Optimization of CNC Turning Parameters & Prediction of Surface Roughness using Machine Learning Algorithm

Vinay P. Mohite [1],
[1]UG Student, Mechanical Engineering Department,
K. K. Wagh Institute of Engineering Education and Research, Nashik -422003, India.

Shiphan R. Pathan [2],
[2]UGStudent, Mechanical Engineering Department,
K. K. Wagh Institute of Engineering Education and Research, Nashik -422003, India.

Adarsh R Patkal[3],
[3]UGStudent, Mechanical Engineering Department,
K. K. Wagh Institute of Engineering Education and Research, Nashik -422003, India.

Divya V. Raut[4]
[4]UGStudent, Mechanical Engineering Department,
K. K. Wagh Institute of Engineering Education and Research, Nashik -422003, India.

--***--

Abstract—In industries,Machining process is gaining importance & more attention in order to manufacture high-quality precision robust products with great performance,which qualifies all stages of its application. In order to achieve it within less time, with less machining cost & maintenance, the need for optimization of machining processes arises. Optimization is a tool in engineering practice for continuous improvement & to get the most excellent results from the available set of resources. Among different machining processes, Turning is most widely used in order to gain the desired dimension and precise surface finish. The projects aim is to optimize various machining parameters of Turning operations i.e Spindle speed, Depth of cut, and Feed rate to gain a good surface finish by practicing optimization techniques of Design Of Experiments (DOE) & employing Taguchi methodology with the least number of experimental runs by developing a mathematical model based on statistical regression and machine learning algorithm for predicting the surface roughness values within the selected specified range.

Keywords: Design of Experiments (DOE), CNC Turning, Surface finish, Optimization, Machine-Learning, Experimentation, Decision-Tree, Flask, Prediction, Python.

1. INTRODUCTION

Optimization is the science of getting the most excellent results from the available resource constraints. There is a lot of scope for optimizing various manufacturing functions such as design, planning, operation (process), quality control, maintenance, and so forth. Nowadays in modern manufacturing processes, optimization techniques in metal cutting are compulsory for manufacturing concerns to respond effectively to severe competitiveness and growing demand for quality products in the market. Optimization methods in metal cutting processes is considered to be viable tool for continuous improvement of the output quality in products and process include modeling of input-output and in process parameter relationship and determination of optimal cutting condition for getting robust product or process. A robust product or process is one that is insensitive to noise. Metal cutting process, generally understand by developing an explicit mathematical model, which can be of two types; mechanistic and empirical, the mechanistic model are inadequate and unacceptable to metal cutting process, but the empirical models are commonly used.

Among all the cutting processes, turning is the most widely used. 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. Today's fast changing manufacturing environment requires the application of optimization techniques in metal cutting processes. The machine tool operators always face the problem in turning process. Machine tool condition, job clamping, tool and work piece geometry and cutting parameters are the major reasons for occurrence of the problem. In machining, there has been recently and intensive computation focusing on surface roughness at international level. This computation can be observed in turning processes especially in plane and automotive industry by increasing the alternative solutions for obtaining more proper surface roughness. So it becomes important to study the effect of machining parameters on multiple quality characteristics like surface roughness and vibration etc.

In present industrial age, the growing competition call for all the effort to be directed towards the economical manufacture of machined best quality part and all these is made possible by use of high-end technology machines i.eCNC lathe. Generally cutting parameters are selected on the basis of experience of operator or from the handbook. Mostly it does not ensure selection of optimal or near optimal parameters. To select the cutting parameters properly, several mathematical models based on statistical regression techniques or neural computing have been constructed to establish a relationship between the response and machining parameters. For getting these relations large number of experiments are to be conducted. In order to reduce the number of experiments of design of experiment (D.O.E) techniques (Taguchi) have been used. D.O.E is a tool in engineering application to reduce the no of experiments without comprising the quality.

2. PROBLEM STATEMENT

To optimize the CNC parameters in turning operations in order to reduce surface roughness of the desired workpiece.

ELABORATION:

Accomplishing a smooth surface finish is significant while machining metal, as it influences both the usefulness and aesthetics of the end product. The determination of cutting parameters, for example, spindle speed, feed rate, and depth of cut, alongside the kind and state of the cutting device, assume a huge part in accomplishing the ideal surface completion. it may, even with proper choice of these parameters, there might be examples where the surface completion isn't great. In such cases, rework is frequently required, which includes extra machining activities, sanding, or other surface planning strategies. This can be a tedious and work-concentrated process, bringing about diminished productivity and expanded costs.

To limit the expense and time related to accomplishing the ideal surface completion and stay away from the requirement for modification, it is fundamental to improve the cutting parameters and utilize suitable cutting procedures. This can be achieved by utilizing measurable strategies, like Design of Experiments (DOE), to recognize the ideal blend of cutting parameters that will bring about the ideal surface finish efficiently. Moreover, high-level machining advancements like CNC Lathe can improve the precision and consistency of machining activities, decreasing the probability of surface roughness issues.

3. OBJECTIVES

1. To study the influence of different machining parameters i.e. speed, feed, depth of cut etc. on surface roughness of machined work piece and predict the best performance characteristics using ANOVA analysis.
2. Determination of optimized values of cutting parameters for minimization /maximization of desired responses using the DOE optimization technique with a minimum number of experimentations.
3. Analysis and prediction of response variable i.e. (Ra, Vibrations) by establishing the empirical equation of in-process parameters & responses using the Minitab statistical Tool.
4. Validation of the predicted results by performing confirmation experiments and checking its accuracy.

4. LITERATURE REVIEW

PrateekVaishnav (Research Scholar, Aravali Institute of Technical Studies, Udaipur, Rajasthan, India.)GauravPurohit (Asst. Prof. & Head, Aravali Institute of Technical Studies, Udaipur, Rajasthan, India) is The goal of the study is to improve the cutting conditions when milling the 8011 aluminium alloy using Computer Numeric Controlled (CNC) equipment in order to achieve the proper surface roughness and enhanced material removal rate (MRR). 27 experimental runs of the full factorial design of experiments technique were used to examine the performance traits under various cutting conditions. The results were analysed using an orthogonal array, analysis of variance (ANOVA), and signal to noise ratio. According to the study's findings, it is possible to accurately determine the quality of surface finish and MRR by taking into account independent criteria that have a major impact. The results of this study can help several fields of study and academics working on this topic.

Shrikant S. Jachak ,Vinay R. Pandey: In the present disquisition an attempt is made to estimate the effect of certain slice variables on face roughness in plain turning of medium carbon sword AISI 1055 under cutting condition. Cutting speed, depth of cut, feed and slice inflow rate are named as the impacting parameters. The trials are conducted by factorial trial medium carbon sword AISI 1055 was machined using tenacious clicked tool and compared the performance with brazed tool.The cutting condition of turning parameters was determined by Design of experiment method to find the optimal levels and to analyse the effect on the turning parameters.

Jacqueline K. Telford: In an experimental design, deliberate modifications to the input variables or their processing are made, and the consequences on the response variables are then observed. It is an effective way to expand knowledge while requiring less data to be collected. Factorial experimental designs can evaluate sensitivity to individual components and combined effects while simultaneously examining the impacts of numerous factors. It has been used to increase data with fewer simulation runs in ballistic missile defence sensitivity tests. In competitive sectors, experimental design is crucial for testing and evaluation.

5. METHODOLOGY

This chapter sets forth the methodology and work flow followed in this project in brief. Provides in-depth insights on workflow and research methodology followed in this project.

Fig.5.1 ResearchWorkflow

6. EXPERIMENTATION

In order to satisfy the desired objectives, the experimental layout has been set up and trials have beenperformed to test the developed algorithm. This chapter covers in-depth details of the experimental setup,procedure and results observed. Different trials have been performed on different objects of differentmaterials.

6.1 ExperimentalSetup

Inordertosatisfythedesiredobjectives,theexperimentallayouthasbeensetupandtrialshavebeenperformed to test the developed algorithm. This chapter covers in-depth details of the experimental setup,procedure and results observed. Different trials have been performed on different objects of differentmaterials.

6.2 CNCTurningSpecification

InordertoachievethegoalofthisexperimentalworkthecuttingtestswerecarriedoutinaSinumerik828DBasic CNC Lathe (JYOTI DX-200 4B). The CNC turning center has 9kw / 13.5 kw spindle motor powerandamaximalmachiningdiameterof150mm,maximalspindlespeedof4000rpm,spindlespeedrange40to3500 rpm and maximal turninglength 400mm.

Fig. 6.1.CNCTurningSpecifications

6.3 WorkPieceMaterial:

In this experimental investigations, EN 8 steel rods have been selected and the work piece were preparedfromtherawmaterialsdimensionsoflength70mmanddiameter33mm.Thechemicalcompositionoftheworkpieceis shown in below table.

TableNo. 6.3.ChemicalcompositionofEn8Material

Elements	C	Si	Mn	S	P
Percentage	0.36-0.44	0.10-0.40	0.60-1.00	0.50(max)	0.50

TableNo. 6.4.MechanicalPropertiesofEn8

Maxstress	**700-850n/mm2**
Yieldstress	**465n/mm2min**
0.2%proofstress	**450n/mm2min**
Elongation	**16%min**
ImpactKCV	**28Joulesmin**
Hardness	**201-255Brinell**

KeyFeatures:

1. Unalloyedmediumcarbonsteel
2. Reasonabletensilestrength
3. Canbeflameorinductionhardened
4. Readilymachinable
5. Moderatewearresistance ifheattreated.

6.4 Selectionof cuttingtool:

Cuttingtoolsmusthavethreepropertiesinordertogeneratehigh-qualityproducts:hardness,toughness,andwear resistance. Thecarbide-coated toolis used tocuttheselectedworkpiece.

TableNo.6.5.CuttingToolSpecificationsTNMGInserts

Tooltype	Manufacturer	Designation	Code	Geometry	Grade
Carbidetool	KORLOY	TNMG	160404	VF	CC115

TableNo.6.6.InsertSpecification

Inserttype	Code	Length of the insertin mm	Thickness of insertin mm	Radiusofinserts
TNMG is a triangularinsert	160404	16	04	0.4

Fig.6. .2.TNMGinsert

6.5 Machinetool:

On the CNC machine tool, the turning operation is performed on the specified work piece EN8 steel bar.The specifications of the CNC machine tool are of Jyoti-DX-200 4B (Sinumerix) CNC system, the numberofworkstations is 8, thechuck sizeis 169 mm,and the spindlespeedrangeis 45-4500 rpm.

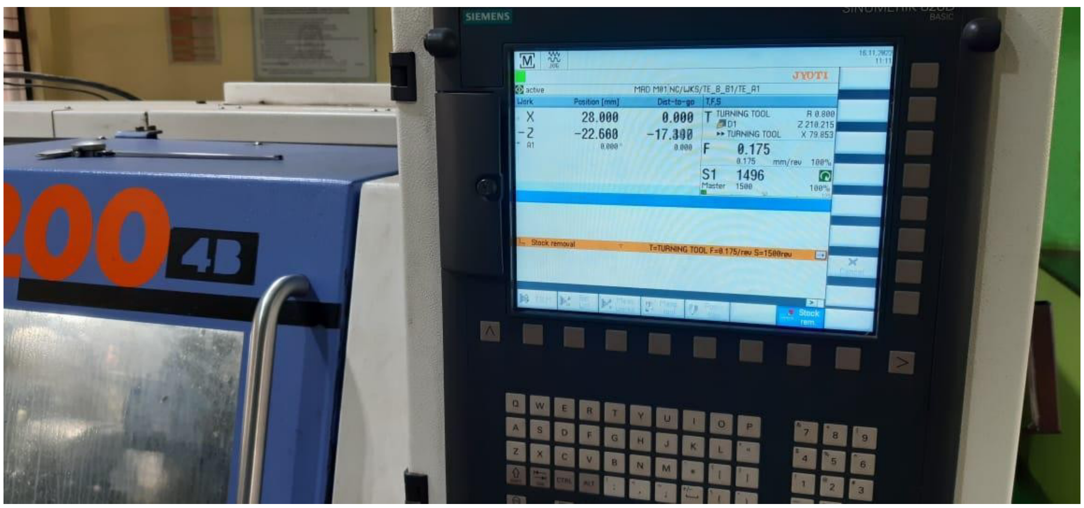


Fig.6.3.CNCLatheMachine&itsControllerTable No.6.7.CNC machinespecifications

S.No	Description	Specifications
1.	**Maximum Swing over carriage**	**150mm**
2.	**Distancebetweencenters**	**220mm**
3.	**Heightofcenter**	**165mm**
4.	**Spindleborediameter**	**70mm**
5.	**Spindlespeed**	**50-4000rpm**

6.6 SurfaceRoughnessRaMeasurementApparatusused:

Roughnessisusuallyagoodpredictoroftheperformanceofmechanicalparts,becausesurfaceirregularitiesmayformcrackso rcorrodednucleationsites.Roughnessisameasureofsurfacetexture.Itisquantifiedbythe vertical deviation of the actual surface from its ideal form. In the trials, a digital surface tester wasutilizedtomeasuresurfaceroughnessRa.SURFTEST,S.J.210,sr.no:178-561-02A,MITUTOYOMECH,anexperimental device for thesurfaceroughnesstester ofJAPAN.

Fig.6.4. MitutoyoSJ-210 Surface roughness testerTableNo.6.8.Specification OfSurfaceRoughness Tester

BrandName	Mitutoyo
Height	10.92centimeters
Weight	2.27kilograms
Length	40.13centimeters
Width	34.29centimeters
ManufacturerSeriesNumber	178-561-02A

6.7 Orthogonalarrayandexperimentalfactors:

The Taguchi technique begins with the selection of a suitable orthogonal array.The L9 (3 3) orthogonalarray, which is a standardized experimental design based on Taguchi. The basic design uses up to threecontrolfactors,ofwhichthreelevelsareusedforcuttingspeed $C0$,cuttingdepth$D$□andfeed$F$.Atotalo9 experimental runs are performed, using the control factors Horizontal combination. The dependentvariableis called the responsevariable.
The purpose of the experiment is to examine how turning factors affect EN8 steel surface roughnessTaguchi's orthogonal array was utilized to create the experiment, lowering the number of trials. TheexperimentiscarriedoutusingthethreefactorsoftheL9orthogonal array's threelevels.

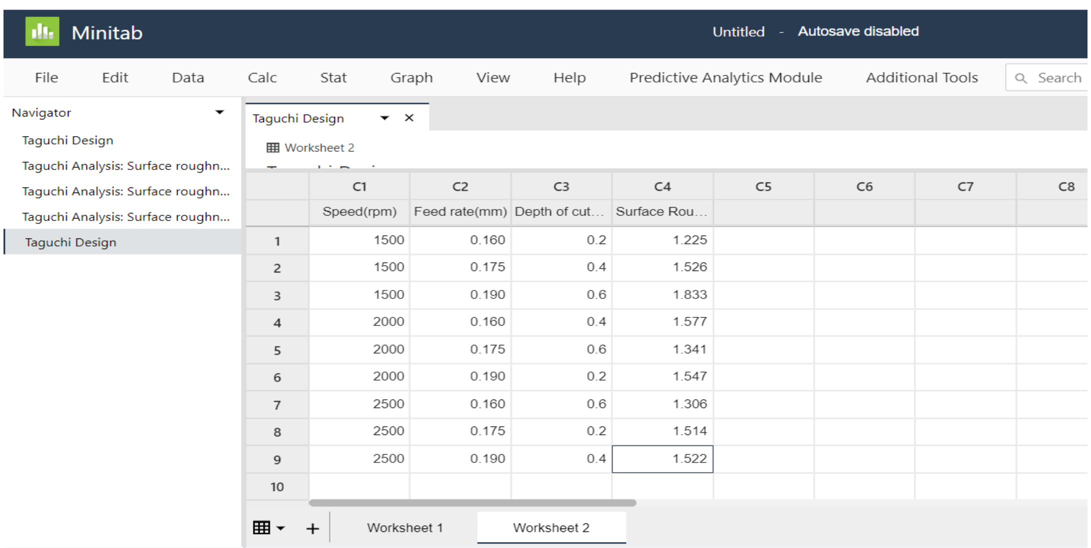
Fig.6.5.Testspecimenafter machining

6.8 DOEforCNC Turning:

TableNo.6.9.Factorsandtheirlevels inCNCStraightTurning

ProcessParameter	Level1	Level2	Level3
Spindlespeed(m/min)	1500	2000	2500
Feedrate(mm/rev)	0.160	0.175	0.190
Depthofcut(mm)	0.2	0.4	0.6

Fromtheabovetableaccordingtodesignofexperimentswith Taguchidesigntotalnumbersofexperimentstobeperformed are09.



	C1 Speed(rpm)	C2 Feed rate(mm)	C3 Depth of cut...	C4 Surface Rou...	C5	C6	C7	C8
1	1500	0.160	0.2	1.225				
2	1500	0.175	0.4	1.526				
3	1500	0.190	0.6	1.833				
4	2000	0.160	0.4	1.577				
5	2000	0.175	0.6	1.341				
6	2000	0.190	0.2	1.547				
7	2500	0.160	0.6	1.306				
8	2500	0.175	0.2	1.514				
9	2500	0.190	0.4	1.522				
10								

Fig.6.6.MinitabTaguchiDesign Plan

7. CONCLUSION

Taguchi methods have been very successful in designing high-quality products andprocessesofmanydifferentfields.Inthisworkanapproachisproposedforselectingthemostpreferred set of parameters for optimal operation of lathe machining. The selection criteria forparametersarebased onphysicalmeasured outputsofmachiningi.e.surfaceroughness.

For our project, we have selected three input turning parameters for optimization i.e Cuttingspeed, feed rate, depth of cut. For each parameter, we selected three levels: low, medium andhigh.

ExperimentswereconductedusingL9orthogonalarray.Foreachexperiment,surfaceroughness was measured, recorded and analysis using Taguchi S/N ratios. These ratios werecalculatedwithconsiderationofperformancecharacteristic:Lower-the-Better,assurfaceroughnessisrequestedtobelow.Theoptimumlevelsofparametersforminimizingthesurfaceroughnesswere determinedfromthe responsetable for Signal-to-Noise ratios.The bestcombinationwas obtained with:

1) Cuttingspeed
2) Feedrate
3) Depthofcut
4) Confirmationexperiment,
5) Developmentof regressionmodelwithinteractionsbetweenparameters.

Fromtheresponse forasignaltonoiseratioitisobservedthatDepthofcutisimpactingmoreonthe surfaceroughness followed byfeedrateandspindle speed.

DesignofexperimentwasdoneusingTaguchimethodandweobtainoptimizelevelofspeed2500and feedratewas 0.4 and depthof cut 0.160.

Machine learning was used for predicting surface roughness was decision tree algorithm wasused.

8. FUTURE SCOPE

Very few attempts have been made to investigate the challenges faced by this technology anddiscover the scope for optimization and refinement. This chapter provides the future scope fortheresearchersto workinthis domain.

Optimization of parameters is important in a every machining process results affected by eachparameterfocusistoproducegoodqualitywithinaminimumcost.CNCturningprocessisthemost common machining process that is used in now days.Present work has been done,Toolvibrationandsurfaceroughnessaretwoimportantparameterswhichaffectqualityofcomponent and tool life which indirectly affect component cost.To optimizethe machiningparameters ,for material EN8, depth of cut, Feed rate,Speed.MINITAB software is used forformulatingmatrixand for theanalysisof taguchmethodologyfor response.

The Machine learning field has encountered a turning point, which allows machines tolearn,improve,andperformaspecifictaskthroughdatawithoutbeingexplicitlyprogrammed.Machine learning can be utilized with machining processes to improve product quality levelsand productivity rates, to monitor the health of systems, and to optimize design and processparameters.Thedomainofthestudyistofindbestsuitablemodelofmachinelearningalgorithmtofindaccuracyandpredict responsevariable.Dataismostimportantpartofmachinelearningwithout data we can’t train any model and datset will be used in this study will be data obtainfromexperiments.

9. REFERENCES

1. ABriefIntroductiontoDesignofExperiments.**Telford,JacquelineK.**
2. Multi Response Optimisation Of CNC Turning Parameters Via Taguchi Method-BasedResponseSurfaceAnalysis.. **IihanAsilTurk,SulemanNeseli.**
3. Optimization of CNC Turning Process Parameters for Prediction of Surface Roughness byFactorialExperimentation.**ShrikantJachak, VinayPandey.**
4. Optimization of cutting parameters in CNC turning operation for optimized surface roughnessand material removal rate using Full Factorial DOE approach. **Pratik Vaishnav, GauravPurohit.**
5. Parameters optimization of CNC machining using Taguchi methodology. . **KrantikumarBhosale,VaibhavPatil,RanjitChavan,VishalMane,AbhijitRamchandraSakharkar.**
6. Process Parameters Optimization By Bat Inspired Algorithm Of CNC Turning On EN8 Steel ForPredictionOfSurfaceRoughness .**OmkarKulkarni,ChaitanyaGirishBurande.**
7. Surface Response Methodology & Taguchi TechquinesTo Optimization Of C.N.C. TurningProcess.. **VipinKumarSharma,QasimMurtaza.**
8. Taguchi Based Fractal Dimension Modelling And Optimization In CNC Turning. **SahooBarman,T.K.&Routara.**

9. https://hwacheonasia.com/wp-content/uploads/2019/04/HI-TECH-450_02.png
10. **https://mellowpine.com/wp-content/uploads/2022/07/Two-axis-lathe-system.jpg**

11. **https://www.researchgate.net/publication/323340273/figure/fig1/AS:596817536352256@1519303797177/Illustration-of-surface-roughness-parameters.png**