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Static and Dynamic Analysis of End Mill Tool for Chatter Vibration Reduction

Mahendra .U. Gaikwad, P.R. Kulkarni

Abstract:- Milling is a very commonly used manufacturing process in the industry due to its versatility to generate complex shapes in variety of materials at high quality. Due to the advances in machine tool , CNC, CAD/CAM, cutting tool and high speed machining technologies in last couples of decades ,the volume and the importance of milling have increased in key industries such as aerospace ,die/ mold, automotive and component manufacturing. But however the unstable machining (namely chatter vibration) is one of the main limitations for high speed machining which shortens the tool life and decreases machined surface quality. In this paper static and dynamic analysis of end mill tool with different geometry is carried out by Finite element analysis (FEA), also some practical equations are developed to predict the static and dynamic properties of end mill tool And the results obtained by both the methods are nearly same. However in case of static analysis amount of deflection of tool for a particular value of cutting force can be easily determined, while in case of dynamic (modal) analysis natural frequencies and mode shapes can be determined.

Keywords- CNC, CAD / CAM, (FEA).

I. INTRODUCTION

Milling is a most widely used process for manufacture of discrete mechanical components. Numerous efforts have been made to improve the efficiency of milling by reducing the machining time. The dimensional accuracy of end mill tool depends upon the rigidity of set up , radial and axial depth of cut and on the thrust force produced .since end mill tool acts like a rotating cantilever which is gripped by the machine tool spindle, the end deflection for a given cutter is directly proportional to thrust and to the effective overhang.

High speed machining demands has increased in recent year such as, automotive, aerospace, and dies/ mould manufacturing industries. Since due to the advantages such as higher material removal rates, better surface finish, lower cost etc milling is effectively used in such areas. However the unstable machining (namely chatter vibration) is one of the major limitation for high speed machining which consequently shortens the tool life and hampers the surface quality required to be produced on work piece/job.

1.1 Chatter:

The onset of chatter during machining is primarily caused by the variation in chip thickness that occurs due to vibration of the tool, work piece, or both. This situation is shown schematically in Figure 1.1. In this figure, the flexible tool engages the work piece and, due to the time-varying cutting force, begins to vibrate.

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This vibration is imprinted on the machined surface. In milling, the next tooth on the rotating cutter encounters this wavy surface produced by the previous tooth. This wavy surface varies the instantaneous chip thickness which,

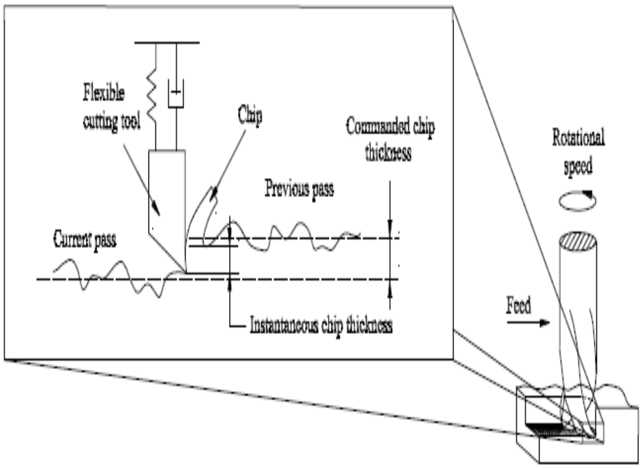

Figure 1.1: Chip thickness variation due to cutter vibrations.

in turn, modulates the cutting force and the cutter vibration (i.e., a feedback mechanism is produced that can lead to self-excited vibrations known as regenerative chatter). Depending on the relationship between the wavy surface left by the previous tooth and the current cutter Vibration, the resulting directions and forces can grow very large, which results in rapid tool wear, an inferior surface quality of the work piece and noise .Chatter can be recognized by the noise provided by these vibrations, the chatter reflects marks on the machined surfaces.

II. PRESENT THEORIES & PRACTICES

(Literature review)

The task deals with chatter vibration reduction in case of milling tool by various methods and in this connection a review of following papers have been studied as listed below:

E.B. Kivanc, E. Budak [1] has presented the method of modeling structural properties of milling tool. Also static and dynamic analysis of end mill tool with different geometry and material are carried out by finite element analysis, finally some practical equations are developed to predict the static and dynamic properties of tool.

Nam H. Kim et al,[2] in this paper a mechanical damper is introduced in the end mill tool for vibration reduction . A mechanical damper composed of Multi Finger cylindrical inserts placed in the matching cylinder of end mill tool.

Further a simple numerical method is presented to estimate the amount of frictional work during the tool bending. FEA is also used to estimate normal and frictional contact forces due to centrifugal forces and cutting forces for calculating the amount of frictional work dissipated by the damper.

Rubio et al,[3] This paper covers analytical procedure,a time domain simulation and stability lobe diagrams. In the time domain simulation,the forth order rungekutta method is employed to solve the differential equation which governs the dynamics of milling system.

T. Prem Singh Inbaraj* and M. Vinoth[4] here author has presented a method for vibration reduction by introducing damper to the cutting tool. Simple numerical analysis using ANSYS is performed to calculate the amount of frictional work during tool bending. These numerical results are compared with analytical results. Further it has been proved form this analytical results that more the frictional work developed grater will be the damping effect.

Md.Anaye,Patwari,A.K.M. NurulAmin,W.Faris[5] author has presented a new technique for investigation of chatter during end milling of medium carbon steel. Experimental investigation has conducted on the cutting chips, and common types of discreteness in the form of serrated saw teeth. Mechanisms of formation of these teeth had been studied and a frequency of their formation has been determined. These different modes of vibrating components of the machine tool have been identified using modal analysis and vibration response during cutting conduction are recorded. The machine tool-work piece–fixture system have various natural mode frequencies, out of which some plays prominent role in chatter formation during end milling of medium carbon steel.

A.P.Xu,Y.X.Qu,D-W Z hang,T.Huang, [6] here new type of modal for end milling process is presented by considering the cutter flexibility which includes not only the static but also dynamic deflection of the cutter. According to basic assumption for a linear elastic body, the force acting on the cutter and its deflection in the milling processes are divided into two parts:

The static and dynamic, by considering regenerative feedback in the practical milling processes also dynamic milling force acting on a unit length of cutter is derived. The good agreement between the measure and the simulated results indicates that these models and its corresponding simulation algorithms are feasible and efficient.

III. FINDINGS OF LITERATURE SURVEY

- End mill tool geometry, sources of vibration and various methods for preventing it are been discussed.
- Static and dynamic analysis of end mill tool with different geometry and material condition are been presented.
- A mechanical damper is use for vibration reduction in case end mill tool is presented, further analytical software results are compared and this method proves to be effective.

All above findings are useful for “static and dynamic analysis end mill tool for chatter vibration reduction”.

IV. PROBLEM DEFINITION:

End mill tool is a segmented beam, whose one segment is for the part of the flute and other segment is for the shank as shown in figure below:

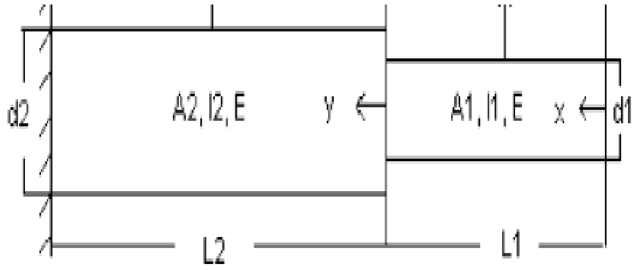

Fig.4.1 .The geometry of the beam (tool) with two different geometric segments.

In the above figure ,

d1 : Mill diameter
d2 : shank diameter
L1 : flute length
L2 : overall length

A1& A2 : area of part with and without flute.

The unstable machining (namely chatter vibration) is one of the major limitation for high speed machining which consequently shortens the tool life and hampers the surface quality required to be produced on work piece/job. Therefore it is required to determine the static and dynamic analysis (behavior) of end mill tool with different geometry and material conditions.

Also in order to reduce the effect of chatter vibration on the end mill tool, some vibration absorber (damper) can be provided for the tool and consequently static and dynamic analysis can be carried out so that tool life and quality of surface finish can be improved effectively.

The work involves identification of chatter vibration problem in case end mill tool and method for reducing it, for which following steps can be carried out:

(1) Selecting the appropriate type of milling tool especially end milling tool with its dimensions also Studying geometry of end mill tool, sources vibration and methods for preventing it .
(2) Modeling of end mill tool with the help of CATIA /ANSYS software.
(3) Carrying out Static and dynamic analysis of the end mill tool with analytical and FEM method
(4) Comparing the results of FEM and analytical method

V. METHODOLOGIES

In this paper both FEA and Analytical methods have been used for static and dynamic analysis of end mill tool. The main objective of static analysis is to determine the deflection of end mill tool, while dynamic (modal) analysis used to determine the mode shapes and natural frequencies of the cutting tool structure. A four flute end mill tool of HSS and carbide material along with its various dimensions (selected from design data book) is used for static and dynamic analysis.

5.1 Analytical Method:

Static characteristics for end mill tool can be easily determine by following equations which is same for HSS and Carbide tool.

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$$\text{deflection}_{\max} = C\frac{F}{E}\left[\frac{L1^3}{D1^4} + \frac{(L2^3 - L1^3)}{D2^4}\right]^N$$

Where , F = cutting force
L1 = flute length
L2 = overall length
D1 & D2 = mill and shank diameter .etc

Values for C, F, L1, L2, D1, D2, E are selected from design data book and susituted in equation (1) to determine the tool defletion for HSS and Carbide tool.

$\text{deflection}_{\max}$ (for HSS tool) = 0.216239 mm

$\text{deflection}_{\max}$ (for carbide tool) = 0.00785 mm

However Dynamic analysis by analytical method is used to determine the natural frequency of end mill tool with the help of the following equation which is same for HSS and Carbide tool :

$$\omega = (\beta L1)\sqrt{\frac{EI1}{\rho A1L1^4}} \quad \text{or} \quad \omega = (\alpha L2)\sqrt{\frac{EI2}{\rho A2L2^4}}$$

Where ,
ω = natural frequency
L1 = flute length
L2 = overall length
A1 & A2 = mill and shank area .. .etc

By substituting the values of LI, L2, A1, A2, E etc in equation (2) the natural frequencies for HSS and Carbide tool is determined .

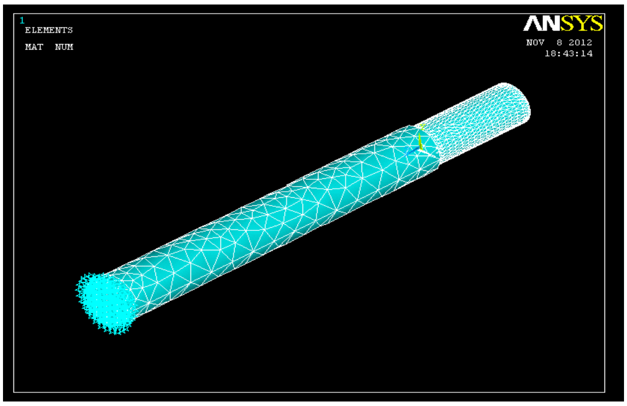
ω (for HSS tool) = 1399.89 HZ

ω (for Carbide tool) = 2019.54 HZ

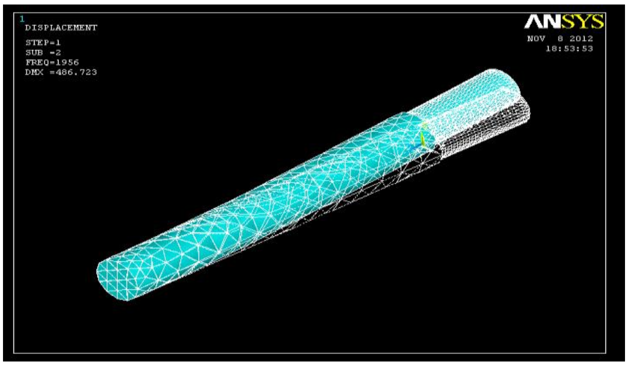
5.2 FEM Method:

In this case end mill tool is simplified as a beam element by ignoring complex tool geometry and dynamic (modal) analysis is carried out to determine the natural frequencies of the tool.

Below image shows the meshed model of end mill tool by imposing the boundary conditions on it.



Whereas the natural frequencies with FEM tool can be found out as mention in the below image, this natural frequency is nearly equal to the analytical method.



VI.CONCLUSIONS

Static and Dynamic properties of end milling tools are very important for machining precision and chatter stability. In this paper, methods for modeling structural properties of milling tools are presented. Static and dynamic analysis of tools with different geometry and material are carried out by finite element analysis (FEA). Also some practical equations are developed to predict the static and dynamic properties of tools. And the results obtained by both the methods are nearly same. However in case of static analysis amount of deflection of tool for a particular value of cutting force can be easily determined, while in case of dynamic (modal) analysis natural frequencies and mode shapes can be determined.

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