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# Effect of Process Parameters and Optimization of MRR in Turning of EN8 Steel on CNC Lathe using Response Surface Methodology

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***Abstract: In order to meet the increasing demand of manufacturing complicated components of high accuracy in large quantities, sophisticated technological equipment and machinery have been developed. The CNC machines often employ the various mechatronics elements that have been developed over the years. The control of a machine tool by means of stored information through the computer is known as Computer Numerically Controlled. In this work, turning operation has been carried out on CNC lathe machine. EN 8 steel bright bars have been used for the experimental analysis. The aim of this research is to optimize the three process parameters such as cutting speed, depth of cut and feed rate for the maximum value of MRR. Response Surface methodology of Design of Experiment (DOE) has been applied for getting the combination of parameters for the experiments. Stat graphics Centurion VI software has been used for the analysis of results and optimizing the response i.e. MRR by applying Response Surface Methodology. Analysis of Variance (ANOVA) has been done with the help of Minitab-18 software to investigate the contribution of process parameters in MRR. The results from ANOVA table show that the depth of cut contributes more than the remaining factors. The ANOVA also investigates that depth of cut and cutting speed are significant factors and feed rate is not that significant in Material Removal Rate. A mathematical model based on Regression analysis has been developed for predicting the MRR. This model gives the linear equation of MRR in terms of cutting speed, depth of cut and feed rate. Results from this model show that the predicted values of MRR are very close to experimental values and the percentage error for the optimum set of parameters is very less.***
***Keywords: CNC, Turning, MRR, ANOVA, DOE, Depth of cut***

## I. INTRODUCTION

In order to meet the increasing demand of manufacturing complicated components of high accuracy in large quantities, sophisticated technological equipment and machinery have been developed. The CNC machines often employ the various mechatronics elements that have been developed over the years. The control of a machine tool by means of stored information through the computer is known as Computer Numerically Controlled. The turning machines are, of course, every kind of lathes. Lathes used in manufacturing can be classified as engine, turret, automatics, and numerical control etc. They are heavy duty machine tools and have power drive for all tool movements. They commonly range in size from 12 to 24 inches swing and from 24 to 48 inches centre distance, but swings up to 50 inches and centre distances up to 12 feet are not uncommon. Many engine lathes are equipped with chip pans and built-in coolant circulating system. Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters.

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface. The three main factors in any simple turning operation are cutting speed, feed, and depth of cut. Other factors such as types of material and variation in tool material have a large influence, of course, but these three are the basic factors which the operator can change by adjusting the controls, at the mean time of machining. To increase the MRR in turning operation is always desirable and the development of many optimization techniques has made it possible. Optimization in the engineering world is the selection of a best element (with regard to some criterion) from some set of available alternatives. It is the selection of a best element (with regard to some criterion) from some set of available alternatives. Optimization in the production field is the practice of making changes or adjustments to a product to make it more desirable. Optimization it is also defined as the process of finding the conditions that give the minimum or maximum value of a function, where the function represents the effort required or the desired benefit. Statistical approaches such as RSM can be employed to maximize the production of a special substance by optimization of operational factors. In contrast to conventional methods, the interaction among process variables can be determined by statistical techniques. Response surface methodology uses statistical models, and therefore practitioners need to be aware that even the best statistical model is an approximation to reality

## II. EXPERIMENTAL SETUP AND METHODOLOGY

### *A. Design of Experiment*

The design of experiments technique is very powerful tool, helped not only in modelling and also helped analysing the effect of process variables on the response variables. The response variable (or parameter of interest) is an unknown function of the process variables (or controllable parameters or as design factors). A Stat graphics generated design was used with three levels of each of the three design factors. The process variables along with their values on different levels are listed in the tables which shown later. The number of experiment was 27 for each set of variable factors.

### *B. Steps for the Experiments*

*1)* Inspection and preparing the CNC lathe MCL 12 ready to perform the machining operation.
*2)* Designing the program using M-Codes and G-codes on CNC lathe MCL 12 machine
*3)* Cutting EN8 bright bars by power saw to get desired dimension of the work pieces
*4)* Calculating diameter of each specimen by the high precision vernier caliper.
*5)* Experiment has been designed using RSM technique of design of experiment.
*6)* Perform turning operation on work piece in selected cutting process parameters like: cutting speed (A), feed rate (B) and depth of cut(C) on the basis on DOE table.
*7)* Measured diameter of each machined bar by vernier caliper.
*8)* Calculate the MR
*9)* Optimize the results with RSM technique.

### *C. Experimental Setup*

Experiments have been performed on a CNC MCL12 2D machine manufactured by 3D Technologies. EN8 Bright bars of medium carbon steel alloy of diameter 20 mm and length 1200 mm have been used as material. En8 bright bar has high tensile strength and used as shafts, Gears, studs, Bolts, Keys etc. EN8 is a graded and is readily machinable in any condition. Its surface hardness to increase wear resistance is in the range of 50-55 HRC via induction process.

### *D. Process Variables and their Levels*

The experiments are performed on CNC lathe MCL 12 selected. The tool and material selected were carbide tool and EN8 Bright bar respectively. Three process parameters which are cutting speed, depth of cut and feed rate have been decided in the study.

Table1. Parameters and Their Levels for Experiment

| S.No | Parameter | L1 | L2 | L3 |
|---|---|---|---|---|
| 1 | Cutting speed(A)(RPM) | 600 | 900 | 1200 |
| 2 | Feed Rate(B)(mm) | 0.15 | 0.20 | 0.25 |
| 3 | Depth of Cut(C)(mm/rev.) | 0.1 | 0.2 | 0.3 |

### *E. Material Removal Rate*

The MRR (Material Removal Rate) in straight turning operation is the quantity of material per unit metal is removed in unit time in mm3/min. The value of MRR can be found manually with the help of given equation.

$$MRR= \pi D_{avg}\, d\, f\, N$$

$D_{avg}$= average dia of work piece$(D_o+D_f)/2$, d= Depth of cut, f= Feed rate, N= RPM

### *F. Experimental Details and Data Collection*

Experiments have been carried out using RSM technique, experimental design which consists of 27 combinations of cutting speed (A), feed rate (B) and depth of cut(C). EN8 bright bars (of diameter 20mm and length 1200mm) required for conducting the experiment have been prepared first. Then, using different levels of the process parameters 27 specimens have been turned accordingly on CNC lathe machine. After machining, diameter of each machined parts have been again measured precisely with the help of the vernier calipers. The results of the experiments have been shown in Table by using material removal rate calculations.

Table 2. Observation table

| S. No. | Cutting Speed(RPM) | Depth of Cut(mm) | Feed Rate(mm/rev) | MRR(mm3/min) |
|---|---|---|---|---|
| 1 | 600 | 0.3 | 0.25 | 2783.61 |
| 2 | 1200 | 0.1 | 0.15 | 1124.748 |
| 3 | 1200 | 0.2 | 0.2 | 2984.256 |
| 4 | 600 | 0.2 | 0.2 | 1492.128 |
| 5 | 900 | 0.1 | 0.2 | 1124.748 |
| 6 | 900 | 0.3 | 0.25 | 4175.415 |
| 7 | 900 | 0.1 | 0.15 | 843.561 |
| 8 | 600 | 0.1 | 0.2 | 749.832 |
| 9 | 600 | 0.3 | 0.2 | 2226.888 |
| 10 | 900 | 0.3 | 0.2 | 3340.332 |
| 11 | 600 | 0.1 | 0.25 | 937.29 |
| 12 | 1200 | 0.1 | 0.25 | 1874.58 |
| 13 | 1200 | 0.1 | 0.2 | 1499.664 |
| 14 | 600 | 0.3 | 0.15 | 1670.166 |
| 15 | 600 | 0.2 | 0.15 | 1119.096 |
| 16 | 900 | 0.2 | 0.2 | 2238.192 |
| 17 | 1200 | 0.3 | 0.25 | 5567.22 |
| 18 | 600 | 0.2 | 0.25 | 1865.16 |
| 19 | 900 | 0.2 | 0.25 | 2797.74 |
| 20 | 900 | 0.2 | 0.15 | 1678.644 |
| 21 | 600 | 0.1 | 0.15 | 562.374 |
| 22 | 1200 | 0.2 | 0.15 | 2238.192 |
| 23 | 1200 | 0.3 | 0.2 | 4453.776 |
| 24 | 900 | 0.3 | 0.15 | 2505.249 |
| 25 | 1200 | 0.3 | 0.15 | 3340.332 |
| 26 | 900 | 0.1 | 0.25 | 1405.935 |
| 27 | 1200 | 0.2 | 0.25 | 3730.32 |

## III. RESULTS AND DISCUSSIONS

### *A. Analysis of Experiments*

For the analysis purpose the Stat graphics software has been used. The value of MRR has been calculated with the assist of equation number 3.8 and has been optimized with the assist of RSM optimization technique.

1) *Least Square Means for MRR:* It shows the usual error of each mean, which is a measure of its sampling variability. The rightmost two columns show 95.0% confidence intervals for each of the means. You can display these means and intervals by selecting Means Plot from the list of Graphical Options. This given table shows the mean MRR for each level of the factors.

Table 3 Least Squares Means for MRR with 95.0% Confidence Intervals

| Level | Count | Mean | Stnd. Error | Lower Limit | Upper Limit |
|---|---|---|---|---|---|
| GRAND MEAN | 27 | 2234.42 | | | |
| Cutting Speed | | | | | |
| 600 | 9 | 1489.62 | 129.977 | 1218.49 | 1760.74 |
| 900 | 9 | 2234.42 | 129.977 | 1963.3 | 2505.55 |
| 1200 | 9 | 2979.23 | 129.977 | 2708.1 | 3250.36 |
| Depth of Cut | | | | | |
| 0.1 | 9 | 1124.75 | 129.977 | 853.62 | 1395.88 |
| 0.2 | 9 | 2238.19 | 129.977 | 1967.06 | 2509.32 |
| 0.3 | 9 | 3340.33 | 129.977 | 3069.2 | 3611.46 |
| Feed Rate | | | | | |
| 0.15 | 9 | 1675.82 | 129.977 | 1404.69 | 1946.95 |
| 0.2 | 9 | 2234.42 | 129.977 | 1963.3 | 2505.55 |
| 0.25 | 9 | 2793.03 | 129.977 | 2521.9 | 3064.16 |

2) *Analysis of Variance of MRR:* The given ANOVA table partitions the inconsistency in MRR into separate pieces for each of the effects. It then tests the statistical significance of each effect by comparing the mean square against an estimation of the experimental error. In this case, 6 effects have P-values a lesser amount of than 0.05, representing that they are notably different from zero at the 95.0% confidence level.

Table 4 Analysis of Variance for MRR

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Cutting Speed | 2 | 9985301 | 4992651 | 32.84 | 0.000 |
| Depth of Cut | 2 | 22089848 | 11044924 | 72.64 | 0.000 |
| Feed Rate | 2 | 5616732 | 2808366 | 18.47 | 0.000 |
| Error | 20 | 3040928 | 152046 | | |
| Total | 26 | 40732809 | | | |

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 389.931 | 92.53% | 90.29% | 86.39% |

The R-Squared statistic indicates that the model as fitted explains 95.53% of the variability in MRR. The adjusted R-squared statistic value which is more appropriate for compare models with dissimilar numbers of independent variables is 90.29%. The Durbin-Watson (DW) statistics test the residuals to conclude if here is any important correlation base on arrange in which they crop up in your data file. Since the P-value is greater than 5.0%, there is no signal of sequential autocorrelation in the residuals at the 5.0% consequence level. Above table shows that the contribution factor of depth of cut is higher than others i.e. 72.64%.the contribution factor of cutting speed is 32.84% so it has less effect on the MRR than depth of cut. On the contrary, feed rate has insignificant effect on MRR

*B. Main Effects of MRR*

As it is mentioned that there are three variables, which were taken in the analysis to evaluate the maximum MRR (Material Removing Rate) in the turning operation. It is also desirable to evaluate that which variables have the maximum contribution in it. And with the help of software it is now easy to plot a graph which shows all three variables and their effects on the MRR.

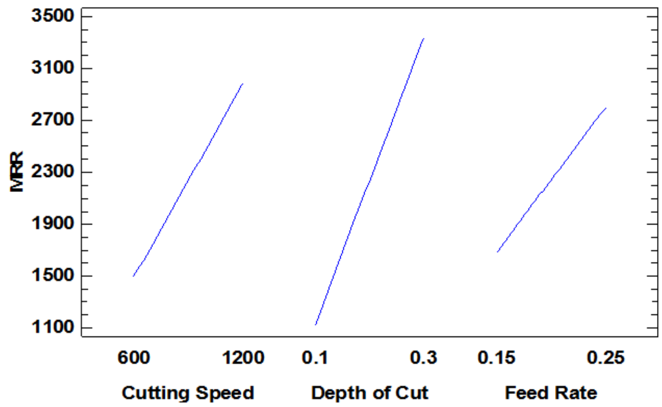


Figure 1. Effect of three variables on MRR

*C. Optimization of MRR*

This table shows the combination of factor levels which maximizes MRR over the indicated region. Use the Analysis Options dialog box to indicate the region over which the optimization is to be performed. It could possible to set the value of one or more factors to a constant by setting the low and high limits to that value.

Table 4.4 Optimized value of MRR

| Factor | Low | High | Optimum |
|---|---|---|---|
| Cutting Speed | 600.0 | 1200.0 | 1200.0 |
| Depth of Cut | 0.1 | 0.3 | 0.3 |
| Feed Rate | 0.15 | 0.25 | 0.25 |

Optimum value of MRR for the given optimum set of parameters = 5476.16 $mm^3$/min.

*D. Development of Mathematical Model*

Regression analysis is carried out to establish the relationship between factors and MRR. While performing the regression analysis, it has been assumed that factors and the response are linearly related to each other. A multiple regression analysis has been used to formulate the Cutting speed, depth of cut and feed rate to the MRR.

The response function, which represents the MRR, can be expressed as:

MRR = f (cutting speed, depth of cut, feed rate)

Taking into consideration linearity of response, a linear polynomial equation is fitted to experimental results. The general form of a regression mathematical model is as follow:

$$y = b0 + b_1x_1 + b_2x_2 + b_3x_3 \quad (1)$$

where, $y$ is response, $b_0$, $b_1$, $b_2$ and $b_3$ are regression coefficient and $x_1$, $x_2$, $x_3$ are process parameters i.e. wheel speed, depth of cut and table speed respectively. The coefficients values are calculated using Minitab -18 software. Using these values regression model is developed as shown below: This predicted equation is also written as:

MRR = - 4450 + 2.483 cutting speed + 11078 depth of cut + 11172 feed rate

*E. Comparison b/w Experimental and Predicted Values*

The predicted values have been compared with the experimental values for all set of experiments. The percentage error has been also calculated. The table which is shown below gives the Predicted values, Experimental values and Percentage error.

Table 4.5 Comparison between experimented and predicted values

| Experiment No. | Experimental Values | Predicted Values | Percentage error |
|---|---|---|---|
| 1 | 2783.61 | 3156.2 | 11.80501869 |
| 2 | 1124.748 | 1313.2 | 14.35059397 |
| 3 | 2984.256 | 2979.6 | -0.156262586 |
| 4 | 1492.128 | 1489.8 | -0.156262586 |
| 5 | 1124.748 | 1126.9 | 0.190966368 |
| 6 | 4175.415 | 3901.1 | -7.031734639 |
| 7 | 843.561 | 568.3 | -48.43586134 |
| 8 | 749.832 | 382 | -96.29109948 |
| 9 | 2226.888 | 2597.6 | 14.27132738 |
| 10 | 3340.332 | 3342.5 | 0.064861631 |
| 11 | 937.29 | 940.6 | 0.351903041 |
| 12 | 1874.58 | 2430.4 | 22.8694865 |
| 13 | 1499.664 | 1871.8 | 19.88118389 |
| 14 | 1670.166 | 2039 | 18.08896518 |
| 15 | 1119.096 | 931.2 | -20.17783505 |
| 16 | 2238.192 | 2234.7 | -0.156262586 |
| 17 | 5567.22 | 4646 | -19.82823935 |
| 18 | 1865.16 | 2048.4 | 8.945518453 |
| 19 | 2797.74 | 2793.3 | -0.158951777 |
| 20 | 1678.644 | 1676.1 | -0.15178092 |
| 21 | 562.374 | 176.6 | -218.4450736 |
| 22 | 2238.192 | 2421 | 7.550929368 |
| 23 | 4453.776 | 4087.4 | -8.963546509 |
| 24 | 2505.249 | 2783.9 | 10.00937534 |
| 25 | 3340.332 | 3528.8 | 5.340852414 |
| 26 | 1405.935 | 1685.5 | 16.58647286 |
| 27 | 3730.32 | 3538.2 | -5.4298796 |

It can be seen from the comparison between experimental values and predicted values by regression analysis that the predicted values are close to the experimental values as shown in table 4.6.

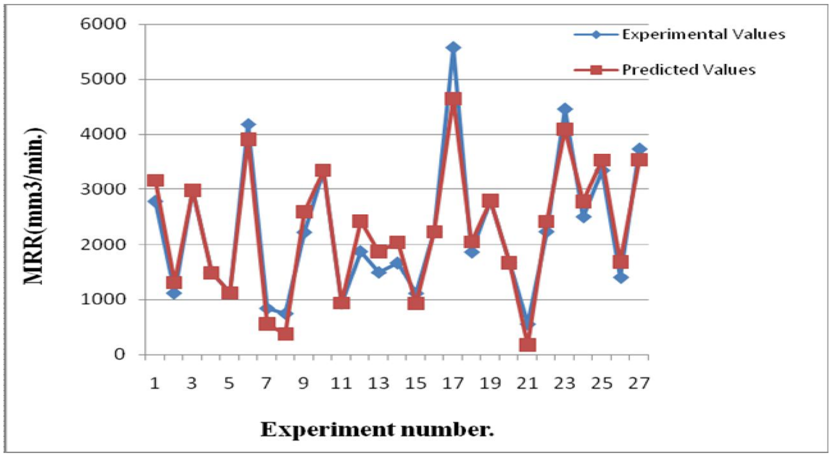


Figure 2. Differences between experimental and predicted values

## IV. CONCLUSIONS

Following conclusions have been drawn on the basis of experimental analysis

*A.* The effects of process parameters – cutting speed, depth of cut and feed rate have been analysed, and it has been found that all the factors contribute in obtaining maximum MRR but depth of cut plays an important role out all three variables.

*B.* Mathematical model has been evaluated using regression analysis to compare the experimental value with the predicted value and this model shows that the predicted values the much closer to experimental values and the percentage error for the optimum of MRR is minimum.

*C.* Response Surface Methodology has been applied to optimize the results. The optimum set of parameters are cutting speed - 1200 rpm, depth of cut – 0.3 mm & feed rate – 0.25 mm/rev. and the optimum value of MRR is 5476.16 $mm^3$/min.

*D.* The contribution factor of depth of cut is higher than others i.e. 72.64%.the contribution factor of cutting speed is 32.84% so it has less effect on the MRR than depth of cut. On the contrary, feed rate has insignificant effect on MRR.

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