Finite Element Analysis of Single Point Cutting Tool for Chatter

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Abstract- *Producers of machined components are continually challenged to improve quality, reduce cost and minimize setup time in order to remain competitive. For hard material, grinding is the traditional operation, involving expensive machinery and long manufacturing cycles, costly support equipment, and lengthy setup time. The new solution is a hard turning process, which is defined as the process of single point cutting of part pieces that has hardness values over 45 HRC. Based on the literature survey it is identified that the chatter is one of the major problems in hard turning. Machine tool chatter must be avoided to for better machine life, improve surface finish, and increase tool life. The chatter in hard turning is reduced by introducing the damper in the cutting tool system.*

Hard turning creates high pulsating pressures on the insert seat and shim. The shim acts as a shock absorber for the insert and work piece. The shim protects both insert and tool holder from damage due to high cutting forces. In the present work, the carbide shim is replaced with Aluminum and Brass shim, cutting tests are conducted to find out there effect on reduction in vibration and improvement in surface finish.

The dynamic characteristic of the damped tool is studied using Finite Element Analysis (FEA). Damping ratio is one of the dynamic characteristic of system. Damping ratio of cutting tools with three different shims is predicted by using frequency response function and half band width method.

Keywords- Chatter, Stabillity, Stiffness, Damping ratio, Single point cutting tool, FEA Analysis.

I. INTRODUCTION

With the modern trend of machine tool development, accuracy and reliability are gradually becoming more prominent. To achieve higher accuracy and productivity it is not enough to design the machine tools from static considerations without considering the dynamic instability of the machine tools. If there are any relative vibratory motion present between the cutting tool and the job, it is obvious that the performance of the machine tool will not be satisfactory. Moreover, machine tool vibration has a detrimental effect on tool life, which in turn, lowers down the productivity and increases the cost of production.

II. PREDICTION OF DAMPING RATIO

This chapter introduces a novel design for turning tool holder assembly with enhanced damping capability. The principle followed in the design phase is to enhance the damping capability of tool by replacing the conventionally used material interface of carbide shim with brass and aluminum shim interfaces. The evaluation criteria are the dynamic characteristics, frequency and damping ratio of the machining system. The main objective of the present chapter is to predict the damping ratio of the cutting tool system by using the following methods.

1. Impact hammer test.
2. Build a FEA model of the turning tool assembly and perform harmonic analysis by ANSYS software.

But we are getting better result using the method of build a FEA model of the turning tool assembly and perform harmonic analysis by ANSYS software.

III. THREE DIMENSIONAL MODELING OF CUTTING TOOL ASSEMBLY

The design of insert, tool holder and shim were done using the PRO-E software as per the original dimension. The coupling and internal clamping mechanisms where neglected because of design software constraints.

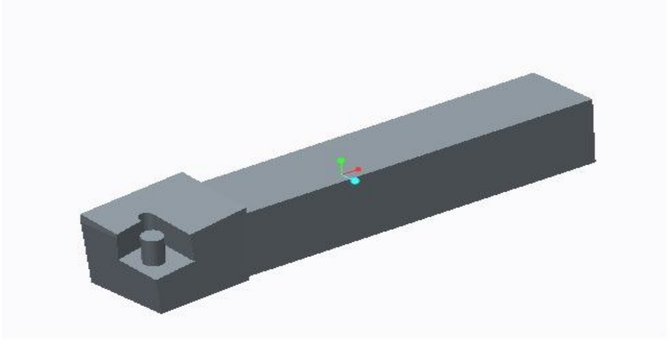

Figure 1: 3D Model of Tool Holder

ISO STANDARDS FOR TOOL HOLDER (PCLNR 2020 K12 WIDAX)

- P - Type of clamping
- C - Shape of insert (Rhomboidal-800)
- L - Style of tool holder
- N - Clearance angle of insert (00)
- R - Hand of cutting (Right hand cutting)
- 20 - Shank height (h) in mm (20 mm)
- 20 - Shank width (b) in mm (20 mm)

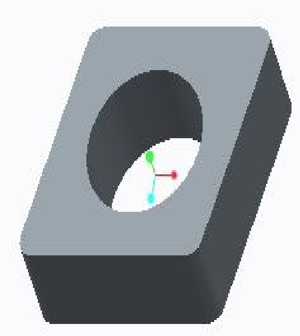

Figure 2: 3D Model Of Shim

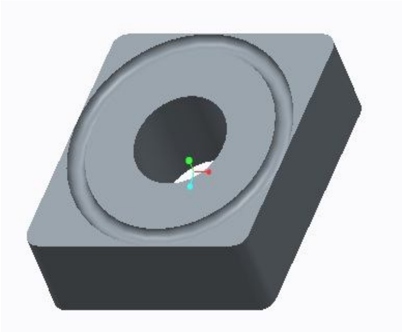

Figure: 3D Model of Insert

ISO STANDARDS FOR TOOL INSERT (CNMG 120408 MJ)

- C - Symbol for insert shape (Rhombic–80°)
- N - Symbol for fixing and/or for chip breaker (without hole)
- M - Symbol for tolerance class (nose height ±0.08 to ±0.18)
- G - Symbol for normal clearance (30)
- 12 - Symbol for insert size (12 mm)
- 04 - Symbol for insert thickness (4.76 mm)
- 08 - Symbol for insert corner configuration (0.8 mm)
- MJ - Symbol for chip breaker

The part model of tool holder, insert, shim are assembled using assembly module of Pro-E. The assembly model of tool holder is shown in Figure 4.

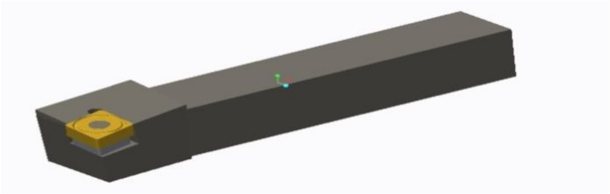

Figure 4: Assembly Model of Tool Holder

IV. HARMONIC ANALYSIS OF DAMPED TOOL USING FEM

The part model of the tool holder, insert and shim are assembled together using assembly module of Pro-E. The assembly model of the tool holder shown in Figure 4 is exported to ANSYS to perform the harmonic analysis.

- The part model of the tool holder, insert and shim are assembled together using assembly module of PRO-E.
- The assembly model is exported to ANSYS to perform the harmonic analysis.
- The response of the tool holder assembly is predicted by using FEA. It consists of following three models.
  1. Tool holder assembly with carbide shim.
  2. Tool holder assembly with brass shim.
  3. Tool holder assembly with aluminum shim.

V. SELECTION OF ELEMENT

The 8-node brick element solid 45 is used to represent the tool holder, carbide insert and shim. The solid 185 is used to represent the PTFE layer. The interior boundaries of the insert are in contact with the shim seat and the holder and the surfaces are assumed to be smooth and held together. The bottom surface of the tool holder, which is held in the tool post and top surface, which is clamped by screws are identified and the all degrees of freedoms are arrested. The material property for holder, insert and shim are defined using linear isotropic models.

Table 1: Material Property of Assembly [5]

Material	Young Modulus (E) (N/mm^2)	Density (kg/mm^3)	Poisson's Ratio
Tool steel	$207*10^3$	$7.85*10^{-6}$	0.3
Carbide	$534*10^3$	$1.59*10^{-5}$	0.22
Brass	$102*10^3$	$8.5*10^{-6}$	0.331
Aluminum	$69*10^3$	$2.7*10^{-6}$	0.334

After defining the material property the part of the model is meshed. The holder is meshed with coarse mesh and the shim and insert are fine meshed as shown in Figure 5 the harmonic analysis module is then used to find the responses of the tool holder, when it is subjected to a force or displacement controlled harmonic excitations.

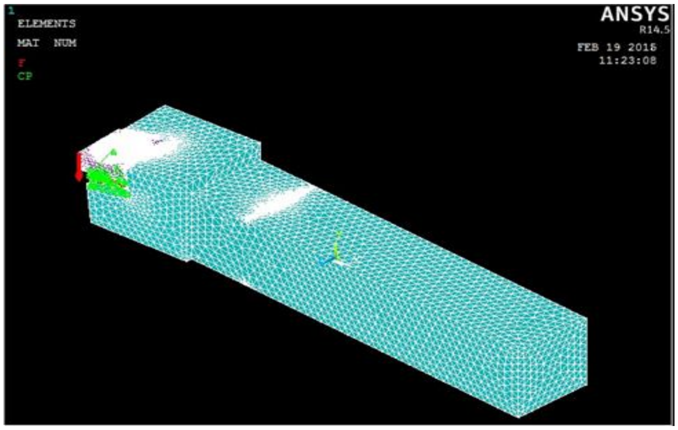

Figure 5: Meshed Tool Assembly

VI. FREQUENCY RESPONSE FUNCTION

A harmonic force is applied to top surface of the holder and nearby the insert as shown in Figure 5. The frequency, response is calculated over the frequency range covering the first mode of the tool. The frequency response curve similar to Figure 6 has been used to calculate the model damping of the tool in its first mode. Damping ratio is predicted by using the half power bandwidth method. The bandwidth is the frequency difference between upper and lower frequencies for which the power has dropped to the half of its maximum value.

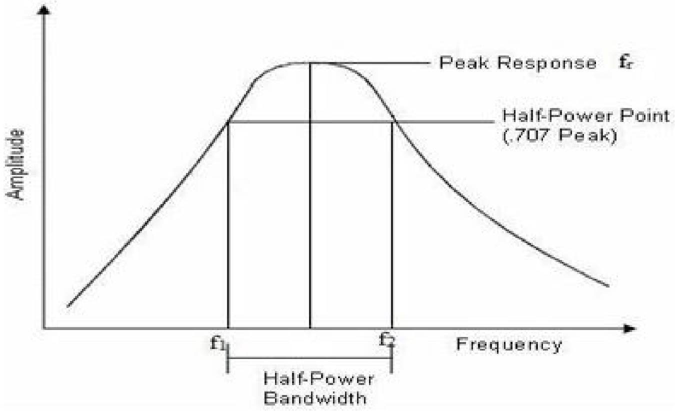

Figure 6: Half-Power Bandwidth [6]

- Damping ratio is predicted using the half power bandwidth method. The bandwidth is the frequency difference between upper and lower frequencies for which the power is dropped to half of its maximum value.
- Damping ratio is given by

$$\xi = \frac{f_2 - f_1}{2 f_r}$$

VII. FREQUENCY RESPONSE CURVE FOR CARBIDE SHIM

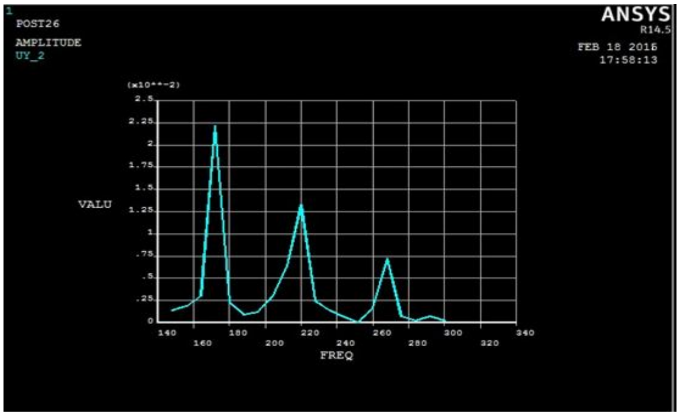

Figure 7: Frequency Response for Carbide shim

From the Figure 7, it is shown as the amplitude peak is 0.022202 mm and the corresponding frequency is 172 Hz. Using the half bandwidth method, the damping ratio for carbide shim tool holder is calculated as follows,

Peak response $f r$ = 172 Hz (at y is 0.22202e-1mm)

Half power point = 0.707 × 0.022202

Half power band width ($f2 - f1$) = 174-170 Hz

Damping Ratio ξ =174 - 170 /2(172) = 0.01162

VIII. FREQUENCY RESPONSE CURVE FOR BRASS SHIM

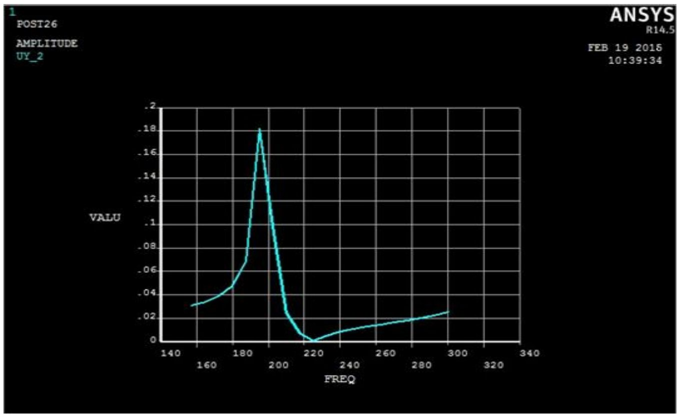

Figure 8: Frequency Response for Brass shim

From the Figure 8, it is shown as the amplitude peak is 0.181833 mm and the corresponding frequency is 195 Hz. Using the half bandwidth method, the damping ratio for carbide shim tool holder is calculated as follows,

Peak response fr = 195 Hz (at y is 0.181833mm)

Half power point = 0.707 × 0.181833

Half power band width ($f2 - f1$) = 200-192 Hz

Damping Ratio ξ =200 - 192 /2(195) = 0.0205

IX. FREQUENCY RESPONSE CURVE FOR ALUMINUM SHIM

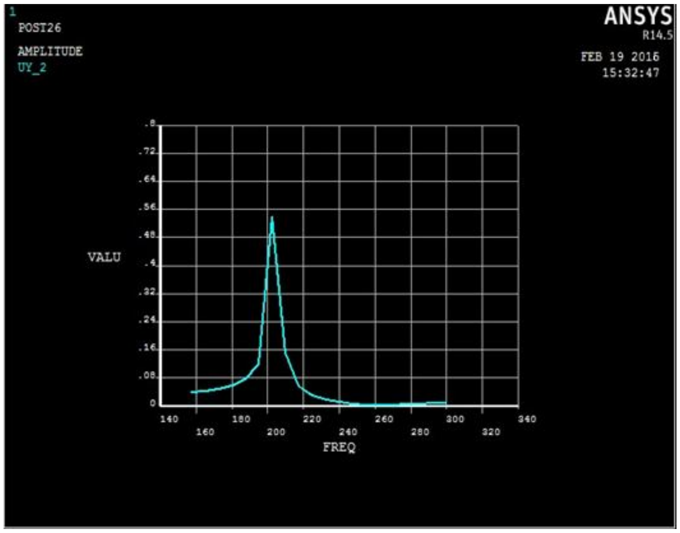

Figure 9: Frequency Response for Aluminum shim

From the Figure 9, it is shown as the amplitude peak is 0.537885 mm and the corresponding frequency is 202.5 Hz. Using the half bandwidth method, the damping ratio for carbide shim tool holder is calculated as follows,

Peak response fr = 172 Hz (at y is 0.537885mm)

Half power point = 0.707 × 0.537885

Half power band width ($f2 - f1$) = 208-198 Hz

Damping Ratio ξ =208-198 /2(202.5) = 0.025

X. DISCUSSION OF RESULT

The damping ratios for the tool holder assembly system with various shims are predicted using FEA which are tabulated in the Table 2.

Table 2. Damping Ratio of Cutting Tool System Using FEA

TYPES OF DAMPER	NATURAL FREQUENCY (f_r) (Hz)	HALF POWER POINT FREQUENCY (Hz)		DAMPING RATIO
		f_1	f_2	
CARBIDE	172	170	174	0.01162
BRASS	195	192	200	0.0205
ALUMINUM	202.5	198	208	0.025

The following results can be concluded from the finite element analysis on cutting tool system.

- Aluminum has the highest value for the damping ratio followed by Brass and Carbide.
- The Aluminum shim shows the peak amplitude at a much higher frequency as compared to the Brass and Carbide shims.
- More confidence can be placed from the results of finite element model if the measurements taken on true structure of cutting tool are performed using impact hammer test to validate the computational modeling.
- Finite element method can predict the approximated damping ratio with minimum cost as compared to impact hammer test as the equipment cost is very high however its accuracy is more compared to finite element method.

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