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Experimental Investigation on the effects of gaseous Nitrogen coolant in CNC Turning of En8

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Abstract— This project aims to study the effects of Nitrogen gas coolant on surface roughness of En8 during CNC turning operation. The experiments are carried out in nitrogen gas cooling environment and dry cutting environment (without coolant). During the experimentation, the machining parameters - speed, feed and depth of cut are varied as per the Design of Experiments and corresponding surface roughness values are measured. The relationship between machining parameters (Independent variables) and surface roughness (Response Variable) are to be studied by Response Surface Methodology and optimized these machining parameters using Taguchi Method.

Index Terms— Optimization, CNC Turning, surface roughness, Taguchi method, Response Surface Methodology

I. INTRODUCTION

CNC turning is one of the manufacturing processes adopted to remove the material from the work piece. Turning is the removal of metal to reduce the outer diameter of rotating cylindrical work piece usually to specified dimension and to produce a smooth finish on the metal. In turning, the machining parameters such as feed, speed, depth of cut, type of coolant used or cooling environment, types of inserts used impact the surface roughness. The three primary input control parameters in turning operation are cutting speed, feed rate and depth of cut. In the type of cooling environment such as dry cutting and using of cutting fluids, dry cutting having several benefits such as increase material removal rate, reduce production costs, and enhance of material properties. Due to the friction between tool and workpiece and between tool and chip, high temperature generated in the machining zone in the time of dry cutting environment . Applying cutting fluid is important during machining process to reduce the temperature and deliver lubrication between the cutting tool and workpiece, provide longer tool life and better workpiece quality. Many techniques such as lubricating and chip-removing, increasing new cutting media such as low temperature air jet, nitrogen gas, water vapor, cryogenic pneumatic mist and minimum quantity lubrication (MQL) are there for special performance but there is no appropriate substitution.

Nitrogen in particular is an inert gas which forms 78% of the atmosphere and is lighter than air. As a result it is dispersed into the atmosphere and does not harm the workers on the shop floor. Nitrogen cutting environments reduces crater wear and flank wear over other environments.

In a turning operation, it is very difficult to select the machining parameters to achieve the high surface finish. To enhance the minimum surface roughness the optimum machining parameters has to obtain from the selected machining parameters.

This study involves in experimentally investigating the effect of applying Nitrogen gas compared with dry cutting on surface roughness under different machining parameters in CNC turning of En8 material to identify the optimized parameters. The optimization techniques – Taguchi method and Response surface methodology for obtaining optimized machining parameters.

II. LITERATURE REVIEW

O. Cakir, M. Kiyak, and E. Altan [1] Studied the effects of cutting fluid, Nitrogen, oxygen and carbon dioxide gases applications and dry cutting on cutting forces, thrust forces, surface roughness, friction coefficient and shear angle in turning of AISI 4140 steel material.

AmadElddeinIssaElshwain, Mohamed Handawi, NorizahRedzuan, NoordinMohdYusof, DenniKurniawan [2] studied on turning of hardened stainless tool steel is performed under various dry cutting and Nitrogen gas coolant conditions. Based on the results of study investigation they concluded as in Nitrogen gas coolant, surface roughness is reduced by 59 %, tool life improved by 11.5% as compared to dry cutting environment.

M.Stanford, P.Lister, C.Morgan, K. Kibble [3] conducted their experiments in turning of En32b low carbon steel with uncoated carbide under following cutting environments: flood coolant, compressed air blast, dry cutting, ambient temperature Nitrogen gas environment, cold nitrogen gas and liquid nitrogen gas environment. In Nitrogen cutting environments, 55% reduction in crater wear and 30% reduction in flank over other environments were observed.

H. Shizuka, K. Sakai, Y. Suzuki [4] investigated the effect of Nitrogen atmosphere on minimum quantity lubrication cutting performance. The Nitrogen gas atmosphere retards oxidation due to heat buildup during cutting. This reduces the cutting temperature and improves the tool life.

Patilshivrajnagnath, Pimpalgaonkar D.S, Ade Santoshlaxmanrao [5] used En8 material to study and optimize the effects of cutting parameters on surface roughness and MRR in turning by Taguchi techniques. They obtained optimum cutting parameters N= 1600 rpm, F= 0.1 mm/min, D= 0.75 mm for minimum surface finish and N= 1900 rpm, F= 0.3 mm/min, D= 0.75 mm for maximum material removal rate. They concluded as Feed rate is the most significant factor for both MRR and Surface Roughness, depth of cut does not affect on surface roughness.

N.E. Edwin Paul, P. Marimuthu, R.VenkateshBabu [6] applied Taguchi method for optimizing the process parameters and their percentage of contribution in affecting variation in surface roughness while machining En8 steel with TNMG insert. They obtained optimum cutting parameters as v= 200m/min , F= 0.15 mm/rev, D= 1.2 mm and feed influences 45.5%, speed influences 16.55%, depth of cut influences 5.56% of the surface roughness.

YacovSahijpaul, Gurpreet Singh [7] determined the influence of various cutting parameters on surface roughness during wet CNC turning of AISI 1040 or En8 medium carbon steel. They obtained optimum cutting parameters N= 1000 rpm, F= 0.125 mm/rev, D= 0.5 mm for minimum surface finish R_a=1.91µm.

Hardeep Singh, Rajesh Khanna, M.P. Garg [8] determines the effect of various cutting parameters on surface roughness and material removal rate during turning of En8. The cutting parameters influences on surface roughness as 63.9% by spindle speed, 11.32% by depth of cut and feed rate contribution with 8.33%. It is clear from the above mentioned literature that much turning work have been conducted on the surface roughness under dry, wet and cryogenic cooling environment but few were reported to see the effect of Nitrogen gas cooling in turning operation. Therefore, in this experimental investigation, the effect of Nitrogen gas coolant on surface roughness and material removal rate during CNC turning of En8 has been studied.

III. MATERIALS AND METHODS

3.1 Materials and its Properties

The workpiece material selected for this experimental investigation is En8. En8 is unalloyed medium carbon steel which has medium strength and good tensile strength. It finds wide varieties of application not only for forging, casting, axle shaft, studs, keys, crank shaft, and connecting rods but also used for low cost die material in tool and die making industries, in moulds slide core, pillar and pillar bush, sliding block, lifter, ejectors and ejector pins, for making gudgeon pins also. This steel can be hardened and tempered to provide a greater strength and wear resistance than low carbon steels.

3.1.1. Chemical composition

Chemical composition of En8 on % of weight is shown in Table 3.1.

ELEMENTS	% COMPOSITION
C	0.4%
Mn	0.8%
Si	0.25%
S	0.015%
P	0.015%
Fe	98.52%

Table 3.1: Chemical Composition of En8

A. *Taguchi Technique*

Taguchi method is an experimental method to find out the effective performance and machining conditions. This methodology offers simple and systematic approach to optimize design for performance, quality and cost. Two major tools in robust design are,i) Orthogonal arrays, which accommodate many design factors simultaneously, ii) Signal to Noise ratio, which measures quality with emphasis on variation.

Taguchi method refers to the parameter design, tolerance design, quality loss function, online quality control, design of experiments using orthogonal array, methodology applied to evaluate measuring system. By applying this technique one can significantly reduce the time required for experimental investigation, as well as to study the influence of individual factors to determine which factor has more influence and which has less.

In this work, smaller is better quality characteristic has been chosen. As the performance characteristic is surface roughness,

$$S/N=-10*\log_{10}(Sum(Ra^2)/n) \quad (1)$$

Where, Ra - Mean value of surface roughness

Equation (1) gives the relation of signal to noise for smaller is better.

B. Response Surface Methodology

Response Surface Methodology(RSM) is a collection of mathematical and statistical techniques for empirical model building to analyze the influence of the independent variable(Input variable) on a specific dependent response(output variables) of a process. The purpose of developing mathematical model relating the machining response and their factors is to facilitate the optimization of the machining process.

The mathematical model commonly used for the machining response Y is represented as

$$Y= \psi(d_c,N,f)+\varepsilon \quad (2)$$

Where d_c,N,f are depth of cut, speed and feed respectively and ε is the error which is normally distributed about the observed machining response Y. Let $\psi(d_c,N,f)=\eta$. The surface represented by 'η' is called response surface.

Second order polynomial model (quadratic model) is represented as

$$y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ii} x_i^2 + \sum_{i<j}^{n} a_{ij} x_i x_j \quad (3)$$

Where x_i are the process variables and a's are the regression coefficient to be obtained by linear multiple regression analysis.

IV. Design Of Experiments

Exp. No.	D_c (mm)	N (rpm)	f (mm/rev)	$R_a(N_2)$	R_a (dry)
1	0.3	1500	0.02	2.3356	2.6743
2	0.3	1500	0.04	2.6842	3.4634
3	0.3	1500	0.06	3.7682	4.6716
4	0.3	2000	0.02	1.8178	2.7990
5	0.3	2000	0.04	2.4753	2.5803
6	0.3	2000	0.06	2.0623	2.2949
7	0.3	2500	0.02	0.8725	1.4114
8	0.3	2500	0.04	0.8829	1.4341
9	0.3	2500	0.06	1.2793	1.7060
10	0.6	1500	0.02	3.0725	3.5806
11	0.6	1500	0.04	3.1518	3.6284
12	0.6	1500	0.06	2.6689	3.3374
13	0.6	2000	0.02	2.3563	2.9133
14	0.6	2000	0.04	1.4886	2.0558
15	0.6	2000	0.06	1.1289	1.1916
16	0.6	2500	0.02	1.0231	1.7394
17	0.6	2500	0.04	0.8926	1.4385
18	0.6	2500	0.06	0.4525	1.0714
19	0.9	1500	0.02	3.9228	4.1065
20	0.9	1500	0.04	2.6476	2.9776
21	0.9	1500	0.06	1.4222	2.5436
22	0.9	2000	0.02	1.8755	2.5856
23	0.9	2000	0.04	0.7390	1.0476
24	0.9	2000	0.06	0.6798	0.7892
25	0.9	2500	0.02	0.8993	1.1491
26	0.9	2500	0.04	0.4758	0.9848
27	0.9	2500	0.06	0.4009	0.6359

The experiment was planned the factorial portion is a full factorial design (3^N) with all combinations of the factors at three levels. The selected machining parameters and their factor levels are given in the table I.

Table I Machining parameters and selected levels.

Factor notation	**Machining parameters**	**Factor levels**		
		Level 1	**Level 2**	**Level 3**
N	Speed	1500	2000	2500
F	Feed	0.02	0.04	0.06
d_c	Depth of cut	0.30	0.60	0.90

V. RESULTS AND DISCUSSION

A. Experimental conditions and S/N ratio

The experiments were conducted based on (3^3) full factorial Design. The observed values of surface roughness on N_2 and Dry cutting Environment are shown in the table II.

Table II 3^3 Full factorial Design Matrix with Observed Ra values on N_2 and Dry cutting

B. Response of Process parameters

Response Table for Signal to Noise ratios of Ra N_2 versus doc, speed, feedare shown in table III. Consider Smaller as better.

Table III Response Table for Signal to Noise Ratios of Ra(N_2)

Level	**Dc**	**N**	**F**
1	-5.7590	-6.7864	-4.3187
2	-3.7075	-4.7584	-3.7540
3	-0.6415	1.4367	-2.0354
Delta	5.1175	8.2230	2.2833
Rank	2	1	3

Response Table for Signal to Noise ratios of Ra Dry versus doc, speed, feedare shown in table IV. Consider Smaller as better.

Table IV Response Table for Signal to Noise Ratios of Ra (Dry)

Level	**Dc**	**N**	**F**
1	-7.124	-9.267	-7.175
2	-5.815	-5.992	-5.131
3	-4.105	-1.786	-4.739
Delta	3.019	7.481	2.436
Rank	2	1	3

C. Response curve

Response curves are graphical representations of change in performance characteristics with the variation in machining parameter level. Fig 1,2 shows the response graph for three factors and three levels. From the graphical representation the peak points are chosen as the optimum levels of machining parameters, such as level three of depth of cut, level three of spindle speed, level three of feed rate.

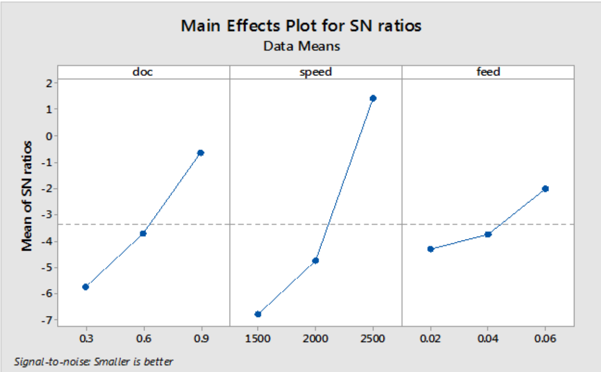

Fig. 1. Effects plot of S/N ratios of Ra (N_2) vs. N,f,D_c

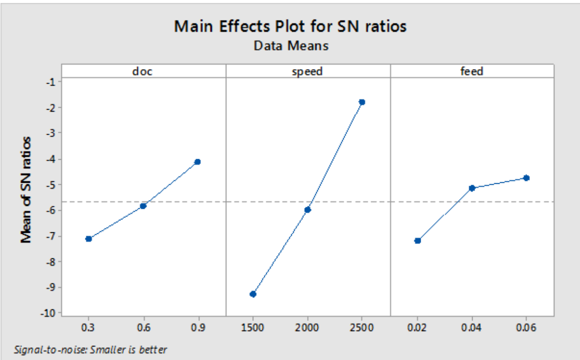

Fig.2. Effects plot of S/N ratios of Ra (Dry) vs. N,f,D_c

Optimum machining parameters

From the responses the optimum set of machining parameters were found as given in the table V .

Table V Optimum machining parameters

For Cutting Environment	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
N_2	2500	0.06	0.9
Dry	2500	0.06	0.9

D. Empirical Relationship between Independent and Dependent Variables

In the response, the mathematical models were developed based on response surface methodology. This is one of the statistical techniques to make an empirical relationship between dependent and independent variables. This work has developed the mathematical models for surface roughness. The independent variables considered to generate the models are spindle speed, feed rate and depth of cut

Regression Equation in Uncoded units

Ra N2 = 4.823 + 2.541 Depth of cut - 0.002055 Speed + 40.3 Feed - 87.2 Depth of cut*Feed

Ra dry = 11.04 + 1.994 Depth of cut - 0.00753 Speed + 34.1 Feed + 0.000001 Speed*Speed - 78.6 Depth of cut*Feed

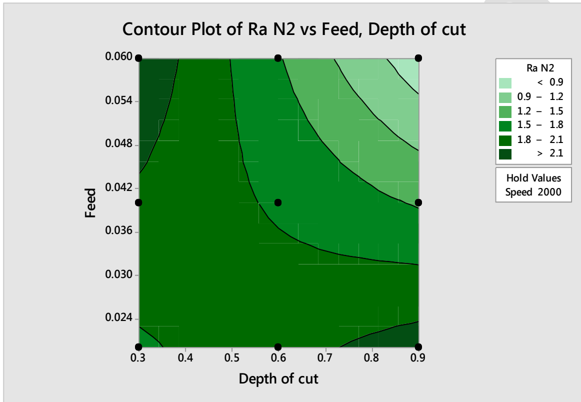

Fig.3. Contour Plot of Ra N2 vs Feed, Depth of cut

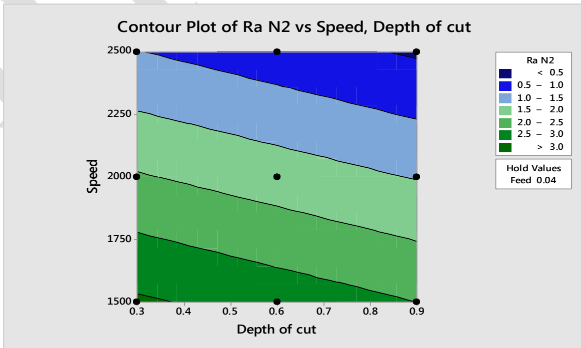

Fig.4. Contour Plot of Ra N2 vs Speed, Depth of cut

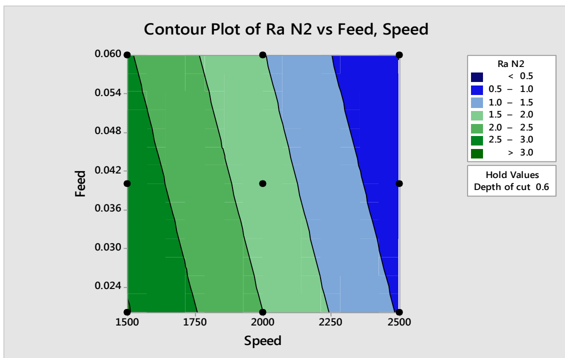

Fig.5. Contour Plot of Ra N2vs Feed, Speed

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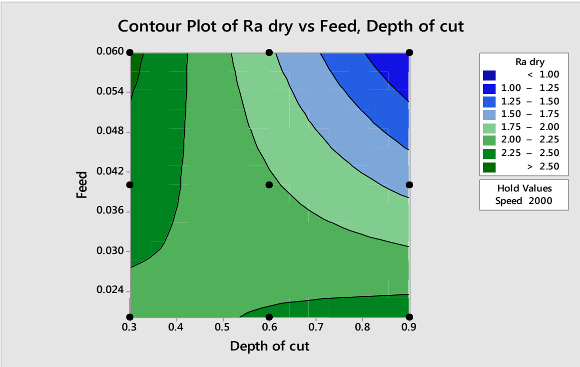

Fig.6. Contour Plot of Ra dry vs Feed, Depth of Cut

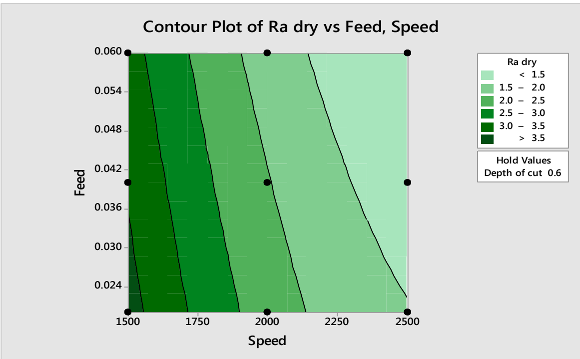

Fig.7. Contour Plot of Ra dry vs Feed, Speed

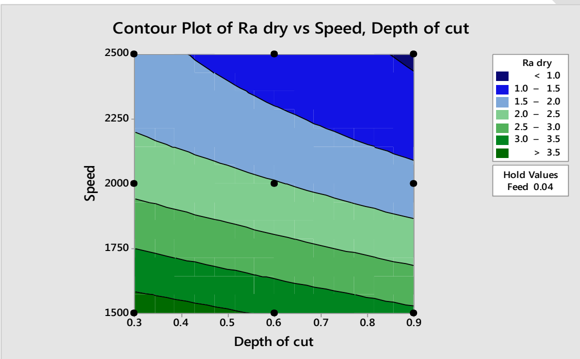

Fig.8. Contour Plot of Ra dry vs Speed, Depth of Cut

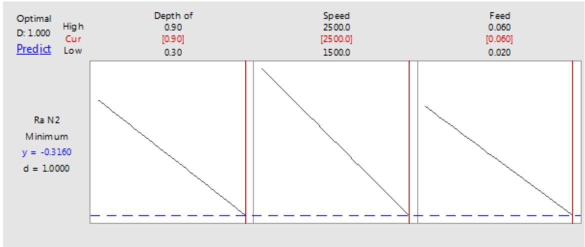

Fig.9. Optimization Plot of Ra(N_2)

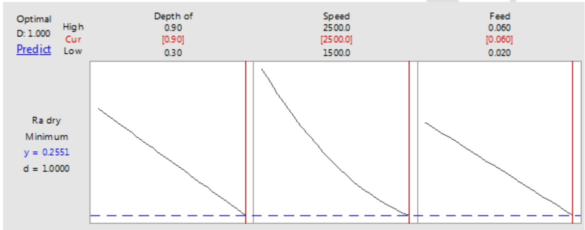

Fig.10.Optimization Plot of Ra(Dry)

From the above optimization plot graphs the optimized values are obtained as N=2500rpm, f=0.06mm/rev, D_c=0.90mm for Nitrogen gas and Dry cutting Environment.

VI. CONCLUSION

The influence of depth of cut, spindle speed and feed rate on machined surface roughness in CNC Turning operation have been studied. The experiment has been performed on En8 material and obtained data has been analyzed using Taguchi technique and Response surface methodology. The analysis of the experiment and the design of control parameter with three level & three parameters to find the optimal control parameter to minimize the surface roughness. The parameter is Speed(N) and the order of significance parameters is $N_3>R_{c3}>f_3$ based on rank obtained from Taguchi method. The optimized values are obtained as N=2500rpm,f=0.06mm/rev,d_c=0.90mm and from these optimized parameters the surface roughness is evaluated as0.4009µm for N_2 cooling and0.9848µm for Dry cutting environment.

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