Determination of Optimal Cutting Conditions Using Design of Experiments And Optimization Techniques

Naresh Kumar Reddy Asst Professor In Mechanical Department Padmasri Dr. B.V.Raju Institute of Technology, Narsapur

Mahesh Mallampati Asst Professor in Mechanical Department EVM College of Engineering & Technology, Nasararaopet

Abstract

In process planning or NC part programming, optimal cutting conditions are to be determined using reliable mathematical models representing the machining conditions of a particular work-tool combination. The development of such mathematical models requires detailed planning and proper analysis of experiments. In this paper, the mathematical models for TiN-coated carbide tools and Rochling T4 medium carbon steel were developed based on the design and analysis of machining experiments. The models developed were then used in the formulation of objective and constraint functions for the optimization of a multipass turning operation with such work-tool combinations.

Keywords: *Machining Operation (turning); Surface Roughness; Lathes Machines and Mathematical Model*

1. Introduction

In a machining process, roughing operation plays an important role in reducing a particular work piece from the original stock to the desired shape and size. In order to achieve the economic objective of this process, optimal cutting conditions have to be determined. Although one can determine the desirable cutting conditions for roughing based on experience or handbook data, it does not ensure that the data obtained will be optimal or near optimal for that particular machine setting and environment. In order to determine the optimal cutting conditions, reliable mathematical models need to be established. To ensure the effectiveness of the models, the design of experimental technique should be used to plan the machining experiments efficiently and multiple regression methods can then be used for the particular work-tool combination based on the machining data collected on a specific machine. After developing the mathematical models, the analysis of variance will then be applied to check the adequacy of each mathematical model and their respective parameters. One can then use the mathematical models developed to formulate the objective function and the process constraints for optimization based on a certain preselected economic criterion.

The main objectives of this work are: (a) to study the effects of depth of cut, feed rate and cutting speed on the tool life, cutting forces and power consumption for Tin coated carbide tools and Rochling T4 medium carbon steel using design of experimental technique; (b) to develop mathematical models to predict tool life, cutting forces and power consumption as a function of depth of cut, feed rate and cutting speed within the operating region; and (c) to demonstrate the use of mathematical models in the determination of optimal cutting conditions using an optimization technique.

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2. LITERATURE SURVEY

Parametric Analysis and Optimization of Cutting Parameters for Turning Operations based on Taguchi Method by **Dr. S.S.Mahapatra Amar Patnaik Prabina Ku. Patnaik (1) in** this paper they have conducted experiment work and done on Genetic Algorithm to optimization the experimental values.

On-line optimization of the turning using an inverse process neurocontroller, Transactions of ASME, Journal of Manufacturing Science and Engineering by **R. Azouzi, M. Guillot,(2)** Process modeling and optimization are the two important issues in manufacturing products. The manufacturing processes are characterized by a multiplicity of dynamically interacting process variables

Surface roughness prediction models for fine turning; International Journal of Production Research by **A. Mital, M. Mehta (3)** a greater attention is given to accuracy and surface roughness of product by the industry these days. Surface finish has been one of the most important considerations in determining the machinability of materials. Surface roughness and dimensional accuracy are the important factors required to predict machining performances of any machining operations.

Present situation and future trends in modeling of machining operations. Progress Report of the CIRP working group on 'Modeling of machining operations by **C.A. Van Luttervelt, T.H.C. Childs, I.S. Jawahir, F. Klocke, P.K.Venuvinod.(4)** The predictive modeling of machining operations requires detailed prediction of the boundary conditions for stable machining. The number of surface roughness prediction models available in literature is very limited. Most surface roughness prediction models are empirical and are generally based on experiments in the laboratory. In addition it is very difficult in practice, to keep all factors under control as required to obtain reproducible results. Generally these models have a complex relationship between surface roughness and operational parameters, work materials and chip-breaker types.

Multi machining output—multi independent variable turning research by response surface methodology, International Journal of Production Research by **K.Taraman(5)** used Response Surface Methodology (RSM) for predicting surface roughness of different materials. A family of mathematical models for tool life, surface roughness and cutting forces were developed in terms of cutting speed, feed, and depth of cut.

Surface roughness model for turning, Tribology International by **R.A. Lindberg** and **M.Hasegawa (6)** conducted 3^3 factorial designs to conduct experiments for the surface roughness prediction model. They found that the surface rough increased with an increase in cutting speed.

Operation By Use Of A Full Factorial Design **Yves Beauchamp,ext (8)** The main objective of this study is to investigate cutting parameter effects of surface roughness in a lathe dry boring operation. A full factorial design was used to evaluate the effect of six (6) independent variables (cutting speed, feed rate, depth of cut, tool nose radius, tool length and type of boring bar) and their corresponding two-level interactions. In this experiment, the dependant variable was the resulting first cut surface roughness (Ra).

Determination of optimal cutting conditions using design of experiments and optimization Techniques **M. S. CHUAT (9)** In process planning or NC part programming, optimal cutting conditions are to be determined using reliable mathematical models representing the machining conditions of a particular work-tool combination. The development of such mathematical models requires detailed planning and proper analysis of experiments. In this paper, the mathematical models for TiN-coated carbide tools and Rochling T4 medium carbon steel were developed based on the design and analysis of machining experiments. The models developed were then used in the formulation of objective and constraint functions for the optimization of a multipass turning operation with such work-tool combinations

3. PROBLEM DESCRIPTION

To find the optimum machining parameters in order to get the minimum surface roughness.

We have taken 14 samples of turning operation in finishing cut the values of the speed, feed and depth of cut and their respective surface roughness. The value obtained in this by varying three parameter are taken in design of expect V-8 software to obtain an equation. In the response surface methodology the linear and second order polynomials were fitted to the experimental data for obtaining regression equations.

In this paper the optimal machining parameters for continuous profile machining are determined with respect to the minimum production time, subject to a set of practical constraints, cutting force, power and dimensional accuracy and surface finish

3.1Objective Function:

The full development of machining process planning is based on optimization of the economic criteria subject to technical and managerial constraints. The economic criteria are the objectives of machining operations in terms of quality.

The objectives considered in this paper are surface roughness to be minimized

4. EXPERIMENTAL PART

The present study has been done through the following plan of experiment.

a) Checking and preparing the Centre Lathe ready for performing the machining operation.

b) Cutting rochling T4 medium carbon steel bars by power saw and performing initial turning operation in Lathe to get desired dimension (of diameter 59 mm and length 100mm) of the work pieces.

c) Performing straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like: spindle speed, feed and depth of cut.

d) Measuring surface roughness and surface profile with the help of a portable stylus-type profilometer, ***Talysurf*** (Taylor Hobson, Surtronic 3+, UK)

EXPERIMENTAL DETAILS:-

Turning is one of the most common of metal cutting operations. In turning, a work piece is rotated about its axis as single-point cutting tools are fed into it, shearing away unwanted material and creating the desired part. Turning can occur on both external and internal surfaces to produce an axially-symmetrical contoured part.

Parts ranging from pocket watch components to large diameter marine propeller shafts can be turned on a lathe. The capacity of a lathe is expressed in two dimensions. The maximum part diameter, or "swing," and the maximum part length, or "distance between centers."

The general-purpose engine lathe is the most basic turning machine tool. As with all lathes, the two basic requirements for turning are a means of holding the work while it rotates and a means of holding cutting tools and moving them to the work.

The work may be held on one or by both its ends. Holding the work by one end involves gripping the work in one of several types of chucks or collets. Chucks are mounted on the spindle nose of the lathe, while collets usually seat in the spindle. The spindle is mounted in the lathe's "headstock," which contains the motor and gear train that makes rotation possible. Directly across from the headstock on the lathe is the "tailstock." The tailstock can hold the work by either alive or dead center. Work that is held at both ends is said to be "between centers." Additionally, longer work pieces may have a "steady rest" mounted between the headstock and tailstock to support the work. Typically work pieces are cylindrical, but square and odd shaped stock can also be turned using special chucks or fixtures.

Lathe cutting tools brought to the work may move in one or more directions. Tool movement on the engine lathe is accomplished using a combination of the lathe's "carriage", "cross slide", and "compound rest".

The carriage travels along the machine’s bed ways, parallel to the work piece axis. This axis is known as the "Z" axis.

Motion perpendicular to the work is called the "X" axis. On an engine lathe this motion is provided by the cross slide mounted on the carriage.

Atop the cross slide is the "compound rest," which can be rotated to any angle and secured. The compound rest also holds the "tool post," where tools are mounted. Tools may also be mounted in the tailstock for end-working operations.

CUTTING TOOL:

Titanium nitride, TiN

TiN: general-purpose coating for improved abrasion resistance. Colour – gold, hardness HV (0.05) – 2300, friction coefficient – 0.3, thermal stability – 600°C.

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ORKPIECE MATERIAL

T4 Medium Carbon Steel

COMPOSITION:

Carbon (C) = 0.45% Silicon (Si) = 0.25%   Manganese (Mn) = 0.70

Typical Applications:

- 0.3-0.4: lead screws, gears, worms, spindles, shafts, and machine parts.
- 0.4-0.5: crankshafts, gears, axles, mandrels, tool shanks, and heat-treated machine parts.
- 0.6-0.7: called "low carbon *tool steel*" and is used where a keen edge is not necessary, but where shock strength is wanted. Drop hammers dies, set screws, screwdrivers, and arbors.
- 0.7-0.8: tough and hard steel. Anvil faces, band saws, hammers, wrenches, cable wire,etc.

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L27 Orthogonal Array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in Table 4.1

Table 4.1: Process variables and their limits

Variables		**Values of different levels**		
Designation	**Description**	**Low (-1)**	**Medium (0)**	**High (+1)**
D	Depth of cut (mm)	1	1.41	2
F	Feed rate (mm/rev)	0.2	0.26	0.35
V	Cutting speed (m/min)	150	178	212

Measuring Surface Roughness:-

Roughness measurement has been done using a portable stylus-type profilometer, *Talysurf* (Taylor Hobson, Surtronic 3+, UK).

Experiments have been carried out using Taguchi's L27 Orthogonal Array (OA) experimental design which consists of 27 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue prepared by Taguchi, L 27 Orthogonal Array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table 4 (all factors are in coded form). The coded number for variables used in Table 4.3 and 4.4 are obtained from the following transformation equations:

By obtain Taguchi's L27 Orthogonal Array the experiment have be conducted and the value of the particular feed, speed and depth of cut are given below

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TABLE -4.4 EXPERIMENTAL RESULTS

Std	Run	Depth of cut	Feed rate	Cutting speed	Ra
		mm	mm/rev	mm/min	µm
1	7	1.00	0.2	150	2.086
2	22	1.41	0.2	150	2.338
3	6	2	0.2	150	2.522
4	10	1.00	0.26	150	4.326
5	13	1.41	0.26	150	4.714
6	14	2	0.26	150	5.044
7	16	1.00	.35	150	6.887
8	17	1.41	.35	150	7.2362
9	21	2	.35	150	7.788
10	5	1.00	0.2	178	3.414
11	27	1.41	0.2	178	3.618
12	4	2	0.2	178	3.773
13	8	1.00	0.26	178	5.966
14	3	1.41	0.26	178	6.1983
15	9	2	0.26	178	6.363
16	23	1.00	.35	178	8.041
17	11	1.41	.35	178	8.197
18	24	2	.35	178	8.303
19	25	1.00	0.2	212	4.391
20	1	1.41	0.2	212	4.521
21	18	2	0.2	212	4.608
22	19	1.00	0.26	212	6.868
23	15	1.41	0.26	212	6.994
24	26	2	0.26	212	7.071
25	12	1.00	.35	212	8.536
26	2	1.41	.35	212	8.304

27	20	2	.35	212	8.653

EXPERIMENTAL RESULTS AND ANALYSIS

The experimental results are presented in Table given below For the purpose of developing the mathematical model; both the data for the machining responses and factors were logarithmically transformed. Using these sets of data, the parameters for the mathematical models were determined using the multiple regression method and the significance of the models and the parameters were then analyses using analysis of variance. In this work, a commercially available statistical software package DOE was used for the computation of regression and statistical analysis of the constants and parameters. The procedure PROC REG from this package was used to compute values of the mathematical models and to carry out the analysis of variance for the models developed. In the following sections, the significance of each model developed will be discussed.

The experimental value were obtain form the experiment is given the following table 5.1 and 5.2 and by using above software's the mathematical equation is obtain in term of speed, feed and depth of cut for the surface roughness .

USING DESIGN-EXPECT SOFTWARE
SURFACE ROUGHNESS (Ra)
TABLE 5.1 ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

	Sum of Squares	**DoF**	**Mean**	**F**	**p-value**	
Source				**Value**	**Prob > F**	
Model	110.4894389	9	12.2766	561.2594	< 0.0001	**Significant**
A-A	15.68472238	1	15.68472	717.0711	< 0.0001	
B-B	18.69230265	1	18.6923	854.571	< 0.0001	
C-C	0.724005556	1	0.724006	33.09994	< 0.0001	
AB	0.889549653	1	0.88955	40.66826	< 0.0001	
AC	0.182698201	1	0.182698	8.352561	0.0102	
BC	4.18053E-05	1	4.18E-05	0.001911	0.9656	
A^2	0.437292007	1	0.437292	19.99203	0.0003	
B^2	73.37755104	1	73.37755	3354.661	< 0.0001	
C^2	0.001906597	1	0.001907	0.087165	0.7714	

Residual	0.37184638	17	0.021873			
Cor Total	110.8612852	26				

TABLE 5.2 Analysis of variance (ANOVA) for Surface Roughness

Actor	Coefficient Estimate	Df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	3.680614352	1	0.077022	3.518111	3.843118	
A-A	0.936539474	1	0.034974	0.862751	1.010328	1.006579
B-B	-1.022395833	1	0.034974	-1.09618	-0.94861	1.006579
C-C	0.200555556	1	0.034859	0.127008	0.274103	1.013333
AB	0.272266667	1	0.042694	0.18219	0.362343	1
AC	-0.122574561	1	0.042412	-0.21206	-0.03309	1.006579
BC	-0.001854167	1	0.042412	-0.09134	0.087628	1.006579
A^2	-0.269966667	1	0.060378	-0.39735	-0.14258	1
B^2	3.497083333	1	0.060378	3.369696	3.624471	1
C^2	-0.01869213	1	0.063312	-0.15227	0.114885	1.013333

Final Equation in Terms of Coded Factors:

$$Ra =+ 6.184 + 0.9711 * A + 2.2593 * B + 0.1811 * C - 0.1991 * A * B - 0.0989 * A * C - 0.0018 * B * C - 0.2677 * A^2 - 0.21277 * B^2 - 0.06667 * C^2$$

Final Equation in Terms of Actual Factors:

$$Ra = -5.257 + 0.0402 * A + 29.4195 * B + 1.50896 * C - 0.0221 * A * B - 0.0016637 * A * C - 0.0311 * B * C\ 4.8\ e^{-5} * A^2 - 14.776 * B^2 - 0.266666 * C^2$$

Conclusion

In this paper, the application of RSM on the hard turning of T4 steel with Titanium nitride, TiN tool has led to obtain mathematical models for both the surface roughness (Ra) and investigating the influences of machining parameters.

Optimum values of machining parameters have been studied and computed.

The foremost conclusions which can be drawn are as follows:

(1) The analysis of machining parameters using RSM technique allows investigating the influence of each one on the cutting process progress outputs such as roughness and force components.

(2)Additionally, this study shows that the feed rate and workpiece hardness have significant statistical influences on the surface roughness. The effects of tow-factor interactions feed rate and depth of cut, cutting speed and workpiece hardness, cuttingspeed and feed rate, workpiece hardness and feed rate, and the products (H2 and ap2) appeared also to be important.

(3) The best surface roughness was achieved at the lower feed rate and the highest cutting speed.

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Authors

Author's Name NARESH KUMAR REDDY PALLELA

Author's profile. WORKING AS ASST PROFESSOR IN Padmasri Dr. B V Raju Institute of Technology

Author's Name MAHESH LLAPATIM

Author's profile. WORKING AS ASST PROFESSOR IN EVM COLLEGE OF ENGINEERING AND TECHNOLOGY