TUNABLE RF CAVITIES USING ORTHOGONALLY BIASED FERRITE*

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Abstract

Originally conceived as a solution for FFAG applications, a new compact RF cavity design that tunes rapidly over various frequency ranges can be used to upgrade existing machines. The design being developed uses orthogonally biased garnet cores for fast frequency tuning and liquid dielectric to adjust the frequency range and to control the core temperature. We describe measurements of candidate ferrite and dielectric materials. The first use of the new cavity concept will be for improvements to the 8 GeV Fermilab Booster synchrotron.

INTRODUCTION

The design discussed here was conceived for FFAG applications such as medical accelerators of protons and light ions for cancer therapy [1], proton drivers for neutron or muon production, and rapid muon accelerators. Another use of compact, rapidly tunable RF cavities is for older machines that require new capabilities but have limited space for new components. In the 8 GeV Fermilab Booster synchrotron, for example, second harmonic RF cavities could provide improved proton capture during injection as well as reduce beam losses as the beam passes through transition. Upgrading the RF system of the Fermilab Main Injector to be ready for a new H minus linac that would replace the Booster is another potential use.

Tunable RF cavities often utilize materials whose magentic permialbility can be changed by applying a variable external magnetic field. In all operating machines that use this principle, the external magnetic field is parallel to the direction of the magnetic component of the RF field, whether in external tuners or in the cavity itself. However, the properties of the ferrite are almost dramatically different if the external magnetic field is orthogonal to that of the RF [2]. The measurements that are described below demonstrate this difference. We also show a conceptual design of a compact, tunable RF cavity that could use the faster response and increased sensitivity of new material in the orthogonal biasing orientation.

FERRITE MEASUREMENTS

Figure 1 shows the schematic of the RF test cell that was used to measure the properties of candidate materials for orthogonally biased RF cavities. Figure 2 is a picture of the test cell and figure 3 a picture of the cell being placed inside a test magnet.

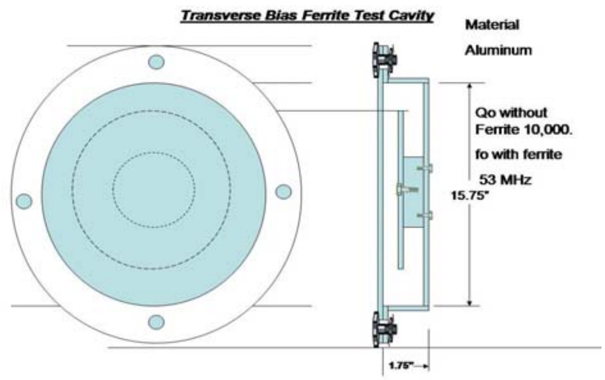

Fig. 1: Schematic of ferrite measurement cell.

Fig. 2: Picture of measurement cell.

Fig. 3: Ferrite measurements in strong transverse field.

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Figures 4 and 5 are the first results of measurements using garnet cores that were available that compare the same material for different field configurations. Figure 4 is the quality factor of the test cell as a function of the external magnetic field Figure 5 shows Q_0 as a function of frequency

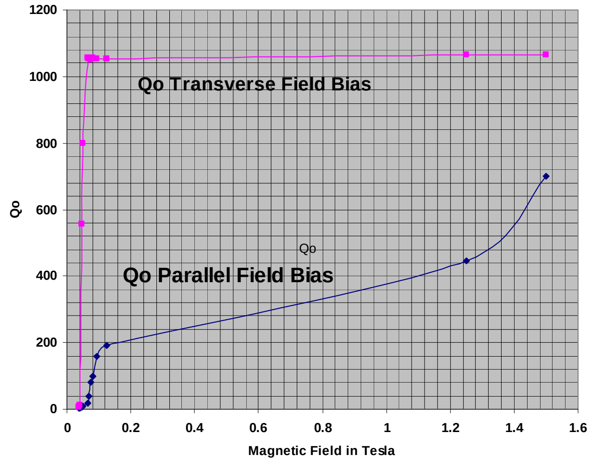

Fig. 4: Comparison of Q_0 as a function of bias magnet field strength for a garnet core for orthogonal (magenta) and for parallel (blue) biasing.

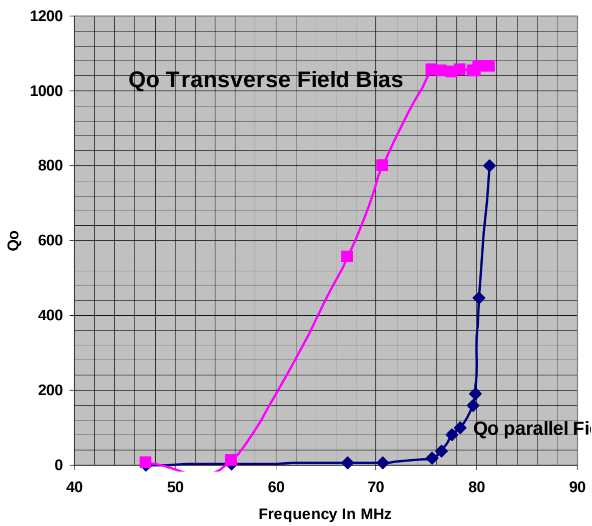

Fig. 5: Comparison of Q_0 as a function frequency for a garnet core for orthogonal (magenta) and for parallel (blue) biasing.

CONCEPTUAL DESIGN

Figure 6 shows the conceptual design of the compact RF cavity that we are developing for FFAG and other applications. The fundamental design is based on a pillbox cavity. Ferrite occupies the region of high magnetic field, and a liquid dielectric occupies the region of high electric field, as shown in the figure. The liquid is also used to cool the ferrite. Fast tuning is accomplished with a solenoid biasing coil that surrounds the cavity. The frequency range is determined by the dielectric constant of the liquid, which can be chosen according to the requirements of a particular machine, and the separation of the irises. An iron return yoke surrounding the cavity shunts the biasing return field and reduces its effect on the beam.

An important feature of this design is that the solenoid biasing magnetic field is orthogonal to the RF magnetic field. There is reason to believe that the orthogonal biasing will have advantages in faster tuning and less RF heating loss.

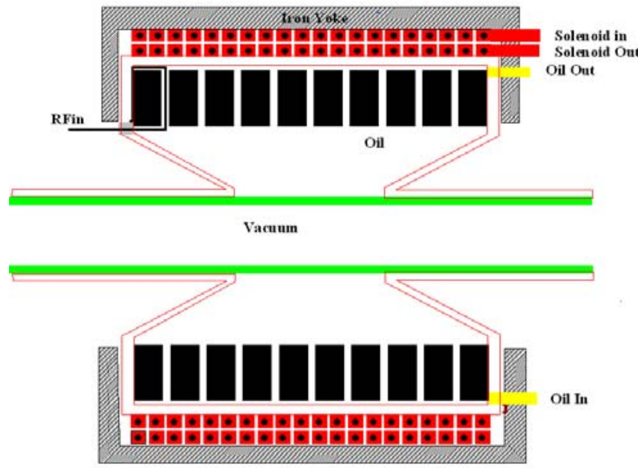

Fig. 6: Conceptual/schematic design of a compact, tunable RF cavity for FFAG and other applications. Ferrite cores (black) and liquid oil dielectric surround a ceramic beam pipe (green) with an RF iris as shown. Coils (red) outside of the cavity generate a solenoid magnetic field that is transverse to the RF magnetic field. A laminated iron return yoke (black) localizes the field.

PHYSICAL MODEL

Fig. 7: Model RF showing the moveable sleeves that allow the separation of the irises to be changed.

Figure 7 is shows the simple model cavity that we have used to verify the mathematical predictions for frequency and quality factor of the design. The aluminum body, which was designed to be easily reconfigured to hold different ferrite rings or different liquid dielectrics, was built around a discarded ceramic beam pipe, with rubber O-rings such that the gap between the irises can be varied. The external solenoid bias winding is water cooled and can provide a magnetic field up to 0.15 T. Figure 8 is a picture of the model cavity open to show ferrite cores inside and the external biasing magnet coil..

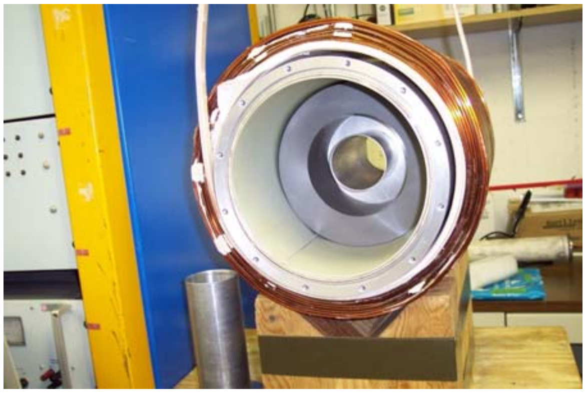

Fig. 8: Open view of model cavity showing cores and external copper biasing coil.

Figure 9 shows the resonant frequency of the model cavity as a function of solenoid biasing current for the cases of air and transformer oil dielectrics.

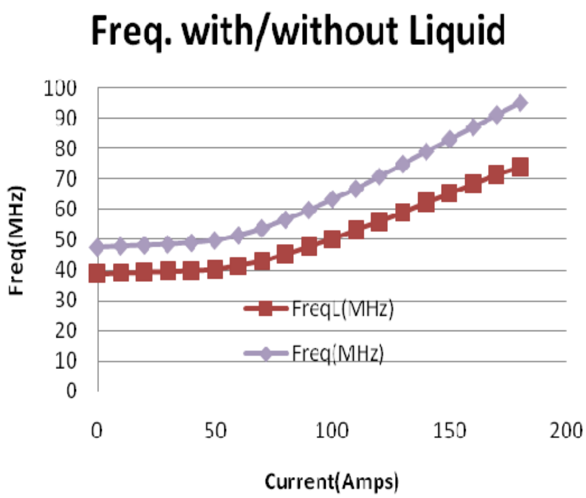

Fig. 9: Resonant frequency of the model cavity as a function of bias solenoid current using Toshiba M4C ferrite. The blue points are without dielectric liquid and the red points are with the cavity filled with dielectric liquid. These data are for Dow Corning 561 Silicon Transformer Liquid.

BOOSTER USE

The most important next step is to construct a useful RF cavity that can be tested in an operating machine. We believe that a second harmonic RF cavity that will improve the Fermilab Booster performance by increasing its capture efficiency provides an excellent opportunity. Figures 10 and 11 are ESME simulations that show the effects of a second harmonic RF system.

Studies that will allow this first implementation include studies of:

1) Eddy current effects, which can be calculated, but not studied in the model cavity which has thick walls;
2) RF power generator and amplifier requirements;
3) Biasing system power supply and controls;
4) Beam instabilities from bias solenoid fringe fields;
5) RF coupling options, capacitive or inductive, single or multiport; and
6) Operational requirements to insure that dielectric fluid cannot enter the machine vacuum system.

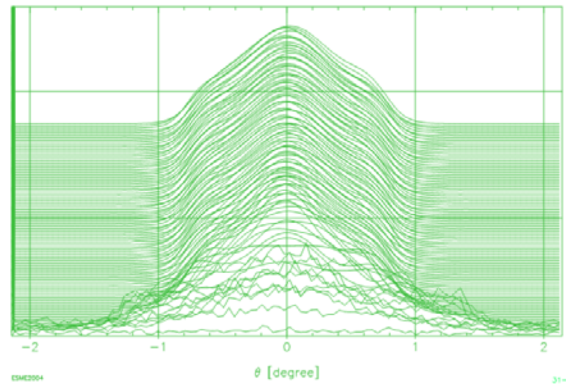

Fig. 10: ESME simulation of one of the 84 proton bunches as it forms in the Booster synchrotron. This plot corresponds to ten turns of H^- injection into the Booster, as it normally happens, without a second-harmonic RF cavity.

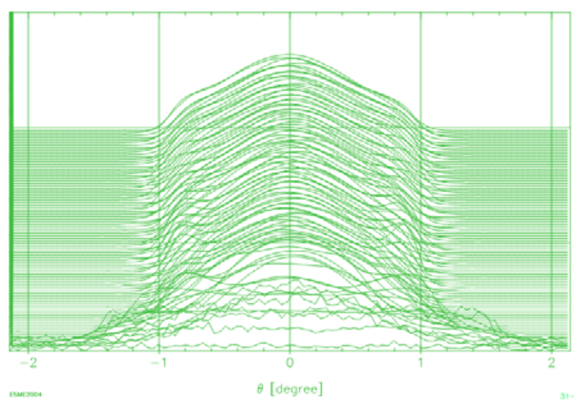

Fig. 11: The same conditions as figure 10, but with an added second-harmonic RF. The total ring voltage is 0.8MVwith second harmonic 0.3MV. The effect of bunch flattening is visible.

REFERENCES

[1] E. Keil, A. M. Sessler, D. Trbojevic, Phys. Rev. ST Accel. Beams 10, 054701 (2007) , http://link.aps.org/abstract/PRSTAB/v10/e054701

[2] J. Griffin, http://www-fmi.fnal.gov/fmiinternal/MI_Notes_Pages/MI-0018.html