MULTI-PURPOSE 805 MHZ PILLBOX RF CAVITY FOR MUON ACCELERATION STUDIES*

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Abstract

An 805 MHz RF pillbox cavity has been designed and constructed to investigate potential muon beam acceleration and cooling techniques. The cavity can operate at vacuum or under pressure to 100 atmospheres, at room temperature or in a liquid nitrogen bath at 77 K. The cavity is designed for easy assembly and disassembly with bolted construction using aluminum seals. The surfaces of the end walls of the cavity can be replaced with different materials such as copper, aluminum, beryllium, or molybdenum, and with different geometries such as shaped windows or grid structures. Different surface treatments such as electro polished, high-pressure water cleaned, and atomic layer deposition are being considered for testing. The cavity has been designed to fit inside the 5-Tesla solenoid in the MuCool Test Area at Fermilab. Current status of the cavity prepared for initial conditioning and operation in the external magnetic field is discussed.

INTRODUCTION

Ionization cooling, where all momentum components are degraded by an energy absorbing material and only the longitudinal momentum is restored by RF cavities, provides a means to quickly reduce transverse beam sizes. However, the beam energy spread cannot be reduced by this method unless the longitudinal emittance can be transformed or exchanged into the transverse emittance. One scheme to achieve emittance exchange is to pass a beam through a bending magnet to introduce dispersion, the beam can then be made incident to a wedge shaped absorber. The higher momentum particles pass through more of the absorber material than the low momentum particles and thus suffer larger ionization energy losses. Much work has been done on a second cooling scheme, one in which a continuous absorber such as gaseous H_2 is used in a Helical Cooling Channel (HCC). In the HCC higher momentum corresponds to a longer path length. The path length dependence means high momentum particles must pass through more absorber and therefore experience a larger ionization energy loss compared low momentum particles. The theory of this helical channel has been described elsewhere [1]. The use of high pressure gas not only serves as an ideal absorber, it helps in the suppression of RF breakdown, and if one can design the appropriate thermal barrier between the RF cavity and magnet it will also function as part of the cavity cooling system.

A HCC consisting of a pressurized gas absorber imbedded in a magnetic channel that provides solenoid, helical dipole and helical quadrupole fields has shown considerable promise in providing six-dimensional cooling for muon beams. The energy lost by muons traversing the gas absorber needs to be replaced by inserting RF cavities into the lattice. Replacing the substantial muon energy losses using RF cavities with reasonable gradients will require a significant fraction of the channel length be devoted to RF. However, to provide the maximum phase space cooling and minimal muon losses, the helical channel should have a short period and length.

Demonstrating the technology of such a cooling channel would represent enormous progress toward the next energy frontier machine. The multipurpose 805 MHz cavity described here will facilitate the understanding of how to build a cooling channel. Additionally it is conceptually compatible with another Muons, Inc. proposal that aims to design and build a 10 T, 805 MHz segment of a helical cooling channel which builds on previous work by Muons, Inc. [2].

The cavity also can serve as a test resonator for large-acceptance high-gradient linac for acceleration of low energy muons and pions in a strong solenoidal magnetic field, [3]. Such a linac was proposed at LANL for homeland defense and industrial applications. The acceleration starts immediately after collection of pions from a target by solenoidal magnets and brings muons to a kinetic energy of about 200 MeV over a distance of the order of 10 m. At this energy, both an ionization cooling of the muon beam and its further acceleration in a superconducting linac become feasible. The required large longitudinal and transverse acceptances can be achieved in a normal-conducting linac consisting of independently fed TM_{010} mode RF cavities with wide apertures closed with thin metal windows or grids. The guiding magnetic field is provided by external superconducting solenoids. Due to the low energy of the initial pions and muons, vacuum cavities are preferred, at least in the beginning of

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the normal-conducting linac to minimize particle energy losses.

FEATURES OF THE CAVITY INTENDED FOR COOLING OF MUONS

The work reflects an attempt to create a universal design of an accelerating cavity model allowing to work with 100 atm. compressed hydrogen or with vacuum. To simplify technology and design the cavity model was made from thick elements of stainless steel SS-316 clamped with bolts, Fig. 1. The sealing is provided by flat pure aluminum sealing rings demonstrated good ability to work with pressurized gas.

The developed pillbox cavity intended to operate with TM_{010} mode of RF field consists of the elements including two covers, cylindrical body and two test plate holders which allow using test plates as insets to check various materials for operation with a high-gradient RF field. All the elements are plated with 25-37 μm thick copper. For sealing the cavity for vacuum using flat aluminum sealing rings we have developed technology for manufacturing of the rings and machining the respective sealing surfaces of the cavity parts.

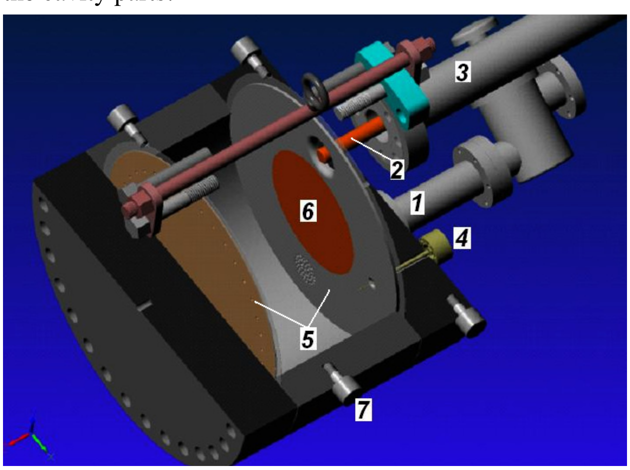

Figure 1: The model of the cavity for cooling of muons. 1-vacuum port, 2- antenna, 3- RF coax feeder, 4- probe, 5- test plate holder, 6- test plate to study materials at high gradients of RF field, 7- roller.

Cleaning of the cavity elements after machining with oil containing coolants was done with a detergent (Palm Olive soap) dissolved in hot (45 C^0) deionized water followed by two rinses in hot deionized water. The developed technology allowed us to reach vacuum of $3x10^{-8}$ Torr after baking at 106° C for a few days. The pumping was provided by a type TMH 071 P turbo pump and the V20 ion pump. The ion pump was turned on after the cavity had cooled down. The cavity temperature and vacuum measured at the cavity evacuation are shown in the vacuum log, Fig. 2.

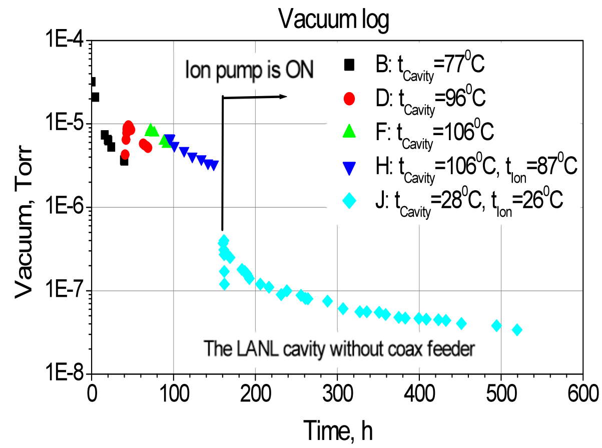

Figure 2: Vacuum log of the 805 MHz pillbox RF cavity.

Installation of the RF coax feeder, which utilizes an epoxy window does not drop noticeably the vacuum value. The epoxy window of the RF coax feeder is designed to work up to 100 atm.

CALCULATED AND MEASURED PARAMETERS OF THE PILLBOX CAVITY

The parameters of the cavity with the coax input were calculated analytically and numerically using 3-D programs (Microwave Studio, Comsol). By choosing the appropriate thickness for the test plates, which are inserted in the test plate holders, one can fit the cavity frequency. Fig. 3 shows the frequency shift vs. the test plate thickness.

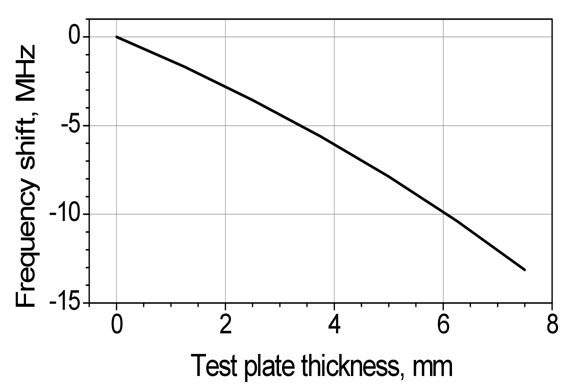

Figure 3: Computed the cavity frequency shift vs. the test plate thickness.

Without the test plates the cavity was machined for resonance frequency of 809.5 MHz, the measured (under vacuum) value is 810.16 MHz. Computed value of the wall-loss Q-factor is: $Q_0=2.882x10^4$, the measured value is $3x10^4 \pm 5\%$.

Computed parameters of the cavity vs. the required gradient of the RF field value are shown in Table 1.

Table 1: Parameters of the Cavity vs. the Gradient of the RF Field

Gradient, MV/m	Stored energy, J	Wall loss power, MW	Feeder voltage, kV	Average wall loss power, W
20	4.715	0.754	8.68	226.2
25	7.367	1.178	10.85	353.5
30	10.61	1.697	13.03	509
35	14.44	2.309	15.2	692.8
40	18.86	3.016	17.37	904.8

The last column of the table shows the expected average power lost in the cavity walls for standard operation of the RF source during conditioning (assuming a repetition rate of 15 Hz and the RF pulse duration of 20 μs).

As follows from the last column of the table, the standard conditioning parameters will lead to noticeable heating of the cavity. Without additional cooling the cavity temperature will rise linearly and after ~8 hr's it will have increased by ≈120°C. This temperature is unacceptable, especially when working with pressurized hydrogen. Moreover, a drift of the cavity temperature causes a drift in the cavity resonance frequency, approximately 13 kHz/C^0. Simple cooling systems can help to solve the problem of heating.

The cavity coupling system utilizes an antenna matched to the coax feeder impedance to provide critical coupling to the cavity. This helps avoid overvoltage in the coax feeder during high power transmission from the RF source, Table 1. Since overvoltage in the antenna neighborhood is undesirable, optimized sizes, design, and positioning of the antenna were chosen based on the 3-D simulations (HFSS and CST Microwave Studio codes). Fig. 4 shows measured the cavity coupling coefficient, β, vs. the immersion depth, δ, of the optimized antenna into the cavity.

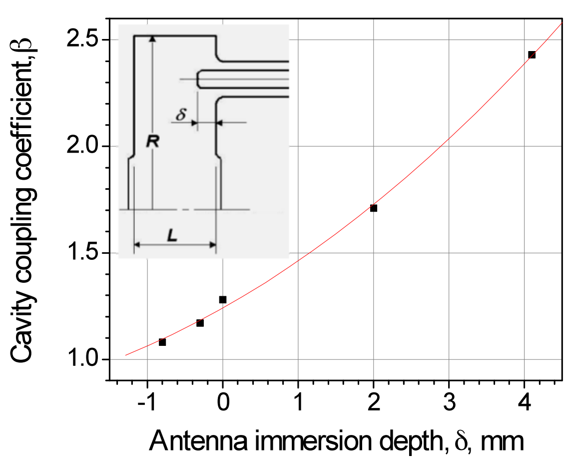

Figure 4: Measured the cavity coupling coefficient vs. the antenna immersion depth.

Tuning of the cavity coupling was done by varying the immersion depth of the antenna, this is facilitated by a sliding collar contact made in the central wire of the coax feeder.

The RF field distribution in the cavity was computed with Comsol for a RF power of 1 MW, this provides an accelerating gradient of 23.4 MV/m is shown in Fig. 5.

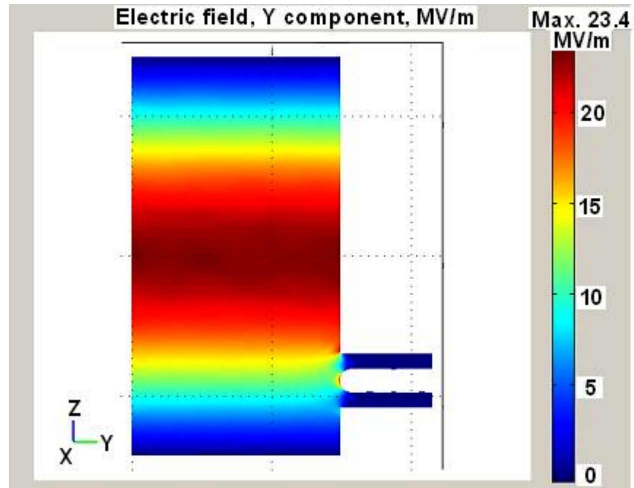

Figure 5: Computed the RF electric field distribution in the pillbox cavity at 1 MW RF power and critical coupling of the cavity.

The cavity has been prepared for conditioning at the FNAL MuCool Test Area [4]. The cavity was mounted in the movable compact vacuum bench including dry scroll pump, turbo pump and ion pump.

SUMMARY

A prototype of a universal TM_{010} mode pillbox accelerating cavity intended for operation with 100 atm. hydrogen or vacuum and the required manufacturing technologies have been developed. The prototype pillbox cavity will be used to study RF operation at high-gradient electric field in the presence of an external magnetic field, a configuration that will most likely be required for muon cooling. Preparation of the cavity conditioning without and with the magnetic field is in progress.

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