PIEZO ACTIVE VIBRATION AND NOISE CONTROL IN HELICOPTERS

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***EADS, **Eurocopter**

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Abstract

The reduction of noise and vibration is still a major task of helicopter development. Comfort, safety and environmental friendliness are key drivers of current active system research projects of EADS and its business unit Eurocopter. Main focus of the research is on reducing rotor induced vibrations and.

The paper reports on recent advances on i) vibration and noise control at the rotor, ii) vibration and noise control at the transmission and iii) vibration and noise control at the fuselage. Emphasis is placed on the reduction of rotor-induced vibrations and noise which is still the key challenge in developing the" jet smooth ride helicopter".

1 Introduction

In the recent years new active noise and vibration systems utilizing electric actuation technologies and advanced control techniques were pushed forward. The superior dynamics of electrical actuators, especially when utilizing the piezoelectric principle, open new fields of application in noise and vibration control. The main principles pushed forward in the recent years at EADS and its business unit Eurocopter are

- Active Rotor Control using piezoelectric driven servo flaps,
- Active piezoelectric struts for isolating the transmission of structure-born noise to the fuselage,
- Piezo-Active Anti-Vibration Control System (Piezo-AVCS) using piezoelectric force generators, and
- Active trim panels.

This list illustrates, that principles of active systems were comprehensively investigated to manage vibrations and noise: Active Rotors were developed to reduce annoying forces as far as possible at its origin, and systems to isolate the transmission of structure-born noise. The third category is represented by effective systems for installation in the fuselage to minimize the dynamic response of the structure to increase pilots and passenger comfort.

All these applications are based on high performing piezoelectric actuators. All have to comply with demanding requirements concerning life, reliability, weight, environmental conditions and installation space. In addition these new actuators put strong requirements on electronics systems design and power amplifier stages. It requires highly efficient and reliable electronics to achieve flight worthy products.

2 Rotor Active Control

An active flap rotor using piezo technology was developed for the hinge-less system of BK117 with the following technical objectives:

- Reduction of rotor noise, cabin vibrations and dynamic loads
- Improvement of rotor blade damping
- Reduction of rotor power consumption

Eurocopter and EADS are pushing the concept of a highly dynamic blade control by applying servo-flaps installed in the outer part of the rotor blade trailing edge [1]. The piezo actuation system developed by EADS Innovation Works

in recent years [2, 3] has been proven to be a successful solution in ongoing flight tests since September 2005.
The flap system consists of three identical units. One pair of piezo-electric actuators runs a flap of 300 mm radial extension and a chord of 50 mm. The trailing edge of the blade was cut out and opened and the blade design modified for inserting actuator-flap modules from behind (see Fig. 1). The actuator- flap module is self-contained and can be run on bench isolated from the blade.

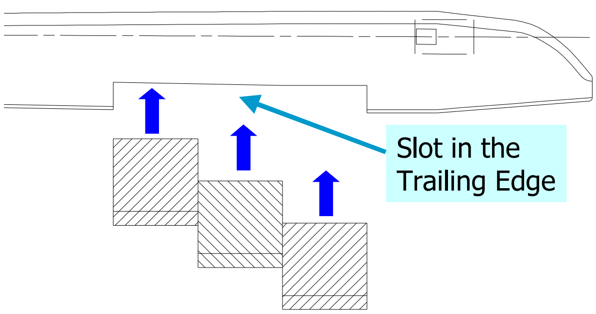

Fig. 1: Installation of the actuator-flap modules from the trailing edge

The flap generates a dynamic control moment around the blade's longitudinal axis as an aerodynamic servo effect which is supported by lower torsional blade stiffness and smaller flap chords. A larger flap chord would increase the flap's lift contribution, a negative effect for frequencies below the 1st natural torsional frequency. It helps in addition to limit the required actuator power [4].

2.1 Flap Module and Actuation

The small flaps are placed close to the blade tips. Each flap is driven by two actuators which are placed close to the leading edge. The flaps and the corresponding actuators, control rods and sensors are contained in a module box which is inserted into the modified rotor blade.

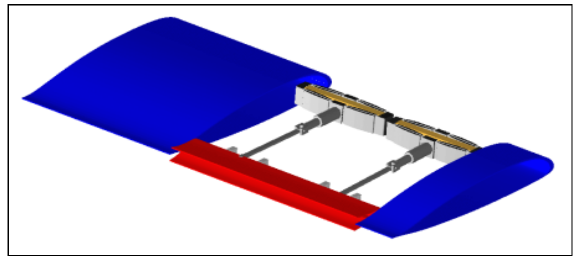

Fig. 2: *Flap-Actuator- System*

The piezo actuators developed by EADS (fig. 3) fully meet the requirements: the very compact actuators deliver 1000 N force, 1.4 mm stroke at a weight of 450 grams and has high mechanical efficiency.

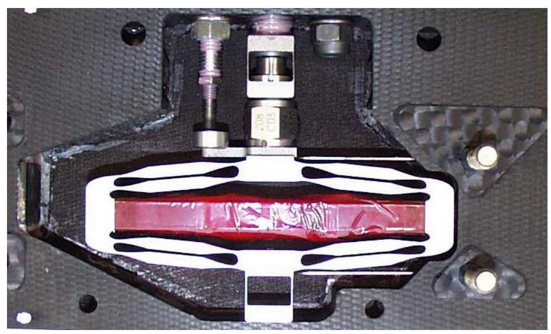

Fig. 3: Piezo actuator

2.2. Flight Test Results

The official maiden flight of a helicopter with active trailing edge flaps took place in September 2005. The test helicopter is depicted in Figure 4.

Fig. 4: BK117 S7045 with active flaps rotor

The controlled 4/rev hub loads during level flight conditions are plotted in Figure 18. A significant reduction of up to 90% could be demonstrated, when the active vibration reduction system was engaged. The corresponding 4/rev gearbox vibrations are depicted in Fig. 5. A remarkable enhancement is obtained especially in longitudinal and lateral direction. In Fig. 6 the vertical 4/rev accelerations in the cabin at the co-pilot position are shown. The vibrations drop down to values below 0.05g. A certain acceleration level remains, since from the 3 hub forces and 3 hub moments only three can be directly influenced. Overall, the achieved low vibration levels were confirmed by the flight test crew's excellent rating. The robustness of the controller was demonstrated in a wide range of the flight envelope. The results show that the controller efficiently rejects the vibratory hub loads (Mx, My, Fz) and reduces the cabin accelerations below the 0.1g level. The reference values are without pendulum absorbers which are used in serial aircrafts. The flight tests were aimed at testing the complete collective and cyclic disturbance rejection control for Fz, Mx, and My, simultaneously. They will be continued with an advanced controller and further optimized parameters.

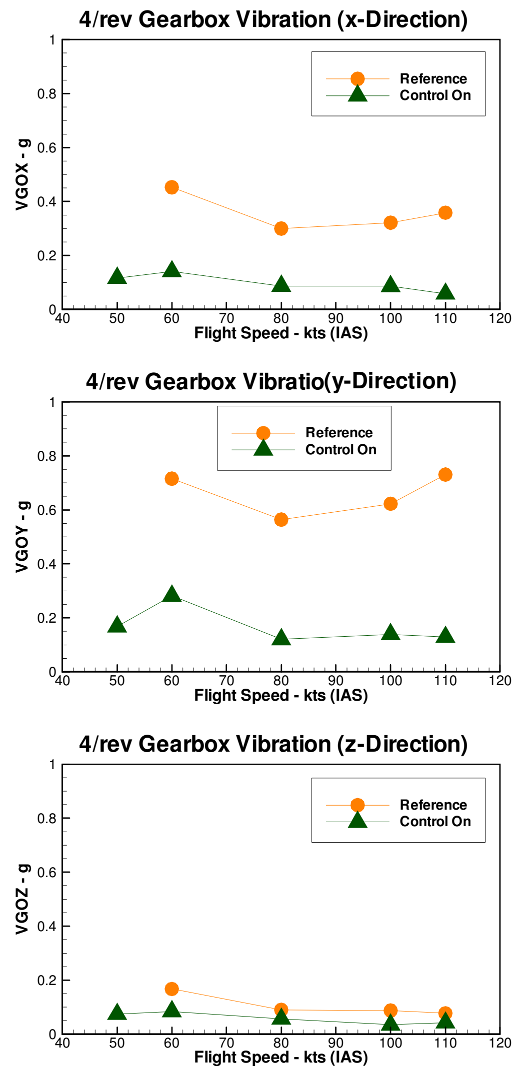

Fig. 5: 4/rev gearbox vibrations vs. level flight speed

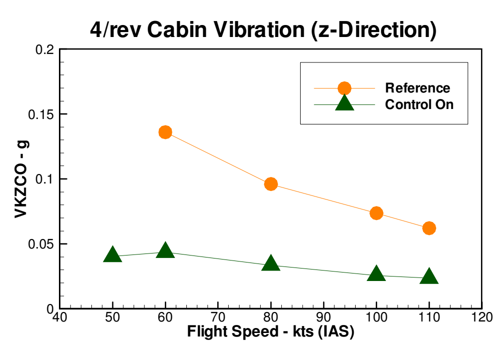

Figure 6: Vertical 4/rev cabin vibration vs. level flight speed

2.3 Alternative Solution – Morphing Airfoil

An alternative approach beyond the concept of servo flap is the active trailing edge. It is based on structurally integrated smart material actuation. A "smart" tab is attached to the trailing edge of the airfoil. It is realized by a multi-morph bender including piezoelectric ceramics and glass fiber reinforced plastics.

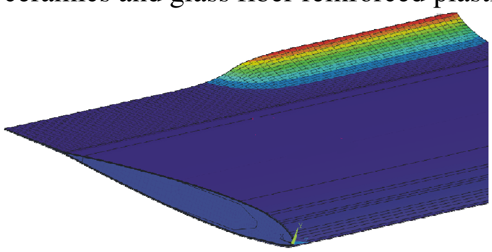

Fig. 6: Smart trailing edge concept using piezo

The integration of piezo actuators into the base structure is highly desirable for many reasons. However, designing the active structure for both active deformation and load carrying capabilities simultaneously is most challenging. For optimization detailed aero-servo-elastic investigations are necessary, see [5, 6].

3 Piezo - AVCS

3.1 Piezo-AVCS Concept

The concept of the Piezo-Active Anti-Vibration Control System (Piezo-AVCS) is shown in Figure 7. Rotor induced vibrations in the cabin are actively reduced by a secondary vibration field generated through Piezo-active inertial force generators. Using acceleration sensors, this remote controlled system ensures the reduction of vibrations at desired locations, i.e. at the pilots' and passengers' seats as well as in the rear compartment for search & rescue tasks.

The foundation for this Piezo-AVCS is an efficient force generator which is realized by innovative actuation technology, namely Piezo-ceramic actuation, see [7].

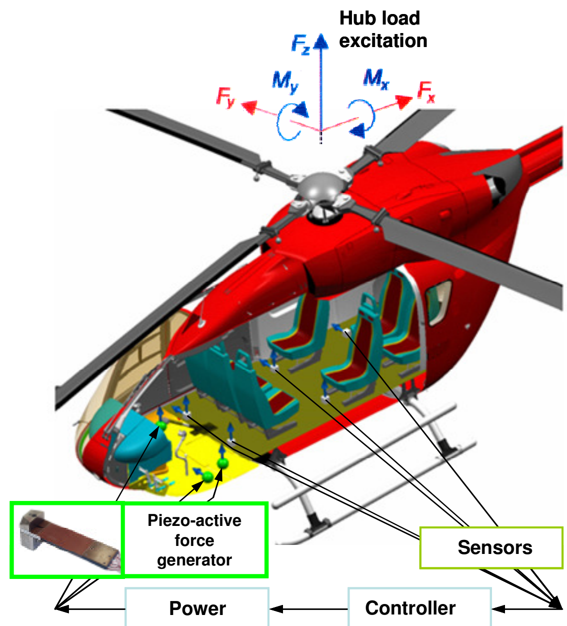

Fig. 7: Piezo-AVCS concept

Based on an active leaf-spring design, as shown in Figure 8, the force generator produces control forces by the inertia of its attached mass.

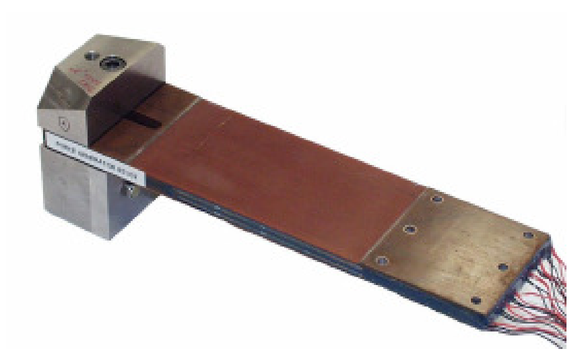

Fig. 8: Piezo-active inertial force generator

The piezo actuation principle was chosen as it provides direct electrical control over the control forces and no moving parts are involved.

3.1 Flight Test Results of Piezo-AVCS on EC135

The Piezo-AVCS is flight-tested on an EC135 prototype aircraft, see Figure 9. The system is installed in the cabin for the reduction of lateral rotor-induced vibrations at 4/rev.

Fig. 9: Piezo-AVCS prototype helicopter

As reference, a non-serial prototype of EC135 is used. Figure 10 shows the flight test results over rotor rpm, i.e. lateral vibrations in y-direction in the pilot/copilot plane, the passenger seat plane as well as the rear compartment plane.

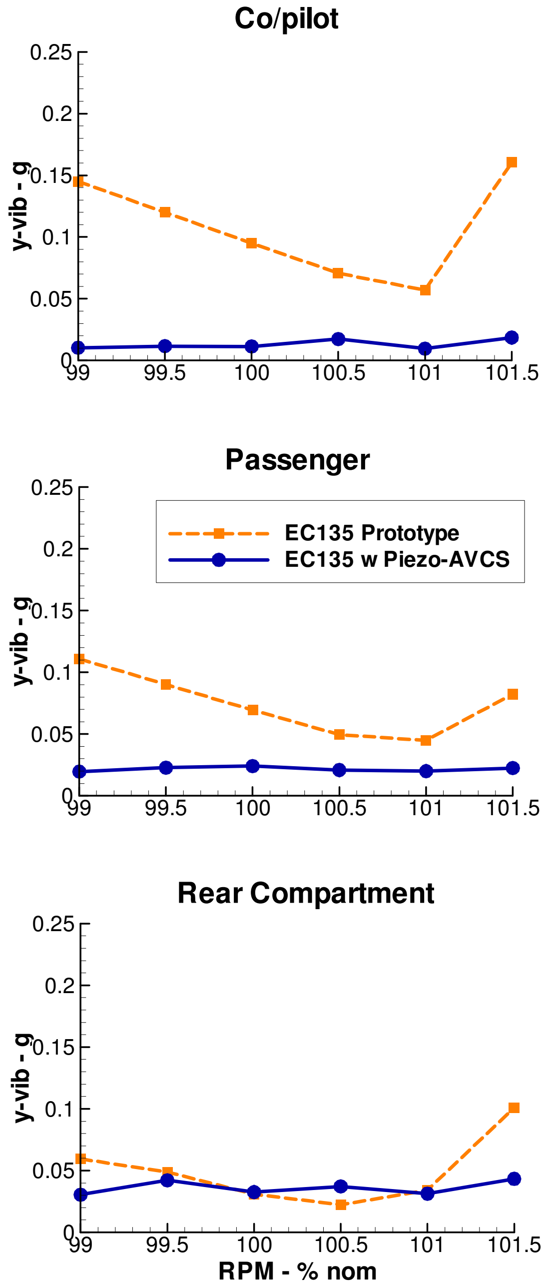

Fig.10: Vibration levels (flight measurement) over rotor speed

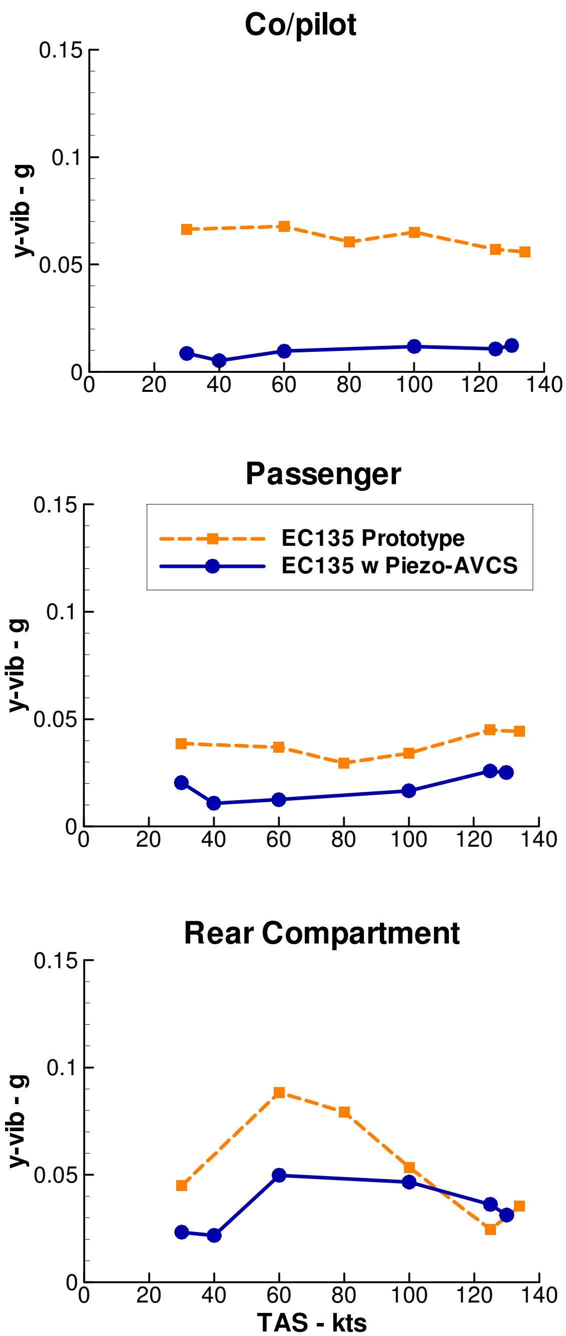

Fig. 11: Vibration levels (flight measurement) over flight speed

As seen, the Piezo-AVCS ensures a considerable vibration reduction over the entire rpm range down to levels lower than 0.05g. In particular, in the pilot/copilot plane the substantial improvement with respect to the reference is clearly visible. Whereas the vibration level of the reference depends on the rotor rpm, the Piezo-AVCS ensures very low vibration levels independent of the rotor rpm. This improvement also holds when lateral vibrations are plotted over flight speed, as presented in Figure 45. Also here, vibration levels lower than 0.05g are achieved over the whole flight speed range in pilot/copilot, passenger and rear compartment plane.

4 Piezo Smart Strut System Based on Piezo

This chapter describes a active system for reducing interior noise caused by gear meshing. The effectors are active gearbox struts using highly-dynamic piezo actuators.

Active noise and vibration control systems using piezo actuation have been a topic of intensive research of the last decade. These systems use the phenomena of destructive interference between the primary disturbance and the inverse secondary signal produced by a control unit. Helicopter cabin noise is dominated by the gearbox intermeshing noise. In order to reduce the structure borne sound transmission to the cabin and related cabin noise an active vibration control system based on ‘smart’ gearbox struts has been developed by EADS and Eurocopter and tested in flight.. A typical schematic block diagram is shown in figure 12 for helicopter interior noise reduction. All seven struts connecting engine/gearbox unit with the fuselage of the test helicopter have been replaced by active struts as shown in figure 8. By using three piezoelectric actuators, it is possible to excite longitudinal as well as bending vibrations in any direction. For optimal actuator authority the actuator design utilizes highly efficient d33-multilayer stacks.) See figure 13 and [8, 9]. It could be shown that the actuator authority is sufficient to reduce the 1st gear-meshing frequency independent from the actual flight condition up to 19.5dB. In the flight test a mean reduction of 15dB has been achieved at the main gear-meshing frequency as highlighted in Fig. 14.

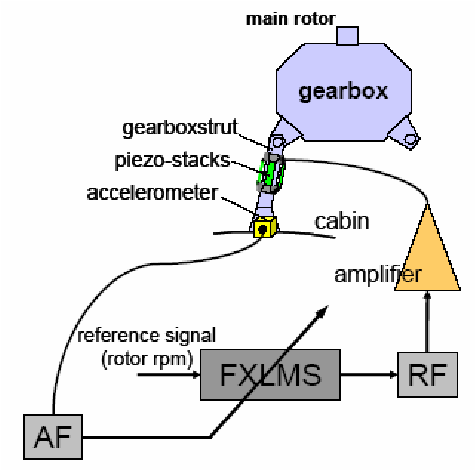

Fig. 12: Schematic Block Diagram of the control loop

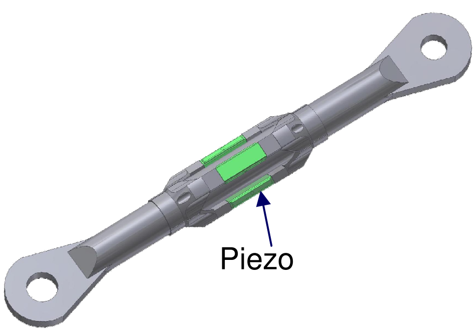

Fig. 13: EADS active gearbox strut using piezo stacks

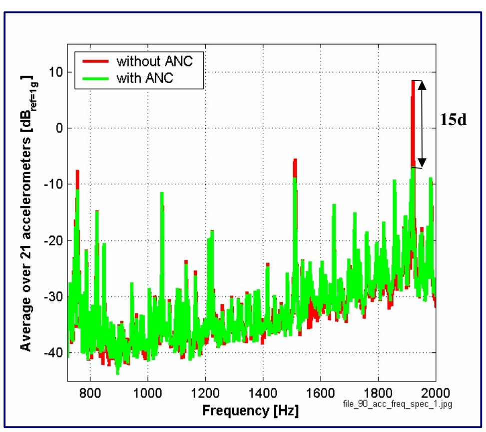

Fig. 14: Mean vibration levels with and without active control

5 Smart Trim Panels

Aircraft fuselage structures show typically a poor transmission loss behavior at low frequencies and it is expected that the situation will become even worse for future composite fuselage structures. Passive noise control measures introduce usually significant additional weight. Therefore active noise control and/or structural control concepts appear quite attractive to improve the noise comfort in commercial aircraft. A new concept based on a trim-panel suspension with active attachment elements has been developed by EADS Innovation Works. This concept provides some inherent advantages compared to other ANVC technologies as active noise control with loudspeakers, active damping of main structure or active panels with structure integrated actuators. Active attachments allow easy retrofitting and maintenance, the actuator authority can be designed according to the requirements and they can be designed to improve the transmission loss by means of passive and active vibration isolation. Therefore this technology is also of interest in helicopter applications. A prototype system has been developed and tested with a 1 by 1m plane CFRP fuselage section and a larger 2.4 by 2m curved CFRP panel.

Fig. 15: Fuselage panel with active attachment elements installed to the frames

The design of the active attachment elements has been based on a comprehensive simulation study. The numerical investigations showed that the attachment element must be able to control three degrees of freedom due to the fact that the sound radiation from the trim-panel is determined by forces in normal direction of the panel as well as by moments in the panel plane. A prototype attachment element, which comprises three independent piezo clamshell actuators (Fig. 16) mounted between two plates has been designed and manufactured (Fig. 17).

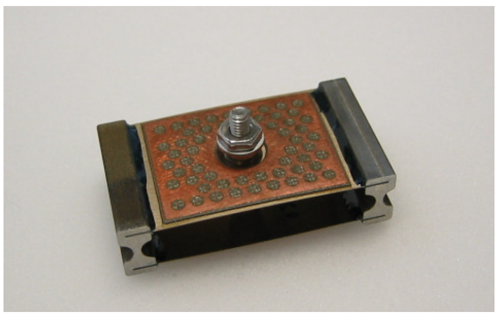

Fig. 16: Clamshell actuator

The attachment elements are equipped with accelerometers, which can be used as sensors e.g. for pure vibration control. However, the simulation study also indicated that pure vibration isolation does not provide a significant improvement in transmission loss in particular at low frequencies. For that reason additional sensors on the trim-panel have been used for the experimental tests. The whole system comprised four active attachment elements to connect the 1x 1m trim-panel to the fuselage frames (Fig. 15).

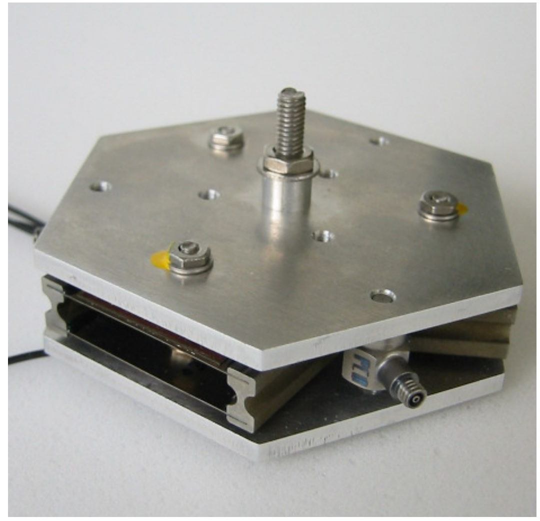

Fig. 17: Active attachment element

For testing the 1x1m panel was mounted between a reverberation and an anechoic room. The reverberation room was used for the excitation with a pair of loudspeakers or a shaker mounted directly on the fuselage skin panel. The sound power radiated into the anechoic room has been measured by a scanning intensity probe. The test results are quite encouraging. For tonal noise the radiated sound power has been reduced by up to 20 dB by the active system and for third octave band excitation still up to 10 dB reduction has been achieved. Fig. 17 shows the sound power level with and without control and the related reduction in radiated sound power for a simulated buzz saw noise excitation whereby 12 harmonics have been controlled. Buzz saw noise occurs typically, in the front of the cabin of commercial aircraft with engines in take off condition. Similar type of excitation can be found in helicopters where tonal noise is generated mainly by the gearbox and cooling fans.

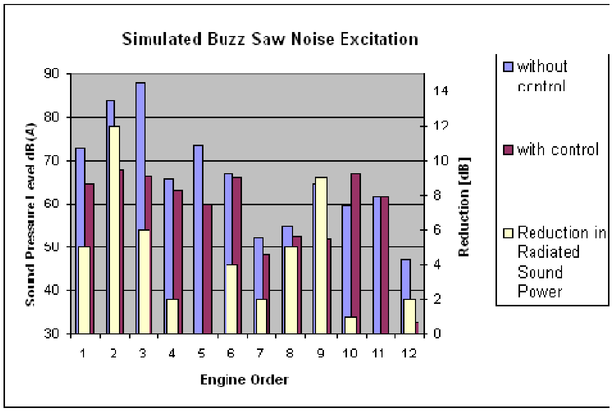

Fig. 18: Test results for simulated buzz saw noise excitation

6 Conclusion

A set of technologies have been developed at EADS and its business unit Eurocopter to improve comfort, safety and environmental friendliness of future helicopters. Several systems arose from an intensive active system research program and these technologies are applicable also for other EADS products like commercial a/c. The systems developed are demonstrated in flight test and in carefully designed laboratory experiments. It has been proved that a significant reduction of rotor and gearbox induced vibrations and noise can be achieved. Thus, we took a significant step toward the" jet smooth ride helicopter".

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