ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 3, January 2018

Prediction of tool force using DOE and design of turning tool

Santosh D N[1], Ravi kumar B N[2], Mahesh B[3], Vijayalaxmi S P[4]
[1]Assistant Professor,Department of Mechanical Engineering, Dayananda Sagar Academy of Technology & Management, Bangalore, Karnataka, India
[2]Lecturer, [1]Department of Mechanical Engineering, Arbaminch University, Arbaminch

ABSTRACT

Quantitative understanding of cutting forces is important for tool life estimation and tool condition monitoring purposes. The cutting forces that are developed during the turning process can directly or indirectly estimate process parameters such as tool wear, tool life, and surface finish. The major factors that affect the tool force are speed, feed and depth of cut. The goal of this work is to obtain a mathematical model that relates the cutting force to three cutting parameters in turning, precisely to the cutting speed, feed rate and depth of cut. In this work, central composite method based on design of experiments approach is used to obtain the mathematical model. On the basis of maximum force acting on the tool a turning tool is designed on strength basis. Inverse finite element method approach is used for checking the strength of the designed tool.

INTRODUCTION

Structural members and machines are designed on the basis of applying force and boundary conditions. Structural members like single point cutting tools being used for turning, shaping, slotting, boring operations etc., are characterized by having only one cutting force during machining. But that force is resolved into two or three components for ease of analysis. Many researchers are conducted experiments and predicted cutting tool life, wear and force during different machining operations. Some of them are as fallows. Amir Mahyar Khorasani [1] presents the role of speed, feed and depth of cut in tool life prediction in milling operations by using artificial neural networks and Taguchi design of experiment.

Machining experiments were performed under various cutting conditions by using sample specimens. A very good agreement between predicted model and experimental results was obtained. The correlation between the estimated and experimental data was 0.96966 for train and 0.94966 for test.Turnad L. Ginta [2] this paper presents an approach to establish models for tool life in end milling of titanium alloy Ti–6Al– 4V using uncoated carbide inserts under dry conditions. Small central composite design (CCD) was employed in developing the tool life model in relation to primary cutting parameters such as cutting speed, axial depth of cut and feed. Flank wear has been considered as the criteria for tool failure and the wear was measured under a Hisomet II Toolmaker's microscope. Further testing was stopped and an insert rejected when an average flank wear greater than 0.30 mm was achieved. The adequacy of the predictive model was verified using analysis of variance (ANOVA) at 95% confidence level. A. Fortunato [3] This paper refers to the prediction of cutting force behavior in milling machining operations.

In literature two different approaches are generally used: analytical models and FEM simulations. Each approach covers different aspects of the global process: while analytical model allows to estimate, in quite short computational time, the three components cutting force distribution and theoretical roughness of the worked surface, the FEM simulations make possible to introduce other aspects such as the thermal effect, the 3D complex shape of the work piece or the tool wear influence. An analytical model, based on Altinitas research activity, has been implemented into the Matlab code and the results, obtained by simulating different process parameters and tool shapes, have been compared to known experimental force distributions. Then the 3D thermo-mechanical FEM simulations of the same operations were realized by means of the Deform code and the results were compared to the previous ones. Finally the advantages of the different approaches have been presented and discussed. K Kadirgama [4] finite element (FEA) method and response surface method (RSM) are used to find the

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 3, January 2018

effect of milling parameters (cutting speed, feed and depth of cut) on cutting force when milling Hastelloy c-22HS. Based on variance analysis of first and second order RSM models, most influential design variable is feed rate. Optimized cutting force values are subsequently obtained from model equations. Tadeusz Uhl [5] presents an overview of a loading force identification technique. The least square error method between the simulated and measured responses is mainly used as the objective function. The method is applied to the identification of wheel-rail contact forces during rail vehicle operation. The algorithm used is based on Tikhonov's regularization, helped to obtain a physically interpretable solution of the inverse identification problem, which is based on standard acceleration measurements at the most sensitive locations on vehicle bogies. Dr: D.S.C. [6] explained the mathematical theory of statistics for curve of best bit called method of least square. The measured values of strain and simulation values of strain are within elastic limit of the material, therefore the plot of force versus strain is a straight line. The least square method for best fit of a line is used in this work. G.R.Liu and X.HAN [7] discusses a computational inverse finite element method in Non destructive evaluation, using forward and inverse problems encountered in structural systems. They also discuss the theory, computational methods and algorithms, and practical techniques for inverse analysis using elastic waves propagating in solids and structures or the dynamic responses of solids and structures. These computational inverse methods and procedures will be examined and tested numerically via large number of examples of force/ source reconstructions, crack detection, flaw characterization, material characterization and many other applications. Some of these techniques have been confirmed with experiments conducted by the authors and co-workers in the past years. From the above literature survey it is clear that many works are done on the tool life, wear and forces acting during operations like milling, turning etc., but prediction of forces on single point cutting tool during turning operation using central composite method are scanty. In this paper an attempt has been carried out to reach the above goal.

PREDICTION MODEL FOR TOOL FORCE

Recognition of and statement of the problem: Quantitative understanding of cutting forces is important for tool life estimation and tool condition monitoring purposes. The cutting forces that are developed during the turning process can directly or indirectly estimate process parameters such as tool wear, tool life, and surface finish. The goal of this work is to obtain a mathematical model that relates the cutting force to three cutting parameters in turning, precisely to the cutting speed, feed rate and depth of cut.

Choice of factors and levels: The major factors that affect the tool force are speed, feed and depth of cut. So in the present work speed, feed and depth of cut parameters are considered as input factors and the ranges over which these factors will be varied are Speed: 125 -50 - 710 rpm, Feed: 0.06 - 0.12 - 0.24 mm/rev, Depth of cut: 0.3 - 0.6 - 1 mm.

Selection of the response variable:
In the present work the three dimensional cutting forces are considered as output response. The three dimensional cutting forces are Tangential or Cutting Force (Fy): This acts in the direction tangent to the revolving member. Longitudinal or Feed Force (Fz): This acts in a direction parallel to the axis of the work. Radial force (Fx): This acts in a radial direction from the centre of the work piece.

4.5.1 Experimental setup:

Experimental set up

In order to measure experimentally the tool forces a three axis lathe tool dynamometer was used. Experiments were carried out on lathe machine (HMT craft master TL20) without coolant. Each experiment stopped after 50 mm cutting length. Each experiment was repeated thrice using a new cutting edge every time for accurate readings of tool forces.

Experimental readings: The design array is developed by using QA six sigma software suite DOE-PC IV. On the basis of input factors, levels and design choices the design array is developed. According to this design array the experiment was carried out to determine the tool forces in three directions. Machining was performed with a 10 mm cross section high speed steel tool. The work piece (Mild steel) is of 26 mm diameter and 300 mm length.

Data analysis: QA six sigma software suite DOE-PC IV is used for data analysis. After the completion of the experiment, the experimental values are

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 3, January 2018

entered in the base analysis array to generate the ANOVA/Regression output display.

DESIGN OF TURNING TOOL

The shank of a cutting tool is generally analyzed for strength and rigidity. The tool is assumed to be loaded as a cantilever by tool forces at the cutting edge. The deflection at the cutting edge is limited to a certain value depending on size of the machine, cutting conditions and tool overhung. The tool overhung (Le) is related also to the shank size as well as to end fixit conditions. The minimum permissible size 0f the shank cross section on strength basis is calculated by equating the actual bending moment to the maximum bending moment permitted by cross section of the shank.

$R \times L_e = \times Z$

Where R=Resultant force = ($Fx^2+Fy^2+Fz^2$)

= Permissible stress for High speed steel =250 N/mm^2

L_e= overhang length of the tool = 25 mm

Z = Section modulus = I/y

RESULTS AND DISCUSSION

The prediction model for the radial force, cutting force and feed force is obtained by using the ANOVA results. The sum of individual product of parameter or source and the corresponding coefficient as in fitted parameter table. The prediction model obtained for radial force, cutting force and feed force is written as

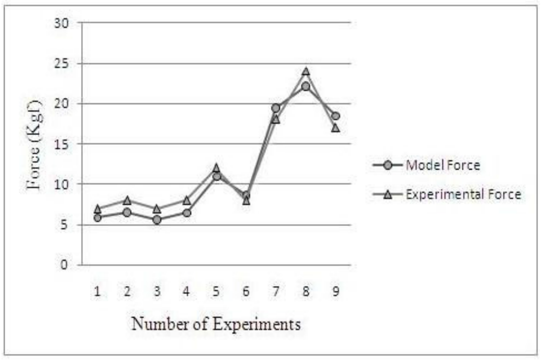
FX = 10.931 + (-0.015)×N + (21.295)×F + (-8.297)×T + (0×N×N) + (-82.554×F×F) + (34.396×T×T) + (0.059)×N×F + (0.021×N×T) + (32.333×F×T) + 1.503

FY = 6.113 + (-0.023) × N+ (163.771)×F + (-1.465)×T + (0×N×N) + (-523.946×F×F) + (11.427×T×T) + (0.103)×N×F + (-0.005× N×T) + (245.684×F×T) + 2.384

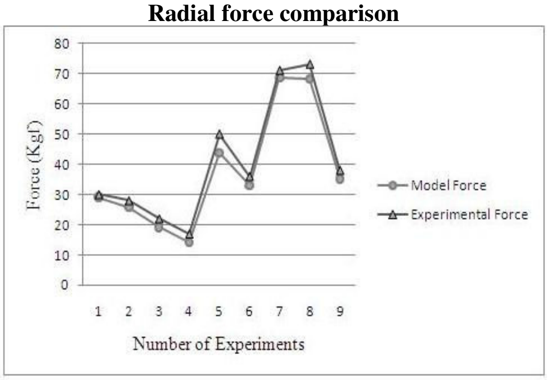
FZ = 8.476 + (-0.024) × N + (16.945)×F + (-3.817)×T + (0×N×N) + (-130.531×F×F) + (16.231×T×T) + (0.109)×N×F + (0.01×N× T) + (120.204×F×T) + 0.906

Validation for radial force, cutting force and feed force:

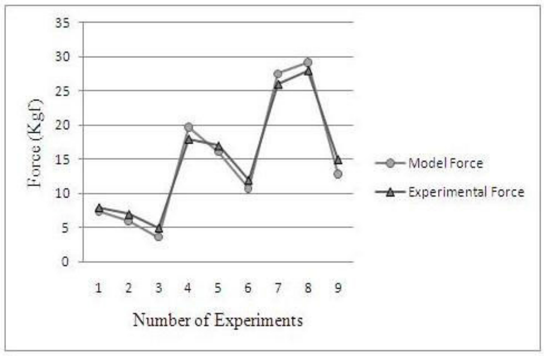
The graphical representation of comparison of the experimental and predicted model force is as shown in figure



Radial force comparison



Cutting force comparison



Feed force comparison

The radial force, cutting force and feed force can be determined by using these equations by the input of speed, feed and depth of cut within the design space. i.e speed between 125 rpm to 710 rpm, feed between 0.06 m/rev to 0.24 mm/rev and depth of cut between 0.3 mm to 1.0 mm.

The optimum tool geometry is obtained by equating the actual bending moment to the maximum bending moment permitted by cross-section of the shank. The maximum force acting on the surface of the tool at the operating condition of speed 710 rpm, feed 0.24 mm/rev, depth of cut 1.0 mm and for this condition the force from lathe tool dynamometer, the radial force is 31 kgs, cutting force is 80 kgs and the feed force is 46 kgs. The maximum resultant force acting on the surface of the tool is 955 N. hence this resultant force is used to

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 3, January 2018

design the tool. The optimum tool geometry obtained from calculation is 9 mm square cross section shank size. The tensile stress induced in the designed turning tool from theoretical formula is 196 N/mm2 which is within permissible stress of HSS i.e 250 N/mm2.

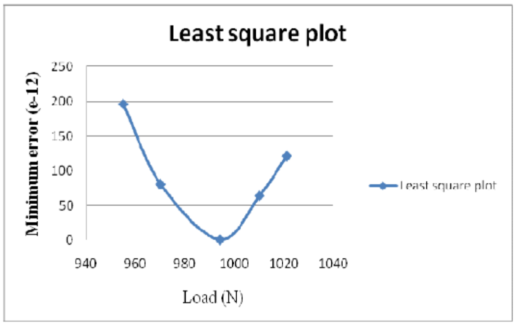
MEASUREMENT OF CUTTING FORCE ON TURNING TOOL

Inverse finite element method is used to determine the forces acting on the designed tool to check the designed tool is within permissible stress of the cutting tool material. Inverse method is applied on a lathe tool for finding the cutting force. A finite element analysis is carried out by applying range of static load at free end of the tool and strains are measured at known locations. The turning operation is carried out using lathe tool and strains are measured at known locations.

The measured strains from lathe tool are compared with the analysis strains by using least square method. The minimum error from the plot of least square will gives the cutting force. A cutting lathe tool is taken for experimentation in the laboratory and strain gauges are mounted at predetermined points on the surface of the lathe tool. When the lathe is in operation, the lathe tool tends to bend during cutting operation. These bending strains are determined by strain gauges. As cutting operation starts the lathe tool gets strained.

It is observed that the maximum force acting on the turning tool within design space is at speed of 710 rpm, feed of 0.24 mm/rev and depth of cut of 1.0 mm. to check the strength of the designed turning tool the same condition of speed, feed and depth of cut is used. The strain is measured using strain gauges mounted at required point, the maximum strain readings for different is 302 microns.

The least square error method is used to determine the load acting on the turning tool. The square of the difference between Ansys strain and experimental strain is the least square error method. The load corresponding to the minimum error is the load acting on the turning tool. In this case the minimum error of least square is 1 corresponding to this error the load is 994 N.



The least square error plot is as shown in figure. The y axis represent the error and the x axis represent the load. The least square eror plot is drawn by using the table (7.3). the minimum error is at the load of 994 N. The stress induced in the designed turning tool is determined experimentally. The inverse finite element approach is used for measuring force on the surface of turning tool during turning operation. Inverse FEM with strain gauge as sensors are used for estimating the cutting force for the operating condition of speed 710 rpm, feed 0.24 mm/rev, depth of cut 1.0 mm because of maximum force is acting on the tool at this condition. For the operating condition of speed 710 rpm, feed 0.24 mm/rev, depth of cut 1.0 mm the cutting force estimated was 994N. For this resultant force the tensile stress induced in the cutting tool is calculated to be 204 N/mm2 which is within permissible stress of HSS i.e 250 N/mm2. Hence the design is safe.

CONCLUSION

A new model for the cutting forces in turning is proposed that relates the forces in to cutting parameters such as speed, feed and depth of cut. The variation between the predicted force and the experimental force is within 10% error. For optimal design of machine and structural members it is necessary that the forces to which such members are subjected to be known before the design process is started. But usually the operating forces are not exactly known and design based on such approximate loads is not optimal. The force acting on the surface of the tool is determined by using lathe tool dynamometer and inverse FEM approach. Hence the stress induced in turning tool is calculated by theoretical as well as Inverse FEM approach. The error in measurement is found to be 4%.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 3, January 2018

REFERENCES

1. Amir Mahyar Khorasani1, Mohammad Reza Soleymani Yazdi2 and Mir Saeed Safizadeh “Tool Life Prediction in Face Milling Machining of 7075 Al by Using Artificial Neural Networks (ANN) and Taguchi Design of Experiment (DOE)” International Journal of Engineering and Technology, Vol.3, No.1, February 2011

2. Turnad L. Ginta, A.K.M. Nurul Amin, H.C.D. Mohd Radzi, Mohd Amri Lajis “Tool Life Prediction by Response Surface Methodology in End Milling Titanium Alloy Ti-6Al-4V Using Uncoated WC-Co Inserts” European Journal of Scientific Research ISSN 1450-216X Vol.28 No.4 (2009), pp.533-541

3. Fortunato, C. Mantega, L. Donati, G. Tani “Milling force prediction by means of analytical model and 3D FEM simulations” International Workshop on Modeling of Machining Operations May 11-12, 2006, Bled, Slovenia.

4. K Kadirgama, K A Abou El Hossein “Cutting force prediction model by FEA and RSM when machining hastelloy c-22HS with 900 holder” journal of scientific and industrial research vol 67, june 2008, pp. 421- 427.

5. Tadeusz Uhl “The inverse identification problem and its technical application” Arch Appl Mech(2006) DOI 10.1007/s00419-006-0086-9

6. Dr: D.S.Chandrashekaraiah. Professor and chairman (Retired), Dept of Mathematics. UVCE. Bangalore. “Engineering Mathematics”. Part IV.

7. G.R.Liu and X.HAN “computational inverse finite element method in Non destructive evaluation”

8. TOOL ENGINEERING AND DESIGN, G.R.NAGPAL, khanna publishers , fifth edition 2002.

9. STATISTICAL QUALITY CONTROL AND DESIGN OF EXPERIMENTS, Montgomery.