Experimental Studies on Perpendicularity of Drilling Operation using DOE

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Abstract – In drilling operation, work piece Geometric dimensions and tolerancing (GD&T) requirements is an important requirement for many applications. Thus, the choice of optimized cutting parameters is very important for controlling the required perpendicularity requirements. The focus of present experimental study is to optimize the cutting parameters through work piece Geometric dimensions and tolerancing (GD&T) requirements as perpendicularity. This paper reports an experimental investigation of a full factorial design performed on EN8 and EN31 materials using HSS drill with point angle 118° and helix angle 30° by varying the drilling parameters such as spindle speeds, feed and coolant ratio to determine optimum cutting conditions. The work piece Geometric dimensions and tolerancing (GD&T) requirements analyzed by perpendicularity. Analysis of variance (ANOVA) was carried out for perpendicularity on EN8 and EN31 materials and their contribution rates was determined. Design of Experiments (DOE) methodology by full factorial Design was used in the multiple objective optimizations (using Mini Tab 16, software) to find the optimum cutting conditions for least perpendicularity defect.

Keywords— Drilling, EN8, EN31, ANOVA, Perpendicularity.

1. INTRODUCTION

Drilling is one of the most commonly used metal removal operations in industry because of its ability to remove material faster giving reasonably good hole quality. They are used in a variety of manufacturing industries including aerospace and automotive sectors, where quality is an important factor in the production of slots, pockets, precision moulds and dies. Greater attention is given to dimensional accuracy and surface roughness of products by the industry these days. [1]Carbon steel materials (EN8 and EN31) play an important role in the field of engineering due to activities in aircrafts, aerospace, automotive, and dies industries.[1,2] These materials have higher hardness that makes their properties particularly superior in strength and modulus. In machining, drilling is essentially required to join different structures but carbon steel materials (EN8 and EN31) drilling poses many problems encountered include GD&T requirements, perpendicularity, surface delamination, hole surface roughness, and higher tool wear due to hardness that decrease the quality and perpendicularity of holes.[10] In order to minimize these machining problems, there is need to develop scientific methods to select cutting conditions for damage-free drilling process.[4]

[2]Geometric Dimensioning and Tolerancing (GD&T) is an international language that is used on Engineering Drawing to describe parts. Perpendicularity is a member of the orientation family (fig 1). It can be used to control the orientation of surface, axes and centerplanes. If used on features of size, it is often used as a refinement of, or to augment a positional control. It is also often used to orient secondary datum features of size to primary plane datums. Perpendicularity is a characteristics of orientation (altitude) applied to a feature or feature of size wherein that considered feature surface, line element, median plane or axis is being controlled (to within a specified tolerance) 90° to a datum plane or datum axis. [3]

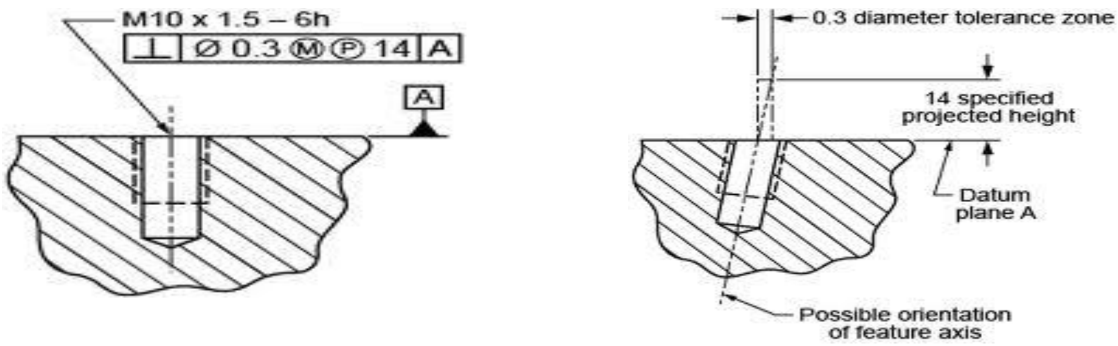

Figure1. Measurement of Perpendicularity.[3]

A number of work done in drilling of metals show that the defect is influenced by the choice of the machining parameters like speed, feed, coolant ratio and geometry of the cutting tool tip[10] etc.In this study, the effects of cutting edge geometry, work-piece hardness, feed rate and cutting speed on surface roughness and resultant forces in the finish hard turning of AISI H13 steel were experimentally investigated. This study shows that the effects on surface roughness are statistically significant. [5]This paper present the effect of drilling parameter such as spindle speed, feed rate and drilling tool size on material removal rate (MRR), surface roughness, dimensional accuracy and burr. Study on optimum drilling parameter for HSS drilling tool in micro-drilling. The increment of spindle speed and feed rate value mostly will affect the tool wear and size of burr on the edge of drilled holes.[6]

The cutting parameters for drilling EN24 material with the high speed steel drill are analyzed using Taguchi method. By using suitable cutting parameters like feed rate, speed and lip angle, the experiment is conducted and that the optimized cutting parameters are found with reference to the surface roughness, metal removal rate and machining time for the operation.[7] Turning component used to achieve both the geometrical and dimensional tolerances requirements. The geometrical requirements are: Circularity, Cylindricity, Perpendicularity etc. The effect of the cutting parameters on them has greater significance.[8]

The aim of this work is to utilize taguchi method to investigate the effects of drilling parameters such as cutting speed (5, 6.5, 8 m/min), feed (0.15, 0.20, 0.25mm/rev) and drill tool diameter (10, 12, 15mm) on surface roughness, tool wear by weight, material removal rate and hole diameter error in drilling of OHNS material using HSS spiral drill.[9]

This paper presents a literature review on mechanical drilling processes for Ti, namely, twist drilling, vibration assisted twist drilling, ultrasonic machining, and rotary ultrasonic machining. It discusses cutting force, cutting temperature, tool wear and tool life, hole quality (diameter and cylindricity, surface roughness, and burr), and chip type when drilling of Ti using these processes.[10] A model is developed to predict the effects of thermal distortion of the drill and workpiece on the diameter and cylindricity of dry drilled holes. The model predicts that thermal expansion of the drill is the dominant effect and leads to oversized holes with diameters that increase with depth.[11]

2. EXPERIMENTAL WORKS

2.1. Specimens

The carbon steel materials EN8 and EN31 were made by extrusion process. The chemical properties of EN8 and EN31 described in Table 1. The mechanical properties of EN8 and EN31 described in Table 2. Each specimens having dimension of (40 x 40 x 90) mm is used for the experiment purpose.

Table 1 Chemical compositions of EN8 and EN31

	C%	S%	P%	Mn%	Si%	Cr%
En8	0.35-0.45	0.015-0.06	0.015-0.06	0.60-1.00	0.05-0.35	0.05
En31	0.90-1.20	< 0.045	< 0.045	0.30-0.80	0.1-0.35	1.00-1.60

Table 2 Mechanical properties of EN8 and EN31

	EN8	EN31
Hardness, Brinell	210-255	350-450
Ultimate tensile strength	550 MPa	580 MPa
Yield tensile strength	280 MPa	305 MPa
Bulk modulus	140 GPa	140 GPa

2.2. Drill tool

For this experiment study HSS fluted drill with point angle of 118° and helix angle 30° is used for drilling operation. Details of drill tool is given in Table 3.

Table 3 Drill tool parameters

Tool Diameter (mm)	Shank Length (mm)	Flute Length (mm)	OAL (mm)
17.5	30	90	120

2.3 Experimental Set up

The experimental set-up is shown in Fig. 2. The workpiece was mounted on the fixture which was fixed on the bed of a vertical machining center with help of clamps and the drill was fed into the workpiece. A vertical machining center made of Haas, Model VF2 was used to perform the experiments. Drilling trials were carried out using 17.5 mm diameter HSS drill. Table 5, 6 summarizes the experimental conditions. Figure 2: Experimental set-up. Table 4 details of VMC (Model VF 2)

Table 4 Details of Vertical Machining Centre, Make Hass,VF2

Parameter	**Values in Metric**	**Parameter**	**Values in Metric**
X axis travel	762 mm	Max. Thrust X	11343 N
Y axis travel	406 mm	Max. Thrust Y	11343 N
Z axis travel	508 mm	Max.Thrust Z	18683 N
Max. Rating	22.4 kw	Max. Weight	1361 kg
Max. Speed	8100 rpm	Max Tool diameter	89 mm
Max. Torque	122 N.m ,2000 rpm	No of Tool Capacity	20

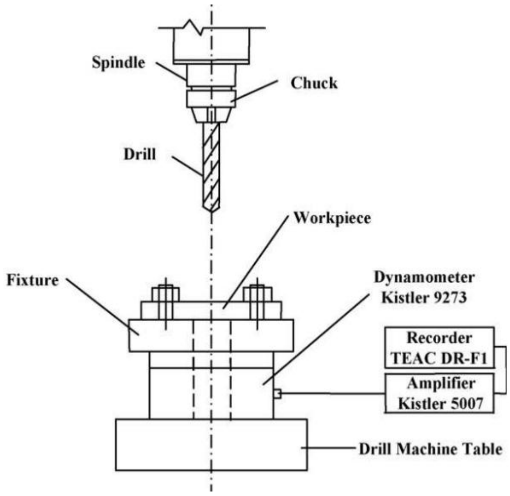

Figure2. Schematic diagram of Experimental Set up.[1]

2.4 Full factorial design

Full factorial design is used for simultaneous study of several factor effects on the process. By varying levels of factors simultaneously we can find optimal solution. Responses are measured at all combinations of the experimental factor levels. The combination of the factor levels represent the conditions at which responses will be measured. Each experiment condition is a run of an experiment. The response measurement is an observation. The entire set run is a design. It is used to find out the variables which are the most influence on the response and their interactions between two or more factors on responses.[4]

Table 5 Cutting parameters for EN8

Factors	Level (-1)	Level (0)	Level (1)
Speed(RPM)(A)	300	400	500
Feed (mm/rev)(B)	0.1	0.2	0.3
Coolant Ratio(C)	2% oil	11% oil	20% oil

Factors	Level (-1)	Level (0)	Level (1)
Speed(RPM)	200	300	400
Feed (mm/rev)(B)	0.15	0.20	0.25
Coolant Ratio(C)	2% oil	11% oil	20% oil

Table 6 Cutting parameters for EN31

3. RESULTS AND DISCUSSION

Experiments are conducted to investigated the effects of cutting parameters like spindle speed, feed and coolant ratio on perpendicularity of EN8 and EN31.

3.1 Analysis of variance (ANOVA)

Presents study used ANOVA to determine the optimum combination of process parameter more accurately by investigating the relative importance of process parameters.

3.2 Main effect plots analysis for perpendicularity of EN8

The analysis is made with the help of a software package MINITAB 16. The main effect plots are shown in fig.3. These show the variation of response with the three parameters i.e. spindle speed, feed and coolant ratio separately. In the plots, x axis indicate the value of each parameter at three levels and y- axis the response values of perpendicularity. Horizontal line indicates the mean value of the response. The main effects plots are used to determine the optimal design conditions to obtain the optimum perpendicularity.

Perpendicularity is one of the most important parameter to check hole quality performance. Measurement of perpendicularity is done by Co-ordinate measuring machine (CMM) which is made by Hexagon Pvt. Ltd.

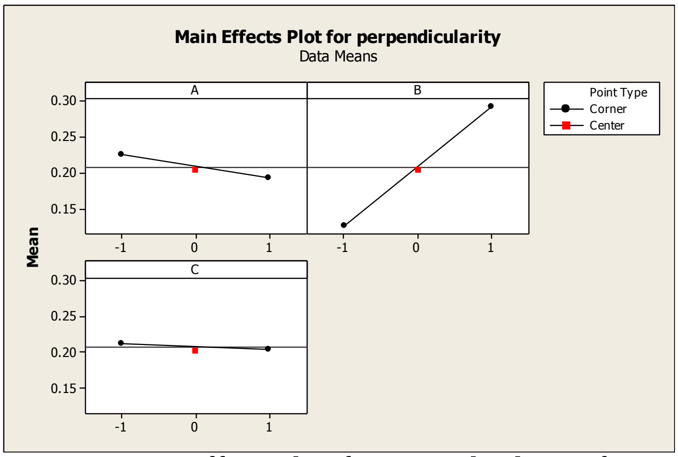

Figure: 3 Main effects plots for perpendicularity of EN8

Fig.3 shows the main effects plot for perpendicularity. According to this main effect plot, the optimal conditions for minimum perpendicularity in EN8 are at spindle speed 500 rpm, feed 0.1 mm/rev and coolant ratio 20% oil.

3.3 Analysis of variance (ANOVA) for Perpendicularity of EN8

Table 4 presents the results of ANOVA for perpendicularity. It is observed from the ANOVA table, the feed is the significant parameter for the perpendicularity. However, the speed and coolant ratio has least effect of in controlling the perpendicularity. Statistically, F-test decides whether the parameters are significantly different. A larger F value shows the greater impact on the machining performance characteristics. Larger F- values are observed for spindle Feed and speed.[4]

Table 7. ANOVA Result for perpendicularity of EN8

Source	DF	SS	MS	F	P
Speed (A)	1	0.0022781	0.0022781	78.78	0.003
Feed (B)	1	0.0552781	0.0552781	1911.6	0
Coolant ratio (C)	1	0.0001051	0.0001051	3.64	0.153
2-way interaction	3	0.0004414	0.0001471	5.09	0.107
3-way interaction	1	0.0000001	0.0000001	0	0.952
Error	3	0.0000867	0.0000289		
Total	11	0.058274			

3.4 Main effect plots analysis for Perpendicularity of EN31

The analysis is made with the help of a software package MINITAB 15. The main effect plots are shown in fig.4. These show the variation of response with the three parameters i.e. Spindle speed, feed and coolant ratio separately. In the plots, x axis indicate the value of each parameter at three level and y- axis the response value of perpendicularity. Horizontal line indicates the mean value of the response. The main effects plots are used to determine the optimal design conditions to obtain the optimum conditions. [4]

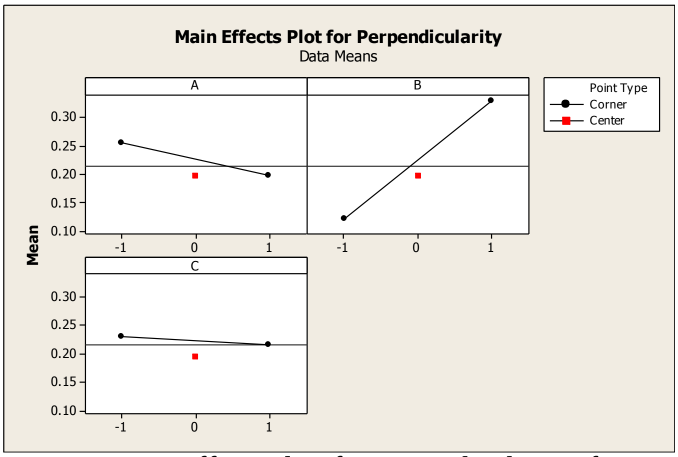

Figure: 4 Main effects plots for perpendicularity of EN31

Fig.4 shows the main effects plot for perpendicularity of EN31. According to this main effect plot, the optimal conditions for minimum perpendicularity are at cutting speed 400 rpm, feed 0.15 mm/rev and coolant ratio 20% oil.

3.5 Analysis of variance (ANOVA) for Perpendicularity of EN31

Table 8. ANOVA Result for perpendicularity of EN31

Source	DF	SS	MS	F	P
Speed (A)	1	0.0066125	0.0066125	90.69	0.002
Feed (B)	1	0.0852845	0.0852845	1169.6	0
Coolant ratio (C)	1	0.0003645	0.0003645	5.00	0.111
2-way interaction	3	0.0002320	0.0000773	1.06	0.481

3-way interaction	1	0.0000125	0.0000125	0.17	0.707
Error	3	0.0002187	0.0000729		
Total	11	0.0948529			

Table 8 presents the results of ANOVA for perpendicularity of EN31. It is observed from the ANOVA table, the feed is the significant parameter for the perpendicularity. However, the speed and coolant ratio have least effect of in controlling the perpendicularity of EN31. Statistically, F-test decides whether the parameters are significantly different. A larger F value shows the greater impact on the machining performance characteristics. Larger F- values are observed for spindle feed and speed.

4. CONCLUSION

This study discussed an application of the full factorial design for optimizing the cutting parameters in drilling operations performance measures perpendicularity of EN8 and EN31. From this research, following conclusions could be reached with an optimum amount of perpendicularity response:

1.EN8: Speed 500 RPM, feed 0.1 mm/rev and coolant ratio 20% oil.

2. EN31: Speed 400 RPM, feed 0.15 mm/rev and coolant ratio 20% oil.

So we concluded from above result that irrespective of the material (EN8 and EN31), Spindle feed is the most significant variable affecting perpendicularity in drilling operation.

5. SCOPE FOR FUTURE WORK

In this present study only three parameters have been studied in accordance with their effects. View of future scope, other factors like Drill geometry, types of drill, Laminates configurations can be studied. Also, the other outputs like surface roughness, tool life, delamination, thrust force etc. can be added.

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