Evaluation and Optimization of Machining Parameter for turning of EN 8 steel

Vikas B. Magdum[#1], Vinayak R. Naik[*2]

[#]Mechanical Engineering Department, Shivaji University, Kolhapur
Textile and Engineering Institute, Ichalkaranji, Maharashtra, India

[*]Mechanical Engineering Department, Shivaji University, Kolhapur
Textile and Engineering Institute, Ichalkaranji, Maharashtra, India

***Abstract*— This study used for optimization and evaluation of machining parameters for turning on EN8 steel on Lathe machine. This study investigates the use of tool materials and process parameters for machining forces for selected parameter range and estimation of optimum performance characteristics. Develop a methodology for optimization of cutting forces and machining parameters.**

***Keywords*— Turning, Optimization, Evaluation, Taguchi method, Orthogonal array, ANOVA.**

I. INTRODUCTION

In today's rapidly changing scenario in manufacturing industries, applications of optimization techniques in metal cutting processes is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality product in the market. This study helpful in evaluating optimum machining parameter like tool geometry, tool Material, cutting speed, feed and depth of cut for cutting force for turning EN 8 steel on Lathe machine. Taguchi's parameter optimization method is used to evaluate best possible combination for minimum cutting force during machinability. This study presents an experimental investigation into the effect of various process and tool-dependent parameters on cutting forces.

R W Lanjewar, P Saha, U Datta, A J Banarjee, S Jain and S Sen investigate the use of different tool material and process parameters for minimum machining forces for selected parameter range. Comparative studies are made to select the process parameters for turning operation on AISI 304 austenitic stainless steel on auto sharpening machine in order to find optimum machining parameter.[1] 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. E. Daniel Kirby found that, Taguchi Parameter Design is a powerful and efficient method for optimizing quality and performance output of manufacturing processes, thus a powerful tool for meeting this challenge. [2] M. Nalbant, H. Gokaya, G. Sur showed that the Taguchi method is used to find the optimal cutting parameters for surface roughness in turning. Three cutting parameters namely, insert radius, feed rate, and depth of cut, are optimized with considerations of surface roughness. [3] G. Akhyar, C.H. Che Haron, J.A. Ghani investigated that Taguchi optimization methodology is applied to optimize cutting parameters in turning Ti-6%Al-4%V extra low interstitial with coated and uncoated cemented carbide tools under dry cutting condition and high cutting speed. [4] Ersan Aslan a, Necip Camuscu a, Burak Birg ren investigated that, due to the high hardness and wear resistance, Al2O3-based ceramics are one of the most suitable cutting tool materials for machining hardened steels. However, their high degree of brittleness usually leads to inconsistent results and sudden catastrophic failures. The present paper outlines an experimental study to achieve this by employing Taguchi techniques. Combined effects of three cutting parameters, namely cutting speed, feed rate and depth of cut on two performance measures, flank wear (VB) and surface roughness (Ra), were investigated employing an orthogonal array and the analysis of variance (ANOVA). [5] Indrajit Mukherjee, Pradip Kumar Ray discussed that, the application potential of several modelling and optimization techniques in metal cutting processes, classified under several criteria, has been critically appraised, and a generic framework for parameter optimization in metal cutting processes is suggested for the benefits of selection of an appropriate approach. [6] J. Paulo Davim , Lui´s Figueira investigated that, a plan of experiments, based on orthogonal arrays, was made in turning with prefixed cutting parameters in tool steel workpieces. A combined technique using orthogonal array and analysis of variance (ANOVA) was employed to investigate the machinability of cold work tool steel. [7] Alakesh Manna, Sandeep Salodkar describes the procedure to obtain the machining conditions for turning operation considering unit cost of production as an objective function. In this study, the Taguchi method a powerful tool for experiment design is also used to optimize the cutting parameters to achieve better surface finish and to identify the most effective parameter for cost evolution during turning. [8] Zhang Xuepinga, Gao Erweia, C. Richard Liu investigate the process parameters of cutting speed, depth of cut, and feed rate on inducing subsurface compressive residual stress. Using a designed experiment based on a Taguchi L9 (3^4) array, they varied process parameters over a feasible space. The resulting residual stresses were examined and evaluated by X-ray diffraction. Using the smaller-is-better objective function for residual stress, and then identified the optimal set of process parameters. [9] Chorng-Jyh Tzeng, Yu-Hsin Lin, Yung-Kuang

Yanga, Ming-Chang Jeng investigated the optimization of CNC turning operation parameters using the Grey relational analysis method. Nine experimental runs based on an orthogonal array of Taguchi method were performed. Additionally, the analysis of variance (ANOVA) is also applied to identify the most significant factor; the depth of cut is the most significant controlled factors for the turning operations according to the weighted sum grade of the roughness average, roughness maximum and roundness. [10] Tzeng Yih-fong showed that, a set of optimal turning parameters for producing high dimensional precision and accuracy in the turning process was developed. Taguchi dynamic approach coupled with a proposed ideal function model was applied to optimize eight control factors for common tool steels SKD-11 and SKD-61. The control factors were coolant, cutting speed, feed, depth of cut, coating type, chip breaker geometry, nose radius and shape of the insert, which were designed in a L18 orthogonal array and carried out in the experiments. [11]

Farhad Kolahan, Mohsen Manoochehri, Abbas Hosseini showed that, the surface roughness is selected as process output measure of performance. A Taguchi approach is employed to gather experimental data. Then, based on signal-to-noise (S/N) ratio, the best sets of cutting parameters and tool geometry specifications have been determined. Using these parameters values, the surface roughness of AISI1045 steel parts may be minimized. [12] Sijo M.T, Biju.N found that for efficient use of machine tools, optimum cutting parameters are required. The turning process parameter optimization is highly complex and time consuming. In this paper taguchi parameter optimization methodology is applied to optimize cutting parameters in turning. [13] Hari Singh investigated an optimal setting of turning process parameters –cutting speed, feed and depth of cut, which may result in optimizing tool life of TiC coated carbide inserts while turning En24 steel (0.4 % C). [15] Hari Singh, Pradeep Kumar developed a experimental based approach to obtain an optimal setting of turning process parameter that may yield optimal tool wear to titanium carbide coated inserts while machining EN 24 steel. [16] Dr. S.S.Mahapatra Amar Patnaik Prabina Ku. Patnaik stated that In order to enable manufacturers to maximize their gains from utilizing hard turning, an accurate model of the process must be constructed. Several statistical modeling techniques have been used to generate models including regression and Taguchi methods for that. [17] Kompan Chomsamutr, Somkiat Jongprasithporn observed that the optimal cutting design for turning can be done to meet the product specifications with parameter design. The problem of spare parts manufacturing are optimum parameters for milling and turning that effect to the life cycle and cost of products. The research methodology was investigated by turning with design parameters and analyze by the Taguchi method. [18] One of the most commonly used methods for optimizing the turning process is the Taguchi approach with the cutting force most commonly selected as the target quality characteristic to investigate the effect of various process parameters on the product.

There were two purposes of this research. The first was to demonstrate a systematic procedure of using Taguchi parameter design in process control of turning machines. The second was to demonstrate a use of the Taguchi parameter design in order to identify the optimum cutting force performance and evaluation with a particular combination of cutting parameters in a turning operation..

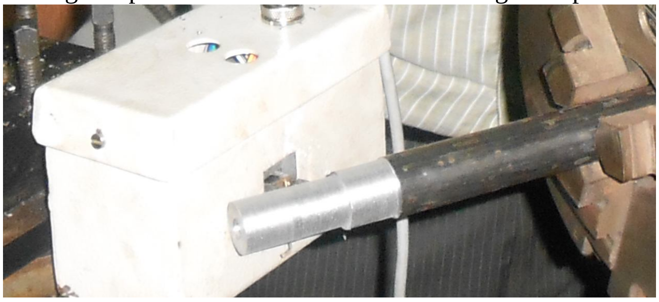

Fig. 1 Experimental set up

II. EXPERIMENTATION

The cutting experiments were carried out on a Panther 1350 Lathe under different cutting conditions are shown in Fig. 1. Machining tests were performed on an EN 8 bar having Diameter Φ 30mm. Experimental data and chemical composition of EN 8 steel which was used in experiments as shown in the Table 1 and Table 2. And Cutting speeds were selected by preliminary experiments conducted on the machine. Tool material for this study was High Speed Steel (HSS-M2), Carbide and Cermet having different tool shapes A1, A2 and A3 respectively. A strain gauge type Dynamometer was used to measure thrust force (F_t) and feed force (F_f). Each experiment was repeated three times and results were recorded for thrust force and feed force. Taguchi parameter optimization method was used to evaluate the best possible combination for minimum cutting force during turning operation.

C	Mn	Si	P	S
0.4	0.8	0.25	0.015	0.015

Table 1 Chemical composition

Process parameter	Levels		
	L1	L2	L3
Tool shape and Material (A)	HSS-M2	Carbide	Cermet
Cutting speed (B)	256	384	512
Depth of cut (C) mm	0.5	0.75	1
Feed (D) mm/rev	0.065	0.13	0.26

Table 2 Experimental data

Determination of optimal cutting parameters:

In this section, the use of an orthogonal array to reduce the number of cutting experiments for determining the optimal cutting parameters is reported. Results of the cutting experiments are studied by using the S/N ratio and ANOVA analyses. Based on the results of the S/N ratio and ANOVA analyses, optimal cutting parameters for cutting force are obtained .

III. SELECTION OF AN ORTHOGONAL ARRAY:

To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. Once the degrees of freedom required are known, the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this study, an L9 orthogonal array was used. This array has twenty six degrees of freedom and it can handle three-level process parameters. Each cutting parameter is assigned to a column and twenty seven cutting parameter combinations are available. Therefore, only twenty seven experiments are required to study the entire parameter space using the L9 orthogonal array. Each parameter was analysed at three levels in order to explore non-linear relationship of process parameter. Designed experiments were based on the orthogonal array (OA) technique, which is a fractional factorial with pair-wise balancing property. The variation of response is examined using an appropriately chosen S/N ratio, depending on the objective function. In present study quality characteristic is a force on tool due to variation of process parameters in designed range to minimize cutting force. So, S/N ratio for 'Lower the better' type of response was used and is given by

$$\text{S/N ratio} = -10 \log\left[\frac{1}{n}\sum_{i=0}^{n} Y_i^2\right] \qquad (1)$$

Where, i = no. of trial,

Y_i = measured value of quality characteristic for i^{th} trial condition,

n= no. of repetitions.

Signal to noise ratios were calculated using above equation for each of the nine experimental conditions. Factors affected can be separated out in terms of S/N ratio and in terms of mean response.

The experimental layout for the three cutting parameters using the L9 orthogonal array is shown in Table 3.

IV. ANALYSIS OF THE SIGNAL-TO-NOISE (S/N) RATIO:

As mentioned earlier, there are three categories of performance characteristics, i.e., the lower-the-better, the higher-the-better, and the nominal-the-better. To obtain optimal machining performance, the lower-the-better performance characteristic for cutting force should be taken for obtaining optimal machining performance. Table 3 shows the experimental results for cutting forces and the corresponding S/N ratio using Eq. (1). Since the experimental design is orthogonal, it is then possible to separate out the effect of each cutting parameter at different levels. The mean S/N ratio for each level of the cutting parameters can be computed. The mean S/N ratio for each level of the cutting parameters is summarized and called the mean S/N response table for cutting force Table 4 In addition, the total mean S/N ratio for the nine experiments is also calculated and listed in Table5

Experiment no.	Tool shape and material	Cutting speed	Depth of cut	Feed	Cutting Force, Thrust Force (Ft)			Cutting Force, Feed Force (Ff)			Z force S/N ratio	Y force S/N ratio
					Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3		
1	1	1	1	1	147	147	157	78	88	88	-43.55	-38.6
2	1	2	2	2	265	275	275	118	128	147	-48.67	-42.37
3	1	3	3	3	608	628	618	226	216	245	-55.82	-47.21
4	2	1	2	3	314	334	363	118	128	137	-50.56	-42.13
5	2	2	3	1	235	245	235	98	108	108	-47.56	-40.4
6	2	3	1	2	284	294	304	137	147	147	-49.38	-43.16
7	3	1	3	2	402	422	441	196	206	216	-52.51	-46.28
8	3	2	1	3	314	294	304	137	128	137	-49.66	-42.55
9	3	3	2	1	275	265	304	108	98	128	-49	-40.97

Table 3 L9 Orthogonal array experimental data

Parameter	S/N ratio for Thrust force (F_Z)			S/N ratio for Feed Force (F_Y)		
	L1	L2	L3	L1	L2	L3
Tool shape and material (A)	-49.35	-49.17	-50.39	-42.73	-41.9	-43.27
Cutting speed (B)	-48.87	-48.63	-51.4	-42.34	-41.77	-43.78
Depth of cut (C)	-47.53	-49.41	-51.96	-41.44	-41.82	-44.63
Feed (D)	-46.7	-50.19	-52.02	-39.99	-43.94	-43.96

Table 4 Result for individual characteristic S/N ratio, S/N ratio for average output quality parameter

V. RESULTS

Mean response referring to average values of performance characteristics for each parameter at different level were calculated (Table 4). Thrust force Z has been found minimum at 2nd level of parameter A (Tool shape and material), 2nd level of parameter B (cutting speed), 1st level of parameter C (Depth of cut), 1st level of parameter D (Feed). Similarly Feed force Y has been found minimum at 2nd level of parameter A (Tool shape and material), 2nd level of parameter B (cutting speed), 1st level of parameter C (Depth of cut), 1st level of parameter D (Feed).

Analysis of variance (ANOVA) and significance of parameters:
Estimation of optimum performance characteristics:

Optimum Thrust force Z (μF_Z) was predicted at selected levels of significant parameters (A_2, B_2, C_1, D_1). Estimated Thrust force Z (μF_Z) can be calculated as

$$\mu F_Z = A_2 + B_2 + C_1 + D_1 - 3\,T_{FZ}$$

Where, μF_Z is optimum thrust force Z, and T_{FZ} is overall mean of thrust force Z with parameter at optimum level. From Table 2 Mean A2=290, Mean B2=271, Mean C1=250, Mean D1=223, and mean T_{FZ}=324.

Hence,
$$\mu F_Z = 290+271+250+223- 3(324) = 62$$

Optimum Feed force Y (μF_Y) was predicted at selected levels of significant parameters (A_2, B_2, C_1, and D1). Estimated Feed force Y (μF_Y) can be calculated as

Where, μF_Y is optimum feed force Y, and T_{FY} is overall mean of feed force Y with parameter at optimum level. From Table 2. Mean A2=125, Mean B2=123, Mean C1=121, Mean D1=100, and mean T_{FY}=141.

Hence,
$$\mu F_Y = A_2 + B_2 + C_1 + D_1 - 3\,T_{FY} = 125+123+121+100- 3(141) = 46$$

Confirmation Experiments:

Nine experiments (3 repetitions for each of 3 experiments) at optimal setting were conducted during turning operation recommended by investigation for thrust force Z, and feed force Y. At investigated parameters optimal levels, following was found: average thrust force, 62N; average feed force, 46N.

Source	Sum of Squares (SS)	Degrees of freedom (f)	Variance (V)	F-ratio	Pure sum of squares (SS')=Sa- (ve*Fa)	Contribution on (P), %
A	16390.09	2	8195.05	41.29	15993.14	3.789
B	77927.53	2	38963.77	196.32	77927.53	18.46
C	150391.07	2	75195.54	378.87	150391.07	35.63
D	173819.75	2	86909.88	437.89	173819.75	41.18
E (error)	3572.52	18	198.47		3969.47	0.94
T (total)	422100.96	26			422100.96	100

Table 5 ANOVA for thrust force

Source	Sum of Squares (SS)	Degrees of freedom (f)	Variance (V)	F-ratio	Pure sum of squares (SS')=Sa- (ve*Fa)	Contribution on (P), %
A	3478.18	2	1739.09	15.83	3258.52	5.925
B	6583.9	2	3291.95	29.97	6583.9	11.97
C	20091.65	2	10045.83	91.47	20091.65	36.53
D	22865.33	2	11432.67	104.09	22865.33	41.58
E (error)	1976.94	18	109.83		2196.60	3.99
T (total)	54996	26			54996	100

Table 6 ANOVA for feed force

VI. CONCLUSION

Optimum parameter level for minimum thrust force Z are 2nd level of parameter A, 2nd level of parameter B, 1st level of parameter C and 1st level of parameter D. This implies that the level of parameters at designated levels as A_2, B_2, $C_{1,}$ D_1 are the best combination to get minimum thrust force Z in turning of EN 8 bar. Optimum parameter level for minimum feed force Y are 2nd level of parameter A, 2nd level of parameter B, 1st level of parameter C and 1st level of parameter D. This implies that the level of parameters at designated levels as A_2, B_2, $C_{1,}$ D_1 are the best combination to get minimum thrust force Z in turning of EN 8 bar.

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