RECTANGULAR BOX CAVITY TESTS IN MAGNETIC FIELD FOR MUON COOLING*

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Abstract

Muon cooling requires high-gradient normal conducting cavities operating in multi-Tesla magnetic fields for muon beam focusing in an ionization cooling channel. Recent experience with an 805-MHz pillbox cavity at the Fermilab MuCool Test Area has shown a significant drop in accelerating field performance for the case of parallel electric and magnetic fields. It has been suggested that having the magnetic field perpendicular to the electric field should provide magnetic insulation and suppress breakdown. An 805-MHz Cu rectangular box cavity was built for testing with the fields perpendicular. It was mounted on an adjustable support to vary the angle between the rf electric and external magnetic field. We report on the design and initial operation of the rectangular box cavity.

RF CAVITIES IN MUON COOLING

Ionization cooling channels designed for Neutrino Factory or Muon Collider facilities [1] involve low-Z energy absorbers placed in low-β sections in a strong focusing (typically solenoidal) magnetic lattice. The lost energy must be restored by rf cavities placed between absorbers and therefore operating in large magnetic fields. The 201-MHz cavities [2] in the MICE channel [3], for example, will be running in a magnetic field of 1.5-2.5T. Characterizing cavity performance limitations in magnetic field and finding appropriate solutions in Neutrino Factory and Muon Collider designs to mitigate that effect are key goals of the R&D program at the MuCool Test Area [4] at Fermilab.

Effect of Magnetic Field

External magnetic fields can significantly modify the performance of rf cavities [5, 6] by deflecting and focusing electrons coming off the surface at field emission sites or shaping any plasma that might form near the surface,

- When the external magnetic field, $\vec{B}_{\rm ext}$, is parallel to the rf electric field, $\vec{E}_{\rm rf}$, electrons can ride the magnetic field lines between the accelerating gap and cause damage on the surface due to the focused current density [7]
- When $\vec{B}_{\rm ext} \perp \vec{E}_{\rm rf}$, electrons can be deflected into grazing angles to the surface before they can be accelerated by the electric field [8]

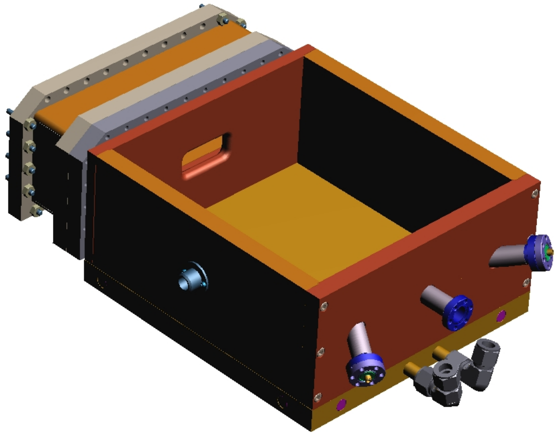

Figure 1: Partial assembly view of cavity showing the coupling aperture and waveguide adapter on one face, flanges for rf pickups and diagnostics on the opposite face, pivot lug on the side for rotation and cooling water fittings on the bottom plate.

BOX CAVITY

A rectangular geometry was chosen for the test cavity to allow for fast fabrication and to simplify analysis. The cavity assembly is shown in Fig. 1. The interior dimensions are 276.5 x 250 x 123.8 mm. The cavity was made of 101 OFE copper plates, 25.4-mm thick top and bottom (horizontal), 19-mm thick on 3 of the vertical sides and 12.7-mm thick on the fourth (the one with the coupling aperture). A rectangular coupling aperture with rounded edges was machined to one of the vertical side plates and a coupling cell was built to match the power coupler to a WR1000 waveguide. The peak field at the aperture is about a quarter of that in the cavity. Interior parts and the aperture were machined to a 32 μ-inch finish. Two hydrogen brazing cycles were required to complete the fabrication. A special compound curved waveguide vacuum tin seal was designed to attach the cavity to the waveguide coupler. At the design gradient of 50 MV/m with 4 MW of peak power, the average power dissipation is expected to be 5 kW, about half of it split equally across the top and bottom plates and the other half distributed equally among the four vertical sides. Cooling tubes were drilled into the top and bottom plates and connected to a chilled de-ionized water system. Three CF flange tubes were installed on the vertical side opposite the coupling aperture for rf pickups and optical diagnostics.

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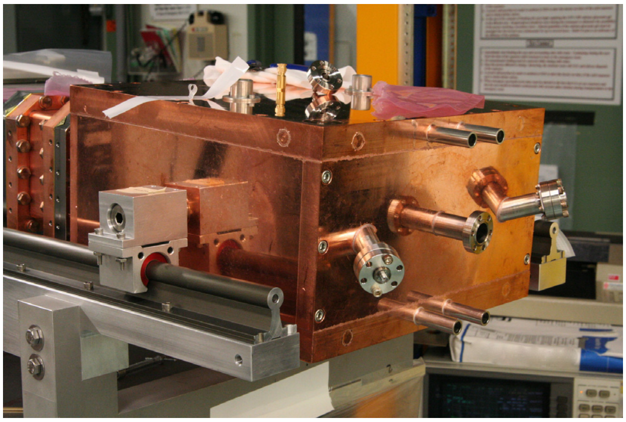

Figure 2: Cavity assembly showing side pivot on rails, water cooling tubes and flanges for diagnostics.

Mechanical Support

We wanted the ability to tilt the cavity electric field axis (nominally vertical) with respect to the external magnetic field direction (horizontal) and explore the effect on cavity performance. Pivot lugs were installed on the sides of the cavity body which mated with holes in blocks mounted on linear bearings riding on rails. This arrangement, shown in Fig. 2, allows rotation of the cavity assembly within the 44-cm magnet bore by up to 12^o.

Instrumentation

Forward and reflected power envelopes from the directional coupler near the cavity were available for monitoring. Two pickup probes were installed in cavity ports for access to the electric field amplitude in the cavity. Also, two sapphire windows were installed on the ports to capture light produced in any breakdown events. The light was channeled through a collimating lens and clear fiber to a spectrometer and photomultiplier tubes (PMTs). Six ionization chambers in the hall were read out and used to monitor the radiation dose rate. Five counters consisting of scintillator blocks and PMTs were also installed around the hall to measure X-ray rates. Figures 3 and 4 depict the cavity and some of the instrumentation installed in the experimental hall.

Operation

The resonant frequency and Q of the cavity were measured as 805.341 MHz and 2.79×10^4. The coupling factor is 0.97. The cavity was powered with 20-μs pulses at 15 Hz. Vacuum pressure was steady below 10^{-8} Torr during normal operation. A LabView based program [9] developed for use at the MuCool Test Area was used to automate the operation, although some manual intervention was required. The program monitored rf pickup and reflected power, vacuum and cavity light signals to detect breakdown and could adjust the rf power and frequency.

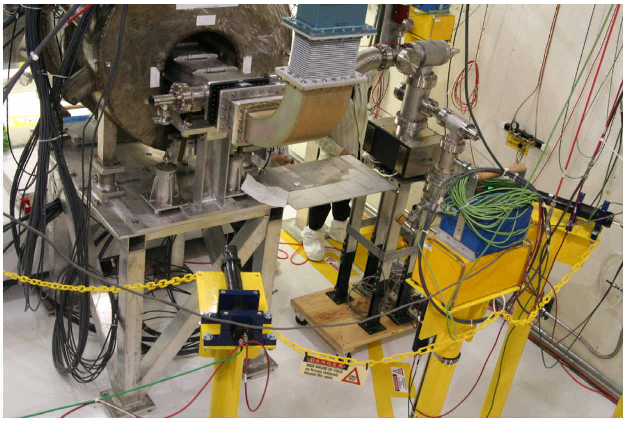

Figure 3: View of hall showing waveguides leading to cavity inside the magnet and several radiation detectors on stands.

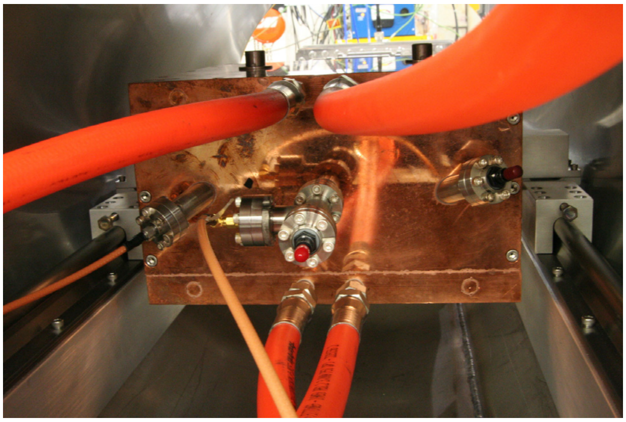

Figure 4: Cavity installed in magnet bore. Two rf pickup connections (left and center), two optical ports (capped, center and right) and water hoses (top and bottom) are visible.

RESULTS

The box cavity was first conditioned with no external magnetic field to 25 MV/m. This level was chosen to be significantly higher than the limit of stable operation observed at B=3T in the past with the 805-MHz cylindrical pillbox cavity (16 MV/m) but still quite low for B=0 in order to minimize the risk of any damage to cavity surface. Next, the magnetic field was set to B=3T with the cavity in the nominal ($\vec{E}_{rf} \perp \vec{B}_{ext}$) configuration, the cavity was conditioned to 32.6 MV/m and operated at that level for over 10^7 pulses. This gradient was also chosen to limit possible spark damage because of the large stored energy (over 15 J at 32.6 MV/m) before other angles were measured. The next step will be to tilt the cavity with respect to the magnetic field and study the limit of stable operating gradient as a function of angle. Detailed analysis of breakdown events recorded during operation will also be reported in the future.

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