Study of Different Piezoelectric Material Stroke Displacement with Respect to Temperature Using SRF Cavity

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Introduction

- Piezoelectric (piezo) actuators have a wide array of applications such as in resonance control in SRF linacs and various experiments in dilution refrigerators (heat capacity μWs).
- In these applications a large stroke and small heat dissipation is crucial, two piezo materials will be compared with these characteristics.
- PZT is the most widely used material for actuators, it provides a larger stroke but it heats up rapidly.

Table 1: Comparison of PZT and LiNbO3 figures of merit. The stroke for LiNbO3 is from -500 V to 500 V. For PZT it is 0 to 100 V.

<table>
<thead>
<tr>
<th>Material</th>
<th>LiNbO3</th>
<th>PZT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length [mm]</td>
<td>36</td>
<td>18</td>
</tr>
<tr>
<td>Cross-section [mm²]</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Stroke (900 K) [μm]</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Stiffness (N/m)</td>
<td>195</td>
<td>200</td>
</tr>
<tr>
<td>Blocking Force [N]</td>
<td>585</td>
<td>3600</td>
</tr>
<tr>
<td>Cure Temperature [K]</td>
<td>1423</td>
<td>623</td>
</tr>
<tr>
<td>Density ρ [g/cm²]</td>
<td>5</td>
<td>7.80</td>
</tr>
<tr>
<td>Relative Permittivity ϵ33/ϵ0</td>
<td>28.7</td>
<td>1750</td>
</tr>
</tbody>
</table>

- LiNbO3 produces 0.3 % of heat dissipation of PZT but has a stroke of 8.3 % of PZT at room temperature, see Table 1 for properties of both.
- From literature it is known that LiNbO3 doesn’t decrease the displacement stroke as drastically compared to PZT.
- An SRF cavity was used to measure the piezo stroke due to its extreme sensitivity to longitudinal deformation.

Cavity Frequency Tuner

- The LCLS-II tuner is used, it consist of a stepper motor and piezos
- The cavity-tuner system is supported by an aluminum frame
- There are two piezos capsules which are used to control the frequency, in this case a PZT and LiNbO3 capsules were used (See Figs. 1 and 2)
- The PZT capsule has a Ceranox RTD attached to the PZT body, this is used to monitor the temperature
- The piezos are preloaded with the tuner to prevent any slack once cooled down
- The whole setup is inserted in a Dewar which is filled with liquid helium
- The frequency sensitivity of the cavity to longitudinal deformation is 2.3 kHz/μm and the cavity stiffness is 23 kN/mm
- The efficiency of the tuner is 40 % when both piezos are used, 20 % when only one piezo is used
- The method of the piezo stroke measurement is illustrated in Fig. 3 where the frequency shift of the cavity is related to the piezo stroke

Measurement at 4 K

- After cooling down to 4 K the stainless-steel frame becomes stiffer by 5% compared to room temperature, this improve the tuner efficiency by the same amount
- This effect is taking into consideration for the stroke calculations

<table>
<thead>
<tr>
<th>Piezo Type</th>
<th>Capacitance [μF]</th>
<th>Piezo Sensitivity [Hz/V]</th>
<th>Calculated Stroke [μm]</th>
<th>Stroke Ratio 4 K/300 K [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>293 K</td>
<td>4</td>
<td>-112</td>
<td>-26.4</td>
<td>22.4 ± 2.2</td>
</tr>
<tr>
<td>4 K</td>
<td>-1.393</td>
<td>3.0 ± 0.3</td>
<td>2.7 ± 0.2</td>
<td>90.4 ± 11.2</td>
</tr>
</tbody>
</table>

- Fig. 5 shows the data for PZT during warmup, the measurements stopped after 91 K because the frequency of the cavity was changing drastically due to thermal effects
- The measurements could not be done for LiNbO3 due to larger frequency shifts due to thermal effects
- The stroke of the piezo is calculated with the equation:

\[
\frac{D}{D} = \frac{\Delta \varepsilon}{\varepsilon_0} + \frac{\Delta \mu}{\mu} + \frac{\Delta \varnothing}{\varnothing_0}
\]

- Where Δ is the frequency shift, E is the efficiency of the tuner at 20 % for a single piezo, and S is the cavity sensitivity at 2.3 kHz/μm
- Each of these parameters carry an uncertainty, the error for the stroke is given by

\[
\Delta D = \sqrt{\left(\frac{\Delta \varepsilon}{\varepsilon_0}\right)^2 + \left(\frac{\Delta \mu}{\mu}\right)^2 + \left(\frac{\Delta \varnothing}{\varnothing_0}\right)^2}
\]

- The calculated stroke is shown in Table 2

Table 2: The piezo sensitivity for 293 K is from 0 to 100 V. At 4 K it is from 0 V to 100 V. For LiNbO3, it is from -500 V to 500 V at room temperature and at 4 K.

Conclusion

- The results show that PZT stroke is reduced to 22.4 % of the value at room temperature which is larger than the previously reported in the literature
- The stroke of LiNbO3 was measured for the first time with an SRF cavity and it is 90.4 % of the room temperature value

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