Potentialities of APA Composite Shell Actuators and SA75D Amplifier for New Dynamic Applications

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Abstract:
The piloting of APA's composite shell by SA75D power amplifier offers new opportunities for dynamic new applications. Two in particular were received and are being studied: the design of a compact table tensile micro machine for characterizing stress-strain laws at high strain rate of wires, fibers, strands and textile samples that will usefully complete the fleet of dynamic testing machines available, the generation of synthetic jets of air pulsed also studied at ONERA. The energy capacity (displacement, force) without or with an external linear load were modeled versus the rise time using the Simulink code and experimentally measured using a very light device. Other identified improvements remain to be implemented both at the APA's actuators as the Amplifier SA75D to get some gains.

Introduction

ONERA activity on Amplified Piezo Actuators APA® from CEDRAT Technologies was initiated by the opportunity to apply them to the flap motion of active blades of helicopters. The main handicap was their weight and the idea of a composite shell came at once to the mind. Other equally interesting properties were also perceived quickly for applications in fast dynamics in other areas of activity.
Different works on the design of various other geometries [1], the manufacture [2], the optimization [3] and the repeatability of the production [4] have been done.

APA500L with Carbon/Epoxy shell

Fig. 1: APA500L with steel shell

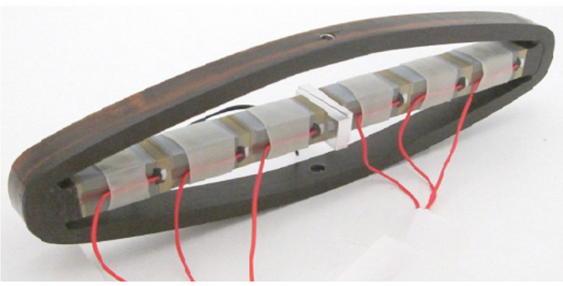

Fig. 2: APA500L with carbon composite shell

The two actuators (figures 1 and 2) are very similar in appropriate comparison purposes. Internal profiles are identical. The thickness more or less constant since the manufacturing method is adjusted for stiffness comparable to the steel shell. Only hooking zones differ, the dishes have not been reproduced. In the case of the composite shell, the stack supports bases are reported. They are of B4C ceramic, EDM machinable and ensure a good transmission of forces. A specific study was conducted to optimize the geometry of these bases and increase energy capacity W = F.d and limit the risk of damage to the shell by punching.
For a shell geometry, identical stacks and a preload of 20 MPa the main properties obtained for the two actuators are shown in Table 1.

Table 1: *Comparison of the actuators properties*

Shell	Steel	Carbon/Epoxy
Number	1	Mean of 4 specimen
Interface	Plate with a ∅M3 hole	Round with a helicoil ∅M3
Short Axis (mm)	56.43	50.09
Great Axis (mm)	124.55	124.51
Thickness (mm)	20	20
Shell Mass (g)	97	28
Actuator total Mass (g)	200	131
Fr blocked-free (Hz)	462	504
Response Time blocked-free (ms)	1.09	1.01
Fr free-free (Hz)	1900	3770
Response Time	0.26	0.14
Stiffness (N/µm)	1.22	1.19
Stroke (µm)	630	630
Blocked Force (N)	769	750
Stacks Pre-stress (MPa)	20	20
Crushing for implementation (µm)	1550	1325
Thermal Coefficient CTE (µm/°C)	7	0.7
Electro-mechanical Coupling (%)	47 (45 at 70°C)	40 (42 at 70°C)
Factor of merit Q (%)	44	28

The electrical capacitance of the stacks is 34 uF. A 630 µm stroke, a blocking force of 750N and a Ky stiffness along the minor axis of 1.20 N/µm, identical for the two actuators were obtained with the advantage of the actuator to composite shell:
- A weight gain of 35%;
- A free-free resonant frequency multiplied by 2;
- A blocked-free resonant frequency multiplied by 1.1;
- A 15% lower crushing;

- Lower response times favorable to improving the dynamic behavior;
- A CTE coefficient divided by 10 is compatible with that of ceramic stacks, suitable to maintain a constant pre stressing force despite the heating of continuous operation stacks;
- A value of merit Q lower reflecting a better damping capacity and therefore rapid positioning and work closer to resonance.

SA75D Amplifier

The Switching SA75D amplifier was specially developed by Cedrat Technologies to meet new needs and fast dynamics for large actuators with high capacity and power seekers and with high bandwidth.
The acquired rack can accommodate and connect up to two actuators in parallel (Figure 3).

***Fig. 3:** View of the SA75D Amplifier*

The main properties are summarized in Table 2. It may be noted the good quality of generated signals (low harmonic distortion and good signal/noise ratio) Components for reliability reasons, the peak current was limited to 20 A.
The input voltage can be controlled by an external generator delivering a voltage of -1 +7.5 V.

***Table 2**: Characteristics of the SA75D Amplifier*

References	Unit	Values
Output Voltage	V	-20 /150
Peak current limitation	A	30 (but limited to **20**)
Peak Output Power	V.A	1900
Control input voltage	V	-1/+7.5
Ripple Current	%	0
Total Harmonic distorsion	%	2
Signal/Noise ratio	dB	70
Output Bandwith (loaded or unloaded)	kHz	22.508
Protections		Thermal Current and Voltage limitations,

The commercial version of the amplifier has in its basic version of any digital control law of the output voltage. This type of control which is rather slow limits the amplifier performance by acting on the output voltage rise time and thus the actuator displacement rise time.
The first trials with this actuator control law (the actuator being not subject to an external load exerted by a spring) showed a leveling of the intensity to 7.5 A compared to the 20 A available**.**
The additional implementation of a purely analogical control of the current has allowed to simplifying the voltage loop to increase the sampling rate and full use of the 20 A available.

***Fig. 4:** Bandwidths according to the control loops*

The break around 1100 Hz that appears on the curve corresponds to the current limit which comes into operation.

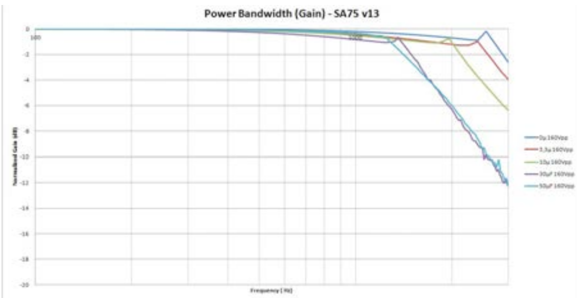

***Fig. 5:** Influence of the capacitance to control*

Bandwidth drop with the capacitance to control (Figure) but remains well above the material competitors. At our knowledge, no comparable equipment delivering 20 A is currently available on the market.
Cedrat Technologies shows that even with a perfect amplifier that can deliver an infinite current, the gain in travel would be limited compared to the performance offered by the SA75D amplifier.
Thus by increasing the current to 30 A, one would obtain a reduction of the rise time of less than 50 microseconds, with a displacement of gain that does not exceed 7% for a current multiplied by 1.5 (Figure 5).

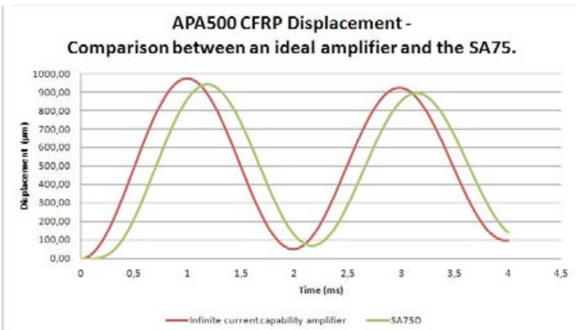

***Fig. 6:** Influence du courant disponible*

Performances of the composite APA500L powered by SA75D

Numerical modeling with Simulink Code

The numerical model developed by Cedrat Technologies on Simulink involves the parameters of the mechanical system including APA500L, an onboard mass and an external spring rate given opposing the movement of the actuator.
The block processing is shown in Figure 7.
Parameters involved in the different transfer functions of different elements generator, amplifier, actuator, force and displacement sensors.
The factor of merit which is an entry has a great influence on results. Numerical simulation has been done with a value of 100, too high both for steel and carbon shells, [5].

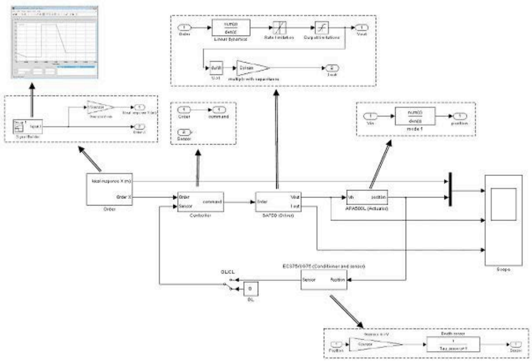

***Fig. 7:** Simulink model of the whole package: generator, amplifier, actuator, force and ECS sensors*

The setpoint input is shown in figure 7. It comprises five sections:
Phase 1: decrease of 0 to 1 V (0 to -20V)
Phase 2: stabilization for damping the resonant frequencies
Phase 3: ramp-up at +7.5 V (+ 150V). The same law, evidenced by a number of points used in the numerical simulation model or programmed into the memory of a signal generator acting amplifier input for controlling the actuators in the experimental phase
Five rise time were mainly studied: 10 ms, 1 ms, 0.50 ms, 0.25 ms and 0.1 ms.
Phase 4: stabilization to dampen any vibrations
Phase 5: slow return to original position.

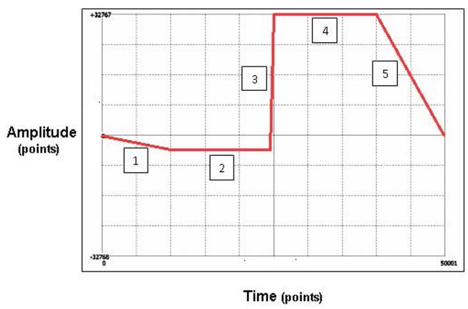

***Fig. 8:** Loading law*

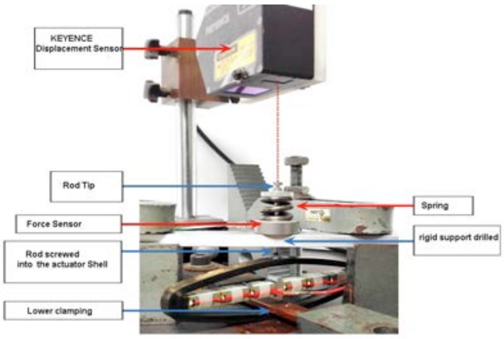

***Fig. 9:** Lightweight Test Fixture*

Experimental characterization
Assembly and instrumentation

The lower arm of the actuator is restricted by interposing a sheet of insulating on marble. The displacement is measured by a contactless optical sensor Keyence acting through triangulation.
Force is measured by a Kistler sensor and is positioned in order not to affect the board mass. The current consumption is continuously recorded during the test

Main results

For each test, generator input, amplifier output, actuator position, force and current are recorded as shown on figure 10.

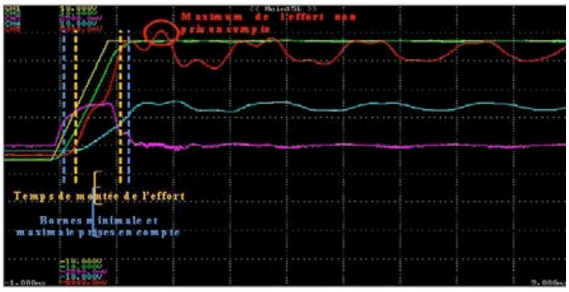

***Fig. 10:** Example of input and output curves*

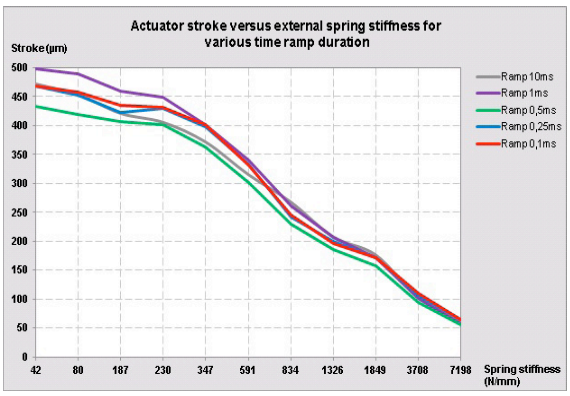

***Fig. 11:** Stroke versus load for various rise times*
It appears that the stroke doesn't vary a lot with the generator rise time change (figure 11).

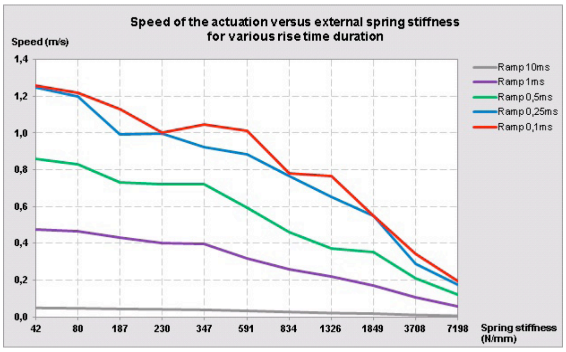

Fig. 12: *Speed versus load for various rise time*

Speed varies a lot with the voltage ramp and the low spring stiffness but beyond a 0.25 ms rise time the actuator speed seems to increase no more, (figure 12). Resonances are excited and appear on the curves.

During the test specimen failure

A small test campaign was conducted to validate the behavior of the actuator including the stacks have not been damaged during a sudden break of fiber under high load as is the case of carbon fiber. A small special device has been conceived. Ten trials were conducted. The actuator was charged with masses ranging from 52 to 484 N. The displacement measurement and its consistency between tests have been verified that the actuator has not suffered any damage.

Tensile table micro machine

The proposed machine is symmetrical and can use both sides 1, 2 or 4 APA500L actuators assembled in series or parallel according to the toughness of the material to be tested

Strain rate is expressed by the relation:

$$\varepsilon^{\cdot} = \Delta L / L_0 \times 1/ \Delta t = V / L_0$$

Also using an actuator of both sides having a 0.5 mm stroke and the specimen a 20 mm useful length (or 10 mm) without fixing jaw, a deformation speed rate of 125 s-1 (250 s- 1) can be achieved with an actuator speed of 1.25 m / s.

The effort capacity at mi stroke (750 N for two actuators with one of each side) and the actuator stroke itself are compatible with the fibers and fiber strands to be tested except for HR strands of carbon fibers which will have to be limited to 1 and 3 k filaments.

Further improvements

Performance gains of at least about 20% are still expected by several ways:

- A more efficient connecting geometry of the stacks support bases to the inner profile of the composite frame, allowing among other things to exert a higher pre-stress on the piezoelectric stacks without locally damaging the composite shell.
- The choice of an intermediary modulus carbon fiber with a modulus higher ultimate tensile strength,

In a more longer future,

- The use of hard ceramic shades for the stacks C / 2.5 Compared to soft ceramics. Lower d33 coefficient is compensated by a larger voltage range ([-150 V, 400 V] instead of [-20 V, 150 V]) needing the development of a new specific amplifier.

Conclusions

The work carried out and presented here were used to measure the performance of a APA500L CFRP actuator controlled by a switching amplifier SA75D. The main results are:

- The maximum displacement of the actuator is close to 500 microns and varies little to an external load of 230 N / mm;
- The maximum force that can produce the actuator is slightly above 467 N;
- The maximum speed of movement of the actuator that can be achieved is 1.25 m/s. It seems no longer increase with a rise time of less than 0.25 ms, a priori due to various limitations current, voltage and power and bandwidth same amp

Over the actuator must generate a high tensile effort, the more his movement is low.

- For a given ramp, the rise time is stable regardless of the effort of the actuator. However, its range of movement and its velocity decreases.
- The shell has two main resonances at approximately 550 and 1500 Hz that can be discerned on the experimental curves and don't affect seriously the measurements;
- The piezoelectric elements do not damage during the simulation of a sudden failure of fiber.

References

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