# Optimization of Turning Process Parameters for EN24 Steel Alloy using Experimental Design

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***How to cite this paper***: C. Shobha | Dr. K. Ganesh Babu | N. Mohammed Raffic "Optimization of Turning Process Parameters for EN24 Steel Alloy using Experimental Design" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-3 | Issue-3, April 2019, pp.574-578, URL: http://www.ijtsrd.com/papers/ijtsrd22911.pdf

**IJTSRD22911**



**ABSTRACT**

The overarching aim of this work is to optimize the various process parameters involved in turning of EN 24 Steel alloy using Tungsten Carbide inserts to enhance the tool life and surface finish. Appropriate or random selection of cutting parameters have serious effect over the final output responses such as Surface Roughness , Tool life and other related properties of both the work piece and tool . Controlling the effective parameters is the need of the hour in any product manufacturing system. In the present work three different turning process parameters such as Cutting Speed, Feed rate and Depth of cut are considered for optimization study by varying them with three levels. The experimental design matrix for conducting experiments were prepared using Taguchi's Orthogonal Array and calculation of Signal to Noise ratio is done for identifying the best combination of parameters. Through ANOVA it is observed that Cutting speed is the most influencing parameter with a maximum contribution of 80.23% comparing to the other input parameters over surface roughness. The S/N ratio method (Smaller is Better) have shown that the parameter level combination A3B1C1 (2000m/min, 0.05 mm/rev, 0.2 mm) can provide good surface finish of the material with enhanced tool life.

***Keywords:*** *EN-24 Steel, Orthogonal Array, Optimization, Taguchi Technique*

## 1. Introduction

Manufacturing is term which used to describe an activity which converts a completed design in to tangible real life products or components. A manufacturing process which is considered consists many parameters involved and each parameter selected for manufacturing the product leads to the degree of acceptability and rejection of manufactured products. The process of identifying the correct combination of parameters involved in a manufacturing process is an essential task before proceeding to the process. Turning is a process which is performed in lathe to reduce the diameter of an work piece using a single point cutting tool to move over the work piece. Various parameters such as Cutting speed, Depth of cut, Feed rate, Nose radius, temperature of the lubricant are generally considered as parameters for optimization by various authors in their study [1-4].

The material considered for study by different authors are Steel with different grades, Composite materials etc. The effect of cutting parameters is reflected on surface roughness, surface texture and dimensional deviations of the product. Surface roughness is a measure of the technological quality of a product and factor that greatly influences manufacturing cost. It describes the machined surfaces and combined with surface texture [1]. Various techniques such as Taguchi's Experimental Design , Response Surface Methodology , Definitive Screening Design , Genetic Algorithm are generally adopted for optimization of machining parameters. Taguchi method seems to be the most suitable approach to determine the optimal cutting parameters for turning operations in a machine shop [1].

## 2. Literature Survey

**L.B. Abhang (2012)** et.al has made an attempt to study the effect of three different parameters namely Feed rate, Depth of Cut and Lubricant Temperature while turning out EN-31 steel using tungsten carbide inserts. The authors have adopted Taguchi's Experimental method and ANOVA analysis to find out the optimal parameter combination and also the influencing parameter over the calculated output response surface roughness. By means of $L_9$ Orthogonal Array nine different experiments have been conducted and surface roughness of individual work piece have been measured and the measured data is inputted to MINITAB software to calculate Signal to Noise ratio. The authors have concluded that Lubricant temperature is the predominant factor which affects the surface finish of the machined work piece than other considered factors. Lubricant temperature is found to be most influencing factor with a maximum contribution of 79.29% followed by Feed rate with 18.05% and Depth of Cut with 0.01%. Low feed rate (0.05 mm/rev) , Medium depth of cut (0.4 mm) and low lubricant temperature (10°C) are recommended to obtain superior surface finish than other experimental conditions.

**Massimo Fornasier (2014)** et.al has investigated the effect of cutting parameters Cutting speed , Feed rate , Depth of cut and combined equal weight fraction of SiC-Gr particulates on turning of Al-SiC-Gr hybrid composites. The authors have developed a second order quadratic model using Response Surface Methodology for identifying the influencing parameter over the measured output response surface roughness. The authors have measured the surface roughness parameter Ra using Mitutoyo Surf test SJ-201 for the 18 different experiments conducted as per RSM technique using Design Expert software. The results obtained from the surface roughness measurement are inputted in to the software to identify the influencing parameter and ANOVA is used to find the contribution of all the influencing factors. The authors have concluded from their observation that high cutting speed , low feed rate and depth of cut with increase in Sic- Gr particles provides a better surface finish than other combinations.

**Dhiraj K Patel (2014)** et.al has reported through a review about the influencing parameters on Material removal rate, Power consumption and Surface roughness of EN-19 steels in turning operation using taguchi method. The authors have reported that four different machining parameters namely Spindle Speed (N), Feed (F), Depth of Cut (D) and Nose Radius (NR). Taguchi technique as the common tool considered by the authors to identify the influencing parameter from the factors considered and their levels. The authors have suggested that a high cutting speed, low feed rate and medium depth of cut can produce a better surface finish and taguchi technique is found to be most efficient technique for the optimization of machining parameters for the output responses in turning of steel with various grades.

**Sayak Mukherjee (2014)** et.al has made a study to optimize the material removal rate during turning of SAE1020 with carbide cutting tool in EMCO concept Turn 105 CNC lathe using taguchi technique. The objective of the study is to identify the turning parameters which maximize the material removal rate by conducting the experiments as per orthogonal array. Cutting speed, Feed rate and Depth of cut are the parameters considered by varying with five different levels. L25 orthogonal array was used to conduct the experiments. The authors have concluded that depth of cut is the most influencing factor followed by feed with a maximum contribution of 64.59% and 29.98% subsequently. The authors have suggested that increase in depth of cut may increase the material removal rate at a considerable level. From the levels selected for cutting speed it is not fond to be influencing over the final output response Material removal rate.

## 3. Materials and Methods

The material of the specimen for the present study is prepared from EN -24 steel alloys in the form of cylindrical bars with dimensions of 25 mm diameter and 100 mm length. The specimen is prepared from lengthy bars by cutting using power saw and subsequently initial turning operation is performed to achieve the required dimension. The grade is a nickel chromium molybdenum combination - this offers high tensile steel strength, with good ductility and wear resistance characteristics. With relatively good impact properties at low temperatures, EN24 is also suitable for a variety of elevated temperature applications. EN24 Engineering Steel is easy to treat and temper and is supplied hardened and tempered. The alloy offers a good combination of strength, ductility and wears resistance. It is a very high strength alloy engineering steel. Its typical applications include High strength shafts, Punches & dies, Drill bushings, Retaining rings and gears. The various elements present in the material with its composition are listed in Table.3.1

**Table 3.1 EN24 Element Composition**

| S. No | Element | Composition |
|---|---|---|
| 1 | Carbon | 0.36-0.44 % |
| 2 | Manganese | 0.45-0.70 % |
| 3 | Silicon | 0.10-0.35 % |
| 4 | Sulphur | 0.04% |
| 5 | Phosphorus | 0.04% |
| 6 | Chromium | 1.00-1.40 % |
| 7 | Nickel | 1.30-1.70% |
| 8 | Molybdenum | 0.20-0.35% |

## 4. Orthogonal Arrays (OA)

Taguchi Orthogonal Array (OA) design is a type of general factorial design. It is a highly fractional orthogonal design that is based on a design matrix proposed by Dr. Genichi Taguchi and allows you to consider a selected subset of combinations of multiple factors at multiple levels. Taguchi Orthogonal arrays are balanced to ensure that all levels of all factors are considered equally. For this reason, the factors can be evaluated independently of each other despite the fractionality of the design. In the present study three different parameters Cutting Speed, Feed and Depth of Cut are considered with three different levels. Hence $3^3$ is the type of 3 Level design with three factors involved and $L_9$ Orthogonal Array is considered.

## 5. Experimental Conditions and Planning of Experiments

A total of 9 experiments with varying turning parameter combination have been considered in the present work. The other parameters or attributes which are kept constant for all the 9 different experiments are summarized in Table No. 5.1

**Table No. 5.1 Constant Experimental Conditions**

| S. No | Parameter | Description |
|---|---|---|
| 1 | Work Material | EN-24 steel alloy, |
| 2 | Dimension | Length = 100 mm Diameter = 25 mm |
| 3 | Tool holder | WIDAX, SCLCR12 FOGT3 |
| 4 | INSERT configurations | CNMA 120412 (Tungsten Carbide Insert) (α=60, γ0=-60, λ=-60, kr=950, Єr=800, r=1.2mm) |
| 5 | Nose radius | 1.2 mm |

The experimental work is carried out in centre lathe with different process parameter combinations by conducting straight turning operation. A steel bar of 25 mm diameter and 100 mm length is considered for the turning process. The various input parameters to be varied in different levels is shown in Table No. 5.2.

**Table No. 5.2 Input Parameters and Levels**

| Symbol | Cutting Parameters | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| A | Cutting Speed | m/min | 1500 | 1700 | 2000 |
| B | Feed Rate | mm/rev | 0.05 | 0.1 | 0.15 |
| C | Depth of Cut | mm | 0.2 | 0.4 | 0.6 |

The experimental design matrix prepared using Minitab software as per $L_9$ orthogonal array with coded and uncoded factors are shown in Table No. 5.3

**Table No. 5.3 Experimental Design Matrix**

| Run. No | A | B | C | A | B | C |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1500 | 0.2 | 0.05 |
| 2 | 1 | 2 | 2 | 1500 | 0.4 | 0.1 |
| 3 | 1 | 3 | 3 | 1500 | 0.6 | 0.15 |
| 4 | 2 | 1 | 2 | 1700 | 0.2 | 0.1 |
| 5 | 2 | 2 | 3 | 1700 | 0.4 | 0.15 |
| 6 | 2 | 3 | 1 | 1700 | 0.6 | 0.05 |
| 7 | 3 | 1 | 3 | 2000 | 0.2 | 0.15 |
| 8 | 3 | 2 | 1 | 2000 | 0.4 | 0.05 |
| 9 | 3 | 3 | 2 | 2000 | 0.6 | 0.1 |

**Fig 5.1 Specimen collection**

The 9 different specimens machined by turning process are further checked for surface roughness in order to evaluate the effect of process parameters over the output response. The measure of surface roughness is conducted using portable stylus-type profilometer, Talysurf (Taylor Hobson, Surtronic 3+ and UK).The Figure 5.2 shows the Profilometer used for measuring surface roughness

**Figure 5.2 Surface roughness measurement**

**6. Results of Statistical Analysis**

The surface roughness obtained for the machined work pieces are inputted into MINITAB software for calculating the Signal to Noise Ratio values by considering the Smaller is better method as the surface roughness value should be low in general. The S/N ratio calculated for the different specimens are shown in Table No. 6.1

**Table No 6.1 Signal to Noise Ratio**

| Run. No | Surface Roughness | Signal to Noise Ratio |
|---|---|---|
| 1 | 0.451 | 6.9357 |
| 2 | 0.302 | 10.3999 |
| 3 | 0.424 | 7.4527 |
| 4 | 0.857 | 1.3404 |
| 5 | 0.743 | 2.5802 |
| 6 | 0.711 | 2.9626 |
| 7 | 0.865 | 1.2597 |
| 8 | 0.897 | 0.9442 |
| 9 | 0.934 | 0.5931 |

From the experimental values of Surface roughness the parameter combination **A1B2C2 (1500 m/min, 0.1 mm/rev, 0.4mm)** is found to have low surface roughness value. Later to that Signal to Noise Ratio plot is obtained by considering smaller is better method and it is observed that the parameter combination A3B1C1 (2000m/min, 0.05 mm/rev, 0.2 mm) provides lesser value for surface roughness measurement. A confirmation experiment is conducted from the obtained setting and it has shown low surface roughness value comparing to the values obtained through experimental work.

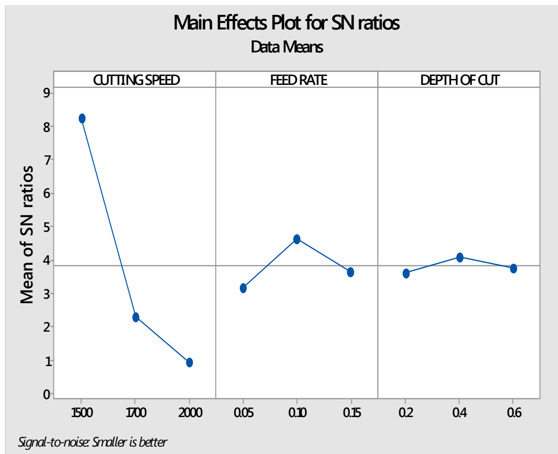


**Figure No. 6.1 Signal to Noise Ratio Plot**

The formulae to calculate Signal to Noise ratio by Smaller the better method is given by equation 6.1

$$\eta = -10\log\,(M.S.D) \quad (6.1)$$

M.S.D- Mean Standard Deviation

**Table 6.2 Mean S/N Ratio values**

| Mean S/N ratio (dB) | | | | | |
|---|---|---|---|---|---|
| Symbol | Cutting Parameter | Level 1 | Level 2 | Level 3 | Delta |
| A | **Cutting Speed** | 8.262 | 2.294 | 0.9323 | **7.331** |
| B | Feed Rate | 3.178 | 4.641 | 3.6695 | 1.462 |
| C | Depth of Cut | 3.641 | 4.111 | 3.7642 | 0.497 |

The Table 6.2 shows the mean values of S/N ratio obtained through Minitab Software and it shows that cutting speed is the predominant factor than other two parameters to obtain better surface finish.

The results are further considered for ANOVA and regression analysis for identifying the influencing parameter and its contribution over the measured response. The Table 6.3 shows the results of ANOVA for surface roughness and from the values of p-test less than 0.05 it can be understood that Cutting speed is the only parameter which influences the response variable surface roughness with a maximum contribution of 80.23%.

**Table 6.3 ANOVA results of Surface Roughness**

| Source | DF | Adj SS | Adj MS | F- Value | P-Value | % Contribution |
|---|---|---|---|---|---|---|
| Regression | 3 | 0.357292 | 0.119097 | 6.95 | 0.031 | |
| **Cutting Speed** | 1 | 0.355411 | 0.355411 | 20.74 | **0.006** | **80.23** |
| Feed Rate | 1 | 0.001768 | 0.001768 | 0.1 | 0.761 | 0.41 |
| Depth of Cut | 1 | 0.000113 | 0.000113 | 0.01 | 0.939 | 0.02 |
| Error | 5 | 0.085676 | 0.017135 | | | 19.34 |
| Total | 8 | 0.442968 | | | | 100 |

The regression analysis is carried out to check the results obtained from ANOVA. Both ANOVA and Regression analysis performs p-test and it considers the p-test results with values less than 0.05 is found to be the significant one which influences the output response. The regression analysis provides an equation to calculate surface roughness theoretically. The table 6.4 shows the regression results of surface roughness.

**SURFACE ROUGHNESS = -0.946 + 0.000967 CUTTING SPEED - 0.34 FEED RATE - 0.022 DEPTH OF CUT (6.2)**

**Table 6.4 Regression Analysis of Surface Roughness**

| Term | Coef | SE Coef | T-Value | P-Value | VIF |
|---|---|---|---|---|---|
| Constant | -0.946 | 0.4 | -2.36 | 0.064 | |
| **Cutting Speed** | 0.000967 | 0.000212 | 4.55 | **0.006** | 1 |
| Feed Rate | -0.34 | 1.07 | -0.32 | 0.761 | 1 |
| Depth of Cut | -0.022 | 0.267 | -0.08 | 0.939 | 1 |

The p-test conducted through regression analysis also ensures that cutting speed is the only parameter which affects the output response considerably than other turning process parameters.

**Conclusion**

The following points is considered for concluding the present work

1. The present work has utilized MINITAB software to prepare the experimental design matrix and ANOVA methodology to identify the most influencing parameter over the output response.
2. From the Input parameters considered for Optimization, Cutting Speed is found to be most significant factor over surface roughness with a contribution percentage of 80.23% than Depth and Feed rate.
3. It is observed that the Parameter combination A3B1C1 (2000 m/min, 0.05 mm/rev, 0.2 mm) can provide better results in terms of enhanced tool life and reduced surface roughness.
4. From the calculated Mean Signal to Noise ratio value, ANOVA and Regression analysis methods it is found that Cutting Speed is the most influencing parameter over the output response.
5. In the present study, only three parameters have been considered for Optimization such as Cutting Speed, Feed and Depth of Cut with three levels. Hence Taguchi's $L_9$ Orthogonal Array is considered. By including other parameters such as Lubricant Temperature, Nose radius etc and increasing the number of experiments more detailed study about the influence of other parameters and their interactions will be known.
6. Other techniques such as Response Surface Methodology, Genetic Algorithm etc., may be utilized for comparison for the results obtained from Taguchi technique as considered by other authors.

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