Reduced Hysteresis Model and Temperature Dependency of Multilayer Piezo Actuators

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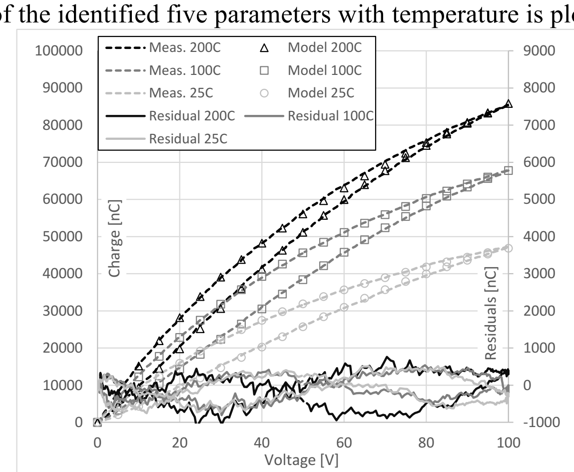
Piezoelectric multilayer actuators are widely used in the field of micro-positioning and nano-positioning plus in applications that require a fast and accurate movement such as hydraulic valves. Unfortunately, the control of these actuators is difficult due to their non-linear response. Creep and hysteresis are two phenomena that can affect the performance and stability of a control loop. In addition, for many applications it is critical to adapt a model characteristics to the ambient temperature to achieve consistent performance.
A common approach to reach an accurate model of hysteresis is to use a Preisach model and an interesting research area lies in reducing the complexity of such models.[1]
A previous paper focused on the measurement of the hysteresis response in terms of polarization *P* versus voltage *U*, through the application of a unipolar sinusoidal signal of decreasing amplitude combined with a measurement using a Sawyer-Tower circuit. A clear shift of the Preisach density with temperature was observed.[2] To match these measurements, a simplified model is proposed. It is composed of:

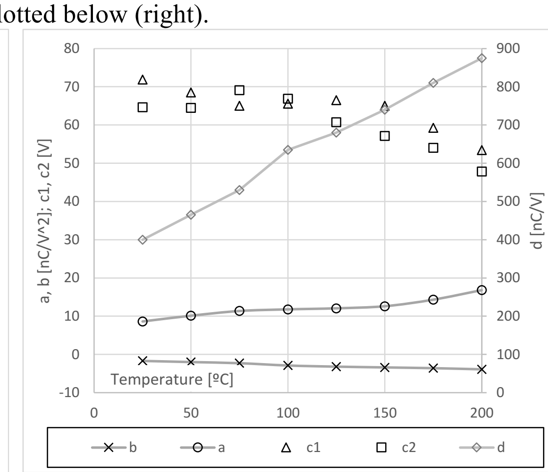
- a linear density (parameters *b*, *d*) along the diagonal of the Preisach plane and
- a Gaussian-Gaussian density centered on the origin with two independent standard deviations.

Therefore it is proposed that the *P-U* response of an actuator can be modeled by five parameters:

$$P(t) = \int (b.U + d).dU + \iint_{\alpha \geq \beta} a.e^{\frac{-(\alpha+\beta)^2}{2.c_1^2}}.e^{\frac{-(\alpha-\beta)^2}{2.c_2^2}}.\gamma_{\alpha\beta}(t).d\beta.d\alpha$$

Where P is the model output, U is the voltage input and $\gamma_{\alpha\beta}$ represents the hysteron elements that can take values from the set $\{0, 1\}$.
This model was applied to the experimental data using a solver. The reconstruction of the major hysteresis loop (markers, below left) shows a good fit with the experimental data (dashed lines, below left). The variation of the identified five parameters with temperature is plotted below (right).





Several observations can be drawn. As observed previously, the linear part of the model (parameters *b* and *d*) increases with temperature. The peak value of the Gaussian distribution *a* increases also with temperature, but the standard deviations c_1 and c_2 both decrease following a similar trend.
The Preisach approach is a phenomenological model, so it is not related to physical phenomena. Nevertheless, the increase in linearity can be interpreted by the higher proportion of polarized material (intrinsic effect) while the decrease in Gaussian density can be interpreted by the higher mobility of the domain walls at high temperature (extrinsic effect).
With only five parameters, this model is simple enough to be used in real-time control systems and could lead to several benefits such as reduction of hysteresis, faster response or sensorless temperature estimation.

References

[1] X. Song, *Modelling and Verification of hysteresis in Piezoelectric Actuator Drive Motors*, Master thesis report, University of Southern Denmark, 2016.
[2] C. Mangeot, T.-G. Zsurzsan, *Temperature dependency of the hysteresis behaviour of PZT actuators using Preisach model*, Actuator 2016 Conference proceedings.