The Passive Control of Machine Tool Vibration with a Piezoelectric Actuator

by

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Summary

The vibration of a machine tool structure reduces the life expectancy of tool tips, the quality of the surface finish and the tolerances obtained by the machining process. The problem is related to the dynamic stiffness of the machine tool structure. Mechanical absorbers were traditionally implemented to improve the dynamic stiffness, however, active control systems have in recent years proved to be more effective. The active control of vibration is a cost intensive solution to the problem of machine tool vibration. A passively shunted piezoelectric stack actuator proved to be an intermediate solution between a mechanical absorber and an active control system. The device is less cost intensive and its adaptation ability is superior to that of the mechanical absorber. A mathematical model of the device was derived and verified experimentally. The objective of the research was set to improve the dynamic stiffness of a CNC lathe's tool changer. A modal analysis was conducted to determine the dynamic properties of the structure and was verified by an operational deflection shape analysis. The shunted piezoelectric actuator was implemented on the tool changer and attenuation of up to 17 percent was obtained at one of the structural modes. Reasonable correlation was obtained between the experimental and simulation results.

Keywords: Absorber, attenuation, control, damper, machine tool, piezoelectric, passive, smart materials.

Die Passiewe Beheer van Masjiengereedskap Vibrasie met 'n Piezoelektriese Aktueerder

deur

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Opsomming

Die vibrasie van masjiengereedskapstrukture verkort die verwagte lewensduur van snypunte, verswak die gehalte van die oppervlakafwerking, en vergroot die haalbare toleransiewaardes. Die vlakke van vibrasie wat tydens masjinering ondervind word is afhanklik van die dinamiese styfheid van die struktuur. Meganiese absorbeerders is tradisioneel geïmplementeer om die dinamiese styfheidseienskappe te verbeter. Die aktiewe beheer van vibrasie is 'n meer moderne oplossing tot die probleem, maar dit is koste-intensief. Die navorsing toon aan dat 'n multilaag-piezoelektriese aktueerder 'n intermediêre oplossing tot die probleem is, as daar 'n passiewe elektriese stroombaan aan die pole gekoppel word. Die toestel is goedkoper en is meer aanpasbaar as 'n meganiese absorbeerder. 'n Wiskundige model is afgelei en eksperimenteel geverifiëer vir die toestel. Die doelstelling van die navorsing was om die dinamiese styfheid van 'n gereedskapwisselaar, wat op 'n numeries beheerde draaibank gemonteer is, te verbeter. 'n Modale analise is op die struktuur uitgevoer om die dinamiese eienskappe daarvan te bepaal. Die dinamiese gedrag van die struktuur onder masjineringstoestande is bestudeer met 'n operasionele defleksie-analise. Die toestel is geïmplementeer op die gereedskaphouer en sewentien persent attenuasie is verkry by een van die struktuurmodusse. Redelike korrelasie is verkry tussen eksperimentele en gesimuleerde resultate.

Sleutelwoorde: Absorbeerder, attenuasie, beheer, demper, masjiengereedskap, piezoelektrisiteit, passief, slim materiale.

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Nomenclature

Piezoelectric

A	Area of the piezoelectric element perpendicular to the poling direction
C_p^T	Inherent capacitance of the piezoelectric element
D	Electrical displacement
E	Electrical field in the material
I	Electrical current
K	Static stiffness of the piezoelectric actuators / element
K_{33}^{ME}	Relation between the applied force and displacement for the uniaxial loading case
L	Length of the piezoelectric element in the poling direction
L_i	Electrical inductance
R	Electrical resistance
S	Material engineering strain
S^{SU}	Compliance of the shunted piezoelectric element
T	Material stress
V	Electrical voltage (Tension)
Y^D	Open circuit admittance due to the inherent capacitance of the piezoelectric element
Y^{EL}	Electrical admittance of the shunted piezoelectric
Y^{SU}	Admittance of the shunt circuit
Z^{EL}	Electrical impedance equal to the inverse of the electrical admittance
ε^T	Dielectric constant
d_{33}	Piezoelectric constant with poling and deformation in the three direction
s	Laplace parameter
s^E	Piezoelectric material compliance at constant field
φ	Mode shape matrix

Structural Dynamic Response Reconstruction

N	Number of sampled time intervals
T	Sampling interval
V_N	Loss function
a	Input parameter
b	Output parameter
$e(t)$	Innovation term at time t
na	Number of input parameters
nb	Number of output parameters
nk	Time delay
$u(t)$	System input at time t
$y(t)$	System response at time t
$\hat{y}(t)$	Estimated output at time t

Abbreviations

ARX	Auto Regressive model with eXternal input
EMA	Experimental Modal Analysis
FEM	Finite Element Model
FRF	Frequency Response Function
ODS	Operational Deflection Shapes
SDRR	Structural Dynamic Response Reconstruction
emf	Electromotive Force