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Optimization of Drilling Process Parameters for Thrust Force: A Review

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Abstract

The big challenge of the industries is concentrated for achieving less wear and thrust force on the drilling tool and more tool life. In this paper an effort is made to review the literature work on investigating the effect of drilling and tool parameters on thrust force in drilling process on lathe machine with different-2 work piece materials, for optimization of thrust force. Most of experiments have been carried out by considering various independent parameters namely spindle speed, drill bit diameter and feed rate. Finally most significant variable is found out among different input parameter for affecting thrust force by using various mathematical and statistical techniques.

Keywords: drilling, feed rate, thrust force, spindle speed

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INTRODUCTION

Now a day's main drawback of industries is machine tools, because machine tools are not operating at their optimum operating conditions and due to this there is loss of man power, material and time. Often, the drilling parameters such as spindle speed, feed and depth of cut are selected based on the worker's experiences. However, the performance of machine and drill bit are not sure to be acceptable. It has been recognized that parameters during metal drilling such as feed and drilling speed should be chosen well to optimize the cost of drilling operations. At present manufacturing enterprises have to deal with increasing demands for improved product quality, tool life, less wear and less drilling force. In today, applications of optimization techniques in metal drilling process is necessary for a manufacturing unit to work effectively for severe competitiveness and growing demand of quality product in the market.

Drilling is a standard process for producing holes and most common material removal process in manufacturing industries. 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 start, a linear movement 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 on effect of drilling parameters like feed, spindle speed and drill bit diameter on thrust force in drilling operation.

LITERATURE REVIEW

Ahmed [1] performed drilling experiments on steel 2080 and also made 3D thermomechanically coupled finite element model of drilling process to study the influence of drilling parameters on thrust force. Experiments were performed on lathe machine for getting thrust force 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.

Alam *et al*. [2] studied thrust force and torque required for drilling at fresh bovine cortical bone by conventional and ultrasonically-assisted tool. Drilling tests were performed with two drilling techniques and the influence of drilling speed, feed rate and parameters of ultrasonic vibration on the thrust force and torque was studied. As the result ultrasonically-assisted drilling (UAD) was found to reduce a drilling thrust force and torque compared to conventional drilling (CD).

Audy [3] studied details data obtained from computer assisted analyses of rake angle distributions along the cutting edges of 6mm diameter, general purpose twist (GPT) drills and deep hole jobber (DHJ) drills for experimental thrust, torque and power values generated when dry drilling performed at Bisalloy 360 (360-400HB/39-44RC) steel work-piece material at a constant cutting speed of 5m/min and a feed rate of 0.075 mm/rev. The main purpose was to assess and compare the cutting efficiency of the above mentioned drill designs. Results disclosing that the modification of drill point geometry reduced the influence of negative rake cutting and as a result it lowered the thrust force, torque and power by 13, 15 and 15%, respectively.

Badan *et al*. [4] reveals the methodology for obtaining a mathematical model which calculates the drilling forces based on experimental researches. The experimental research aims to determine the influence of the drilling parameters like depth of cut, drilling speed and feed rate on the thrust force for 40CrMnMoS8-6 steel using HAM 280 Super drill solid carbide drills. The mathematical model is based on a power regression modeling dependent on the three above mentioned parameters.

Bakkal *et al.* [5] worked for the thrust force, torque and tool wear in drilling of Zr-based bulk metallic glass (BMG) material. As result they find that drilling the BMG at high speed generates the chip emission, high tool temperature and severe tool wear. At low spindle speed, the BMG work-material builds up the major and margin cutting edges and it may break the drill. A range of feasible spindle speed and feed rate for the efficient drilling of BMG without the detrimental chip emission and cutting edge work material build-up has been identified in this study. Finally, it was concluded that under the same drilling condition, the WC-Co tool generally requires less thrust force and about the same torque as the high-speed steel tool.

Baptista *et al*. studied the relationship between cutting forces and tool wear of PCD tool while machining A356/SiC/20p metal matrix composite in turning and drilling. In their observation they found that when the cutting speed was around 250 and 350 m/min with a feed of 0.1 mm/rev and depth of cut 1 mm, feed force varied between 100 and 200 N for a cutting time of 20 and 40 minutes, respectively. It was observed that at higher cutting speed wear increased the feed force and depth force also. It was also observed that the increase of cutting speed make a decrease of the cutting force. It was reported that the excessive cutting speed made a premature wear in the tool, leading to an accelerated increase of cutting force. As a conclusion, they have recommended PCD or diamond coated tools for reducing the cutting forces while machining MMCs.

Baroiu *et al*. [6] did research regarding measurement of axial force and torque for drilling of two steel brands (A570 and 16MnCr5). They also did comparison and experimental research regarding force size and torque for standard drills with the same diameter. As the result they find that the axial force due to the action of the transversal edge can be considered approximately equal to half of the total axial force. At the same time they observed lowering of the axial force in working with twist drills.

Cicek *et al*. [7] studied the effects of drilling parameters (i.e. drilling speed, feed rate) and deep cryogenic treatment on thrust force (F_f) in the drilling of AISI 316 stainless steel with M35 HSS twist drills. Drill bit was cryogenically treated at –196°C for 24 h and tempered at 200°C for 2 h after conventional heat treatment. The experimental results revealed that the lowest thrust forces were measured with the cryogenically treated and tempered drills. In addition, artificial neural networks (ANNs) and multiple regression analysis were used to model the thrust force. The scaled conjugate gradient (SCG) learning algorithm with the logistic sigmoid transfer function was used to train and test the ANNs. The ANN results showed that the SCG learning algorithm with five neurons in the hidden layer produced the coefficient of determinations (R2) of 0.999907 and 0.999871 for the training and testing data, respectively. In addition, the root mean square error (RMSE) was 0.00769 and 0.009066, and the mean error percentage (MEP) was 0.725947 and 0.930127 for the training and testing data, respectively.

Das and Das [8] the applicability and relative effectiveness of artificial neural network based model has been investigated for rapid estimation of thrust force and torque. The results obtained are found to correlate well with the actual experimental readings of thrust force. Experiments were conducted at different drilling parameters in vertical drilling machine at work piece of brass, aluminum, cast iron, mild steel and copper. The proposed work has wide application in selection of tools and online tool wear monitoring. Finally they concluded that on increasing the drill bit diameter, spindle speed and feed thrust force and torque increases.

Guibert *et al*. [9] the aim of the work is to propose an experimental methodology to identify a thrust force model for one pair of drill bit and work-piece material depending on the uncut chip thickness. This methodology proposes to divide cutting edges into several parts in order to define the local contribution of this part to the macroscopic thrust force. Local models are identified during the penetration of the drill by limited number of experiments with various feeds, it becomes possible to identify all the coefficients of an accurate thrust force model.

Iliescu *et al.*[10,11] the present aspects of the experimental research developed for the purpose of determining new and more adequate mathematical models of the thrust force and torque in drilling of 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 influence on the dependent variable (thrust force or torque) is due to cutting tool diameter (D) means larger the drilled hole higher the force and moments values. The lower influence on dependent variables is due to the cutting speed, but it is having reveres influence means higher values of v the lower values of thrust force and torque.

Kaplan *et al*. [12] investigated the effects of work piece hardness, drill bit diameters, drill bit lengths, spindle speeds and feed rates on the thrust force in drilling of AISI D2 and AISI D3 cold work tool steels under dry drilling conditions. The experiments were 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 was taken for making hole and with the help of drilling dynamometer they find out the thrust force. On basis of result of ANOVA analysis, the effective parameters on thrust force were feed rate, drill diameter, drill length, work piece hardness, number of holes and cutting speed, respectively.

Kuram *et al.*[13] studied the influence of three different vegetable-based cutting fluids developed from raw and refined sunflower oil and two commercial types (vegetable and mineral based cutting oils) on the thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel with HSSE tool. The uses of vegetable cutting oils was found as 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.

Kyratsis *et al*. [14] the study acknowledges use of modern CAD systems and subsequently using the application programming interface (API) of a typical CAD system for drilling simulations. The developed DRILL3D software routine creates via specifying parameters and tool geometries for different realistic solid models. The 3D solid models of the undeformed chips coming from both cutting areas, which are segmented into smaller pieces in order to calculate every primitive thrust force component involved with high accuracy. The resultant thrust force is verified by adequate amount of experiments using a number of different tools, speeds (15, 20 m/min) and feed rates (0.10, 0.15, 0.20, 0.25, 0.30 mm/min). The final data consist of a platform for further direct simulations regarding the determination of tool wear and drilling thrust optimizations.

Madhavan *et al*. [17] experimented the effect on thrust force during drilling of 10 mm diameter holes in 20 mm thick Carbon Fiber Reinforced Plastic composite laminate using HSS, Solid Carbide (K20) and Poly Crystalline Diamond drill bits. Experiments were conducted on a vertical drilling machine and also did 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 material of drill bit and the feed rate are the dominant factors that influence the thrust force. Thrust force recorded for HSS drill was high as compared to Carbide drill bit. Since the hardness of HSS tool is less than the carbide drill.

Matsumura *et al.* [18] presented an analytical model to predict the cutting forces in drilling of multi-layered materials. The force model shows chip flow on the chisel and the lips with piling up the orthogonal cuttings in the planes containing the cutting velocities and the chip flow velocities along the cutting edges. The chip flow directions on the chisel and lips are determined to minimize the cutting force. The cutting force is predicted to determine the chip flow models. In the CFRP/titanium alloy stacks, the material to be removed by changing the cutter feed. Therefore, the orthogonal cutting data of CFRP and those of titanium alloy are applied to make the cutting models according to the change of material. The force model is verified in comparison between the predicted and the measured cutting forces.

Miller *et al*. [19] investigated the effect of drilling parameter on low-carbon steel, aluminum and magnesium alloys at cnc vertical drilling machine and experimentally explored 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 spindle speed taken in between (5500–15,000 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 is beneficial to reduce the thrust force for friction drilling of brittle cast metals.

Muniaraj *et al*. [20] conducted experiments to study the effect of spindle speed and feed rate on the thrust force and surface roughness with coated carbide and carbide multifaceted drill bit of 4 mm diameter under various cutting conditions. They have 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 having significant influence on the thrust force and surface finish and on increasing feed rate thrust force increases and on increasing speed it decreases. And also coated carbide tool exhibits higher thrust force as compared to multifaceted carbide drill for all cutting conditions.

Nagaraja *et al*.[21] did the drilling tests on bi-directional carbon fiber reinforced epoxy composite (BCFREC) laminate by using high speed steel drill bit 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 bit of 6 mm diameter and 118^0 tip angle. The study reveals that there is a positive correlation between thrust force, torque and delamination. The feed rate has 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 with higher spindle speed in HSS drill bit in order to reduce the delamination damage.

Osman *et al*. made the measurement and analysis of torque and thrust in drilling mild steel with twist drills using a specially designed two-component piezoelectric dynamometer which was both statically and dynamically calibrated. As the result they concluded that on increasing feed rate force and torque both increases but spindle speed has reverse effect on thrust force and torque.

Rajamurugan *et al*. [22] in this work an attempt has been made to develop empirical relationship for thrust force in drilling of GFRP composites by multifaceted drill bit. The empirical relationship was developed by response surface methodology and 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 fiber orientation angle (0° or 90°) is preferred for minimizing the thrust force in drilling of GFR-Polyester composites.

Ramakrishna *et al.* did an effort to understand the influence of important machining parameters like spindle speed and feed rate on thrust force that is produced during drilling of Granite particulate Reinforced Epoxy Composite. Experiments were conducted by using High Speed Steel (HSS) Drill Bits of different diameters. Drilling damage was analyzed by using Stereo Microscope. The results also depicted the drilling speed and feed rate as an important variable that influences induced drilling damage and by increasing feed rate thrust force increases and on increasing spindle speed thrust force decreases.

Reddy *et al*. [23] studied the effect of the mechanical properties of aluminum alloys, cutting speed (90, 20,250,400 rpm), feed rate (0.15, 0.20, 0.30, 0.36 mm/rev) and the point angle on diametric error and thrust force by using Taguchi method. Al-6061, Al-6351 and Al- 7075 were selected as the work piece materials for experiments. The analysis of variance and signal-to-noise ratio were employed to analyze the effect of drilling parameters. As the result they given that the best parametric combination of the three control factors for minimization of both the diametric error and thrust force and optimum parameter are cutting speed i.e. at level-1(90 rpm), feed rate i.e. at level-1 (0.15 mm/rev) and point angle i.e. at level-1 (900). Thrust force (minimum) obtained on Al-6061 is better than Al-7075 and Al-6351 alloys.

Sekulic *et al*. gave a new model for drilling process. The key of the model is the decomposition of the drilling process. The thrust force structure is determined by experimental decomposition of the drilling process. In this study they taken spindle speed (450-710), feed rate (0.056- 0.179 mm/rev) and drill bit diameter (10, 12, 15 mm) for drilling of C1220 (C15). The method used for determination of thrust force structure in drilling has shown that it depends on chisel edge, the main cutting edges and margins. And also revealed that chisel edge has certainly the greatest influence on the thrust force because of his characteristics and influence of friction between the drill margins and machined surface cannot be ignored for thrust force.

Singh *et al*. [24] conducted experiments on drilling by using 8 Facet Solid Carbide drills based on L27 Orthogonal Array. The process parameters were spindle speed (500, 1500, 2500 rpm), feed rate (100, 300, 500 mm/min) and drill diameter (6, 8, 10 mm) with the help of these parameters a fuzzy rule based model was developed to predict thrust force and torque in drilling of GFRP composites. The verification results reveal that the fuzzy rule based model is suitable for predicting the thrust force and torque in drilling of composites.

Szwajka [25] gave a theoretical model to predict thrust force and torque in drilling. The model shows continuous distributions of thrust force and torque along the lip and the chisel edge of a twist drill. Calculations for thrust force and torque are taken on the basis of oblique cutting model for the lip and the orthogonal cutting model for the chisel edge. Thrust force and torque are obtained in terms of the geometric features of the drill, the cutting conditions and the properties of the machined material.

Tsao and Hoccheg [26] did experimental investigation for thrust force by core drill with different drilling parameter in carbon fiber reinforced plastic (CFRP). The experimental result shows that reduced diameter of core drill, large grit size of diamond, low feed rate and medium spindle speed are effective in reducing the thrust force. The grit size of diamond is the most significant factor among the four control factors, while the drill bit diameter shows limited influence. The correlation between thrust force and drilling parameters is obtained by multi variable linear regression and experimental results.

Vankanti *et al.* [27] worked to optimize process parameters namely cutting speed, feed, point angle and chisel edge width for drilling of glass fiber reinforced polymer (GFRP) composites. In this work, experiments were carried out as per the Taguchi experimental design and an L9 orthogonal array to study the influence of various combinations of process parameters on hole quality. Analysis of variance (ANOVA) test was conducted to determine the significance of each process parameter on drilling. The results indicate that feed rate is the most significant factor influencing the thrust force followed by speed, chisel edge width, point angle and cutting speed is the most significant factor affecting the torque, speed and the circularity of the hole followed by feed, chisel edge width and point angle. This work is useful in selecting optimum values of various process parameters that would not only minimize the thrust force and torque but also reduce the delimitation and improve the quality of the drilled hole.

Vaishak *et al.* [28] studied the influence of important machining parameters on thrust force and torque that are produced during drilling of Granite particulate Reinforced Epoxy Composite. Experiments were conducted by using High Speed Steel (HSS) Drill Bits of different diameters. Drilling damage was analyzed using Stereo Microscope. The results also depicted the cutting speed and feed rate as an important variable that influences drilling damage. Drilling damage decreases with increase in cutting speed and increases with increase in feed rate. [29]

Zitoune *et al.*[30] studied the parametric (feed and spindle speed) influences on thrust force, torque as well as surface finish for specimen of aluminum 2024 and carbon-fiber reinforced plastic (CFRP). The experimental results show that the quality of holes can be improved by proper selection of drilling parameters. For the CFRP, the circularity is found to be around 6 µm at low feed rates, when the feed is increased the circularity increases to 25 µm. The wear tests shows that during first 30 holes thrust force in CFRP undergoes a more important increase (90%) than thrust force of aluminum (6%) (Table 1).

Table 1. *Summary of Review Paper.*

Journal no.	Year	Name of author	Work piece material	Input parameter	Response variable	Most significant
1	2014	Ahmed	Steel 2080	Spindle speed, feed rate	Thrust force, torque	Feed rate
2	2010	Alam *et al.*	Bovine cortical bone	Speed, feed rate, vibration	Forces, torque	Vibration, feed rate
3	2007	Audy *et al.*	Bisalloy 360	Drill bit diameter, rake angle	Thrust force, torque, power	Rake angle
4	2012	Badan *et al.*	40CrMnMoS8-6 steel	Cutting depth, cutting speed and feed rate	Drilling thrust force	Feed rate
5	2004	Bakkal *et al.*	Zr-based bulk metallic glass (BMG)	Spindle speed and feed rate	Thrust force, torque	Tool material
6	2000	Baptista *et al.*	A356/SiC/20p	Cutting speed and depth of cut	Cutting force	Speed
7	2012	Baroiu *et al.*	steel brands (A570 and 16MnCr5)	Drill bit material	Axial force and torque	Drill bit material
8	2011	Cicek *et al.*	AISI 316 stainless steel	Cutting speed, feed rate and temperature	Thrust force (F_f)	Temparature
9	2015	Das *et al.*	Brass, steel, wood etc.	Drill bit diameter	Thrust force and torque	Drill bit diameter
10	2009	Guibert *et al.*	Steel	Drill bit material and	Thrust force	Feed rate

				feed rate		
11	2008	Iliescu *et al.*	20MoCr130 stainless steel	Cutting speed and drill diameter	Thrust force and torque	Drill bit diameter
12	2014	Kaplan *et al.*	AISI D2 and AISI D3 cold work tool steels	Work piece hardness, drill bit diameters, drill bit lengths, spindle speeds and feed rates	Thrust force ANOVA analysis	feed rate, drill diameter
13	2010	Kuram *et al.*	AISI 304 austenitic stainless steel	Spindle speed, feed rate cutting fluid	Thrust force and surface roughness	cutting fluid
14	2011	Kyratsis *et al*.	Steel	Spindle speed, feed rate	Thrust force	Feed rate
15	2012	Madhavan *et al*.	Carbon fiber reinforced plastic	Spindle speed, feed rate and drill material	Thrust force	Drill bit material
16	2014	Matsumura *et al.*	CFRP/titanium alloy	Drill bit material	Cutting force	Drill bit material
17	2005	Miller *et al.*	Low-carbon steel, aluminum and magnesium alloys	Spindle speed and feed rate	Thrust force and torque	Spindle speed
18	2013	Muniaraj *et al*.	Sic and graphite reinforced aluminum	Spindle speed and feed rate	Thrust force and torque	Feed rate
19	2013	Nagaraja *et al*.	Carbon fiber reinforced epoxy composite (BCFREC)	Spindle speed and feed rate	Thrust force and torque	Feed rate
20	1979	Osman et al.	Mild steel	Spindle speed feed rate, drill diameter	Torque and thrust force	Drill diameter
21	2012	Rajamurugan *et al.*	GFR-Polyester composite	Spindle speed feed rate, drill diameter	Thrust force	feed rate, drill diameter
22	2014	Ramakrishna *et al.*	Granite particulate Reinforced Epoxy Composite	Spindle speed and feed rate	Thrust force and torque	cutting speed and feed rate
23	2013	Reddy *et al.*	Al-6061, Al-6351 and Al- 7075	Spindle speed and feed rate	Thrust force	feed rate
24	2008	Sekulic *et al*.	C1220 (C15)	Spindle speed feed rate and drill diameter	Thrust force	Feed rate
25	2009	Singh et al	GFRP composites	Spindle speed feed rate and drill diameter	Thrust force and torque	Drill bit diameter and feed rate
26	2011	Szwajka *et al*	Wood	Spindle speed and feed rate	Thrust and torque	Feed rate
27	2007	Tsao *et al*	Carbon fiber reinforced plastic (CFRP)	Spindle speed feed rate and drill diameter	Thrust and torque	Feed rate and drill diameter
28	2013	Vankanti *et al*	Glass fiber reinforced polymer (GFRP)	Cutting speed, feed, point angle and chisel edge	Thrust force and torque	Feed rate
29	2014	Vaishak *et al*	Granite particulate reinforced epoxy composite	Cutting speed and feed speed	Thrust force and torque	Feed rate
30	2010	Zitoune *et al*	Aluminum 2024 and Carbon-fiber reinforced plastic (CFRP)	Spindle speed and feed rate	Thrust force, torque, surface finish, circularity and hole diameter	Feed rate

CONCLUSION

From literature review it has been found that most of researchers had taken input parameters such as spindle speed, feed, depth of cut and drill bit diameter in some case other parameters such as chisel edge, point angle, lubricant, properties of work piece and tool material, etc. are also taken. In drilling operation researchers had tried to found out effects of such input parameters on output parameters such as thrust force, torque, power consumption and surface roughness, etc. in order to optimize process parameter so that desired value of performance parameters can be obtained.

From literature review it has been concluded that with increase in drill bit diameter and feed rate thrust force increases while thrust force decreases with increase in spindle speed and feed rate has greater influence on thrust force as compared to depth of cut, point angle and spindle speed.

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