PICA Stack Reliability Investigation

Introduction

PI Ceramic (PIC) has been investigating the reliability of PICA actuators for many years. This paper contains some typical test results that demonstrate the reliability of PICA Stack actuators under AC- and DC-operation conditions.

1. AC operation

The stacks for these tests were built from pellets with 10 mm diameter and 0.75 mm height. The applied voltage was a unipolar sine wave 0…1000 V. The resulting electric field E at 1000 V is 1.5 kV/mm.

Test conditions: normal laboratory environment; room temperature 20 to 25°C, humidity 30 to 60% rh.

Tab. 1: Tests with AC operation

Material	Stack Height [mm]	Stack Diameter [mm]	Pellet Height [mm]	Electric Field [kV/mm]	Frequency [Hz]	No. of Failed Stacks	Reached No. of Cycles
PIC151	21	10	0.75	1.5	120	0 of 4	$1.2 \cdot 10^{10}$
PIC151	21	10	0.75	1.5	30	0 of 19	$1.7 \cdot 10^{9}$
PIC151	40	10	0.75	1.5	30	0 of 11	$1.7 \cdot 10^{9}$

A lifetime could not be calculated for these samples because none of them failed. So, with this drive signal the meantime to failure (MTTF) of all stacks is much better than $2 \cdot 10^{9}$ cycles, in the first case even better than 10^{10} cycles.

2. DC operation

The DC-lifetime of an actuator is limited by a decrease of its insulation resistance. In the tests a sample failure is defined as the decrease of the resistance to 0.1 % of its initial value. Please consider that this value is no specification because the tolerable leakage current depends also on the power of the amplifier which is used. The MTTF was calculated when at least two thirds of the samples had failed, otherwise the testing time was considered to be the lower limit of the MTTF.

Tests in a normal laboratory environment showed that it is nearly impossible to find a dependency of the MTTF from the electric field in a short time (see section 2a). Therefore tests under severe conditions were made (see section 2b).

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a) long-term lifetime tests under lab conditions

For these tests, the sample stacks were built from different materials and feature different pellet heights. Therefore the applied DC-voltage of 1000 V results in different electric fields.
Remark: a standard PICA Stack actuator has a pellet height of 0.5 mm. Hence the nominal voltage of 1000 V induces a nominal electric field of 2 kV/mm.

Test conditions: normal laboratory environment; room temperature 20 to 25 ℃, humidity 30 to 65% rh. Test duration: 17,900 hours (2 years).

Tab. 2a: Tests with DC operation in a normal laboratory environment

Material	Stack Height [mm]	Stack Diameter [mm]	Pellet Height [mm]	Electric Field [kV/mm]	No. of Failed Stacks	MTTF [hrs]
PIC255	72	10	2.00	0.5	0 of 3	**much better than 2 years**
PIC255	36	10	1.00	1.0	0 of 3	**much better than 2 years**
PIC255	28	10	0.75	1.5	0 of 3	**much better than 2 years**
PIC153	34	25	0.75	1.5	1 of 3	**much better than 2 years**
PIC255	34	25	0.50	2.0	2 of 3	**13150**
PIC151	19	10	0.50	2.0	3 of 3	**13110**

b) accelerated lifetime test in a severe climatic environment

In this test PICA actuators with 10 mm diameter that consist of pellets of different heights were tested with an applied DC-voltage of 1000 V. The environment was chosen to simulate severe climatic conditions especially high humidity.

Test conditions: temperature 40℃, humidity 70% rh.

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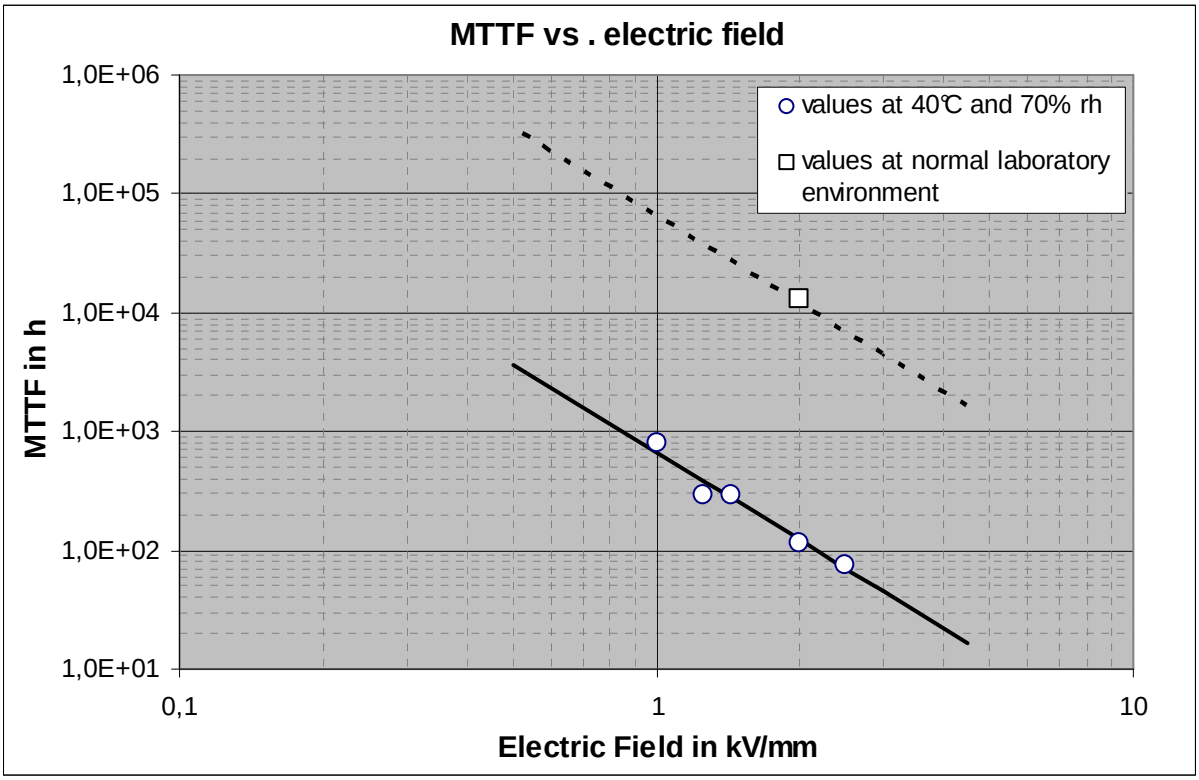
Tab. 2b: Tests with DC operation in a severe humid environment

Material	Stack Height [mm]	Stack Diameter [mm]	Pellet Height [mm]	Electric Field [kV/mm]	No. of failed stacks	MTTF [hrs]
PIC 151	16	10	0.4	2.50	3 of 3	76
PIC 151	19	10	0.5	2.00	3 of 3	117
PIC 151	26	10	0.7	1.43	3 of 3	296
PIC 151	30	10	0.8	1.25	3 of 3	290
PIC 151	36	10	1.0	1.00	3 of 3	803

Comparing these results with the results of the test under normal climatic conditions at 2 kV/mm (see section 2a) one recognizes that under dry conditions the lifetime is about 100 times better.
With the results from the accelerated test the following dependency of the MTTF from the electric field can be observed:

Fig. 2b: Lifetime in dependency of the electric field



The linear fit-curve on the log-log-plot shows the characteristics of the relation between electric field E and the MTTF (circles in Fig. 2b). The MTTF is proportional to $(1/E)^n$, where an exponent **n = 2.45** can be calculated.

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This exponent can be used to estimate the increase in lifetime when lowering the voltage. In addition it is also possible to extrapolate the MTTF for the values in section 2a with the given values at 2 kV/mm (see dashed line in Fig. 2b).

3. Conclusion

PICA Stack actuators show an excellent behavior at AC-signal driving. Lifetimes far above 10^9 cycles are proven in several tests.

More care has to be spent at DC-signals especially under humid conditions.
A two-year DC-lifetime test under lab conditions on PICA Stack actuators made of different materials and geometries showed very good results at electric fields which correspond to reduced DC-driving voltages.
An accelerated lifetime test was conducted at elevated humidity which lowers the measured DC-lifetime considerably. Therefore, PI Ceramic recommends to use PICA Stack actuators at elevated humidity just at significantly reduced DC-voltages. The results showed an exponential law for the MTTF-DC-electric-field-relation where the exponent is 2.45. This relation can be used to extrapolate the measured MTTF of the tests in this report to lower voltage ranges.

Remark: humidity effects on the lifetime are just relevant for DC-signals because the self heating effect of the stack during AC-operation results in a dramatically lower local humidity.

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