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Optimization of CNC Lathe Machining Parameters by Using Taguchi Method.

Mr. Gunnam. HemaKiran[1], Dr.B.S.V. RamaRao[2], Mr.P.Ram Prasad[3]

[1]*M.Tech Student (CAD/CAM),Dept. Of ME, Pragati Engineering College(Autonomous),*
[2]*Professor and HOD Dept. Of ME, Pragati Engineering College(Autonomous),*
[3]*Assistant Professor Dept. Of ME, Pragati Engineering College(Autonomous),*

Abstract- *This paper is about the Optimization of CNC lathe Machining Parameters such as Speed, Feed, Depth of Cut, by using TAGUCHIMethod to improve the quality of manufactured product. TAGUCHI orthogonal array is generated with the three levels of turning parameters by using MINITAB 19 software. In this Study, The Material Removal Rate, Tool Wear Rate is taken as the quality characteristic output with the concept of Larger The Better and Smaller The Better respectively. TAGUCHI method gives the importance of analyzing the response variation using the Signalto Noise Ratio or (S/N) Ratio. The signal to noise ratio for the larger the better for MRR and smaller the better for TWR. The signal to noise ratio values are calculated by taking consideration by using the software MINITAB19. The M.R.R, TWR values are measured from the analysis and their optimum value for maximum removal rate also measured. Aluminium is used as the work piece material for experimentation to optimize the M.R.R. and T.W.R. ANOVA(Analysis of Variance) was employed along with Signal To Noise Ratios to determine the optimum values for MRR and TWR.*

Keywords- *Step Turning, Machining Parameters, Signal To Noise Ratios, ANOVA, MINITAB19.*

I. INTRODUCTION

Step Turning process is the Removal of Material from the outer diameter of a rotating cylindrical work piece by means of single point cutting tool which is held stationary on the tool post and moved parallel to the work piece axis with suitable Speed, Feed and Depth of Cut, Step Turning is used to produce cylindrical surface on the work piece. Step Turning is carried out on lathe that provides the power to turn the work piece at a given speed and to feed the cutting tool at specified rate and depth of cut. Therefore, three cutting parameters or input parameters namely cutting speed, feed, and depth of cut need to be determined in a turning operation.

1.1 Computer Numerical Control lathe machine

A Computer numerical control (CNC) machine is mostly preferred to meet the complex designs like curved geometries in 2-Dimensional and 3-Dimensional which are very expensive to be done by conventional machines. These CNC machines can make sound machining components with high repeat-ability and precision. We can easily operate the CNC machine with less work force and these plays a key role in improved production planning and also increases productivity. We can get almost close tolerance which we desired by using the CNC machine. Actually, conventional machine has 2 axes only x-axis and y-axis. there is z-axis also but only the bed moves vertically. But in CNC machine x, y, z-axis is there with spindle moving parallel to z-axis.

CNC machines have rigid construction when compared with the conventional one. The slide ways, guide and spindles of the CNC machine all look over proportioned when compared to the conventional one. The structure of the CNC machine is therefore designed to cope with the torsional forces and heavy duty cutting imposed on these machines. In CNC rolling friction is used instead of sliding one, this implies in longer life, less frictional resistance, more precise position of slides, and lower torque required. A computer numerical control (CNC) lathe machine processes a work piece to meet the specifications by following a coded programmed instruction and without a manual operator. A series of coded instructions are given to a CNC machine in the form of a sequential programme of machine control instructions such as G-code and M- code etc. The programme can be written by a person manually or, computer– aided design software. The machine control unit (MCU) is the heart of the CNC machine which controls the whole operations performed by the CNC machine. It reads the code and decodes the coded instructions, implements the interpolations like linear, circular, helical to generate axis motion commands. It also feeds the axis motion commands to the amplifier circuits for driving the axis mechanisms. There are two types of systems are there, open loop and closed loop. In which open loop operates manually and closed loop contains feedback system which is referred as the measuring system. The MCU uses the difference between the reference signals (source signals) and feedback signals to generate the control signals for correcting position and speed errors.

1.2 Cutting Tool

In any machining process, cutting tool plays a vital role, which is the heart of the process. There are so many types of cutting tools are there, depending up on the operations the required tool would be selected. Cutting tools are available in three basic material types, they are High-speed steel, tungsten carbide, and ceramic. High-speed steel is generally used on aluminium and nonferrous alloys, while tungsten carbide is used on high-silicon aluminium, steels, stainless steels, and exotic metals. Inserted carbide tooling is becoming the preferred tooling for many CNC applications. For the full utilization of CNC machines, it is essential to pay due attention to the selection and usage of tooling. The tools for the CNC machines must be quickly changeable to reduce no-cutting time, preset and reset outside the machine, high degree of interchangeability, increased reliability and high rigidity.

1.3 InputParameters

1.3.1 Spindle Speed(rpm)

The angular velocity of the work piece is called the Spindle speed (rev/min). It is defined as the surface speed, or the speed at which the work piece material is rotating fast against the stationary cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is denoted in rotations per minute (rpm).

1.3.2 Feed Rate(mm/min)

It is termed as the distance the tool travels during one revolution of the work piece. (inches/min or mm/min). The auxiliary cutting motion is provided by the feed rate or feed velocity.The primary objective of feed velocity is to advance the cutter with respect to the workpiece to remove material from a wider surface. Basically, it helps in covering the entire surface of the workpiece by moving either cutting tool or workpiece. Feed rate can be imparted either on the cutter or on the workpiece.

1.3.3 Depth of Cut

It is defined as the thickness of the material that is removed during cutting. (mm) or the tertiary cutting motion that provides necessary depth within work material that is intended to remove by machining. It is given in the third perpendicular direction and the simultaneous action of three cutting parameters results in removal of excess material from workpiece.

1.4 Output Parameters

The turning input parameters in various papers were cutting speed, feed rate and depth of cut whereas output parameters were surface roughness, cutting forces, tool wear rate and MRR.

1.4.1 Surface Roughness

Machine-ability can be based on the measure of the surface roughness. Surface roughness depends up on factors such as speed, feed, depth of cut. Surface roughness is treated as one of the quality outputs for machine-ability. The presence of coolant also effects the surface roughness.

1.4.2 Cutting Forces

The force exerted to do the machining plays a key role in determining the quality final output. Cutting force is the most sensitive indicators of machining performance. The static and dynamic components of the cutting force contain information about the state of chip formation and cutting tool. These machining forces can be measured directly or indirectly. The measuring method requires mounting of Dynamo-meter on the machine tool. The indirect one requires measuring of the power consumption of spindle or feed drive motors. A single point cutting tools have only one cutting force during machining. But the force is resolved into two or three components for ease of analysis and exploitation. they are:

The cutting force include in turning operations are Thrust Force(FX), Feed Force(FY), Tangential Force(FZ).

1.4.2.1 Tangential Force(FZ)

It is called the main or major component as it is the largest in magnitude. It is also known as power component cutting force acts in tangential direction.

1.4.2.2 Feed Force(FY)

It may not be the larger in magnitude, but is responsible for causing dimensional inaccuracy and vibration. Feed force acts in the direction of feed (axial direction).

1.4.2.3 Thrust Force(FX)

It even if larger than FY, is less least harmful and hence least significant. Thrust force acts in radial direction.

1.4.2.4 Material Removal Rate

It is the amount of material removed from the work piece per unit of time. It expresses the speed of the machining of the work piece. Maximum Material Removal Rate indicates the maximum efficiency. In this study it is taken as the one of the quality characteristics with the concept of Larger The Better. It is calculated by using the conventional method.

$$\text{Material Removal Rate} = \frac{(W_{t1}-W_{t2})}{(t_m)(\rho)} \ (mm^3/min)$$

where W_{t1} is the weight of the work piece before the machining (g)

W_{t2} is the weight of the work piece after the machining(g)

Time taken is the time taken for machining measures in (min).

ρ= Density of the material (g/cm^3).

1.4.2.5 Tool Wear Rate

Cutting tools are subjected to an extremely severe rubbing process. They are in metal to metal contact between the chip and work piece, under high stress and temperature. The situation becomes very severe due to the existence of extreme stress and temperature gradients near the surface of the tool. Tool wear is generally a gradual process due to regular operation. The key variables that influence the tool wear rate are tool and work piece material, tool shape, cutting fluids used, cutting speed, feed rate and depth of cut. The major influence on the tool wear rate is due to the variation in cutting speed. This implies increased cutting speed results in increased cutting tool wear and it reduces the life of the cutting tool.

In this study we calculate the tool wear rate by using conventional method.

$$\text{Tool Wear rate} = \frac{(W_{t1}-W_{t2})}{(t_m)(\rho)} \ (mm^3/min)$$

where W_{t1} is the weight of the work piece before the machining (g)

W_{t2} is the weight of the work piece after the machining(g)

Time taken is the time taken for machining measures in (min)

ρ= Density of the cutting tool material (g/cm^3).

1.5 Taguchi Method

Taguchi method is a well-known technique that provides a systematic and efficient methodology for design and process optimization. This method uses a special set of arrays called Orthogonal Arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information on all factors that affect the performance parameter. Taguchi method is helpful to design 9 number of Experiments based on the L9 orthogonal Array approach with different combinations of parameters for each Experiment. The L9 orthography array is meant for understanding the effect of 3-4 independent factors each having 3 factor level values. The L9 experiments will give maximum accuracy rate up to 99.9%. by using this Taguchi L9 orthogonal array method number of experiments reduced from 27 to 9 with almost same accuracy.

Steps involved Designing an experiment in Taguchi method

(1) Selection of independent variables
(2) Selection of no of level settings for each independent variable
(3) Selection of orthogonal array
(4) Assigning the independent variable to each column
(5) Conducting the experiments
(6) Analyzing the data
(7) Inference.

1.6 Regression

The REGRESSION equations formed by this software are plays a key role in the phase of Analysis. Regression is a statistical model that determined the specific relationship between the predictor variable and the out- come variable. A model regression equation allows us to predict the outcome with a relatively small amount of error.

The main benefit of the statistical model is that we can able to predict the outcome variable with great precision. Regression models are used to predict the response based on the measurable values of the variables. It is even possible to have more than one predictor variable with linear regression. Basically, there are two types of regressions are there they are Linear regression and multiple linear regressions.

1.7 ANOVA(Analysis of Variance)

Analysis of variance can be used as an exploratory tool to explain observations. It is a collection of statistical models and their associated estimation procedures, used to analyse the differences among the group means in a sample. The basic principle of ANOVA is Law of Total Variance. The ratio between the Regression Mean square and Mean Square error is determined by ANOVA, and it is known as F-ratio or ratio of the variance. Clearly, ANOVA test find outs the influence of the Independent variables on the dependent variables or response in the regression study. There are two types of ANOVA is there, unidirectional (one-way ANOVA) and bi- directional (two-way ANOVA). This one way and two way are by depending up on the no of independent variables in our analysis of a variance test.

1.1.1 ONE WAY ANOVA

The One-way ANOVA expresses the impact or influence of a sole factor on a sole response variable. It is used to find out whether there is any statistically significant variation between the means of three or more independent or unrelated groups.

1.7.2 Two-way ANOVA

The Two-Way ANOVA is an extended version of the one-way ANOVA. In One-Way ANOVA, we have one independent variable affecting a dependent variable. But in Two-Way ANOVA, there are two independents that effect the dependent response variable.

Ⅱ.Problem Description

CNC lathe is programmed by speed, feed rate and depth of cut by depending on the type of the job, here it is Turning. However, the performance of the machine and characteristics of the product are not constant. Therefore, the optimum turning conditions are needed to calculate. Here, nine experiments are carried out by taking 9 work pieces of same dimensions. Initially before the experiment weight of the tool and work piece is calculated by using highly sensitive weighing machine. After the operation, again weights of the tool and work piece are noted down. Time is noted for every operation of removing 10mm of work piece material in the turning process by using stop watch. After 9 operations, MRR and TWR values calculated. These values are tabled in MINTAB19 software to calculate Signal to Noise ratios and values are tabulated.

The parameters that influence the output are classified into two types, they are controllable and uncontrollable, the controllable (design) parameters that may contribute to reduced variation can be easily identified by finding the amount of variation present in the Response. But The uncontrollable (noise) factors are the sources of variation associated with the operational environment, so to find this variance we use a tool called ANOVA (Analysis of Variance).

By using ANOVA variance values are calculated and tabulated. Regression Equations of MRR and TWR are tabulated and optimized values of input parameters are tabulated.

2.1 work piece material

Aluminium is used as a work piece material to optimize the Material Removal Rate in the Turning process. The measurements of the pieces are length-60mm and diameter- 40mm. The Density of aluminium is 2.7 g/cm^3. here, AL-2024 Alloy is used as work piece material the composition of this AL-2024 is copper-3.8% to 4.9%, magnesium-1.25% to 1.85%, manganese-0.5% to 0.6%, silicon-0.5%, iron-0.5%, chromium-0.1%, zinc- 0.25%, titanium-0.15%.

2.2 Cutting Tool Material

Single point turning tool is made of High-Speed Steel Carbide tip. Which is inserted in CNC lathe for the experiment purpose. The Density of High-Speed Steel is 8.1 g/cm^3.

Ⅲ. Design of Experiment

In this case, Orthogonal array of L9(3) was selected for the parameters (speed, feed, depth of cut) the experiment consists of three factors, then total no of experiments is 27. But by using this Taguchi method no of experiments reduced to 9 instead of 27 with same accuracy. Taguchi experimental design is classified into three main phases, they are planning, conducting of experiments and analyzing phase. In this the planning phase is the utter most important phase in which the required information for experiment is provided, whether it is in positive or in negative sense. The positive information indicates the which factor of which level lead to improves the process or product. The negative information indicates of which factor doesn't leads to improvement of process or product. The main aim of Taguchi function is to understand the changes that are occurred during experiment, and analyse them and obtains the optimal values of the input parameters.

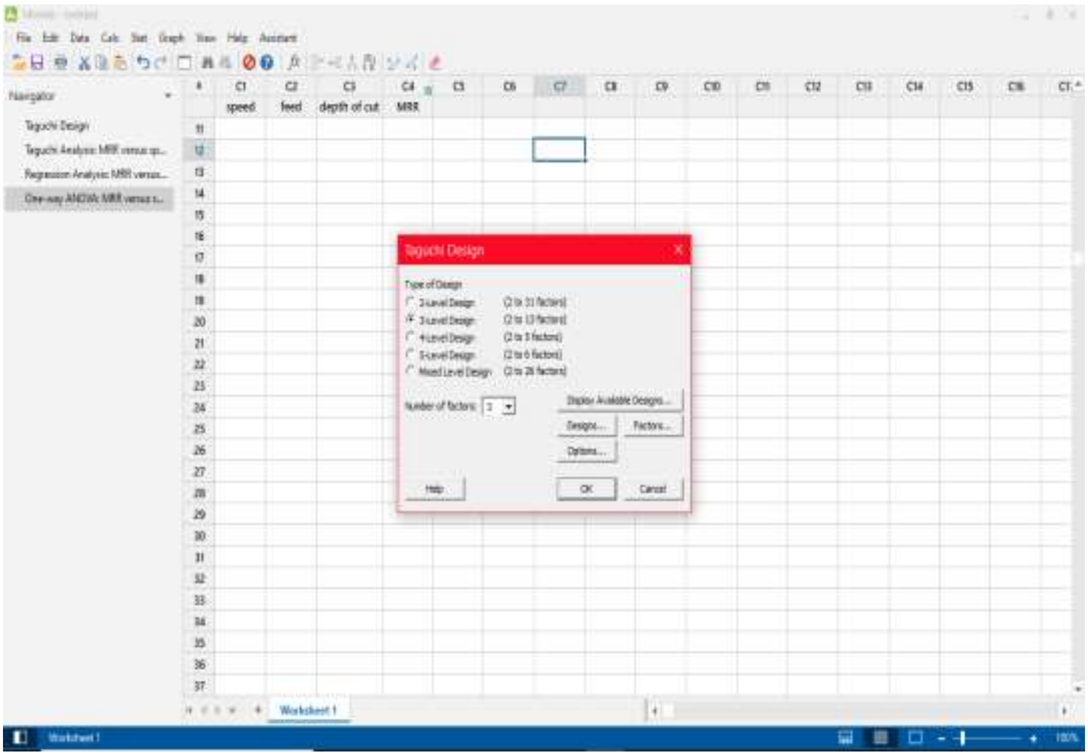


Figure 1. Taguchi 3 level design interface MINITAB19

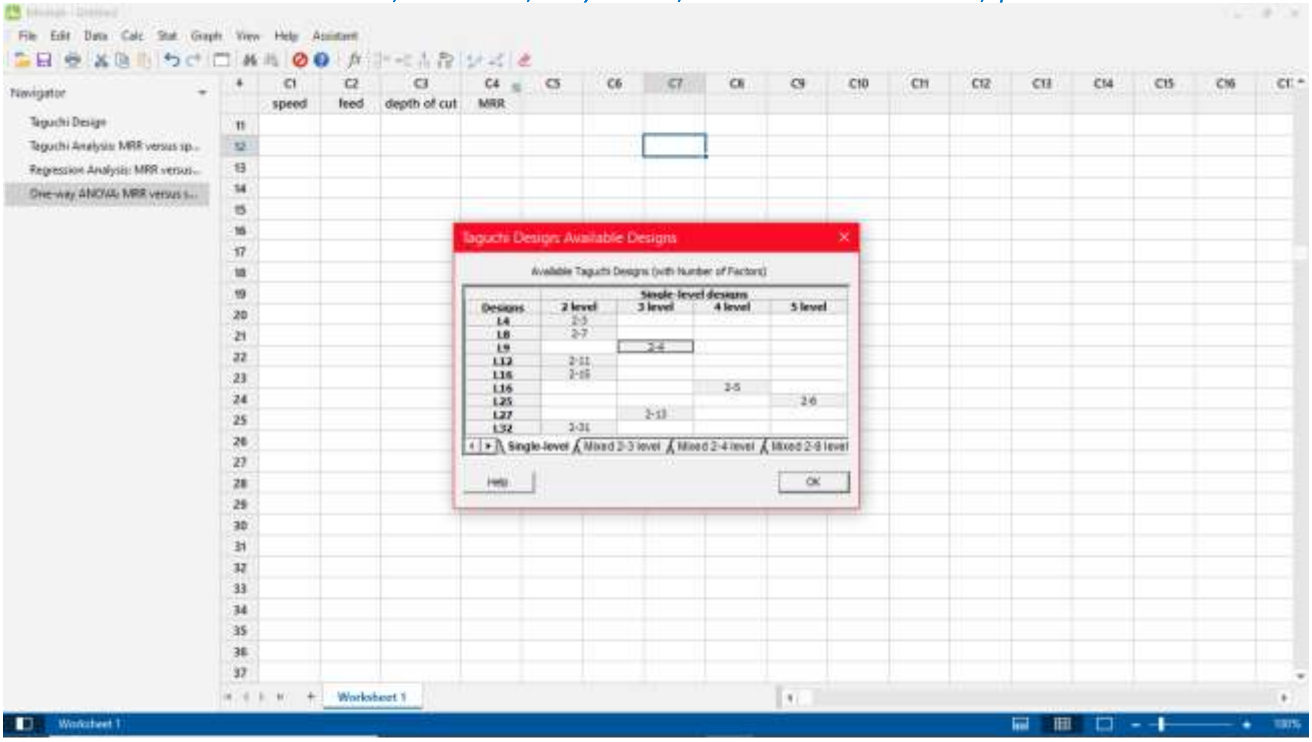


Figure 2.creation of Taguchi Orthogonal Array parameter specification MINITAB19

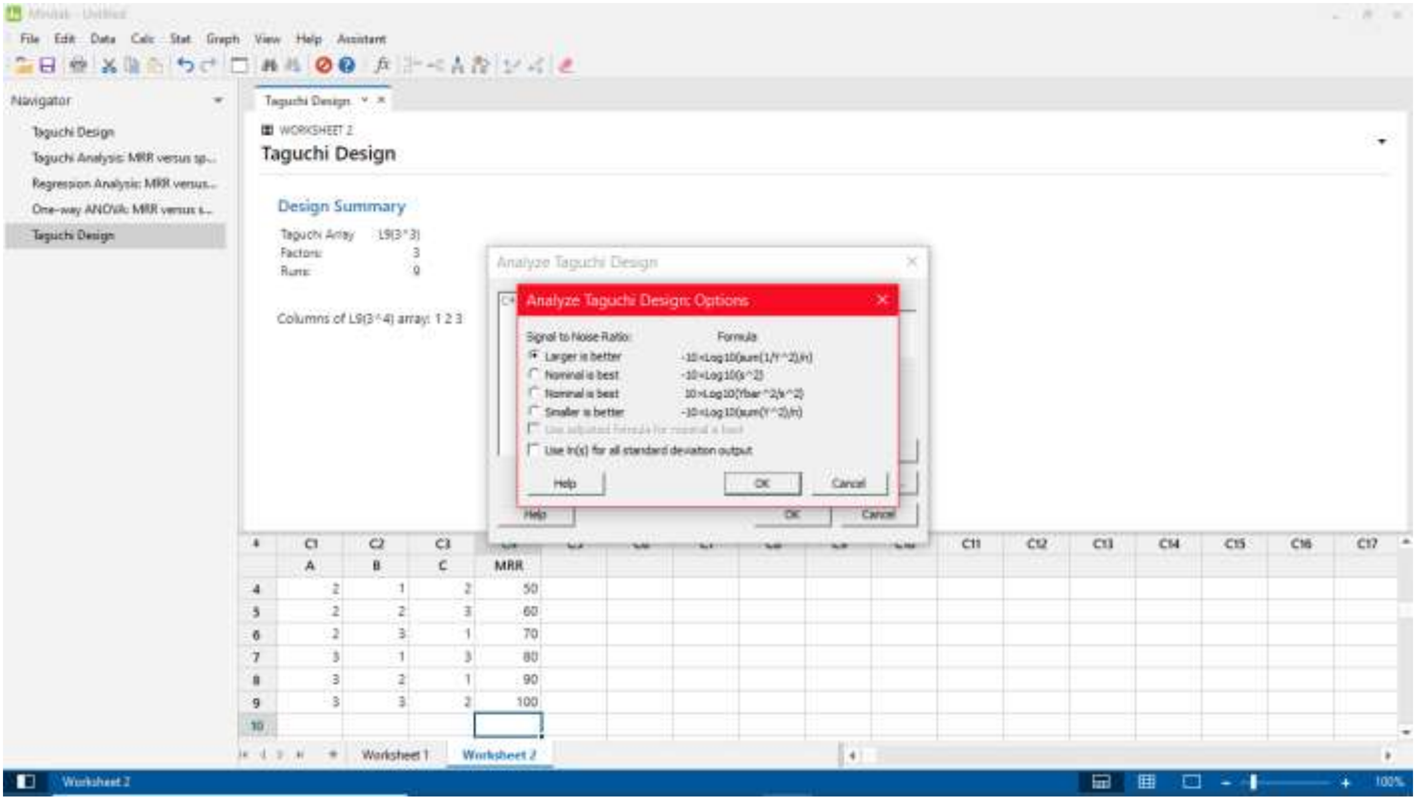


Figure 3. Signal to Noise ratio(Larger is Better criterion) for MRR.

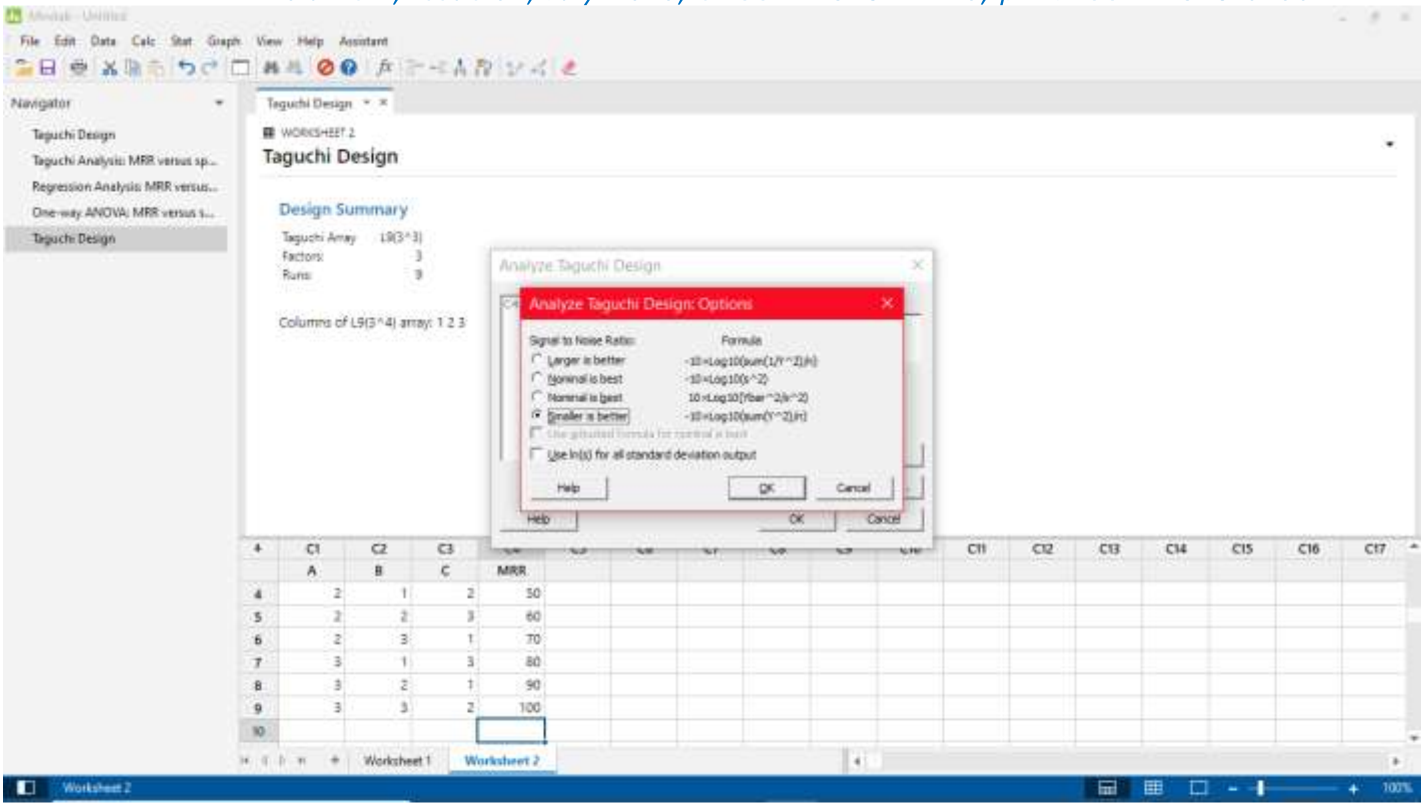
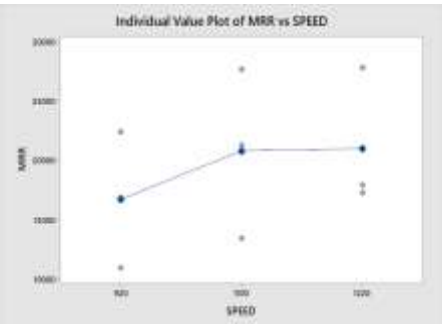
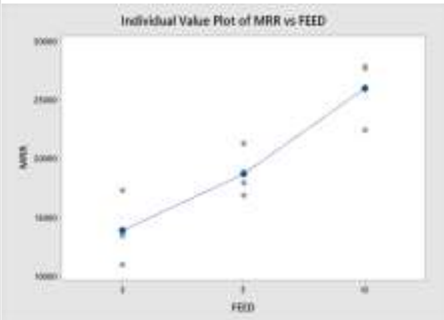


Figure 4. Signal To Noise Ration (Smaller is Better) criterion for TWR.

Ⅳ. RESULT





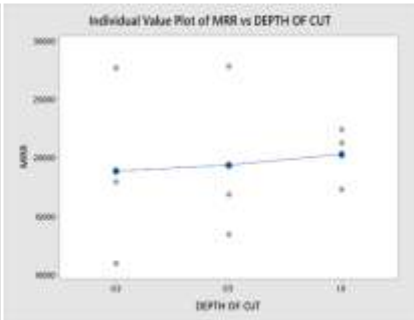


Figure 5. Indicates Speed vs MRR *Figure 6. Indicates Feed vs MRR* *Figure 7. Indicates Depth of cut vs MRR*

Response Table for Signal to Noise Ratios for M.R.R.

TABLE 1. Indicates the Delta values for S/N ratios.

Level	SPEED	FEED	DEPTH OF CUT
1	83.02	83.96	83.98
2	86.18	84.63	84.23
3	85.12	89.32	85.09
Delta	2.21	5.42	1.3
Rank	2	1	3

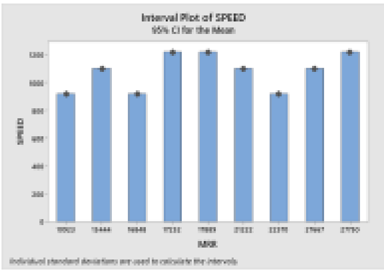
Here, from the table 1, shows that the MINITAB19 assigns the first rank to highest delta value for Feed Rate (mm/rev). the second rank for Speed (rpm), and the third to Depth of Cut (mm).

The results show us that controlled parameters Feed and Speed have most significant influence on optimization of Material Removal Rate. On the other hand, Depth of Cut has some shared effect on the response.

Analysis of Variance for M.R.R

TABLE 2. Indicates Analysis of Variance and coefficients for MRR.

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	-7758	6151	(-23569, 8052)	-1.26	0.263	
speed	14.81	5.38	(0.98, 28.63)	2.75	0.040	1.00
Feed	1672	225	(1093, 2251)	7.42	0.001	1.00
depth of cut	2028	2252	(-3761, 7818)	0.90	0.409	1.00



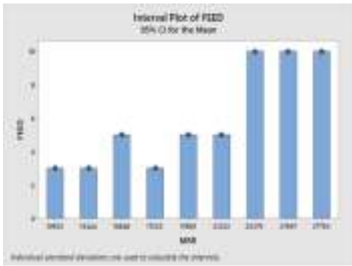
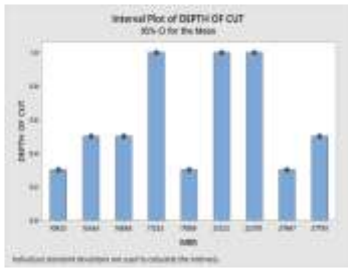



Figure 8. interval plot Speed vs MRR Figure 9. Interval plot Feed vs MRRFigure 10. Interval plot Depth.of.cut vs MRR

Figure 11. show the Response Optimization of MRR

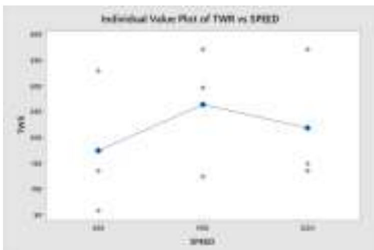
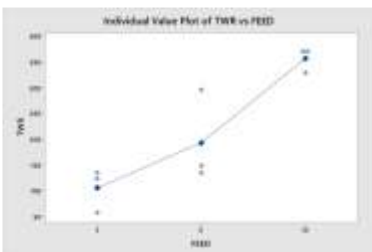
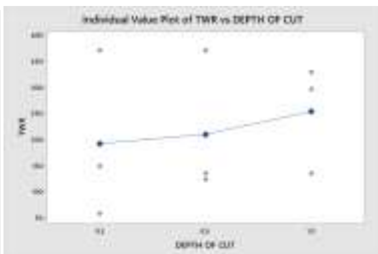


Figure 12. Indicates Speed vs TWR Figure

13. Indicates Feed vs TWRFigure 14. Indicates Depth of cut vs TWR

Response Table for Signal to Noise Ratios for TWR

TABLE 3. Indicates the Delta values for S/N ratios.

Level	SPEED	FEED	DEPTH OF CUT
1	-41.86	-38.94	-42.90
2	-46.45	-44.41	-44.65
3	-46.88	-50.21	-48.96
Delta	4.21	10.91	3.96
Rank	2	1	3

Here, from the table 3, shows that the MINITAB19 assigns the first rank to highest delta value for Feed Rate (mm/rev). The second rank for Speed (rpm), and the third to Depth of Cut (mm).

The results show us that controlled parameters Feed and Speed have most significant influence on optimization of Tool Wear Rate. On the other hand, Depth of Cut has some shared effect on the response.

Analysis of Variance forT.W.R.

TABLE 4. Indicates Analysis of Variance of coefficient for TWR

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	-235	145	(-608, 138)	-1.62	0.166	
SPEED	0.175	0.127	(-0.152, 0.501)	1.38	0.227	1.00
FEED	35.33	5.32	(21.66, 48.99)	6.65	0.001	1.00
DEPTH OF CUT	87.9	53.2	(-48.7, 224.6)	1.65	0.159	1.00

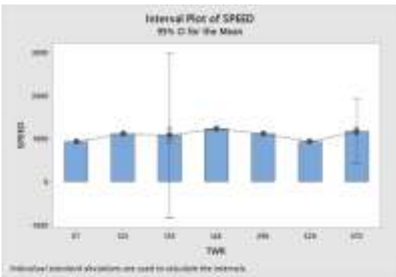
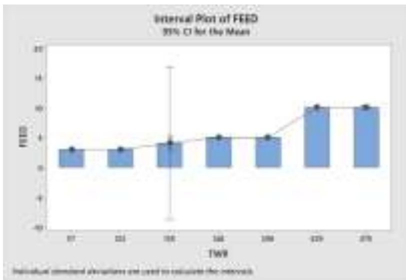



Figure 15. Interval plot Speed vs TWRFigure 16. Interval plot Feed vs TWR

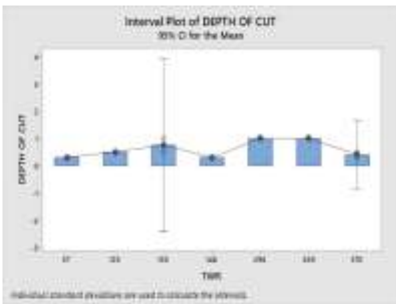


Figure 17. Interval plot Depth of Cut vs TWR

V. CONCLUSION

In this investigation, a study has been carried out to optimize the process control parameters such as Speed, Feed, Depth of Cut with respect to the MRR and TWR in dry turning environment using CNC lathe. The Material used for this study is Aluminium-2024 and tool material is high speed steels (M2). The $L_{9,}$ (3^3) orthogonal Array has been employed for experimental design and Analysis of MRR and TWR.

Based on the Results of S/N ratio and ANOVA, It is concluded that Feed rate has most significant factor compared to cutting speed and depth of cut on MRR. The optimal combination of cutting parameters for MRR is cutting speed 1220 (rpm). Feed rate 10(mm/rev). Depth of cut 1(mm). On the other hand, Analysis of S/N ratio and ANOVA show that Feed rate and cutting speed has most significant factor compared to depth of cut on TWR. The optimal combination of cutting parameters for TWR is cutting speed 1100(rpm). Feed rate 10(mm/rev). Depth of cut 1(mm).

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