International Journal of Research (IJR) Vol-1, Issue-8, September 2014 ISSN 2348-6848

Modeling and Harmonic Analysis of Turning Operation

Pramod Kumar N[1],Avinash N V [2],Sudheer K V[3]and Umashankar K S[4]

[1,2,3] PG Students., Dept. of Mechanical Engineering, KVGCE, SULLIA, DK – 574327
VTU, Belgaum. Karnataka, India, [1]E-mail:pramodnk90@gmail.com
[4]Professor., Dept. of Mechanical Engineering
KVGCE, SULLIA, DK – 574327, VTU, Belgaum, Karnataka, India ,[4]E-mail:ukskvgce@gmail.com
[2]E-mail:nvavinash50@gmail.com, [3]E-mail:sudheerkv21@gmail.com

Abstract:

The present work involves the study of tool deflection and tool failure due to vibration while turning on the lathe. The problem of tool failure monitoring in machining operations, has been an active area of research for quite a long time. The accurate prediction of tool failure or fracture is important to have a better product quality and dimensional accuracy. In This work Experiments were performed with mild steel as work piece and HSS as a tool material and the various machining forces have been measured experimentally. Lathe tool model being designed by taking existing lathe tool dimensions. Finite element analysis is done using ANSYS 10.0 software tool to find natural frequency of HSS lathe tool. Modal analysis done to determine the vibration characteristics (natural frequencies and mode shapes) of a lathe tool. The Natural frequency found in Harmonic analysis is well agreed with the experimental values got from literature. The dynamic failure of lathe tool is predicted in terms of critical speed and surface roughness of work material to avoid critical frequency.

Keywords:

Finite element analysis, Tool deflection,Cutting force,Natural frequency, Critical frequency

Introduction

Manufacturing & machining of metals is still not completely understood because of the highly non-linear nature of the process and the complex coupling between deformation and temperature fields [1]. Metal cutting can be associated with high temperatures in the tool-chip interface zone and hence, the thermal aspects of the cutting process strongly affect the accuracy of the machining process [2]. The deformation process is highly concentrated in a very small zone and the temperatures generated in the deformation zones affect both the tool and the workpiece. High cutting temperatures strongly influence tool wear, tool life, workpiece surface integrity, chip formation mechanism and contribute to the thermal deformation of the cutting tool, which is considered, amongst others, as the largest source of error in the machining process [1]. Measuring heat generated and the prediction of heat distribution in metal cutting is extremely difficult due to a narrow shear band, chip obstacles, and the nature of the contact phenomena where the two bodies, tool and chip, are in continuous contact and moving with respect to each other. The ever-increasing demand on cost reduction and improving quality of final products are driving metal cutting research into new areas. As for high speed machining (HSM) [3], it has become a key technology of particular relevance to the aerospace, mould and die and automotive industries. In HSM, cutting speed has a predominant effect on the dynamic charateristics and the heat transfer mechanism. As cutting speed increases, the cutting process becomes more adiabatic and the heat generated in the shear deformation zone cannot be conducted away during the very short contact time in which the metal passes through this zone. Consequently, highly localized temperatures in the chip occur. Therefore, it appears that in HSM, where the process is nearly adiabatic, the effect of the thermal phenomenon should become more important. The metal cutting is a coupled of thermo-mechanical process. During the process, the heat generation occurs as a result of plastic deformation and friction along the tool–chip and tool–work piece interface [4]. The maximum heat generated region occurs at the tool– chip interface. The tool–wear and fracture or tool failure considerably increases at higher temperatures. Temperature rise in machining has a controlling influence on the cutting parameters. Many parameters depend on the temperature field during cutting tool life, mechanics of chip formation, surface quality, cutting forces, cutting speed, process efficiency etc. A lot of efforts have been made to measure the temperatures at the tool-chip interface zone, chip, cutting tool and the work piece [4]. A review of the common experimental techniques designed for temperature measurement in metal cutting processes reveals that these techniques can be classified as direct conduction, indirect radiation, and metallographic. In the machining the dynamic characteristics also to be considered along with tool wear and temperature concepts to avoid tool failure during manufacturing.

Modern machining processes face continuous cost reduction requirements and high quality expectations. To remain competitive a company must continually identify cost reduction opportunities in production, exploit economic opportunities, and continuously improve production processes. A key technology that represents cost saving opportunities related to improve the overall performance of cutting operations [1]. The tool–fracture or tool failure considerably increases at higher speeds and higher cutting parameters. Higher speeds in machining has a controlling influence on the cutting parameters [2].

The dynamic characteristic of the machine tool, affected by the machine tool structure and all the components taking part in the cutting process, plays an important role for a successful cutting. Instable cutting processes with large vibrations (chatters) result in a fluctuating overload on the cutting tool and often lead to the premature failure of the cutting edge by tool chipping and excessive tool wear. [3]The problem of tool wear monitoring in machining operation has been active area of research. [7]This is because tool change strategies, product quality, tooling costs, and productivity are all influenced by tool wear.[4] Reduction in production cost and increase in productivity can be realized by making the most use of a tool's life and therefore increasing the time between tool changes.

The finite element method is a numerical technique for obtaining approximate solution to a wide variety of engineering problem.[5] The method originated in the aerospace industry as a tool to study stresses in complex air frame structure. The method has gained increased popularity among both researcher and practitioners.

The finite element method (FEM),sometimes referred to finite element analysis (FEA),is a numerical method used to obtain approximate solutions of boundary value problem in engineering. In this method given problem or domain is converted or divided into smaller region called elements. [6]These elements are interconnected at specified joints called nodes. [8]These are points where properties are to be determined for an element. Since, actual variation of field variables such as displacement, temperature, heat flux, fluid velocity are not known inside the domain, it is assumed that the variation of field variable within each element can be approximated by a simple function. These approximating functions are designed in terms of field variables of the nodes.

[8]ANSYS is a finite element analysis (FEA) software package.[6] ANSYS is a commercial finite element program designed to handle large-scale, complex loading, multi-physics problems (fluid flows, stress analysis of solid structures, heat transfer, electromagnetic).It uses a pre-processor software engine to create geometry. Then it uses a solution routine to apply loads to the meshed geometry. Finally it outputs desired results in post-processing.

Finite element analysis was first developed by the airplane industry to predict the behavior of metals when formed for wings.[6]Now FEA is used throughout almost all engineering design including mechanical systems and civil engineering structures.

[9]The modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a

structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis. [11]Normally researcher use modal analysis to determine the natural frequencies and mode shapes of a structure. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions.

Figure 1. MS-Rods used work

Materials and Methods Used

In the present work mild Steel is used as a work material to estimate the HSS single point cutting tool wear. Mild SteelBright Mild Steel Chemical Composition (0.16 % Carbon, 0.70% Manganese, 0.40% Silicon, 0.040% Phosphorus, 0.040% Sulphur), As turning of mild steel, using HSS is one among the major machining & manufacturing operations in manufacturing industry. In present investigation HSS tool was used for performing the experiments.work material used is mild steel of diameter 32 mm length 150 mm cutting conditions.

The cutting tests were performed using a Turn maser 35 lathe. A strain gauge dynamometer was used to measure the cutting forces. The experiments were made on the Lathe using a bar turning process under dry conditions. For the range of cutting conditions (cutting speed, feed, and depth of cut) it was required to measure the three force components Fc and Ft, Fn .A total of two experiments were carried out, all with the same basic 75mm HSS single point cutting tool.

Figure 2. HSS Tool Used for Tests

The cutting tests were performed using a Turn maser 35 lathe. A strain gauge dynamometer was used to find the cutting forces. The tool material used shown in fig 1. should be capable of high speed machining with dry cutting conditions. In present investigation HSS tool was used for performing the experiments. Work material used is mild steel of diameter 32 mm length 150 mm cutting conditions were speed of motor 1500rpm, Feed 0.24mm/rev,Depth of cut 1mm

Figure 3. Mild steel rod Fitted on Lathe

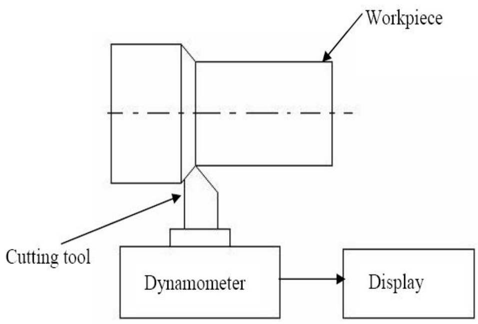

Figure 4. Schematic diagram of setup

A lathe was utilized, fitted with a HSS tool. The other parameters were selected in order to obtain prompt treatment and to identify the most appropriate method to analyze the forces. One single sample was prepared and fixed on the Dynamometer for the force acquisitions are shown in Fig 2.

Experiments were done and all the data obtained are recorded systematically and force values are tabulated below, Table 1. The experiments are done with 2 trials, ie cutting speed 1450,1500 rpm,average value of force values of Fc,Ft,Fn are used as a boundary conditions for the structural as well as dynamic analysis.

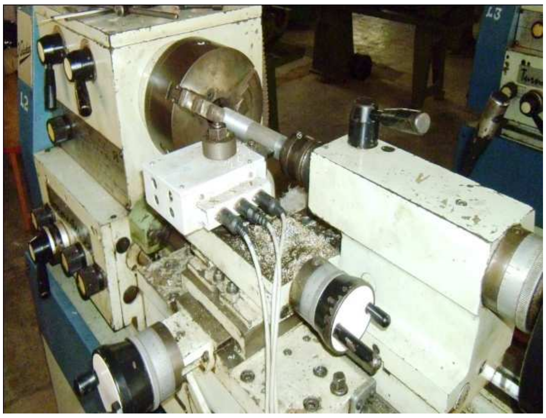

Figure5.Lathe Tool dynamometer Setup

A Lathe tool Dynamometer was used to measure the cutting forces. The cutting forces were measured according to the three principal directions, cutting force, tangential and normal respectively.

Figure6. Dynamometer Output

Modeling And Assumptions

In this present work a practical high speed HSS single point lathe tool taken as a case study, first plotted the lathe tool 2D model and then its developed into key points to build lathe tool model and modelling is done on 3D modeling ANSYS 10.0 software tool.

For modeling the existing lathe tool is taken and with the help of measuring instruments we measured the length, width, thickness and different angles of the tool. Using the measured values we created a 2D model with solid modelling software . This 2D model was then converted to 3D model with help of ANSYS software.

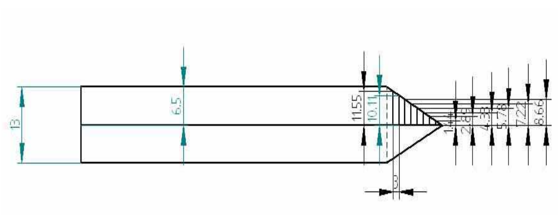

Figure 7.Model lathe tool dimensions & angles

Figure 8. Tool volume in ANSYS modeling

HSS tool having its Young's modulus 200-210 Mpa, High-speed steel is a term given to a tool steel material that can be used for machining at high speeds. Following assumptions are, cutting speed, fem model for 3D structural analysis. Fem element taken is,3D Brick 8 node 45, Cutting force Fc = 4910 N ,Tangential force Ft= 5090 N, Normal force Fn = 4910 N.

Results And Discussions

Modal analysis was done to find the different modes of lathe tool and first five natural frequencies are tabulated and different modal shapes are plotted. Harmonic analysis was carried out with frequency ranging from 1Hz to 605Hz. Amplitude values verses frequency are plotted and from the plot the maximum amplitude occurs at 121Hz.

Table 1.: Modal Analysis Values

Modal Analysis	Time/Frequency

First mode	113.63
Second mode	121.90
Third mode	577.00
Fourth mode	582.85
Fifth mode	605.13

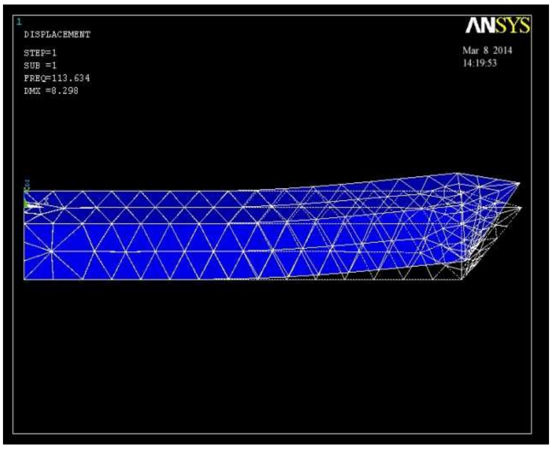

Figure 9. First mode deflection

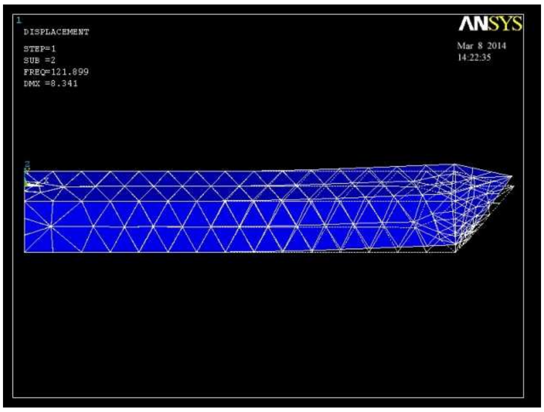

Figure 10. Second mode deflection

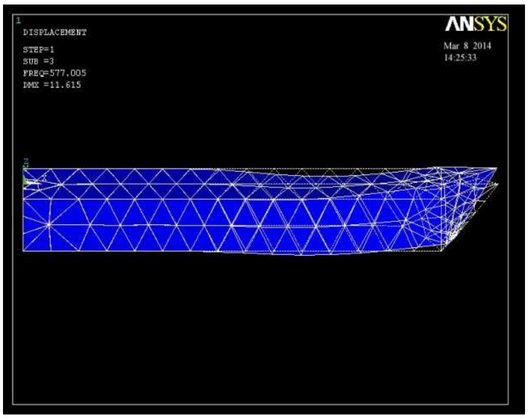

Figure 11. Third mode deflection

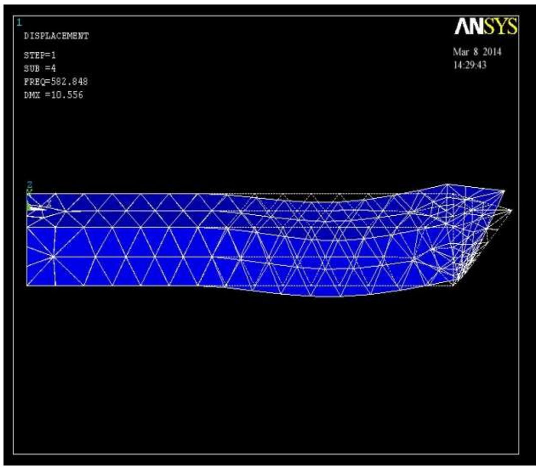

Figure 12. Fourth mode deflection

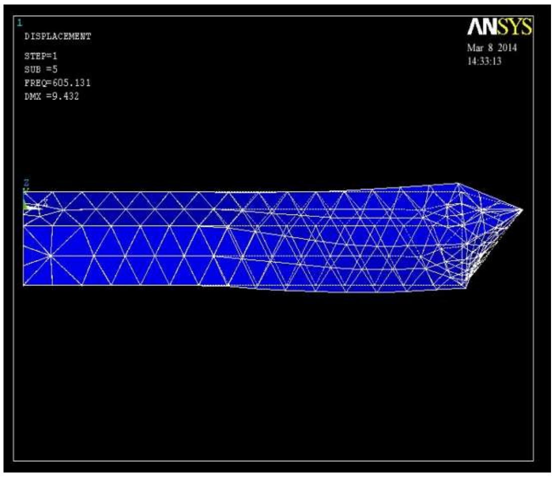

Figure 13. Fifth mode deflection

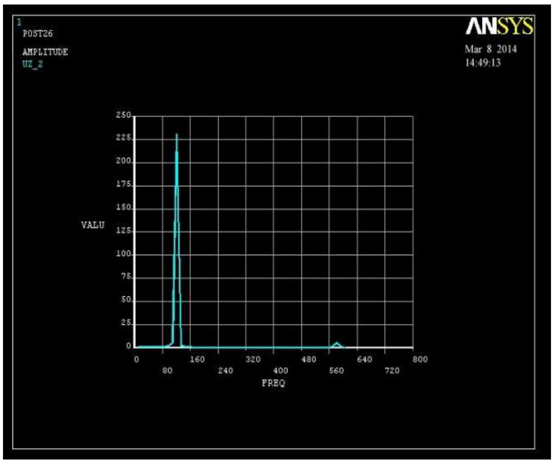

Figure 14.Amplitude for applied Frq

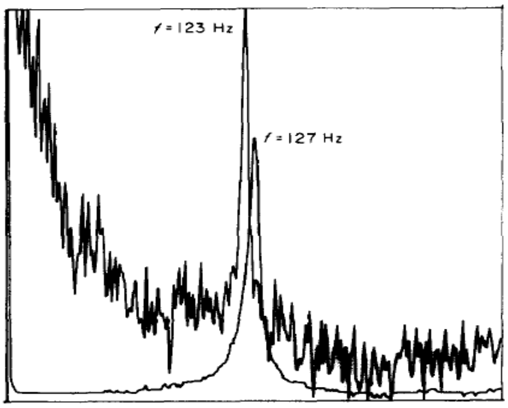

Figure 15. Superposition of frequency measurements from experiment

Figure above shows experimental studies done on lathe tool to find natural frequency of HSS single point cutting tool, In the above work the similar analysis was carried out for HSS tool and amplitude frequency graph was plotted and the maximum amplitude value was found to be 123Hz. The FEM analysis results was found to be in partial agreement with the experimental studies. The present analysis shows Natural frequency value of lathe tool is lies between 121Hz to 127Hz.

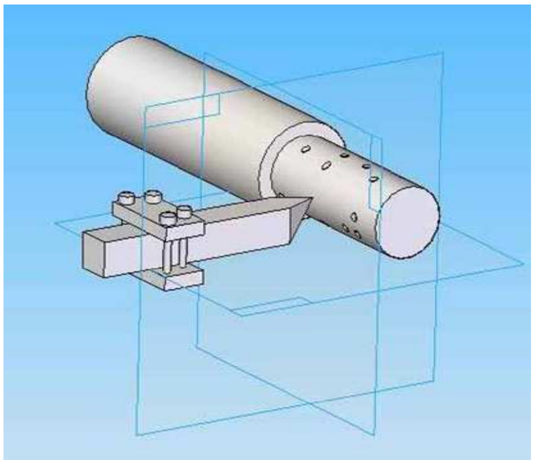

Figure 16.Non-uniform surface.

Experiment was carried out at a speed of 1500rpm which corresponds to 25Hz. At this frequency there is no maximum amplitude. For our analysis we assumed the material to be non-uniform surface. If we assume that there are 5 or more uneven surface or holes , then for the same rpm the tool reaches the value of 125Hz and above. At this stage the natural frequency of the tool matches the critical frequency i.e(121Hz). This results in the failure of the tool. Hence we conclude that if there is non-uniformity in work material then the working speed should be reduced to avoid critical frequency.

Conclusions

The Modal and Harmonic analysis gives some useful results in relation to machining speed and work material while machining with High speed steel tool which will be useful in developing turning process optimization with respect to tool consumption and tool failure, tool life prediction. The focus should be on choosing an appropriate combination of machining speed and depth of cut and feed values while machining avoid tool fracture or tool breakage, which will be helpful in manufacturing automobile parts and other structural parts contributing to the cost reduction in the overall production process.

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