High precision feed forward control of piezo actuators

Markus Raab, Stefan Baueregger, Eike-Oliver Schäfer-Nolte, Axel Witt, Volker Tietsch

Carl Zeiss SMT

Markus.Raab@Zeiss.com

1. Introduction

In high precision systems, many components need to be actively manipulated. A fundamental design decision is the selection of the employed actuator type: Force actuators (e.g. voice coil actuator) can only be used in combination with a displacement sensor, displacement actuators (e.g. ferroelectric actuators) can also be driven in open loop. The methodic actuator selection is discussed in the first part of this abstract, the second part describes the model based design of an open loop algorithm for ferroelectric actuators.

2. Actuator selection

For choosing a suitable actuator type, two major classes of actuators can be considered: Force and displacement actuators. A comparison based on two typical examples is given in table 1.

Table 1: Basic actuator types

	Force actuator	**Displacement actuator**
Example	Voice Coil	Piezo actuator (ferroelectric actuators)
Actuator input	Current [A]	Voltage [V]
Actuator output	Force [F]	Displacement [m]
Static power dissipation	P ~ F_static^2	P_static = 0
Open Loop use for static accuracy	Not possible	Possible within reproducibility of the actuator

It can be seen, that especially for quasistatic applications with constant forces displacement actuators have benefits as the power dissipation there drops to zero. In addition, the possibility for open loop operation of these actuators is advantageous, especially in use-cases where there is no space for an additional sensor.

The class of displacement actuators, especially ferroelectric actuators, are evaluated in more detail to identify the most suitable actuator material and the expected accuracy. Potential improvements by additional model based corrections are taken into account.

By reviewing literature data, the following ferroelectric actuator materials are potential candidates which need to be selected based on the given requirements

- PZT which typically has a high range (0.1 % strain) but large hysteresis (>10 %) and creep
- Lithium Niobate which have small ranges but very low hysteresis and creep
- Relaxor Ferroelectric which have large strain and low hysteresis (<3 %)

3. Control strategy

When controlling ferroelectric actuators, a first basic decision needs to be taken wether the actuator shall be controlled by voltage or by charge.

- Voltage control offers a long term stable positioning
- Charge Control offers a higher accuracy for short timescales

When the focus is set to long term stable positioning, voltage control is therefore a preferable control architecture.

Independent from the selected class of ferroelectric actuator, a model based improvement of the actuator accuracy can be achieved. Typically, relevant parasitic effects are hysteresis, settling, creep as well as actuator to actuator variations.

One approach of improving the actuator overall accuracy is to correct every actuator effect independently and connect all strategies in a unified control scheme. An example is shown Figure 1 which is explained in more in detail in the following.

- In order to get the basic actuator response into an accuracy range, the strain to voltage curve needs to be calibrated for every actuator and every system. This curve can than be fitted by means of the constitutive equations of the ferroelectric actuator material
- To improve set-get accuracy, feed forward models of hysteresis and settling of the actuator need to be implemented. This can be done by differentail equations or event based model approaches
- The 3rd class of effects are slow drifts arising predominantly from actuator creep and temperature changes. The actuator creep can be compensated by feed forward models based on a prony-series. To reduce temperature induced effects, the temperature at the actuator is to be measured and its effects are compensated based on feed forward models.

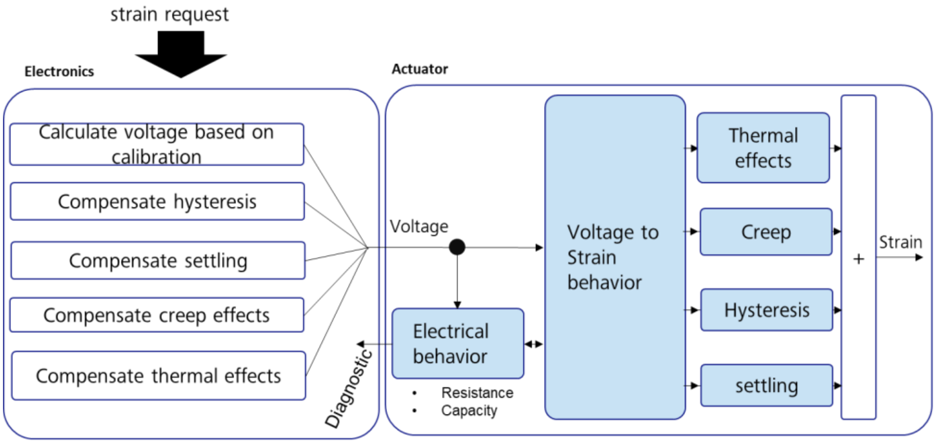

Figure 1 Compensation algorithm

Using this described algorithm, the improvement of the basic actuator accuracy in a range of x2 to x10 can to be expected.