

Predictive Modelling and Optimization of Cutting Tool Life and Machine Vibration for Making a Poppet Valve

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Abstract

The present work has been done to investigate experimentally the relationship between Machine Vibration and Tool Life in turning of EN 31 steel for making a Poppet Valve using Response Surface Methodology (RSM) & Fuzzy Logic. Response Surface Methodology (RSM) is a method of obtaining the best suited result from minimal number of experiments and Fuzzy logic is used for optimization. Thus the work process becomes less tedious, i.e., with minimal effort one can come to an almost precise outcome. In this case, RSM has been used to predict the Machine Vibration and Tool Life under various machining conditions. Machine Vibration and Tool Life are the main parameters that have been dealt with in this work. The proposed work is mainly based on finding a relationship about how machine vibration can affect the tool life of the cutting tool. The proposed method is easy to carry out in the workshop area, easy to maintain and easy to understand because assessing the images of cutting tool is easy. Also, this method is flexible to use for different machining process using this Carbide Insert (CNMG 120408 EA TT5080). After the experiments has been done the following results has been found: the levels of process cutting parameters in the study are limited to the following data Speed (900, 1400, 1900 rpm), Feed rate (0.07, 0.12, 0.17 mm/rev.), Depth of Cut (0.08, 0.18, 0.28 mm).

Keywords: Machine Vibration, Tool Life, Response Surface Methodology (RSM), Fuzzy Logic, EN 31, Carbide Insert.

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INTRODUCTION

Increase of efficiency and decrease of production costs are the two primary goals of mechanical machining. Cutting tools and the whole system of machine-tool-work piece are constantly improving to reach this aim. Surface finish and Quality of machined part are depended on parameters such as cutting forces, temperature in contact surfaces, and wear of cutting tool, friction between tool and chip etc. These parameters give the measure of performance of machining. During the search for more effective cutting methods it was found that cutting quality can also be improved. It is seen

that if vibration cutting method is used, the cutting force magnitude can be reduced significantly. ^[21]

Hence, it is important not only to increase efficiency, but also to meet ecological requirements. During vibration-assisted cutting temperature in work piece & contact tool is decreasing together with decreasing friction forces. This results in lower consumption of cutting oil, which in turn reduces costs for oil removal, storage and utilization.

Vibration is a frequent problem in the turning operation, which influenced the

result of the machining and in particular, the surface finish. Vibration influenced Tool life. Spartan acoustic noise in the working environment often occurs due to the result of dynamic motion between the cutting tool and the work piece. Cutting like turning, boring and milling, vibrations are induced in all operations. There are several adverse effects in economical as well as environmental. The typical procedure to escape vibration during machining is by careful planning of the cutting parameters. The methods are usually founded on experience and trial and error to get suitable cutting data for each cutting operation complicated in machining a product. Machining vibration happens throughout the cutting process. While influenced by many sources, such as machine structure, tool type, work material, etc., the arrangement of the machining vibration is complex. There are two types of vibrations, forced vibration and self-excited vibration, as machining vibrations. Forced vibration is an outcome of certain periodical forces that exist within the machine. The bad gear motivations can be source of these forces, unstable machine-tool components, misalignment, or motor sand pumps, etc. Self-excited vibration is also called as chatter; the chip removal process and the structure of the machine too are produced by the communication, which results in turbulences in the cutting zone. Chatter always designates faults on the machined surface; vibration particularly self-excited vibration is related with the machined surface roughness^[25].

The total cost per operation is involved of four individual costs: machining costs, tool costs, tool changing costs and handling costs. The machining cost is observed to decrease with increasing cutting speed because cutting time decreases. Cutting time is proportional to the machining costs. Both the tool costs and the tool-changing costs increase with increase in

cutting speeds. The handling costs are independent of cutting speed. Adding up each of the individual costs results in a total unit cost curve that is observed to go through a minimum point. For a turning operation, the total cost per piece C equals

$$\begin{aligned} \text{Total Cost} &= \text{Machining costs} + \text{Tooling costs} \\ &+ \text{Tool changing cost} + \text{Handling cost per piece} \\ C &= C_1 + C_2 + C_3 + C_4 \end{aligned} \quad \text{Eq (1)}$$

This 'C' is not the same as the 'C' used in Taylor Tool life equation. In this analysis, that 'C' will be called 'K'.

In factory situations, one frequently encounters the problems of selection of cutting conditions, tool and work piece materials etc. The machining parameters will definitely affect the production rate as well as the total cost involved in producing a part. Initially proposed by Gilbert (1950), machining economics analysis largely concerns itself with selection of machining parameters for an optimum production cost or production rate. Again tool life becomes significant in this context since the cost of the tools influences the machining cost considerably.^[23]

B. Fnides *et al.*^[13] have studied on machining of slide-lathing grade X38CrMoV5-1 steel treated at 50 HRC by a mixed ceramic tool (insert CC650) to disclose the influences of cutting parameters: feed rate, cutting speed, depth of cut and try to measure flank wear on cutting forces as well as on surface roughness. The authors have established that tangential cutting force was very sensitive to the variation of cutting depth. It has observed that surface roughness is very sensitive to the variation of feed rate and that flank wear have a great influence on the evolution of cutting force components and on the criteria of surface roughness^[13].

The following tasks are set in order to reach the objective: To develop a physically model of Poppet valve using Carbide inserted cutting tool. To measure vibration of machine using Pico scope (2202). To find minimum cost using Taylor's Tool life equation. Analysis of the data gave rise to predictive equation for vibration and also for machining economy.

MATHEMATICAL MODELLING

A system using mathematical concepts and language are used to describe the mathematical model. Mathematical modelling of cutting process is very important, not only for understanding the nature of the process itself, but also for planning and optimizing the machining operations. However, many complex and nonlinear relationships between different variables and parameters are encompasses hard machining. Modelling of these relationships is difficult task. The type of chatter can be determined by measuring the wavelength of the chatter marks on the work piece surface. The wavelength is equal to the disturbance between corresponding points on chatter marks as. The frequency of vibration can be calculated by the expression.

$$f = v/WL \tag{Eq (2.1)}$$

where, f= vibration frequency (cycles per second), v = cutting speed (mm/sec), WL= wavelength of vibration (mm) [25].

Taylor's Tool Life Equation is expressed by

$$vt^n = C \tag{Eq (2.2)}$$

where, v = cutting speed, t = tool life, n and C = constants.

Let, t_c = machining time per part

Then, machine time per part could be expressed as:

$$t_c = \frac{\pi DL}{v.f} \tag{Eq (2.3)}$$

where, D = dia. Of work piece, L = axial length of work to be cut, v = cutting speed

and f = feed, if t = tool life for the cutting conditions, the costs involved are:

$$\text{Direct labour \& machine cost} = X_1 t_c$$

$$\text{Tool changing cost per part} = X_1 t_d t_c / t$$

$$\text{Tool cost per part} = X_2 t_c / t$$

$$\text{Total cost per part,}$$

$$TC = X_1 t_c + X_1 t_d t_c / t + X_2 (t_c / t) \tag{Eq (2.4)}$$

where, X_1 = Machine and Operator costs with Overhead (Rs /min), t_d = Down time in minutes to change a Tool and X_2 = Mean cost of the cutting edge.

Modelling of Tool Life for Minimum Cost

Substituting for t_c and t from equations (2.2) and (2.3) and making d(TC)/dv=0, the tool life for minimum cost is found as[23]:

$$t_0 = \left[\frac{1}{n} - 1 \right] \left[\frac{X_1 t_d + X_2}{X_1} \right] \tag{Eq (2.5)}$$

The corresponding cutting speed,

$$v_0 = \left(\frac{C}{t_0^n} \right) \tag{Eq (2.6)}$$

Or

$$v_0 = C \left[\frac{1}{\frac{1}{n} - 1} \right]^n \left[\frac{X_1}{X_1 t_d + X_2} \right]^n \tag{Eq (2.7)}$$

DESIGN OF EXPERIMENTS (DOE)

To govern simultaneously the individual and interactive effects of many factors that could affect the output results in any design, designers can enables Design of Experiments (DOE) techniques. DOE also affords a full understanding of interaction between design elements which is designed; therefore, it helps turn any standard design into a healthy one. [31]

Process Variables and Their Limits

Response Surface Methodology with rotatable design has been selected for the working ranges of the parameters for subsequent design of experiment. Spindle speed, feed rate and depth of cut have been considered as process variables in the present experimental study. Notations and units of process variables are listed in Table 1.

Table 1 Process Variables

VARIABLES	LEVEL		
	-1	0	-1
Speed(rpm)	900	1400	1900
Feed(mm/rev)	0.07	0.12	0.17
Depth of Cut(mm)	0.08	0.18	0.28

Material Selection

It is hard to select a particular W/P material & corresponding cutting tool material from huge range of standard material & tool material. The plan is to make a poppet valve so EN 31 alloy steel has been selected as work piece material for the present work as EN 31 High carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance is a good quality steel for wear resisting machine parts and for press tools which do not merit a more complex quality. This type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion by its character, wear or high surface loading. Select cutting tool insert and job material as CNMG120408 EN-TMR CTC1135 Carbide insert and EN 31 alloy steel respectively. The EN 31 steel rod of size 120 mm and diameter 25 mm has been used for present work which is known for its high quality.

EXPERIMENTATION

For successful completion of the experimentation some prerequisite steps have to be maintained. These steps will

Data Collection

Table 2 Input and Output of Experiment

Sl. No.	Coded Data			Actual Data			Response		Tool Life (min)
	DOC (mm)	Feed Rate (mm/rev)	Speed Rate (RPM)	DOC (mm)	Feed (mm/rev)	Speed (RPM)	Frequency (Hz)	Cycle Time (min)	
01	-1	1	-1	0.08	0.17	900	500	17.06	360
02	0	0	0	0.18	0.12	1400	670	16.02	335
03	0	0	0	0.18	0.12	1400	690	16.18	330
04	1	1	1	0.12	0.17	1900	590	08.50	255
05	0	0	0	0.18	0.12	1400	715	16.21	331
06	0	0	-1	0.08	0.12	1400	450	15.37	338

minimize the experimental errors as well as experimental hazards. An experiment needs proper planning. The following steps are maintained for this purpose:

- a) Checking and preparing the CNC lathe (such as proper electrical connections, proper lubricating oil level, cleaning chips of previous work etc.)
- b) Performing initial turning and facing operations on EN 31 to get desired dimension of the job piece.
- c) Performing straight turning operations on specimen in various control parameters.
- d) Measuring frequency while performing each turning operations.
- e) Measure the machining time (Cycle Time)

Cutting Tool Material and Tool Holder Carbide Insert Specification



Fig.1: Carbide Insert Tool

Made: Taegu Tec (TT) Member IMC Group

Specification: CNMG 120408 EA TT508

EXPERIMENTAL SETUP

The EN 31 steel bar is held on the three jaw auto-centre pneumatic chuck on CNC turner. For machining, suitable CNC programming is used.

07	1	-1	1	0.12	0.07	1900	790	18.50	351
08	0	0	0	0.18	0.12	1400	720	16.20	337
09	-1	1	1	0.12	0.17	900	1010	16.57	315
10	1	0	0	0.08	0.12	1900	930	12.01	336
11	-1	-1	1	0.12	0.07	900	1250	09.20	402
12	1	-1	-1	0.08	0.07	1900	810	19.40	347
13	0	-1	0	0.18	0.07	1400	770	17.55	350
14	0	1	0	0.18	0.17	1400	630	11.14	342
15	-1	0	0	0.18	0.12	900	970	23.15	336
16	1	1	-1	0.08	0.17	1900	880	08.42	385
17	0	0	0	0.18	0.12	1400	730	18.10	341
18	-1	-1	-1	0.08	0.07	900	521	16.26	295
19	0	0	1	0.12	0.12	1400	712	15.20	322
20	0	0	0	0.18	0.12	1400	680	16.29	331

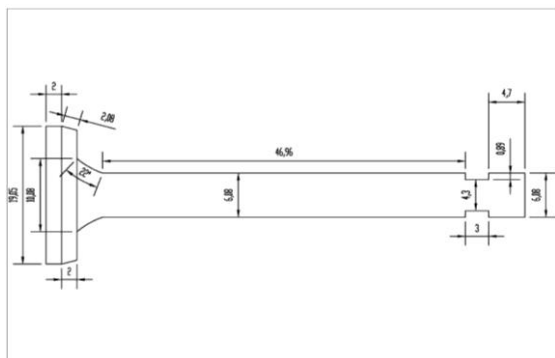


Fig.2: Outline of a Poppet Valve

This is a schematic diagram Fig. 2 of 2D layout of a Poppet Valve. This has been made by Auto CAD software.



Fig.3: 3D Modelling of Poppet Valve

This 3D Model has been done through Inventor Software.

RESULT AND DISCUSSION

In this study, an investigation is made for finding out optimum cutting parameters that is speed, feed and depth of cut. While

the output parameters are Frequency of Tool Vibration and Tool life are kept to a minimum. Work piece material is selected as EN31 and cutting tool is selected as coated carbide alloy.

20 observations have been carried out to determine Design of Experiments (DOE). The Table 2 gives the experimental data. With the experimental data a nonlinear regression model is obtained using Response Surface Methodology (RSM). The model is obtained using RSM is given below.

For optimization, Multi-objective Optimization tool Fuzzy Logic is selected. The ability of Fuzzy is to state that the statements are true or false to only some degree in a continuous or vague logic. Objects belong to fuzzy sets is only some degree.

Fuzzy systems are sets of fuzzy rules that map inputs to outputs. Most applied fuzzy systems map sensor measurements to control actions. Fuzzy Inference system can help find and tune the rules in fuzzy system.

Response Optimization

For the optimization current values of A,

B, C, is shown here in Figure 4 with the particular composite desirability corresponding minimum value of frequency is obtained

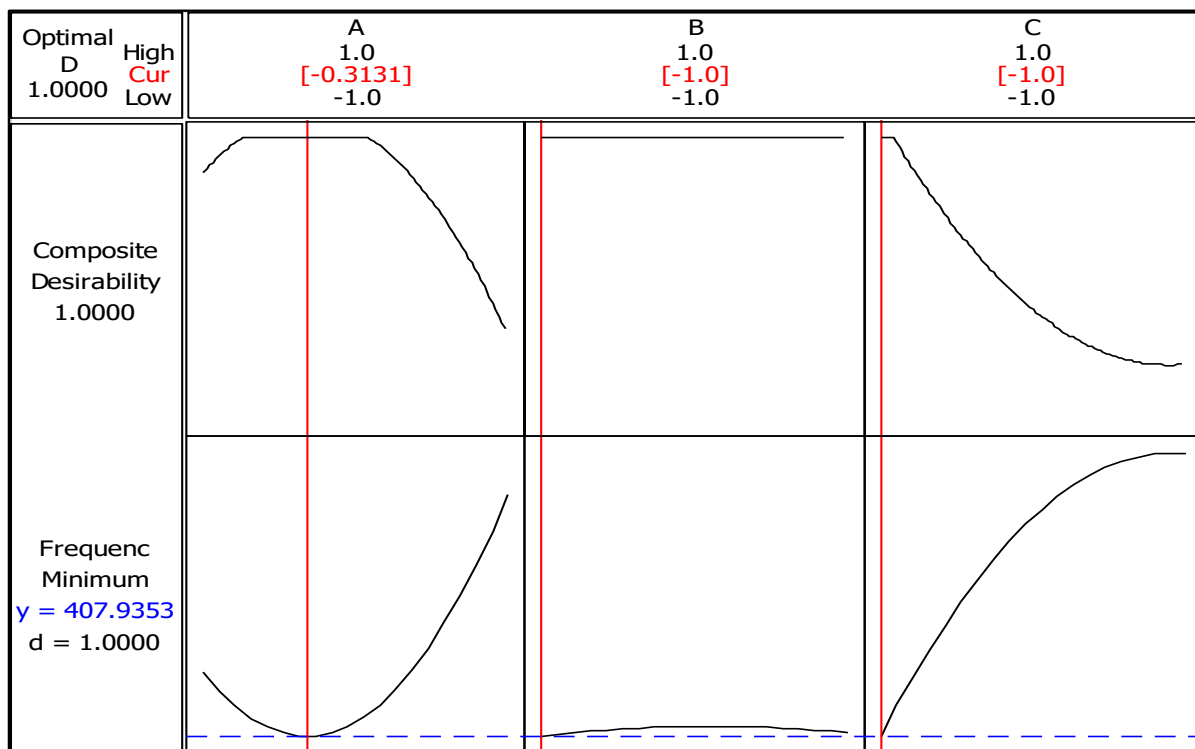


Fig.4: Response Optimization

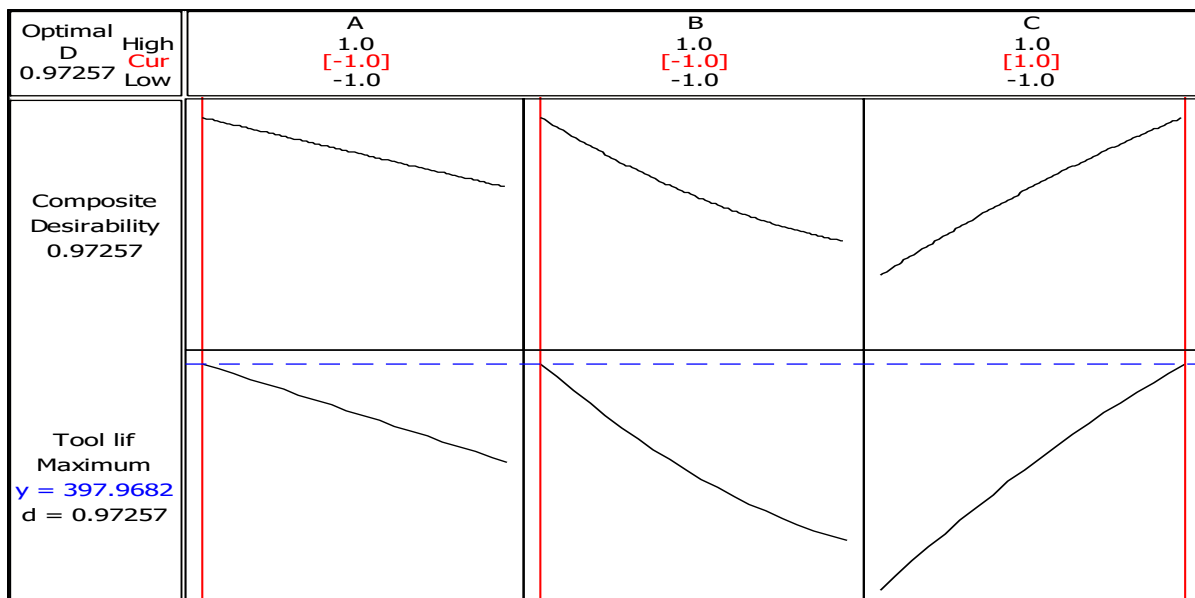


Fig. 5: Response Optimization

For the optimization current values of A, B, C, is shown here in Figure. 5 with the particular composite desirability corresponding minimum value of tool life is obtained.

MATLAB implementation of the fuzzy Inference system is described. A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or

degree of membership) between 0 and 1. Using AND logic between two input functions got a corresponding membership

value or degree of membership which is shown in Figure. 6

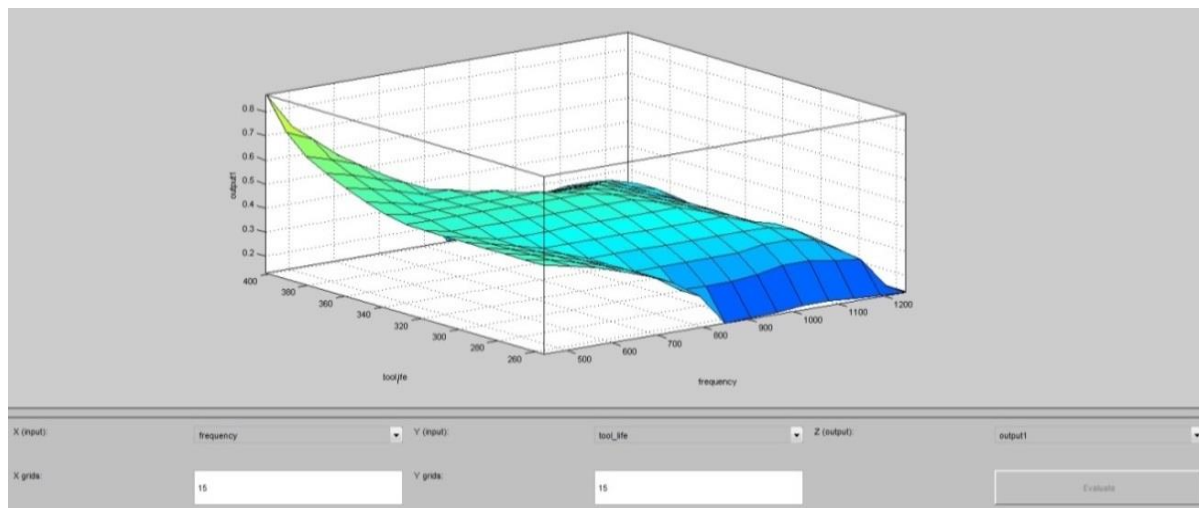


Fig. 6: Surface view of Fuzzy Interference System

By visualising the surface view of Fuzzy Interference System in Figure 6 it has been clearly showed that membership value for a particular data is shown in 3D view.

Rules

In this Fuzzy System there are two inputs Frequency and Tool life. Membership function as Mamdani is consider as Triangle form (trimf). Input Variables Function is Frequency & Tool life. Coded values 1, 2, 3 as follows-1 for low, 2 for mid, 3 for high is shown in Table 3.

Table 3 Input Variables Vs. Response

Input Variables		Response
Frequency	Tool life	Optimization
1	3	3
3	3	1
2	3	1
1	2	2
2	2	2
3	2	1
1	1	2
2	1	1
3	1	1

Fuzzy Value

Table 4 shows the Fuzzy value. The table shows corresponding Fuzzy value for a

particular frequency in Hz and tool life in minutes.

Table 4 Fuzzy value of 20 Experiments

Expt.	Frequency (Hz)	Tool life (min)	Fuzzy value
01	500	360	0.56
02	670	335	0.50
03	690	330	0.50
04	590	255	0.47
05	715	331	0.50
06	450	338	0.50
07	790	351	0.48
08	720	337	0.50
09	1010	315	0.451
10	930	336	0.50
11	1250	402	0.13
12	810	347	0.491
13	770	350	0.482
14	630	342	0.50
15	970	336	0.48
16	880	385	0.19
17	730	341	0.50
18	521	295	0.50
19	712	322	0.50
20	680	331	0.50

Figure. 7 shows the plot of Fuzzy value for 20 observations corresponding to the Frequency and Tool Life for a machine.

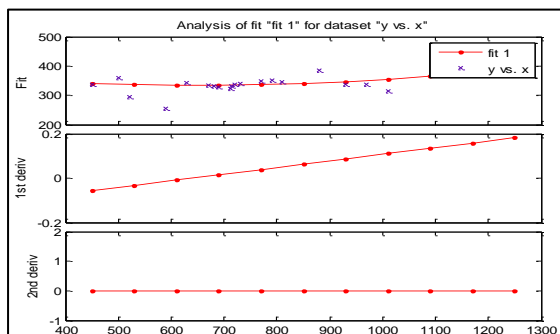


Fig. 7: Analysis of 'fit 1' for Dataset 'y' vs. 'x'

In this Figure 8 it is shown that how this fitted value is varied with the corresponding 1st & 2nd order derivative. Graph represents abscissa as Frequency and Tool life as ordinate. Linear polynomial shows as a one degree polynomial. Linear relationship between Frequency and Tool life is shown here.

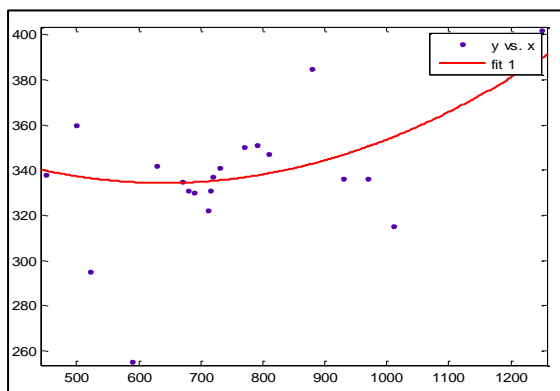


Fig. 8: Linear Model for Polynomial

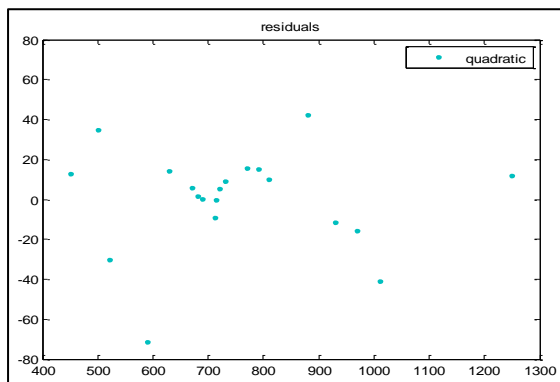


Fig. 9: Scatter Plot

Figure. 9 shows a Scatter Plot of a quadratic model, which means residuals, are quadratically fitted.

Quadratic Equation for the Best Fitted Curve is
 $y = 0.00011 * x^2 - 0.1 * x + 3.5e + 002$

CONFIRMATION TEST

Confirmation test is done to check the adequacy of the developed RSM model and the experimental results thus found on the basis of optimized process parameters are given in table. The predicted results are in acceptable zone with respect to the experimental results which is concluded that the developed model seems to be satisfactory.

Table 5 Result of Conformation Test

Sl. No.	Response	Unit	Response Value	
			Predicted	Experimental
1	Frequency	Hz	407.935	450
2	Tool life	Min	397.968	402

From Fuzzy Logic interference system with Experiment Number (01) gives the highest value. So such Experiment gives best fitted solution.

Manufacturing processes like CNC Turning are greatly practised in almost all type of industry specifically in Automotive Industry, Aeronautical Industry etc. Thus it is very important to know the machining performance for a particular machining condition. In this investigation, responses were predicted for a set of machining parameters and also optimum machining conditions are evaluated considering each of the responses.

During the present investigation, experiments are carried out using Response Surface Methodology design. It has been monitored throughout the test that the parameters of the Tool Life of the machined could not be hampered due to Machine Vibration. From the analysis of

the parameters it has been revealed that all the selected parameter vary in the same nature with respect to the change in Spindle Speed, Feed Rate and Depth of Cut.

The result of optimization considering the responses showed the optimum conditions for the responses with the optimum value or the best fitted value. According to the confirmation test the developed model seems to be satisfactory because the predicted results are in acceptable zone with respect to the experimental result.

CONCLUSION

Manufacturing processes like CNC Turning are heavily practised in almost all type of industry specifically in Automotive Industry, Aeronautical Industry etc. Thus it is very important to know the machining performance for a particular machining condition. In this investigation, responses were predicted for a set of machining parameters and also optimum machining conditions are evaluated considering each of the responses.

1. During the present investigation, experiments have been carried out using Response Surface Methodology design.
2. It has been monitored throughout the test that the parameters of the surface integrity of the machined surface could not be hampered due to tool wear.
3. With variation of Speed, Feed & DOC will effect on Machine Vibration.
4. Tool Life is also dependent on Machine Vibration.
5. The result of optimization considering the responses showed the optimum conditions for the responses with the optimum value or the best fitted value.
6. According to the confirmation test the developed model seems to be satisfactory because the predicted results are in acceptable zone with respect to the experimental result.

The Results showed that response obtained from frequency of Vibration & Tool Life is 407.935 HZ, 397.968 min & 450 Hz, 402 min, predicted & experimentally respectively. Fuzzy Logic has been used for optimization of responses for getting a predictive relationship between them.

SCOPE OF FUTURE WORK

In the present investigation, only three machining parameters have been considered for analysing Tool Life and frequency of vibration. Further work could be carried out to investigate the influence of following parameters on surface integrity:

1. Tool geometry (nose radius, rake angle, helix angle etc.)
2. Vibrational effect over surface integrity.
3. Heat generated in cutting tool.
4. Tool or flank wear.
5. Thermal analysis of work surface.
6. Effect of cutting fluid.

From optimization point of view other processes like Artificial Neural Network, Fuzzy Logic etc. can be compared with Genetic Algorithm.

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ANNEXURE

Main Program

G91G94
 G75X0Z0
 T04D1
 M03S1500
 G0G90X28Z5
 CVCLE95 (“T1, 0.30000, 0.10000, 0.10000, , 250.00000, 200.00000, 250.00000, 9, , 1.00000)
 G75X0Z0
 M5
 M9
 M30

==eof==

Sub Program

G01X8.0
 Z0
 G01X8.0
 G01Z-72.7
 G01X14Z-76.7
 G01X20
 G01X24Z-81.7
 G01Z-86.7
 G01X25
 M17
 ==eof==



Fig.10: Pictorial Views of Work Pieces after Experimentation