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MEASUREMENT AND SUPPRESSION OF CUTTING TOOL VIBRATION USING PIEZOELECTRIC CERAMIC IN ANSYS

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To measure vibration produced in lathe cutting tool various kinds of procedures are adopted. Small patch of piezoelectric ceramic material is successfully incorporated into turning cutting which is modeled in Pro Engineer and examined in finite element analysis to check vibrations in material cutting processes. Model and harmonic analysis are performed. The relative amplitudes of mode shapes and frequencies are identified by analyses which are causing chatter. The results are compared with the analysis which is performed without using piezoelectric material patch.

Keywords: ANSYS, ProEngineer, Pzt 5A

1. Introduction

Chatter measurement is a process which affects results of machining. It is produced in all kinds of machining process as it directly affects surface finish and tool life. Vibration is the most adverse phenomenon which influences surface finish quality, precision of the components machined and life of the cutting tool. Tool life is directly affected by the vibrations which are produced during machining. The amplitude of these vibrations alters surface finish and the cutting life. Vibrations in machining are produced because of less dynamic stiffness of the machine tool, tool holder, cutting tool, work piece system [1].Chatter vibrations critically affect tool life, surface finish and production rate in machining processes. Regeneration and mode coupling were numbered as the major cause for tool chatter [2].Chatter adversely affects the rate of production and machining quality [3]. In many cases its elimination can be achieved only by reducing the rate of metal removal. Machine-tool chatter is characteristically erratic since it depends on the design and configuration of both the machine and the tooling structures, on work piece and cutting tool materials, and on machining regimes. Self-excited vibration or chatter is the most significant kind of vibration in machining processes [4]. There has been a lot of work in the field of reducing tool vibration error in old turning machines which can reduce industrial waste, save money, and improve design flexibility for new cutting tools. Using smart materials in curing machine tool vibration requires special attention [5]. Piezoelectric materials convert mechanical strains into electrical charge. Dissipation of the charge results in attenuation of vibration [6]. Solution for improvement of surface quality of the workpiece is proposed by Ostasevicius [7].The industrial and scientific groups conveyed a real need for the capability of pressure, acoustic and vibration sensing tool. The piezoelectric sensor approach offers several advantages including cost and design and covering above mentioned problem [8]. Experimental and analytical method for reduction of vibration, involving the use of static and dynamic components of the cutting forces resulted in ensuing analyses in time and frequency domains which showed some components of the measured signals to correlate the accrued tool wear [9]. The vibration amplitude is reduced to about 15 dB at targeted second mode frequency by using shunted piezoelectric patch [10]. Piezoelectric patch of lead zirconate titanate 5A (10 x5 mm) is incorporated into the lathe cutting tool which is used for turning process.The shunt is comprised of an inductor (comparable to the mass), and a resistor (comparable to the damper). As the structure vibrates, the piezoelectric element transforms a portion of the strain energy into electrical energy [11].

Cutting tools usually vibrate during operation when in contact with the specimens. This vibration may damage the surface of the material and further cause in reduction of strength. The aim of this research work is to numerically analyze the vibrations of cutting tool and control of its vibration

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during operation by using piezoelectric ceramics patch to reduce the surface roughness and definitely the tool life enhancement.

Material used for cutting tool is high strength steel 4340, Density is 7800 kg/m^3, Elastic modulus 210e9 GPa and Poison ratio 0.29.solid 186 is used for finite element simulation. In ANSYS solid 226 is used to analyze piezoelectric material PZT 5A. Value for density is 7750 kg/m^3. Values for elastic modulus, coupling factor and relative permittivity PZT have been mentioned in the following equations.

	x	y	z	yz	xz	Xy
X	12.03	7.51	7.50	0	0	0
Y	7.51	12.03	7.50	0	0	0
Z	7.50	7.50	11.08	0	0	0
Yz	0	0	0	2.10	0	0
Xz	0	0	0	0	2.10	0
Xy	0	0	0	0	0	2.25

(1)

Values for anisotropic elastic matrix are C_E x 10^{10} pa.

	X	y	z
X	0	0	-5.4
Y	0	0	-5.4
Z	0	0	15.78
Xy	0	12.29	0
Yz	12.29	0	0
Zx	0	0	0

(2)

Coupling matrix e (C/m^2)

919.1	0	0
0	919.1	0
0	0	826.6

(3)

Relative permittivity ε_r values of lead zirconate titanate 5A.

2. Experimentation

The lathe turning tool is modeled in Pro Engineer 3.0 the patch of PZT 5A as shown in Figure 1 is assembled with the turning tool and then imported in ANSYS.

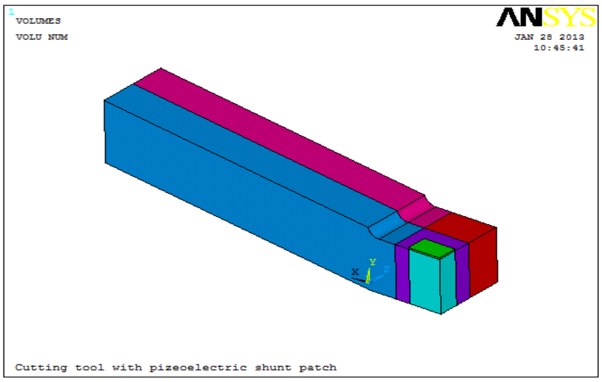


Figure 1. Cutting tool with PZT patch.

Piezoelectric patch is shunted with resistance of 1000Ω and inductance of 3500 L.A force of 50N is applied at the cutting edge of tool.

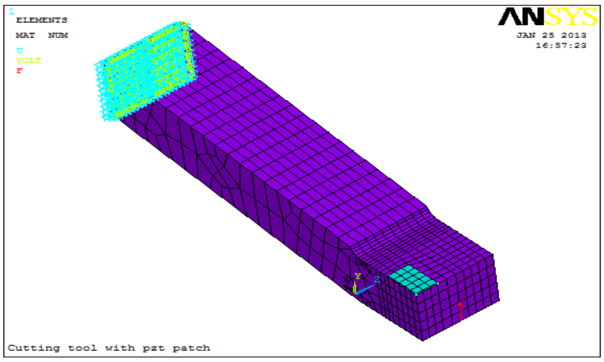


Figure 2. Boundary conditions of cutting tool with PZT patch.

Modal analysis is performed; produced results are then collected for first five modes of frequency as given in Table 1.

Table 1. Model frequency for cutting tool with pzt material.

Time / Frequency	Load Step
1	454.70
2	470.27
3	2043.4
4	2395.1
5	2449.3

3. Results and Discussions

The results of modal analysis are compared with the results of ANSYS simulation without piezoelectric material. Mode shape deformation is higher in simple turning tool. Results are compared in Figure 3.

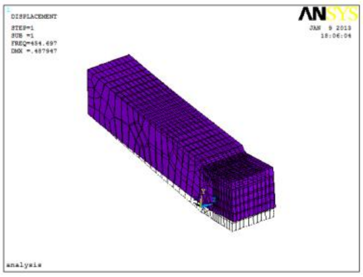
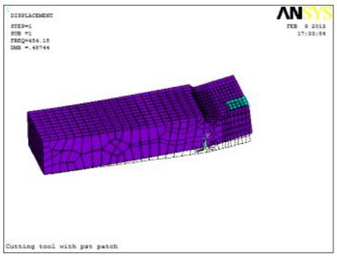
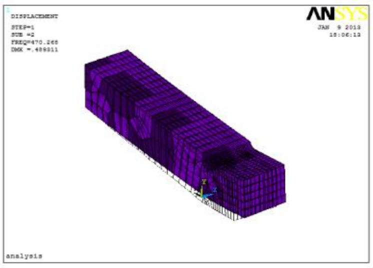
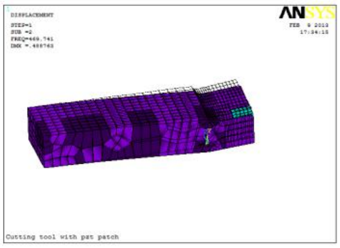
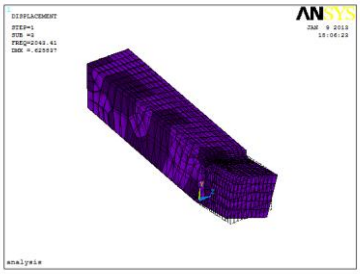
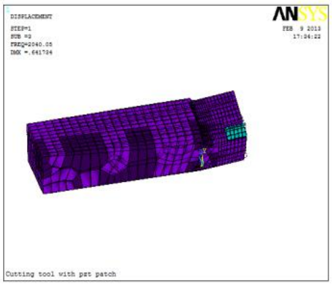
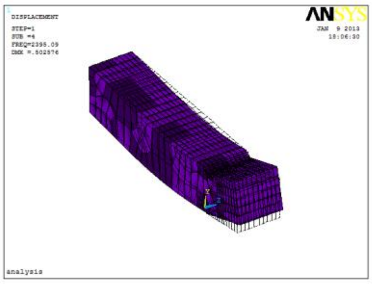
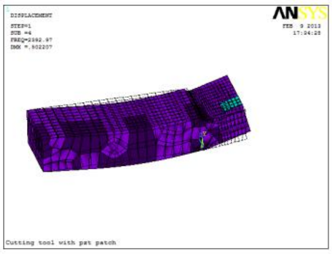
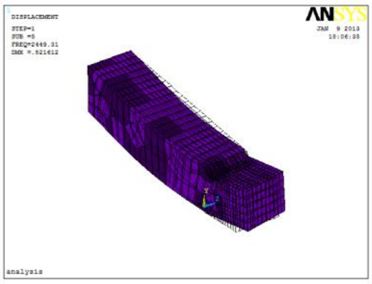
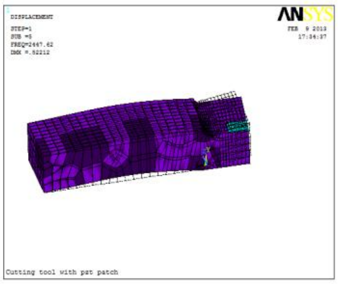
No.	Simple cutting tool	Tool with shunted PZT patch
1		
2		
3		
4		
5		

Figure 3. Mode shape comparison for cutting tool with and without PZT material.

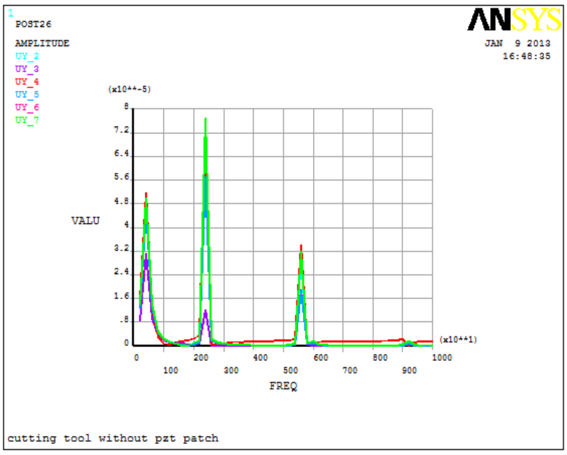
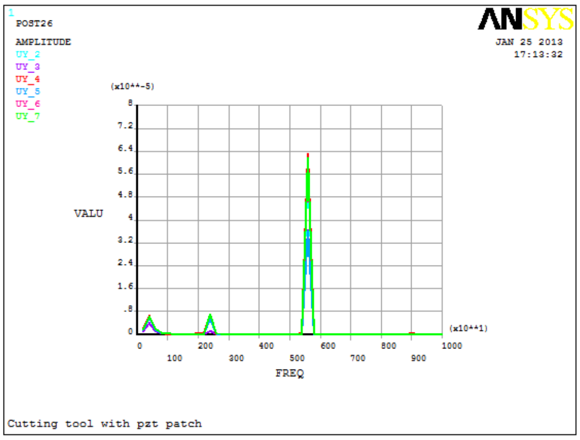
Amplitude Without PZT patch	Amplitude With PZT Patch
	

Figure 4. Comparison of amplitude of vibration in ANSYS.

Harmonic analysis is then performed and the results are compared at specific node points given in Table 2.

Table 2. Nodal points at which amplitude of vibration is listed.

S. No.	Nodal point
1	6334
2	3010
3	4648
4	5225
5	4756
6	4771

The amplitude of vibration with or without PZT patch at various nodes is then plotted in time history processor and is shown in Figure 4. The amplitude of vibration for both cases is then compared and listed in Figure 4. Vibration produced in simple cutting tool is abrupt and amplitude is higher while on the other hand vibration produced in the proposed cutting tool is less. Amplitude of vibration is only higher at the node which is near to the applied force.

The vibrational amplitude values are then listed in Table 3, which clearly shows that the values for simple turning tool without PZT patch are higher.

Amplitude of vibration with and without piezoelectric patch is then compared and plotted in Figure 5. A few nodes of the cutting tool with and without piezo patch were selected and by considering the graph in Figure 5, it is clear that the vibrations can be minimized by the adhesion of small piezo patches on the cutting tool and can reduce the surface roughness and enhancement of cutting tool. Furthermore the voltage produced during the operation can further be utilized in electromechanical system.

Table 3. Comparison of vibrational amplitude values.

S. No.	Node #	Without PZT	With PZT
1	3010	3.5	3.7
2	4648	7.6	6.4
3	4756	7.7	5.8
4	4771	7.7	5.8
5	5225	3.6	3.6
6	6334	7.3	5.8

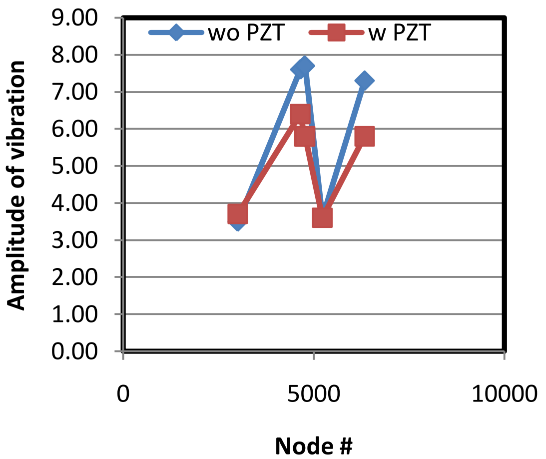


Figure 5. Comparison of vibrational amplitude values.

4. Conclusion

The cutting tool is first analyzed with piezoelectric shunt patch and after that it is compared with simulation of cutting tool which is without piezoelectric material. It is clearly shown in modal analysis that there is only a slight difference in their modal frequency and shape. Mode shape deformation is less in the cutting tool with PZT patch. Harmonic analysis is performed to get the amplitude of vibration for both cases at various nodes at the same conditions. It is concluded that the amplitude of vibration is higher for simple cutting tool. By applying a simple shunted piezoelectric patch vibration decreases incredibly. There is about 34% reduction in machining vibration by using piezoelectric patch which definitely enhance the tool life.

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