PARAMETRIC ANALYSIS AND MULTI OBJECTIVE OPTIMIZATION OF CUTTING PARAMETERS IN TURNING OPERATION OF AISI 4340 ALLOY STEEL WITH CVD CUTTING TOOL

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Abstract

Modern manufacturers, seeking to remain competitive in the market, rely on their Manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes for new products. This paper presents the multi response optimization of turning parameters for Turning on AISI 4340 Alloy Steel. Experiments are designed and conducted based on Taguchi's L_{27} Orthogonal array design. This paper discusses an investigation into the use of Taguchi parameter Design and Regression analysis to predict and optimize the Surface Roughness, Metal Removal Rate and Power Consumption in turning operations using CVD Cutting Tool. The Analysis of Variance (ANOVA) is employed to analyze the influence of Process Parameters during Turning. This paper also remarks the advantages of multi-objective optimization approach over the single-objective one. The useful results have been obtained by this research for other similar type of studies and can be helpful for further research works on the Tool life and Vibration of tools etc.

Keywords: *Turning, Ra, MRR, PC, Taguchi, Anova etc…*

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1. INTRODUCTION

The production of super alloys, high hard and smart materials have become extremely essential to satisfy the design requirements for critical equipments, aerospace and defense industries. The machining of such materials has always been a great challenge before the production engineer [1].

EN24 is a medium-carbon low-alloy steel and finds its typical applications in the manufacturing of automobile and machine tool parts. Properties of EN24 steel, like low specific heat, and tendency to strain-harden and diffuse between tool and work material, give rise to certain problems in its machining such as large cutting forces, high cutting-tool temperatures, poor surface finish and built-up-edge formation. This material is thus difficult to machine [2]. The proper selection of cutting tool material has also different advantages such as reducing the manufacturing cost and lead time, machining more difficult materials, moving to unmanned machining operations, improving surface integrity and achieving high metal removal rates. Coating provides Improved lubrication at the chip-tool and work-tool interface to reduce friction and consequently to reduce the temperatures at the cutting edge. Coated carbides tools ensure higher wear resistance, lower heat generation and lower cutting forces, thus enabling higher cutting speeds than uncoated carbides [3].

The huge amount of money spent on any one class of cutting tool is spent on turning. Therefore, from view point of cost and productivity, modeling and optimization of turning process are extremely important for the manufacturing industry [4]. The difficulties in optimization operations made the determination of cutting parameters an important and complex case [5]. To maintain the desired quality of machining products, to reduce the machining cost and to improve the machining effectiveness, it is vey important to select the optimal machining parameters when the Machine tools are selected. Thereafter, an Optimization Technique is used to search the optimal control parameter setting for the desired response [6]. Optimization of Machining parameters increases the utility for machining economics and also increases the product quality to greater extent [7].

The objective of this experimental investigation is to ascertain the effects of cutting speed, feed rate, and depth of cut on Surface Roughness, Material Removal Rate and Power Consumption in Turning of AISI 4340 medium Alloy steel. The survey showed that there are many papers in the field of turning parameters optimization, but there is a lack in studies of the Response Power Consumption Optimization in Turning operation which is very important aspect in machining operation. Power Consumption plays vital role. One its cuts down the Cost per product, secondly the environmental impact by reducing the amount of carbon emissions that are created in using by electrical energy and finally the minimization of Power Consumption. Design of experiment techniques, i.e. Taguchi‘s technique have been used to accomplish the objective. L27 orthogonal array used for conducting the experiments. And ANOVA technique is employed to analyze the percentage contribution and influence of Process Parameters.

2. MATERIALS AND METHODS:

2.1Specification of Work Material:

The work material used for the present study is AISI 4340 alloy steel. The chemical composition of the work material is shown in Table 1.

Table 1: Specification of work material

Element	C	Si	Mn	S	P	Cr	Ni	Mo
Composition%	0.38	0.15	0.60	0.040	0.035	0.70	1.65	0.20

2.2 Process Parameters

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

2.3 Taguchi Method

The Taguchi experimental design method is a well-known, unique and powerful technique for product or process quality improvement. It is widely used for analysis of experiment and product or process optimization. Taguchi has developed a methodology for the application of factorial design experiments that has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing [13]. Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases. In order to minimize the number of experiments required, Taguchi experimental design method, a powerful tool for designing high-quality system. This method uses a special design of orthogonal arrays to study the entire parameter space with minimum number of experiments [2]. Taguchi strategy is the conceptual framework or structure for planning a product or process design experiment.

2.4 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a statistical method for determining the existence of differences among several population means. While the aim of ANOVA is the detect differences among several populations means, the technique requires the analysis of different forms of variance associated with the random samples under study- hence the name analysis of variance. The original ideas analysis of variance was developed by the English Statistician Sir Ronald A. Fisher during the first part of this century. Much of the early work in this area dealt with agricultural experiments where crops were given different treatments, such as being grown using different kinds of fertilizers. The researchers wanted to determine whether all treatments under study were equally effective or whether some treatments were better than others.

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.

3. EXPERIMENTATION AND MATHEMATICAL MODELING:

The experiment is conducted for Dry turning operation of using AISI 4340 Alloy steel as work material and CVD 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 (surf test 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 $$Ra = 0.237 S^{0.389} f^{-0.392} d^{0.305} \quad \ldots(3.1)$$

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
$$MRR = 0.004\, S^{0.988} f^{0.004} d^{0.672} \quad (3.2)$$

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 $$PC = 0.052\, S^{0.995} f^{0.469} d^{0.0970} \quad (3.3)$$

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, 8 and 9.

Table 3: Experimental data and results for 3 parameters, corresponding Ra, MRR and PC for CVD 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	2.8422	0.75	9.3416
2	740	0.09	0.1	4.7161	0.394737	11.75489
3	740	0.09	0.05	2.8118	0.266667	10.3628
4	740	0.07	0.15	4.1796	0.4	10.5261
5	740	0.07	0.1	4.8156	0.674157	8.74391
6	740	0.07	0.05	4.6386	0.514286	7.73641
7	740	0.05	0.15	5.2697	0.580645	9.164832
8	740	0.05	0.1	4.1441	0.45283	7.66528
9	740	0.05	0.05	3.9445	0.514286	5.3281
10	580	0.09	0.15	2.73	0.761905	7.286254
11	580	0.09	0.1	5.8497	0.461538	5.01187
12	580	0.09	0.05	2.8809	0.48	6.17281
13	580	0.07	0.15	4.8045	0.643432	7.848
14	580	0.07	0.1	4.2464	0.571429	6.72485
15	580	0.07	0.05	3.733	0.45	8.766383
16	580	0.05	0.15	6.985	0.638298	5.445271
17	580	0.05	0.1	4.3915	0.633803	4.361176

18	580	0.05	0.05	3.9445	0.327273	5.12973
19	450	0.09	0.15	3.4964	0.461538	7.659078
20	450	0.09	0.1	3.7343	0.164384	4.970542
21	450	0.09	0.05	1.972	0.338028	7.3297
22	450	0.07	0.15	5.4475	0.474308	3.792101
23	450	0.07	0.1	3.9944	0.645161	4.56132
24	450	0.07	0.05	2.518	0.116732	5.37698
25	450	0.05	0.15	5.1373	1.929825	6.42373
26	450	0.05	0.1	2.6061	0.098361	5.61887
27	450	0.05	0.05	2.8618	0.106572	3.709838

Table 4: Response Table for Signal to Noise Ratios for Ra

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	-10.517	-12.447	-9.981
2	-12.505	-12.424	-12.447
3	-12.181	-10.333	-12.776
Delta(max-min)	1.988	2.115	2.795
Rank	3	2	1

Table 5: Response Table for means for Ra

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	3.530	4.365	3.256
2	4.396	4.264	4.278
3	4.151	3.448	4.544
Delta(max-min)	0.866	0.917	1.287
Rank	3	2	1

Table 5: Response Table for Signal to Noise Ratio for MRR

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	-10.516	-7.647	-10.397
2	-5.405	-6.859	-8.172
3	-6.288	-7.703	-3.639
Delta(max-min)	5.111	0.844	6.757
Rank	2	3	1

Table 6: Response Table for means for MRR

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	0.4817	0.5869	0.3460
2	0.5520	0.4988	0.4552

3	0.5053	0.4532	0.7378
Delta(max-min)	0.0703	0.1337	0.3918
Rank	3	2	1

Table 7: Response Table for Signal to Noise Ratio for PC

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	-14.54	-15.08	-16.09
2	-15.79	-16.64	-15.93
3	-18.85	-17.46	-17.15
Delta(max-min)	4.31	2.38	1.22
Rank	1	2	3

Table 8: Response Table for means for PC

Level	**Speed(S)**	**Feed(f)**	**Depth of Cut(d)**
1	5.494	5.872	6.657
2	6.305	7.120	6.601
3	8.958	7.766	7.499
Delta(max-min)	3.465	1.894	0.897
Rank	**1**	**2**	**3**

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

SOURCE	**DOF**	**SUM OF SQUARES**	**MEAN OF SQUARES**	**F RATIO**	**% OF CONTRIBUTION**
Speed(S)	2	3.590962	1.7954809	1.557132	13.7285501
Feed(F)	2	4.549644	2.2748221	1.972841	17.393674
DOC(D)	2	8.315008	4.1575039	3.605597	31.7889771
SXF	4	0.342662	0.0856655	0.074293	1.31002538
SXD	4	2.63119	0.6577975	0.570475	10.0592617
FXD	4	6.727423	1.6818557	1.45859	25.7195053
ERROR	8	9.224555	1.1530694		
TOTAL	26	26.15689			100

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

SOURCE	**DOF**	**SUM OF SQUARES**	**MEAN OF SQUARES**	**F RATIO**	**% OF CONTRIBUTION**
Speed(S)	2	0.023041	0.0115203	0.054739	1.73986563
Feed(F)	2	0.083111	0.0415555	0.197452	6.2759712
DOC(D)	2	0.735871	0.3679354	1.748256	55.5679469
SXF	4	0.109602	0.0274004	0.130194	8.2763776
SXD	4	0.24736	0.0618401	0.293835	18.678971

FXD	4	0.125288	0.0313219	0.148827	9.46087847
ERROR	8	1.683668	0.2104585		
TOTAL	26	1.324272			100

Table 9: ANOVA for the response Power Consumption (PC)

SOURCE	DOF	SUM OF SQUARES	MEAN OF SQUARES	F RATIO	% OF CONTRIBUTION
Speed(S)	2	59.10341	29.55171	7.220334	66.75899
Feed(F)	2	16.6795	8.339748	2.037641	18.83997
DOC(D)	2	4.548608	2.274304	0.555678	5.137782
SXF	4	1.759423	0.439856	0.107469	1.987318
SXD	4	3.999739	0.999935	0.244313	4.517819
FXD	4	2.44184	0.61046	0.149153	2.758128
ERROR	8	32.74276	4.092845		
TOTAL	26	88.53252			100

Main Effect Plot Analysis:

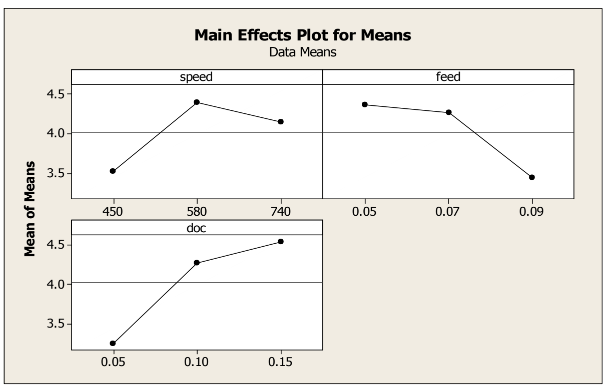

Fig 1: Plots of main effects for means for Surface roughness (Ra)

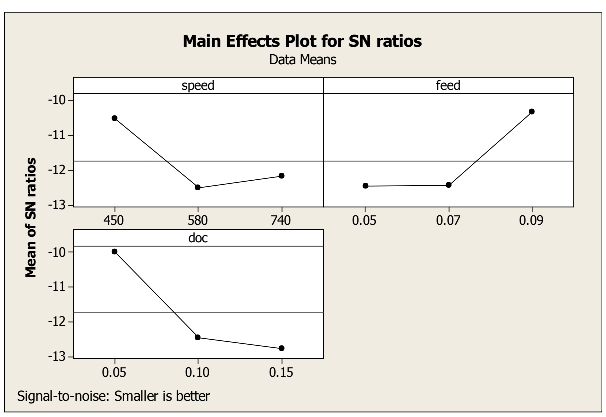

Fig 2: Plot of S/N ratio for Surface roughness (Ra)

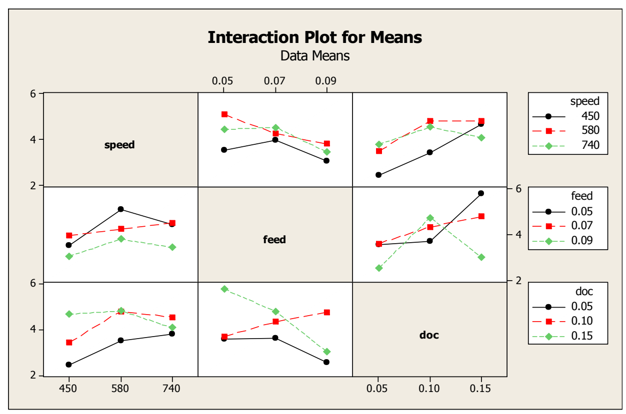

Fig 3: Plot of Interaction data means for Surface roughness (Ra)

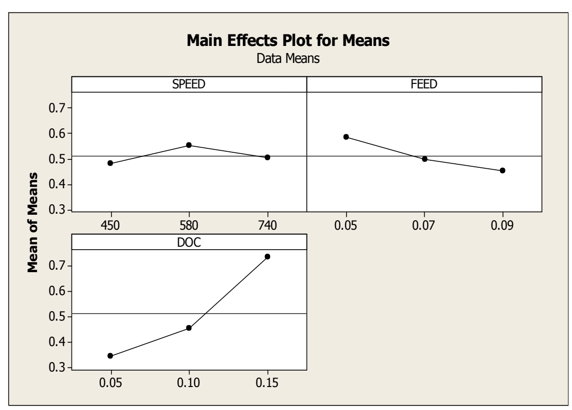

Fig 4: Plots of main effects for means for Material removal rate

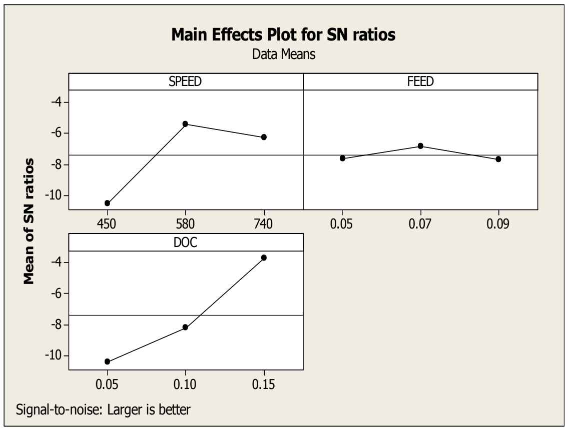

Fig 5: S/N ratio for Material removal rate (MRR)

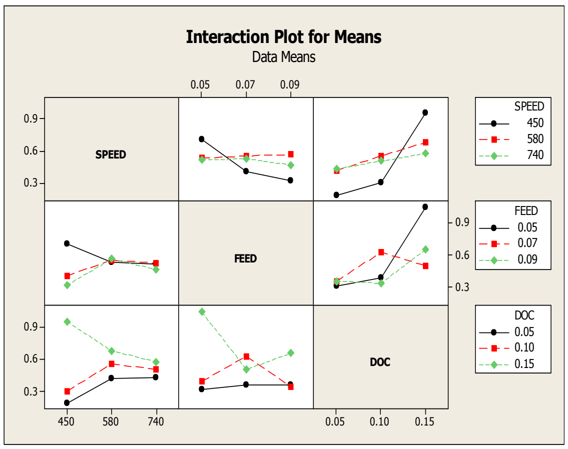

Fig 6: Interaction data means for Material removal rate (MRR)

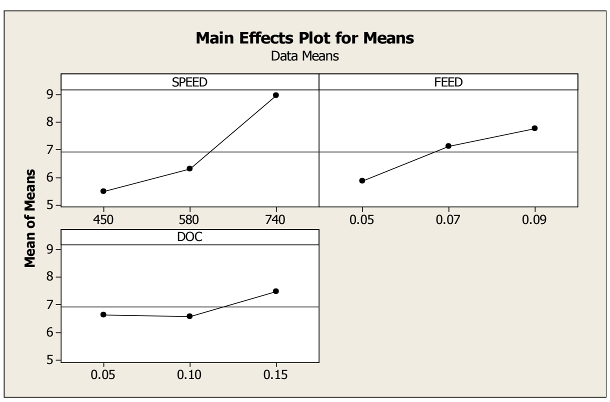

Fig 7: Plots of main effects for means for Power Consumption (PC)

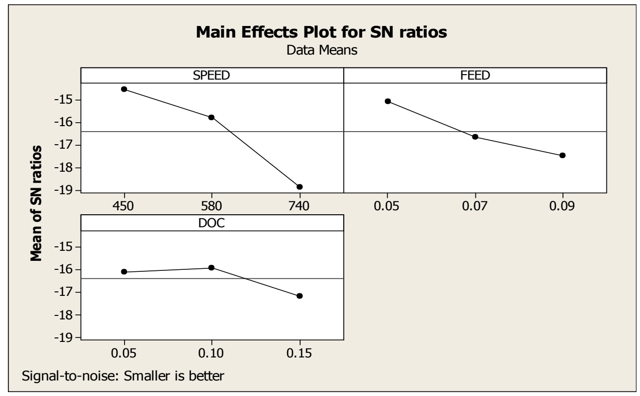

Fig 8: Plot of S/N ratio for Power Consumption

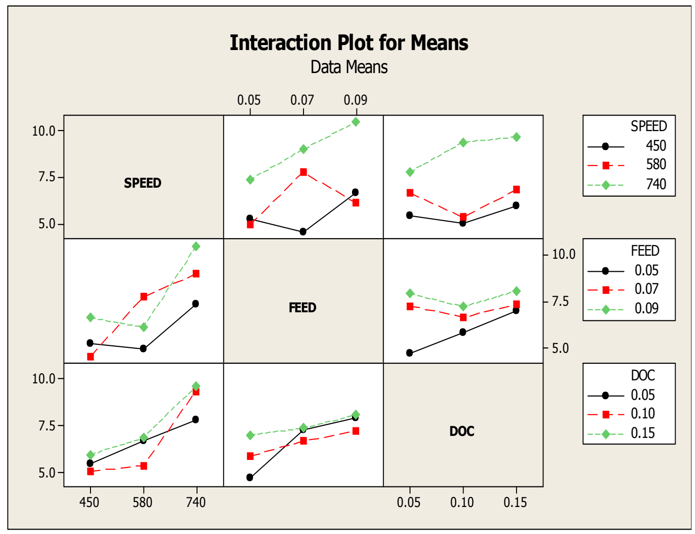

Fig 9: Interaction data means for Power Consumption (PC)

CONCLUSIONS

The results obtained in this study lead to conclusions for turning of AISI 4340 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) Taguchi method is applied for optimization of cutting Parameters

Responses	Input parameters		
	Speed(rpm)	Feed(mm/rev)	DOC(mm)
Ra (min)	**580**	**0.05**	**0.15**
MRR(max)	**580**	**0.07**	**0.15**
PC (min)	**740**	**0.09**	**0.15**

(3) Analysis of Variance (ANOVA) is done and found that it shows The depth of cut has great influence for the Response surface roughness (31.78%), Speed has great Influence for the response Material removal rate (55.56%), Depth of cut has great influence for the Response Power consumption (66.75%).

(4) The interaction of cutting parameters is also studied for the three responses Ra, MRR and PC as follows

Responses	INTERACTIONS (%)		
	S x F	**S x D**	**F x D**
Ra	1.31	10.05	25.71
MRR	8.27	18.67	9.46
PC	1.98	4.51	2.75

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