HIGH POWER RF TEST OF AN 805 MHZ RF CAVITY FOR A MUON COOLING CHANNEL*

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Abstract

We present recent high power RF test results on an 805 MHz cavity for a muon cooling experiment at Lab G in Fermilab. In order to achieve high accelerating gradient for large transverse emittance muon beams, the cavity design has adopted a pillbox like shape with 16 cm diameter beam iris covered by thin Be windows, which are demountable to allow for RF tests of different windows. The cavity body is made from copper with stiff stainless steel rings brazed to the cavity body for window attachments. View ports and RF probes are available for visual inspections of the surface of windows and cavity and measurement of the field gradient. Maximum of three thermo-couples can be attached to the windows for monitoring the temperature gradient on the windows caused by RF heating. The cavity was measured to have Q_0 of about 15,000 with copper windows and coupling constant of 1.3 before final assembling. A 12 MW peak power klystron is available at Lab G in Fermilab for the high power test. The cavity and coupler designs were performed using the MAFIA code in the frequency and the time domain. Numerical simulation results and cold test measurements on the cavity and coupler will be presented for comparisons.

1 INTRODUCTION

Design of muon ionization cooling channels for a neutrino factory or a muon collider calls for very high gradient RF accelerating structures to compensate for the muon energy losses in absorbers. Depending on at which cooling stages, high gradient RF cavities are needed for a frequency range of 200 MHz to 805 MHz. Detailed information on muon cooling research, cooling channel layouts can be found at [1]. Taking advantage of muon beam's penetration property, a RF cavity with its beam irises covered by thin Be (low Z) windows was proposed to achieve a higher gradient or shunt impedance [2]. Taking an ideal pillbox RF cavity as an example, a closed cylindrically symmetric pillbox cavity typically has a factor of two higher in shunt impedance comparing to open iris ones. This is due to electric field enhancement on axis resulting from the Be windows used to close the cavity. For an ideal RF cavity in a cooling channel, we expect these windows be mechanically strong and thin, and have good electric and thermal conductivity. There are four main reasons associated with the expectations: (a) low Z and thin to minimize muon beam scattering by the windows; (b) good electric conductivity to minimize RF power dissipation on the windows; (c) good thermal conductivity to conduct the RF heating more efficiently if can not be avoided; (d) mechanically strong to ensure the cavity not to be detuned by the windows due to the RF heating power. Studies have shown beryllium is the best candidate in all respects. Tremendous efforts have been devoted to the design study of a high gradient RF cavity with thin Be windows [3,4]. An 805 MHz low power test cavity with Be windows was built and tested to study the Be windows' thermal and mechanical property heated by a halogen lamp under different cavity temperatures [5]. A high power 805 MHz test cavity was designed and built recently, is currently under test at Lab G in Fermilab, a high RF power test facility developed and dedicated for the 805 MHz muon RF cavity research. Theoretical studies have been concentrated on the Finite Element Modeling of RF cavities with thin Be foils or grids using ANSYS code [4,5,6]. This paper reports recent progress on high power test of the 805 MHz RF cavity.

2 THE 805 MHZ CAVITY

2.1 The Cavity Design

The 805 MHz high power test cavity is a cylindrical pillbox cavity with Be windows. Detailed information on its design and fabrication were reported in [7]. Main parameters of the cavity are listed in Table 1. The cavity design allows for demountable windows to be installed. RF probes, view ports and thermo-couple ports are available for measuring peak RF power inside the cavity, visual inspections of the windows using bore-scope and monitoring temperatures of the windows.

Table 1. Main design parameters of the test cavity

Name	Value	Unit
Frequency	805	MHz
Cavity Radius	15.62	cm
Cavity Gap	8.1	cm
Coupling slot span angle	50	Degree
Shunt Impedance Z_0	38	MΩ/m
Shunt Impedance ZT^2	32	MΩ/m
Quality factor Q_0	18,800	
Window diameter	16.0	cm
Be Window thickness	127	μm
Design Gradient on-axis	30	MV/m
Design Coupling constant	1.0	

The cavity was fabricated at the University of Mississippi. Tuning of the cavity and coupler were conducted before final brazing at the University as well.

2.2 Tuning of the Cavity and Coupler

The cavity was ready for final tuning at the end of June 2001. Excess cavity gap space was intentionally left in the design allows for being machined for the cavity frequency tuning. The coupler tuning was mainly performed by widening the span angle of the kidney shaped coupling slot on cavity wall. RF measurements were conducted by measuring S_{11} and S_{21} using a HP8720 Network Analyzer. The measured frequency and coupling agree well with the MAFIA simulations performed in the frequency and time domain (for coupling constant calculations only). The results are shown in Figure 1 and 2. The tuning process involved a few iterations between RF measurements and machining and finished in three days. Table 2 summarizes the measurement results before and after the tuning. The tuned cavity was then sent to Alpha-Braze, a company in Fremont, California for final brazing.

Table 2. RF measurement results

Parameters	Before Tuning	After Tuning	Unit
Frequency	803.198	805.486	MHz
Q_0	9,480	13,500	
Q_{ext}	78,680	12,800	
Coupling β_c[∀]	0.19	1.17	

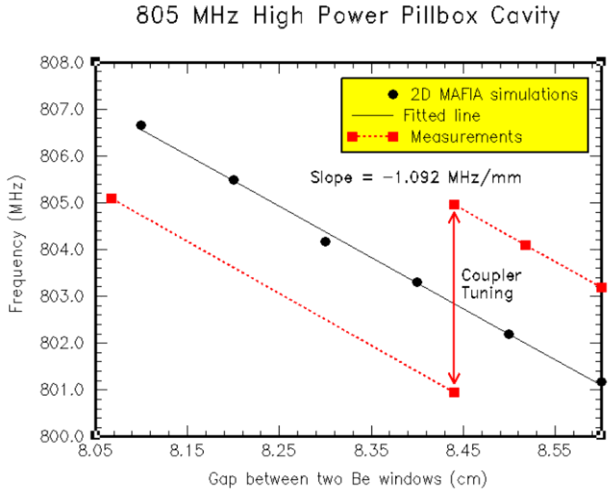

Figure 1. Measurements and simulation results of the 805 MHz cavity tuning

2.2 Integration of the Cavity

Final UHV cleaning and assembling were carried out and completed at LBNL in November 2001. Figure 3 is a photo taken at LBNL when the cavity was under vacuum. The cavity was vacuum leak tight and ready for shipping for the high power tests at Fermilab. The vacuum was measured at the time to be around 10^{-8} torr with an acceptable RGA scan spectrum. Final RF measurement results performed (in air) at LBNL are summarized in Table 3.

Table 3. Final RF measurement results at LBNL

Cavity frequency [MHz]	804.946
Quality Factor Q_0	15,000
Coupling constant β_c	1.3

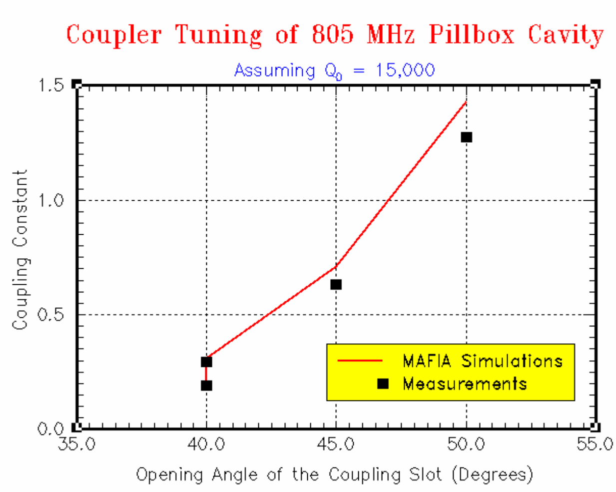

Figure 2. Comparison of Measurements and simulation results of the RF coupler for the 805 MHz cavity

Figure 3. The RF cavity measurements setup at LBNL. The cavity, coupler, transition waveguide, vacuum port and supporting racks can been seen in this photo.

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3 HIGH POWER TEST

The cavity was shipped to Lab G of Fermilab in March 2002. A 12 MW peak RF power klystron and a superconducting solenoid are available at Lab G for the high power tests to study the high gradient cavity with Be windows with/without magnetic fields. Experiences on the high power tests of a Fermilab 805 MHz open iris structure indicated that severe surface damages can occur possibly because of multipactings, sparkings and with combinations of strong solenoidal magnetic fields. High dark currents and x-rays were observed and measured during the test. Data analysis on these measurements is in progress and preliminary understanding and theory have been presented recently [8]. Considering possible surface damages may happen to the LBNL cavity with the Be windows, we have decided to start the high power tests

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[∀] We have assumed Q_0=15,000 for coupling constant calculations.

with copper windows (plates) in stead. A plan will be developed soon to systematically study the surface damage and RF breakdown.

The last low power RF measurement was performed at Lab G when the RF cavity was under vacuum and ready for RF conditioning. The measurement results are presented in Table 4.

Table 4. Last low power RF measurements (vacuum)

Cavity frequency [MHz]	805.135
Quality Factor Q_0	15,080
Coupling constant β_c	1.08

A RF probe was attached to the cavity through an end plate. The probe was calibrated for peak RF field measurement inside the cavity. The probe length was adjusted to have 55.2 dB attenuation from the RF window to the probe. An analogy scope was used to measure the signal from the probe. The signal allows for an indirect measurement of the peak RF field in the cavity. After a through calibration of the measurement loop, peak electric field gradient on axis can be calculated using the measured amplitude of the waveform on the scope and simulated cavity parameters in Table 1.

The RF conditioning of the cavity was started in March 14, 2002 with RF pulse length of 19 μs and repetition rate of 5 Hz. RF power was gradually ramped up once the vacuum started to improve to the order of 10^{-8} torr during the conditioning. Multipactings were observed at gap voltage below 600 kV as expected. In Figure 4, a typical multipacting pattern is shown in a photo taken directly from the scope at Lab G.

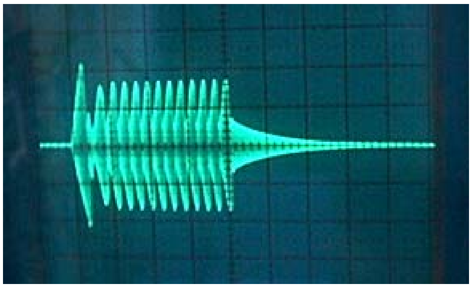

Figure 4. This photo shows a typical multipacting pattern of the LBNL 805 MHz cavity during the RF conditioning at Lab G of Fermilab in March 2002.

The cavity went through the multipacting zones within about one week and there almost no sparking was observed during the process. As much as 29 MV/m was reached in four weeks with little sparking rate. For unknown reasons, the cavity experienced slightly higher sparking rate at 30 MV/m. We were concerned about possible surface damages may have happened. Somehow this situation started to improve after a couple of weeks of continuous running at slightly lower gradient. The cavity has been running for over two months so far. The highest gradient was at 34 MV/m with little sparking rate; this gradient is 10% higher of our design value. To prevent possible surface damages, we set this gradient as the up-limit.

The SC solenoid magnet will be turned on to study the multipacting and RF breakdown under magnetic fields. Since severe damages were observed on the Ti windows mounted at one end of open iris structure during the RF conditioning with the magnet on. We decided to exam the copper windows first before turning the magnet on. This should help us to distinguish the effects from the magnetic fields. A test plan is being developed soon.

4 FUTURE PLANS

Future test plan will develop based on the measurement results and experience we learn from the current tests. We have five Be windows (different thickness) and two more copper windows available for the tests. They were all coated thin TiNi on one surface side and can be flipped over for studying multipactings with/without magnetic fields. Due to complexity of ES&H in handling Be materials, high power test for the cavity with the Be windows will be determined once we have better understanding on the surface damages of the cavity. For the near future, only the copper windows with/without TiNi coatings will be studied for the cases with/without magnetic fields.

5 SUMMARY

The 805 MHz pillbox cavity has been built, and tested at high RF power. The low power measurements of the finished cavity agree well with the design parameters simulated by the MAFIA. The cavity achieved 80 % of its theoretical Q_0. The RF gradient has reached and exceeded its design value of 30 MV/m with very low sparking rate.

6 REFERENCES

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* This research work is supported by the US Department of Energy, under Contract No. DE-AC03-76SF00098