RF INTEGRATION INTO HELICAL MAGNET FOR MUON 6-DIMENSIONAL BEAM COOLING*

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Abstract

The helical cooling channel is proposed to make a quick muon beam phase space cooling in a short channel length. The challenging part of the helical cooling channel magnet design is how to integrate the RF cavity into the compact helical cooling magnet. This report shows the possibility of the integration of the system.

INTRODUCTION

The helical cooling channel (HCC) is proposed to obtain the exceptional cooling performance in a short channel length [1]. It consists of a helical dipole and a solenoid magnet to generate a continuous dispersion. A helical quadrupole component is superimposed to increase the beam acceptance. A high pressurizing hydrogen gas filled RF cavity [2] is incorporated into the HCC magnet to make an ionization cooling and an energy loss compensation at the same time. Because the HCC makes a continuous emittance exchange it generates the six-dimensional phase space cooling.

The HCC simulation has been demonstrated by using the realistic helical magnet. The helical magnetic field is generated from the helical solenoid (HS) coils [3]. The helical magnet is a series of simple coil rings with each ring center located along with the helical beam path. The RF cavity is located in the center of the HS coil. There must be a gap between the RF cavity and the HS coil for a pressure wall, a thermal isolation, and a space for a cooling pipe of the RF cavity and for an RF power transport cable. In this document, we will discuss what is the required gap and how the HCC will preserve the cooling performance with the realistic geometry configuration.

DESIGN REALISTIC HELICAL MAGNET

Required Gap between RF Cavity and HS Coil

In the current HCC design, the RF cavity is operated under liquid nitrogen (LN2) temperature. The density of a 50 atm gaseous hydrogen absorber in the HCC is, therefore, 1/8 of the liquid hydrogen density. The pressure wall is designed by using the ANSYS mechanical analysis package. A typical result is shown in Figure 1. The helical tangential pitch is 1.0 and the helical period is 1.6 m. These geometric parameters are close to the first and second HCC segments (shown in Figure 5). SS316, Inconel625, and Inconel718 were tested as wall materials. The inner diameter of the helical tube is 0.5 m. The required thicknesses for these wall materials are 0.75, 0.5, and 0.35 inches, respectively, using a safety factor 4 based on the ASME code. From the mechanical analysis, 10 mm thickness wall with Inconel718 will be sufficient for the pressure barrier.

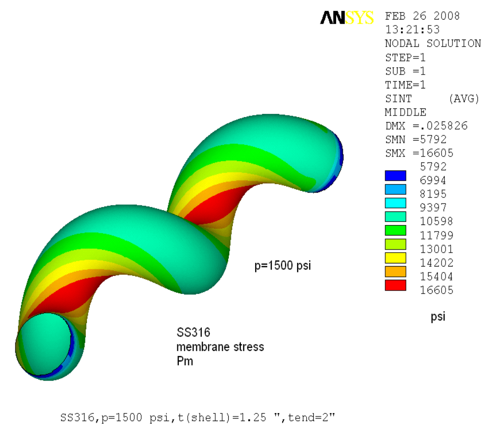

Figure 1: Mechanical analysis of high pressurized helical tube.

There is a liquid nitrogen (LN2) jacket outside the pressure wall to operate the RF cavity at LN2 temperature. The thickness of LN2 will be strongly dependent on the RF power loss on the wall. A LN2 will use convection flow to remove the heat effectively for high heat deposition. We assume that 10 mm LN2 jacket would be sufficient to keep the temperature of RF cavity. There must be a vacuum gap between the LN2 and the liquid helium (LHe) layers for thermal insulation. An RF power transport cable will be stretched in this gap. We assume that 1 inch diameter coaxial cable will be sufficient for the RF power transportation. Hence, the vacuum gap is designed to be 40 mm.

The helical magnet will be made of a superconducting (SC) cable. The magnet is in an LHe bath. There must be a SC support and a super insulator to avoid the radiation heating from the LN2 jacket. We expect that a 20 mm gap will be sufficient for those layers.

Figure 2 shows the schematic picture of the required thickness for each layer. The gap in the vacuum layer seems to be larger than the requirement. This overestimated space will be absorbed by some unknown factor in some layer. In the current design, the total gap between the HS coil and the helical RF cavity is designed to be 80 mm.

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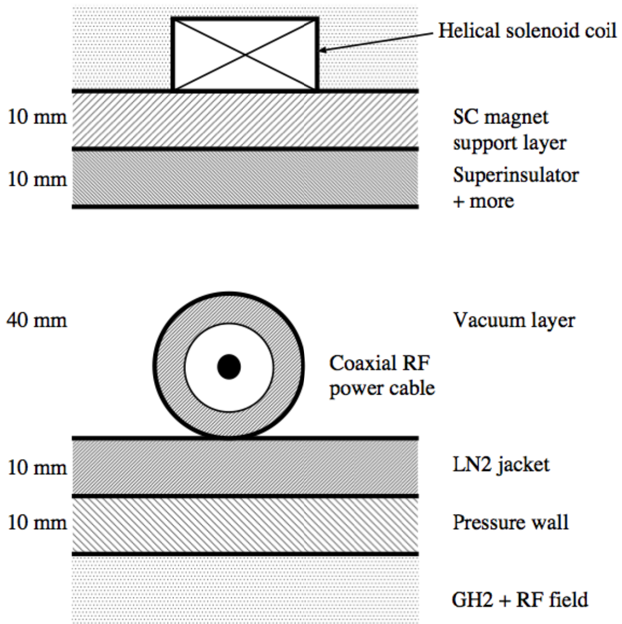

Figure 2: Schematic draw of layers between the HS coil and the high pressurizing hydrogen filled RF cavity.

Generate Helical Field by Helical Solenoid Coil

The HS coil has a geometric approach to aid in the tuning of the required helical dipole and solenoid fields. Figure 3 is a schematic drawing to show how to tune the dipole and solenoid field strengths on the reference orbit. The drawing shows the reference orbit from the end view of HCC. Three thick circles show the schematic HS coils. Let us find out the field on "Coil-2" center. The solenoid field is dominantly generated by the "Coil-2". On the other hand, the helical dipole field (Bφ) is dominantly generated by "Coil-1" and "Coil-3", those are upstream and downstream of the "Coil-2", respectively.

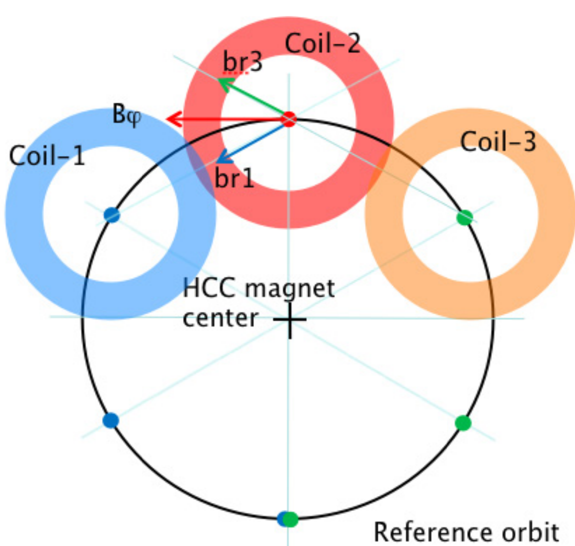

Figure 3: Schematic view of the HS coil from the end of HCC.

The coil diameter is additional degree of freedom to adjust the helical field gradient. However, this geometric effect is too weak to optimize the field gradient. Besides, an 80 mm gap requirement limits the maximum field gradient.

Add Correction Helical Solenoid Coil to Generate Proper Helical Quadrupole Component

In order to reduce the geometrical limitation of the HCC field, a correction coil is introduced. Figure 4 shows the modified configuration of the helical magnet by adding the correction HS coils. The red circle is a 200 MHz pillbox RF cavity. Blue and green circles are the primary and correction HS coils, respectively. There is an 80 mm gap between the RF cavity and the primary HS coil. A large green ring is a pure straight solenoid conductor. The tuning process of the helical magnet is as following.

The optimum helical dipole and helical field gradient are realized by tuning the position, size, and current of the primary and correction HS coils. Then, the solenoid component is tuned by adjusting a large solenoid conductor current.

The cooling simulation has been made in this configuration and shown that the field quality is well for muon collider application. However, there are two problematic issues in this design. First, the correction HS coil generates a large wasted energy since no beam path through it. Second, the field strength on the correction HS coil is quite large near the primary HS coil.

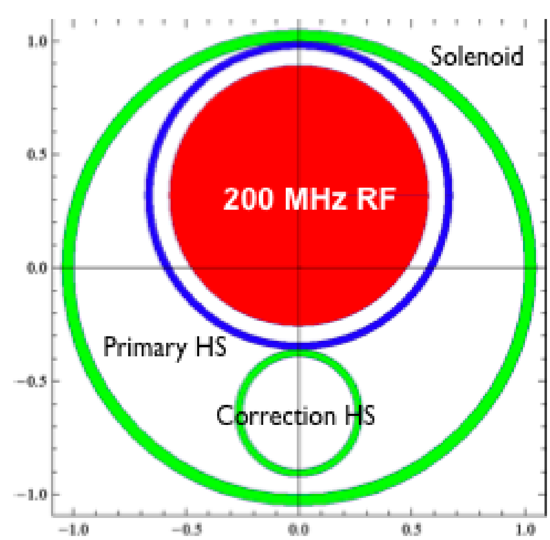

Figure 4: Schematic view of modified helical magnet with correction coils. The unit is meter. The origin is the helical magnet center.

Add Helical Coil to Generate Proper Helical Quadrupole Component

In order to increase the efficiency of the magnet system, a new HCC magnet has been designed. As shown in Figure 5, the correction HS coil is replaced with four helical quadrupole conductors. The quadruple conductor will wind around the primary HS followed by the helical pitch. The field quality on the reference is almost identical as the previous design.

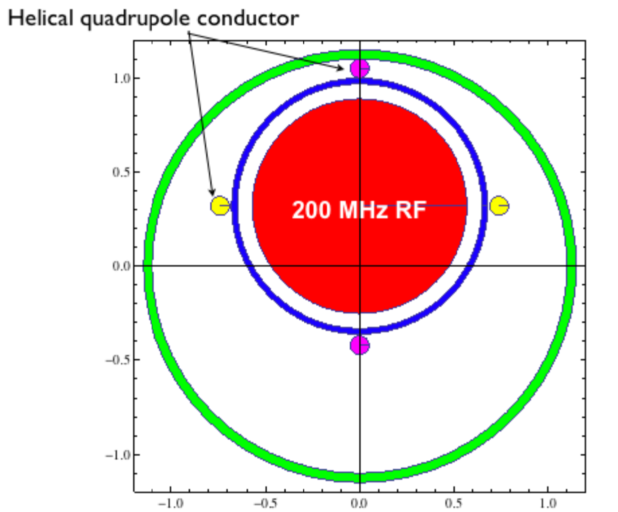

Figure 5: Schematic view of a new HS configuration with a helical quadrupole conductor.

Figure 6 shows the transverse and longitudinal phase space evolutions in a series of HCCs with the helical quadrupole conductor as shown in Figure 5. The RF frequency is shifted from 200 to 1600 MHz following the beam size reduction as a function of path length. The field optimization in a 1600 MHz HCC is on going.

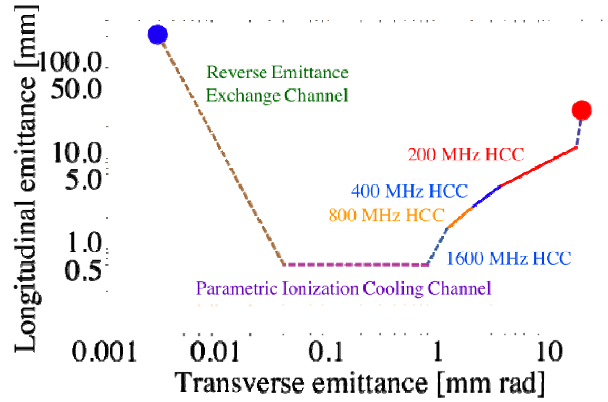

Figure 6: Transverse and longitudinal phase space evolutions in a series of HCCs.

CONCLUSION

The realistic HCC magnet system has been designed by taking into account the spacing between the HS coil and the RF cavity. The cooling performance in the HCC has been investigated. So far, the RF cavity size is determined from the pillbox structure. However, the cavity size can be made smaller by changing the shape of the cavity and by introducing dielectric loaded RF cavities [4]. The phase space matching will be the next issue. To fix it, we will introduce the adiabatic ramping frequency RF as a function of the channel length. We also plan to fine tune the HCC field quality to reduce the mismatching.

REFERENCES

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