Amplified Piezo Actuators (APA®) Enhancement for Active Vibration Control (AVC)

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Abstract:
Amplified Piezo Actuators (APA®) from CEDRAT TECHNOLOGIES are known to be compact and especially performing in dynamic applications. The recent evolutions realized on the APA® and drive electronics allow them to address active damping better than magnetic proof mass in terms of the Force to Volume ratio above some 10Hz. The dynamic capability of the APA® has been improved thanks to preload method enhancement. Research has successfully shown the possibility to achieve a high dynamic force level similar to the static blocked force of the piezo actuator. This technical progress coupled with an amplified motion makes possible the generation of high mechanical proof mass load at relatively low frequency. It produces a force higher than 100N in a volume of Ø40x75mm within a range of [100-300Hz]. This paper presents relevant uses of APA® for active damping in machining applications. Several machining case studies are reported integrating Amplified Piezo Actuators within the spindle head, inside the cutting tool or beside the workpiece clamp.

Keywords: Active Damping, Amplified Piezo Actuators, Machine Tool, Chatter Cancellation.

Introduction

Active Vibration Control (AVC) involves different types of actuators: Piezo and magnetics are commonly used depending the range of frequency to be damped. This publication focuses on the performances of piezo actuators used in proof mass configuration for AVC purposes in machine tools.
Whereas proof-mass based on piezo actuators are known to produce high force at high frequency (>1kHz typical), proof-mass based on APA® Amplified Piezo Actuators from CEDRAT TECHNOLOGIES (CTEC) can address a wider range of low frequencies (>10Hz). The combination of high stroke (>100µm), high dynamic force capability (>100N), thermal management and compact design make the APA® be in competition with magnetic proof mass.

Why APA® are deemed good candidate for AVC

Low voltage piezo components are known to be laminated materials. In that regard they display high compressive capability but become fragile when used in traction. When used in dynamic operation, a piezo actuator provides dynamic forces coming from inertial acceleration [1]. Whereas piezo component can supply a blocked force in static condition, the use in dynamic is limited by the max. tensile stress. To overcome this limitation, preloading systems such as spring washers, threaded studs, and compliant elastic structures are used to extend the dynamic range (Fig.1)
Typical high value of preload achieved in standard actuators from CTEC is 50% of the blocked force achieved in dynamic, which make possible use of APA® in dynamic operation up to half the blocked forced. This result is achieved by means of flextensional shell surrounding the piezo element (Fig.2) ensuring both preload and amplification.

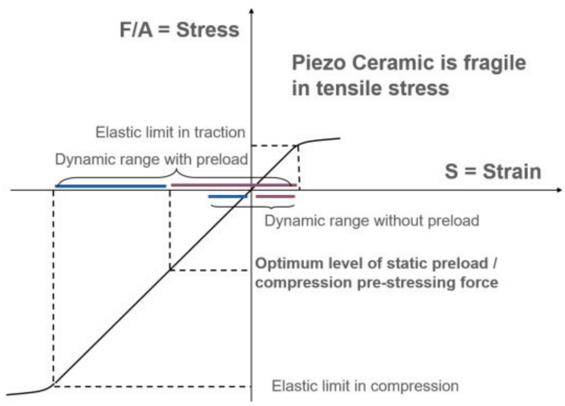

***Fig. 1:** Dynamic range of piezo actuators*

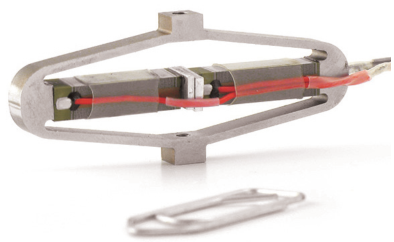

***Fig. 2:** APA® 150M*

Advantages of high preload was experimented for increasing vibration below and at resonance [2] and motivates further industrial exploitation.
An innovating approach of preload method applied on the APA® enhances the possible level of preload. Regarding a standard APA150M, the piezo dynamic force has been increased from 65N up to 100N. The

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result is a dynamic force increase at low frequency [100Hz-200Hz] with 1kg payload mass(Fig.3).

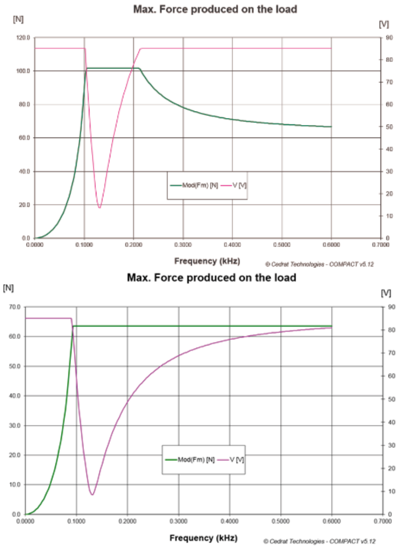

Fig. 3: *APA150M dynamic force with enhancement (TOP) and without (Bottom)*

Elsewhere, since the APA® is an amplified piezo actuator the height is reduced down to 22mm compared with 120mm height piezo stack usually necessary without magnification to get similar stroke (150µm). Finally the result is a compact actuator able to provide more than 100N of dynamic force at from 125Hz into a diameter smaller than one inch and two inches long, a mass of one kilo, and a displacement of 150µm 0-peak.

Proof mass Design

The proof mass system has been built using APA150M actuator. It includes three distinct elements (Fig.4):

- Flexure guidance of the mass,
- Increased preloading actuator,
- One mass of 1kg.

The guidance has to be flexible only in the direction of the actuator, the other translation directions have to remain stiff by a significant factor in comparison. This is especially important where two mass systems are present so that the activation of one mass does not influence the second mass system. Ideally the mass/volume ratio needs to be as high as possible, therefore tungsten becomes the ideal material. However the material is difficult to machine resulting in a high cost, and alternatives include brass or bronze.

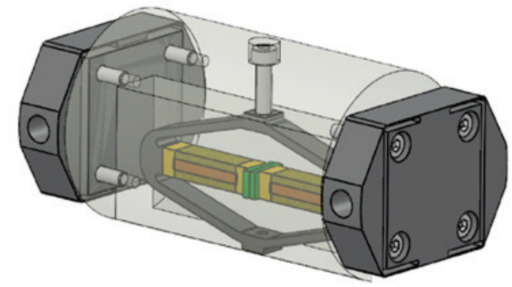

Fig. 4: *Proof mass design*

The stroke simulation is achieved through FEM (Fig.5). Equally the system resonance has to be calculated, the first mode will be in line with the actuator and as same as possible, while the higher modes need to be considerably greater than the range of frequencies to be damped (Fig. 6).

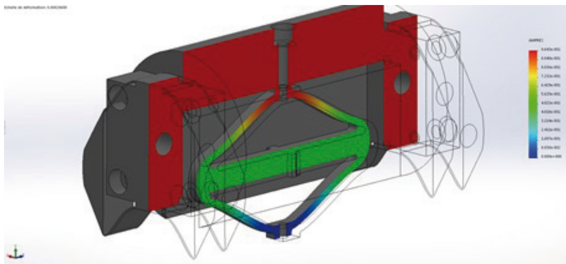

Fig. 5: *Proof Mass max. Possible stroke*

Finally the complete system including the proof mass system(s) needs to be considered. Here a tube where the length is 10 times the diameter is being damped by two proof mass systems.

Fig. 6: *System modal analysis*

Proof mass systems including enhanced preload and precision guidance are challenging to design, however the rapid response of piezo actuators, and the overall compactness of the design greatly offset these difficulties.

Closed loop design

In order to realise the close loop strategy, the behaviour of the proof mass is extracted from FEM computation. The transfer function is built considering a multimodal system.

$$H(j\omega) = \sum_j H_j(j\omega) \qquad (1)$$

The harmonic response of the system is given in Fig.7

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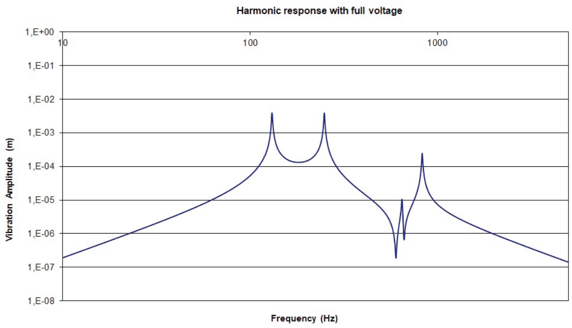

Fig. 7: Harmonic response of the proof mass to the bar at full power

The two main peaks correspond to the resonance of the proof mass in phase with the bar or at 180° phase shift. To monitor the vibrations, the control loop is closed with an accelerometer. Then a damping feedback is applied on the main resonance frequency.
The simulation realised with Simulink® shows the expected efficient damping: Without the AVC, an established vibration is damped in 1s, as shown in Fig.8.

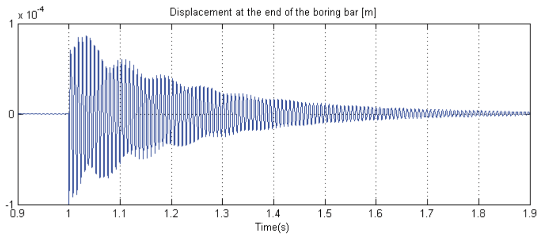

Fig. 8: Displacement of the bar resulting from force step and proof mass OFF

With the AVC, an established vibration is damped in 100ms. Fig.9 shows the driving voltage applied to the proof mass to achieve this damping.

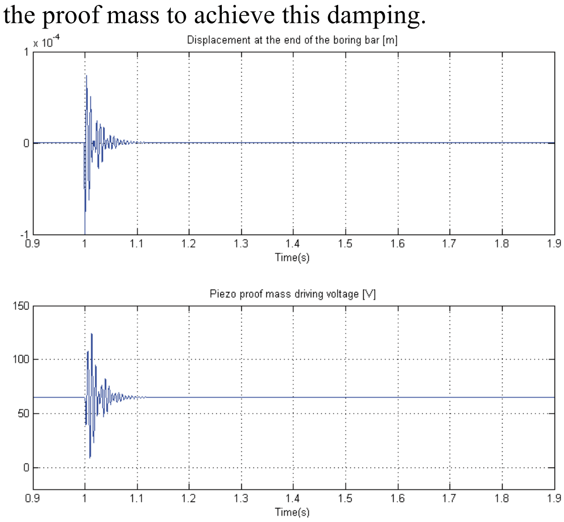

Fig. 9: Displacement of the bar resulting from force step and proof mass ON

Prototyping and test bench set up

The prototype of proof mass so called PM150M is being built using brass mass payload (Fig. 10).

Fig. 10: Piezo proof mass PM150M

The PM150M is being used to damp a long tube of steel, diameter 50mm, length 500mm (Fig.11), excited by hammering.

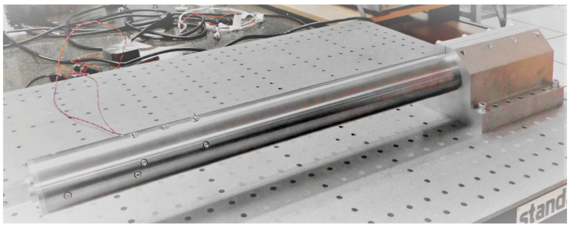

Fig. 11: Test bench set up

Practical tests are carried out to consolidate the performances achievable with AVC.

Results

A hammer shock test is performed, the open-loop / closed-loop comparative response is shown in Fig.12.

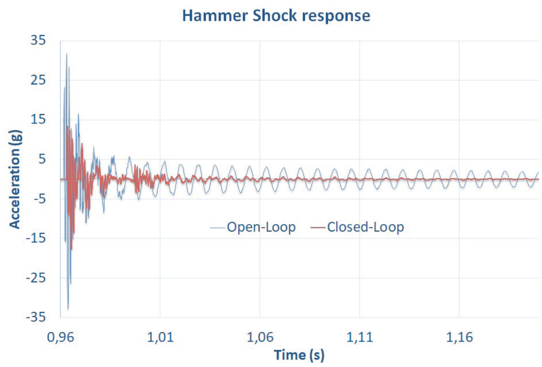

Fig. 12: Acceleration of the bar tip resulting from hammer shock (ON/OFF)

In open-loop that the first resonance frequency is the only one not self-dampen. The AVC works as expected, with a damping time lower than 100ms in closed-loop.

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The power spectral density is given in Fig.13. A damping of 20dB is achieved at resonance in closed-loop.

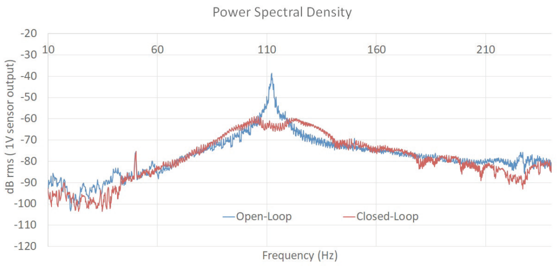

***Fig. 13:** FFT resulting from hammer shock (ON/OFF)*

Conclusions

CEDRAT TECHNOLOGIES has demonstrated AVC using APA®. The results is a proof mass capable of providing 100N in a range of 100-300Hz within a volume of Diam. 40 x L. 70mm. Successful integration into a tube beam shows -20dB of damping of the main parasitic mode at high level (30G).

Industrial Applications

APA® actuator used in proof mass has already covered several applications in machine tool mainly for chatter cancellation:

- Damping at 400Hz for milling applications. In this case the Proof mass is plugged at the spindle head level.
- Damping at 200Hz for turning applications. Proof mass integrated within the tool holder.
- Damping at 100Hz for deep drilling applications. Proof mass integrated within the tool holder.

These results overcome the use of APA® in semi active damping [3] in machine tool. In major cases 20% to 50% of chatter damping is achieved leading to quality improvement and manufacturing time saving. Important feedback is the stability of damping according to the clamping and changing process parameters: The variation of frequency of the chatter do not affect the efficiency of the damping. The proof mass does not need to be tuned and remains efficient even if temperature, speed, boundary conditions change during the machining process. Such a feature combine with high damping value is a breakthrough enhancement to Passive dampers (elastomeric, dissipative…).

Comparison with magnetic technology

CEDRAT TECHNOLOGIES owns a full range of APA® that can address a large range of frequencies [50Hz-1000Hz] and force amplitudes [20N; 1000N]. Outside this range MICA™ technology completes low frequency and higher force (see Fig. 14) by a magnetic patented actuator [4]:

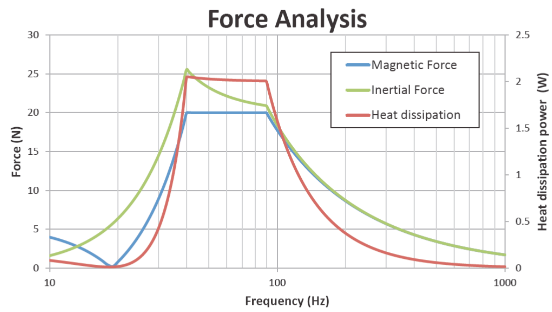

***Fig. 14**: Force and heat dissipation vs frequency of the proof mass PM-MICA20CS*

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References

[1] F. Barillot, S. Rowe, A. Pages, Ed Messe-Bremen (2016) – Proceedings N°A1.9 / P86
[2] F Claeyssen et al, Dynamic strain limits of Amplified Piezo Actuators, Proc Actuator 2010, Messe Bremen (G), 2010
[3] A.Kras, F.Bourgain, Journal of Machine Engineering, Vol. 14, No. 3, 2014
[4] P. Meneroud, C. Bouchet; A. Pages, 2016 Ed Messe-Bremen - Proceedings N°A6.3 / P143

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