Dynamic Analysis Of Milling Machine Chatter Vibration Reduction Using Mechanical Damper

Roshan Patel[1], Urvish Patel[2], Er. Dharmendra Dubay[3]
[1,2,3] Department of Mech. Engineering, Bhagwant University, Ajmer, Rajasthan, India.

Abstract—
Milling is widely used in the manufacturing industry. Numerous efforts have been made to improve the efficiency of milling. For the efficiency of the milling process, high demands on the material removal rate and the surface generation rate. The process parameters determining the two rates are restricted by the occurrence of regenerative chatter. This project deals with reduction of chatter vibration in end milling tool by introducing the dampers. The main objective of the present work is to design a damped milling tool. A mechanical damper has been introduced to reduce tool vibration in milling tool. The mechanical damper is composed of multi-fingered cylindrical inserts placed in a matching cylindrical hole in center of standard end mill cutter. Centrifugal forces during high speed rotation press the flexible fingers against the inner surface of the tool. Bending of the tool and damper assembly due to cutting forces causes relative axial sliding between the tool inner surface and damper fingers dissipates in the form of friction work simple numerical analysis using ANSYS is performed to estimate the amount of friction work during bending. The numerical results are compared with analytical results. It is ascertained that there is a possibility of more damping the vibrations using multi-fingered mechanical damper.

Keywords—Milling machine, Chatter, Mechanical damper, Vibration, Tools.

I. INTRODUCTION

In the present manufacturing industry, milling process plays an important role. Therefore many efforts have been made to improve the efficiency of milling. The main limitation of milling is caused by the vibration of machine tool and work piece. As the speed and the power of milling are increased, it is very important to control vibration of the tool. The chatter vibration is affecting the cutting operation. This project is focused on the chatter which produces a wavy surface during the milling operation. The relative vibration between the tool and the work piece causes a wavy surface. This project involves designing and analyzing a damper to improve the stability of end mills and to achieve higher material removal rate. Long end mills are most widely used tools in high speed machining operation. During machining beyond a certain depth, vibration may become unstable. This characteristic of a tool creates an uneven surface and reducing tool life. In order to reduce the chatter vibration and increase the tool life, damper has been introduced. Therefore if a tool is to be designed with increased damping, it should have enhanced stability against chatter. The addition of a mechanical damper to the cutting tool can potentially help to stabilize the system against chatter vibration and allows higher productivity. In the present manufacturing industry, milling process plays an important role. Therefore many efforts have been made to improve the efficiency of milling. The main limitation of milling is caused by the vibration of machine tool and work piece. As the speed and the power of milling are increased, it is very important to control vibration of the tool. The chatter vibration is affecting the cutting operation. This project is focused on the chatter which produces a wavy surface during the milling operation. The relative vibration between the tool and the work piece causes a wavy surface. This project involves designing and analyzing a damper to improve the stability of end mills and to achieve higher material removal rate. Long end mills are most widely used tools
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The tool that is taken for our analysis in this project is long end mill as shown in the Figure 1. Most end mills are of the solid beam type. In this type of tool only available damping mechanism is structural damping, which is very small. Structural damping is a variant of viscous damping that is usually caused by an internal material friction.

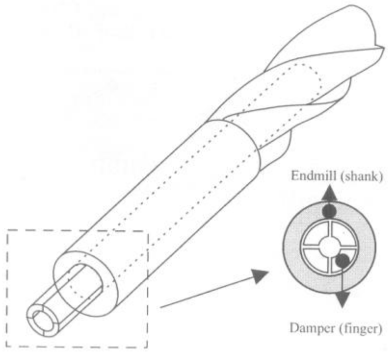

Figure 1 Geometry of milling tool

When a layered beam damper is inserted into the hollow tool, the high speed rotation causes a strong contact between the beam and the tool. Due to the contact force during relative motion causes a friction force in the interface which damps the vibration. This damping mechanism will be referred to as a mechanical damper. The end mill model can be simplified as a cylinder as shown in Figure 2, because focus of interest is in the contact surface, which is the inner surface of the tool.

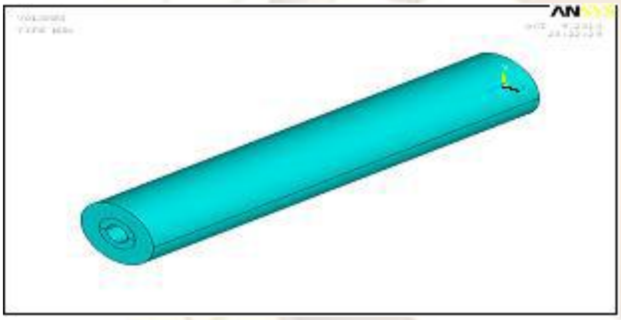

Figure 2 Simplified model using hollowed cylinder.

II. FINITE ELEMENT ANALYSIS PROCEDURE

The general finite element modeling procedure consists of the following steps.

PREPROCESSING
- Element type definition
- Material properties definition
- Building model

SOLUTION
- Defining initial condition
- Applying boundary condition
- Applying Load
- Solving for results

POST PROCESSING
- Reading result file
- Viewing results.

The material properties are shown in Table 1.

HIGH SPEED STEEL	
Young's modulus	206780 MPa
Mass density	7820 kg/m3
Friction coefficient	0.15

A. *Boundary Conditions*

According to the forces apply to the end mill an analysis procedure is divided into two steps the first step is when the end mill starts rotating. In this step, only the angular velocity of 104 red/sec is applied without considering the cutting force. The second step is when the end mill starts the cutting process at this time a vertical force of 100 N is applied at the tip of the end mill.
The force boundary condition in each step divided into five sub steps in order to improve the convergence of nonlinear analysis.

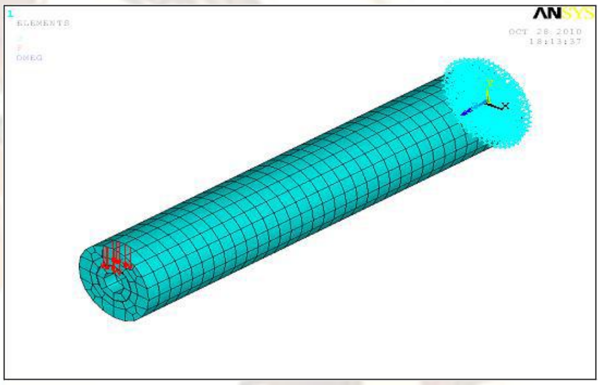

Figure 3 Boundary Conditions

The sequence of loading conditions is shown in Figure 4. First the centrifugal force due to tool rotation is increased linearly with five sub steps (load step 1) and then the lateral force is applied gradually with five sub steps (load step 2). During load step 2 a centrifugal force is maintained at a constant value.

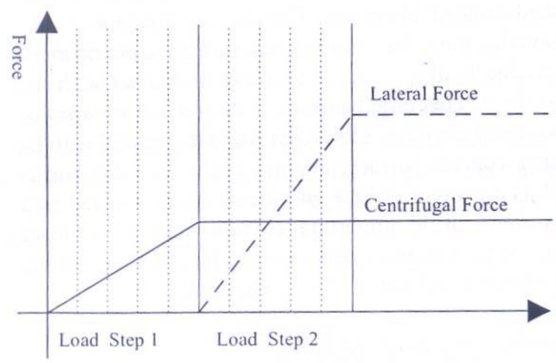

Figure 4 Applied load conditions.

A load step 1 is not used to calculate friction work. The load steps 2 are used to compute friction work, simulating the situation during machining. The use of additional loading sub steps increases the computational time, but improves the convergence of non linear analysis and the accuracy of the friction work computation and the stages of loading is shown in Figures 5 and 6.

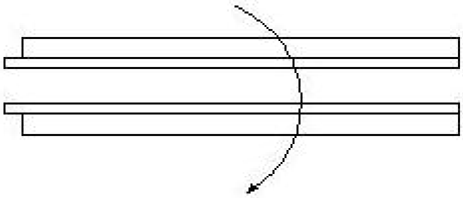

Figure 5 The initial stage of centrifugal loading when the end mill starts rotating

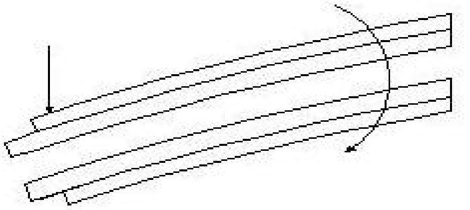

Figure 6 Second stage of loading of End mill applied with lateral force along with centrifugal force.

III. RESULTS AND COMPARISON

Milling tool contact pressure is analyzed by using ANSYS. The tool is subjected to different loads centrifugal force due to tool rotation and the lateral forces from the machining. First the tool is rotated with a constant angular velocity, generating the contact force at the interface. Next a lateral force is applied at the tip to simulate cutting forces during machining.

A. Results with Load Step 1

The tool is subjected to different loads-centrifugal force due to tool rotation and the lateral forces from the machining. First the tool is rotated with a constant angular velocity, generating the contact force at the interface. Next a lateral force is applied at the tip to simulate cutting forces during machining. Contact pressure calculated using ANSYS which is shown in Figure 7.

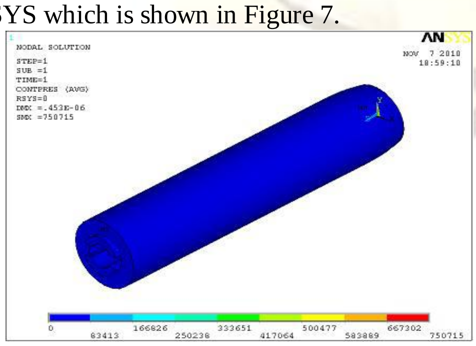

Figure 7 Contact Pressure

During load step 1 there is a relative motion at the contact surface due to the diameter change of the shank. However this relative motion in this step is not used in the computation of friction work, since it is not related to bending of the tool due to cutting forces.

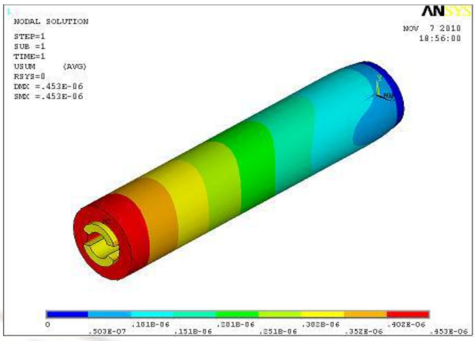

Figure 8 Component displacement

Frictional Stress is calculated using ANSYS and is displayed in Figure 9.

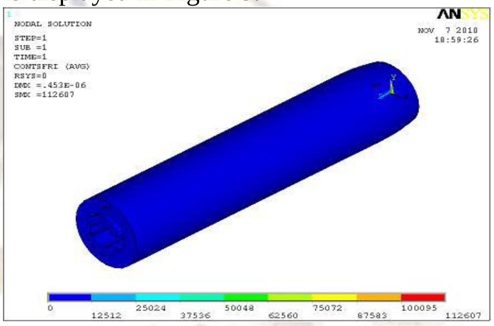

Figure 9 Frictional Stress

B. Results with Load Step2

Load steps 2 are used to compute friction work simulating the situation during machining. The bending deformation of the shank and finger generates a relative displacement at the interface because of difference in the location of neutral axis of the element. The Contact pressure and frictional stress are calculated using ANSYS which is shown in Figures 10 and 11.

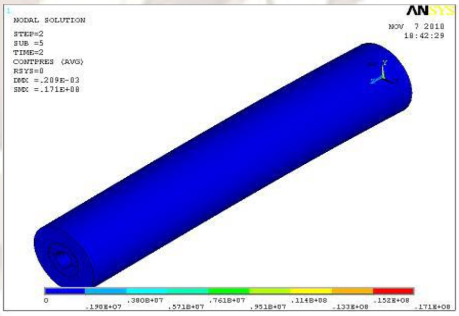

Figure 10 Contact Pressure

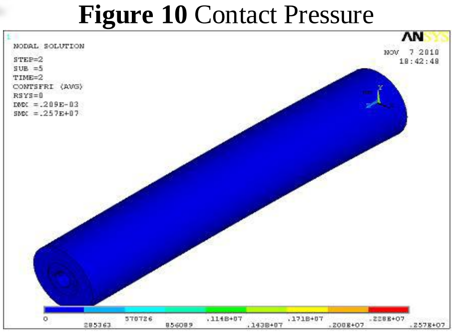

Figure 11 Frictional Stress

C. Calculation of the Normal Force and the Contact Pressure

In this section, normal force and pressure that are caused by the rotation motion of the tool will be calculated. There are three assumptions for the analytical method.

- There is no angular acceleration, which means angular velocity is constant.
- There is no relative motion between the two contact surfaces during the first step, which means there is no slip in the contact surface during the rotational motion.
- Contact occurs throughout the entire contact area during the second state.

Due to the second assumptions the contact pressure is calculated using the centrifugal force only and is assumed to remain constant.

Considering two fingers with the inner radius of 0.0035 m.

R1=0.0035 m
R2=0.0047625 m
L=0.1016 m
ω=2094.39 rad/sec
ρ=7820 kg/m3
α=90°

$$R = \left(\frac{2}{3}\right) \times \left(R_2^3 - R_1^3\right) \times \frac{\left(\sin\frac{\alpha}{\alpha}\right)}{\left(R_2^2 - R_1^2\right)} \qquad (3)$$

$$R = \left(\frac{2}{3}\right) \times (0.0047625^3 - 0.0035^3) \times \frac{\left(sin\,\frac{90}{90}\right)}{(0.0047625^2 - 0.0035^2)}$$

R=0.00265 m
Mass, M = 0.0130 Kg
Normal force, N = MRω2

$$N = 0.0130 \times 0.00265 \times 1884.95^2 \qquad \ldots\ldots\ldots\ldots (4)$$

N = 122.40 N

Area of contact,
Ac= π × 0.0047625 ×0.1016
Ac =0.000158 m2

Contact pressure, P = N/AC (5)
= 122.40/0.000158
P = 0.77468 MPa

The contact pressure has been computed by analytical method and the values obtained by Finite Element Method using ANSYS software are nearly same. Contact pressure using ANSYS is 0.75 MPa and the analytical value is 0.77468 MPa computed. The contact pressure is computed theoretically and validated with FEA results which are shown in Table. The values obtained are nearer and the vibration of the tool is found to be reduced.

	ANSYS	Theoretical	% Error
Contact Pressure	0.75MPa	0.77468MPa	3.18

IV. CONCLUSIONS

It has been proved from this analysis that the frictional work is developed by the mechanical damper during the operation of milling tool and the same can damp the machine chatter vibrations. More the frictional work developed; greater will be the damping effect. It is possible to apply this methodology for the finite element analysis of mechanical damper provided with multi fingers. Thus this work has been done with two fingered mechanical damper and it has been analyzed the contact pressure due to centrifugal forces during operation by finite element analysis using ANSYS and also calculated by analytical method. Both the results are compared. Further the analysis of frictional stress can be carried out by introducing multi-fingers using ANSYS.

- To calculate the Contact pressure by varying the inner radius of damper in load step 1
- To calculate the Friction work done by damper by introducing the multiple fingers and justify the best configuration in which vibration is much reduced

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