805 MHz and 201 MHz RF Cavity Development for MUCOOL

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Abstract. A muon cooling channel calls for very high accelerating gradient RF structures to restore the energy lost by muons in the absorbers. The RF structures have to be operated in a strong magnetic field and thus the use of superconducting RF cavities is excluded. To achieve a high shunt impedance while maintaining a large enough aperture to accommodate a large transverse emittance muon beam, the cavity design adopted is a pillbox-like geometry with thin Be foils to terminate the electromagnetic field at the cavity iris. The possibility of using grids of thin-walled metallic tubes for the termination is also being explored. Many of the RF-related issues for muon cooling channels are being studied both theoretically and experimentally using an 805 MHz cavity that has a pillbox-like geometry with thin Be windows to terminate the cavity aperture. The design and performance of this cavity are reported here. High-power RF tests of the 805 MHz cavity are in progress at Lab G in Fermilab. The cavity has exceeded its design gradient of 30 MV/m, reaching 34 MV/m without external magnetic field. No surface damage was observed at this gradient. The cavity is currently under conditioning at Lab G with an external magnetic field of 2.5 T. We also present here a 201 MHz cavity design for muon cooling channels. The proposed cavity design is also suitable for use in a proof-of-principle Muon Ionization Cooling Experiment (MICE).

1. Introduction

Designs of muon ionization cooling channels for a Neutrino Factory, a Muon Collider or the Muon Ionization Cooling Experiment (MICE) call for very high gradient RF accelerating structures. Depending on which cooling stage is considered, high-gradient RF cavities are needed at frequencies in the range of 201 MHz to 805 MHz, with peak accelerating gradients of 16 MV/m to 30 MV/m, respectively. Detailed information on muon cooling research can be found on the Web at [1]. Taking advantage of the muon's penetration property, an RF cavity with its beam irises covered by thin Be windows was proposed to achieve a higher gradient or shunt impedance. This is due to electric field enhancement on axis resulting from metallic windows used to terminate the cavity. Ideal windows for RF cavities used in a cooling channel should be thin and mechanically strong, be made of a low-Z material, and have good electrical and thermal conductivities. Low-Z and thin material is needed to minimize multiple scattering in the windows. Good electrical conductivity is needed to minimize RF

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power dissipation on the windows. Good thermal conductivity is needed to conduct away the RF-induced heat efficiently. Mechanical strength is needed to ensure that the cavity is not detuned by the deformation of the windows resulting from the RF heating. Our studies have shown that beryllium is the best candidate for the windows in all the above respects.

Significant efforts have been devoted to the design of a high-gradient RF cavity with thin Be windows. An 805 MHz low-power test cavity with Be windows was built and tested to study the Be windows' thermal and mechanical properties when heated by a halogen lamp under different cavity temperatures [2]. A high-power 805 MHz test cavity, designed and built recently, is currently under test in Lab G at Fermilab, where a high-power RF test facility has been dedicated for the 805 MHz muon RF cavity research. A superconducting magnet is also available in Lab G for tests with strong magnetic fields. In principle, grids consisting of thin-walled metallic tubes can also be used to terminate the cavity irises electromagnetically. Thin walled tubes are mechanically stronger than thin foils. Engineering efforts have been initiated to study how to model, design, and fabricate a cavity with such grids.

This paper reports on the 805 MHz cavity design and recent progress on high-power tests of the cavity. In addition, a 201 MHz cavity design that could be used for muon cooling channels and/or the MICE experiment is presented.

2. 805 MHz High-Power Test Cavity Design

The 805 MHz cavity design adopts a cylindrically symmetrical pillbox geometry with conventional beam irises covered by metallic windows, either Cu plates or thin Be foil. Detailed information on the cavity design and fabrication have been reported in [3]. RF power is fed through a coupler that has a kidney-shaped coupling slot in one end-plate of the cavity and is attached to a transition waveguide to a standard WR975 waveguide. Figure 1 is a mechanical drawing showing a cross section of the cavity geometry and the coupler. Main

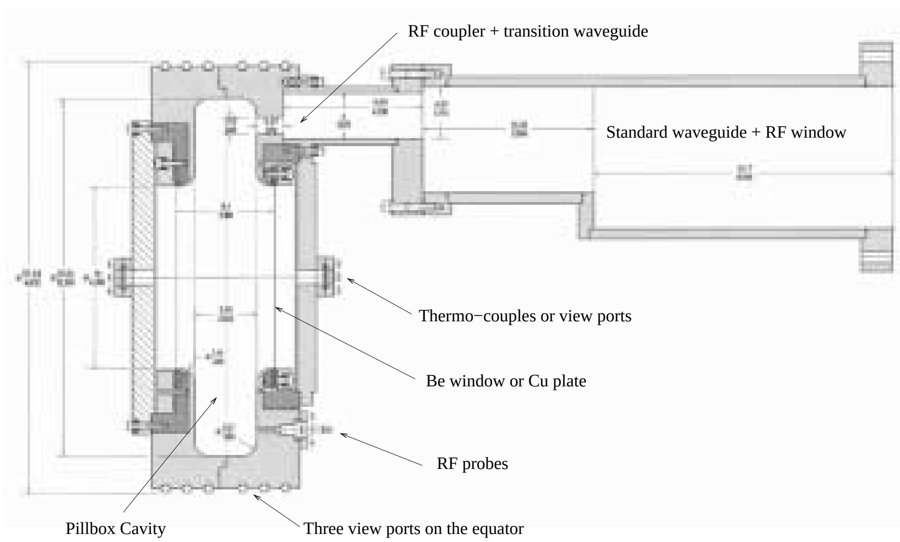

Figure 1. Cross section of the 805 MHz high power test cavity.

cavity parameters are listed in Table 1. The cavity design allows for demountable windows to be installed. As shown in Figure 1, RF probes, view ports and thermocouple ports are available for measuring peak RF power inside the cavity, for visual inspections of the windows using a bore-scope, and for monitoring window temperatures.

Table 1. Main design parameters of the 805 MHz cavity. The shunt impedance used here is defined as $V_{0,T}^2/P$

Parameter	Value	Unit	Parameter	Value	Unit
Cavity radius	15.62	cm	Shunt impedance Z_0	38	MΩ
Cavity length	8.1	cm	Shunt impedance ZT^2	32	MΩ
Coupling slot span	50	degree	Quality factor	18,800	
Be window diameter	16.0	cm	Coupling constant	1.0	
Be window thickness	127	μm	Gradient E_0	30	MV/m

The cavity design was performed using the MAFIA code in both the frequency and the time domains [4]. The cavity was fabricated at the University of Mississippi, and brazed at Alpha-Braze, a company in Fremont, California. Cavity and coupler tuning were conducted at the University of Mississippi as well. Final cavity integration and assembly were carried out at LBNL. Microwave measurements performed at LBNL and at Lab G (before high-power testing) showed good agreement between design and measured values.

3. High Power Testing of the 805 MHz Cavity

High power RF tests have been conducted in Lab G. A 12 MW peak power klystron and a superconducting solenoid are available for the tests to permit studying the cavity with Be windows both with and without magnetic fields. Previous experience from a Fermilab 805 MHz open-iris structure indicated that severe surface damage could occur, especially in the presence of a strong solenoidal magnetic field. Large dark currents and x-ray intensities were measured during the test. Analysis of these measurements is in progress and our preliminary understanding has been presented recently [5]. Recognizing that surface damage might occur in the 805 MHz cavity with the Be windows, we started high power tests with copper windows (plates) instead.

The cavity was conditioned to reach 34 MV/m rather quickly, with a low sparking rate. After this initial test, the cavity was taken apart and a new thinner Cu window was installed to permit better x-ray measurements. No surface damage was observed after careful inspection. The cavity is currently being tested with the superconducting magnet on. The magnet is operated in its solenoidal mode, at a magnetic field of 2.5 T. More multipacting zones were observed and a much higher radiation level was measured during this conditioning compared with the no-magnetic-field case. The conditioning process has been slow; a gradient of $\sim$10 MV/m was reached after two and a half weeks of conditioning. More measurements and data analysis are under way, and will be reported later.

4. 201 MHz Cavity Design

The cavity uses a slightly reentrant rounded profile with a large beam aperture, as shown in Figure 2, covered either by thin flat Be windows or grids of thin-walled aluminum tubes [6]. Based on experiments with pre-stressed Be foils in the 805 MHz cavity, the thickness of the foils was chosen so that the temperature rise at the center is below that at which the foils buckle. Table 2 lists main parameters of the cavity.

Figure 2. Conceptual design of the 201 MHz cavity.

The cavity design was performed using the MAFIA code; thermal analysis was done with ANSYS. The grid design is still under investigation to find the optimal size and spacing of the tubes. RF heating on the tubes needs to be further studied.

Table 2. Main RF design parameters of the 201 MHz cavity

Radius (cm)	Length (cm)	E_0 (MV/m)	E_{peak} on surface (MV/m)	Be diameter (cm)	Be thickness (mm)
61	43	16.2	26.5	21	1.15

5. Conclusion

The 805 MHz cavity has been successfully tested and reached 34 MV/m without magnetic fields. High power RF testing with magnetic fields is ongoing. Possible surface damage and the radiation level from dark currents will be studied carefully. The 201 MHz cavity design is nearly completed and ready for fabrication.

Reference

[1] http://www.fnal.gov/projects/muoni_collider/cool.html

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