MINIATURE PIEZOELECTRIC RELAY WITH LOW OPERATE VOLTAGE AND SHORT SWITCHING TIME USING A MONOLITHIC MULTILAYER BENDER ACTUATOR

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Abstract

Through the use of a special measurement assembly the characteristics and behaviour of monolithic multilayer bender actuators under normal and increased temperature are determined, resulting in a new type of piezoelectric relay developed using systematic design methods. This new piezoelectric relay contains a bender actuator designed and developed using technical data gathered from tests and also a low cost permanent magnet to achieve the bistable operating characteristics of a conventional relay. Prototypes the size of small signal relays and their characteristics are specified from an extensive test program. The result is an alternative to an electromagnetic relay with ultra slim shape, and very low power consumption.

Introduction

Actuators that can be used in relay technology must be producable in large numbers, at low cost, have sufficient displacement and force, and a low operate voltage. Conventional relay construction achieves this using a cylindrical electromagnet, and possibly a permanent magnet. Consequently minimization of actuator height is relatively difficult. The development of new PZT based ceramics combined with monolithic multilayer techniques were applied to the design of the bender actuator element. This technique achieves features, that substitute the traditional drive in a relay, allowing it to be built in a slim-shape and

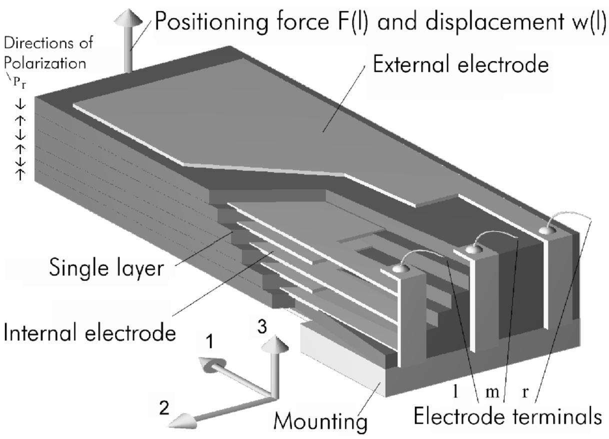

Fig. 1 Monomorph cantilever in multilayer technique

with a quasi-powerless on position. A three dimensional representation of the strip shaped piezoelectric bender element is shown in Fig. 1. Similar to the principle function of well-known bimetal actuators, positive and negative curvature of the bender can be achieved through the voltage control at the three electrode terminals. The application of the simple electrical circuit shown in Fig. 2 causes the full displacement range of the bender defined as mode 1 and 2 through the stimulation of the specific layers. Because of the

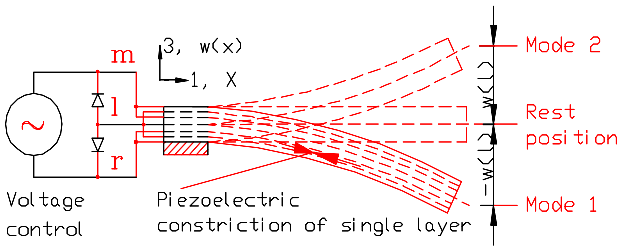

Fig. 2 Function of the multilayer monomorph

directions of polarization a positive and negative control voltage can be applied. The bender is driven as a monomorph, by an electrical field only

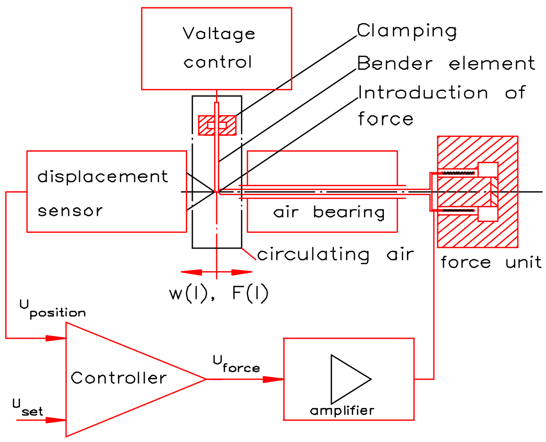

Fig. 3 Principle of the measurement assembly with a closed loop

in the direction of the remanent polarization in order to avoid parasitic depolarisation. Both diodes of Fig. 2 control the charging and discharging of the active layers, to achieve displacement mode 1 and 2.

Characterizing of the actuator

In the equations, which describe the linear behaviour of the actuator [1];[2], material coefficients must be inserted in the large signal range (E>0.1 kV/mm). Since an analytic description of the macroscopic domain processes in the large signal range and under increased temperature is not possible, or only with for e.g. a FEM simulation, the piezoelectric coefficients were determined from a series of tests on prototypes of the actuator. The relevant data to design a piezo relay can be parametrized from the test results. A specially conceived computer aided measurement assembly [3] has been constructed for this at the TU Cottbus. The displacement and force of the cantilever can be measured within different time ranges and under increased temperature. To measure the force, a new assembly of electrodynamic force compensation with a laser triangulation displacement sensor in a closed loop (see Fig. 3) were used. Independent of the level of bender deflection and where the actuator force is introduced the measurement assembly counteracting force powered from a current in the moving coil is directly proportional to the generated force.

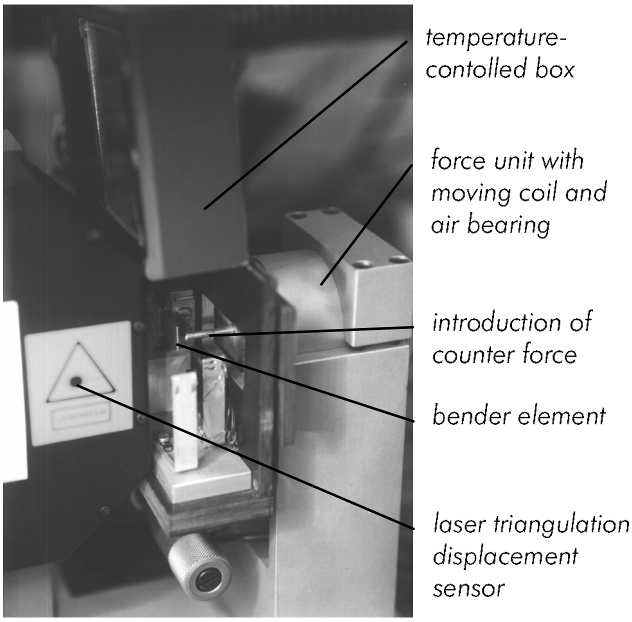

Fig. 4 *Measurement assembly for characterization of bender*

In addition the principle of the measurement assembly is very stable in this force range, so that it is possible to measure a static force for a long time.

The measurement of displacement and force characterizing drift, hysteresis, relaxation of tension, switching times and the stability of rest position are decisive for an application of the actuator in a relay. The flow behaviour of the ceramic requires a specific time base for all measurements. Consequently, for every measurement there must be information of voltage slew rate, and respective rate of loading, which must be chosen as a compromise between drift behaviour and influence of the moved inertial mass.

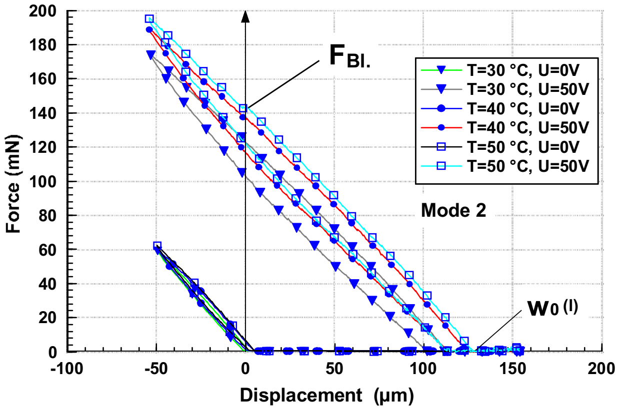

Fig. 5 Dependence of force on displacement of an actuator with active length=15,6 mm, width=7,0 mm and height=0,43 mm.

A so performed measurement is displayed in Fig. 5 as a force displacement diagram, with specific parameter temperature, and excitation voltage.

The generated deflection of the actuator is countered by the force unit with a constant rate of velocity (1 µm/s) and afterwards released.

The results shown in Fig. 5 demonstrate, that under increased temperature the stiffness of the not driven (U=0V) transducers changes only negligibly. The blocking force $F_{Bl.}$ and the unloaded deflection $w_0(l)$ is shown to be more significant with high electrical field strength (>1kV/mm), and even more with increased temperature.

A test method, to simulate the static load case in a relay, represents the measurement of the force of the actuator by excitating it with a triangular pulse

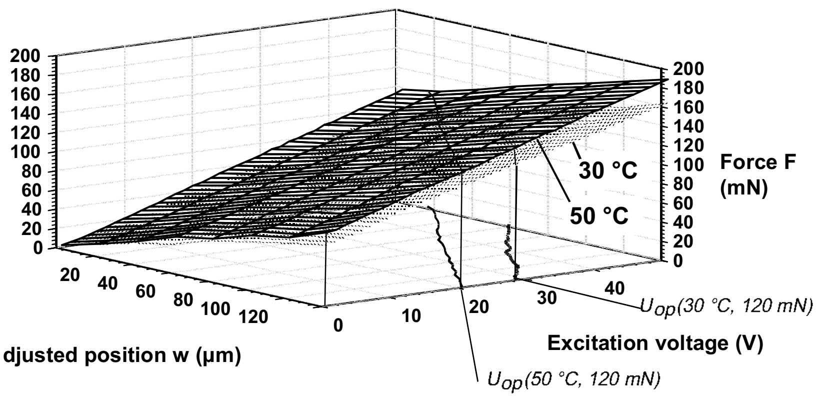

Fig. 6 Excitation of the bender in an adjusted position (active length=15 mm, width = 8 mm and height = 0,3 mm).

shape (50V/s, U_{max}=50V) in an adjusted position that is held constant. The Fig. 6 shows the result of this test taken with two different external temperatures.
The iso-force-lines indicate the range of the operating voltage U_{op} for a constant actuator force according to a constant temperature and an adjusted position, see for example Fig. 6 for a constant force of 120 mN. When the iso-force-line is exceeded by increasing the level of control voltage the actuator in a built relay is switched. This is the basis for setting the parameters of a piezo relay in a defined control voltage, and temperature range.

Prototype of a piezoelectric relay

The design of a piezo relay with the proportional charge curvature actuator must meet additional requirements to achieve the operating characteristics of a conventional relay. These requirements are:

- Achievement of switch hysteresis through a mechanism similar to a snap-action device
- Guarantee a sufficient high contact gap and a constant contact force in all control states
- Compensation of the negative actuator behaviour (for example drift)
- A defined operational voltage range
- Components producable in large numbers

Some design ideas could use a so called omega-spring [4], snap-spring or several permanent magnets [5].
The new developed piezo relay using systematic design methods, shown as a protoype in three dimensional representation in Fig. 7, combines

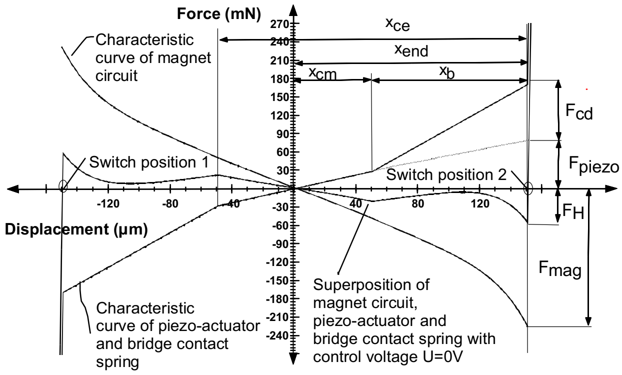

Fig. 8 Superposition of force displacement curves of the individual components to achieve a bistability

various advantages:

– The bridge contact doubles the contact gap and avoids the need for a wire to the moving contact.
– The „pole forks" shape of the flux guide in the magnetic circuit make it possible to use only one low cost and flat permanent magnet.
– To achieve a bistable characteristic the permanent magnet can be trimmed.
– The fully symmetric construction prevents actuator drift. Because of the excitation in mode 1 and 2 the actuator quasi „refreshes".
– The contact circuit is independant of any negative actuator behaviour, such that a secure defined contact can be achieved.
– The galvanic disconnection between driving

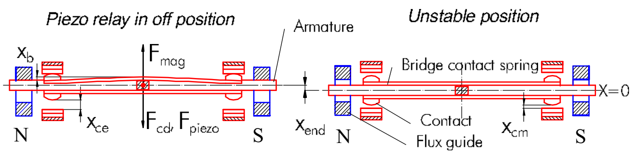

Fig. 9 Cross-section A-B of Fig. 7

circuit and contact circuit is completely guaranteed.
The parameters for a signal relay as an example are illustrated in Fig. 8. The distances and forces of the piezo relay in Fig. 8 are also presented in the cross-section in Fig. 9. The superposition of the characteristic force and displacement curves of the individual component demonstrates the achieved bistability.
The use of the permanent magnet shifts the blocking force, which usally appears at the rest position, to the switch position 1 or to switch position 2. There is even an enlargement of the actuator deflection through bending by the magnetic force. By using an actuator with low stiffness the required magnet energy is minimized. If

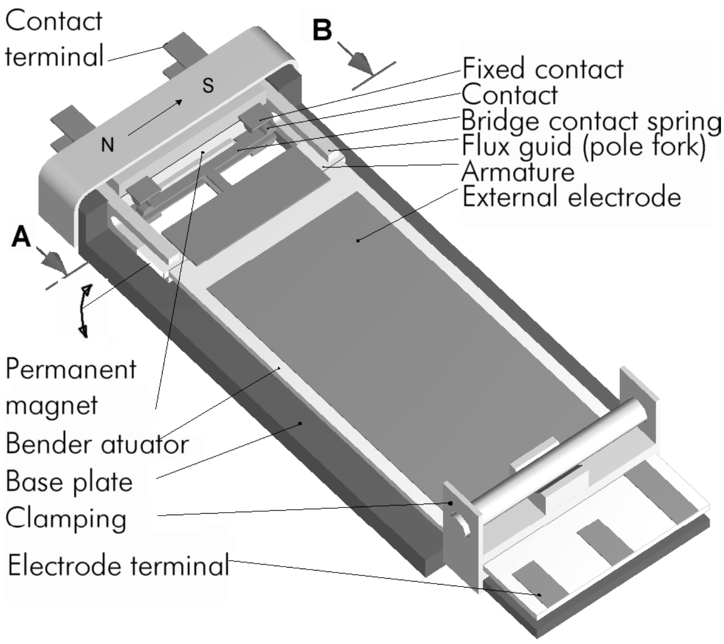

Fig. 7 Bistable piezo relay with one change over contact

the actuator is activated in mode 1 or 2 the superpostion curve shifts in vertical direction. As a consequence the holding force F_H decreases to zero and the opposite switch position 1 or position 2 is achieved. This happens when the control voltage has a specific level U_{op1}, and respectively U_{op2}, as shown in the measurement curve of Fig. 10 that was carried out on the prototype pictured in Fig. 12. The movement of the armature was registered by the laser triangulation deflection sensor when the piezo relay was driven by a triangular pulse shape (50 V/s and U_{max}=45 V). Because of the perfect symmetrical construction the operate voltages U_{op1} and U_{op2} must be the same. Different operate voltages may occur due to non symmetrical adjustment, manufactoring error and

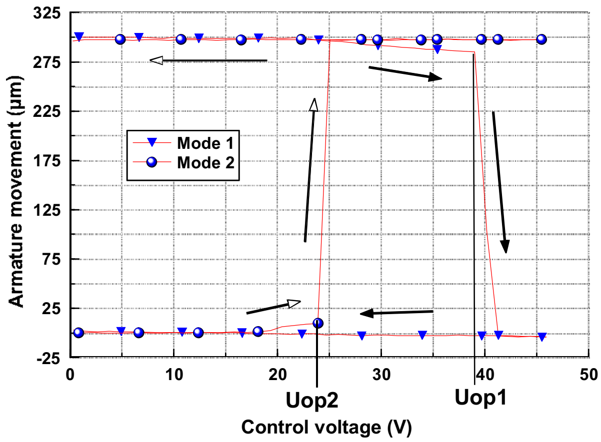

Fig. 10 Specification of the operate voltage by driving with a triangular pulse shape

the hysterisis of the actuator.

In the result in Fig. 11 the dynamic response of the armature was measured with the same method as that used to measure the operate voltage. Additional to the control voltage curve, the current is measured, so that the total power control consumption can be determined. The power consumption of the piezo relay specified in Fig. 11 was 85 mW based on a 2 ms charging time. A good result compared to a conventional relay.

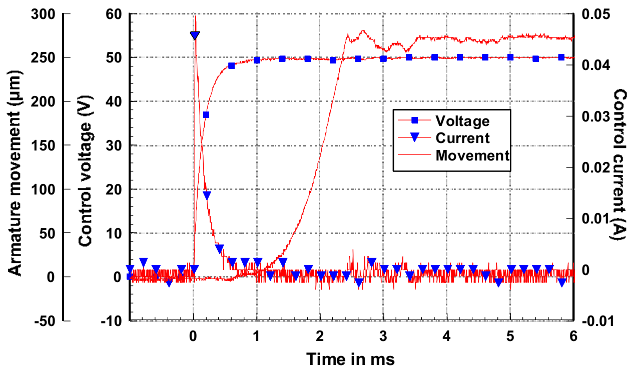

Fig. 11 Specification of switching time and power consumption by dynamic response

Fig. 12 Mini series of piezo relays as a prototype with device data: length≈20mm, width≈9mm and height≈2mm

With additional measures against bouncing the mechanical switching time of the armature movement measured at under 4 ms (see Fig. 11) will be even better.

Conclusions

The resulting slim shape piezo relay prototype was constructed in the laboratory using methods that demonstrate that automatic assembly of the bridge contact with the piezoelectric bender actuator is possible. Progress in piezoelectric material, especially increasing the piezoelectric coefficient d_{31}, and increasing the Curie temperature T_C, would improve the performance by reducing the device size, and lead to the possibility of a piezo relay as a surface mounted device.

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