Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory

Title

A 201 MHz RF cavity design with non-stressed pre-curved Be windows for muon cooling channels

Permalink

https://escholarship.org/uc/item/4kw8z2zn

Authors

Li, Derun
Ladran, A.
Staples, J.
et al.

Publication Date

2003-05-01

A 201 MHZ RF CAVITY DESIGN WITH NON-STRESSED PRE-CURVED BE WINDOWS FOR MUON COOLING CHANNELS*

Derun Li[+], A. Ladran, J. Staples, S. Virostek, M. Zisman
Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
W. Lau, S. Yang, Dept. of Physics, Oxford University, Oxford, UK
R.A. Rimmer, Jefferson National Accelerator Facility, Newport News, VA, USA

Abstract

We present a 201-MHz RF cavity design for muon cooling channels with non-stressed and pre-curved Be foils to terminate the beam apertures. The Be foils are necessary to improve the cavity shunt impedance with large beam apertures needed for accommodating large transverse size muon beams. Be is a low-Z material with good electrical and thermal properties. It presents an almost transparent window to muon beams, but terminates the RF cavity electro-magnetically. Previous designs use pre-stressed flat Be foils in order to keep cavity from detuning resulted from RF heating on the window surface. Be foils are expensive, and it is difficult to make them under desired tension. An alternative design is to use pre-curved and non-stressed Be foils where the buckling direction is known, and frequency shifts can be properly predicted. We will present mechanical simulations on the Be foils in this paper.

INTRODUCTION

High gradient RF cavities at 201 MHz are required for muon cooling channels of a neutrino factory or a muon collider, and also for a recently proposed a muon cooling demonstration experiment at RAL (Rutherford Appleton Laboratory) - MICE (An International **M**uon **I**onization **C**ooling **E**xperiment) cooling channels. As high as 16 MV/m at frequency of 201 MHz is requested, compared to 15 MV/m of Kilpatrick Criterion at this frequency. Eight 201 MHz cavities are needed for MICE cooling channels, but accelerating gradient for MICE will have to be limited to ~ 8 MV/m restricted by budget for RF power sources, not by cavity design. The cavity design aims at gradient of 16+ MV/m. In order to achieve such a high gradient for naturally large dimension muon beams, using conventional open iris structures would inevitably introduce very high peak surface field, which in fact limits achievable accelerating gradient. A closed-cell (pillbox like) cavity design was proposed and reported [1] where the open beam apertures are electro-magnetically terminated by low Z and thin Be foils. To keep the cavity from detuning by RF heating power, these Be foils are under tension which is introduced by small CTE (coefficient of thermal expansion) difference between the thin Be foils and thick Be window frame during brazing process. Theoretically the pre-stressed windows should stay flat up to certain temperature gradient limit where pre-tension becomes zero. This temperature gradient limit determines how much heating power it can take for a given window thickness. Manufacturing of the pre-stressed Be windows is very expensive. Predictions on the temperature gradient limit are difficult. Previous Be window design for the 201 MHz cavity was scaled from the pre-stressed Be windows for an 805 MHz cavity. Recent experimental tests on the 805 MHz cavity found that the cavity frequency started to shift at lower than predicted temperature gradient on the windows. The frequency shift was quite small and well within the klystron bandwidth. By taking advantage of the pillbox-like profile, non-stressed and pre-curved Be windows should result in smaller frequency shifts should both windows are installed in orienting to the same direction in a cavity. Detailed FEA studies on the non-stressed and pre-curved window designs will be presented in this paper.

THE 201-MHZ CAVITY

Cavity Profile

The cavity shape has a slightly re-entrant round profile with a large beam aperture of 21 cm in radius. The cavity profile has been updated recently, and a small 2° tilt angle has been added at radius out of iris region to avoid having a two-parallel-plane configuration in consideration of possible multipacting problem, as shown in Figure 1.
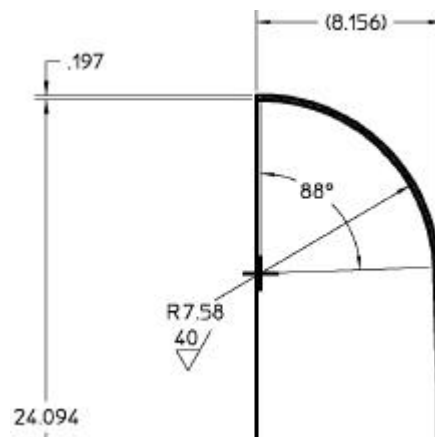

Figure 1: The 201 MHz cavity profile (only 1/8 of the cavity is shown here)

Cavity Parameters

The cavity parameters are listed in Table 1 for Study-II and MICE muon cooling channels.

Table 1: 201 MHz cavity parameters

Name	Study-II	MICE
Length (cm)	43	43
Radius (cm)	61.2	61.2
Accelerating Gradient (MV/m)	16.2	8.0
Voltage on crest (MV)	5.76	2.84
Peak forward power[*] (MW)	4.63	1.0
Peak surface field (MV/m)	26.5	13.1

[*] Assumed 3τ filling time and 85% of theoretical Q_o

NON-STRESSED AND PRE-CURVED BE WINDOWS

Window Profile

Experimental studies on pre-stressed flat Be windows have shown that the window started buckling at a limiting temperature gradient where the pre-tension in the foil became zero. The measurements were conducted on 16 cm diameter windows in an 805 MHz cold-test cavity using halogen lamp as a heating source. Both no-stressed Al and pre-stressed Be windows were measured. These measurement results are summarized in Figure 2. It is worthy of pointing out that it is difficult to predict the buckling direction of the pre-stressed flat windows once the re-tension becomes to zero.
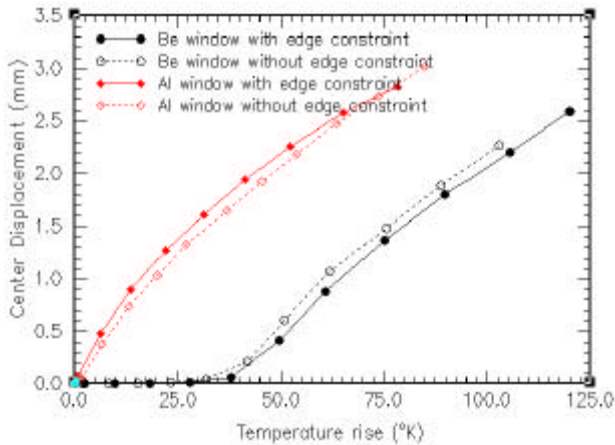

Figure 2: Experimental measurements on pre-stressed Be windows in an 805 MHz cold-test cavity. Temperature rise here is defined as the temperature difference between the window center and window frame. Limited by measurement sensitivity (resolution), a measurable displacement seemed to start at 35 °C.

A non-stressed and pre-curved window design has been developed to replace the pre-stressed flat windows. The following criterions have been in consideration during the evolution of the designs:

- Low thermal stress within the window for a given temperature gradient
- Window displacement for the given temperature gradient limit
- Ability for window to deform in a single direction regardless of the through thickness thermal gradient
- Thinner window (less material and less scattering)
- Mechanical stiffness (characterized by mechanical resonant frequency)
- Cost and manufacturing

Figure 3 shows the window profile evolutions during the design process. We started with a single bow (curvature) window and found the thermal stress was too high at the annular frame. Then a new window design is developed to having an intersection between a concave and a convex in a region away from the edge of the frame, which makes the window more flexible and allow for more free expansion. The thermal stress is then further reduced.
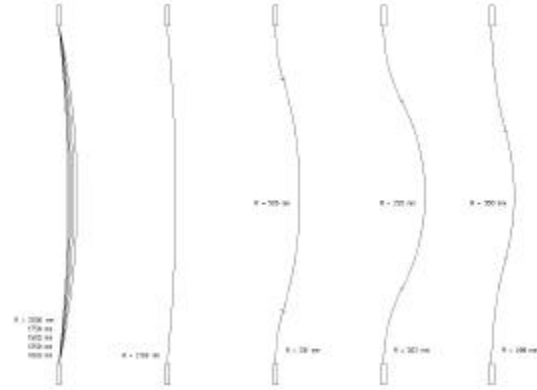

Figure 3: Window cross-section profile evolutions: from one to two curvatures (left to right)

The window thickness has been varied from 0.125-mm to 0.5-mm to study its effects on thermal stress. Since thinner than 0.125-mm windows tend to be more expensive, we chose window thickness at 0.38-mm as baseline study parameter for the window with 42-cm diameter.

FEA Modeling

Each window profile configuration has been modeled using FEA (Finite Element Analysis) code ALGOR in 2-D and 3-D. The following temperature distribution is then applied over the window for thermal and mechanical simulations [2].

$$T(r) = T_{max}\left(1 - \left(\tfrac{r}{R}\right)^4\right),$$

where T_{max} is the temperature gradient limit, R the window radius. This temperature distribution is a result of magnetic field distribution of TM_{010} mode in a pillbox cavity. The fact that the window center as the hottest spot is due to the limited thermal conduction within the thin Be foil. As one would expect that T_{max} is proportional to the

total RF heating power over the window, and inversely proportional to window thickness. $T_{max}=100$ $^{\circ}$C, which is higher than the temperature limit for operational gradient of 16 MV/m, have been assumed and used for all the simulations.

Figure 3 shows a 3-D FEA model of the non-stressed and pre-curved Be windows with two curvatures, together with their mechanical resonant frequencies. In this example, two lowest and one higher order mechanical resonant vibration distributions are shown in this figure.
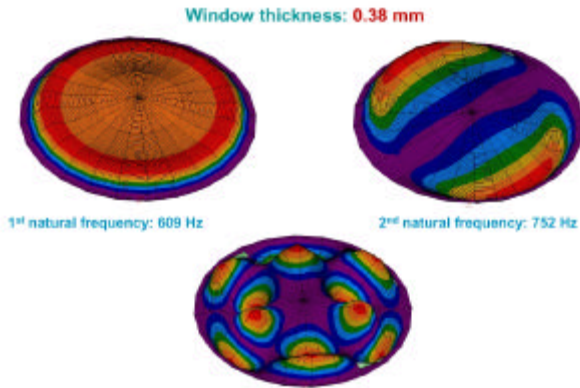

Figure 4: 3-D FEA model of a 42cm diameter, 0.38-mm thick and non-stressed and pre-curved Be window. Vibration distributions and their natural resonant frequencies have also been shown.

Window Displacement

Window displacements of the 42 cm diameter Be foils of different thickness were simulated after applying the temperature distribution. Table 2 lists the maximum displacement at the window center from its natural position.

Table 2: Be window displacement versus thickness

Thickness (mm)	0.25	0.38	0.50
Displacement (mm)	2.42	2.25	2.13

The amount of the displacements is considered to be acceptable as long as all the windows are installed oriented in the same direction, which also results in minimum frequency shifts of the cavity.

Thermal Stress

Similarly, the corresponding stresses due to the thermal load ($T_{max}=100$ $^{\circ}$C) are simulated and their results are listed in Table 3.

Table 3: Thermal stress versus window thickness

Thickness (mm)	0.25	0.38	0.50
Thermal Stress (MPa)	150	169	179

Considering temperature gradient for thicker windows are lower (scaled linearly with *d*, the window thickness), all above windows should work, and yet give enough safety margin. The thermal stresses are much less than the Be stress limit of ~ 340 MPa.

Window Fabrication

A concept for fabrication of the pre-curved Be window is shown in Figure 4. A smaller window of 16 cm diameter using the same concept will be tested first. This test may be conducted in either room temperature or up to the recommended forming temperature of Be depending on the resulted window profile. We expect that the window may spring back slightly to its natural shape after the forming process. This will be quantified during the tests.
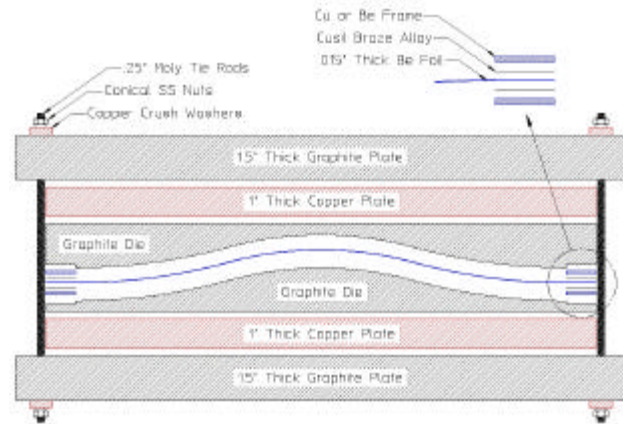

Figure 4: A concept for fabrication of pre-curved Be window.

Future Work

The fabrication concept of pre-curved windows will be realized in 16 cm diameter windows using materials having similar mechanic properties as beryllium. Time domain simulations will be performed to study possible mechanical resonant excitations by RF impulse using operational parameters for Study-II and MICE cooling channels.

CONCLUSION

A non-stressed pre-curved Be window has been designed. FEA simulations show it has more mechanical flexibility and thermal capability to handle the RF heating power while keeping the required cavity performance. More experimental tests and engineering efforts will be spent to the realization of the window.

REFERENCES

[1] R. Rimmer, *et al*., "Closed-Cell 201.25 MHz RF Structures for a Muon Ionization Cooling Experiment", EPAC 2002, Paris, France
[2] D. Li, *et al*., "Temperature Distribution Calculations on Be windows in RF Cavities for Muon Colliders, International LINAC Conference 1998, Chicago, IL, USA