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Five-axis milling vibration attenuation of freeform thin-walled part by eddy current damping

Mashhood Asad Butt, Yiqing Yang*, Xingzheng Pei, Qiang Liu

School of Mechanical Engineering and Automation, Beihang University, Beijing 100191 China

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ABSTRACT

Passive control has been effective in damping the machining vibration of thin-walled parts. However, physical addition onto the part causes the dynamics change and limits the engagement of cutting tool, especially in the application of multi-axis machining. Utilizing the non-contact eddy current damping, a two-degree-of-freedom apparatus is designed after experimental investigation into the magnet combination, magnetic flux density and magnetic flux mode on damping behaviors on a specifically designed platform. The apparatus is set up by mounting on the stationary spindle head of a five-axis CNC machine tool. The included neodymium magnets, and then the induced eddy current damping force are able to follow the feeding cutter through the control of two servo motors, keeping out of touch with the thin-walled part to be damped. As the damping force is able to resist the vibration of the machining point induced by the cutting force directly, it allows the design with less volume and mass (i.e. magnets and conductors). In the end, hammer tests are performed to verify the additional damping ratio imposed by the apparatus. Three-axis milling tests of a thin-walled frame are carried out to validate the damping of the apparatus, and five-axis milling tests of thin-walled blade type part are conducted to demonstrate its controllable damping and adaptability to complex tool path.

1. Introduction

Freeform thin-walled parts are quite common in aeronautic industries. Its machining has been a great challenge due to the conflict between low flexibility and high accuracy of desired geometry. A large number of publications have investigated the techniques to avoid machining vibration, including cutting process optimization based on the stability lobes and structural dynamics modification by active or passive control [1].

Passive control technology is effective, low cost and easy to achieve; therefore, it has been widely used in the industry. Nakano et al. attached three dynamic absorbers to a collet chuck in order to suppress chatter in end milling operations [2]. Kolluru et al. presented a surface damping solution composed of thin flexible layer and distributed masses for large thin-walls [3]. Brecher et al. presented an analytic tuning method of multi-stage multi-mass damper that highly increases effective frequency range and robustness [4]. However, the disadvantage of a passive damper is that there is physical contact between the damper and the part to be damped, which causes the mass loading and added stiffness of the primary structure and limits the engagement of cutting tool especially in case of multi-axis machining.

Eddy current damping is generated based on the electromagnetic induction. When a conductor is vibrating in the presence of a magnetic field, in a way that the magnetic lines are perpendicular to the surface area of the conductor and are continuously changing with time, an eddy current is induced in the conductor. This current always opposes the change in magnetic flux thus causing a damping effect on the motion of the conductor. According to the literature review, the eddy current damping can be generated by utilizing different magnetic flux components. The radial magnetic flux is contributing the eddy current damping when the conductor is moving (Fig. 1a) parallel to the magnets poling axis, while it is axial magnetic flux when the conductor is moving perpendicular to the magnets poling axis (Fig. 1b). As non-contact fashion, the eddy current damping functions as a form of viscous damping with adjustable damping characteristics and independent external power supply. Therefore, it has found very wide applications in vehicle and civil engineering.

Sodano et al. proposed a concept using the eddy currents induced in a conductive plate to suppress the vibration of a cantilever beam [5]. Bae et al. introduced a design of magnetically tuned mass damper including the classical tuned mass and eddy current damping [6]. Ebrahimi et al. proposed magnetic spring-damper to generate variable damping and spring effects [7]. The above works are using magnet's radial flux to generate eddy current damping (Fig. 1a), while some

* Corresponding author.
E-mail address: yyiqing@buaa.edu.cn (Y. Yang).

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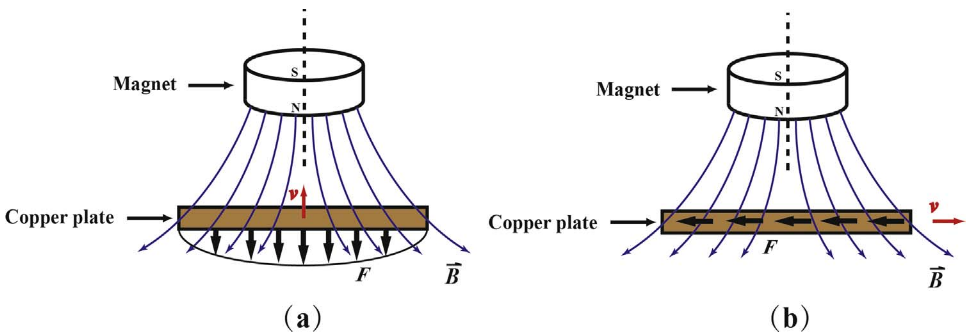

Fig. 1. Eddy current damping. (a) radial flux mode; (b) axial flux mode.

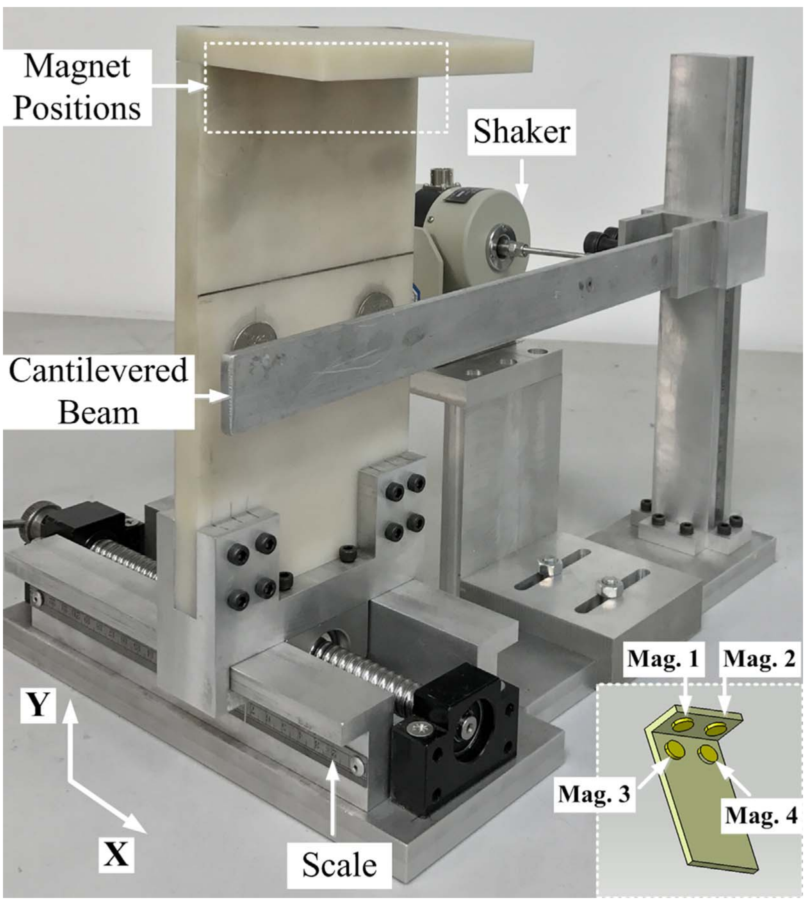

Fig. 2. A platform for investigating the eddy current damping.

Table 1
Combinations of magnets located on the platform.

Combinations No.	Position 1	Position 2	Position 3	Position 4
1	X	X	X	X
2	S	S	X	X
3	S	S	S	S
4	X	X	N	S
5	X	X	S	S
6	N	N	S	S
7	N	S	S	N

X represents no magnet. S/N represents the South/North magnetization direction facing the cantilever beam.

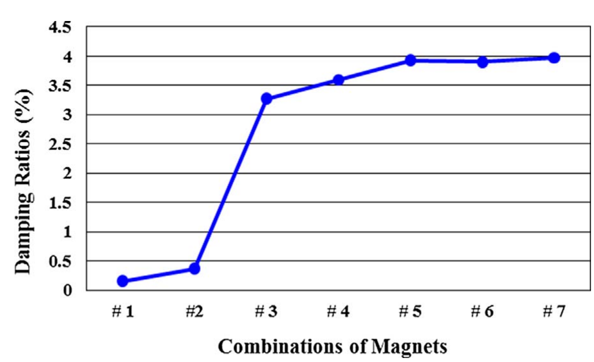

Fig. 3. Identified damping ratios of the cantilever beam under different combinations of magnets.

works are using axial flux (Fig. 1b). Bae et al. investigated the modeling of eddy current damper and was able to predict the dynamic characteristics of the cantilever beam after damping [8]. Lei et al. presented design and analysis of an eddy current damper with high efficiency and compactness by splitting the magnetic field and arranging the poles in an alternating pattern [9]. However, current publications are mostly focused on theoretical formulation, numerical simulation and experimental validations of eddy current damping model. There is a lack of