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Topology and Shape Optimization of Reamer

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Abstract: This paper introduces the application of Taguchi methodology in optimizing the cutting parameters of drilling process for nozzle of DSLA injectors. There are four parameters have been selected in this study speed (A),feed rate (B),depth of cut (C) and coolant pressure (D). Taguchi method is used to determine the best combination of machining parameters which can provide the optimal machining response conditions which are lowest surface roughness with lowest cutting force value. For the best surface finish A1-B2-C2-D2 (A1=6500 RPM, B2=700 mm/min, C2=2000 mm ,D2=90bar) is found to be the optimized combination of levels for all the four control factors from the analysis.

Index Terms: ECN 200, Spindle Speed, Feed rate, Depth of cut And Coolant Pressure

I. INTRODUCTION

Single lip deep hole drilling is commonly used in several industrial applications to manufacture bore holes with diameters in the range of d = 0.5 … 40 mm with a high length-to-diameter-ratio (l/d-ratio) up to l/d = 200. In addition to the high l/d-ratio, a major advantage of the single lip deep hole drilling is the ability to generate high bore hole qualities. The main characteristics are minor deviations in diameter and straightness, high shape accuracy and high surface quality of the bore hole. [2]Thus, bore holes can be manufactured very efficiently without subsequent processes for increasing quality, such as reaming or honing. A disadvantage of single lip deep hole drilling is the high mechanical tool load during the cutting process that limits the feed rates in particular for smaller diameters. [4]

This adversely affects the the efficiency of the process. To improve the efficiency of the cutting process, the microscopic shape of the cutting edge is particularly important. to enhance the tool performance . In this research the influence of cutting edge preparation using an abrasive water jet blasting process is analyzed for single lip deep hole drilling. For this purpose, mechanical load, tool wear, bore hole quality and chip forms are ascertained for different cutting edge designs. The aim of the study is to investigate the influence of cutting edge preparation on the cutting process so as to generate a specific cutting edge design for an improved feed rate.

Taguchi Method

Taguchi method is one of the simplest and effective approaches for parameter design and experimental planning (Fisher, 1925). In this method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value i.e. standard deviation (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. There are three types of S/N ratio depending on type of characteristics-the lower-the-better, the higher-the-better, and the nominal-the-better. The details of the calculation of the S/N ratio for these three types of characteristics are available in Siddiquee et al. (2010). Optimization of quality characteristics using parameter design of the Taguchi method are summarized in the following steps (Nian et al., 1990): [23]

- Identification and evaluation of quality characteristics and process parameters.
- Identification of number of levels for the process parameters and possible interactions between the process parameters.
- Assignment of process parameters to the selected appropriate orthogonal array.
- Conduction of experiments based on the arrangement of the orthogonal array.
- Calculation of S/N ratio.
- Analyze the experimental results using the S/N ratio and ANOVA.
- Selection of the optimal levels of process parameters. Verification of the optimal process parameters through the confirmation experiment.

II. LITERATURE REVIEW

So many influences on design have been proposed for cutting edge of reamer and we can classify them into several categories as follows:

1. Influence of the cutting edge design on the cutting process.
2. Influence of the cutting edge design on the mechanical
3. Influence of the cutting edge design on bore hole quality

4. Tool wear Mechanism Study
5. Chip Profile Study
6. Effect of point angle on flank wear
7. Effect of point angle on chisel edge wear

1. Influence of the cutting edge design on the cutting process

The influence of the cutting edge design on the tool wear is shown for the feed rates applied. The quantitative comparison of the tool wear is given by the width of flank wear land VB. This was measured along the drilling length at the flank faces of the tools. The related values are averaged over fixed reference points along the inner and outer cutting edge. Furthermore, scanning electron microscopic (SEM) pictures of the outer cutting edge and corner area expresses the tool wear qualitatively.[3]

2. Influence of the cutting edge design on the mechanical tool load:

The comparison of the mechanical tool load for the different cutting edge designs and feed rates is presented in Figure 3 with respect to the feed force Ff. The values along the drilling length are illustrated. The uniform increase in the feed forces along the drilling length, for all tools investigated, when applying conventional feed rate of f = 0.03 mm/rev, is due to the uniform wear [2].

3. Influence of the cutting edge design on bore hole quality

The bore hole quality was measured with respect to the surface roughness, the bore diameter, the roundness and the straightness accuracy. The influence of the cutting edge design and feed rate on the mean surface roughness Rz is shown in Figure. Furthermore, Figure shows pictures of the chips generated.

4. Tool Wear Mechanism Study:

Wear is the removal of the material from the surface of a solid body as a result of mechanical action of the counter body. Wear may combine effects of various physical and chemical processes proceeding during the friction between two counteracting materials such as micro cutting, micro-ploughing, plastic deformation, cracking, fracture, and welding, melting and chemical interaction.

5. Chip profile study:

Chip shape is the most important factor for the smoothness of a drilling process. The drilling process will be smooth if chips are well broken. While drilling CFRP/Ti stacks, CFRP chip are broken into smaller dust particles because of high abrasive characteristic.[4]

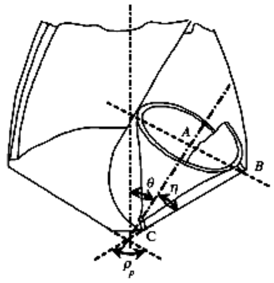

Fig.1. Drill Geometry

6. Effect of point angle on flank wear

The chisel edge wear depends on the feed rate and relief angle. The wear increases with spindle speed. The complex hard phase within Ti abrades the flank surface after shearing the 3D microstructure. Due to the rapidly evolving flank wear with number of holes, the thrust force increased more rapidly at the higher spindle speed over the lower spindle speed.

7. Effect of point angle on chisel edge wear

The chisel edge wear depends on the feed rate and relief angle. The wear increases with increase in feed rate. Smaller relief angles are not recommended because their contribution to chisel edge wear is high. Furthermore Ti alloy adhesion causes built up edge (BUE) on the chisel edge.[6]

III. EXPERIMENTAL SETUP AND DESIGN

The experimental set-up is discussed below,

A. Specification of Drilling Machine

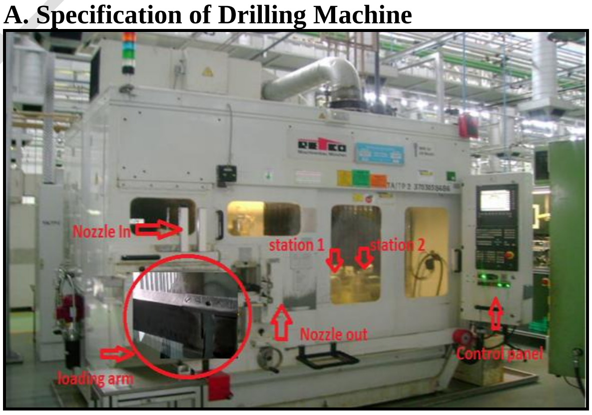

Fig 2. CNC Machining Centre RETCO

Machine : Turning & Drilling
Operations : Collar & top face turning, guide bore, extension
Bore, Seat & sack hole drilling
Make : RETCO, Germany
Cycle Time : 28.5+_0.5 sec

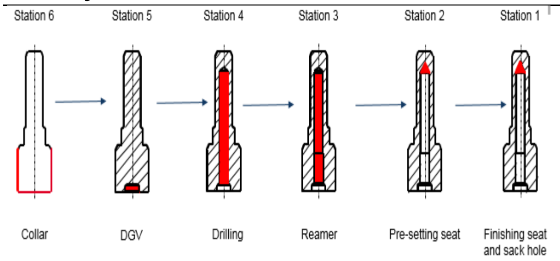

Fig.3. Operation Sequence for the Product Component

B. Work-piece Material

Fig.4. Product Component

The component used for drilling is 18CrNi8 (Steel Rod). K1 max 1 Ø14,3

C. Cutting Tool

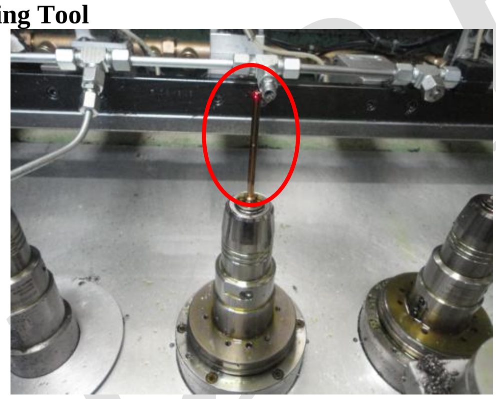

Fig.5. Reamer for CNC

The cutting tool reamer is K-30 carbide grade with coating of TiAlN with step diameter. There is are 2 diameter of this tool

1. Ø 3.949-0.004 mm
2. Ø 3.825-0.002 mm

Total length of this tool is 95±1.5 mm and shank length is 36mm.Following are the process parameters limits used for the experimentation.

Speed : 7000± 500 RPM
Feed rate : 700±50 mm/min
Depth of cut : 2000± 500 mm
Coolant Pressure : 90±10 bar

IV. OBJECTIVE OF STUDY

In this study, the Taguchi method is applied to optimize the parameters design phase. It is most important design phase and served the objective of determining the optimal drilling parameters to achieve the minimum surface roughness with cutting forces
The following factors are considered in this study

- The relationship between the control factors (Spindle speed, feed rate, depth of cut and coolant pressure) and the output factor (Surface roughness).
- The optimal conditions of the drilling parameters for surface roughness.

IV EXPERIMENTAL DESIGN

A.Orthogonal array and experimental factors

In the parameter design stage of the Taguchi method the first step is to set up and select a proper orthogonal array (OA).To accommodate four control factors into the experimental study, a standardized Taguchi based experiment design, L9 array (3^4)was chosen in this study. There are four control factors (Spindle speed, Feed rate, Depth of cut and coolant pressure) which are independent variables while the response factor (Surface roughness) is dependent variable.

B.Material and methods

Experimental runs need to be conducted to collect desirable data.

Materials

The sample material used for this experiment is nozzle body which is made of 18CrNi8 (Steel)

Experimental details

This experiment was done in RETCO TC machine which drilling and turning operations. This machine is having total six stations. The reamer is used for this process is step reamer means it is have two diameters Ø 3.949-0.004mm and Ø 3.825-0.002mm. The roughness of parts or nozzle body is measured in FMR (Fine Measurement Room) with the help of roughness tester. Also the product diameter is measured in Heidenhen unit with the help of split diameter probe gauge.

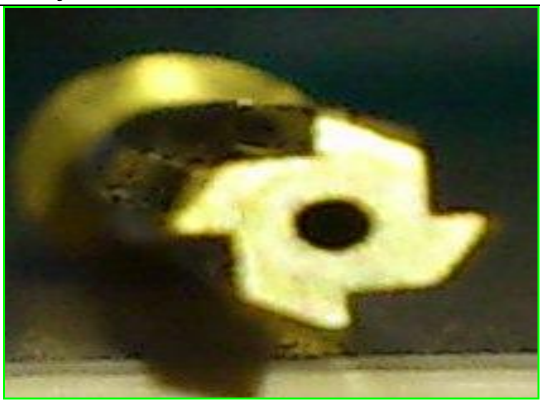

Fig.6. Top view of the reamer used

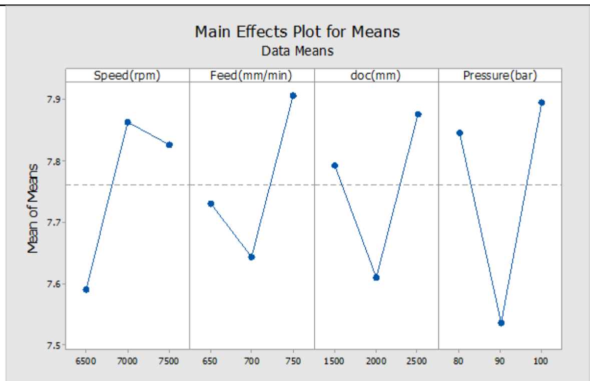

Fig.7. Main Effects Plot for Means of Surface Roughness using MINITAB 17

VI. RESULT AND ANALYSIS

Data analysis on the optimal levels for the control factors is the first step after completing the experimental stage. The main aim is for this experiment is to optimize the drilling parameters to obtain lower surface roughness.

TABLE I
RESPONSE TABLE FOR MEANS SURFACE ROUGHNES

Level	Spindle Speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Coolant pressure (bar)
1	7.590	7.730	7.793	7.847
2	7.863	7.643	7.610	7.537
3	7.827	7.907	7.877	7.897
Delta	0.0273	0.263	0.267	0.360
Rank	2	4	3	1

TABLE II
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO (SMALLER THE BETTER)

Level	Spindle Speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Coolant pressure (bar)
1	-17.59	-17.76	-17.83	-17.89
2	-17.91	-17.65	-17.62	-17.54
3	-17.87	-17.96	-17.93	-17.95
Delta	0.32	0.31	0.31	0.41
Rank	2	4	3	1

Determination of the optimum machining parameters

Surface Roughness

The smaller the better characteristics was used to determine the smallest surface roughness that would be the ideal situation for this study . Meanwhile the larger S/N ratio would be projected as the best response given in the machine set-up system which would be the ideal situation. There are no conflicts in determining the optimal depth of cut, spindle speed, feed rate and coolant pressure and the criteria of the lowest response and highest S/N ratio were followed. Thus, the optimized combination of levels for all the four control factors from the analysis which provides the best surface finishes as shown in TABLE III , IV and V

TABLE III
OPTIMUM PARAMETERS FOR SURFACE ROUGHNESS

Factors	Optimum parameter values
A.Spindle Speed(rpm)	6500
B.Feed rate (mm/min)	700
Depth of cut (mm)	2000
Coolant pressure (bar)	90

TABLE IV
CONFIRMATION TEST RESULT FOR SURFACE ROUGHNESS

$\eta_{confirmation}$			Mean (Ra) µm
Run 1	Run 2	Run 3	
6.9	7.1	7.0	7.0

TABLE V
COMPARISON OF RESULT FOR SURFACE ROUGHNESS

$\eta_{Predicted}$	$\eta_{Confirmation}$	% Error
7.27	7.0	2.7

VII. CONCLUSIONS

Based on the results of experiment the following conclusions can be drawn,

- Taguchi method was performed to select the optimal cutting parameters from varying combinations of cutting parameters for drilling machine.
- The optimum value for component roughness are found to be 6500 rpm spindle speed ,700mm/min feed, 2000 mm depth of cut and 90 bar coolant pressure.
- Coolant pressure is found to be the most significant parameter affecting Surface Roughness and Spindle speed, Depth of cut and Feed rate follows respectively.
- The problem can be extended further for multi-objective optimization and may include advance analysis of parameters. ANOVA can be done to find out contribution percentages of each parameter also the work can be extended by varying the most sensitive parameters like coolant pressure in this case keeping other parameters constant which is tolerance design of the Taguchi approach.

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