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Multi Objective Optimization during Turning of EN24 Alloy Steel

M. Adinarayana[1], G. Prasanthi[2], G. Krishnaiah[3]
[1](Assistant Professor, Department of mechanical Engineering, Sir Vishvesvaraiah Institute of Science & Technology Angallu , Madanapalli)
[2](Professor, Department of Mechanical Engineering,JNTUA College of Engineering, JNTUA, Anantapuram)
[3](Professor, Department of Mechanical Engineering, SVU College of Engineering, S.V.University, Tirupati)

ABSTRACT
The paper envisages the study to optimize the effects of process variables on surface roughness, MRR and power consumption of En24 of work material using PVD coated tool. In the present investigation the influence of spindle speed, feed rate, and depth of cut were studied as process parameters. The experiments have been conducted using full factorial design in the design of experiments (DOE) on a conventional lathe. A Model has been developed using regression technique. The optimal cutting parameters for minimum surface roughness, maximum MRR and minimum power consumption were obtained using Taguchi technique. The contribution of various process parameters on response variables have been found by using ANOVA technique.
Keywords - En 24 alloy steel, PVD tool, DOE, Taguchi technique, ANOVA.

I. INTRODUCTION

Increased in Productivity and machined part quality characteristics are the main hinderness of metal based industry [1]. Surface finish is the prime requirement of the customer satisfaction and also productivity which fulfills the customer demand. For this purpose, quality of the product should be well with in customer satisfaction and also productivity should be high. In addition to the quality of the product, the material removal rate (MRR) is also an important characteristics in machining operation and high MRR is always desirable [2]. To ensure the cost of the final finished product, power consumption should be as low as possible. Hence the objective of the present work is to optimize spindle speed, feed and depth of cut so as to minimize surface roughness, and maximize MRR and minimize power consumption.

En 24 is a medium carbon low alloy steel and finds its typical applications in the manufacture of automobile and machine tool parts, low specific heat, tendency to strain harden, and diffuse between tool and work material En24 alloy steel gives rise to problems like large cutting forces. High cutting tool temperatures , poor surface finish and built up edge formation[3]. In today’s manufacturing industry, special attention is given to surface finish and power consumption. Traditionally the desired cutting parameters are determined based on hands on experience [4]. Of the many goals focused in manufacturing industry, power consumption plays vital and dual role. One its cuts down the cost per product and secondly the environmental impact by reducing the amount of carbon emissions that are created in using by electrical energy.

II. MATERIALS AND METHODS

2.1Specification of work material:

The work material used for the present study is En 24 alloy steel. The chemical composition of the work material is shown in Table 1.

2.2 Taguchi Method

Taguchi method is an effective tool in designing of high quality system. It provides simple efficient and systematic qualitative optimal design to aid high performance, quality at a relatively low cost. Conventional methods for experimental design are of complex in nature and difficult to use. In addition to that these methods require a large number of experiments when the process parameters increase. In order to minimize number of experiments, a powerful tool has been designed for high quality system by Taguchi. For determination of the best design it requires the use of statistically designed experiment [5].Taguchi approach in design of experiments is easy to adapt and apply for uses with limited knowledge of statistics and hence gained wide popularity in the engineering and scientific community [6-7].The cutting parameters ranges were selected based on machining guidelines provided by manufacturer of cutting tool manufacturers Kayocera. The control factors and levels are shown in Table 2.

2.3Analysis of variance (ANOVA)

ANOVA is used to determine the influence of any given process parameters from a series of experimental results by design of experiments and it can be used to interpret experimental data. Since there will be large number of process variables which control the process, some mathematical model are require to represent the process. However these models are to be develop using only the significant parameters which influences the process, rather than including all the parameters. In order to achieves this, statistical analysis the experimental results will be processed using analysis of variance (ANOVA) [8].

III. EXPERIMENTATION AND MATHEMATICAL MODELLING

The experiment is conducted for Dry turning operation of using EN24 Alloy steel as work material and PVD as tool material on a conventional lathe PSG A141. The tests were carried for a 500 mm length work material. The process parameters used as spindle speed (rpm), feed (mm/rev), depth of cut (mm). The response variables are Surface roughness, material removal rate and power consumption, The experimental results were recorded in Table 3. Surface roughness of machined surface has been measured by a stylus (surftest SJ201-P) instrument and power consumption is measured by using Watt meter. Material removal rate is calculated by following formula.

MRR = (Initial weight - final weight) / Density x Time

Where Density of EN 24 material = 7.85 gm/cc

Surface roughness need to the minimum for good quality product

(Lower is the better)

The surface roughness, Ra

Min R_a (s, f, d)

Minimizing

$$Ra = 3.158 S^{0.135} f^{0.110} d^{0.105} \quad \ldots \ (3.1)$$

MRR need to be maximum for increasing the production rate

(Higher is the better)

The material removal rate, MRR

Max MRR (s, f, d)

Maximizing

$$MRR = 0.003 S^{1.23} f^{0.675} d^{0.181} \quad \ldots \ (3.2)$$

Power consumption need to be minimum for reducing the cost of finished product,

(Lower is the better)

The Power consumption, PC

Min PC (s, f, d)

Minimizing

$$PC = 0.053 S^{1.01} f^{0.472} d^{0.156} \quad \ldots \ (3.3)$$

Ranking of various process parameters for the desired conditions of surface roughness, material removal rate and power consumption shown in Tables 4,5 and 6. And the percentage contributions of various process parameters on response variables such as surface roughness, material removal rate and power consumption were shown in Tables 7,8and 9.

IV. TABLES AND FIGURES

Table 1: Chemical composition of EN 24 alloy steel

Element	C	Si	Mn	S	P	Cr	Ni	Mo
Composition	0.38-0.43	0.15-0.30	0.60-0.80	0.040	0.035	0.70-0.90	1.65-2.00	0.20-0.30

Table 2: Process parameters and their levels

Level	Speed (s) (rpm)	Feed rate(f) (mm/rev)	Depth of cut(d) (mm)
1	740	0.09	0.15
2	580	0.07	0.10
3	450	0.05	0.05

Table 3: Experimental data and results for 3 parameters, corresponding Ra, MRR and PC for PVD tool

S.No	Speed, s (rpm)	Feed, f (mm/rev)	Depth of cut, (mm)	Surface Roughness Ra (µm)	Material removal rate (mm^3/min)	Power Consumed (kw)
1	740	0.09	0.15	3.0598	0.514286	12.26053
2	740	0.09	0.1	3.9465	0.636364	12.035
3	740	0.09	0.05	6.1885	0.553846	8.37689
4	740	0.07	0.15	3.0729	0.292683	10.91348
5	740	0.07	0.1	3.4368	0.27907	9.56774
6	740	0.07	0.05	6.5319	0.404494	6.53712
7	740	0.05	0.15	6.1136	0.542169	9.164832
8	740	0.05	0.1	3.4316	0.350877	7.66528

9	740	0.05	0.05	5.1471	0.705882	4.89326
10	580	0.09	0.15	6.3332	0.292683	6.457821
11	580	0.09	0.1	5.1596	0.677419	5.01187
12	580	0.09	0.05	3.8766	1.037037	7.286254
13	580	0.07	0.15	7.8758	0.336	7.848
14	580	0.07	0.1	3.4517	0.677419	6.72485
15	580	0.07	0.05	3.9452	0.194805	8.766383
16	580	0.05	0.15	5.8248	0.393443	5.80663
17	580	0.05	0.1	2.6401	0.32345	4.361176
18	580	0.05	0.05	4.0198	0.224439	5.445271
19	450	0.09	0.15	4.2968	0.314136	7.659078
20	450	0.09	0.1	5.863	0.48913	4.970542
21	450	0.09	0.05	3.7452	0.157068	6.541089
22	450	0.07	0.15	3.5772	0.339623	3.792101
23	450	0.07	0.1	3.5979	0.327869	4.56132
24	450	0.07	0.05	3.6215	0.218182	5.541289
25	450	0.05	0.15	6.504	0.26087	6.42373
26	450	0.05	0.1	4.1852	0.257143	5.37698
27	450	0.05	0.05	2.5687	0.083916	3.709838

Table 4: Response Table for Signal to Noise Ratios for PVD tool [Ra]

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	-12.20	-12.60	-12.55
2	-13.16	-12.31	-11.75
3	-12.77	-13.22	-13.83
Delta(max-min)	0.97	0.92	2.08
Rank	2	3	1

Table 5: Response Table for Signal to Noise Ratio for PVD tool [MRR]

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	-12.181	-10.368	-10.413
2	-7.965	-9.886	-7.597
3	-6.877	-6.769	-9.014
Delta(max-min)	5.304	3.599	2.816
Rank	1	2	3

Table 6: Response Table for Signal to Noise Ratio for PVD tool [PC]

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	-14.41	-15.07	-15.77
2	-15.95	-16.62	-16.00
3	-18.81	-17.47	-17.40
Delta(max-min)	4.39	2.39	1.62
Rank	1	2	3

Table 7: ANOVA for the response surface roughness (Ra) on PVD tool

SOURCE	DOF	SUM OF SQUARES	MEAN OF SQUARES	F RATIO	% OF CONTRIBUTION
Speed(S)	2	1.494399	0.7471995	0.201548	6.72979001
Feed(F)	2	0.635909	0.3179545	0.085764	2.86371581
DOC(D)	2	6.831865	3.4159325	0.921404	30.7662257
SXF	4	3.202954	0.8007385	0.215989	14.4239978
SXD	4	1.847163	0.4617908	0.124562	8.31840701

FXD	4	8.193438	2.0483595	0.552519	36.8978547
ERROR	8	29.65849	3.7073112		
TOTAL	26	22.20573			100

Table 8: ANOVA for the response Material removal rate (MRR) on PVD tool

SOURCE	DOF	SUM OF SQUARES	MEAN OF SQUARES	F RATIO	% OF CONTRIBUTION
Speed(S)	2	0.232972	0.116486	1.693354	39.1905918
Feed(F)	2	0.181899	0.0909495	1.322131	30.5990825
DOC(D)	2	0.030228	0.015114	0.219712	5.0849596
SXF	4	0.003399	0.0008498	0.012353	0.57178039
SXD	4	0.137133	0.0342833	0.498375	23.0685379
FXD	4	0.008828	0.002207	0.032083	1.48504775
ERROR	8	0.550321	0.0687901		
TOTAL	26	0.594459			100

Table 9: ANOVA for the response Power Consumed on PVD tool

SOURCE	DOF	SUM OF SQUARES	MEAN OF SQUARES	F RATIO	% OF CONTRIBUTION
Speed(S)	2	63.8412	31.9206	7.194574	9.901974
Feed(F)	2	17.98143	8.990715	2.026415	16.80153
DOC(D)	2	10.59735	5.298675	1.194267	59.65207
SXF	4	0.507796	0.126949	0.028613	0.474475
SXD	4	13.57496	3.39374	0.764914	12.6842
FXD	4	0.51991	0.129978	0.029296	0.485795
ERROR	8	35.49408	4.43676		
TOTAL	26	107.0226			100

Main Effect plot Analysis**:**

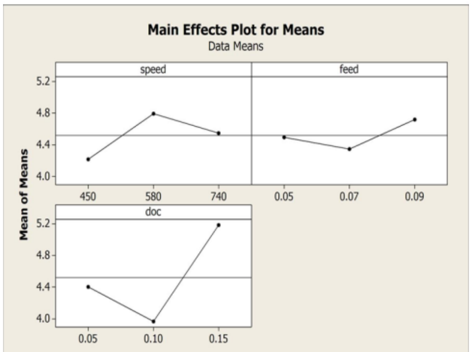

Figure 1: Plots of main effects for means for Surface roughness (Ra) on PVD tool

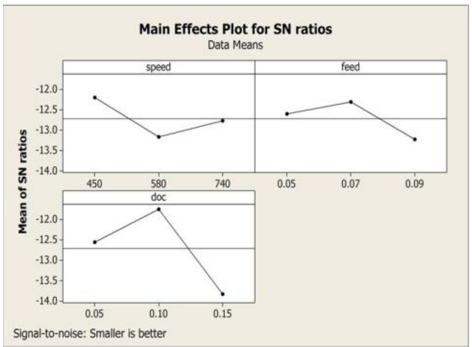

Figure 2: S/N ratio for Surface roughness (Ra) on PVD tool

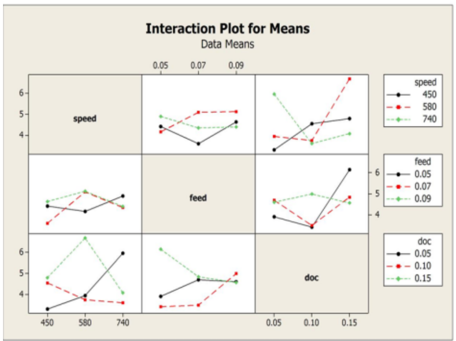

Figure 3: Interaction data means for Surface roughness (Ra) on PVD tool

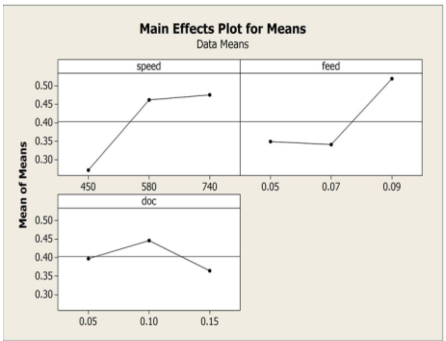

Figure 4: Plots of main effects for means for Material removal rate on PVD tool

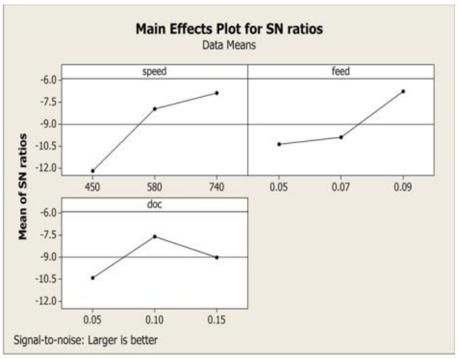

Figure 5: S/N ratio for Material removal rate on PVD tool

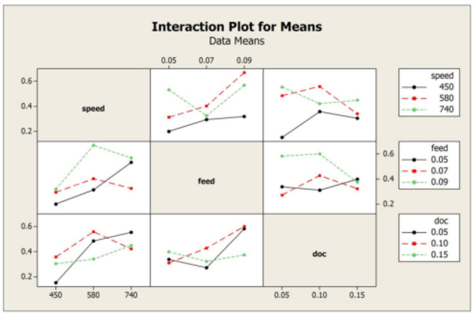

Figure 6: Interaction data means for Material removal rate on PVD tool

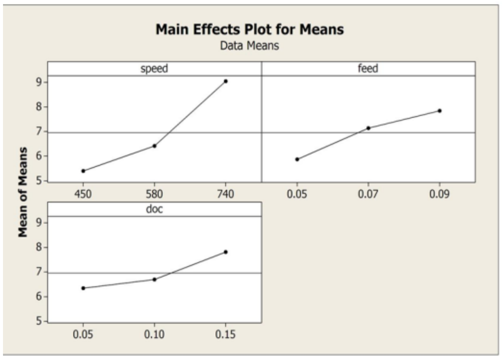

Figure 7: Plots of main effects for means for Power Consumed on PVD tool

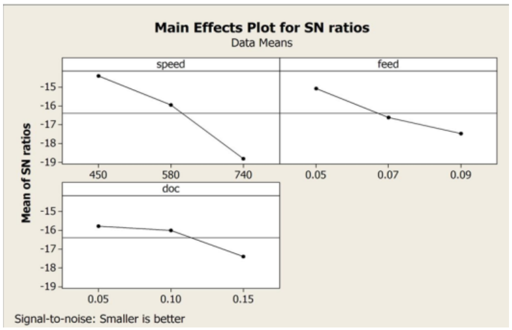

Figure 8: S/N ratio for Power Consumed on PVD tool

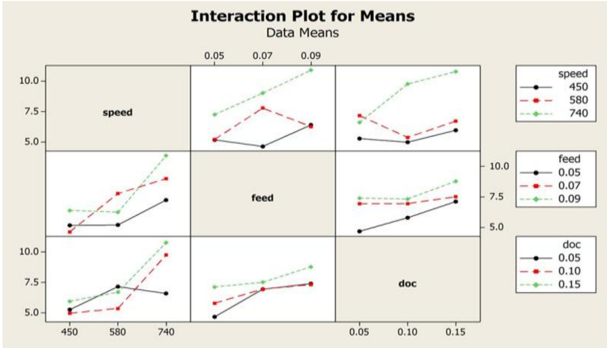

Figure 9: Interaction data means for Power Consumed on PVD tool

V. ANALYSIS OF RESULTS

In the Taguchi method the results of the experiments are analyzed to achieve one or more of the following three objectives:

a) To establish the best or the optimum condition for a product or a process.

b) To estimate the contribution of individual factors.

c) To estimate the response under the optimum conditions.

Studying the main effects of each of the factors identifies the optimum condition (Figures 1 to 9). The process involves minor arithmetic manipulation of the numerical result and usually can be done with the help

of a simple calculator. The main effects indicate the general trend of the influence of the factors. Knowing the characteristic i.e. whether a higher or lower value produces the preferred result, the levels of the factors, which are expected to produce the best results, can be predicted.

The knowledge of the contribution of individual factors is the key to deciding the nature of the control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiment to determine the percent contribution of each factor. Study of the ANOVA table for a given analysis helps to determine which of the factors need control and which do not. In this study, an L27 orthogonal array with was used.

VI. CONCLUSION

The results obtained in this study lead to conclusions for turning of EN 24 after conducting the experiments and analyzing the resulting data.

1) From the results obtained by experiment, the influence of surface roughness (Ra), Material Removal Rate (MRR) and Power Consumption (PC) by the cutting parameters like speed, feed, DOC is
   a) The feed rate has the variable effect on surface roughness, cutting speed and depth of cut an approximate decreasing trend.
   b) Cutting speed, feed rate and depth of cut for Material Removal Rate have increasing trend.
   c) Power Consumption is increase with increase

in cutting speed, feed rate and depth of cut.

2) For the design of Experiments, Taguchi method is applied for finding optimal cutting parameters of cutting parameters
   a) For minimum surface roughness, the optimality conditions are: Speed: 580 rpm, Feed: 0.09 mm/rev, and Depth of cut: 0.15 mm
   b) For maximum material removal rate, the optimality conditions are: Speed: 740rpm, Feed: 0.09 mm/rev, and Depth of cut: 0.10 mm
   c) For minimum power consumption, the optimality conditions are: Speed: 740 rpm, Feed: 0.09 mm/rev, and Depth of cut: 0.15 mm
3) Analysis of Variance (ANOVA) is done and found that it shows :
   a) The depth of cut has great influence for the response surface roughness (30.76%), Speed has great influence for the response Material removal rate (39.19%) , Depth of cut has great influence for the response Power consumption (59.65%).
   b). The interaction of cutting parameters is also studied for the three responses Ra, MRR and PC as follows :
   (i) For minimum surface roughness, the percentage contributions of various interacting parameters are: speed x feed : 14.42%; speed x depth of cut : 8.31% ; feed x depth of cut : 36.89%
   (ii) For maximum material removal rate, the percentage contributions of various interacting parameters are: speed x feed : 0.57%; speed x depth of cut : 23.06% ; feed x depth of cut : 1.48%
   (iii) For minimum power consumption, the percentage contributions of various interacting parameters are: speed x feed : 0.47%; speed x depth of cut : 12.68% ; feed x depth of cut : 0.48%.
4) Using the experimental data, a multi linear regression model is developed for the responses Ra, MRR and PC.

This research highlighted the use of Taguchi design of experiments and analysis of variance(ANOVA). In the present study, the process parameters such as spindle speed, feed and depth of cut is considered. Further the study may be extended for more parameters such as nose radius, rake angle, introduction of cutting fluids etc.

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