BERGISCHE UNIVERSITÄT WUPPERTAL

IGF / AiF-Project
ZQF

Reliability and degradation analysis of smart material actuators

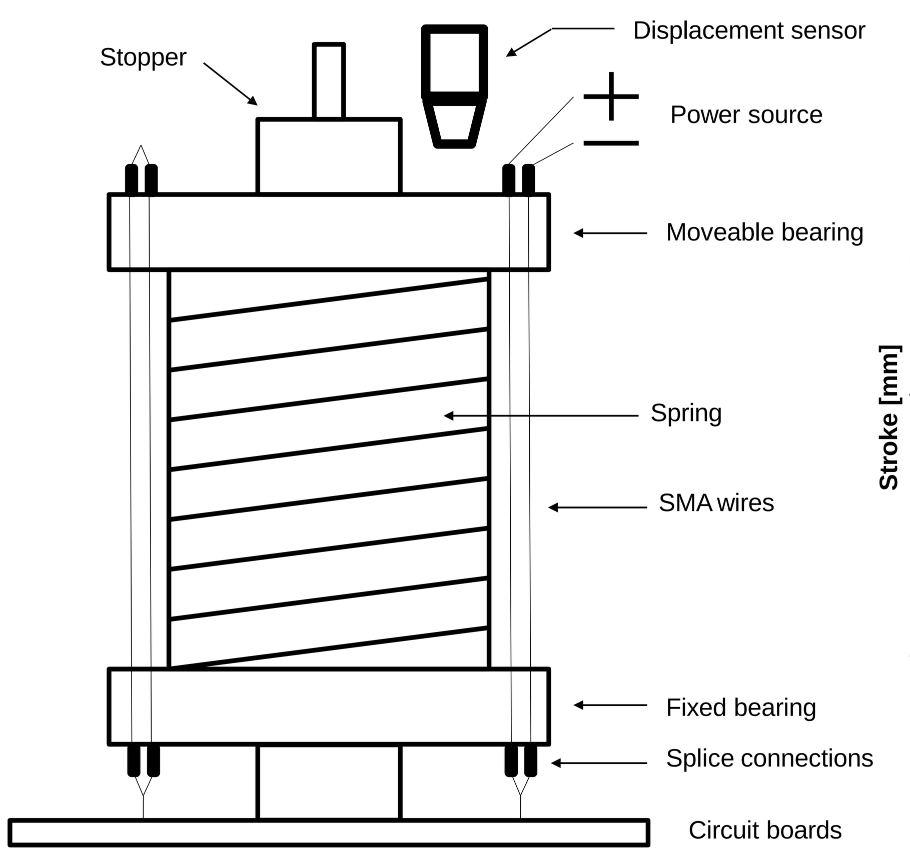
M.Sc. Philipp Heß, Univ.-Prof. Dr.-Ing. Stefan Bracke, University of Wuppertal

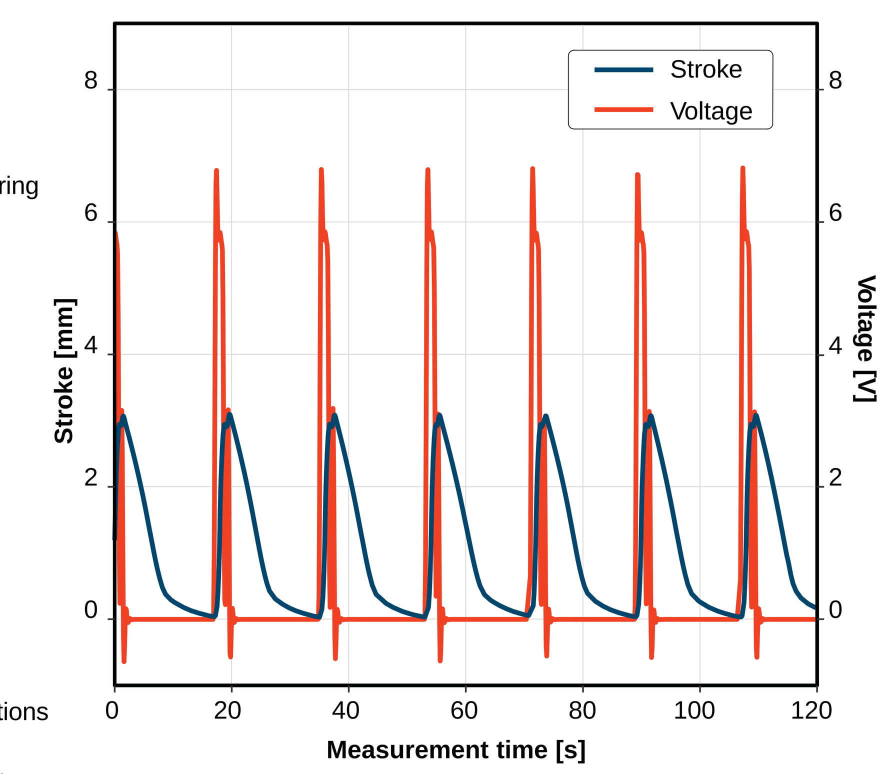
Introduction

The shape memory effect of smart material alloys (SMAs) is the ability to recover a large deformation and restore a previously imprinted shape. The effect is used in many smart material actuators (smart actuators, shape memory actuators) which have been developed and tested for various applications. The required testing time is significantly higher compared to conventional actuators. A full fatigue test of about 135.000 cycles lasts for months. An approach to shorten the testing time is a development of a prediction model to determine the End of Life (EoL) at an early stage of a fatigue test with a defined accuracy (e.g. 90%).

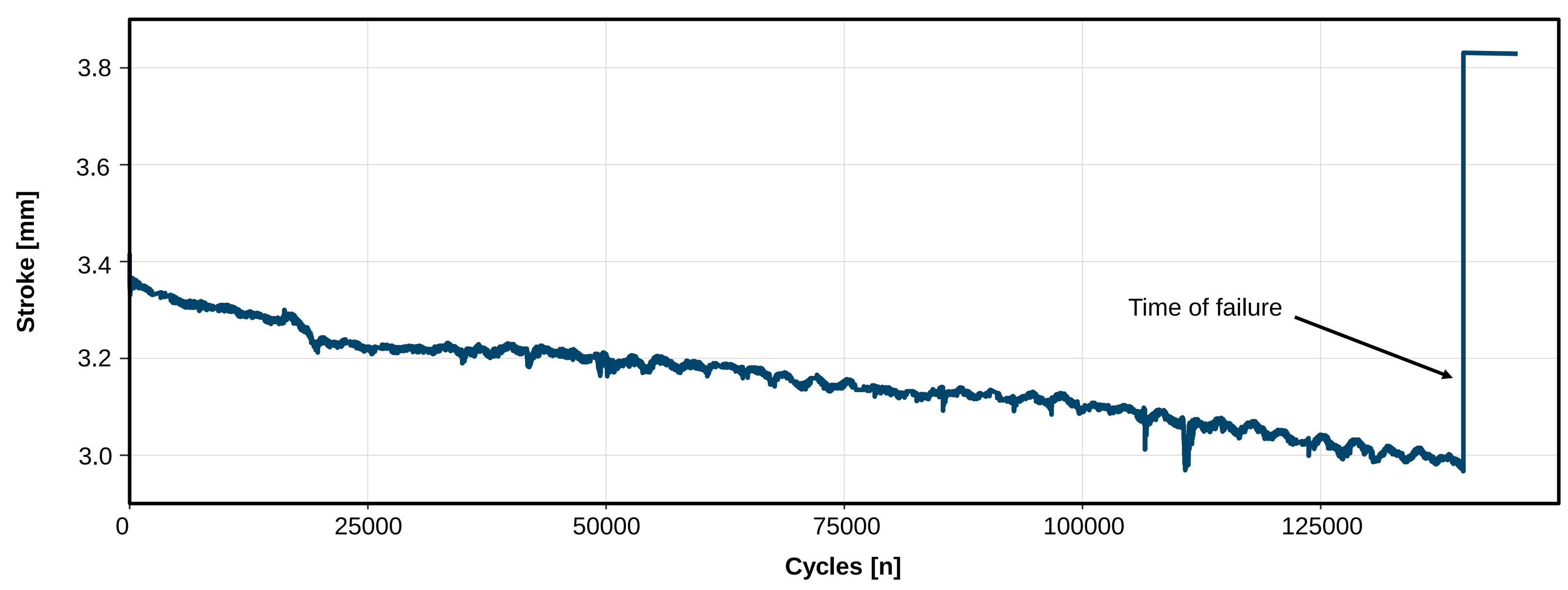
Testing of smart material actuators

Various actuator types are tested with different test benches. One type of shape memory actuators which has a spring as the resetting element is shown in the figure below. During the endurance test, the actuator is cyclically stressed (e.g. resetting force, voltage for activation, ambient temperature, etc.). The actuator is activated by a current pulse which heats up the SMA wires causing the shape change to its previously imprinted shape. Working against the force of the spring, the wires pull down the moveable bearing. During the cooling time of the wires, the spring pushes the bearing back against the stopper to its initial position. An exemplary recorded measurement time series of stroke and voltage is shown in the figure below on the right side.



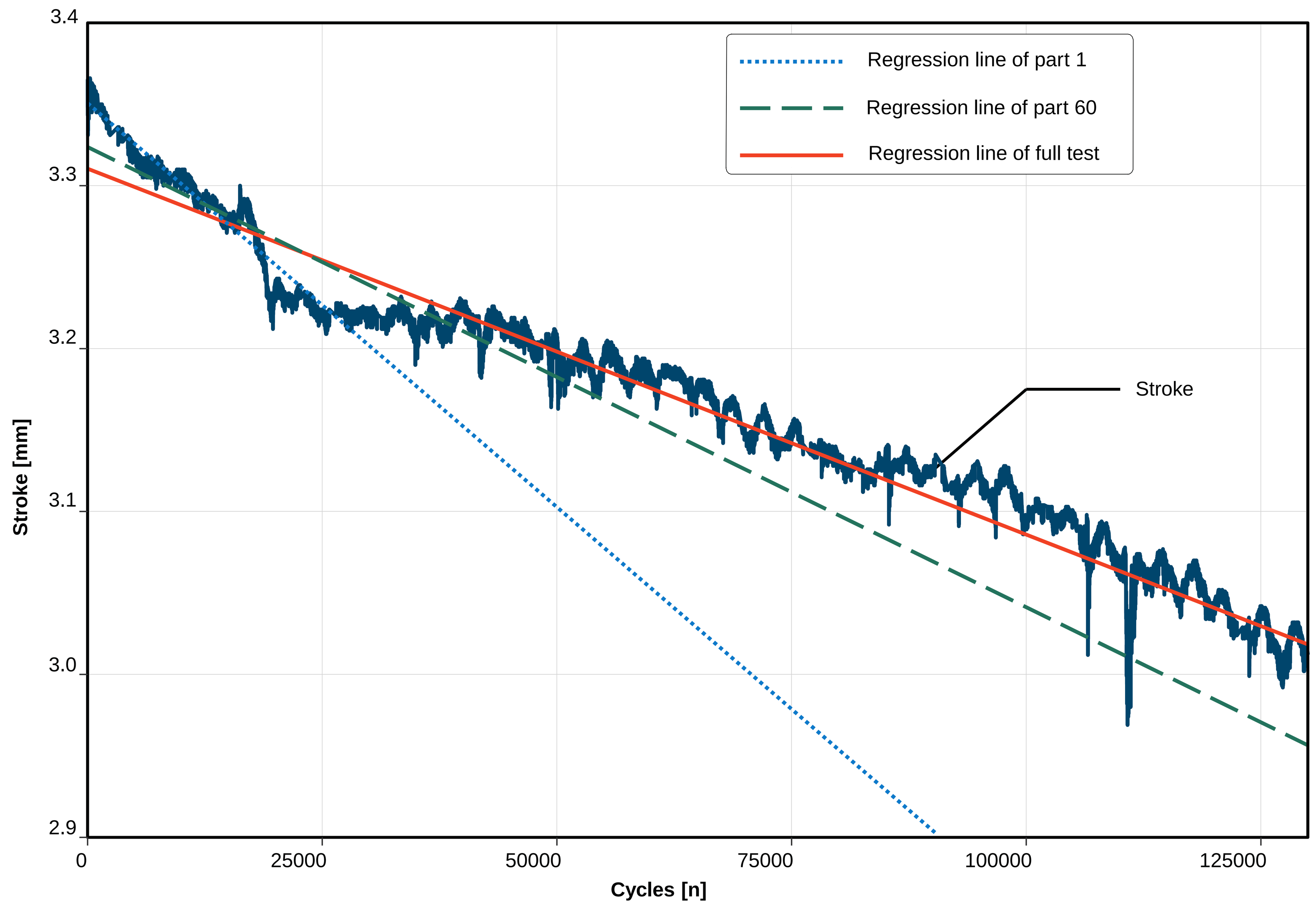


The extraction of each peak value of the fatigue test provides an overview of the stroke behavior. The diagram below shows the behavior for one actuator of one specific test rig. A clear decrease of the stroke from about 3.3 mm to 3.0 mm can be observed over the duration of the entire test. At approximately 140.000 cycles the wire breaks. The remaining actuators, coming from the same test rig, as well as actuators of another rig, show a similar course of the measured values.



Prediction of stroke values

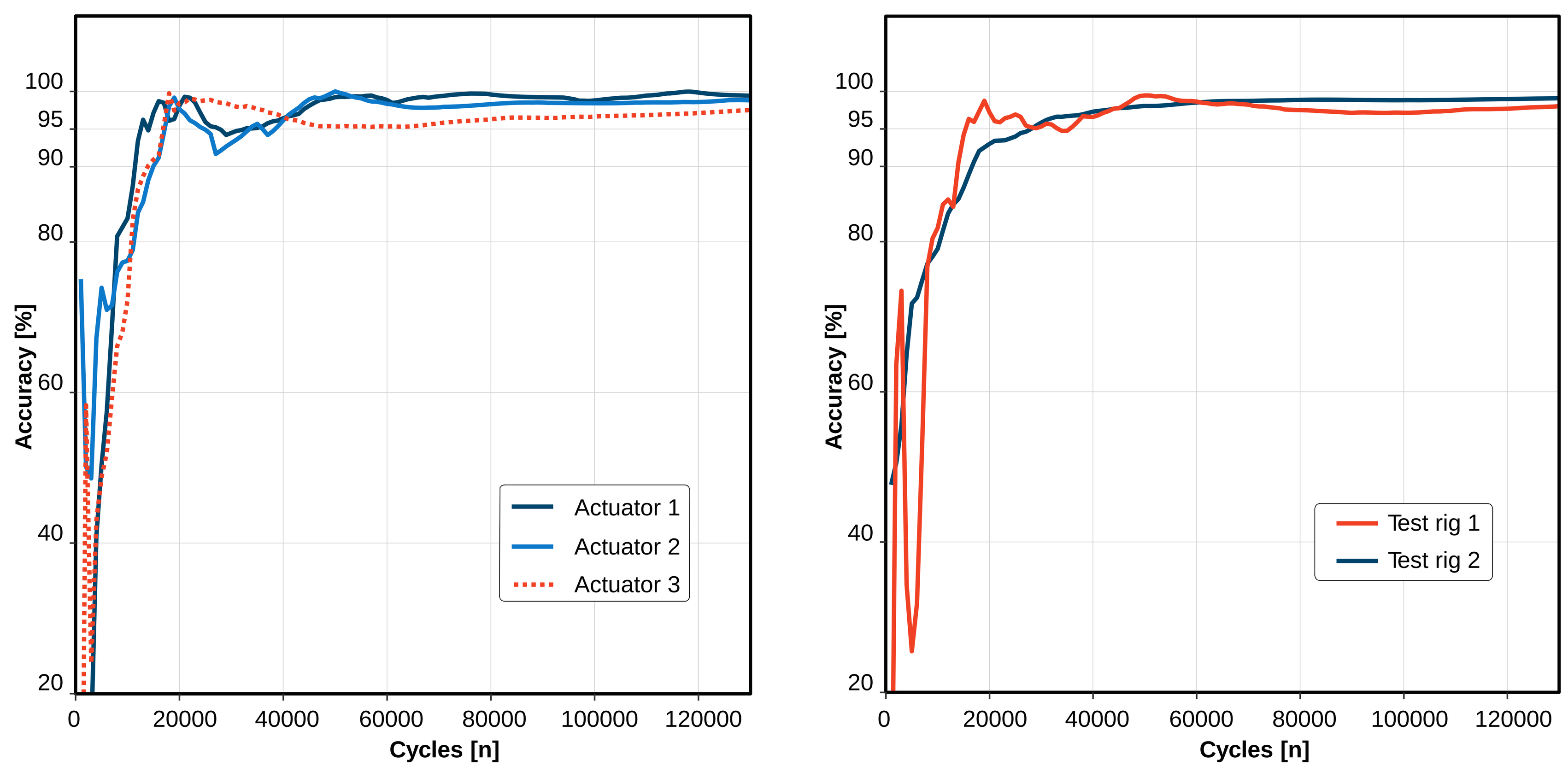
For the determination of the number of test cycles to predict the failure time with an accuracy above 90%, the measurement series is divided into accumulatively expanding parts (sections, ranges) in which only the testing range until failure is considered. The accumulation of a certain part follows the rule of interval increase by 1.000 cycles. A regression analysis is performed for each part. The regression lines are extended to the EoL point by a appropriate prediction model. The development of the stroke over time within the fatigue test with the according regression lines of two different parts and of the full test are exemplary shown in the figure below.



The predicted endpoints $Y_{predicted}$ of the regression lines are compared with the real value $Y_{failure}$, which is measured at the time of failure (reference value). The percentage of accuracy Z_Z is calculated using the following equation:

$$Zz = 1 - \frac{|Y_{predicted} - Y_{failure}|}{Y_{failure}} \; x \; 100\%$$

The graphical representation of all 130 sections of three actuators as well as the average accuracy of both test rigs is shown below.



As it can be observed, the accuracy of the prediction increases with the size of the considered measurement range until a stagnation occurs by 60.000 cycles. The value at time of failure $Y_{failure}$ with less than 50% of total cycles can be predicted with a probability of more than 90%.

CONTACT: M.Sc. Philipp Heß, Chair of Reliability Engineering and Risk Analytics, University of Wuppertal, Gaußstraße 20, 42119 Wuppertal
E-Mail: hess@uni-wuppertal.de, Homepage: www.lzr.uni-wuppertal.de, fon: +49 202 439 5091