

Based on review of literature and some preliminary experiments (now reported here), the following process parameters were selected for the present work:

- Spindle RPM - A
- Feed Rate - B
- Drill Diameter - C

The following parameters were kept fixed during experimentation:

- Work material: BM-35
- Tool material: Carbide

The range of the process parameters and their levels (Table 3.2) were ascertained based on preliminary experiments and the literature survey.

Table 1: Levels of various process parameters

Designation	Process Parameter	Unit	Level 1	Level 2	Level 3
A	Spindle Speed	rpm	60	96	132
B	Feed rate	mm/rev	0.10	0.20	0.30
C	Drilling diameter	mm	8	10	12

A drill tool dynamometer is used for measuring the forces during the process. The process parameters are shown in table 1.

4. Results and Discussion

4.1 Selection of Orthogonal Array

Each three level parameter has 2 degrees of freedom (DOF= no. of levels - 1); the total DOF required for three parameters, each at three levels is 6 [3*(3-1)][6-7].

As per Taguchi's method, the total DOF of selected OA must be greater Chan or equal to the total DOF required for the experiment. So an L9 OA (a standard three level OA) having 8 DOF was selected for the analysis as give in Table 2.

Thus for three levels and three factors, nine experiments are to be performed.

Based on L9 OA, the control log for the experimentation has been designed as given in Table 2. All process parameters have three levels and hence, column 1 was assigned to the spindle RPM, column 2 to the feed rate and column 3 to the drill diameter. The nine rows of the L9 orthogonal array represent the nine experiments to be conducted during experimentation. Since the L9 orthogonal array has four columns, one column elide array is left empty for the error estimate of experiments.

Table 2: Orthogonal Array L9

Table 2. Control Log for experimentation			
Experiments	Spindle Speed	Feed rate	Drilling Diameter
1	60	0.10	8
2	60	0.20	10
3	60	0.30	12
4	96	0.10	10
5	96	0.20	12
6	96	0.30	8
7	132	0.10	12
8	132	0.20	8
9	132	0.30	10

The level of each process parameter during each trial is more conveniently expressed by means of experimenter's log sheet. In the present investigation, two response variables have been selected i.e. Thrust force and Torque. The details of these response variables are given in Table 3. It is observed that both the variables are of continuous type.

The experimentation for the study undertaken consisted of nine trials, with each trial having three replications. The experiments were conducted in completely randomized order. The experimental data are reported in table 4.

Table 3: Experimental results for Thrust and Torque (raw data)

S. No	Spindle Speed (RPM)	Feed (mm/rev)	Drilling Dia (mm)	Thrust force (Kgf)
1	60	0.1	8	95.41
2	60	0.2	10	96.067
3	60	0.3	12	115.733
4	96	0.1	10	95.733
5	96	0.2	12	111.067
6	96	0.3	8	136.067
7	132	0.1	12	115.733
8	132	0.2	8	117.067
9	132	0.3	10	139.62

4.2 Evaluation of S/N Ratio

The S/N ratio is obtained using Taguchi methodology. Here the term 'signal' represents the desirable value (Mean) and the 'noise' represents the undesirable value (standard deviation.) Thus, the S/N ratio represents the amount of variation present in the performance characteristic. Here the desirable objective is to optimize the response variable (thrust and torque). Hence, S/N ratio equation for smaller the better type of quality characteristic was applied for transforming the raw data for cutting forces as smaller value of cutting force is desirable. For thrust, the value of SM ratio (smaller-the-better) and mean values corresponding to different experimental runs have been tabulated in Table 5.

4.3 Main Effects due to Parameters

The main effects can be studied by the level average response analysis of mean data and S/N data. The analysis is done by averaging the mean and/or S/N data at each level of each parameter and plotting the values.

The level average response from the mean data helps in analyzing the trend of performance characteristics with respect to the variation of the factor under study. The level average response plots based on the S/N data helps in optimizing the objective function under consideration. The main effects of raw data and those of the S/N ratio for response variable have been reported in Tables 4 & 5 and plotted in Figures 2 - 5.

Table 4: Factor Effects on S/N data (Thrust)

Level	Spindle Speed (RPM)	Feed (mm/rev)	Drilling Dia (mm)
1	-40.17	-40.16	-41.21
2	-41.07	-40.64	-40.72
3	-41.85	-42.28	-41.15
Delta	1.68	2.12	0.49
Rank	2	1	3

Table 5: Factor Effects on average response (Mean) (Thrust)

Level	Spindle Speed (RPM)	Feed (mm/rev)	Drilling Dia (mm)
1	102.4	102.3	116.2
2	114.3	108.1	110.5
3	124.1	130.5	114.2
Delta	21.7	28.2	5.7
Rank	2	1	3

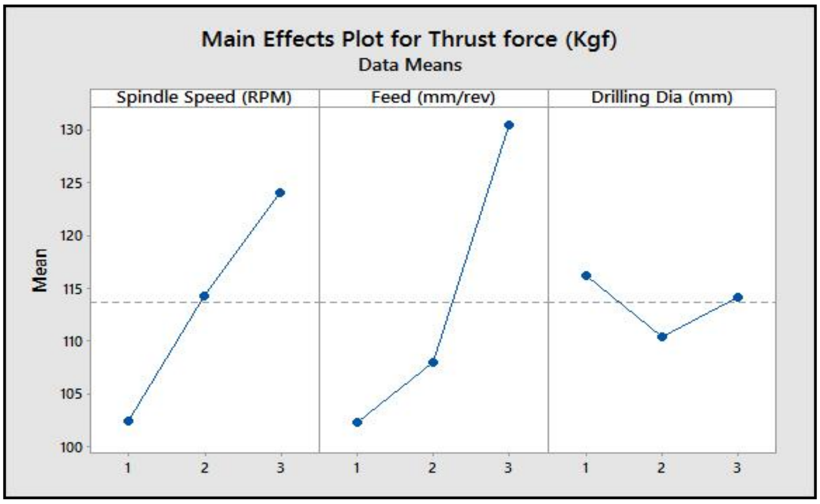

Figure 2: Effect of Process Parameters on Thrust Force (main effect)

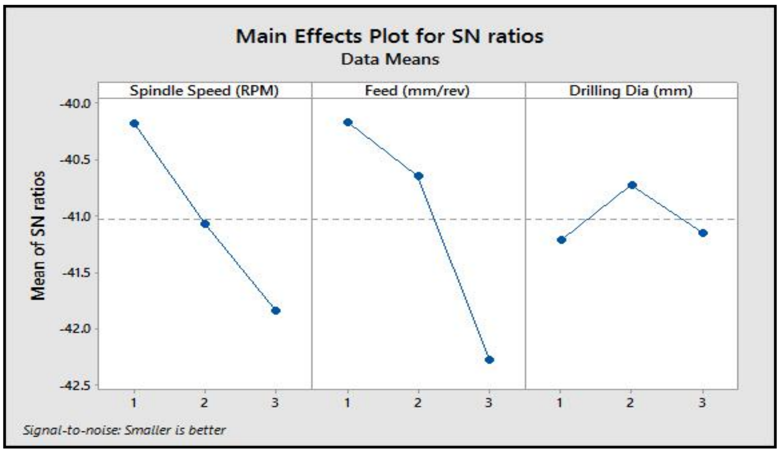

Figure 3: Effect of Process Parameters on Thrust Force (S/N ratio)

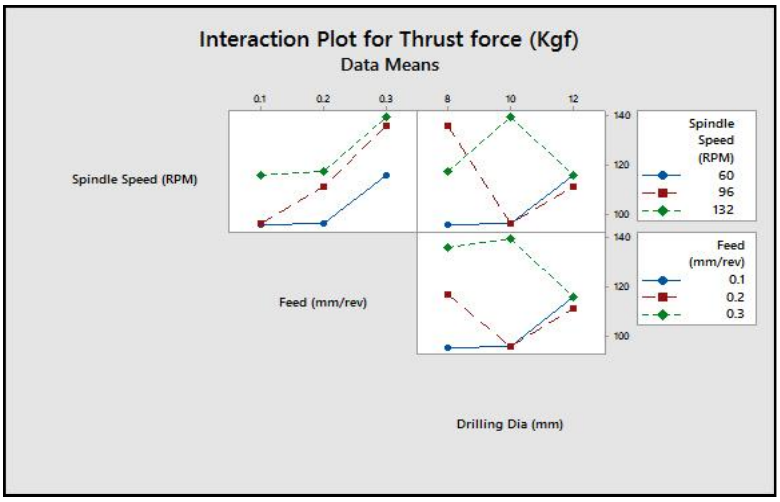

Figure 4: Interaction plot for Thrust force

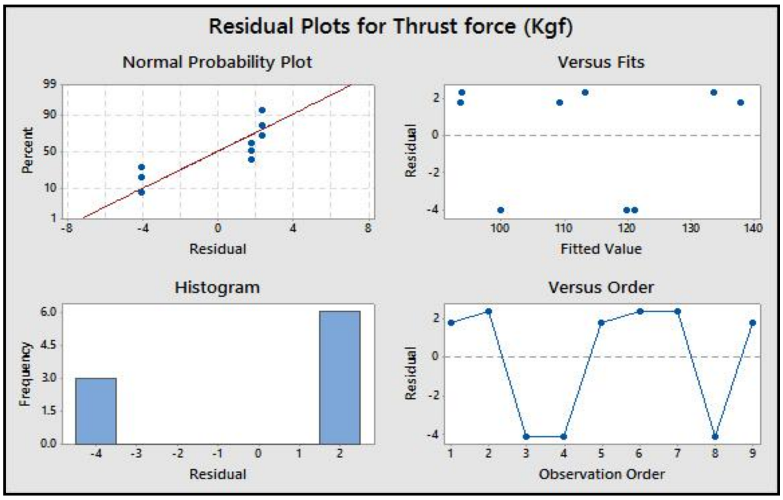

Figure 5: Residuals plot for Thrust force

4.4 ANOVA

The percentage contribution of various process parameters on selected performance characteristic can be estimated by performing ANOVA test. The ANOVA (general linear model) for mean and S/N data has been performed to identify the significant parameters to quantify their effects on the performance characteristics. The most favorable condition or optimal levels of process parameters have been established by analyzing response curves of S/N ratio associated with raw data. The AVOVAs for both raw and S/N data are given in Table 6.

Table 6: ANOVA result for thrust force (raw data)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Spindle Speed (RPM)	2	711.02	355.51	9.34	0.0471
Feed (mm/rev)	2	1329.81	664.9	17.47	0.034
Drilling Dia (mm)	2	50.27	25.13	0.66	0.0402
Error	2	76.12	38.06		
Total	8	2167.22			

Table 7: Comparison of predicted and experimental results

Sr. No	Response	Predicted mean value	Experimental Value	CI
1	Thrust Force	87.94	85.32	64.53 < μTh < 111.55 kgf

4.5 Range of Applicability

In the present study the process parameters setting (spindle speed, feed rate and drill diameter) in drilling operation has been accomplished for optimizing two characteristics - thrust force and torque. The results obtained under the optimization process settings have been found to be within the 95% confidence interval of the predicted optimal value of the selected quality characteristics (thrust force and torque). As per the concept of the Taguchi robust design methodology, the process or product development for one particular application should possess the design transferability to accommodate change from time to time and also to be applicable to the other applications. In the present study, the process has been applied to the drilling of BM-35 steel.

This process can also be applied for the other materials by making minor alteration in the optimized conditions, taking into account the change in values of response variable when the original process applied to the machining. Thus, a significant amount of effort and time can be saved in developing a new process for machining the other grades of stainless steels.

5. Conclusion

Based on the experiments conducted in the present investigation, the following conclusions can be made:

- Feed rate significantly affects the thrust force in drilling operation. With regard to the average response, feed rate has emerged out to be the most significant factor followed by spindle RPM and drill diameter. It is evident from the ANOVAs for the raw data and S/N data that feed rate is significant in both and thus affect the variation and average value of the thrust force. Therefore, feed rate is classified as Class 1 factor. Whereas spindle RPM and drill diameter are significant in the raw data ANOVA only, and therefore both are classified as Class 3 factors. Further, it can be concluded from the results that input parameters setting of RPM at 60, feed rate at 0.10 mm/rev and drill diameter at 10 mm has given the optimum results for thrust force while drilling. The percentage contribution of RPM is 33%, feed rate is 65% and drill diameter is 2% with regard to the thrust force.

- The 95% C.I of the predicted optimal thrust Force is : $64.53 < \mu Th < 111.55$ kgf.

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