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Experimental Investigation of Thrust Force in Drilling Operation

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Abstract*-Drilling is one of the major operations to be carried out in almost every mechanical industry. During this operation drilling tool drills the metal continuously which increases thrust force. Due to this force, power consummated during drilling operation. So in this research work an attempt to experimentally investigate the effect of different drill parameter like feed rate and spindle speed on the thrust force. The main purpose of this work is save energy and useful production time during drilling operation on mild steel work piece. Research work basically involved the use of drilling operation on conventional lathe as it is most widely adopted method for machining and also plays a crucial role in affecting thrust force. In research work, experimental investigation of thrust force by the change in the feed rate and spindle speed of multi point cutting tool for a drilling operation in the oblique cutting to be carried out with the set of machineries. Thrust forces measured using lathe tool Dynamometer. Once the experimental work had been performed, Taguchi's method used to evaluate the best possible combination of input parameters for minimizes thrust force.*

Keywords: Taguchi's method

I. INTRODUCTION

In industry, main drawback is that not operating the machine tools at their optimum operating conditions so that there is loss of man power, material, time. The drilling parameters such as speed, feed and depth of cut on conventional lathe machine are often selected based on the worker's experiences. However, the performance of machine and drill bit are not sure to be acceptable. It has long been recognized that circumstances during metal drilling such as feed and drilling speed should be chosen to optimize the economics of drilling operations.

Manufacturing enterprises presently have to deal with increasing demands for improved product quality, tool life, less wear and cutting force. In today's fast changing situation in manufacturing industries, applications of optimization techniques in metal cutting processes is necessary for a manufacturing unit to work effectively to severe competitiveness and growing demand of quality product in the market.

Drilling, the standard process for producing holes, is among the most common material removal process. Drilling is performed by a tool (named "drill bit") which is rotated by the spindle of a machine. The work-piece and the revolving drill (although in some cases the work-piece can be revolving and attached to the spindle) are positioned by movements of the machine table and/or the spindle assembly. When drilling starts, a linear movement (along the drill rotating axis) occurs between the rotating drill and work-piece. Most of the time drilling operations are performed on specialized drilling machines of different configurations (upright, radial or specialized), but drilling can also be performed on lathes, boring mills and milling machines. With all the view points above, this paper present review of effect of drilling parameters like feed and speed on thrust force in drilling operation.

II. LITERATURE REVIEW

N. Ahmed [1] performed a experiment on 3D thermo mechanically coupled finite element model of drilling process of steel 2080 to study the influence of drilling parameters on thrust force. Experiments are performed on lathe machine for getting thrust force and torque with different -2 machining parameters and these result are validated by using 3D DEFORM software . In this experiment four different speeds (360-1400) and feed rates (0.125-0.352) were taken. At the experiment single material of work piece and drill bit was taken. And finally concluded that the thrust force increases with increasing speed and feed for drilling and reaming processes. Changing the feed had an approximate linear effect on the thrust forces.

A. Cicek *et al.* [2] In this study, the effects of cutting parameters (i.e., cutting speed, feed rate) and deep cryogenic treatment on thrust force (F_f) have been investigated in the drilling of AISI 316 stainless steel. To observe the effects of deep cryogenic treatment on thrust forces, M35 HSS twist drills were cryogenically treated at –196 °C for 24 h and tempered at 200 °C for 2 h after conventional heat treatment. The experimental results showed that the lowest thrust forces were measured with the cryogenically treated and tempered drills.

Iliescu *et al.*[3] the present aspects of the experimental research developed in the purpose of determining new and, more adequate, mathematical models of the cutting force and torque, in drilling 20MoCr130 stainless steel. Graphs, as well as further application of the obtained relationships are also, mentioned. From these models, one can notice that the higher

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influence on the dependent variable (F, or M) is that of cutting tool diameter, D, meaning, the larger the drilled hole, the higher the force and moments values. The lower influence, on the same studied dependent variables is that of the cutting speed, v, but, it is a reveres influence – the higher values of v, the lower values of F and M.

Y. Kaplan *et al*. [4] investigated the effects of work piece hardness, drill bit diameters, drill bit lengths, spindle speeds and feed rates on the thrust force on drilling of AISI D2 and AISI D3 cold work tool steels under dry drilling conditions. The experiments are performed at three cutting speeds (5, 10, 15 m/min) and three feeds (0.04, 0.05, 0.06 mm/rev). In these experiments vertical drilling machine is taken for making hole and with the help of drilling dynamometer they find out the thrust force. In the result of ANOVA analysis, the most effective parameters on thrust force were feed rate, drill diameter, drill length, work piece hardness, number of holes, and cutting speed respectively.

E. Kuram *et al.* [5] In this study, three different vegetable-based cutting fluids developed from raw and refined sunflower oil and two commercial types (vegetable and mineral based cutting oils), were carried out to determine for thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel with HSSE tool. The uses of vegetable cutting oils was investigated in reducing thrust force and improve surface finish at different spindle speeds (520, 620 and 720 rpm) and feed rates (0.08, 0.12, 0.16) during drilling.

S. Madhavan and S. B. Prabhu [6] this experiment reports the effect of thrust force during drilling of 10mm diameter holes in 20mm thick Carbon Fiber Reinforced Plastic composite laminate using HSS, Solid Carbide (K20) and Poly Crystalline Diamond insert drills. Experiments are conducted on a vertical machining centre using Taguchi design of experiments. A model is developed to correlate the drilling parameters with thrust force using Response surface Methodology (RSM). Analysis of variance for the developed model revealed that the type of drill and the feed rate are the dominant factors that influence the thrust force. Thrust force recorded for HSS drill was high when compared to Carbide. Since the hardness of HSS tool is less than the Carbide drill.

S. F. Miller *et al*. [7] investigated the effect of drilling parameter on low-carbon steel, aluminum and magnesium alloys on cnc vertical machine, and explored experimentally to the thrust force under different-2 spindle speeds and feed rates. However, the effects of drill bit diameter and drill bit material on thrust force has not been studied. In this experiment speed taken in between (5500-15000 rpm) and feed (254 -406 mm) for finding the effect of these parameter on thrust force, finally it was concluded that the work piece pre-heating and high spindle speed had proven to be beneficial to reduce the thrust force for friction drilling of brittle cast metals.

A. Muniaraj *et al*.[8] the experiments were conducted to study the effect of spindle speed and feed rate on the thrust force and surface roughness using coated carbide twist drill and carbide multifaceted drills of 4 mm diameter under various cutting conditions. They taken Feed rate: 0.05, 0.10, and 0.15 mm/rev and Spindle speed: 1000, 2000, 3000 rpm on vertical drilling machine. As the result they find that Feed rate is found to have significant influence on the thrust force and surface finish on increasing feed rate thrust force increases and on increasing speed it decreases. Coated carbide tool exhibits higher thrust force when compared to multifaceted carbide drill for all cutting conditions.

Nagaraja *et al*. [9] In this study, the drilling tests are carried on bi-directional carbon fiber reinforced epoxy composite (BCFREC) laminate by using high speed steel drill at different feed rate (0.01, 0.05, 0.1, 0.15 mm/rev), spindle speed (900, 1200, 1500, 1800 rpm) and a HSS drill of 6 mm diameter with 118^0 tip angle is used for conducting the drilling experiments. The study reveals that there is a positive correlation between thrust force, torque and delamination. The feed rate is observed to make the largest contribution to delamination, thrust force and torque. Furthermore, the study indicates that the effect of spindle speed on thrust force and torque is not significant and lower feed rate has to be used for higher spindle speed in HSS drill in order to reduce the delamination damage.

T. V. Rajaurmugan *et al.*[10] in this work an attempt has been made to develop empirical relationships to model thrust force in drilling of GFRP composites by Multifaceted drill bit. The empirical relationships were developed by response surface methodology incorporating above drilling parameters spindle speed (500, 875, 1250, 1500, 1625, 2000 rpm) feed rate (50,112.5, 175, 237.5 mm/min) and drill bit diameter (4, 6, 8, 10, 12 mm).It has been clearly seen that minimum feed rate, reasonably small drill diameter and 0° or 90° fiber orientation angle is preferred for minimizing the thrust force in drilling of GFR-Polyester composites.

III. EXPERIMENTAL METHODOLOGY

1. Material Selection

Mild Steel is use in present experimental work due to its durability, light weight, economical properties. The work pieces drill for the experiment were of similar dimensions and depth of cut from 20 mm diameter work piece. High speed steel used as tool material due to easy detection of thrust force with changes in parameters and high hardness, abrasion resistance properties. Mechanical properties of work piece and tool material are given in Table 1.

S.NO.	Object	Material	Density (kg/m^3)	Elasticity (MPa)	Measurement (mm)

1.	Work piece	Mild steel	7861.093	210,000	20×100
2.	Tool	High speed steel	7900	207,000	

2. Experimental Setup

The measurement of cutting forces is done on the conventional lathe machine shown in **Fig. 1** and measured by Lathe Tool Dynamometer by changing the cutting parameters as rake angle and spindle speed.

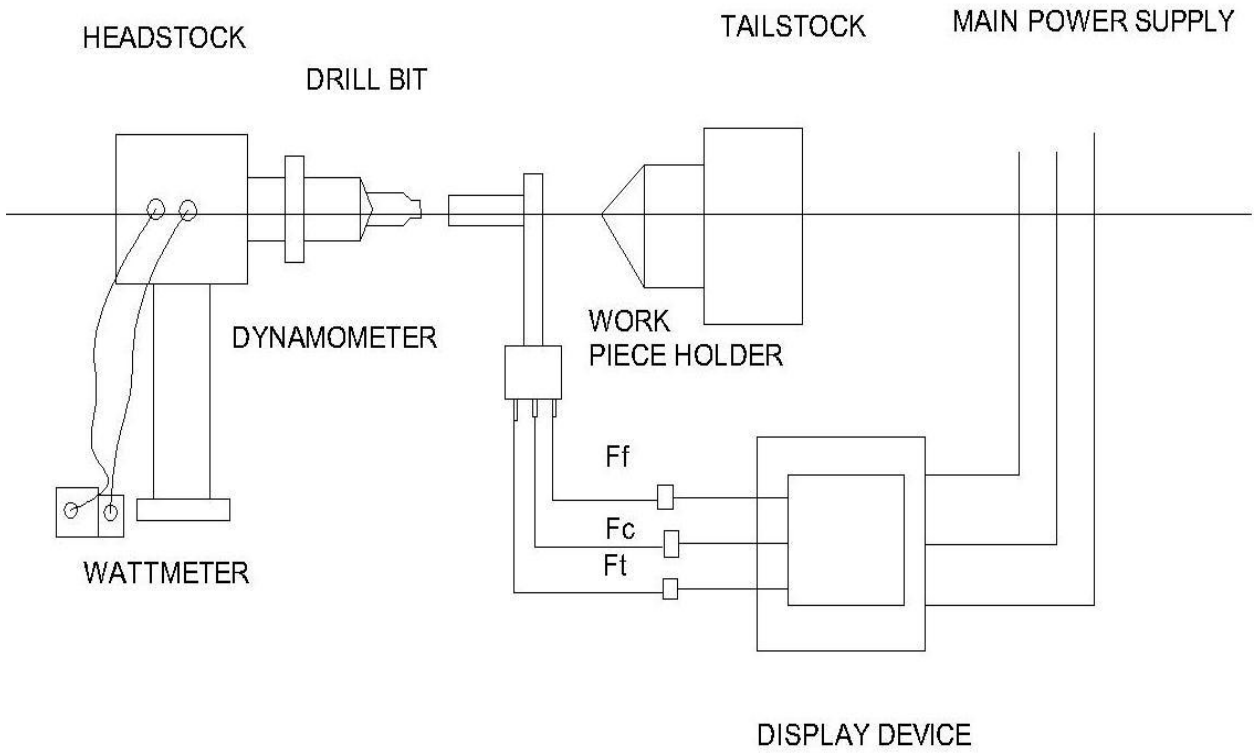

Fig. 1: Line diagram of experimental setup

3 Data Collection and Analysis -

The experiment involves two independent parameters (rake angle and spindle speed) and one dependent variable (cutting force) is show in **Table 2**.

Table 2: Experimental Levels of drilling Parameter

Drilling parameter	Units	No of levels	Values for each level			
			Level 1	Level 2	Level 3	Level 4
Spindle speed	rpm	4	52	88	150	250
Feed	mm/rev	4	0.05	0.07	0.10	0.13

The experimental work is divided basically into two phases. In the first phase, the experiments are performed for individual run at different levels and all the data are collected. In the final phase, analysis task is performed over the collected data using various mathematical and statistical tools for optimization of the results.

To determine the effect of each variable on the output, the signal-to-noise (S/N) ratio calculated for each experiment by using Taguchi method in Minitab 17 statistical software and result of total 16 (4x4) runs are given in **Table 3.**

Table 3 Cutting force for different independent parameters

Independent parameter		Dependent variable		
Feed	Spindle speed	Thrust force (N)	S/N ratio	Mean
	52	721.7	-57.1671	721.7

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0.05	88	650.0	-56.2583	650.0
	150	580.0	-55.2686	580.0
	250	600.0	-54.8073	600.0
0.07	52	978.3	-59.8094	978.3
	88	900.0	-59.0849	900.0
	150	875.0	-58.8402	875.0
	250	820.0	-58.2763	820.0
0.10 0.10	52	1385.0	-62.8290	1385.0
	88	1225.0	-61.7627	1225.0
	150	1102.0	-60.8436	1102.0
	250	985.0	-59.8687	985.0
0.13	52	1606.7	-64.1187	1606.7
	88	1495.0	-63.4928	1495.0
	150	1417.0	-63.0274	1516.7
	250	1334.0	-62.5031	1334.0

(a) Taguchi method: In Taguchi method, there are three categories for analysis of S/N Ratio i.e. the smaller is better, the larger is better and the nominal is best. For this experimental analysis, the first category 'The smaller is better' was chosen to reach the optimization conditions for minimization of cutting force which is the desired condition for drilled machined parts.

Main effects plot for S/N ratio and for Means generated by using MiniTab-17 statistical software as shown in Fig.2 and Fig. 3 respectively.

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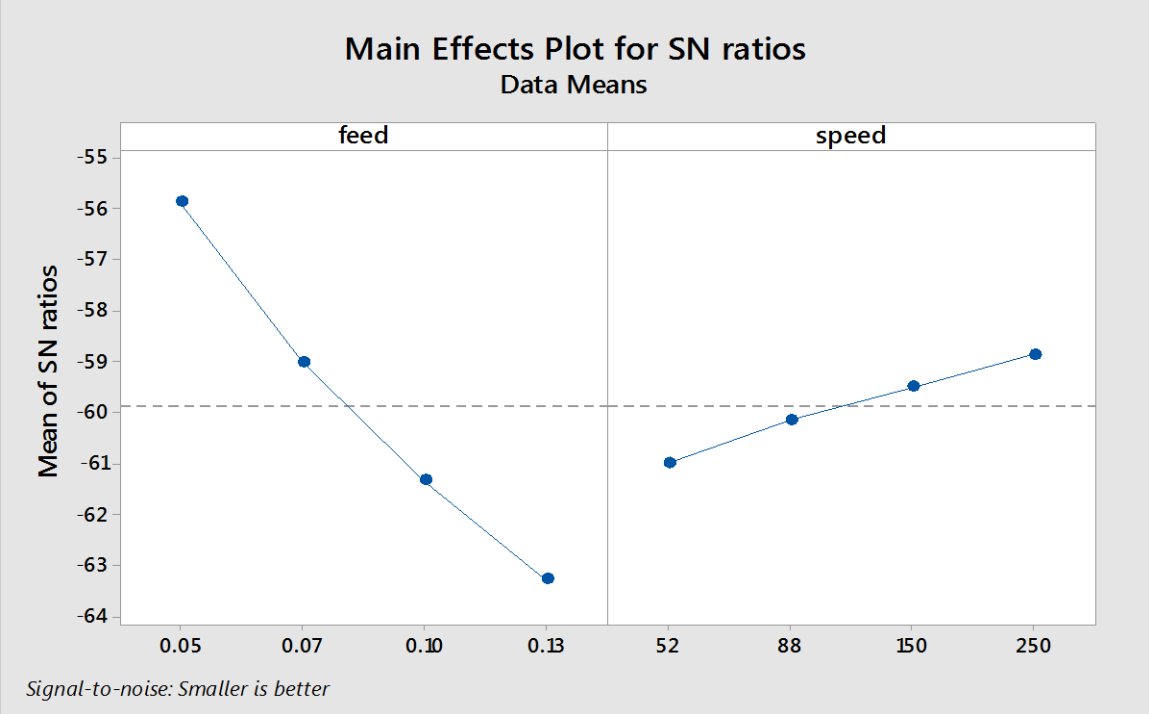

Fig. 2: Main effects plot for S/N ratios

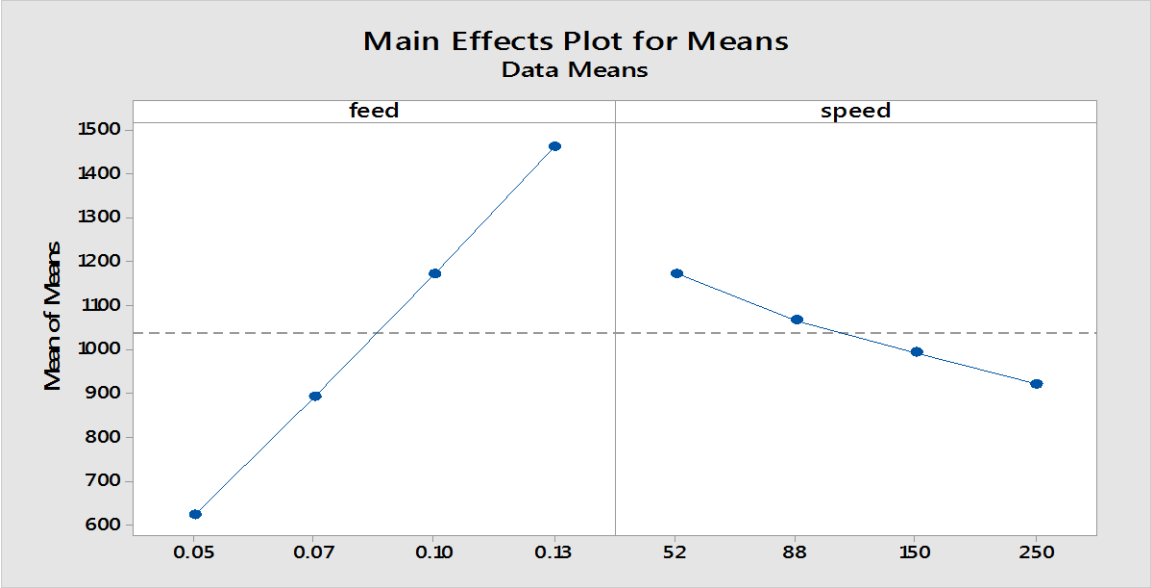

Fig. 3: Main effects plot for Mean

(b) ANOVA (Analysis of Variance): ANOVA (Analysis of variance) table generated for determined percentage contribution of different independent parameters on dependent variable by using Minitab 17 statistical software is shown in Table 4.

Table 4: Analysis of Variance for thrust force

Source value	DF	Seq.SS	Contribution	Adj.SS	Adj.SS	F value	P value
Spindle speed (rpm)	3	137796	8.01%	137796	54932	19.44	0.00
Feed	3	1561930	90.76%	1561930	520643	220.36	0.00

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(mm/rev)							
Error	9	21264	1.24%	21264	2363		
Total	15	1720990	100.0%				
S = 48.6076			R-sq = 98.76%		R-sq (adj) = 97.94%		

It is clear from this table that the effect of feed and spindle speed on thrust force is 90.76%, and 8.01% respectively. R-sq represents the significance of experimental work which is 98.76%.

The interaction plot generated for given experimental measurements show the change in Thrust force for given parameters with combination of feed rate and spindle speed in Fig. 4.

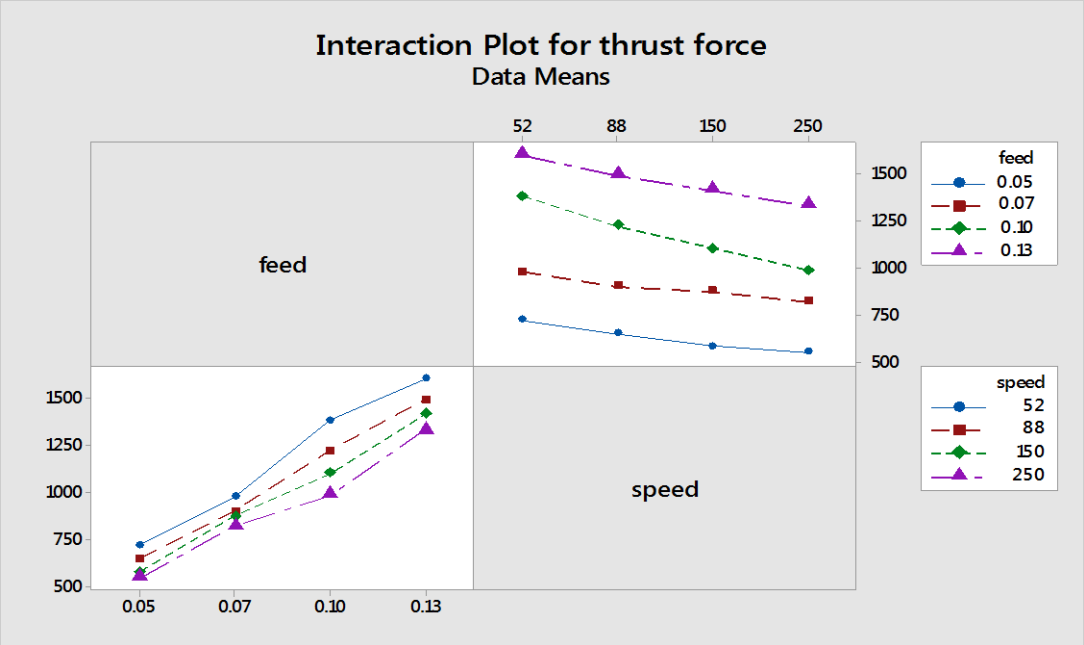

Fig. 4: Interaction plot for thrust force

Regression: Regression equation is formulated to predict the desired thrust force value. This term is use for finding out the correlation between the data. In the present work, regression equation was obtained by Minitab 17 statistical software.

Thrust force (N) = 298.6 + 10279 feed (mm/rev) – 1.178 speed (rpm) (1)

IV. RESULT AND DISCUSSION

The result shows that both two parameters have their effect on the measured thrust force. The effect of feed rate is more than spindle speed. As feed rate vary, thrust force value also vary due to change in amount of material removal from work piece by tool. There is less effect of spindle speed on thrust force as the increase in spindle speed leads decrement in thrust force.

After analysis of data, it is clear that minimum thrust force developed at 0.05 mm/ rev of feed rate and at 250 rpm of spindle speed which save energy and useful production time during drilling of mild steel work piece.

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