New developments in piezo actuators: Long stroke actuators and high power electronics

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Abstract: In many cases piezoelectric actuators reach limitations in terms of maximum displacement and cycling frequency. Most amplified actuator technologies struggle to go over the millimeter of stroke. Furthermore certain closed-loop applications demand stroke measurement integrated into the actuator. While few amplifiers on the market can offer 20Amps current over a few 100ms, development of high power supply units runs parallel with actuator improvements. However with the introduction of high power supplies comes the problem of self-heating of the piezo ceramic. Finally extreme environmental conditions in terms of harsh conditions and high temperatures need to be addressed in order to open these markets for piezo actuators. Cedrat Technologies has been heavily investigating in solutions to overcome all of these drawbacks and these solutions are presented here.

Keywords: Piezoelectric actuator, ECS sensor, switching amplifier, Encapsulation.

1. INTRODUCTION

Cedrat Technologies has been making piezoelectric actuators for more than 20 years and has been innovating constantly to answer to demanding applications in Mechatronics. The APA® and PPA actuators offer dynamic capacities able to deal with high levels of shock and vibrations.

Existing APA's® have been limited in stroke to the 1mm range this article presents the development of new long stroke actuators and the integration of an ECS stroke measurement sensor inside the actuator.

High power supply units are also presented, capable of driving several actuators simultaneously or a single actuator at very high frequency, these units are pushing the limits of operating frequency.

With high power comes the problem of self-heating, encapsulation is used to manage this in high dynamic application.

Finally encapsulated actuators are shown, capable of operating in harsh/humid and high temperature environments.

In its simplest form encapsulation provides a physical barrier between the environment and the ceramic, restricting direct contact between the two. This form of encapsulation is ideal where the environmental conditions are either humid or harsh and contact between both the environment and the ceramic would limit the actuator life.

Furthermore traditionally two temperature-related problems have limited the number of applications for piezo actuators: firstly, internal heating of the ceramic from use at high frequency for extended periods; and secondly, external environmental conditions.

Some of the work presented here has been performed within the project AeroPZT, specifically funded under the Clean Sky Joint Technology Initiative (EUFP7). The project partners, Plant Integrity Ltd (UK), Cedrat Technologies (France), Noliac (Denmark) and Politecnico di Torino (Italy), are targeting the development of materials and processes for the application of piezoelectric actuators in aero engine controls, which implies harsh environmental conditions, particularly elevated temperature. Applications of such actuators could include valve control for fuel staging or clearance control.

2. LARGE STROKE ACTUATOR

Typically the multilayer piezoelectric actuators provide around 0.1% of displacement, which is insufficient in many applications. The simplest method to increase the stroke of the actuator is to increase the piezo stack length. Unfortunately this causes an increase in the overall size, mass and volume of the actuator.

A second technique is to use mechanical amplification in order to improve the maximum stroke of the actuator. This technique allows obtaining high stroke actuators within a compact size. Cedrat Technologies has a long tradition of producing mechanically amplified actuators. This type of actuators is called an APA® which stands for Amplified Piezoelectric Actuator.

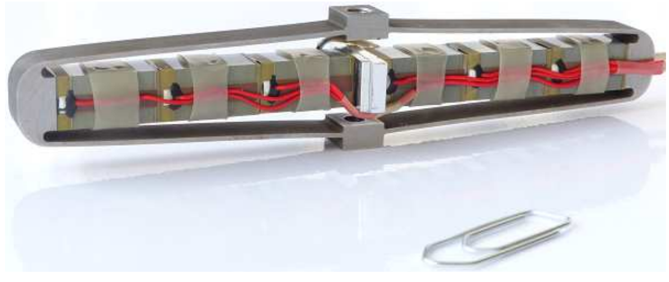

Figure 1: Long stroke amplified piezoelectric actuator APA2000L.

The actuator mechanism is composed of two major parts: piezoelectric ceramics that generates force, and a metal shell that mechanically amplifies the displacement of the ceramics. The overall stroke of the actuator depends on the displacement of the ceramics and amplification ratio of the shell.

Commercially available actuators have a free displacement between 0.5mm and 1mm [1]. The idea was to increase the maximum stroke up to 2mm. It was decided to design the new APA® based on the L series actuators. This series uses 6 (10x10x20mm³) ceramics to generate the displacement. The length and width is the same for each actuator in the series (145x10mm²) while the height changes as this has an influence on the amplification ratio.

The highest stroke actuator is the APA2000L and provides 1968µm of stroke. The resonant frequency is 90Hz in with one extremity blocked and 487Hz with both extremities free. The blocked force of actuator is 60N. Based on free stroke and force the generated power of this actuator is 15J. The amplification ratio of the actuator is 15 times.

A derivate called the APA1500L has also been design, which produces a stroke of 1480µm and a blocked force of 121N.

3. Sensor integration

The most common sensors integrated in the piezoelectric actuators are strain gauges. This type of sensor has many advantages including good reliability, conditioning and accuracy. The strain gauge is directly glued to the ceramics and measures strains on the piezoelectric component, which is then converted by the conditioner into a standard ±10V signal. The calibrated output signal is proportional to the displacement of the whole actuator with a specific gain value.

Although this sensor presents many advantages, the measured displacement in APA® actuators is indirect due to the mechanical amplification. This means that displacement of the actuator is measured based on the ceramics displacement. This solution works well, as long as the actuator is not subject to dominant external forces, unfortunately, it is often the case.

The possibility of a direct measurement of the displacement in APA® has been investigated. A solution has been developed using Eddy current technology. This sensor allows for a contactless and direct measurement of the actuator displacement. The integration of the sensor in the APA® actuator was initiated by designing a support that could be integrated into the actuator. Evaluation of various supports was based on thermal testing and measurements at low and high frequencies.

Figure 2: ECS with support intergrated into the APA

The ECS probe mounted inside the APA® shape allows direct measurement of the actuator displacement. The compact dimensions of the probe and the fixing method do not increase the total volume of the actuator. At the same time the hysteresis correction and thermal behaviour presented the best conditions with this support design.

Both sensors strain gauges and ECS can be easily used and integrated into fatigue test benches. Signals coming from the sensor can be used for monitoring and controlling the actuator, via a closed loop system.

4. High power supply

One advantage of piezoelectric actuators for fatigue testing machines is the opportunity to work at high frequency. But with large actuators, this requires a high power amplifier, as the current needed is proportional to the frequency. The most common amplifiers used for driving capacitive loads are linear amplifiers. Although this type of amplifier provides smooth supply signals with low output noise (THD), their configuration causes huge power losses. At the same time power and current values require large components and heat sinks that make this amplifier massive. Due to this disadvantage the maximum current value is limited.

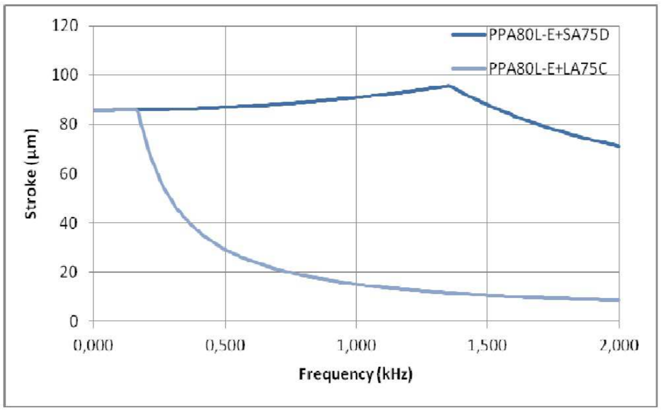

Figure 3: Power capabilities comparision of a switching amplifier (SA) and linear amplifier (LA) on a PPA80L actuator

A new amplifier has been developed for overcoming the limitation in current. In order to get an amplifier capable to generate more power, a design based on switching technology was used. This enables much more power with negligible losses making this amplifier very efficient.

The design of the amplifier has focused on driving capacitive loads, particularly piezoelectric actuators. The low voltage piezoelectric materials require a driving range between -20 and 150V (170Vpp). At the same time, driving these actuators at high frequency require a high current. The amplifier can provide up to 20A continuously, in the SA75D version. This is sufficient enough to drive one large actuator from the L or XL range from Cedrat Technologies, at high frequency or a couple of actuators in parallel.

Figure 4: *SA75D assembled in standard 19 inches rack.*

Tests with the SA75D and PPA80L-E showed that this amplifier can easily provide 18.3A peak value while driving the actuator at 1300Hz. In these conditions, the PPA80L-E provides 3500N and a stroke of 94µm. At 1300Hz, the mechanical reactive power stored in the actuator is 1.3kVA, whereas the maximum electric reactive power provided by the amplifier is 1.5kVA. Power consumption benefits from the low losses of switching technology. Moreover, an energy recovery system has been included for driving capacitive loads. Finally, at maximum driving parameters (20A and 170Vpp) the required active power is less than 100W. Low power consumption and a recovery system allows using smaller components. The mass of the core amplifier is less than 850g with a total volume of 100x100x100mm^3. The power ratio of the amplifier is 1.75kVA/kg.

5. HEAT MANAGEMENT IN DYNAMIC APPLICATIONS

The availability of new high power amplifiers has allowed actuators to operate at high frequency, maximum stroke and for extended periods of continuous operation. However self-heating of the ceramic under high power loads has up to date restricted either the maximum operating frequency or the time of operation, where short bursts of high loading has had to be followed by extended periods of no operation in order to cool down the ceramic.

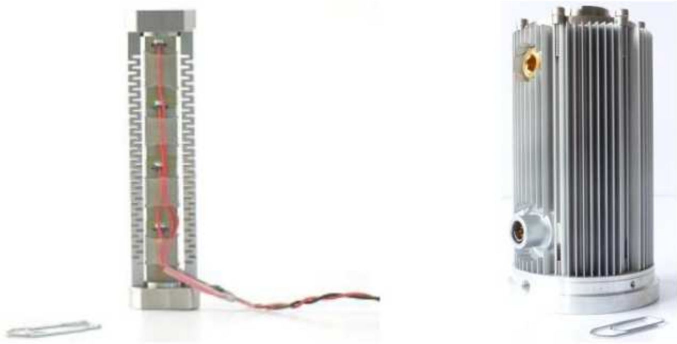

Figure 5: *View of PPA80L actuator (to the left) and the PPA80L-EA includes the fluid cooling and compressed air option (to the right).*

Encapsulation offers the option of incorporating a cooling fluid. By immersing the ceramic within a fluid any heat generated during operation of the actuator can be transferred to the body of the encapsulation and rapidly removed, either by natural convection or by the use of a secondary system.

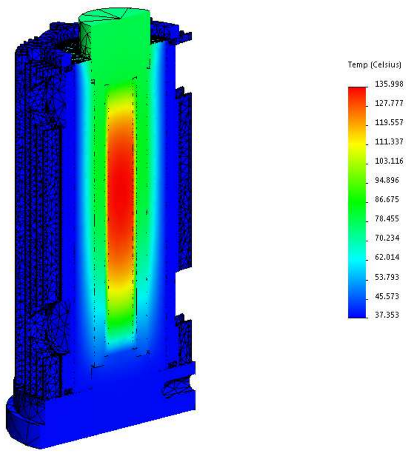

Figure 6: *Thermal simulation showing the temperature difference between the ceramic and encapsulation*

Tests comparing a standard PPA80L, and encapsulated PPA80L-E with cooling fluid and an encapsulated PPA80L-EA using both cooling fluid and compressed air at 0.25 bar have been carried out, when all three were run at 230Hz full stroke the following results were produced:

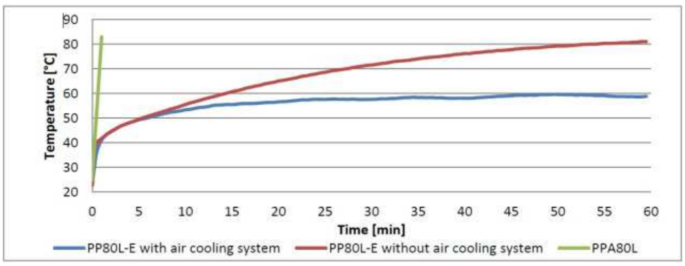

Figure 7: *PPA80L/PPA80L-E and PPA80L-EA temperature stabilising time*

It can be seen that it takes around one minute for the PPA80L to reach a temperature in excess of 80°C. The encapsulated actuator using only the cooling fluid system reached the same temperature of 80°C in 53 minutes and stabilises at 82°C, while the PPA80L-EA. never exceeds 60°C.

The high efficiency of the air cooling system has allowed a drastic increase in driving frequency for the actuator. The air pressure was kept at the same level of 0.25bar while the frequency was increased. It was observed that the encapsulated air cooled actuator can be driven constantly even in excess of 1300Hz.

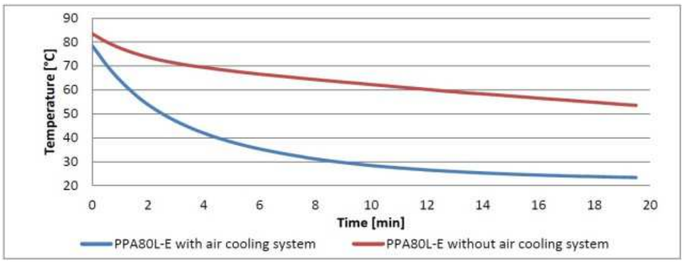

Figure 8: *Ceramic cooling graph on the PPA80L encapsulated actuators with and without compressed air cooling*

The two configurations of an encapsulated actuator show many advantages, compared to the standard PPA80L version of the actuator, the driving frequency has increased over 20 times for the encapsulated actuator fitted with the forced air cooling system (1300Hz). The encapsulated actuator without air cooling system can be used at a frequency that is nearly 5 times higher (230Hz) compared to regular actuator (50Hz for PPA80L).

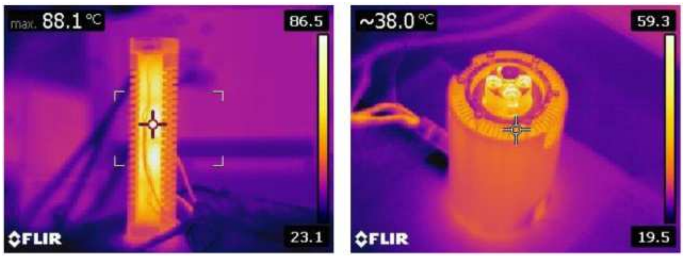

Figure 9: *PPA80L (left) and PP80L-EA (right) working at the same ceramic surface temperature but different frequencies, note the encapsulation surface temperature.*

6. HARSH/HUMID ENVIROMENTS

As the applications for piezo actuators continue to expand especially into fields such as aerospace, oil/gas and science there is a requirement for the actuator to be used within increasingly harsh environmental conditions.

In the simplest form encapsulation systems, provides a single layer physical protection for the ceramic against the environmental conditions.

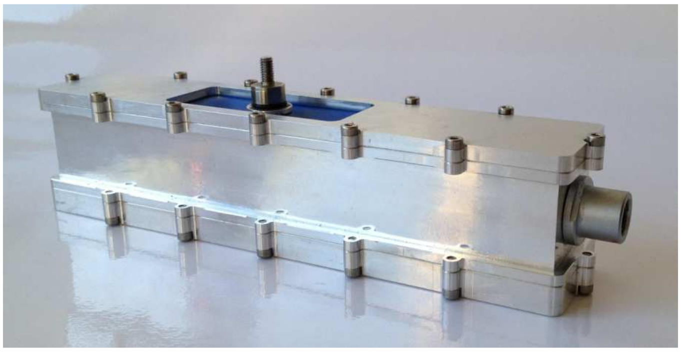

Figure 10: *APA2000L-E*

The APA2000L-E developed with the AEROPZT project is able to reach 2mm of stroke and is hermetically sealed to IP68 for use in harsh environmental conditions, the overall size of the encapsulated actuator is 160mm long x 34mm wide x 38mm high, compared to the standard non encapsulated APA2000L of 140mm x 20mm x 20mm.

Encapsulated actuators have also been developed for use below ground level, here the temperature conditions remain fairly stable however the environment contains high levels of moisture and solid contaminates.

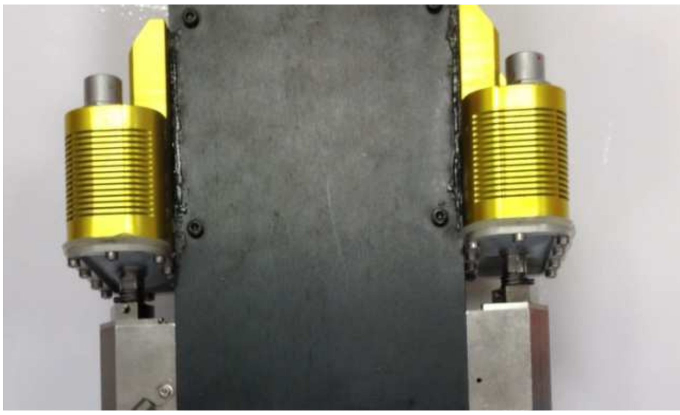

Figure 11: *Twin encapsulated actuators for use on a machine tool within a water spray environment, furthermore the actuators are required to operate at 250Hz for 8 hour periods, successful trials show the ceramic temperature stabilises at 50°C – Note the air fins*

7. CONCLUSIONS

Long stroke actuators generate up to two times larger stroke compared to standard actuators, with maintained dynamic performance.

For a complete mechanism, an ECS displacement sensor can be integrated within the piezoelectric actuators. This can be used for monitoring and controlling the actuator within a closed loop system.

The high power switching amplifier range provides sufficient power to drive large piezoelectric actuators at high frequency, or a number of smaller actuators at the same time.

Encapsulation offers the opportunity to dissipate self generated heat from high power applications, or to allow actuators to operate within a high temperature environment. Furthermore it protects the actuator from harsh or humid environmental conditions.

8. ACKNOWLEDGEMENT

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9. REFERENCES

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