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ADVANCED PIEZOELECTRIC SERVO FLAP SYSTEM FOR ROTOR ACTIVE CONTROL

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Abstract

Rotor active control technology using piezo driven trailing-edge flaps is pushed ahead by Eurocopter and EADS Corporate Research Centre. The system developed in the completed project ADASYS has been already demonstrated successfully in flight. It comprises hinged trailing edge flaps, actuation, power electronics, power and signal transmission, and a control system.

The paper reviews the research activities in the current project LARS concerning the trailing edge system which will be implemented in a bearing-less five-bladed rotor. Despite the encouraging results further efforts are inevitable to meet tough requirements helicopters impose on this system. The urging tasks are to drastically minimize weight and size of the system as well as increasing reliability and performance. The prototype electronics which presently represents a major part of system weight and size will be replaced by a new design. The piezo actuator will be optimized and weak points of the flap mechanism eliminated. Based on a comprehensive analysis of the system behavior including hysteresis, friction effects etc. a model is set up as a basis for system monitoring and built-in-test as well as control design which includes compensation of disturbing effects found.

1 ACTIVE ROTOR CONTROL FOR HELICOPTER – STATUS AND CHALLENGES

Active helicopter rotor control has the following technical objectives:

- Extension of the flight envelope
- Reduction of rotor noise and cabin vibrations
- Improvement of rotor aerodynamics
- Reduction of rotor power consumption

The technical concept comprises servo flaps installed in the outer part of the rotor blades which are actuated by piezo stacks. This technology allows highly dynamic blade control with little control power needs. The highly efficient actuation system has been developed by EADS Corporate Research Centre in recent years [1,2]. An experimental BK117 was the first worldwide flying helicopter with an active rotor system based on piezoelectric driven trailing-edge flaps [3]. First flight of the system was in September 2005 and the subsequent intensive flight-test campaign revealed superior results regarding system performance as well as endurance. No substantial problems occurred so far.

Nevertheless, significant effort is indispensable to pave the way towards serialisation. Further development efforts are directed on two areas:

1. electronic system: reduction of size, efficiency, and complexity
2. actuators and flap module: endurance, efficiency, and increased specific performance

2 FURTHER DEVELOPMENT

2.1 Electronics System

The electronic system contains the data acquisition, the power electronic and the data and power transmission. In the current system main components of the power electronics are located at the top of the rotor hub (see Figure 1 left). A quite bulky body is installed on the rotor head containing communication and power electronic systems. Obviously, this body causes a lot of aerodynamic drag. This design limits maximum speed of helicopter and is thus only applicable for flight testing.

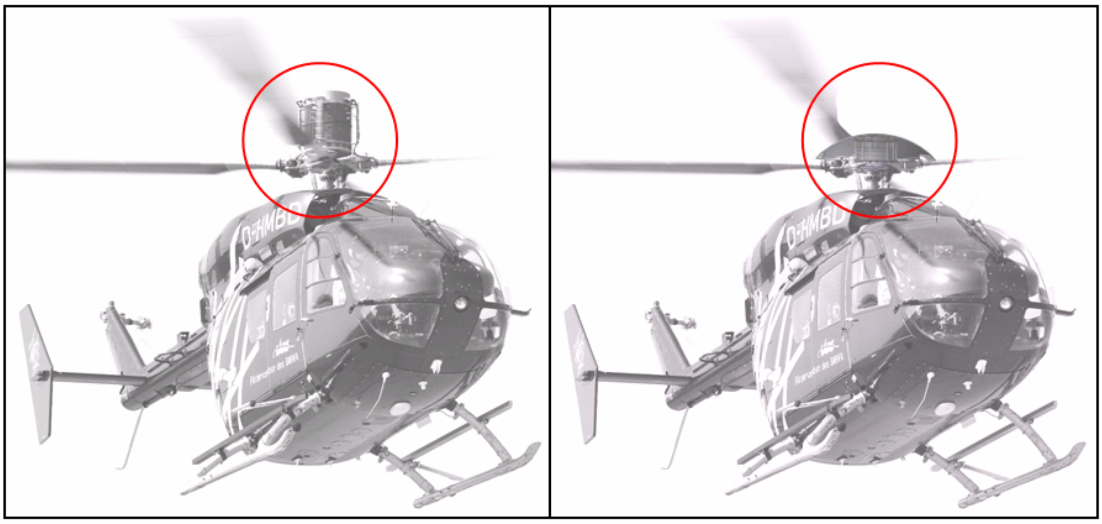


Figure 1: left - Status (ADSYS) and right- target layout of the LARS project

Consequently, it is a main objective to reduce the dimensions and the weight of the electronic equipment on the rotor head to make it installable under the hub cap (see Figure 1, right). In Table 1 the necessary reduction in weight and volume are shown.

	ADASYS	LARS
Volume	21 dm³	5 dm³
Weight	~ 68 kg	~ 10 kg

Table 1: Reference values for the rotor head electronics

The current electronics which is only an experimental system comprises a large number of components merged together in one integrated device. All essential electronic components are placed in the rotating system.

Reduced space and weight requirements as well as techno-economic aspects lead to splitting the system into modules. The new concept is shown in Figure 2. Only necessary components will remain at the rotor head. Sensors and their signal conditioners are advantageously directly located in the actuator-flap modules. These sensor signals as well as signals reporting the state of the rotor blades such as mechanical strain and aerodynamic pressure are processed by a data acquisition system placed in the rotor head. These data are transmitted as a pulse code modulated data stream to the helicopter fuselage. A slip ring connects rotor and fuselage by galvanic coupling. The pulse code modulated signals are fed into the real time control computer system placed in the fuselage. This computer processes the signals and commands the actuators driving the flaps. Intermediary power electronics placed in the fuselage amplifies these command signals and drive the piezo actuators via the slip ring power contacts.

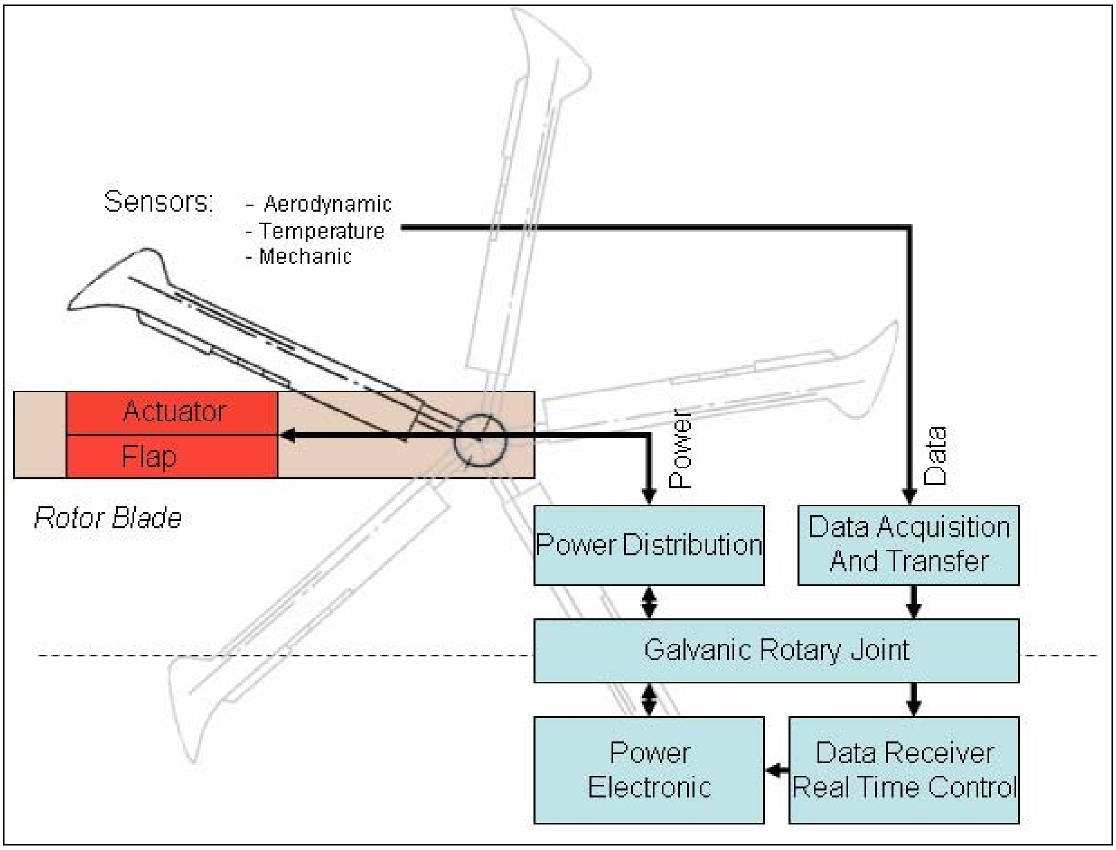


Figure 2: Electronic System Layout

Power electronics modules are the core of the electronic system. Efforts are focused on minimizing weight, envelope and power efficiency. Only switching amplifiers, known as class-D amplifiers, are suitable. These amplifier class allows a four quadrants operation leading to a highly power efficient system allowing to reduce energy dissipation, minimizing size of heat sinks, and reducing electrical power consumption. Operation of piezo actuators creates a high amount of reactive power. In order to handle that, a special amplifier design is necessary. For current design studies recent advances in power electronics have been taken into account leading to small and efficient amplifiers

Most of the electronics installed in the rotor head is used for providing experimental data to evaluate Rotor Active Control. This electronics will not be installed in a serial helicopter and will thus release additional space for installing an integrated system comprising power, communication and control electronics. Transfer of power and data between fixed and rotating system could be done either by galvanic as well as by inductive coupling.

2.2 Flap Actuator Module

The flap system is based on a compact piezo actuator developed by EADS CRC. Two of these actuators are arranged in a pull-pull mode articulating a hinged flap via two pull rods. The whole unit is built as a plug-and-play module allowing efficient installation of the active rotor.

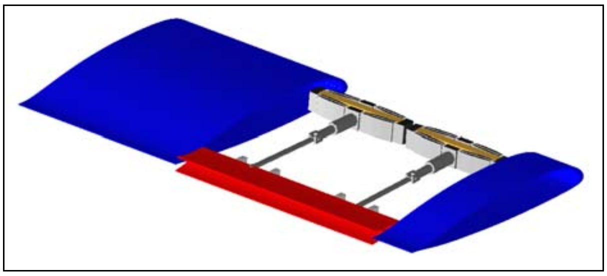
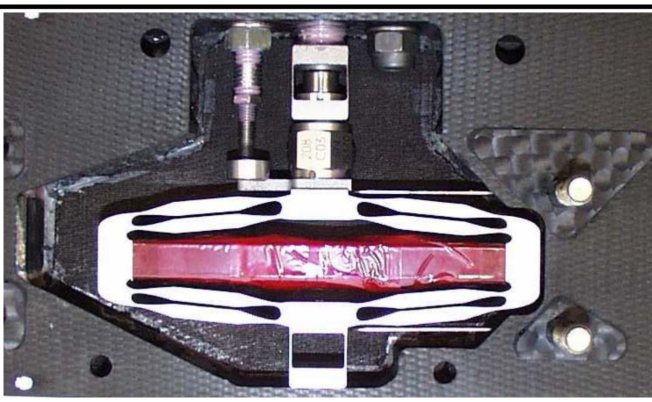


Figure 3: Actuator-Flap Modul

It is a major task in the LARS project to further improve the actuator. The current actuator was developed in the project RACT (Figure 4). It employs a metallic frame to amplify the relatively small stroke of the piezo stack. The metal frames were manufactured by wire-electro discharge machining.



Blocking force:	1000N
Free displacement:	1,4mm
Mech. efficiency:	83%

Figure 4: Piezo actuator with metal frame

The metal frame amplifies the stroke of the piezo element and ensures that the piezo stack always is under compression stress and is never exposed to a potentially destructive tensile load. Crucial parts of the frame are the joints which are exposed to bending as well as tension. To handle the high loads the joint and lever construction of the framework is designed as a double framework. Careful design work kept mechanical stresses in the joints within limits and a sufficient endurance is ensured.

In order to expand the limits further a new design is under development utilizing an approach which takes advantage of composite materials. It is our opinion that the use of CFRP will allow to further reduce weight in addition to increasing reliability.

3 MODELLING & SIMULATION OF THE SERVO FLAP

Further optimisation of the Rotor Active Control system asks for concurrent design of electronics, actuation, control, and electronics. To prepare a sound technical fundament the essential components have been modelled. These models are important prerequisites for designing suitable controllers, onboard diagnostic systems, and optimal sensor placement. The main challenges are:

- hysteresis of the piezoelectric actuator,
- nonlinear friction of the bearing,
- dynamical simulation model of the large signal behaviour of the flap.

The modelling of the hysteretic behaviour of the piezo is based on the phenomenological Preisach-Model. For proper implementation the hysteresis curve has been measured with high resolution followed by extraction of high quality parameters. A new implementation method was applied to obtain “continuous Preisach functions” (Figure 5) derived from the intrinsically discrete Preisach-Model. This then allows further integration into a dynamic system simulation.

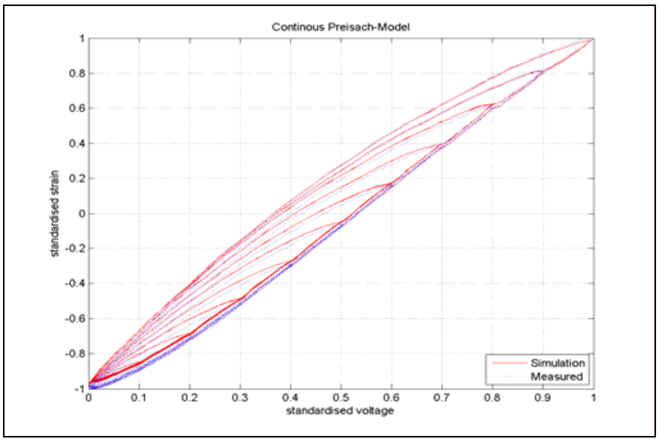


Figure 5: Comparison of measured data with model results

Based on a in-depth study of an existing prototype some simplifying assumptions could have been made which led to the following simplified mechanical model of the flap module.

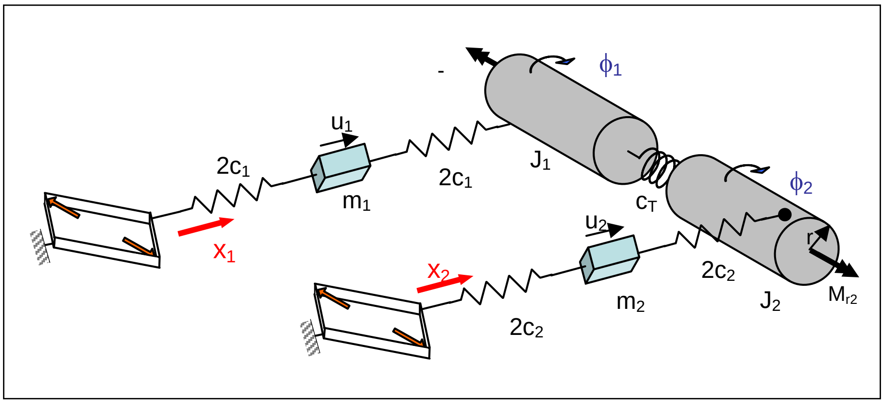


Figure 6: Schematic model of the actuator flap module

Equations of motion for the four state variables of the system were derived. Together with the nonlinear friction moment $M_{r1/2}$ and the imposed momentum $x_{1/2}$ of the piezoelectric actuators, a comprehensive system model was set up.

Classical friction models are too inadequate to represent the real behaviour of the flap module. It needs a modern model like the LuGre-model which was chosen for better physical representation and improved numerical efficiency.

Complete simulation runs were performed with MATLAB/Simulink software. Figure 7 shows exemplarily the system response at 1 Hz in comparison to measurements proving the consistency of the model.

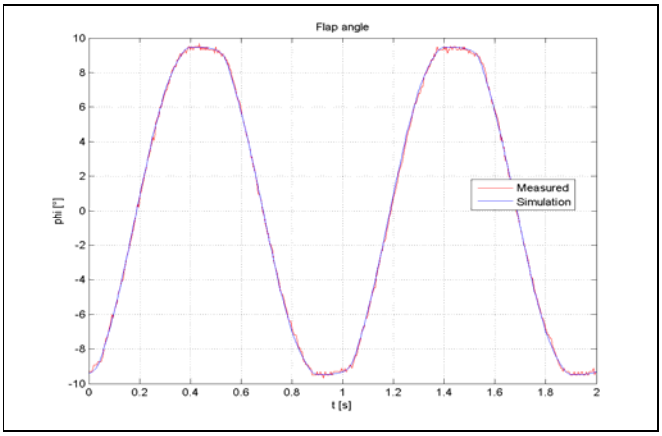


Figure 7: Flap response - Simulation versus measurement

4 OUTLOOK – DISTRIBUTED ACTIVE TRAILING EDGE

An alternative approach to the servo flap is the active trailing edge concept. It is based on the “smart aerostructures” paradigm, i.e. structurally integrated smart material actuation [4].

A smart tab is attached to the trailing edge of the airfoil or an active trailing edge is integrated into the airfoil. It is realized by a multi-morph bender including piezoelectric ceramics and glass fibre reinforced plastics, see Figure 4.

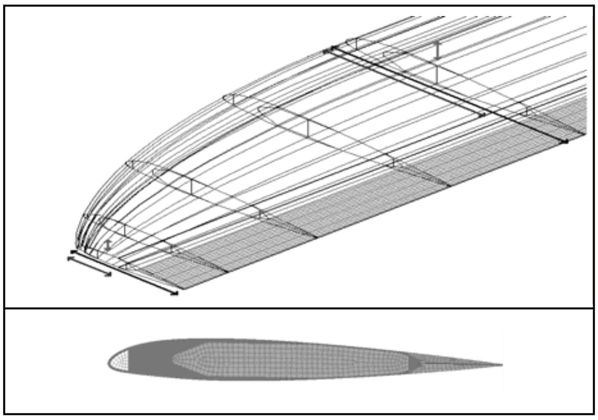


Figure 8: Active trailing edge for helicopter rotor blade. EASD CRC design.

It is current opinion that integration of distributed smart material actuators into the base structure is highly desirable. However, designing the active structure for both active deformation and load carrying capabilities simultaneously is most challenging. In the case of adaptive helicopter rotor blades, performance requirements result from the aerodynamic effectiveness of active blade deformations like twist or camber variations. On the other hand, the corresponding aerodynamic loads act on the active structure, counteract the active deformation and reduce aerodynamic effectiveness. For optimization detailed aero-servo-elastic investigations are necessary, see [4, 5] for some recent aero-servo-elastic studies of adaptive airfoils or helicopter rotors in transonic flow.

5 CONCLUSION

Active Rotor Control using servo flaps was recently successfully demonstrated on a Eurocopter BK117 test helicopter. This paper describes the current flap system and deduces necessary steps towards optimisation. The advanced system developed represents a modular system concept comprising piezo actuators, flap mechanics, power and communication electronics and control computer. The intermediate results of R&D reveal that significant savings in weight and installation space could be achieved. On the far side structurally integrated actuators allows distributed shape control and have significant potential for advanced aerodynamic concepts. Having these two technologies at our disposal we are encouraged to taking next steps towards introducing Rotor Active Control in future advanced helicopters.

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