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GRID WINDOW TESTS ON AN 805-MHz PILLBOX CAVITY*

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Abstract

Muon ionization cooling channel designs use pillbox shaped RF cavities for improved power efficiency and fine control over phasing of individual cavities. For minimum scattering of the muon beam, the ends should be made out of a small thickness of high radiation length material. Good electrical and thermal conductivity are required to reduce power dissipation and remove the heat efficiently. Thin curved beryllium windows with TiN coating have been used successfully in the past. We have built an alternative window set consisting of grids of tubes and tested these on a pillbox cavity previously used with both thin Be and thick Cu windows. The cavity was operated with a pair of grids as well as a single grid against a flat endplate.

CAVITY WINDOWS FOR MUON COOLING

Muon ionization cooling requires sections of RF acceleration at fairly low muon energy ($\beta \simeq 0.85$) interspersed with energy absorbers at low-$\beta_\perp$ locations in a strong focusing magnetic lattice. Since there is already material in the beam path and muons do not interact strongly, additional material at high-$\beta_\perp$ locations where the RF cavities are can be acceptable as long as the contribution to beam scattering is small compared to the absorbers. Thus, the pillbox cavity geometry can be used for muon beams if electrical termination of cavity irises is done with high radiation length material. This typically yields a factor of two or higher gain in the ratio of accelerating to peak surface field compared to the standard elliptical cavity geometry with open irises. The requirements for the windows are:

- thickness that is a small fraction of radiation length for minimal beam scattering
- high electrical conductivity for reduced RF power dissipation
- high thermal conductivity to carry away the heat
- mechanical strength to withstand pulsed heating from the RF field
- mechanical strength to limit Lorentz force detuning
- low secondary electron yield to avoid multipacting
- low dark current
- ultra high vacuum compatibility

Thin curved beryllium windows with TiN coating have been used in 805- and 201-MHz prototype cavities with excellent results [1]. However, beryllium is expensive and requires special precautions due to personnel safety issues. Thermal stress at the center of the window as well as Lorentz force detuning can force a gradient limit that is lower than that due to surface breakdown considerations alone [2]. Table 1 shows a summary of window configurations used in the past on cavities built for muon cooling R&D.

Table 1: Window Configurations Tested for Muon Cooling

Window type	Application: 805-MHz pillbox	Application: 201-MHz MICE prototype
Flat thick Cu endplates	OK	OK
Flat thin pre-stressed Be	Unstable at high power	–
Curved thin Be foils	OK	OK

GRID WINDOWS

A solid conductor is not needed to achieve a pillbox-like field pattern at RF frequencies. An alternative window layout has been studied [3] and consists of a grid of tubes. This configuration has the following useful features:

- Mechanical strength
  - less prone to electromagnetic impulse detuning for the same thickness
  - can be made thinner than solid windows for the same strength
- Cooling: hollow tubes can accommodate active cooling
- Holes: beam aperture can be left open in the middle
- Cost: cheaper than curved Be foils
- Safety: no Be

There are potential disadvantages as well:

- Electric field enhancement
  - smaller radius of curvature than solid curved window means higher surface field on the grids which may lead to higher field emission and breakdown probability
- Irregular material distribution in beam path
  - the effect on the beam needs to be evaluated for a cooling channel application

TEST SETUP

In order to carry out a first test of the concept on an actual pillbox type cavity, we have built a pair of 16-cm-diameter windows consisting of 1-cm-diameter solid tubes spaced 3.2-cm apart. These prototype windows were made out of aluminum, their surfaces were electropolished after fabrication and one of the windows was TiN coated on one side. They were designed to fit on an existing pillbox type cavity used in the past with Be windows.

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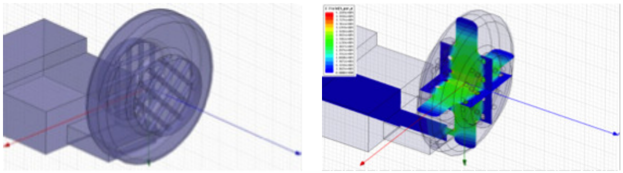

Figure 1: Dual-grid window configuration.

Two configurations were used for the tests:

1. Grid window on each side
    - rotated 45^o to reduce multipacting
    - TiN coated side facing in
2. One grid and one solid (8.1-mm-thick) Cu window
    - Cu plate electropolished
    - no coating on either window

The average on-axis accelerating gradient is half the peak surface field on the grids in both cases. The simulated field distribution is shown in Figs. 1 and 2. Photos of the windows and the dual-grid layout are shown in Fig. 3.

RESULTS

The cavity was installed and operated inside the bore of the solenoid in the MuCool Test Area experimental hall at Fermilab. A series of operating points were established for several magnetic field settings including 0, 0.25 T and higher values up to 5 T. The values listed below refer to the gradient on the surface with a breakdown rate of 1 in 10^5 pulses or less:

- 25 MV/m at B=0
- 22-23 MV/m for B=0.25-5 T

These apply to both configurations. The breakdown behavior of the cavity was sensitive to how fast power was ramped – this may be due to multipacting on Al surfaces.

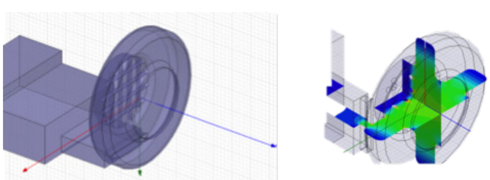

Figure 2: Grid-flat window configuration.

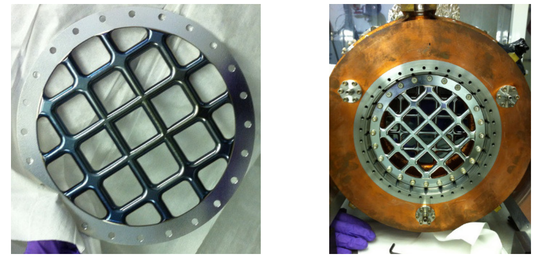

Figure 3: TiN coated side of the grid tube window (left); dual-grid configuration (right).

CONCLUSION

We have tested a new type of window geometry for use in RF cavities for muon acceleration. The grid tube windows have shown electromagnetic performance similar to Be foils and may have significant advantages for practical applications. Further simulation studies are needed to quantify the effect of this type of window on beam dynamics. This can be followed up by more advanced prototypes built out of hollow tubes, including cooling.

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