CONSTRAINED MACHINING PARAMETERS OPTIMIZATION OF EN8 STEEL USING TAGUCHI APPROACH

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Abstract-- **Recently EN8 having better mechanical properties and it is used for manufacturing rollers, bolts, screws and connecting rods. Turning operation is the basic metal removal process, during this process heat is generated between the work piece and cutting tool which affects the surface finish of the work piece. The advantage of using this CNC turning process is to reduce the cost and also enhance the quality of the finished component. In this experimental work conducted on EN8 material using CNC Lathe with SINUMERIK 802D Control System with variable spindle rotating speed of 60 rpm, 80 rpm and 100 rpm based on the L9 orthogonal array. The turning parameters such as spindle speed, feed rate and depth of cut was selected and investigated at three different levels to study the effect of metal removal rate. The optimum level of turning parameters was determined by using Taguchi design of experiments.**

Index Terms- **Turning, Design of Experiments, Metal Removal Rate.**

I. INTRODUCTION

The turning process parameters such as spindle speeds, feed rates and depth of cuts are the main factors that affect the metal removal rate. The main objective of this experimental work is to find the maximum metal removal rate.

Shreemoy Kumar Nayak et al (2014) investigated the influence of machining parameters namely cutting speed, feed and depth of cut on turning of AISI 304 stainless steel using ISO P30 grade uncoated cemented carbide insert and adopted L27 orthogonal array to measure the characteristics of machinability such as material removal rate (MRR), Cutting force (Fc) and surface roughness (Ra). The machining parameters are optimized using gray relational analysis.

Ali Yildiz (2013) used evolutionary based optimization technique of artificial bee colony algorithm for selecting the optimal cutting parameters in multi-pass turning operations and compared with previously published results. Doriana Addona et al (2013) determined the optimal cutting parameters during turning process using genetic algorithm for reducing the production cost and time.

Abhang et al (2012) carried out the turning process in EN31 steel alloy using tungsten carbide inserts by varying the cutting parameters namely feed rate, depth of cut, and lubricant temperature to observe the effects on surface finish. Khaider Bouacha et al (2014) conducted an experimental study of hard turning of AISI 52100 bearing steel, with CBN tool by using response surface methodology (RSM) to find the relationship between process parameters and performance characteristics. The results show that the cutting speed exhibits maximum influence on abrasive tool wear and depth of cut affects strongly the cutting forces.

Arshad Noor Siddiquee et al(2014) focused on optimizing deep drilling parameters based on Taguchi method for minimizing surface roughness by conducting experiments on CNC lathe machine using solid carbide cutting tool on material AISI 321 austenitic stainless steel and determined the machining parameter which significantly affects the surface roughness and also the percentage contribution of individual parameters.

Murat Sarıkaya et al (2014) used design of experiments to study the effect of turning parameters such as cooling condition, cutting speed, feed rate and depth of cut on arithmetic average roughness (Ra) and average maximum height of the profile (Rz) by turning of AISI 1050 steel. The mathematical model for surface roughness is created using response surface methodology and concluded that feed is the most effective parameter on the surface roughness.

Mustafa Günay et al (2013) performed experimentation in the CNC lathe using ceramic and cubic boron nitride (CBN) cutting tools on Ni-Hard materials with two different hardness levels 50 HRC and 62 HRC. Taguchi L18 Orthogonal array design of experiments is used for finding out the optimum turning parameters and also studied the effect of parameters on surface roughness.

Rajasekaran et al (2013) examined the process parameters such as cutting speed, feed and depth of cut for machining carbon fiber reinforced polymer material and studied the effect of these parameters on surface roughness. Senthilkumar et al (2014) investigated the effect of machining parameters such as cutting speed, feed rate and depth of cut, geometrical parameters of cutting insert shape, relief angle and nose radius on flank wear, Surface Roughness (SR) & Material Removal Rate (MRR) were optimized using Taguchi based grey relational analysis.

Dipti Kanta Das' et al (2014) dealt with investigations on surface roughness during hard machining of EN 24 steel with the help of coated carbide insert. The process parameters are optimized by using Grey based Taguchi approach and it was found that the feed is the most dominant parameter for surface roughness. Umesh et al (2014) investigated the turning parameters namely cutting speed, feed rate and depth of cut resulting in an optimal value of feed force, tangential force and surface roughness for machining EN-19 steel with an coated carbide tool insert.

Ramazan Çakıroğlu et al (2013) evaluated the cutting parameters on drill bit temperature in drilling process of Al7075 work piece with coated carbide drill tool using Taguchi method. Empirical equation is derived using regression analysis for the drill bit temperature and the obtained equation results were compared with experimental results. The empirical equations results indicated a good agreement with experimental results.

Venkataramaiah et al (2014) studied the the influence of feed rate and tool geometry on cutting force during turning using Taguchi Method and Fuzzy Logic. Series of turning experiments are conducted by using Taguchi Experimental Design on Aluminium work piece with the HSS cutting tools. The cutting forces are recorded for different angle geometry and feed rate.

From the literature survey, the identification of machining problem for EN8 steel rods which cannot be tackled using conventional technique because of the following problems occurs in turning process.

- Poor chip breaking.
- High work hardened.
- Transformation induced plasticity.
- Affect the passive surface.
- Machining distortion.

The above problems are to overcome during CNC turning to achieve maximum metal removal rate and with close dimensional accuracy.

II. EXPERIMENTAL DETAILS

When the number of processing parameters increases, the classical methods of experimental design are too complex and large numbers of experiments are to be carried out. To overcome these issues, Taguchi method used an orthogonal array to investigate the process parameters with only a few experiments. In this experimental work, experiments were carried out with three independent factors namely cutting speed, feed rate and depth of cut at three levels each. Here a standard L9 orthogonal array was used. The various cutting parameters and their levels are shown in Table 1 and Table 2 shows standard L9 orthogonal array

TABLE 1 CUTTING PARAMETERS AND LEVELS

Levels	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
Low	60	0.2	2
Medium	80	0.3	3
High	100	0.4	4

TABLE 2 ORTHOGONAL ARRAY L9 OF TAGUCHI EXPERIMENT DESIGN

Experiment	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
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

A. Work piece material

In this experimental work, EN 8 steel is used to find out the optimum turning parameters for metal removal rate (MRR). Initially a EN8 rod of 25 mm diameter and 70mm length is taken and 30 mm length is placed inside the chuck of the CNC machine, the remaining 40mm were turned for each trail.

TABLE 3 CHEMICAL COMPOSITION OF EN 8 STEEL

Elements	Weight %
C	0.36
Mn	0.66
Si	0.27
S	0.016
P	0.020

TABLE 4 MECHANICAL PROPERTIES OF EN 8 STEEL

Sl. No	Mechanical Property	Range
1	Max Stress	700-850 N/mm^2
2	Yield Stress	465 N/mm^2
3	Elongation	16%
4	Impact KCV	28 J
5	Hardness	201-255 Inell

Table 3 and 4 shows the chemical composition and mechanical properties of EN 8 Steel material.

B. Cutting inserts

Carbide insert of ISO designation CNMG 120408 (80^0 diamond shaped inset) without chip breaker geometry has been used for experimentation.

C. Experimental Procedure

The turning tests on the work piece were conducted under dry conditions on a CNC lathe SINUMERIK (802 D) which have a maximum spindle speed of 5000 rpm and maximum power of 16 kW. The weight of the work pieces before machining and after machining is noted down using electronic weighing machine to find out the metal removal rate. The CNC machine shows the machining time taken for turning each work piece.

Figure 1 shows the CNC lathe machine SINUMERID (802D). Table 5 shows the specifications of CNC Lathe.

TABLE 5: MACHINE SPECIFICATION OF CNC LATHE

Sl.No	Specifications	Dimensions/Range
1	Max. Swing Over Carriage	180mm
2	Distance between centers	220mm
3	Height of the center	165mm
4	Spindle bore diameter	40mm
5	Spindle speed	5000 rpm

Fig. 1 CNC lathe SINUMERIK (802 D)

III. RESULTS AND DISCUSSION

The experimental trails were conducted according to the standard L9 Orthogonal array. The metal removal rate of each trail is found by using the equation (1). The use of Taguchi method for experimental design is to determine significant parameters which affect the machining performance.

After determining the signal-to-noise (S/N) ratio of the experimental results, a statistical analysis using analysis of variance (ANOVA) was conducted to reveal significant machining parameters that affect the MRR. MINI TAB 17.0 software was used for Taguchi's Method and for analysis of variance (ANOVA).

TABLE 6: S/N RATIOS OF EXPERIMENTAL RESULTS FOR MRR

Cutting Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Weight before machining (g)	Weight after machining (g)	Machining time (min)	M.R.R (g/min)	S/N Ratio for MRR (dB)
60	0.2	2	156.22	127.74	1.46	19.50685	25.8037
60	0.3	3	156.22	119.34	1.3	28.36923	29.0569
60	0.4	4	156.22	106.89	1.2	41.10833	32.2786
80	0.2	3	156.22	118.12	1.29	29.53488	29.4067
80	0.3	4	156.22	106.24	1.19	42	32.4649
80	0.4	2	156.22	128.83	1.39	19.70504	25.8915
100	0.2	4	156.22	106.94	1.09	45.21101	33.1048
100	0.3	2	156.22	133.16	1.21	19.05785	25.6014
100	0.4	3	156.22	120.08	1.15	31.42609	29.9458

A. Regression equations

The mathematical predictive regression models developed for the MRR as shown in equations (1)

MRR = -7.83 + 0.0559 A- 3.36 B + 11.675 C (1)

where 'A' represents cutting speed, 'B' represents feed rate, 'C' represents depth of cut.

B. Analysis of Metal Removal Rate (MRR)

The metal removal rate has been calculated from the difference of weight of work piece before and after machining divided by the machining time.

$$M.R.R = (W_A - W_B) / T \qquad (2)$$

where W_A is the initial weight of work piece in 'g'; W_B is the final weight of work piece in 'g'; T is the machining time in minutes.

(3)

larger is better;

$$\eta = S/N_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right),$$

In general, there are three different quality characteristics in S/N ratio analysis namely "Larger is the better", "Nominal is the best" and "Smaller is the better". For each level of turning process Parameters signal-to-noise ratio is calculated based on Larger is the better S/N analysis for metal removal rate.

TABLE 7: MRR RESPONSE TABLE S/N RATIOS

Level	Cutting speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	29.05	29.44	25.77
2	29.25	29.04	29.47
3	29.55	29.37	32.62
Delta	0.50	0.40	6.85
Rank	2	3	1

Table 7 shows that Depth of cut is given with rank 1, cutting speed given with rank 2 and feed rate given with rank 3. It meant that depth of cut is plays dominant role in metal removal.

TABLE 8: RESULTS OF ANOVA FOR METAL REMOVAL RATE

Source	D.o.f	Sum of Square	Mean square	F value	Contribution %
Cutting speed (rpm)	1	7.505	7.505	3.91	0.898
Feed rate (mm/rev)	1	0.676	0.676	0.35	0.08
Depth of cut (mm)	1	817.825	817.82	425.77	97.87
Error	5	9.604	1.921	-	1.149
Total	8	835.609	-	-	100

To analyze the effects of cutting sped, feed rate and depth of cut on metal removal rate ANOVA is used. ANOVA is a statistical tool to determine and analyze the individual interactions of all control factors. From the table 7 & 8, the depth of cut had a dominant effect (97.87%) on metal removal rate whereas the other actors were found small comparing with depth of cut.

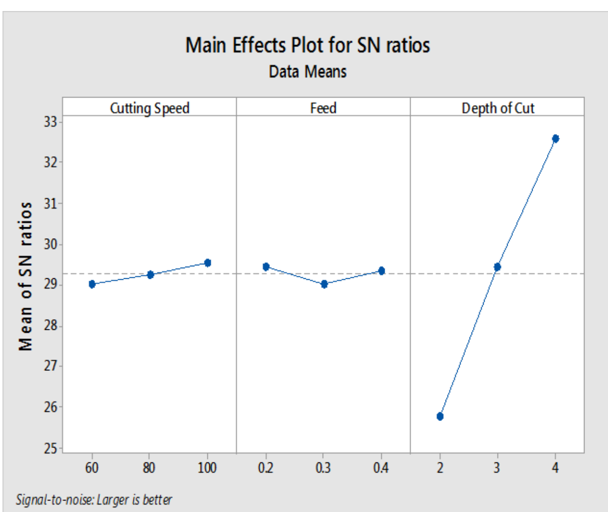

Fig. 2 Main effects plot for S/N ratio of MRR

Figure 2 shows the main effect plots based on S/N ratio (larger the better) for MRR. The metal removal rate is increasing with increase in cutting speed up to 100 rpm. So the optimum cutting speed is level 3. The optimum feed rate is level 1 since the metal removal rate starts decreasing with increase in feed rate. Similarly the MRR is increasing with increase in depth of cut therefore the optimum depth of cut is level 3.

TABLE 9 CONFIRMATION RUN OF MRR

Response	Optimal parameters	Predicted Value	Experimental Value
MRR (g/min)	A3B1C3	45.211	43.688

Table 9 shows the optimal setting from the Taguchi's approach gives an appropriate combination as cutting speed of 100 rpm, feed rate of 0.2mm/rev and depth of cut of 4mm. The predicted value from regression models for MRR is 45.211 g/min. The confirmation experiment gives 43.655 g/min for MRR for the same parameter combinations.

IV. CONCLUSIONS

In this work, Taguchi's methodology has been utilized to determine the optimal parameters which affecting the performance measures namely MRR. Based on the results presented the conclusions are as follows:

The use of a L9 orthogonal array, with three control parameters at three levels required only nine work pieces to conduct the experimental portion, which is less than required for a full factorial design.

Depth of cut played a dominant role on metal removal rate. The parameters considered in the experiments are optimized to attain maximum MRR. The best setting of input process parameters for defect free turning (maximum material removal rate) within the selected range is cutting speed of 100rpm, feed rate of 0.2mm/min and depth of cut of 4mm.

A parameter design gives the optimum condition of the controlled parameters, as well as a predictive equation. A verification procedure is then performed, which indicates that the selected parameters and predictive equation were accurate to within the limits of the measurement.

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