EVALUATION OF PIEZOCERAMIC ACTUATORS

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ABSTRACT

The paper describes a lot acceptance test program performed on piezoceramic actuator components (MLA). Electrical tests are based on multilayer capacitors standards. Functional, mechanical, and lifetime tests, specific to piezo components, are added. The procedure was validated by a full test campaign on 2 piezoceramic actuator component references, from 2 different manufacturers.
The sources tested are compliant with the space applications needs. Some precautions shall be taken into account for the on-ground operations, because of the humidity susceptibility.

1. INTRODUCTION

The number of space applications using piezoelectric actuators is growing years after years (submicron positioning for optics, shutter, nonmagnetic motors, etc). A few years ago, a manufacturing source of piezo ceramics was qualified by CNES and CEDRAT. But the disengagement of this manufacturer from the space market showed the difficulty to have a sustainable source. Instead of qualifying a manufacturer, the solution was to establish a lot acceptance test plan.

The two sources were selected on the basis of the known reliability of their actuators, the sizes and geometries available, the production flexibility. The samples used for this evaluation test campaign were similar for the 2 sources: same size, same voltage, and same stroke. The piezo material is a PZT ceramic, semi soft type, displaying a Curie temperature of 300 °C. This material also displays a moderate high d_{33} coefficient allowing achieving 1000 ppm under 150 V.

The samples sources are called S1 and N17. Their size is 10mm length with an active surface of 5x5mm.

The S1 piezo is in fact composed of 3 MLA, glued together. The component uses a buried internal electrode scheme. The electrical insulation is obtained at the ceramic level. The link between the MLAs is obtained through a curved copper wire, soldered to the component external electrodes.

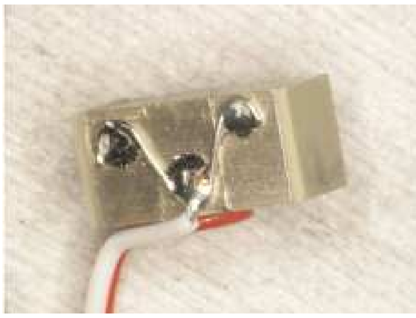

Figure 1. S1 piezoactuator

The N17 piezo uses open internal electrodes. The electrical insulation is performed by using half cylinders made from glass. The external insulation is deposited onto these insulation half cylinders. The soldered wires are connected to the external electrodes in a non active zone of the component (end plate).

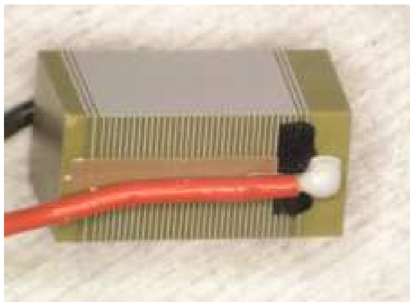

Figure 2. N17 piezoactuator

2. TEST PLAN

The piezo multilayer actuators use a similar construction with the multilayer ceramic capacitors. Then, the electrical tests are based on the capacitor ESCC standards [1]. The mechanical and humidity tests are specifically defined to cover most of the space applications requirements.

For each source, the test plan use 4 groups of components from the same lot production.

- 1st group (3 samples) is the reference group dedicated to functional characterization. A destructive part analysis (DPA) is also planned
- 2nd group (3 samples) is dedicated to electrical characterization

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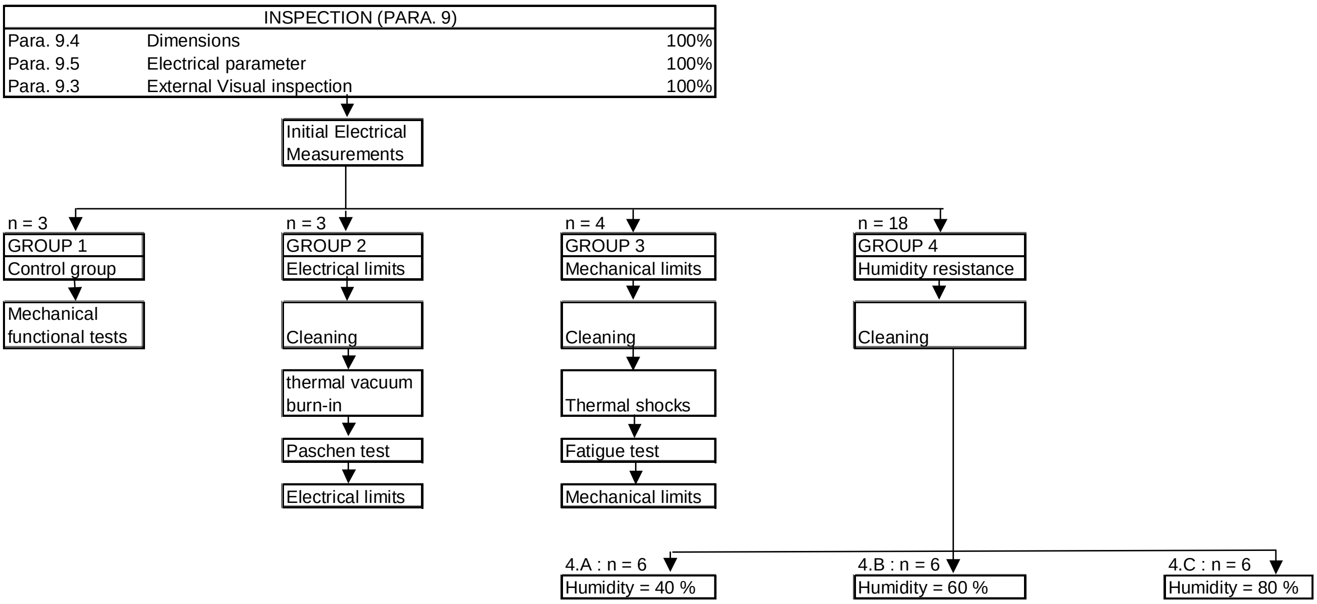

Figure 3. Test plan

- 3rd group (3 samples) is dedicated to mechanical characterization
- 4th group concerns the life test of the MLA when operated under a high humidity environment. It is divided into 3 subgroups of 6 samples for different humidity levels.

3. TEST RESULTS

3.1. Electrical Measurements

This test is done on all the samples. Its purpose is to evaluate the performance of the piezoceramic. The parameters measured are the no-load stroke and the resonance frequency. The resonance frequency is an important information about the mechanical health of the ceramic. Any out of family piece shall be rejected.
For the S1 component the deviations are about 5% on the frequency and 10% on the stroke. For the N17 component, the deviations are about 3% on the frequency and 15% on the stroke.
A shift on the resonance frequency after a mechanical or thermal test is a sign of a mechanical deterioration of the piezo. This parameter has to be controlled after each phase of the test campaign.

3.2. Mechanical functional test

In addition to the no-load stroke, a blocked force measurement was carried out. The S1 and N17 piezos achieve respectively a 950N and 1050N force at 150V, corresponding to a stress of 40MPa.

Figure 4. Test bench for blocked force measurement

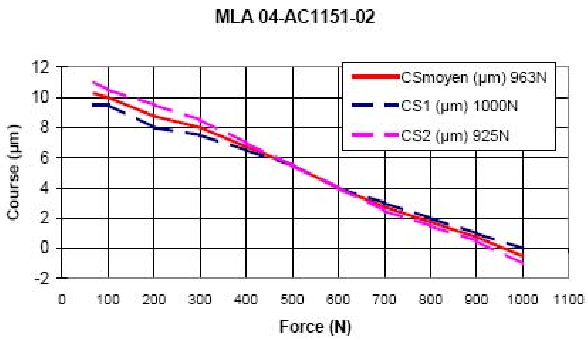

Figure 5. Measured load characteristics

3.3. Electrical limits

This test is performed to evaluate the margin on the voltage supply, and so to confirm the derating hypothesis. The maximum voltage during nominal operation is 150V. For the test, the DC voltage was increased step by step up to 450V. The step is 25V and its duration is 1minute. One S1 piezo failed at 450V after 40sec. No other failure was recorded.

3.4. Thermal vacuum test

The piezo are operated in a thermal vacuum chamber. This test is used as a burn-in test to evaluate the reliability of the lot.
8 cycles were executed between -30/+85°C. A 150V voltage at 100Hz was applied during this test. Note that when the piezo is dynamically operated, the self heating is not negligible at all.
All components from the 2 sources passed this test.

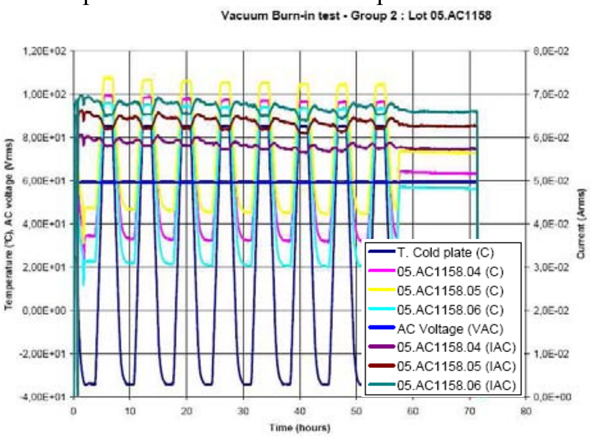

Figure 6. Voltage and current during thermal cycles

As the electrical field is important in the piezo (about 1.5kV/mm), it could be subject to the Paschen effect. At the thermal vacuum test, a Paschen test was performed. The thermal vacuum chamber was progressively filled in with dry nitrogen, whilst the samples were driven at 150VDC. No current surge was observed.

3.5. Thermal shock test

The MLAs are composed of different materials: PZT, internal electrode, external electrode, coating. Thermal shocks create differential strain in the component which can lead to cracks.
The piezo were submitted to:

- 10 cycles -20/+70°C
- 15 cycles -30/+80°C
- 25 cycles -55/+85°C

The functional tests after thermal shocks (resonance frequency, no-load stroke) were compliant to the initial test.

3.6. Mechanical limits

The MLA can not accept any tensile force by itself. So, for the 3rd group (mechanical), they were prestressed at 20MPa thanks to steel structure. Its design is the standard concept of Cedrat PPA actuators.
This test is used to validate the hypothesis used for the mechanical design: limit of 100MPa for compression and 0MPa for tensile.
The mechanical strength is dependant on the prestress applied on the ceramic. In our case, this was of 20MPa.
The compression test was done until 2000N, corresponding to 100MPa (including prestress). No failure was observed.
The tensile test is a more difficult measurement. The design rule is that piezoceramics can not withstand any tensile stress. The mechanical strength in this direction is only fixed by the prestress. So this test has to be done at the actuator level.
The measures show an important non linearity before the prestress level. The presence of contact stiffness is the most probable reason. The flatness and the parallelism of the two external active faces of the MLA is then a point to control.

3.7. Fatigue test

1.2 billion cycles at 80% of the full stroke were performed to test the mechanical fatigue. The component is driven in blocked-free conditions at the mechanical resonance and a forced convection is used to limit the self heating.
One S1 piezo failed this test. The other samples were compliant to the functional test.

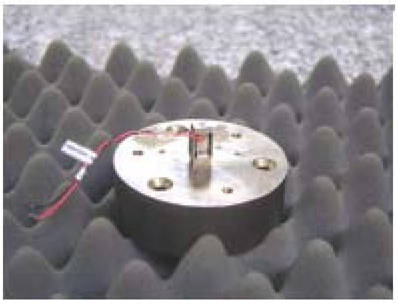

Figure 7. Piezoactuator PPA10M

3.8. Humidity test

The purpose of the humidity test is to validate the use of the MLA during the on-ground operations. A clean room environment is of 55%Rh +/-10%. This phenomenon is known by all the manufacturers, but not clearly understood. Note that this problem is only present when the piezo is ON, and only with a DC voltage. That means that there is no criticality for the storage period, nor when it is used for a dynamic application (that's the case for example in the automotive applications).

3 humidity rates (40%, 60% and 85%Rh) were tested with 3 subgroups of 6 components. On each subgroup, 3 components were continuously driven with a maximum DC voltage (150V). The 3 others were driven with the following ON/OFF cycle: 150V during 8hr, 0V during 8hr. The test duration was 2000hr, at room temperature.

The control parameter is the leakage current. At the beginning, the current is under 0.1mA for all the piezo of the 2 sources. After some tens of hours, the leakage current increases progressively, but with a wide dispersion between the components of a same subgroup. Some remain stable; others have an increase up to more than 1mA. This insulation resistance deterioration is permanent after the test.
Note that the ON/OFF cycle is the most critical driving mode regarding to humidity resistance.

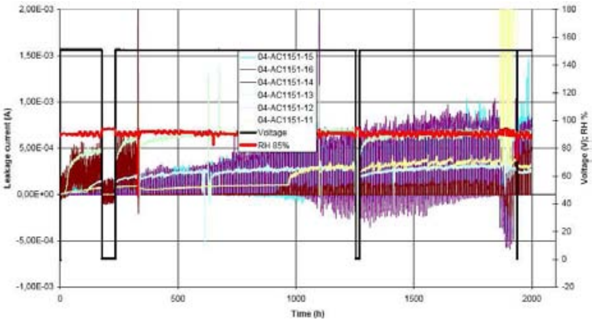

Figure 8. N17 leakage current during humidity test at 85%Rh

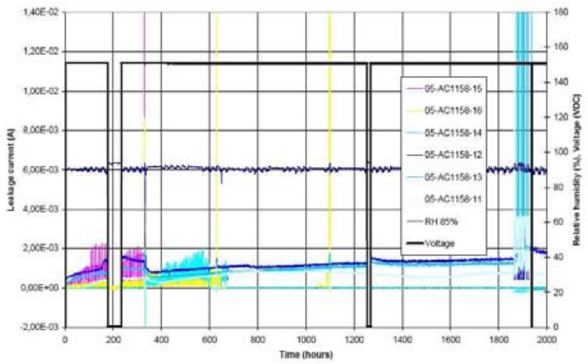

Figure 9. S1 leakage current during humidity test at 85%Rh

3.9. DPA

A destructive physical analysis is an operation that helps understanding and comparing the internal construction of piezoelectric multilayer components. The level of porosity, the presence of cracks, the quality of the soldering connection between the wire and the external electrode, are aspects easily revealed during this Destructive Physical Analysis.

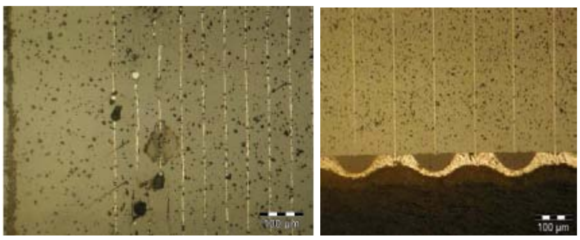

Figure 10. Two examples of destructive physical analysis

Cracks or delaminations sometimes occur in piezoelectric components (Fig. 10): it is sometimes difficult to judge the severity of such cracks and its effect on the reliability of the component. Another typical defect is the lack of thickness homogeneity of the layers, which may result from a thermo-mechanical mismatch during sintering, or production problems of the green layers.

More recently, the application of the Reduction Of Hazardous Substances (Rohs) on piezoelectric component has lead to problems. The piezoelectric material itself often contains lead oxides that are exempted from this directive. However, the soldering connection concerned: non-lead soldering connections are more difficult, due to a higher temperature. The Fig. 11 shows an example of a non lead soldering connection of bad quality that is also responsible for a crack occurrence. The aerospace industry requires such Destructives Physical Analysis to be performed for each production lot, to monitor the quality assurance product.

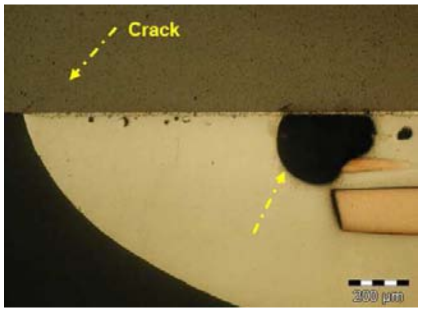

Figure 11. View of a non-lead soldering connection

4. CONCLUSION

The tested lot of 28 components of the N17 component was divided into 4 groups and the evaluation test program was completed according to the test plan.

No failure has been encountered, despite relatively long humidity resistance tests.

On the contrary, the results have been less positive for the S1 component. Similarly, the tested lot of 28 components of the S1 was divided into 4 groups and the evaluation test program was also completed according to the test plan.

In the group 2 involving destructive tests (electrical limits), 1 failure was encountered, but with a voltage 3 times higher than the operational voltage.
In the group 3, one (unexpected) failure was encountered during the mechanical fatigue test.

In the group 4, one early failure was encountered after 300 hours of DC voltage = 150 V at the humidity rate 85 %Rh. Two additional failures were encountered

between 1000 and 2000 hours of operation (DC voltage = 150V; Relative humidity = 85 %Rh).
This last result implies user guidelines during AIT operations: limit DC driving to a total of 150hr in clean room conditions.

The mechanical limits and DPA have been executed at CNES. All the other tests at Cedrat Technologies.

This test plan allows validating the piezo characteristics (stroke, admittance), its physical limits (mechanical resistance of the PZT, electrical limits, fatigue) and its behaviour under space environment (thermal vacuum, thermal shocks). It can be adapted for specific applications like cryogenic environment.

A DPA appears to be the most important control to check the lot production quality. For future procurements, the DPA must be carried out to check that the manufacturer has not changed its design or quality process, allowing keeping valid the evaluation campaign heritage.

This work could be a first step to establish an ESA SCC standard documents (generic and detailed) for the piezoceramic actuator components.

5. APPLICATION

The N17 source will be used on the SODISM instrument, which is one of the 3 instruments of the PICARD satellite. SODISM is an imaging telescope (11cm diameter) accurately pointed and a CCD which allows to measure the solar diameter and shape, and to perform helioseismologic observations to probe the solar interior. It is designed by the "Service d'Aéronomie" laboratory (CNRS). The instrument pointing accuracy is achieved thanks to a piezoelectric system acting on the telescope primary mirror which allows to stabilize the sun image on the CCD with an accuracy of 0.1 arc second. This system is composed of 3 piezoactuators PPA40M from CEDRAT Technologies, that are modified to get a higher mechanical preload and include N17 piezoceramics.

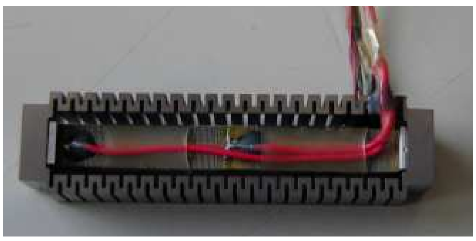

Figure 12. Direct Piezo Actuator used in PICARD

6. REFERENCES

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