Properties of PZT Multilayer Actuators

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Abstract:
Co-fired piezoelectric multilayer actuators have found an increasing interest in the last years. Especially, influenced by the development of the piezoelectric driven fuel injection technology new products have been commercialized. The known actuators are based on the well known interdigital design. We have focused our work on the development of an actuator design with buried electrodes (cofired encapsulation). Results of the investigations of the actuator properties and of some life time tests will be presented.

Introduction

Piezoelectric multilayer actuators became more and more of interest because of their excellent properties. Stimulated by the development of piezoelectric driven fuel injection valves, intensive research and development work in the fields of new material compositions and new actuator designs as well as in the field of the technology took place in the last years. The design and the properties of the actuators which were commercialized [1, 2] in the last years are mainly adapted on the requirements of the fuel injection which are characterized by high dynamical pulse excitations.
On the other hand, in the field of micro- and nano-positioning applications the working conditions are quite different compared to the fuel injection application. The actuators are mostly biased by a DC voltage over a long time period and the position control requires only a part of the full stroke in a static or low frequency regime. Under these conditions, the life time of the actuators is strongly determined by environmental influences and the quality of the protecting coating. Furthermore, strain gages will be mounted directly to the actuators for closed-loop systems. Many efforts are necessary to realize high performance and high reliable solutions with polymer coated actuators.
Therefore, we have focused our work on the development of an actuator design with buried electrodes [3]. This design has the advantage that the inner electrodes comes out only at the termination surfaces. Because of that, no polymeric coating for insulation and protection is required. Strain gages can be glued directly to the ceramic surface insulated to the inner electrodes. Last but not least, an improved resistance against environmental effects can be expected.

Design and Technology

The actuators are made from a modified PZT material with a Curie–temperature of 320 °C by a common multilayer process. After mixing and calcining the powder is milled in two steps to the desired grain size. A slurry is prepared based on a organic binder and solvents and tape cast according to the Doctor Blade method. The dried tapes are cut, printed with the required AgPd electrode pattern and laminated to a package up to a certain height using an automatic printing and laminating machine. Then the packages are cut into stripes and the stripes are stacked and pressed to bars with passive layers on top and bottom sides of the bars up to a green height of 25 mm and then cut into green stacks. After binder burn out, the stacks are sintered at temperatures below 1100 °C. Finally, the top and the bottom surfaces are ground and AgPd termination electrodes are printed and fired.
The actuators are designed for a maximum driving voltage of 120 V, which corresponds to a maximum electric field strength of 2 kV/mm at a thickness of the active layers of 60 µm.

Piezo Actuator Performance

All measurements were carried out at samples with a length of 18 mm and a cross section 5x5 mm^2. Some measurements were performed up to the poling voltage of 150 V. Results of the measurements under different electrical, mechanical and thermal conditions will be shown.

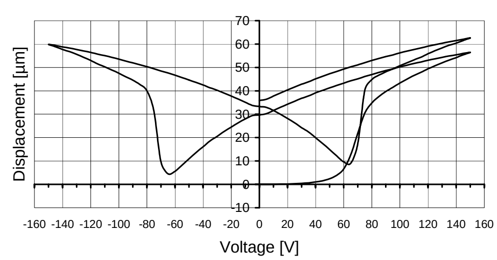

Fig. 1: *Displacement hysteresis with virgin curve*

Fig.1 shows the displacement behavior during the poling and the first Butterfly-loop after poling. As it can be seen, the used material is characterized by a coercive field strength of 1.1 kV/mm and a remnant strain of approximately 0,16 %.

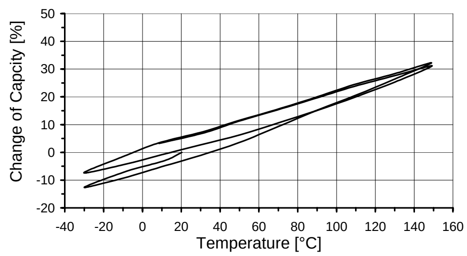

Fig. 2: *Temperature change of the small signal capacitance*

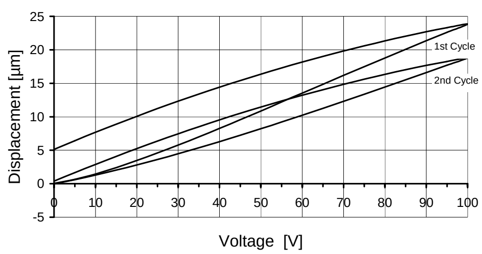

Fig. 3: *First and second displacement cycle after temperature cycling from –40 °C to 150 °C*

Fig.2 shows the temperature dependence of the small signal capacitance in the temperature range from –40 °C to 150 °C. After this temperature cycling, the first and the second displacement cycle were measured. Due to thermally stimulated domain reorientation's in the first cycle an enlarged displacement occurs. But the displacement behavior is stabilized after the second cycle.

Large Signal Measurements

The large signal behavior of the stacks was measured under unipolar driving conditions according to the method described in [4]. In Fig.4 to 7 the driving voltage dependencies of the displacement, the effective capacitance, the loss tan and the loss power at different temperatures are shown.

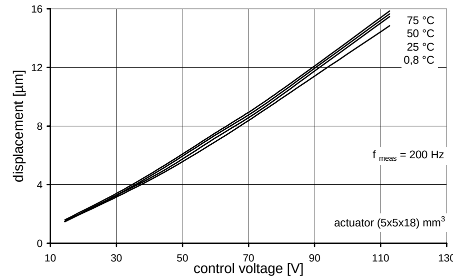

Fig. 4: *Displacement versus voltage at different temperatures*

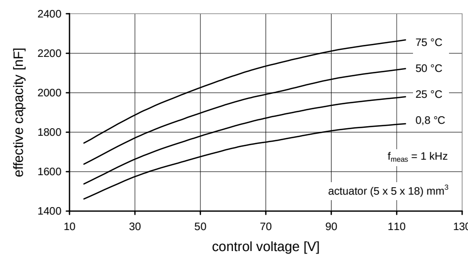

Fig. 5: *Large signal capacitance versus voltage at different temperatures*

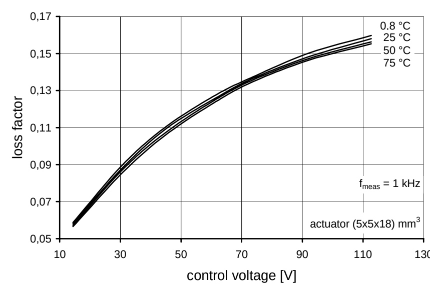

Fig. 6: *Loss tan versus voltage at different temperatures*

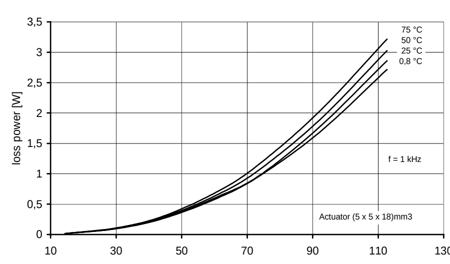

Fig. 7: *Loss power versus voltage at different temperatures*

Elastic Measurements

The mechanical stiffness and the influence of static mechanical load on the displacement behavior play an important role for the application of the stack actuators. Therefore, first investigations were performed [5].

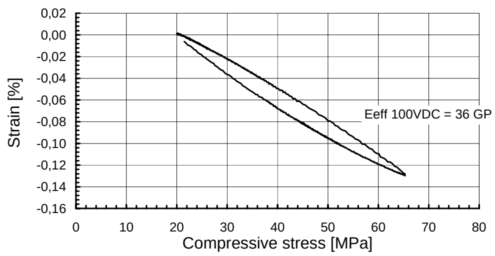

Fig. 8: *Strain versus compressive stress @100V*

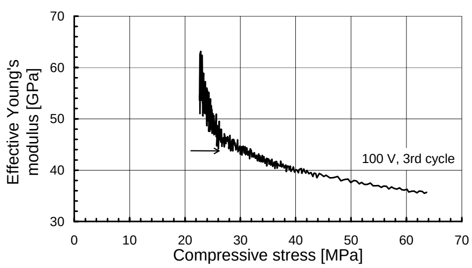

Fig. 9: *Effective Young's modulus versus compressive stress @100V*

Fig.8 shows the strain-stress relation of an actuator biased with the nominal voltage of 100 V. Because of influences of the measuring setup at low stresses, the starting point was set to 20 MPa. Fig.9 shows stress dependence of the effective Young's modulus calculated by numerical differentiation of the strain-stress curve from Fig.8. The strong stress dependence of the effective Young's modulus up to 30 MPa is caused by the measuring method and not a material property. From a linear fit of the strain-stress relation in Fig.8 an effective Young's modulus of 36 GPa can be calculated.

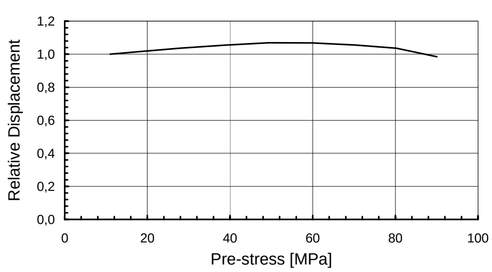

Fig. 10: *Relative displacement versus pre-stress*

Fig.10 shows the displacement dependence on the mechanical pre-load related to the free displacement of an actuator driven at 100 V. As an consequence of the chosen PZT material composition only a small increasing of the displacement of about 10% with increasing pre-load occurs.

Cyclic Fatigue Test

The life time of the actuators under cyclic driving conditions was tested up to $1.2*10^9$ cycles until now. For the test, the actuators were pre-stressed with a load of 15 MPa and driven with sinusoidal voltage from 0 V to 100 V and a frequency of 116 Hz. Fig.11 shows the displacement before and after the cycling test up to poling voltage of 150 V.

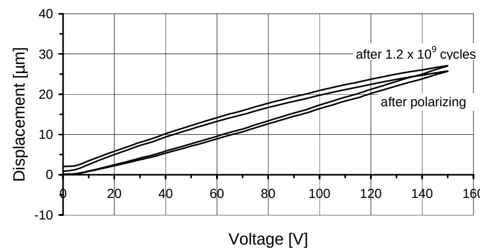

Fig. 11: *Displacement versus voltage before and after cycling test*

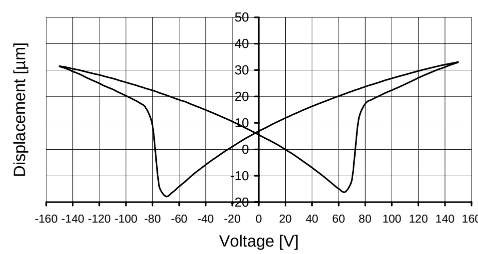

Fig. 12: *Butterfly-loop after cycling test*

In Fig.11 the displacement-voltage curves before and after the cycling test are shown. As it can be seen, a small increase in the displacement occurs after $1.2\ 10^9$ cycles. A similar behavior was observed elsewhere [1]. After the cycling test, the ferroelectric Butterfly-loop was measured again, see Fig.12. Due to the very symmetric curve there is no indication for a material degradation. Compared to the initial loop in Fig.1 no remarkable differences can be observed.

References

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