1.1 Actuator review for smart rotor blades

1.1.1 *Technology Review by the University of Twente*

References:

[1]: A. Paternoster, P. De Jong, R. Loedersloot, A. De Boer, R. Akkermann, Initial Technology Review, IGOR - Actuator and Control System for Green Rotorcraft I.T.D., *University of Twente, Engineering Technology*, 2009.

In this report are detailed the various technologies available for piezoelectric actuators which ranges from stack and patch actuators to linear ultrasonic actuators. It details the methods to solve analytically the piezoelectric equations for standard piezoelectric actuators to have their characteristics. Finally, it presents in an applications part the commercial solutions available and their performances relative to each others.

[2]: Physik Instrumente website, http://www.physikinstrumente.com/, last consultation on the 2/11/2009.

[3]: New Scale Technologies website, http://www.newscaletech.com/, last consultation on the 2/11/2009.

[4]: Cedrat website, http://www.cedrat.com/, last consultation on the 2/11/2009.

[5]: Yung H. Yu, Bernd Gmelin, Wolf Splettstoesser, Jean J. Philippe, Jean Prieur, Thomas F. Brooks, Reduction of helicopter blade-vortex interaction noise by active rotor control technology, *Progress in Aerospace Sciences*, Volume 33, Issues 9-10, 1997, Pages 647-687.

The bases for active noise reduction are stated in this detailed review of the blade dynamic behaviour and its interaction with vortexes. Active control of vibrations requires excitation at frequencies equal to 4/rev.

[6]: Altmikus A., Dummel A., Heger R., Schimke D., Actively controlled rotor: aerodynamic and acoustic benefit for the helicopter today and tomorrow, *34th European Rotorcraft Forum Liverpool, UK*, September 2008.

This conference paper presents research made at Eurocopter on active trailing flaps driven. It focuses on the acoustic improvement over multiple active control techniques and displays a demonstrator with active trailing edge flaps driven by piezoelectric stacks.

[7]: Comparison of defence standard 00-56 and ARP 4761/4754, ASSC/330/6/2/4754, Issue 1, 2002.

This report presents the characteristics of multiple standards used in the aerospace industry with failure and reliability requirements.

[8]: Guang Hong, Effectiveness of micro synthetic jet actuator by flow instability in controlling laminar separation caused by adverse pressure gradient, *Sensors and actuators A 132*, 2006, 607-615.

This article studies a micro synthetic jet to prevent a laminar separation in the flow boundary layer. It uses a piezoelectric diaphragm inside a cavity and analyse the efficiency of the actuation for various frequencies with and without cross-flow conditions.

Introduction:

Various technologies are available for actuation. They range from conventional screw-jack electrical actuators to ultrasonic travelling wave actuators. Each of them is used for specific purposes and has their limitations in terms of force, response, stroke, life time, speed, weight and power consumption. This review summarises the actuators presented in the detailed actuator review and links the technologies available for various actuations problems [1].

Performances of the various technologies:

Within the detailed review, many concepts are discussed to show all the technologies available. Commercial references are then listed and compared according to relevant figures. The figures considered are: the mechanical work per weight, the time needed to achieve one cycle and the mechanical work per weight that is possible to achieve at a given frequency. This last value is of primary importance for the actuator selection as most of the time a trade-off needs to be found between mechanical energy developed and the displacement speed.

The actuators listed came form online datasheets from renowned manufacturer of piezoelectric material and actuators:

- Physik Instrumente [2]
- New Scale Technologies [3]
- Cedrat [4]

The following figures present two charts for all the actuators referenced in order to spot easily the difference and the proximity between the various existing technologies.

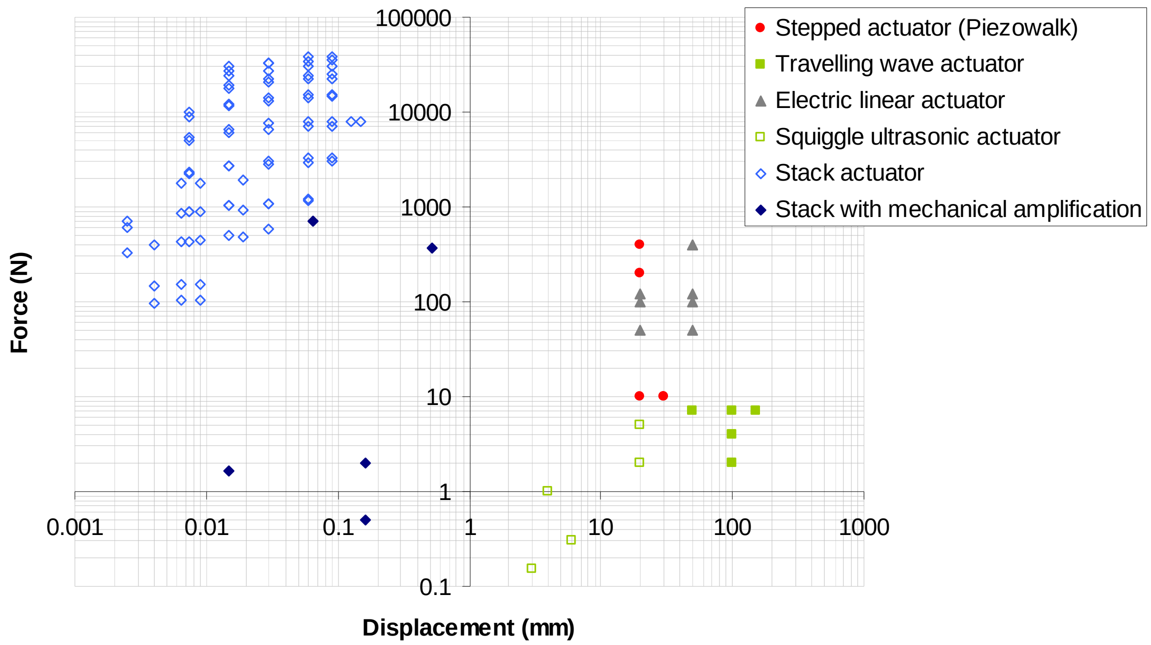

Figure 1: Force versus displacement chart for the actuators referenced in the detailed review.

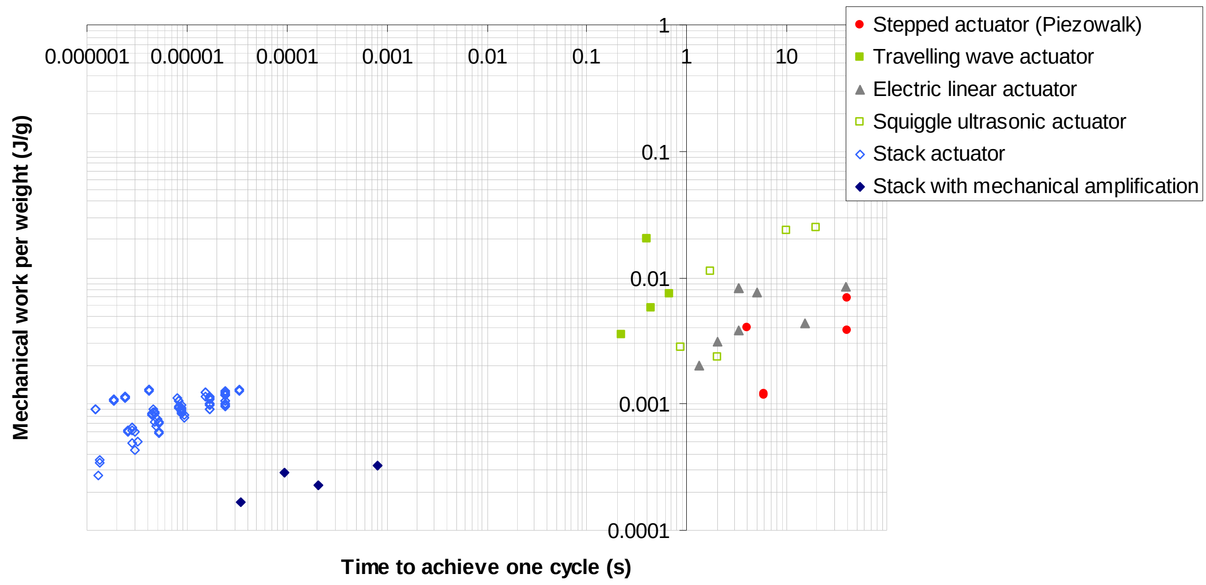

Figure 2: Time to achieve one cycle versus mechanical work per weight.

The technologies like, the Travelling wave actuators or the Squiggle actuator from New Scale Technologies seem really good in terms of performance per weight [3]. However, the time to achieve one cycle (i.e. to develop the mechanical energy) is longer. Therefore, the work achieve at a much higher speed will be decreased because the actuator does not have the time to perform a full stroke. The stack actuators with mechanical amplification do not show a large mechanical work per weight compared to stack actuators alone due to the mechanism's weight. This mechanism is required to increase the stroke at a force cost.

Actuators:

According to those graphs, it is possible to classify the actuators in two class:

- High force and high bandwidth but low stroke
- High displacement but poor speed and bandwidth.

Actuators with high force and speed but with small stroke

The technology in these actuators is simply the piezoelectric effect. These actuators can be manufactured in various shapes and dimensions. Big stacks will develop enough mechanical energy for control application although the stroke needs to be converted into a much larger displacement. The large bandwidth allows active control at much higher frequencies than the blade revolution frequency and therefore is suitable for not only driving control surfaces but also for active modification of the flight envelope and active vibration damping [5]. The same actuators can be also used in a piezoelectric diaphragm to serve as vibrating membrane for zero-mass flux jets [8]. Their high bandwidth and straightforward design make them perfect to embed inside a structure.

Actuators with high displacement but small operating frequency

High displacements are achieved by linear actuators. They are able to sustain a significant force at a small space and weight penalty. The technologies reviewed are commercially used for nano-positioning and precise motion [2, 3, 4]. These actuators deliver large motion that made their integration easier than stacks that need mechanical amplification. The ultrasonic actuators are fast enough to be competitive for frequencies close to the revolution period of a rotor blade. The stepped actuators are much slower although they have similar weight efficiency. However one actuator can deliver the same mechanical energy as 20 ultrasonic actuators. Their compact size makes them perfect for delivering force and displacement at one specific point in a structure. Secondly, would be an obvious choice for slow changes in shape configurations.

Reliability & Toughness:

Two important characteristics of the actuators need to be considered for including actuators inside a rotor blade. Firstly, the reliability of the actuator and the number of cycles possible to achieve without significant loss in performance or failure. Then the toughness of the actuator to sustain the high *g*-forces inside the blade.

Piezoelectric stacks

Piezoelectric stacks actuators are very reliable and will achieve the same performance for at least 10^9 cycles. They have already been integrated into helicopter rotor blade to actuate flaps [6].

Stepped actuators

Stepped actuators do not contain moving parts like conventional electrical actuators. The linear motion achieved is the result of successive small contact steps performed by piezoelectric elements. The Nextline actuators (Piezowalk stepped actuators) sold by Physik Instrumente have obtained the space certification. This means that the probability of a major failure is less than 10^{-5} per hour of flight or that the actuator can normally function for 100,000 hours without major failure [7].

Ultrasonic actuators

Ultrasonic actuators are using vibration modes of friction elements to transfer motion from the stator. These parts are more prone to wear. Physik Instrumente advertises their components to have a minimum time between failures of 20,000 hours [2]. Ultrasonic actuator can be really small and have a mass of a couple of grams. With such a weight, the *g* force has hardly any effect on the device. New Scale technology says that their Squiggle actuator can sustain up to 2500 *g* of acceleration and one million cycles [3].

Screw jack actuators

Screw jack actuators are conventional electrical actuator. An electrical motor rotates a lead screw which provides linear motion. This actuator contains moving parts and is less robust that piezoelectric actuators. Physik Instrumente is delivering actuators with a minimum time between failures of 20,000 hours [2]. Screw jack actuators are not used for surface control due to this lack of reliability. Hydraulic actuators are preferred. They meet the high requirements for airborne mechanisms.

Maturity:

All the actuators in this report are commercially available solutions. They are extensively used in the industry for nano-positioning. Only the stack actuator has already been used for actuation in rotorblades [6]. The Nexline actuators from Physik Instrumente have recently obtained the space certification which shows their relevance for actuation in extreme conditions.

Conclusion:

This report presents the performances of actuators currently available and highlights about some specific technologies. Stepped actuators are a natural choice for robust actuation mechanisms to slowly deliver mechanical work for shape morphing. Stack actuators large bandwidth makes them perfect for applications that requirement actuation at high frequencies. Ultrasonic actuators have not been used yet into high demanding mechanical applications but their low weigh and relatively large displacement capabilities may ease the design of actuation mechanisms.