World Journal of Engineering Research and Technology
WJERT
www.wjert.org
SJIF Impact Factor: 4.326

EFFECT OF PROCESS PARAMETERS ON MATERIAL REMOVAL RATE (MRR) DURING TURNING OF MILD CARBON STEEL CS 1030 USING TAGUCHI METHOD

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Article Received on 08/05/2017 Article Revised on 29/05/2017 Article Accepted on 18/06/2017

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ABSTRACT

An experimental investigation of the effect of process parameters (cutting speed, feed rate and depth of cut) on Material Removal Rate (MRR) have been carried out during CNC turning of Mild Carbon steel CS 1030 using Taguchi experimental design. An Orthogonal array has been selected and constructed to find the optimal levels and to analyze the effect of the turning parameters. The signal-to-noise (S/N) ratio has been calculated to construct the analysis of variance (ANOVA) table to study the performance characteristics in dry turning operations. The ANOVA shows that, the feed rate has the most significant role (56.79%) in producing higher MRR, followed by cutting speed (31.95%). Interaction of feed and speed has a highest significant effect on Material removal rate with 11.18% contribution. Also maximum material removal rate was achieved at optimal parametric combination of 347mm/min cutting speed, 0.458 mm/rev feed rate and 1.1 mm depth of cut.

KEYWORDS: Taguchi method, CNC Turning, Cutting Parameters, MRR.

INTRODUCTION

High speed machining (HSM) and modern machining technologies are being used to machine the parts that need significant amount of material removal. Turning has been described as one of the most important machining process in which a single point cutting tool removes unwanted material from the surface of a rotating cylindrical work piece (Rao, 2008). The process parameters like cutting speed, feed rate, depth of cut, coolant condition and tool geometry affects the material removal rate in turning. The proper selection of process parameters is essential to optimize the metal removal rate. The present study considers application of Taguchi method to optimize the CNC turning operation for maximum material removal rate. The objective of this paper is to investigate process parameters for turning of mild carbon steel, CS 1030 work piece on CNC lathe machine. In this study, speed, feed and depth of cut are evaluated for high material removal rate (MRR).

The choice of CNC manufacturing process is based on cost optimization, improvement of productivity and quality of the product by precision manufacturing. In manufacturing industries after optimal selection of cutting conditions and cutting tools, experienced shop-floor machine tool operators play a vital role in producing high quality product and improving the productivity of the products. From last few decades, it has been observed that selecting and implementing optimal machining conditions and most suitable cutting tool during machining operations. There are many cutting parameters like cutting speed, feed rate and depth of cut which has been selected to optimize the economics of machining operations, as assessed by productivity, total manufacturing cost per part or some other criterion. Regardless of early works on setting up optimum cutting speeds in Computer Numerically Controlled (CNC) machining, the recent research have detailed that the process parameters need to be optimized as CNC machining is an essential and costly process for small and medium type manufacturing industries (Sanjit et al., 2010; Kadirgama et al., 1996; Basim et al., 2010). Cutting parameters were analyzed based on the cutting characteristics of S45C steel using Taguchi method and ANOVA analysis for determination of optimal cutting parameters (Yang and Tamg, 1996). The parameter optimization of machining hardened steel have been described. The common tendency of process is to reduce the machining cost and time and increasing the accuracy of the product. By considering this problem, this paper uses Taguchi Method develop a machining technique with higher cutting speed, feed rate and depth of cut with better surface finish (Gopalsamy et al., 2009; Sujit, 2014).

Taguchi method is a statistical method developed for the production of robust products. According to Taguchi, quality of a manufactured product is total loss generated by that product to society from the time it is shipped. Taguchi stresses the importance of designing quality into product into processes, rather than depending on the more traditional tools of on-line quality control. Taguchi developed a method based on orthogonal array experiments, which reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the combination of Design of Experiments (DOE) with optimization of control parameters to obtain best results is achieved in the Taguchi Method. Signal to noise (S/N), ratio and orthogonal array are two major tools used in robust design. Signal to noise ratio, which are log functions of desired output measures quality with emphasis on variation, and orthogonal arrays, provide a set of well balanced experiments to accommodate many design factors simultaneously presented (Sujit, 2014; Phadke, 1998). Taguchi's robust design method is suitable to analyze the metal cutting problem by considering the optimization in end milling using S/N ratio approach and Pareto ANOVA method. It has been established that the conceptual S/N ratio and Pareto ANOVA approaches for data analysis in end milling uses at high cutting speed of 355 m/min, low feed rate of 0.1mm per tooth and low depth of cut of 0.5 mm (Ghani et al., 2004). Application of Taguchi's method for parametric design was carried out to determine an ideal feed rate and desired force combination although small interactions exist between a horizontal feed rate and desired force, the experimental results showed that surface roughness decreases with a slower feed rate and larger grinding force, respectively presented (Liu et al., 2004). Studies on the performance characteristics in turning operations of Df2 (1.2510) steel bars using TiN coated tools using three cutting parameters namely, cutting speed, feed rate, and depth of cut; they were optimized with considerations of surface roughness (Jafar and Afsari, 2010). Systematic procedure of using Taguchi technique for optimizing the MRR in Electric Discharge Machine (EDM) was also carried out (Pramod et al., 2006). Taguchi methodology was also applied to optimize cutting parameters in CNC turning for surface roughness turning of aluminum with parameters of turning at three levels and four factors each in order to achieve the optimal material removal rate (Thamizhmanii et al., 2007).

MATERIALS AND METHODS

The turning tests were carried out to determine the material removal rate under various turning parameters. The workpiece used was mild carbon steel, *CS1030* whose major chemical compositions and mechanical properties are given in Table 1. Turning experiments were carried out using tools of grade *TP20* carbide flat-top inserts and 8 μm TiN coating on a PRODIS CORP CNC lathe.

Table 1: Chemical compositions and mechanical properties of carbon steel, *CS1030*, Source: (eFunda, 2011).

C	Mn	P	S	Density, ρ (Kg/m^3)	Tensile strength (MPA)	Hardness (BHN)
0.3%	0.6%	0.04%	0.05%	$8.03x10^3$	463.7	126

The workpiece were prepared in cylindrical shapes with a wall thickness of 3mm and diameter of 100mm and length 300mm, and were machined from one. The feed rates to be set by the lathe will correspond to the cut thickness *t* in orthogonal cutting and the wall thickness of the workpiece represents the width of the cut b.

The product / process diagram is as shown in Figure 1 which shows the various influencing factors of product/process design. The control factors are the factors, which can be controlled to obtain the desired output, like speed, cutter radius, etc. The noise factors are the uncontrollable factors, like temperature, humidity, vibration, friction, etc for the deviation of the output from the desired output. Response is the outcome of the Product/Process after giving three input variables.

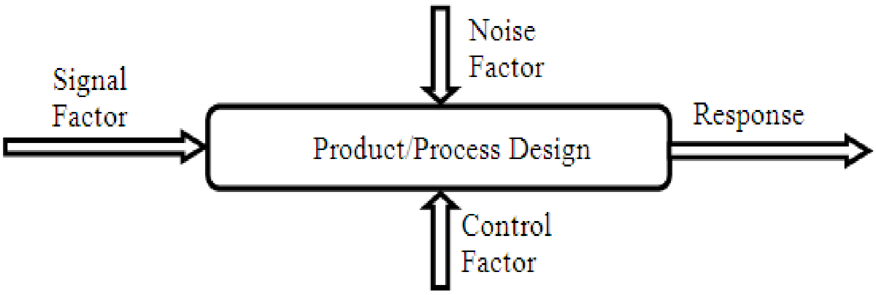

Figure 1: Product/process diagram.

Taguchi Method

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 (Lan et al., 2008; Palanikumar and Karunamoorthy, 2006; Dhavamani. and Alwarsamy, 2011). In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only. Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N). There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

1. **Smaller-the-better**

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} {y_i}^2\right)$$

2. **Larger-the-better**

$$S/N = -10\log_{10}[\text{mean of sum squares of reciprocal of measured data}]$$

$$= -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right)$$

3. **Nominal-the-best**

$$S/N = 10\log_{10}\left(\frac{square\ of\ means}{variance}\right) = 10\log_{10}\left(\frac{\bar{y}^2}{{s_y}^2}\right)$$

In practice MRR should be high, thus Taguchi method refers to select the process parameter having more S/N ratio. Therefore, we would use the larger the better S/N ratio. That is;

$$S/N = -10\log_{10}[\text{mean of sum squares of reciprocal of measured data}]$$

Where, $\bar{y}$ is the average of observed data, ${S_y}^2$ is the variance of y, n is the number of observations and y is the observed data.

Regardless of category of the performance characteristics, the lower S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the lowest S/N value. The statistical analysis of the data was performed by analysis of variance (ANOVA) (Selvaraj and Chandarmohan, 2010; Kamarudin and Rahim, 2007) to study the contribution of the factor and interactions and to explore the effects of each process on the observed value.

RESULTS AND DISCUSSION

A series of turning tests was conducted to assess the influence of turning parameters on material removal rate during turning of CS 1030. Results of the material removal rate for the turning process with various turning parameters are shown in Table 2. Table 2 also gives S/N ratio for material removal rate. The S/N ratios for each experiment of L27 were calculated (Sahoo et al., 2008). The objective of using the S/N ratio as a performance measurement is to develop products and processes insensitive to noise factor.

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the greatest value. The effect of spindle speed on the metal removal rate values is shown in Figure 2 for S/N ratio. Its effect is increasing with increase in spindle speed up to 347 mm/min, beyond 347 mm/min, the effect begins to decrease. Therefore, the optimum spindle speed is level 2 i.e. 347 mm/min. Similarly, the effect of feed rate on the metal removal rate values is also shown in Figure 2 for S/N ratio. Its effect is increasing with increase in feed rate. So the optimum feed rate is level 3 i.e. 0.458 mm/rev. it can be seen also that, the effect of the depth of cut on the metal removal rate values for the S/N ratio is also increasing with increase in depth of cut. So the optimum depth of cut is level 3 i.e. 1.1 mm.

Table 2: Experimental Result and Corresponding S/N Ratio.

Expt. No.	Control Parameter (Level)			Observed/Computed Results				
	Cutting speed (mm/min)	Feed rate (mm)	Depth of cut (mm)	Wieght of chip (g)	Time taken to remove material (s)	MRR (g/min)	MRR (mm^3/min)	S/N Ratio
1	216	0.388	0.9	3.479	135	1.546	192.5557	45.691
2	216	0.418	1.0	5.763	112	3.087	384.4734	51.697
3	216	0.458	1.1	9.544	130	4.405	548.5583	54.784
4	216	0.388	0.9	11.65	121	5.777	719.4097	57.140
5	216	0.418	1.0	3.932	118	1.999	248.9816	47.923
6	216	0.458	1.1	4.783	116	2.474	308.0904	49.774
7	216	0.388	0.9	8.207	113	4.358	542.6773	54.691
8	216	0.418	1.0	9.135	111	4.938	614.9238	55.776
9	216	0.458	1.1	3.912	108	2.173	270.6517	48.648
10	347	0.388	0.9	4.955	92	3.232	402.4311	52.094
11	347	0.418	1.0	7.869	104	4.540	565.3559	55.046
12	347	0.458	1.1	6.229	36	10.382	1292.86	62.231
13	347	0.388	0.9	3.378	88	2.303	286.8221	49.152
14	347	0.418	1.0	5.22	85	3.685	458.8675	53.234
15	347	0.458	1.1	9.888	82	7.235	901.0115	59.095
16	347	0.388	0.9	10.717	79	8.139	1013.636	60.118
17	347	0.418	1.0	3.47	76	2.739	341.1549	50.659
18	347	0.458	1.1	5.3	73	4.356	542.4862	54.688
19	536	0.388	0.9	8.762	68	7.731	962.7866	59.671
20	536	0.418	1.0	10.479	64	9.824	1223.42	61.752
21	536	0.458	1.1	4.237	60	4.237	527.6463	54.447
22	536	0.388	0.9	4.015	56	4.302	535.7143	54.579
23	536	0.418	1.0	6.863	52	7.919	986.1577	59.879
24	536	0.458	1.1	8.15	48	10.188	1268.68	62.067
25	536	0.388	0.9	4.056	44	5.531	688.7807	56.762
26	536	0.418	1.0	5.304	40	7.956	990.7846	59.920
27	536	0.458	1.1	8.512	86	5.939	739.5523	57.379

The following formulae are used to compute Table 2;

$$MRR\ (g/min) = \frac{\text{Wieght of chip (g)}}{\text{Time taken to remove material (min)}}$$

$$MRR\ (mm^3/min) = \frac{MRR\ (g/min)}{Density,\ \ \rho\ (g/mm^3)}$$

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right)$$

The Analysis of Varieance (ANOVA) table for material removal rate is presented in Table 3.

Table 3: Analysis of Varieance (ANOVA) table for MRR.

Source	DF	SS	MS	F	P	% contribution
Speed	2	95289827	47644913	27645.96	0.000	31.95385
Feed Rate	2	169349860	84674930	49132.62	0.000	56.78864
Depth of cut	2	198955	99477	57.72	0.00	0.066716
Speed*feed rate	4	33351297	8337824	4838.02	0.000	11.1838
Speed*depth of cut	4	1583	396	0.23	0.914	0.000531
Feed rate*depth of cut	4	5478	1369	0.79	0.561	0.001837
Error	8	13787	1723			0.004623
Total	26	298210787				100

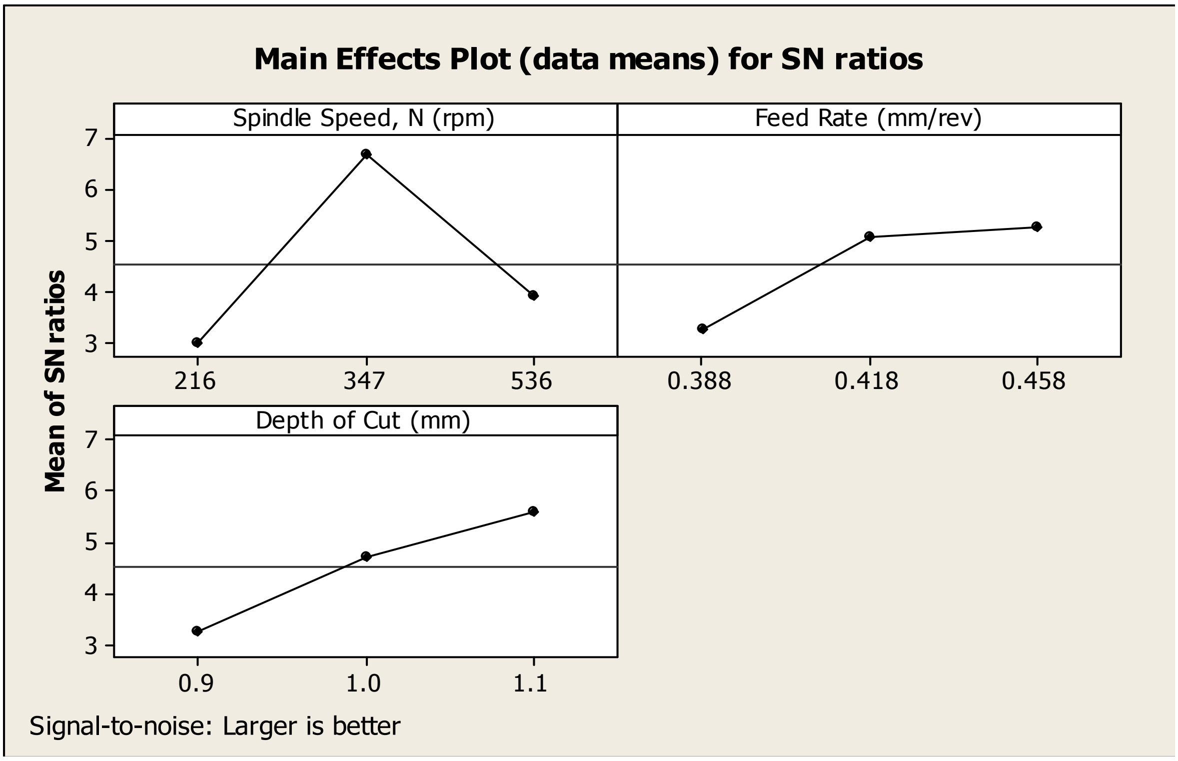

Figure 2: Effect of Turning Parameters on Material Removal Rate for S/N Ratio.

The effect of parameters, that is cutting speed, feed rate and depth of cut and some of their interactions were also evaluated using ANOVA analysis with the help of MINITAB 17 software as shown in Table 3. The purpose of the ANOVA is to identify the optimum parameters for maximum material removal rate. From the ANOVA table it is clear that the most significant factor at 95% confidence is the feed rate, having a percentage contribution up to 56.79% to material removal rate. After that, the second main contribution is the cutting speed with a percentage contribution of 31.95%. This means that, the combined effect of feed rate and speed has the most significant effect on material removal rate with a percentage contribution of 11.18%. From Table 2 and Figure 2, it is observed that the maximum material removal rate was achieved during machining of mild carbon steel CS 1030 workpiece at cutting speed of 347 mm/min, feed rate of 0.458 mm and depth of cut of 1.1 mm/rev.

CONCLUSIONS

The effect of process parameters (cutting speed, feed rate and depth of cut) on material removal rate (MRR) during turning operation using Taguchi method have been studied using mild carbon steel CS 1030 as workpiece. With the increase in cutting speed, the material removal rate is increased and as the feed rate increases the material removal rate also increases. Results of ANOVA analysis show that, material removal rate (MRR) is mainly affected by feed rate (56.79%) and cutting speed (31.95%). Interaction of feed and speed has a highest significant effect on material removal rate with 11.18% contribution. It was also observed that, for maximum material removal rate, the optimal parametric combination of 347mm/min cutting speed, 0.458 mm/rev feed rate and 1.1 mm depth of cut should be used when machining mild carbon steel CS 1030.

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