Π/2 INTERLEAVED CAVITY DEVELOPMENTS FOR THE MUON COLLIDER COOLING EXPERIMENT

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Abstract

In this paper we discuss the development of a π/2 interleaved standing wave linac for the proposed muon cooling experiment. The nominal beam momentum is 186 MeV/c (beta=0.87). Each muon cooling channel section contains a 1.3m rf accelerating linac separated by 0.64m of liquid hydrogen absorbers immersed in a alternating superconducting solenoidal magnetic transport line. Instead of conventional open cavity beam apertures, the 805 MHz linacs have thin Be windows covering the iris apertures. The accelerating cavities closely resemble pillbox cavities and have little or no field enhancement due to iris aperture corners. Further, since the peak field is on the axis, the shunt impedance is about a factor 2 larger than conventional designs. It is also proposed to cool the cavity to liquid nitrogen temperature to reduce the losses and increase the shunt impedance. Our π/2 interleaved cavity design is essentially two chains of side coupled π/2 cavities interleaved to form a continuous chain of accelerating cells on the beam axis. Each accelerating cell has a phase advance of π/2 and, therefore, a favorable transit time factor. This paper will discuss the design of the cavity, MAFIA calculations, low-power rf model cavity measurements, low-temperature effects with Be windows, design of high-power rf test models and a proposed high-power rf test facility.

1 INTRODUCTION

Studies of muon colliders have been going on for about five years and more recently a international collaboration has been formed to study the feasibility of muon colliders for high energy physics research. The collaboration is focused at BNL, Fermilab, and LBL [1,2]. For a practical high-luminosity collider, large numbers of muons must be produced and transported through the collider complex. Because of the short lifetime of the muon, this must be accomplished very quickly to minimize loss of muons and to preserve the machine luminosity. The muons are generated from the decay of pions produced in proton-nucleus interaction in a high-Z target and collected in a solenoidal decay channel. This produces muons with a large initial phase volume which must be reduced (cooled) quickly by several orders of magnitude. The technique of ionization cooling has been adopted to reduce the phase-space volume of the muons. In this technique, muons lose both transverse and longitudinal momentum while passing through low-Z material and the longitudinal momentum is then restored by acceleration in rf cavities. This process is repeated numerous times to reduce the phase-space volume sufficiently for acceptance by the acceleration system of the collider complex.

After studying a number of cavity designs, the interleaved π/2 side coupled cavity, Fig. 1, with thin (125 μm) beryllium windows over the cavity apertures was selected [3,4,5]. This design resembles a pillbox cavity and achieves a high shunt impedance over the required large beam aperture (16 cm). The peak accelerating electric field and maximum surface field are identical. This gives a maximum possible accelerating field limited only by electrical breakdown. In addition, the π/2 interleaved pillbox design gives a transit time factor of 0.90. This design has the highest group velocity (being in the center of the passband) and is more tolerant of dimensional errors, beam and mechanical perturbations. The pillbox design is made possible because of the low scattering rate of muons in matter, especially low-Z beryllium. Further, the cavity is to be cooled to liquid nitrogen temperature to increase the shunt impedance by about a factor two and reduce the large peak power requirements of the muon cooling channel. This feature requires the design of bi-metallic transitions between the copper cavity walls and Be window foils to compensate for differences in the material thermal expansions and keep the window flat during cool-down and operation. Also, the high group velocity of the π/2 mode will make it more tolerant of thermal distortions during cool-down and operation.

2 RF CAVITY DETAILS

The cooling channel rf cavity details are shown in Fig. 1. It is a 805 MHz interleaved side-coupled π/2 cavity. (The same frequency as the Fermilab Upgrade Linac commissioned in 1993.) The interleaved design was chosen over the more conventional side-coupled cavity design because of its larger shunt impedance (ZTT=38MOhm/m and Q=19,600 from MAFIA calculations). The conventional design, because of the required large beam aperture of 16 cm, had a ZTT about a factor two smaller. The operating principle can be understood with reference to Figs. 1 and 2.

The upper part of figure 1 shows cells labeled C coupled together to form a side-coupled cavity while the cells labeled D form another independent side-coupled cavity. Structures C and D have been designed with the computer program MAFIA to resonate in the π/2 mode and are excited with high fields in the on-axis accelerating cells

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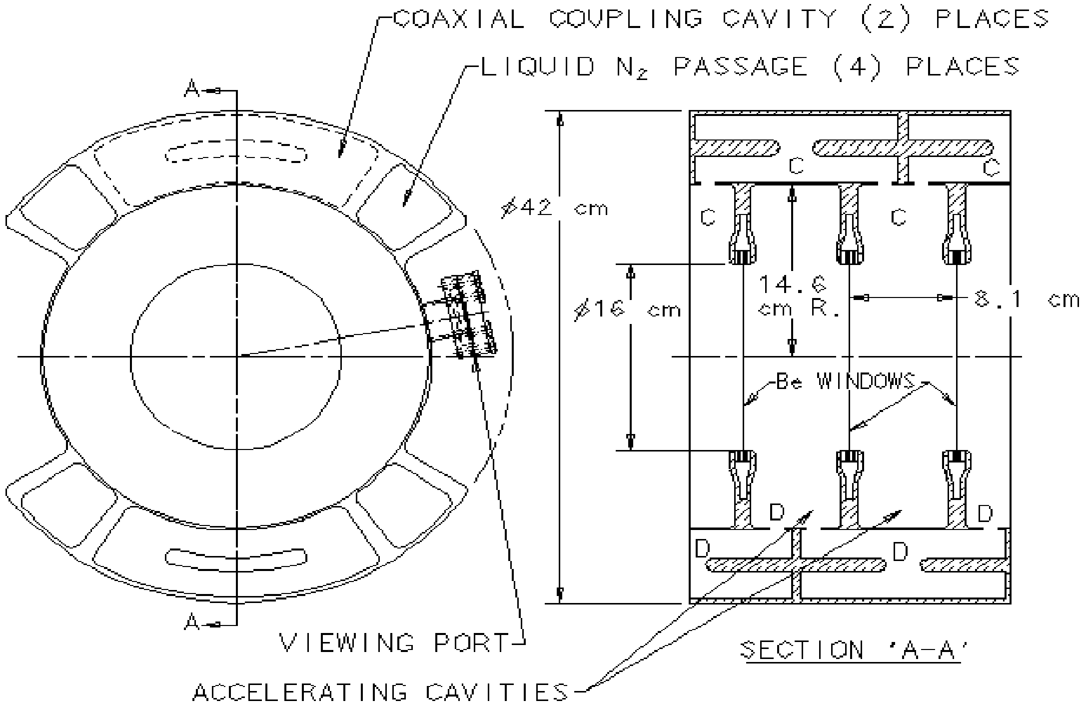

Figure 1: $\pi/2$ Interleaved Cavity Cross Section

and near zero fields in the off-axis coupling cells. The on-axis cells of the C structure and the D structure each have a phase advance of π per cell, but together have the transit time factor of 0.90 of a $\pi/2$ mode cell rather than 0.637 of a conventional side-coupled structure. Fig. 2 shows the method of excitation. Two independent waveguides are slot coupled to adjacent accelerating cells and are driven $\pi/2$ apart in phase through a 90 degree waveguide hybrid.

Figure 1 gives some details of the bi-metallic transition between the outside cavity iris walls and the central 125 μm Be foil. Because of the large difference in thermal expansion between copper and beryllium from room temperature to liquid nitrogen temperature, a buffer material must be used to bridge this difference. Large distortions will otherwise occur resulting in detuning of the cavity and distortions in the required fields. Molybdenum has been chosen as the buffer material. Its Young's modulus is about the same as Be and three times that of copper at room temperature. Its thermal expansion coefficient is about 30% less than Be. With proper design (ANSYS calculations are under way) this should result in slight tension on the Be foil and keep it flat at liquid nitrogen temperatures. Keeping the foil flat will preserve the cavity tune and field flatness. This is illustrated by the rings of different material surrounding the Be window foils in Fig. 1.

3 EXPERIMENTAL STATUS

The design of a low-power three cell test cavity has been completed at LBL using MAFIA. Copper for the cavity has been ordered by the University of Mississippi where the final machining will be done. Testing of this cavity to liquid nitrogen temperature will take place at LBL in the next few months. Studies of the electrical properties of Be at liquid nitrogen temperature are underway at BNL and Mississippi. A high-power three cell cavity is currently being designed at LBL. This cavity will also be machined at Mississippi and then tested at low power at LBL. A high-power 805 MHz test facility is now being planned at Fermilab. It will use a high-power Litton klystron and a Fermilab built modulator to produce up to 15 MW of rf power for 50 μs at 15 Hz. Testing will take place to determine the upper power limit of the klystron. The cavity will be put in a pair of 5.5T superconducting solenoids to simulate the alternating solenoid environment of the cooling channel. The solenoids are being designed and built at LBL and will be shipped to Fermilab as part of the test facility.

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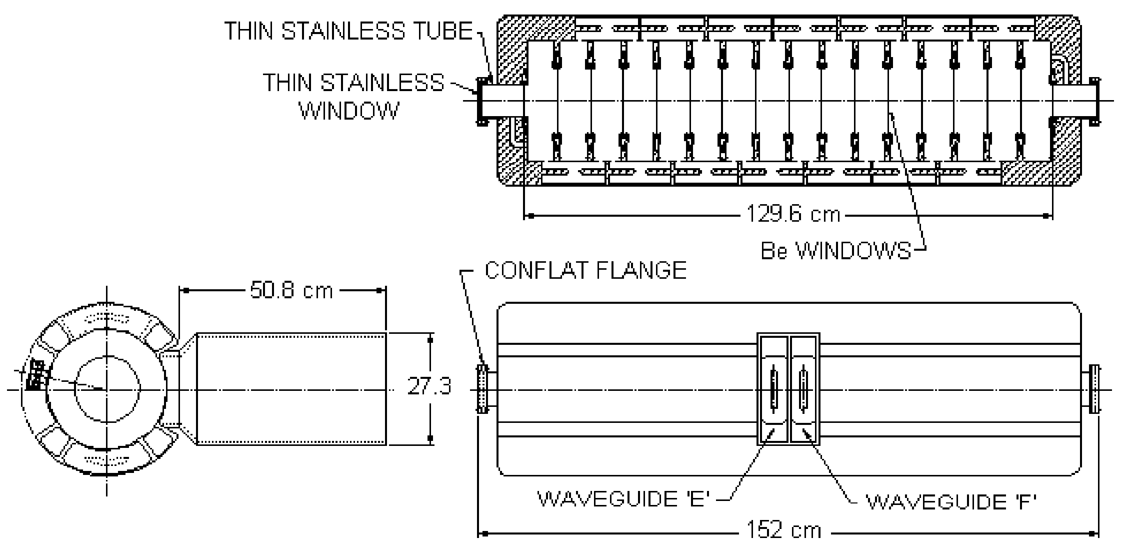

Figure 2: Cooling Channel rf Cavity