The design of dielectric gas-filled RF cavity

Muon accelerator has been proposed as one of the new generation accelerators at Fermilab. Muon has a distinct advantage in lowering synchrotron radiation due to its large mass. This advantage makes the building of a Muon collider very appealing. However, different from electron, Muon is a very unstable lepton with a lifetime only about 2.2 μs in the lab frame. This lifetime requires the cooling and acceleration process of Muon to be accomplished all within a short time. To achieve the cooling effect, an innovative cooling system called helical cooling channel (HCC) is proposed. For accelerating structure, the radio frequency (RF) cavity must be able to fit in the solenoid of HCC and have an electric gradient as high as possible. Besides these requirements, the RF cavity has to be resonated with the driving frequency of power source if a current power source is to be used.

Here at Fermilab, klystron power source produces power at 800 MHz. Since the resonant frequency of RF cavity is only depended on three properties: Radius, dielectric constant and magnetic permeability, if a standard vacuum RF cavity is to be used, its radius will be too large to be fit in the solenoid. Hence, a method is proposed as building a cavity with a dielectric material inside so the dielectric constant is changed and therefore the size can be reduced. Another problem called surface breakdown is emerged due to this method. The dielectric material has a second electron emission rate bigger than one and therefore generates extra electrons when an electron hit. Electrons in high electric field will be focused and hit the dielectric material, causing breakdown at the surface. This problem can be solved by using buffer gas to stop the transmission of electrons.

Different dielectric materials have different effects on resonant frequency. Three distinctive materials are therefore tested in the cavity: Alumina, Teflon and TiO. Alumina has an outstanding dielectric constant and it is easy to shift resonant frequency with a small amount of material. Teflon is, on the other side, with a smaller dielectric constant and harder to change frequency. But, due to its cheap price and manufacturability, it is still considered as an option. TiO is a novel material which has large dielectric constant and strength. Another method to shift frequency is to change the geometries of cavity and dielectric material. This method has a limited effect; therefore it is only used as a supplemental method.

This paper discusses the effects of different sets of materials and geometries. Testing of those materials is first conducted in software called Superfish. Superfish can simulate electric field and magnetic field inside the RF cavity and generate outputs for many useful properties. With a constant resonant frequency, cavities with different materials and geometries are modeled. Several important properties and the realistic design for the cavity are further discussed as well.