Development of a low voltage Dielectric Electro-Active Polymer actuator

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1.1 Abstract:

In the present paper, a low-voltage Dielectric Electro-active Polymer (DEAP) device is presented. It is based on the DEAP technology, together with a very compact driver, utilising piezoelectric transformer technology.
A major limitation for the use of DEAP for actuator application is the high voltage required for operation. The device presented in this paper is only supplied by low voltage and control signals leading to volume and mass savings for the overall system as well as easier integration.
The driver is based on a piezoelectric transformer, combining high step-up ratio, high efficiency and small size. Several prototypes have been produced and tested. Test results indicate that the mechanical integration between electronics and DEAP has some impact on performance. However, performance and reliability are still very good, so this technology is promising. New prototypes are being developed with even improved performance.

Keywords: DEAP, piezoelectric, transformer

1.1.1.1 ntroduction

Dielectric electro active polymers (DEAP) have the possibility to enable unique new designs for the actuator industry. During the last decade, the technology developed rapidly and with a high interest from the actuator industry, related to its advantages in terms of low power consumption, short response time and potential for high volume production.
The strain generated by the DEAP material is based on the electrostatic field created between the 2 electrodes of a capacitor. The dielectric layer is based on a soft silicone with a high relative permittivity and using metallic electrodes. Due to manufacturing limitations in terms of dielectric layer thickness, most DEAP actuators operate under high voltage, in the range 1-3 kV. On the other hand, many applications are operated and supplied by low voltage power sources, such as 24V DC. Although the generation of high voltage through electromagnetic transformers is possible, it has limitations such as large component size and often low efficiency. When designing a system, the overall dimensions of the actuation part needs to be taken into account. Commercially available solutions can easily double the required installation volume compared to the DEAP only (see Fig. 1).

Fig. 1: *Comparison of a DEAP actuator and an adapted commercial driving unit (courtesy of Danfoss Polypower).*

Locating a power supply far from the DEAP makes it easier to integrate, however for operation in the kV range and taking into account safety requirements, the required wiring tends to be bulky and difficult to handle.

Recovery of the dielectric charge stored in the DEAP is also a challenge for conventional transformer technology, so that in many cases the stored energy is wasted, leading to low overall efficiency at high frequency.
The development of an integrated solution with a state of the art, high efficiency and small size high voltage driver combined with DEAP technology will increase tremendously the range of applications and change the way engineers design actuator applications.

Actuator design

The actuator design is based on what is becoming an industry standard for DEAP actuators: the tubular design, sometimes referred to as “push” actuator [1]. This design is quite compact and offers interesting performance with a free stroke around 1mm and blocking force in the 5-10N range.
This actuator concept includes an empty “core”, normally unused. A target of this project was to design a driver that would be small enough to fit in this core. Any large inductive component (transformer, inductor) would lead to difficulties for the integration of the driver in the DEAP. It was therefore crucial to use a technology compatible with this flat design.
The driver is supplied with 24V dc and with an input setpoint 0-5V dc. A simple voltage regulation is used, the voltage applied to the DEAP being proportional to the input (gain of 500).
The driver is connected to the DEAP through a HV flex circuit. A critical aspect of the design is the mechanical interface between the DEAP and the driver. Given the configuration and the available volume, the only reliable interface points are the extremities of the polymer tube. A difficulty lies in the fact that the distance between these points varies with the elongation of the actuator. Similarly, any friction or additional stiffness would affect the free movement of the DEAP. To address this issue, specific end-caps have been designed, fixed at one end and sliding at the other end.

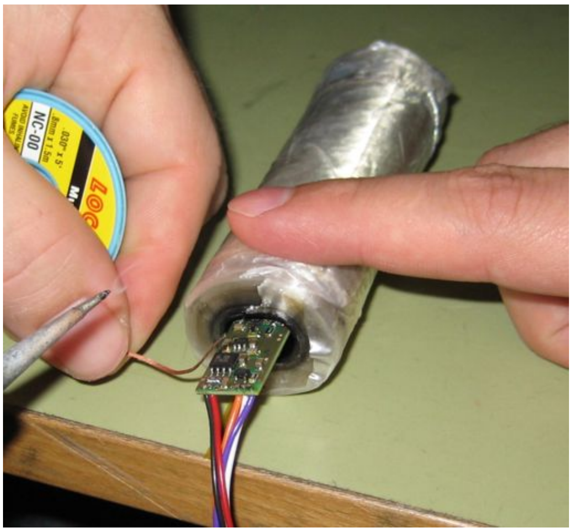

Fig. 2: *Integration of the driver board in the DEAP*

The driver board can be inserted in the DEAP and retained at the fixed end with silicone.
Seen as a whole, the solution is as compact as the original DEAP.

Transformer design

There has been a lot of activity in the recent years in the field of piezoelectric transformers, both in development and in regular production. These transformers have the capability of generating high voltages (step-up ratio of 100 are not uncommon) and are known for their high power density. They are therefore good candidates for integration with a DEAP actuator.
The design is based on Rosen type transformer [2], with some major improvements:

- Its proportions have been adjusted to ensure inductor-less operation [3]
- It is interleaved (primary located in the middle of the secondary)
- The primary section makes full use of the multilayer technology in order to reach the high step-up ratio.

The transformer was modelled using COMSOL Multiphysics® (fig. 3).

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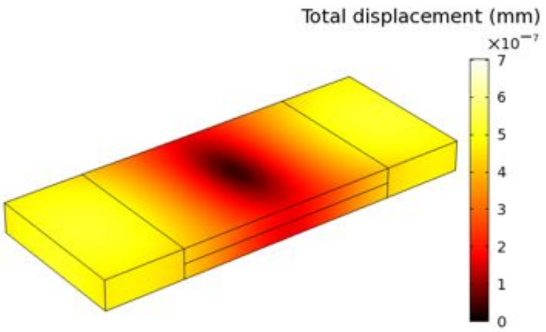

Fig. 3: *FEM results on piezoelectric transformer, first mode. The colouring illustrates the total displacement, where dark colours refer to a low displacement and light colours to at high displacement, as the colour bar indicates.*

The transformer is used at its first longitudinal mode ($\lambda/2$) at 65kHz. It is fixed on the driver board through rigid primary connections situated at nodes of the vibration.
A series of transformers was produced in Noliac using state of the art multilayer technology (fig. 4). Although the reference design is 25mm long, transformers of 20, 30 and 35mm were also produced for the purpose of testing.

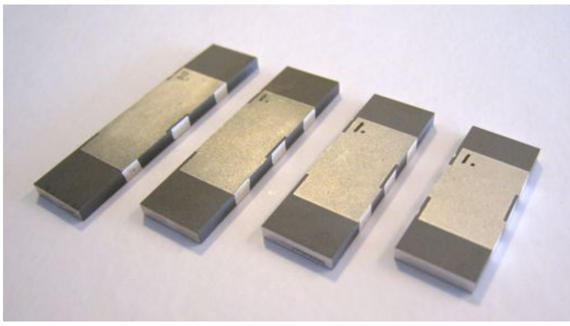

Fig. 4: *Produced prototype multilayer PT.*

More details concerning the piezoelectric transformer design have been published in [4].

Test results

Several prototype low voltage DEAP actuators have been produced, assembled and tested (fig. 5).

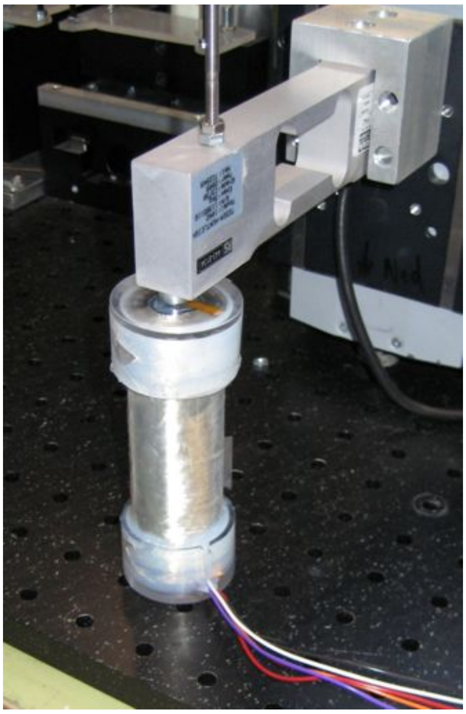

Fig. 5: *Low voltage DEAP under initial testing.*

Initial performance results showed that the integration of the driver induces a small change in performance (fig. 6). There is a relatively large dispersion, indicating that the mechanical integration DEAP/electronics is a critical aspect. This is related to the low stiffness of the DEAP.

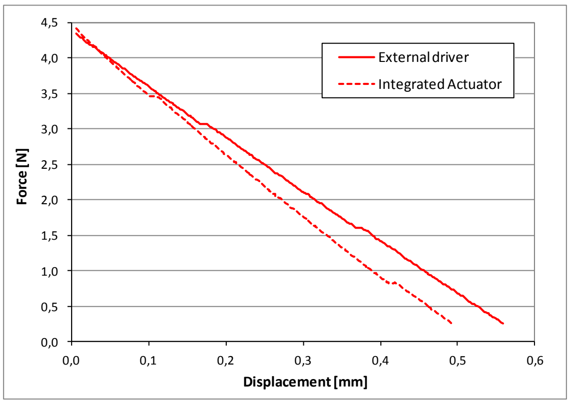

Fig. 6: *Prototype LV DEAP initial force-displacement characteristics at 2000V, with or without integrated driver.*

With the integration, the stiffness of the DEAP increases from 7,3 to 8,3 N/mm (fig. 6). The additional stiffness of 1N/mm is provided by the driver and reduces the free displacement accordingly.
A test was run in a climate chamber (fig. 7), measuring performance in the range 0 to 80°C. The prototypes were submitted to a constant force (mass of 1kg) and displacement was monitored using LVDTs.

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Fig. 7: *Prototype LV DEAPs on test bench in climate chamber.*

Results (fig. 8) indicate that stroke decreases about 20% at high temperature. This is probably due to increased friction in the driver/end-cap interface at high temperature.

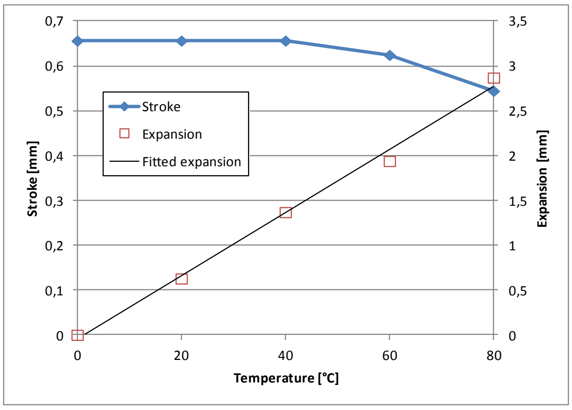

Fig. 8: *Thermal expansion and stroke according to temperature for LV DEAP.*

In addition, the thermal expansion of the LV DEAP is about 50% higher than for conventional DEAP. This indicates that changes in the design (new end-caps) as well as the thermal expansion of the driver board affect the dimensions of the LV DEAP. This is however not necessarily a problem for application

The LV DEAP were tested in endurance for 2,5 million cycles at 1Hz, pushing a mass of 1kg.

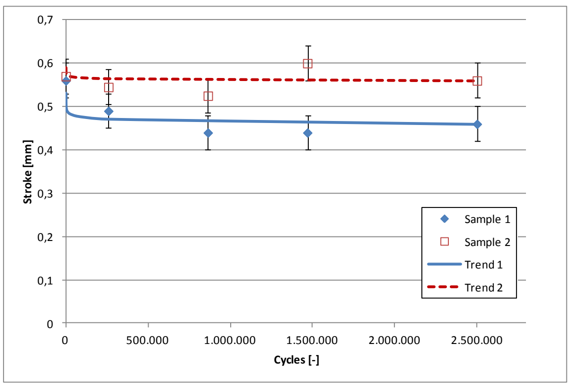

Fig. 9: *Evolution of displacement on two LV DEAPs during 2,5 million cycles.*

An expected aging can be measured (fig. 9), related to the material. Stroke decreases by up to 17% after 2,5 million cycles (<10% in average).

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In addition, a shock test was performed in standard conditions (half-sine, 20 ‘g’ peak, 10ms, 250 shocks in each of the 6 directions). The test identified a weakness in the electrical connection between the driver and the DEAP, that could later be corrected. Both the DEAP and the driver survived the test.
Based on these encouraging results, a new generation of actuators is being developed, capable of higher power and dielectric energy recovery. These actuators will enable the use of the DEAP technology for a wider range of applications.

Conclusions

In this project, driving electronics small enough to fit in the core of a cylindrical DEAP actuator have been developed, making the system a low voltage DEAP actuator.
Static performance shows higher stiffness and lower displacement due to the integration of the driver board. The system was tested in temperature in the range 0 to 80°C.
The LV DEAP survived a shock test and was validated in endurance for 2,5 million cycles.

Acknowledgements

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