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Optimization of Turning Parameters Using Taguchi Technique for MRR and Surface Roughness of Hardened AISI 52100 Steel

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ABSTRACT
In this paper, Taguchi technique is used to find optimum process parameters for turning of hardened AISI 52100 steel under dry cutting conditions. A L9 orthogonal array, signal-to-noise(S/N) ratio and analysis of variances (ANOVA) are applied with the help of Minitab.v.16.2.0 software to study performance characteristics of Machining parameters namely cutting speed, feed rate and depth of cut with consideration of Material Removal Rate (MRR) and surface roughness. The results obtained from the experiments are changed into signal-to-noise ratio(S/N) ratio and used to optimize the value of MRR and surface roughness. The ANOVA is performed to identify the importance of parameters. The final results of experimental study are presented in this paper. The conclusions arrived at are significantly discussed at the end.

Keywords: *ANOVA, Hardened, MRR, Surface roughness, Taguchi technique*

I. INTRODUCTION

In metal cutting industries the foremost drawback is not operating the machine tool to their optimum operating conditions and the operating conditions continue to be chosen solely on the basis of the handbook values or operator's experience. In metal cutting industries turning is the majorly used process for removing the material from the cylindrical work piece. In turning that to turning of hardened steels such as AISI52100 is a challenging process. Turning of hardened material is a process, in which materials in the hardened state (above 45HRC) are machined with single point cutting tools. This has become possible with the availability of the new cutting tool materials (cubic boron nitride and ceramics). The traditional method of machining the hardened materials includes rough turning, heat treatment followed by the grinding process. Turning of hardened material eliminates a series of operations required to produce the component and thereby reducing the cycle time and hence resulting in productivity improvement [1,2]. Turning of hardened material is an alternative to conventional grinding process; it is a flexible and economic process for hardened steels [3]. The advantages of tuning of hard materials are higher productivity, reduced set up times, surface finish closer to grinding and the ability to machine complex parts. Rigid machine tools with adequate power, very hard and tough tool materials with appropriate tool geometry, tool holders with high stiffness and appropriate cutting conditions are some of the prerequisites for hard turning [4].Material Removal Rate (MRR) is a vital factor to be considered in hard turning of steels since it is directly affects the machining time. It also had been reported that the resulting machining time reduction is as high as 60% in hard turning compared to grinding [5]. Surface properties such as roughness are critical to the function ability of machine components. Increased understanding of the surface generation mechanisms can be used to optimize machining process and to improve component function ability.

Numerous investigators have been conducted to determine the effect of parameters such as feed rate, tool nose radius, cutting speed and depth of cut on surface roughness in hard turning operation [6,7].Taguchi's Parameter design suggests an efficient approach for optimization of various parameters with regard to performance, quality and cost [8,9]. Taguchi recommends the use of S/N ratio for the determination of the quality characteristics implemented in engineering design problems. The addition to S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on MRR and surface roughness. In this paper Taguchi's DOE approach is used to analyze the effect of turning process parameters-cutting speed, feed and depth of cut while machining for hardened AISI52100 steel and to obtain an optimal setting of the parameters that results in optimizing MRR and Surface roughness.

II. DETAILS OF EXPERIMENT

2.1Workpiece Material, Cutting Tool and Machine

The AISI 52100 steel work piece material is selected for the present work and the chemical composition of work piece material includes C-0.93%,Cr-1.43%,Mn-0.43%,Si-0.2%,P-0.08%,S-0.0047% and balance Fe. The work pieces of diameter 18mm and 100mm length has been used for trials. For all the work pieces heat treatment was carried out. Initially before the heat treatment average hardness of the work piece was 22HRC. The heat treatment includes Hardening at 850^0C for two hours and quenched with oil and also Tempering at 200^0C for one hour. After heat treatment the average hardness value of 48HRC was obtained. The cutting tool insert used for machining AISI 52100 was carbide insert of ISO number: CCMT 32.52 MT TT8020 of TaeguTec make under dry cutting conditions. The Cutting Tool holder used was of Specification SCLCR1212H09 D 4C of WIDIA make.

The machine used for turning was all geared Head Precision lathe (Preci-Turnmaster -350) of OM JINA MACHINE TOOLS make. The instrument used for measuring weight of the specimen and surface roughness was weighing balance and Mitutoyo surface roughness tester respectively. Machining time is noted by stopwatch and measured final weight of all jobs. Material removal rate (MRR) is calculated by using relation MRR = (Wi.–Wf) ÷ Machining Time, where W_i is the initial weight of the workpiece and W_f is the final weight of the work piece. The Taguchi method developed by Genuchi Taguchi is a statistical method used to improve the product quality. It is commonly used in improving industrial product quality due to the proven success [10].With the Taguchi method it is possible to significantly reduce the number of experiments. The Taguchi method is not only an experimental design technique, but also a beneficial technique for high quality system design [11].

2.2 Taguchi Method

The Taguchi technique includes the following steps:

- determine the control factors,
- determine the levels belonging to each control factor and select the appropriate orthogonal array,
- assign the control factors to the selected orthogonal matrix and conduct the experiments,
- analyze data and determine the optimal levels of control factors,
- perform the confirmation experiments and obtain the confidence interval,
- improve the quality characteristics.

The Taguchi method uses a loss function to determine the quality characteristics. Loss function values are also converted to a signal-to-noise (S/N) ratio (η). In general, there are three different quality characteristics in S/N ratio analysis, namely “Nominal is the best”, “Larger is the better” and “Smaller is the better”. For each level of process parameters, signal-to-noise ratio is calculated based on S/N analysis.

2.3 Selection of Control factors and orthogonal array

In this study Cutting speed, Feed rate and Depth of cut (DOC) was selected as control factors and their levels were determined as shown in the Table 1.

Table 1Turning Parameters and their levels

Factors	Level 1	Level 2	Level 3
Cutting Speed(rpm)	450	710	1120
Feed rate(mm/rev)	0.05	0.12	0.18
Depth of cut(mm)	0.2	0.3	0.4

The first step of the Taguchi method is to select an appropriate orthogonal array. The most appropriate orthogonal array (L9) was selected to determine the optimal turning parameters based on the total degree of freedom (DOF) and to analyze the effects of these parameters. The L9 orthogonal array has eight DOF and can handle three level design parameter. The L9 orthogonal array is as shown in the Table2.

Table 2 Orthogonal L9 array of Taguchi

Experiment	P1	P2	P3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

III. ANALYSIS AND DISUSSION OF EXPERIMENTAL RESULTS

Table 3 shows the experiment results for the average Surface roughness (SR) and MRR and corresponding S/N ratios were obtained with the help of Minitab.v.16.2.0 software.

3.1 Cause of Cutting speed, feed rate and Depth of cut on MRR

From the response Table 4 and Fig.1 it is clear that cutting speed is the most influencing factor followed by depth of cut and feed rate for MRR. The optimum for MRR is cutting speed of 1120rpm, feed rate of 0.12mm/rev and depth of cut of 0.4mm.

3.2 Cause of Cutting speed, feed rate and Depth of cut on Surface roughness

From the response Table 5 and Fig. 2 it is clear that cutting speed is the most influencing factor followed by feed rate and depth of cut for surface roughness. The optimum conditions for Surface roughness are cutting speed of 450rpm feed rate of 0.05mm/rev and depth of cut of 0.4mm.

3.3 Analysis of variances (ANOVA)

Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA.Using Minitab.v.16.2.0 software ANOVA module can be employed to investigate effect of parameters. It is clear from the Table6 cutting speed (rpm) it is contributing of about 28.33%, depth of cut 24.3% and feed rate 19.55% on Material Removal Rate (MRR). It is evident from Table 7 cutting speed (rpm) is the most significant factor contributing of about 56.75%, followed by feed rate 32.7% and depth of cut 8.37% on surface roughness.

Table 3 Experimental results for the surface roughness, MRR and corresponding S/N ratios

Sl.No	SPEED (rpm)	FEED (mm/rev)	DOC (mm)	Average SR(µm)	S/N Ratio for SR	MRR(g/min)	S/N Ratio for MRR
1	450	0.05	0.2	10.33	-20.28	0.008	-41.89
2	450	0.12	0.3	11.33	-21.08	0.296	-10.55
3	450	0.18	0.4	11.33	-21.08	0.086	-21.23
4	710	0.05	0.3	12.7	-22.07	0.012	-38.061
5	710	0.12	0.4	13.2	-22.41	0.113	-18.87
6	710	0.18	0.2	14.22	-23.057	0.067	-23.37
7	1120	0.05	0.4	11.36	-21.10	0.542	-5.30
8	1120	0.12	0.2	13.3	-22.47	0.089	-21.00
9	1120	0.18	0.3	15.2	-23.63	0.233	-12.63

Table 4 Response Table for Signal to Noise Ratios (Larger is better)

Level 1	Speed(rpm)	Feed(mm/rev)	DOC(mm)
1	-24.56	-28.42	-28.76
2	-26.77	-16.81*	-20.42
3	-12.98*	-19.08	-15.41*
Delta	13.79	11.61	13.62
Rank	1	3	2

***** indicates optimum level

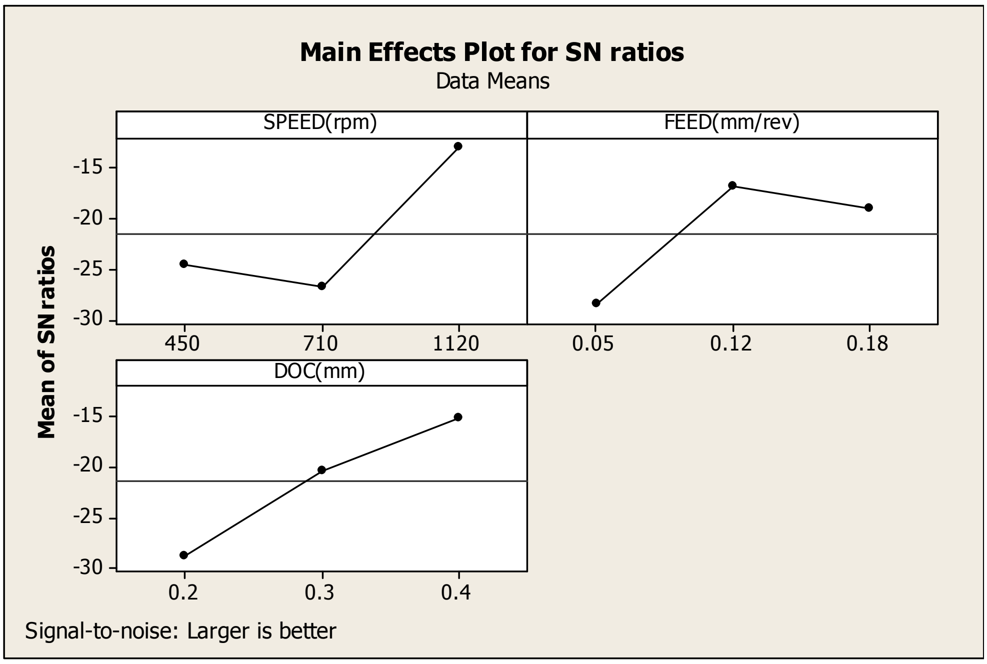

Figure 1 Main effects plots for MRR

Table 5 Response Table for Signal to Noise Ratios (Smaller is better)

Level 1	Speed(rpm)	Feed(mm/rev)	DOC(mm)
1	-20.82*	-21.61*	-21.94
2	-22.52	-21.99	-22.27
3	-22.41	-22.59	-21.53*
Delta	1.70	1.44	0.73
Rank	1	2	3

***** indicates optimum level

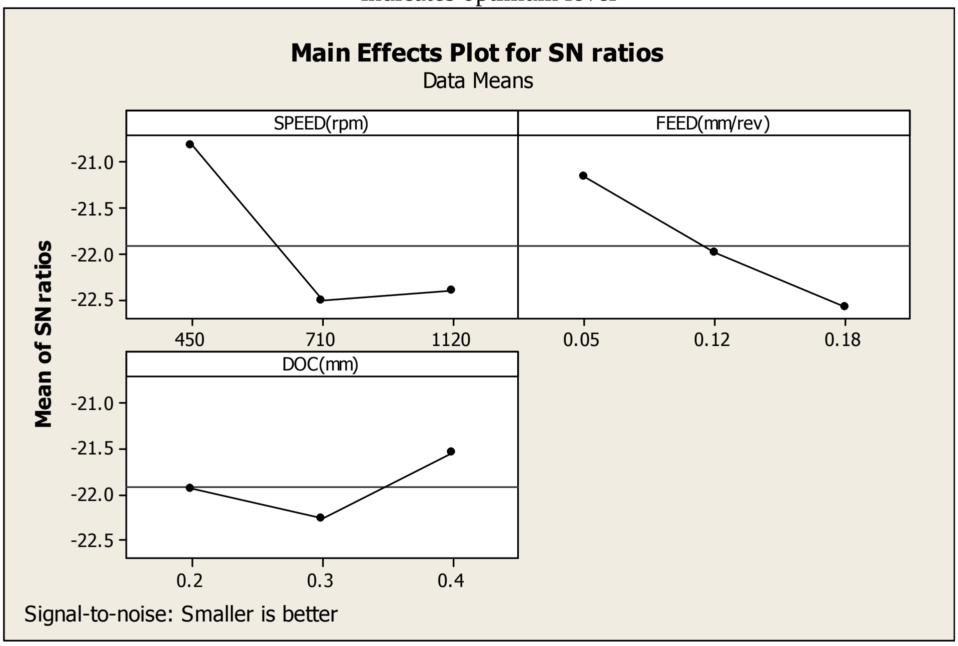

Figure 2 Main effects plots for Surface roughness.

Table 6 ANOVA for S/N ratio for MRR

Source	DOF	SS	MS	F	P	% contribution
Speed(rpm)	2	329.2	164.6	1.02	0.495	28.33%
Feed(mm/rev)	2	227.2	113.6	0.70	0.587	19.55%
DOC(mm)	2	282.8	141.4	0.88	0.533	24.3%
Error	2	322.5	161.2	-	-	27.7%
Total	8	1161.7	-	-	-	100%

Table 7 ANOVA for S/N ratio for Surface roughness

Source	DOF	SS	MS	F	P	% contribution
Speed(rpm)	2	5.42	2.71	27.17	0.036	56.75%
Feed(mm/rev)	2	3.12	1.56	15.67	0.060	32.67%
DOC(mm)	2	0.80	0.40	4.03	0.199	8.37%
Error	2	0.19	0.09	-	-	1.98%
Total	8	9.55	-	-	-	100%

IV. VALIDATION OF EXPERIMENTS

After obtaining optimum conditions from Taguchi method of both MRR and Surface roughness the prediction was made for MRR and Surface roughness. The predicted value of MRR for optimum conditions of cutting speed 1120rpm feed rate0.12mm/rev and depth of cut 0.4mm is 0.782g/min and when the actual experiment was done using these optimum conditions the MRR obtained is 0.807g/min therefore the error obtained 2.5% as shown in Table8. The predicted value of surface roughness for optimum conditions of cutting speed 450rpm feed rate0.05mm/rev and depth of cut 0.4mm is 9.63µm and when the actual experiment was done using these optimum conditions the surface roughness obtained is 9.85µm therefore the error obtained 2.23% as shown in Table 9..From these confirmation tests, good agreement between the predicted machining performance and the actual performance were observed.

V. CONCLUSION

- The optimum conditions obtained from Taguchi method for optimizing Material Removal Rate (MRR) during turning of hardened AISI52100 steel under dry condition are cutting speed of 1120rpm Feed rate of 0.12mm/rev and depth of cut of 0.4mm.
- From response table for S/N ratio of MRR it is clear that cutting speed is the most significant factor influencing MRR followed by Depth of cut and Feed rate is the least significant factor.
- Analysis of Variances (ANOVA) for S/N ratio for MRR clearly indicates that the cutting speed is majorly contributing of about 28.33% in obtaining optimal MRR followed by depth of cut 24.3% and feed rate 19.55%.
- Optimum conditions for optimizing Surface roughness are cutting speed of 450rpm Feed rate of 0.05mm/rev and depth of cut of 0.4mm
- From response table for S/N ratio of surface roughness it is clear that cutting speed is the most significant factor influencing MRR followed by Feed rate and depth of cut is the least significant factor.
- Analysis of Variances (ANOVA) for S/N ratio for surface roughness clearly indicates that the cutting speed is majorly contributing of about 56.75% in obtaining optimal surface roughness followed by feed rate of 32.67%.and depth of cut of 8.37 %.

Table 8 Confirmation test for MRR

Optimum Values	S/N ratio obtained	Predicted MRR(g/min)	Actual MRR(g/min) obtained	Error%
Speed:1120rpm Feed:0.12mm/rev DOC:0.4mm	-2.05574	0.782	0.807	2.5%

Table 9 Confirmation test for Surface roughness (SR)

Optimum Values	S/N ratio obtained	Predicted SR(µm)	Actual SR(µm) obtained	Error%
Speed:450rpm Feed:0.05mm/rev DOC:0.4mm	-19.68	9.638	9.85	2.23%

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