Smart Actuators for Aircraft applications.

F. Claeyssen, R. Le Letty, F. Barillot, N. Lhermet - CEDRAT TECHNOLOGIES.

Smart actuators and intelligent structures receive a considerable interest in the fields of Air & Space, to realise new functions or more efficient functions than passive structures. In these fields, there are needs for actuation means offering high mechanical energy density (product of stroke and force divided by the mass), a low power consumption, a resistance to severe environment (such as vibrations) as well as other case by case needs : High resolution (embedded active optics for cameras and telescopes), fast response (active control of structures shape, active damping of vibration)...

Because Multilayer Piezo Ceramics for Actuators (**MLAs**) offer many advantages compared to other active materials, they are increasingly used in various smart actuator applications and contribute to the development of the new field of intelligent structures. They offer an expansion deformation roughly proportional to the voltage, up to about 0.1% (1µm/mm) at typically 150V. A stack of 100mm long (which is the maximum realistic length) and of $1cm^2$ in section provides a free stroke of 100µm and a blocked force of about 3kN. Although usable in some cases, such actuators are not suited to most applications because too small a stroke. In addition, as underlined by ceramic manufacturers the tensile strength of these ceramics is low. So this is a source of failure in bending conditions, in vibration environment and in dynamic applications where high transient stresses are met. At last, such stacks do not offer a very practical mechanical interface. For all these reasons, in spite of their high energy density, the MLA ceramics are not really suitable, in their raw form, for fulfilling the needs of Air & Space applications.

To overcome these limits, CEDRAT TECHNOLOGIES has proposed different innovative concepts of piezo actuators and mechanisms meeting space and aircraft requirements. These actuators have been selected by several European Air & Space organisations (CNES, ESA, ONERA...) to receive a support for their development and they are available as products since 1998. Among these actuators, the development of the Amplified Piezoelectric Actuators, so called **APA**, is achieved and they are used in several air & space applications. These actuators cover a large range of displacements (up to 1mm) and forces (up to 1kN) while needing low Electrical power. They have been designed for withstanding large external forces. Therefore they successfully pass all severe qualification tests they have been submitted, such as launching vibration forces or centrifugal forces. They have been developed initially for positioning control space optics but they are spreading widely in other engineering fields such as the active damping and the control of shapes in aircraft.

The object of this paper is to review these actuators and their qualification results in the air applications.

Helicopter piezo-actuated flaps

A project called RPA (Actives Blade Rotor) was launched three years ago by ONERA, DLR and EUROCOPTER to study the possible benefits of implementing active trailing edge flaps on a helicopter main rotor. The main objectives of this project carried out by ONERA (French Aircraft Design Institute) are to decrease BVI noise in descent flight and improve the dynamic behaviour of the rotor throughout the largest possible flight domain.

A large array of technical solutions to actuate the flaps was considered by ONERA during the design phase : pressurised air, hydraulics, electric motors, and various smart materials configurations. The specifications, notably in terms of actuation frequencies and due to the requirement of operating in the rotating system, led to the selection of a solution based on smart materials. Existing commercial actuators, such as those proposed by CEDRAT TECHNOLOGIES, as well as recently developed prototypes such as that of University of Maryland were selected for a comparison of performance. Although the respective scales of University of Maryland and ONERA blade models are not directly comparable, the energy to weight ratio clearly showed that the standard CEDRAT solution yields significantly better results (see referenced paper). As a result, standard APAs from the CEDRAT were selected. It has to be noted that when Onera performed its selection, they considered the APA230L version of 1997 (Figure 1). Since this time, a new version of the APA230L was developed by Cedrat offering much higher forces and energy density.

After a first phase dedicated to the design of the best flap configuration at scale 1, the second phase of the project dealt with the design of a wind-tunnel scale model of a rotor equipped with active flaps. Off-the-shelf piezoelectric actuators from CEDRAT TECHNOLOGIES were used together with a specific ONERA patented flap-driving mechanism. Using a standard APA500L with 170V range, this mechanism is able to produce a tilt motion of 9°. The maximum

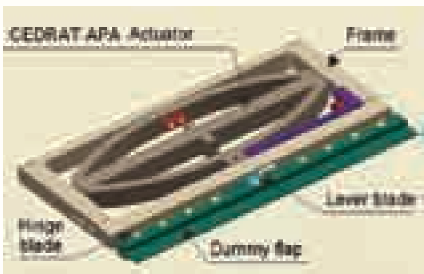

Figure 1: Active flap system based on APAs.

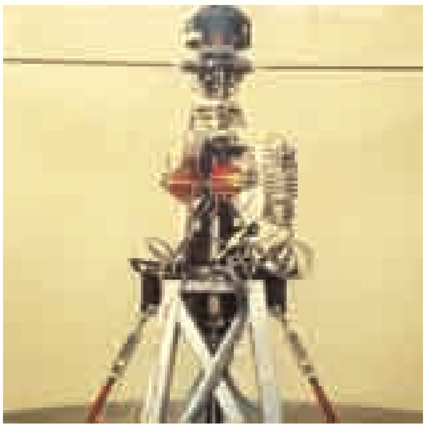

Figure 2: Active Flap on Bravo Rig for centrifugal tests.

(continued on page 3)

Smart Actuators for Aircraft applications. (continue)

F. Claeyssen, R. Le Letty, F. Barillot, N. Lhermet - CEDRAT TECHNOLOGIES.

tested frequency was 80Hz, corresponding to flap frequencies extending till 5-per-rev.

Centrifugation tests demonstrate the ability of the mechanism to produce the desired tilt motion with a frequency varying up to 80Hz, and with a centrifugal force from 0 to 2000g. The aerodynamic testing program included several Mach numbers (0.3, 0.45, 0.65, 0.8) and various airfoil angles of attack (Figure 2). According to ONERA, it can be said that the behaviour of the flap system under aerodynamic loads is satisfactory at low wind speeds, but that an improved pseudo-knee joints need to be implemented at both ends of the flap for getting a fully satisfying system behaviour at high wind speed. From the APA point of view, one can conclude that these aircraft qualification tests have successfully passed.

The transposition of the technical solution to full scale has been engaged by ONERA. For weight, technical and cost reasons, a larger actuator, so called APA750XL was defined as an extrapolation of the APA500L with a scale factor 1.5. So it has been designed without optimisation and then manufactured by CEDRAT using non standard piezo MLA (section 15mm x 15mm). Then it has been characterised before delivery to ONERA for application tests. Several possible improvements have been identified among which the use of a composite shell for reducing the mass and increasing again the energy density. This kind of work could be made by CEDRAT using its optimisation tools and its know-how, following the same route as used to get the APA500L-SV from the standard APA500L.

Airplane piezo-actuated flap

Other similar applications of APAs are in progress in the field of aircraft. For example, the APA500L-SV has been developed for ONERA for flap applications in the context of aerodynamic tests of air planes (Figure 3). This Special Version APA500L actuator has been designed to meet ONERA specific requirements. Being ligther (- 15%), it develops a blocked force of 780N (instead of 570N) and a free stroke of 560 µm (instead of 500 µm). So it presents an output energy density increased of +82% over the standard APA500L.

Electro Hydrostatic Actuators (EHA)

Airplanes manufacturers such as AIRBUS also consider the trend for more Electrical aircraft. In this context, piezo actuators are considered serious candidates for several functions. By piezo it is often understood piezo electric but piezo magnetic (biased magnetostrictive) actuators are also of interest for high forces (>3kN) applications, as studied in MESA. In previous examples, piezo actuators are used as direct drive of a flap, but this is not adequate for applications requiring both large strokes (much larger than 1mm) and large force (much larger than 1kN). In this case, hydraulic energy is still more realistic, noting it can benefit from the high energy density of piezo actuators. For example the Electro Hydrostatic Actuators (EHA) is a concept based on an hydraulic jack which is controlled by electric valves. It is anticipated by CEDRAT TECHNOLOGIES that the usual solenoid valves can be replaced advantageously by fast lightweight control valves based on APAs. For a similar stroke and force, the APA500L mass is about 10 times lighter than the usual linear electromagnet used this application. The other advantage is a much smaller power consumption (less than 0.5W instead of 50W) and a higher bandwidth. First experimental results have been obtained providing the proof of concept (Figure 4). A normally closed piezo valve has been build using an APA500L and taking advantage that it is a pulling actuator. At rest, this piezo valve is able to withstand 220Bar without leakage. When powered, the APA500L produces on stroke of 460µm in the valve piston, which leads to a flow rate of 2.5 l/min. The maximal working pressure is presently of 100bars. The maximal working frequency was 400 Hz, due to present power supply limitation.

Conclusion

Piezoelectric actuators are no more in their infancy. Amplified Piezo Actuators from CEDRAT TECHNOLOGIES have been designed to meet requirements of space applications. They present high output energy to mass ratio. Due to efficient prestress means, they are able to withstand large external forces such as vibrations.

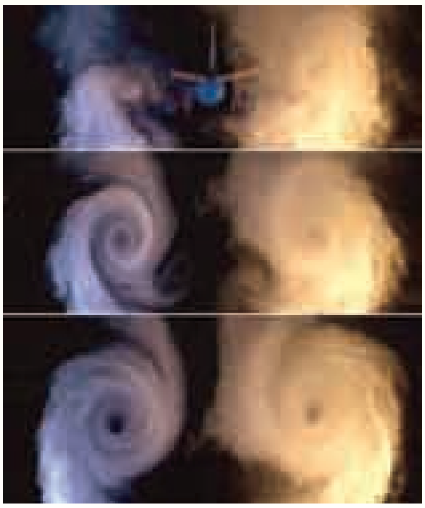

Figure 3: Application of Active Flap in AWIATOR Aircraft aerodynamic tests [1].

Figure 2: Piezo Hydraulic valve in test bench for an EHA actuator [13,14].

(continued on page 4)

LA75B : A powerful electronic that makes APA sing higher in volume and larger in frequency.

T. Maillard - CEDRAT TECHNOLOGIES.

Next May 2003, CEDRAT TECHNOLOGIES will release the **LA75B** from its electronic lab, a new and powerful linear amplifier for driving its whole range of piezo products. The max output current of **300 mAmp, under 150 Volt per channel**, allows the LA75B to explore a **10 times larger frequency range than the LA75A** (see table 1). The LA75B board takes its power from a new AC/DC converter, so called LC75B, delivering a continuous current of **600 mAmp**. As a consequence, each LA75B can be equipped with **two output channels** (see figure 1) in order to drive any kind of piezo mechanisms (APA, PPA, XY stages,...) presented in CEDRAT TECHNOLOGIES' catalogue. This new LA75B electronic is the first step of a larger project, aided by ANVAR, for developing future powerful versions. Nevertheless, the LA75B already offers relevant solution for **high frequency actuation, scanning and fast shutter** based applications (spectrometry, X ray diffraction, optical switch,...).

Figure 1: View of a LA75B-2 rack.

Actuator	Unit	APA25XS	PPA10M	APA100S	APA60SM	APA200M	APA120ML	APA500L
Capacitance (*)	µF	0.25	0.7	1	1.55	3.2	22	32
Load time	ms	0,14	0,40	0,57	0,88	1,81	12,4	18,1
Max. triangle freq.	Hz	3 529	1 261	882	569	276	40	28
Max. sine frequency	Hz	2 246	802	561	362	175	25	17

(*) the capacitance values are those at low frequency and room temperature.

Table 1: Frequency range of some APAs and PPA driven by LA75B.

Smart Actuators for Aircraft applications. (continue)

F. Claeyssen, R. Le Letty, F. Barillot, N. Lhermet - CEDRAT TECHNOLOGIES.

They pass various life time tests, thermal-vacuum tests, radiation tests... In addition they offer a low power consumption and short time response. The concept can be declined from micro-actuators (u=35µm, F=20N, m=2gr) to large actuators (u=1mm, F=1kN, m=0.6kg) see APA 750XL figure 6. Thanks to all these specifications, the applications of these actuators, especially APAs, are expending in space (up to NASA & JPL !) both for payload (optical devices, instruments) and for platform (propulsion valves). Benefiting from their space qualification and their high output energy density, they also found a serious interest in aircraft, for direct-drive of flaps in helicopters and airplanes mock-up, as well as for valves in Electro Hydraulic Actuators. First specific aircraft qualifications such as wind tunnel and centrifugation being successful open large application fields in aircraft.

Acknowledgement

The authors would like to thank the French Space Agency CNES and the European Space Agency ESA/ESTEC as well as ONERA CERT, ONERA IMFL and European Commission.

Referenced paper

F. Claeyssen & G. Rajeev, Amplified Piezoelectric Actuators for Air & Space Applications, AERO INDIA 2003 conferences.

Figure 5: View of the APAs family.

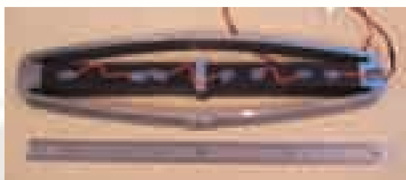

Figure 6: View of the APA 750XL.