Deflection measurements of thin foils for the muon cooling channel RF cavities

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Introduction

The RF accelerating section of the muon cooling channel benefits from high accelerating gradient and high shunt impedance. One means of achieving this is to use interleaved chains of pillbox cavities, with a phase shift of $\pi/2$ between sets of cavities. RF isolation between adjacent cells is achieved by the presence of thin Be foils, through which the muon beam passes, and which define one surface of the "pillbox" cavities. Thus configured, the accelerating field is equal to the surface field, and is maximum on the cavity axis. Engineering such foils to successfully operate in a demanding environment with RF heating and deformation of the foil presents a challenge. This note describes experiments at room temperature to measure the temperature distribution and deformation of thin foil windows, in particular Be windows for the above application.

Be windows

The neutrino factory and muon collider collaboration has purchased three beryllium windows from Brush Wellman Electrofusion Products, for test purposes, see Figure 1. These windows are fabricated from a circular disc of 0.005" thick, 99.8% Be foil, diffusion bonded into an annular beryllium frame. The frame consists of two 0.063" thick rings, internal diameter 6.3", outside diameter 7.58", and the foil is sandwiched between these rings. The foil is under tension at room temperature, and is flat to within 0.001".

Experimental technique

The experimental layout is shown in figure 2. Figures 3 and 4 show photographs of the apparatus. The window under test is clamped against an annular flange through which coolant flows to maintain a constant temperature at the frame. One surface of the foil is blackened with a thin water-based paint to increase its emissivity. A halogen lamp connected to a variable power supply is mounted behind the foil at a distance of approximately 5 cm, calculated to provide a temperature profile approximately equivalent to that produced by RF heating of the foil in an 805 MHz RF cavity [1]. The lamp, designed to be a point source which gives us a known heat input distribution, illuminates the blackened surface of the foil. On the opposite side of the foil a mechanical displacement probe is mounted against the window to measure deflections of the foil. The force of the displacement probe is 40.5 grams at zero displacement, rising to 45.6 grams at 5mm displacement. This defines the direction in which the foil will move when it buckles. The probe is mounted on a traversing stage to allow the profile of the foil to be measured - point measurements are taken across the diameter of the foil, in a horizontal

Figure 1. Be window assembly

line. A thermal imaging camera views the window, as well as some reference temperature sources to the side of the window for calibration purposes. The output of the camera is digitized and the temperature profile across a diameter of the foil can be derived.

As the lamp power is increased (determined from current and voltage measurements), the temperature of the window rises and is measured by the thermal camera. Once at equilibrium (which takes only a few seconds for the very thin foils), the mechanical displacement probe is scanned across the surface of the foil to measure its profile.

In addition to the Be foils purchased from Brush Wellman Electrofusion Products, we fabricated Al and Cu foils of the same dimensions, using screw-together frames to support the foils. These were to be used as test pieces of known physical properties, for comparison with the Be window. Two Al foils were made, one with no pre-stress applied when mounting the foil into its support ring, and another which was heated before being clamped into the support ring in an attempt to provide some tension in the foil. Measurements were made in a temperature-controlled low-humidity enclosure to minimize external effects and improve accuracy of the thermal measurements [2].

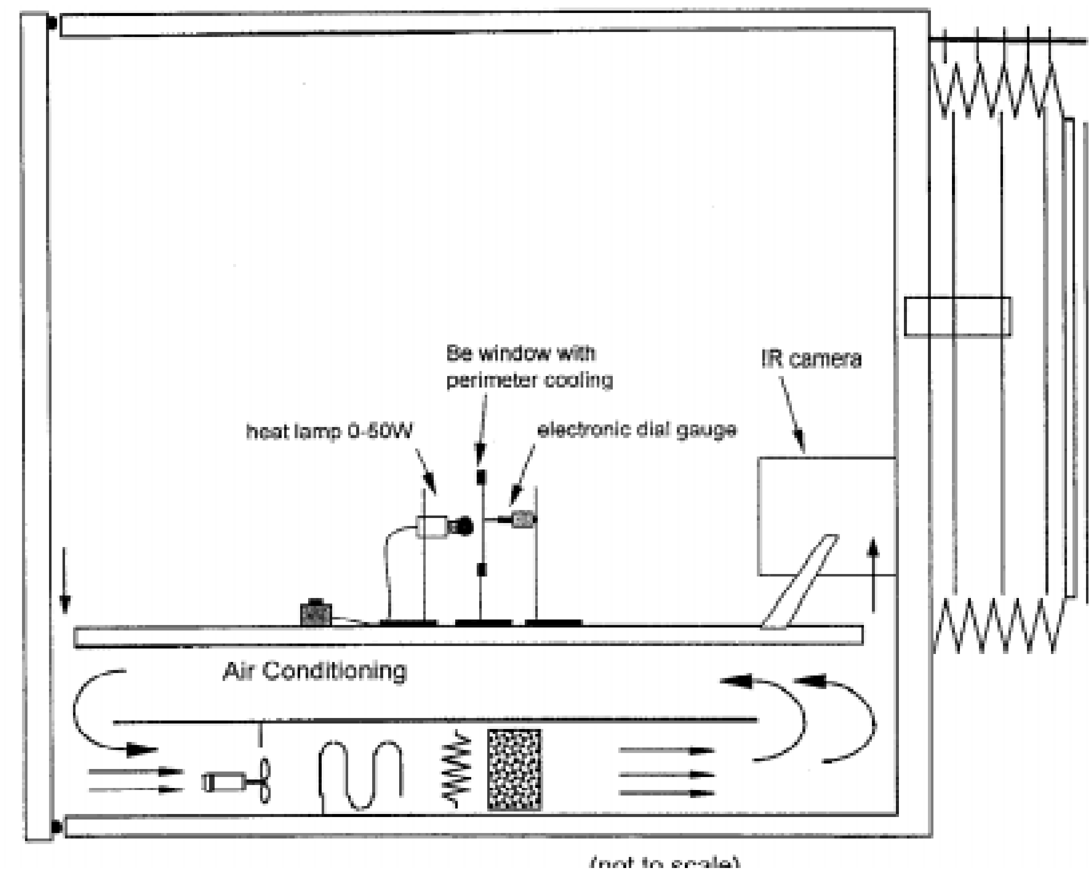

Figure 2. Experimental layout in temperature-controlled enclosure.

Results

Measurements were made for two conditions: 36 W and 71 W dissipated in the halogen lamp. The frames (periphery of the foils) were held at approximately 21°C for each condition . The resultant temperature at the center of the foil was up to 34°C for the 36 W case and 47°C for the 71 W case. Figures 5 and 6 show the thermographs for the Be window for these two power levels, (the H,V aspect ratio is distorted).

Figures 7 and 8 show the temperature distribution along the horizontal axis of the foil, for each of the four windows measured. The annotation *ns* indicates no-stress, and *ps* indicates pre-stressed foils. The Be window and the two Al windows show similar temperature distributions, to be expected from these materials having similar thermal properties at room temperatures. The Cu window shows a lower temperature rise, also expected from the higher thermal conductivity of Cu.

The temperature distribution is qualitatively similar to that predicted for RF heating in the cavity [1].

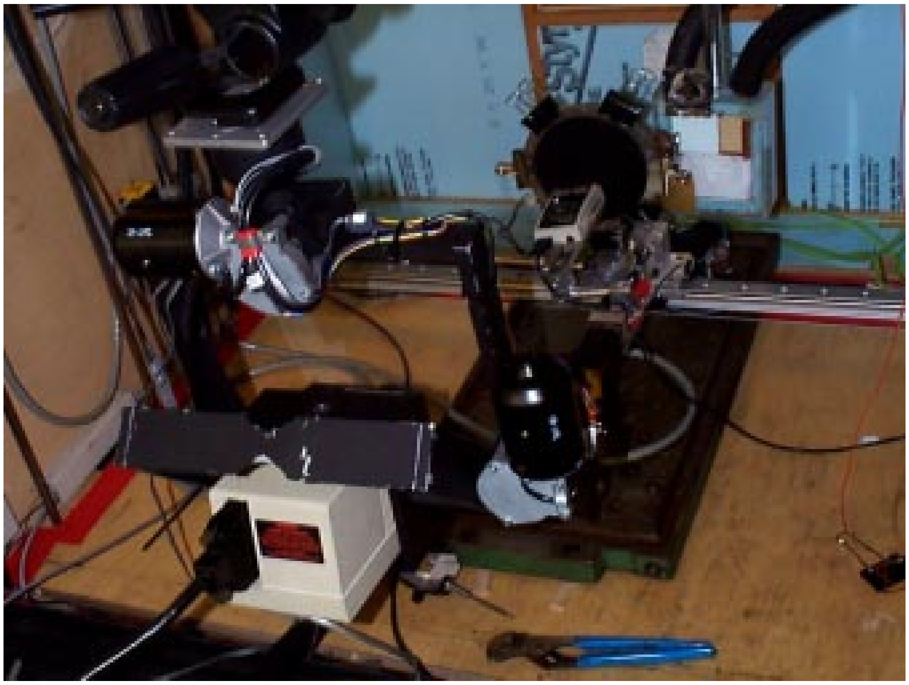

Figure 3. Experimental layout. The thermal imaging camera is the white box on the left.

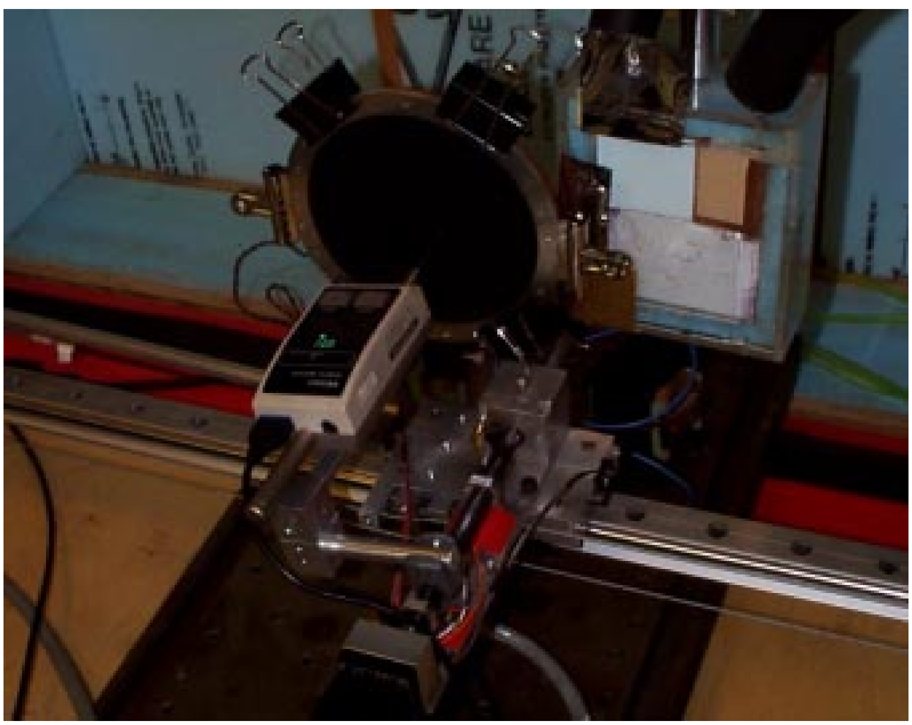

Figure 4. Experimental layout. The blackened window, cooling ring clamps, displacement probe on its traversing system, and reference temperature strips (to the right of the window) can be seen. The halogen lamp is behind the window in this view.

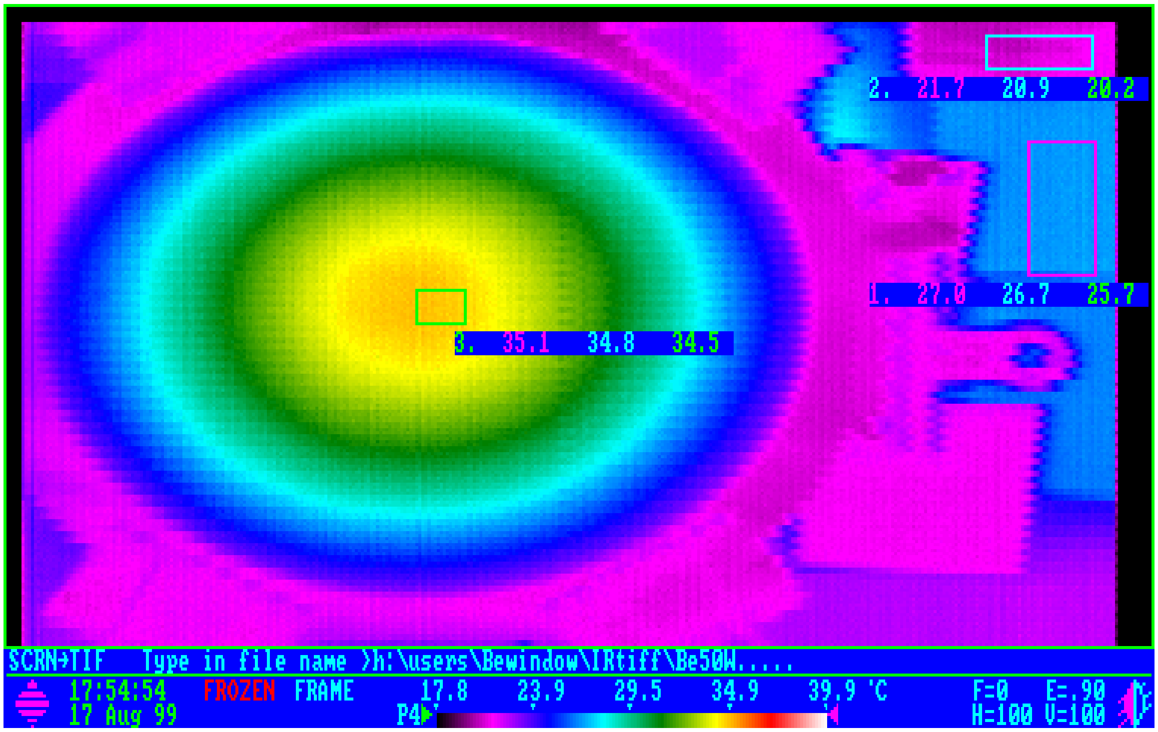

Figure 5. Thermal image of beryllium foil, 36W lamp power.

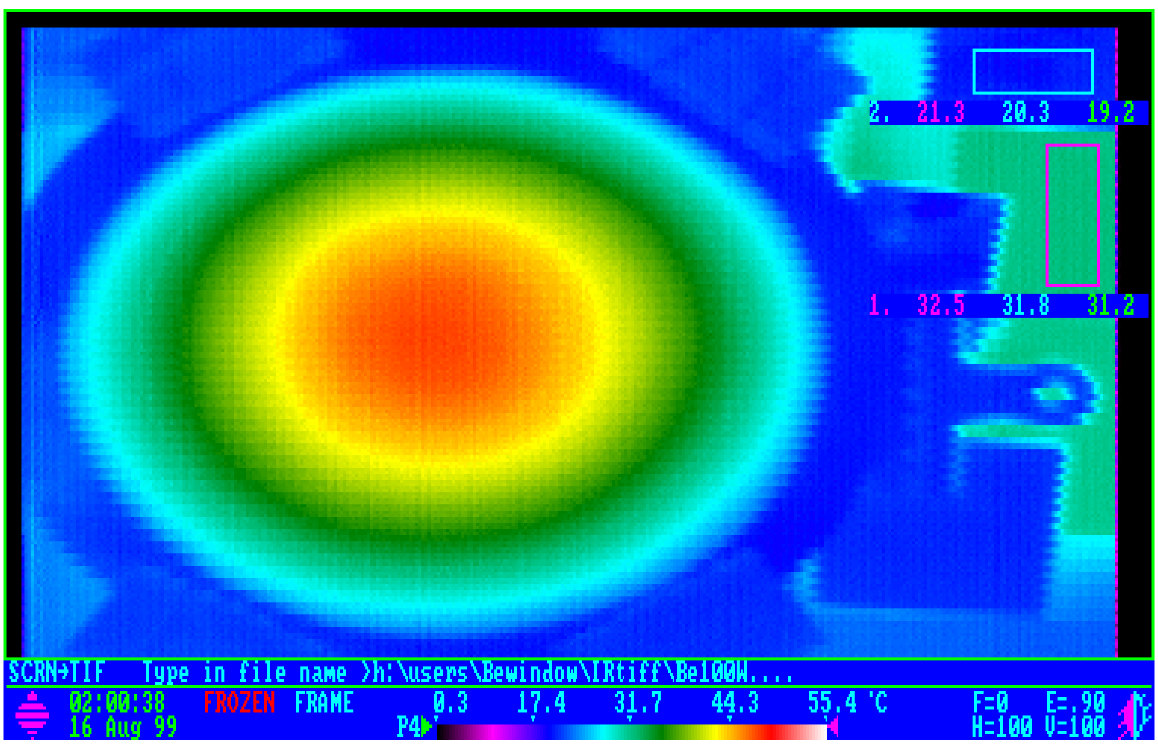

Figure 6. Thermal image of beryllium foil, 71W lamp power.

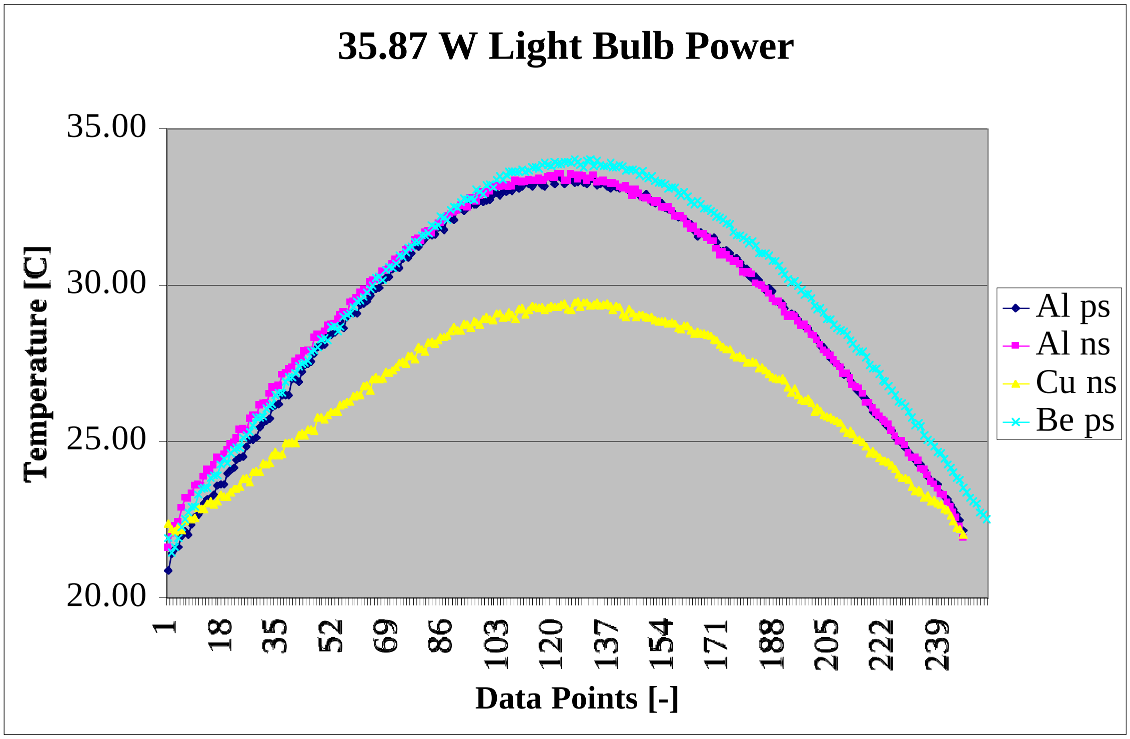

Figure 7. Temperature profile of foils, 36W.

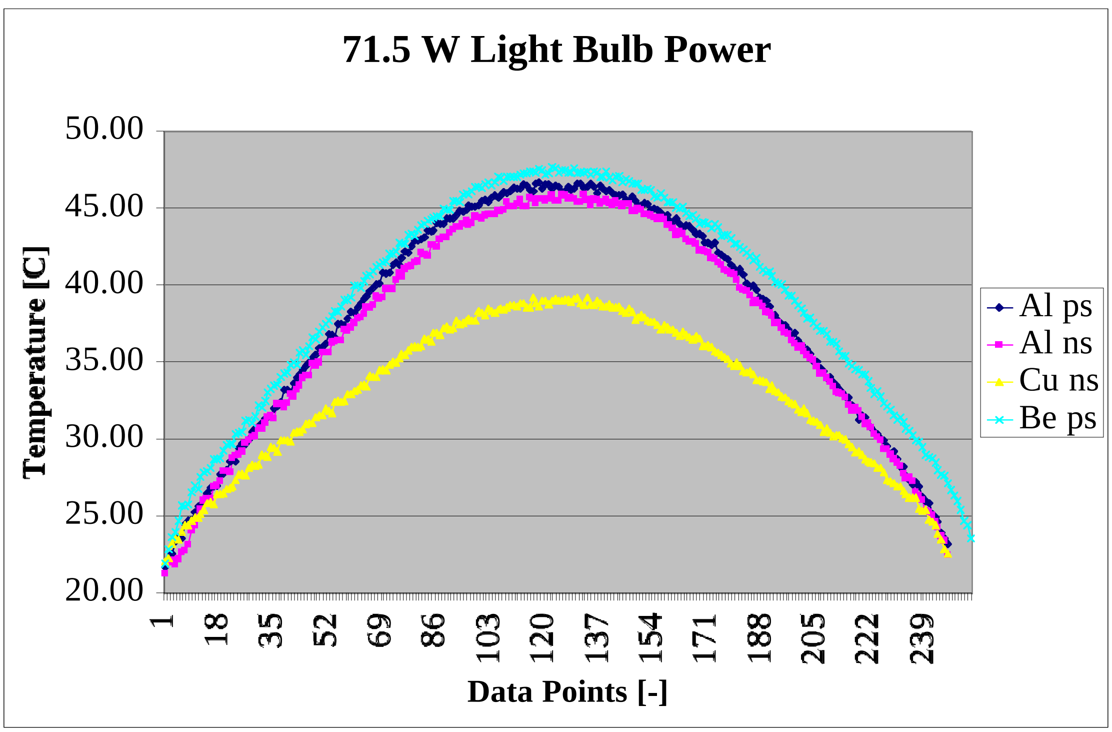

Figure 8. Temperature profile of foils, 71W.

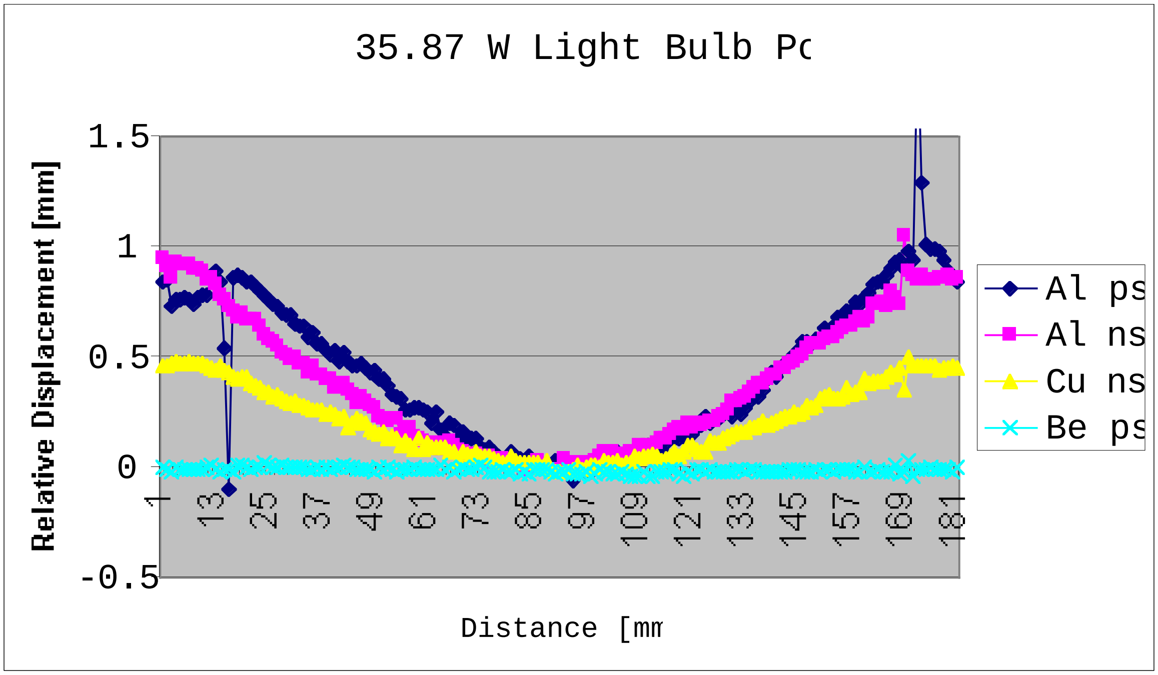

Figure 9. Displacement profile of foils, 36W lamp power.

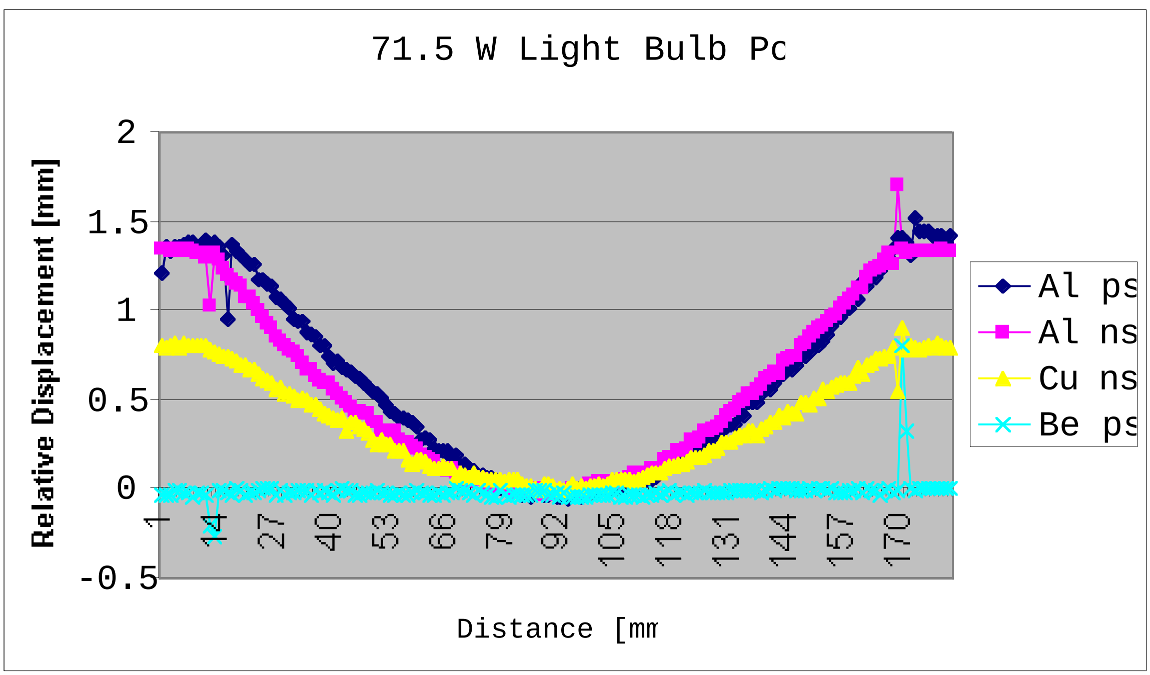

Figure 10. Displacement profile of foils, 71W lamp power.

Displacement measurements for the windows are shown in figures 9 and 10. The reference in each case is the room-temperature measurement (no power in the lamp), so the displacements are negative in this representation. "Spikes" in the displacement reading result from slight differences in alignment of measurement points during the traversal - the edge of the frame is detected one point earlier or later between the reference/equilibrium temperature measurements.

The Al pre-stressed foil shows the same behavior as the no-stress foil, and we believe that our attempts to tension the foil were unsuccessful. Note that each of the "home-made" windows exhibited deformation of the foil as a result of thermal expansion, by up to 1.4 mm for the 71 W lamp power case. The Be foil, however, did not move. This suggests that the Be window is under considerable pre-stress and is strongly bound to it's frame.

Conclusions

We conclude that the Be windows may possibly accommodate RF heating in the cavity without distortion due to the RF currents. This may allow their use in pillbox cavities without the problem of cavity detuning resulting from movement of the foils. There are, however, other aspects to this problem not considered here, such as contraction of the window during cooldown to liquid nitrogen temperature in the cavity, and the effects of compression from the surrounding copper cavity.

Further measurements are planned to explore the temperature rise and displacement of a Be window in a test cavity at liquid nitrogen temperature, with power supplied from a 500W RF amplifier.

Discussions with the manufacturer are hoped to provide insight into the pre-stress achievable.

Comparison with finite element analysis (FEA) of foil deflections will be made, to gain better understanding of and confidence in our FEA model.

References

[1] "Temperature distribution calculations on beryllium windows in RF cavities for a muon collider", D. Li, J. Corlett, W. Turner, Linac Conference, Chicago 1998.

[2] Türler D., Griifith B. T., and Arasteh D. K., “Laboratory Procedures for Using Infrared thermography to Validate Heat Transfer Models”, Insulation Materials: Testing and Applications: Third Volume, ASTM STP 1320, R. S. Graves and R.R. Zarr, Eds., American Society for Testing and Materials, 1997.