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Title

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RF TESTS OF AN 805 MHZ PILLBOX CAVITY AT LAB G OF FERMILAB*

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Abstract

We report recent high power RF tests on an 805 MHz RF pillbox cavity with demountable windows for beam apertures at Lab G of Fermilab, a dedicated facility for testing of MUCOOL (muon cooling) components. The cavity is installed inside a superconducting solenoidal magnet. A 12 MW peak RF power klystron is used for the tests. The cavity has been processed both with and without magnetic field. Without magnetic field, a gradient of 34 MV/m was reached rather quickly with very low sparking rate. In a 2.5 T solenoidal field, a 16 MV/m gradient was achieved, and it had to take many weeks of conditioning. Strong multipacting effects associated with high radiation levels were measured during the processing with the magnetic field. More recently Be windows with TiN-coated surface have been installed and tested at conditions of with and without the external magnetic field. A conservative 16 MV/m gradient without magnetic field was reached quickly as planned. Less multipacting was observed during the conditioning, it indicated that the TiN-coated surface on the windows had indeed helped to reduce the secondary electron emissions significantly. A modest gradient of 16.5 MV/m was finally achieved with magnet on in solenoidal mode and the field up to 4 T. Preliminary inspection on Be windows surface found no damage at all, in comparison with Cu windows where substantial surface damage was found. Preliminary understanding of conditioning cavity in a strong magnetic field has been developed. More through window and cavity surface inspection is under way.

INTRODUCTION

Accelerators for intense muon beams call for uses of very high gradient RF cavities at various frequencies. The high gradient is a must to manipulate muon beams that are created large in 6-D phase space, and decay fast (muon lifetime is about 2 μs at rest). Any manipulation to muon beams has to be done quickly including cooling. For instance, muon cooling channel design for Study-II [1] calls for accelerating gradient of ~ 16 MV/m at 201 MHz, compared to ~ 15 MV/m of Kilpatrick criterion at the same frequency. Moreover these cavities have to be installed inside superconducting magnet where magnetic fields are as high as a few-T. Therefore normal (warm) conducting RF cavity technology has to be used, but the peak surface field of the cavity has to be further reduced in order to achieve the required high acceleration gradient provided using normal open iris RF cavities. However cavity geometry optimization is not good enough to bring the peak surface field down and at the same time to provide high shunt impedance with large beam iris needed for muon beams. Taking advantage of muon beam's penetration property, closed cell RF cavity was proposed [2] where the large beam iris may be terminated by thin low Z conducting material, say Be foil. The closed cell cavity resembles to a cylindrical pillbox cavity where peak surface field is the same as the peak acceleration filed on beam axis. Furthermore the cavity allows for choices of phase advance per cavity, which in turn offers independent phase control of each cavity so that provide more freedom for beam dynamics design. Efforts have been put on design of such a high gradient cavity, it has bean an engineering challenge on how to incorporate thin Be windows in the cavity. Conditioning and operating a RF cavity in strong magnetic field of a few-T have never been done before, strong magnetic field could pose potential difficulty in overcoming multipacting zones, surface damage and many possible unknowns. As part of ongoing R&D activity for the high gradient RF cavity for muon beams, we have designed and constructed an 805 MHz pillbox cavity with demountable windows [3]. The cavity design allows for tests of different windows. The cavity has been under high power RF tests at Lab G, FNAL since March 2002. In this paper, we report recent test results and future plans. Preliminary data analysis will be presented. Surface inspection and analysis of windows are being analyzed, and is reported in another paper at this conference [4].

THE 805 MHZ CAVITY

The 805 MHz pillbox cavity was reported before [3]. The cavity and its power coupler were designed at LBNL using MAFIA code in frequency and time domain, respectively. Good agreements were achieved between the design values and low power RF measurements. The cavity body was fabricated at University of Mississippi, final cavity braze was carried out at Alpha-Braze company in Fremont, California. Final cavity cleaning, assembly, system integration and vacuum checking were conducted at LBNL. Four pre-stressed flat Be windows were purchased from Brush-Wellman Company in Fremont for tests. The cavity was shipped to Lab G of Fermilab for high power tests in March 2002. Table 1 lists main RF parameters of this cavity in comparison with the last low power RF measurements at Lab G.

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Table 1: Main parameters of the cavity in comparison with measurements

Name	Design	Measured	Unit
Frequency	805.00	804.946	MHz
Q_0	18,800	15,080	
Coupling constant	1.0	1.08	
Radius	15.62		Cm
Gap Length	8.1		cm
Window diameter	16		
Be window thickness	0.127		mm
Gradient on axis	30		MV/m
Shunt Impedance‡	32		MΩ/m

RF TEST OF THE CAVITY

Test Set Up at Lab G

A 12 MW peak power klystron and a superconducting solenoid magnet up to 5 Tesla are available for the RF tests. The SC magnet can be powered to operate in either solenoidal mode or gradient mode. Figure 1 is a photo taken inside Lab G test cave showing the test set up.

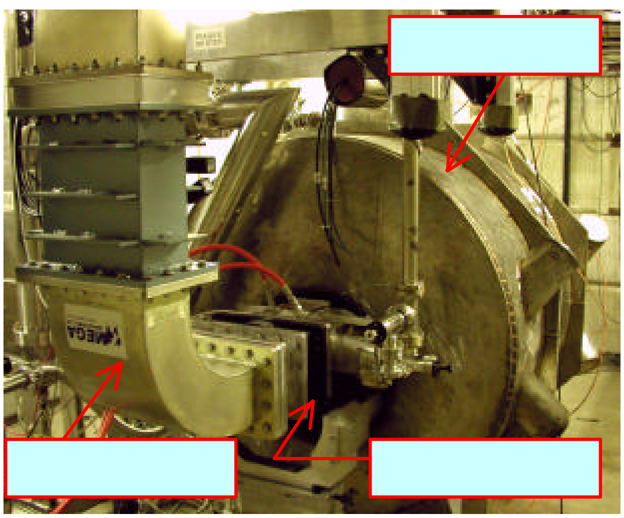

Figure 1: RF test set up at Lab G, FNAL

The 805 MHz pillbox cavity sits inside the center of the warm bore of the superconducting solenoid. All necessary measurement equipments and probes needed for RF, vacuum, x-ray and dark currents are available. The RF tests can be set and controlled either by computers or manually.

Test Results

The cavity was first baked up to 115 °C with hot N_2 purge for 2 days and then pumped down to vacuum at the order of 10^{-8} Torr before RF conditioning started. We will report the test results according to the timeline. High power RF conditioning was conducted on Cu windows first, and then followed by the tests of Be windows with one TiN-coated surface facing RF for with and without magnetic field cases.

Test of Cu Window without External Magnetic Field

High power RF conditioning started with Cu windows, rather than Be windows, without magnet on first. Combinations of different pulse lengths and repetition rates were used at initial conditioning phases. Multipacting effects were observed at low RF power as we normally expected. Typical two-plate multipacting zones were observed, and passed rather quickly. As high as 34 MV/m accelerating gradient was achieved with low x-rays, low dark currents and little sparking rate. This gradient has exceeded our designed value of 30 MV/m. Cavity was then taken apart for surface inspection on cavity body and window, no surface damage was found.

Test of Cu window with External Magnetic Field

The cavity was resumed for tests with the super-conducting magnet on at 2.5 T in solenoidal mode. The cavity seemed to have lost its conditioning history and behave like a brand new cavity again. More multipacting zones popped up, and they were much harder to go through. Radiation levels went up by almost 1000 times, compared to the case without the external magnetic field. Details on x-ray, dark current and radiation measurements are reported in [Jim]. Higher radiation levels and more severe sparking prevented us from pursuing for higher accelerating gradients. Nevertheless we found a possible surface *self-healing* effect that seemed had happened during a period of the conditioning. That is, after a period of conditioning with magnet on which associated with strong multipacting zones and high radiation levels, we turned the magnet off and continued re-conditioning the cavity without magnetic field for one to more days. The dark currents and radiation levels were measured to be dropping continuously with the conditioning time. This process was repeated and verified for a few times. High or the same gradient was then re-gained at much less radiation levels. This suggests re-conditioning without the external magnetic fields seem to be able to cure or condition the damaged surface caused by strong magnetic field.

Experiments indicated that is difficult to run a RF cavity in a strong magnetic field without extensive conditioning. We are still exploring what's the best way to condition a cavity in such an environment. As one may imagine that in addition to RF fields in the cavity, the external magnetic field (in longitudinal direction) forms strong focusing channels for electrons and ions and force them to orbit within the channels. As focusing force from the external magnetic field is much stronger then that of RF field, multipacting zones are no longer bonded in the region of two parallel windows at low RF powers only. Multipacting conditions may be satisfied and expand to outer radius areas. Numerical simulations of experimental

‡ Shunt impedance definition used here: $ZT^2=V^2/P$

set up conditions are required and will be conducted in near future to further study and understand these effects.

A modest 18 MV/m of the accelerating gradient was reached with the Cu windows at 2.5 T magnetic field in solenoidal mode. The Cu windows were taken out for surface examination after reaching this gradient. Surface damages on the windows were apparent, as shown in Figure 2.

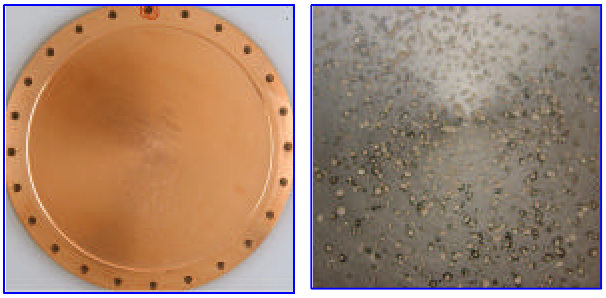

Figure 2: Cu window after RF conditioning with the external 2.5 T magnetic field in solenoidal mode. Surface damage (pitting) can be seen clearly on the photo (right), which is a close-up view of the center region of the same window.

Test of Be Windows with TiN Coated Surface Without External Magnetic Field

Two Be windows with TiN coated surface were installed face-to-face in the cavity. They are pre-stressed flat windows of 0.25 and 0.5 mm thickness, respectively. The coating thickness is ~ 200 A which is intended for suppressing multipacting. As we have experienced from previous tests of the Cu windows, conditioning with external magnetic field tends is mainly responsible for the window surface damage. A modest gradient limit of 16 MV/m was set for the conditioning without magnetic field. The purpose of this test was to make sure that we can condition the cavity with the thin Be windows, and yet do not damage (as we may expect) the window surface before the magnet on. Less multipacting was indeed observed as we expected from the TiN-coated surface. The target of 16 MV/m was achieved quickly without difficulty.

Small cavity frequency shifts were measured during the conditioning. This suggested that the pre-stressed thin Be windows may have deformed slightly (lost their tension) or vibrated due to either RF heating or the RF impulse. The frequency shifts were small and slow, and they were well within the bandwidth of the klystron. Conditioning was continued with manual adjustment of the driver frequency.

Test of Be Windows with TiN-coated Surface With External Magnetic Field

The high power tests were resumed with the TiN-coated Be windows with magnet on. After weeks of the conditioning, only 16.5 MV/m gradient was achieved with the magnetic field up to 4 T. Higher than this gradient would result in more sparking. Fearing possible damage on the Be windows (Be is a health hazardous material), we stopped the test at this gradient and inspected the window surface. Fig. 3 shows a Cu and a Be window side by side after the conditioning, for comparison purpose.

Figure 3: Cu window (left) and Be window (right) after RF conditioning with magnetic field. Deposited Cu particles on the Be window can be seen clearly.

Preliminary surface analysis indicated that no surface damage to the Be window. Copper particles or beads were deposited on the Be window surface. This indicated that they must come from cavity body surface, not from the window region. Further inspection found that there was minor surface damage around the normal iris area where the Be windows were bolted on. The distribution pattern of the Cu particles (beads) was not well understood now, and will be further studied by numerical simulations and experiments in near future.

Future Test Plan

A new pair of Be windows with TiN-coated surface were installed and ready for tests to the highest gradient. Bare Be windows will be tested for multipacting studies. Other window options such as pre-curved windows or grids will be designed and tested at Lab G.

CONCLUSION

We have tested the cavity with Cu and Be windows for with and without external magnetic fields. 16.5 MV/m was achieved with TiN-coated Be windows with magnet on. We believe the gradient is not limited by the Be windows. Preliminary surface analysis indicated no damage on the Be windows which further suggests that Be windows can withstand high RF gradient in a few-T magnetic field. Coating on high field region of the cavity body, say TiN, may reduce multipacting and improve the cavity performance.

REFERENCES

[1] M. M. Alsharo'a, et al., "Status of neutrino Factory and Muon Collider Research and Development and Future Plans", PRST-Accelerators & Beams (2002)

[2] W. Turner, et al., "RF System Concept for a Muon Cooling Experiment", EPAC 1998, Sweden

[3] D. Li, et al, "High Power RF Test of an 805-MHz Cavity for a Muon Cooling Channel", EPAC 2002, Paris, France

[4] J. Norem, et al., "Dark Current and X-ray Measurements of an 805 MHz Pillbox Cavity", this conference.