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PIRest Actuators - Active Shims with Long-Term Stability and Nanometer Resolution

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Abstract

PIRest actuators are based on a completely new piezo technology and will be used for semiactive long-term stable micro- and nanopositioning. The classical approach to compensate position errors by passive shims that are ground exactly to the required dimension becomes more and more difficult for micrometer or even nanometer level. In contrast to the classic approach, the piezo-based PIRest shims, which only need to be inserted once, can actively adjust or readjust the dimension that has changed between two components. Although the PIRest technology is based on piezo actuators with a special optimized material, it nevertheless maintains a stable displacement in the micrometer range with nanometer accuracy after adjustment, even without an offset voltage applied. This considerably simplifies remote operated alignment tasks at unreachable positions of optical components inside semiconductor manufacturing equipment, astronomy instrumentation, or material research in synchrotrons and vacuum environment. A complete phenomenological model of the actuators was developed and implemented in a micro-controller. It includes static and time dependent data sets of the nonlinear behaviour of the most important parameters like temperature and preload.

Keywords: PIRest, active shimming, PZT- actuators, micropositioning, nanopositioning, remanent strain, piezo

1. Introduction

The disadvantage of conventional flat washers or spacers that are ground exactly to a required thickness is that it is not always possible to adjust them as precisely as required and the predefined dimension can't be changed anymore. Using piezoelectric actuators working in conventional mode for these kinds of applications requires a stable, low-noise power supply. Moreover, the actuators' lifetime is reduced by applying an offset voltage over a long period of time especially in high humidity environment.

The adjustment procedure can be simplified and considerably accelerated with the help of PIRest actuators. The main advantage is that the last piezo position can be held without an offset voltage and alignment tasks within difficult-to-access areas and systems are simplified.

2. Principle of operation

The new technology is based on ferroelectric domain switching processes that occur during polarization and depolarization of PZT actuators.

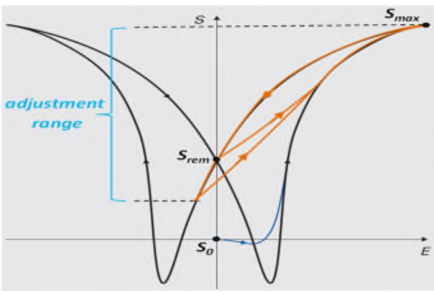

Figure. 1: Hysteresis loop and adjustment range of standard PZT-actuators operating mode , [1], (extended)

After PZT- actuators have been sintered, all domains are orientated statistically (see S0 in Fig. 1). Conventionally, the actuators are polarized by applying an electric field E > Ec for a certain period of time (Ec = coercive field). The mechanical strain S increases to Smax. At this point, all domains are aligned parallel to the electric field vector. When the electric field is reduced to zero again, the mechanical strain won't be zero. It is called the remanent strain Srem of the actuator. At this point, the actuator can be driven unipolar or with limitations also bipolar. The nominal displacement for PICMA-Actuators @100V is approx. 0.1- 0.15% of the actuator's length. If the electrical voltage is set to zero, the mechanical strain will always be reduced to Srem.

The new PIRest technology uses the lower part of the hysteresis loop. By controlling a piezoelectric actuator based on a specially optimized material with positive voltage pulses, the polarization and mechanical strain can be increased step by step. This is shown by the schematic magenta hysteresis loops in Fig. 2.

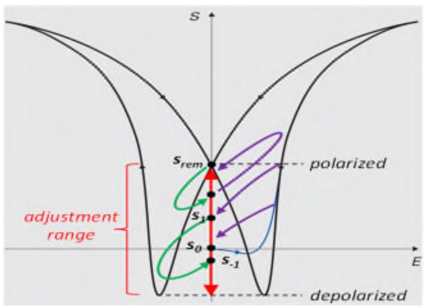

Figure. 2: Hysteresis loop and PIRest operating mode of a PZT-actuator, [1] (extended)

This can be done until Srem has been reached. At this point, the length can't be increased anymore, because all domains are aligned parallel to the electric field vector. The actuator is fully polarized. Controlling the actuator with negative voltage pulses will decrease the actuator's length again which is shown by the schematic green hysteresis loops. The length can be reduced down to the completely depolarized state. The PIRest technology's adjustment range depends on the material used and is approx. 0.06 - 0.1% of the actuator's length (see Fig.3).

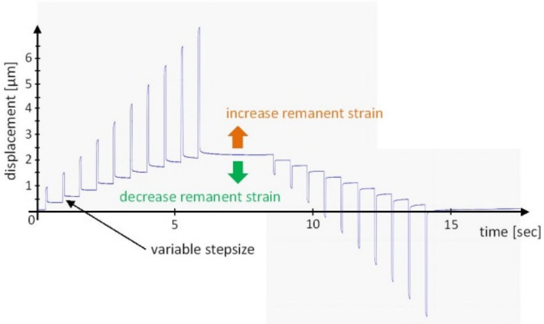

Figure 3: Forward and backward motion by increasing or decreasing remanent strain

3. Phenomenological model and stability test

A phenomenological model emulates the change of the remanent strain during the polarization and depolarization process. Influencing factors for this kind of operation are the voltage pulse's height and width, the actuator's temperature and prestress level as well as the time factor. By paying attention to all of these factors, the model calculates a sequence of electrical signals to get to the new target position.
Setting the actuator to a definite position by controlling a constant voltage in the conventional mode, leads to a material-based creeping process. The position changes in a logarithmic way with approx. 1%/decade. After controlling the actuator with voltage pulses in the PIRest mode, the length changes in a logarithmic way too. However, the phenomenological model is able to compensate this creeping process by a combination of pulses in both directions.

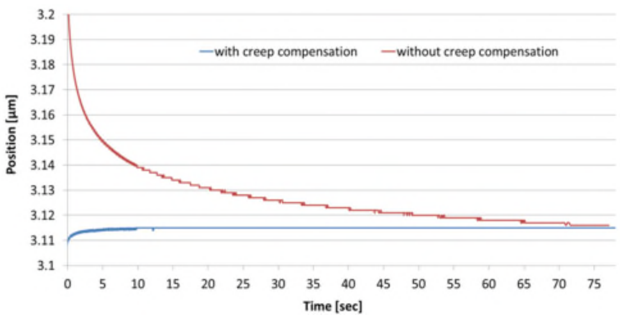

Figure 4: Position stability with creep compensation on/off

A position stability test in a nonstable thermal environment is shown in Fig.5. The measured position changes are mainly temperature induced effects with a negative CTE. After cancelling out temperature changes, approx. 0.1µm drift remains. Actual tests show this level of stability over min. 12 weeks. Because the PIRest actuators are used in partially-polarized states, there can be positive (fully depolarized state) and negative (fully polarized state) temperature coefficients as well.
Furthermore, the model provides different operating modes for bidirectional, incremental motion with adjustable step size,

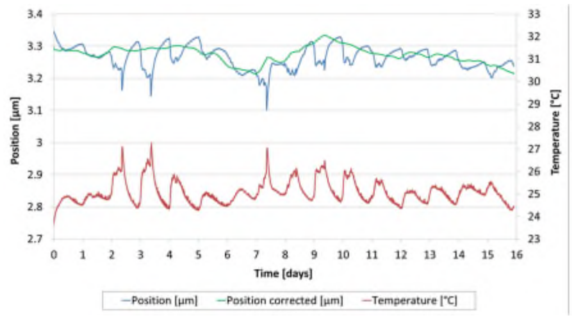

Figure 5: Position stability in a nonstable thermal environment

referencing the minimum and maximum position and setting the actuator to a definite position with an accuracy of ± 3.5 % of the actuator's adjustment range.

4. Control unit and actuator types

The phenomenological model is implemented in a control unit which is driven by a microcontroller and an integrated optimized piezo amplifier. The actuator needs to be connected to the control unit only once to set a new position. After this has been done, the actuator can be disconnected from the control unit and the new position is held without additional power supply. To support multi-axis alignment tasks the control unit can drive up to six actuators and by using a coordinate transformation matrix, parallel kinematics can be aligned in all degrees of freedom, To avoid overconstrained situation multi-axis applications should be decoupled by elastic hinges.

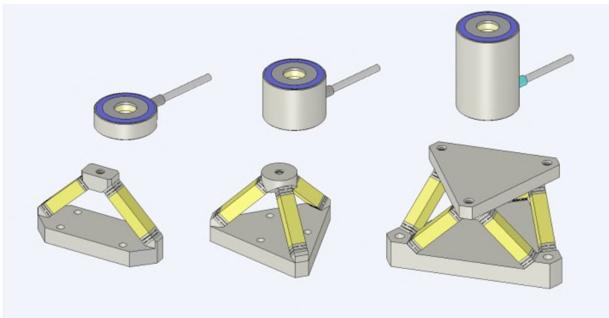

Figure 6: PIRest actuator types: Top: Single axis high stiffness types up to 4kN load capability and center preload option; Bottom: Multi-axis versions with 2, 3 and 6 DoF, decoupled by elastic hinges

5. Conclusion

The PIRest technology demonstrates that the PZT- actuator's remanent strain can be controlled effectively. The phenomenological model provides different operating modes.
Main applications are quasistatic fine alignments and error corrections with micrometer ranges and nanometer resolution in difficult-to-access areas and systems. The classical approach of compensating differences in dimensions with passive shims or spacers can be simplified and considerably accelerated. Compared to the conventional operating mode, the actuator's lifetime will be significantly increased in quasistatic applications, because no electrical voltage needs to be applied for holding the last position.

References

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[2] Physik Instrumente (PI) GmbH & Co. KG, Karlsruhe, Germany, Brochure PIRest Actuators, (2017).