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Chatter Attenuation of Five-axis CNC Machining by Eddy Current Damping

Yiqing Yang, Mashhood Asad Butt

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

yyiqing@buaa.edu.cn, mashhoodbuaa@yahoo.com

Abstract
Machining of thin-walled part has been a great challenge due to its low flexibility, resulting in narrow stable cutting zone. Cutting parameter selection based on stability prediction is restricted by the dynamics change during the material removal.
An apparatus is designed to attenuate the machining vibration in thin-walled freeform aluminium workpiece using eddy current for damping. The apparatus, containing neodymium magnets, is capable of moving with the cutting tool. The whole assembly does not make any contact with tool or workpiece while effectively enhancing the workpiece damping and suppressing the chatter without altering the workpiece dynamics.

Eddy Current Damping, Vibration Attenuation, Five-axis Machining, Chatter, Thin-walled Part

1. Introduction

Thin-walled components are widely used in aeronautics industries (i.e. Jet engines and impeller) because of their light weight. When it comes to machining any thin-walled workpiece, there is a hindrance due to its flexibility that generates chatter. A large number of publications have investigated the vibration suppression during machining; including cutting process optimization based on the stability lobes and modification of the workpiece dynamics by active or passive control [1]. Among these methods, passive control technology is low cost and easy to achieve, but most of these methods use contact dampers that stay intact with workpiece while machining [2, 3]. This causes increase in dynamics changes of workpiece and limiting the movability of five-axis machining especially for freeform surface. Therefore; the focus of this research is to develop a setup that can attenuate vibrations in workpiece without having any above mentioned hindrances.

Vibration of a conductor in the presence of a magnetic field such as 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 due to such motion of surface area. This induced current opposes the change in magnetic flux thus causing a damping effect.

Eddy current has significant effect on vibration attenuation [3]. If the magnetic flux is equal to magnetic field (B) times the area (A):

$$I = B.A$$

Then according to Faraday – Lenz's law induced emf will be:

$$\xi = -\frac{\Delta I}{\Delta t}$$

The negative sign in the equation indicates that the magnetic field induced by the current opposes the magnetic flux producing it.
The objective of this work is to develop a device such as to utilize the effects of eddy current on vibrations during five-axis machining. The designed setup can be used to damp the workpiece vibrations without the damper in physical contact with it [4]. The eddy current is induced in the vibrating body using neodymium magnets. The Damping effects are analysed while performing machining test on two different freeform aluminium workpieces at various thicknesses.

2. Experimental Setup

Eddy current damper works by keeping a specific distance from the surface to be damped. In five-axis machining, it is hard to maintain that distance from the workpiece while cutting in different axis. A special apparatus *Fig. 1* is designed to eliminate that limitation whilst performing the damping effectively.
The apparatus is mounted on a stationary tool post of five-axis CNC machine by round shaped apparatus gripper. The gripper has the same internal diameter as tool post's outer diameter so that it can fit together. A 70 teeth ring gear is inserted in a slit of the apparatus gripper. This ring gear is capable of freely rotating 360^0 on the apparatus gripper using a servo motor (DF15RSMG 36^0 Degree, 20Kg.cm). Motor is controlled through a control unit placed outside the machine. A hanging mechanism with screwed neodymium magnets (Nd2Fe14B) is attached to the ring gear. This part can move back and forth with respect to the tool using another servo motor (DSS-P05 Standard Servo, 5kg.cm). The rotational motion of this hanger motor is converted in to linear motion by Scotch yoke Mechanism. Similarly, the servo motor controlling the back and forth movement of this hanging mechanism is controlled by an external control unit. The combination of both movements allows the magnets to move around the tool. These movements help to maintain the distance between magnets and the workpiece during five-axis cutting.

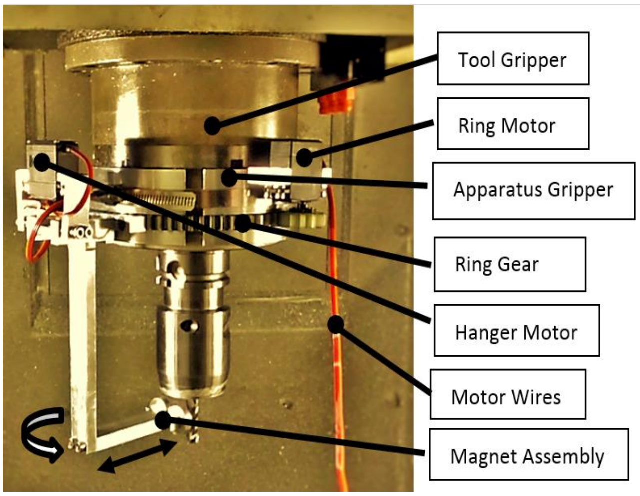

Figure 1: Eddy Current Damper Apparatus.

The external control unit contains an Arduino Uno board with ATmega328 microcontroller that is programmed to achieve precise movement of both motors separately by two-2way switches *Fig 2*.

Figure 2: Control for Motors. **Figure 3**: Aluminium freeform

To keep the uniformity in tests, the machining is carried out on two identical freeform aluminium workpieces *Fig 3* i.e. one freeform is machined with the eddy current damper and the other is machined without it. The workpieces are 40mm in height and 4mm in thickness. Several machining tests are performed on both freeforms keeping the basic parameters constant i.e. Spindle speed is n = 6000 rev/min, feed rate is F = 200 mm/min, and cutter is Sandvik Coromant 1P230-1200-XA 1630 with D = 12mm diameter and N = 2 flutes, the radial depth of cut is a_c = 0.2mm, axial depth of cut is a_p = 5mm. Two (30mm X 5mm) Neodymium magnets were used side by side. Each surface of both freeforms was machined one by one and vibrations were recorded by an accelerometer (KISTLER-8778A500) having sensitivity of 10.45 mV/g. This data was fed to the CutPro V9.3 software using data acquisition card NI 9234.

While doing the five-axis machining, the distance between the workpiece and magnets was kept constant through external control unit to 1mm.

3. Experiments and Results

Under similar conditions, both free-form surfaces are machined from 4mm to 1.8mm by keeping radial depth of cut 0.2mm each time. The most obvious results appear at the least thickness i.e. 1.8mm. When the machining is performed from 2.2mm to 2.0mm and results are collected, the acceleration of vibrations falls from about 100g to 50g as shown in *Fig 4*. Similarly, while cutting from 2.0mm to 1.8mm the damping effect is more prominent as the magnitude of acceleration falls from about 200g to 50g as shown in *Fig 5*.

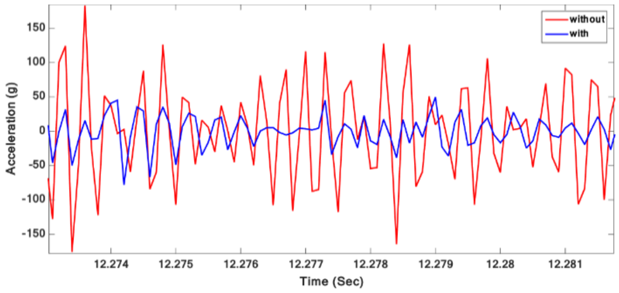

Figure 4: Workpiece vibrations with and without damping when machined from 2.2mm to 2.0mm.

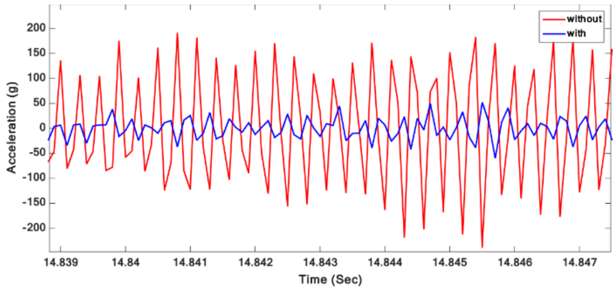

Figure 5: Workpiece vibrations with and without damping when machined from 2.0mm to 1.8mm.

4. Conclusion

Freeform thin-walled part can be machined effectively using the eddy current based damping apparatus without restricting any movement of five-axis CNC machining. Two servo motors are attached for precise motion of magnets around the workpiece. This movement can be controlled by the controller outside the CNC machine. The affectivity of the eddy current damper increases as the thickness of the wall decreases. This apparatus has significant effects on machining thin-walled workpieces as the maximum vibration reduction is 75%

5. Acknowledgements

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