PARALLEL BIAS VS PERPENDICULAR BIAS OF A FERRITE TUNED CAVITY FOR THE TRIUMF KAON FACTORY BOOSTER RING

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Abstract

The RF cavity reference design for the Kaon Factory booster ring is a double gap drift-tube cavity with parallel biased ferrite tuners to vary the frequency from 46 MHz to 62 MHz. LAMPF has developed a single gap cavity with perpendicularly biased ferrite to vary the frequency from 50 MHz to 60 MHz. Measurements on the LAMPF cavity have indicated that their frequency range could be extended to cover our requirements while still maintaining a reasonable magnetic Q. The analysis and comparison of the RF circuit and the AC magnetizing circuit for both designs are reported.

Introduction

The reference design[1] for the Kaon Factory booster ring cavity is shown in Figure 1. It consists of a double gap drift-tube structure with frequency tuning from 46 MHz to 62 MHz provided by parallel biased Ni-Zn ferrite tuners off axis to the accelerating cavity. RF power is coupled directly into the cavity from an Eimac Y567B tetrode. LAMPF has developed a single gap cavity with a perpendicularly biased yttrium-garnet ferrite tuner[2] to vary the frequency from 50 MHz to 60 MHz as shown in Figure 2. The RF power is coupled capacitively to the accelerating cavity. The ferrite tuner is part of the accelerating cavity and on the accelerating cavity axis. Since the measurements on the LAMPF cavity show that the frequency range can be extended to meet our requirements, the possibility of using a LAMPF type cavity for the TRIUMF Kaon factory booster ring looks very attractive. A comparison is made between a parallel biased nickel-zinc ferrite design and a perpendicularly biased yttrium-garnet(microwave) ferrite design. On almost all counts the perpendicularly biased ferrite is favoured. However further development is required on the biasing techniques and cavity geometry to improve the tuner response time and reduce eddy current losses.

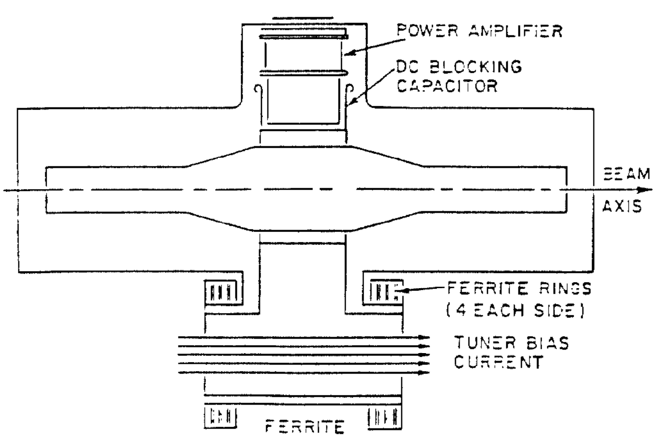

Figure 1: Reference design for the ferrite tuned amplifier cavity for the TRIUMF Kaon Factory.

Measurements at LAMPF

LAMPF has made extensive measurements and calculations on their cavity[3,4] but only in the frequency range of 48.5 MHz to 63.3 MHz. This corresponds to a permeability range of 2.64 to 1.34. The ferrite magnetic Q measurements are reproduced in Figure 3 to show that even with a permeability of 3.5 the magnetic Q of the ferrite is still above 3000.

The results of TRIUMF measurements on the LAMPF cavity shown in Figure 4 indicate that our lowest frequency requirement of 46 MHz can be obtained with a permeability of 2.9 which would still give a very high magnetic Q for the ferrite material.

RF Amplifier Design

An analysis of the two amplifier designs using transmission line equations[5] shows that the LAMPF cavity design has the advantage that the voltage step-up ratio from the tetrode to the accelerating gap and the R/Q are relatively insensitive to changes of frequency over the range of interest. Also, because of the small compact design and the lower values for ferrite permeability this cavity design would be expected to have the least problems with parasitic modes.

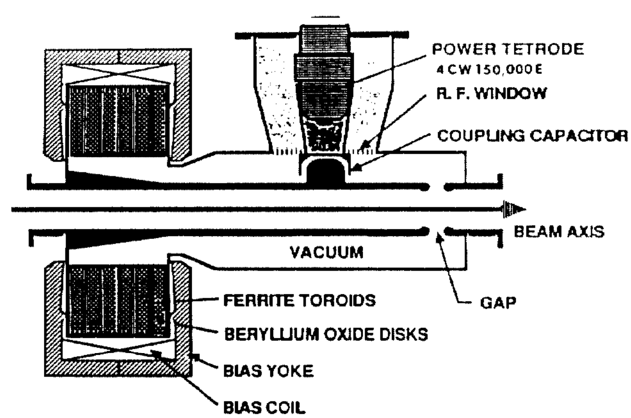

Figure 2: A cross section view of the Los Alamos prototype ferrite tuned cavity.

AC Magnetizing Circuit

The cycling frequency for the booster ring is 50 Hz with a rise to fall time ratio of 3:1. During the 15 ms rise time the power supply must be capable of varying from minimum current to maximum current and during the 5 ms fall time be able to recover to minimum current to start the cycle over again. In the parallel bias mode the magnetic path is a circumferential closed loop through the ferrite rings. The coaxial structure of the tuner with an rf short at both ends makes the solenoid design straightforward. The shorted turn produced by the end shorts and the inner and outer conductors can be made a high impedance by making the inner conductor thin walled stainless steel, copper plated on the outside for the rf

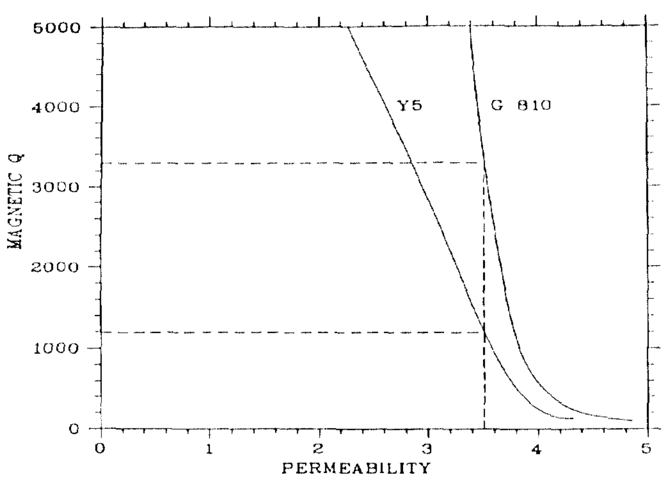

Figure 3: Results of magnetic Q measurements at LAMPF.

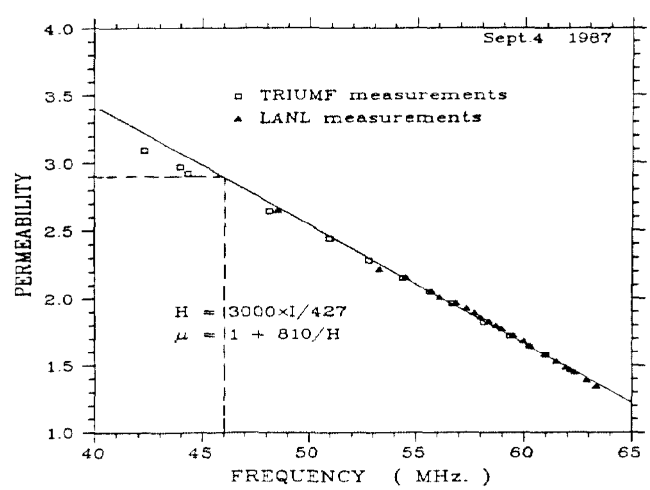

Figure 4: Results of TRIUMF's measurements on the LAMPF prototype cavity.

currents. In the perpendicular bias mode the magnetic path consists of a toroidal C-shaped return yoke, air gaps, metal walls and ferrite rings. There is also leakage flux set up in the solenoid and the annular wall surrounding the ferrite rings. The power supply must be capable of providing all these losses. The ac magnetizing circuits for both designs were analyzed[6,7] and the operating parameters for one cycle are plotted in Figure 5 and Figure 6 for the parallel and perpendicular biased cases respectively.

These graphs were used as a basis for quotation requests with a tracking accuracy of 0.125% specified. Five companies submitted quotations with the price of the perpendicular bias power supply being only 10% higher than the parallel bias power supply.

Cooling of Ferrite Rings

The cooling of the ferrite in the parallel biased case is accomplished by placing 1 cm. thick water cooled copper rings between the ferrite rings. Since the biasing field is circumferential there is no eddy current losses in the cooling rings. In the perpendicularly biased case the cooling of the ferrite rings becomes a little more complicated . The LAMPF design uses beryllium oxide rings between the ferrite rings with a water bladder at the outer circumference of the ring. Beryllium oxide has very good thermal conductivity to conduct the heat to the cooling bladder and its insulating properties avoid eddy current losses. Beryllium oxide has the disadvantage of being poisonous and special safety precautions must be taken when working with this material.

Ferrite Material Characteristics

It is important to keep in mind that the comparison being made in this paper is between parallel biased nickel-zinc ferrite and perpendicularly biased yttrium-garnet (microwave) ferrite. In general ferrite materials are magnetically lossy at low magnetization and the losses become smaller at high magnetization. In order to take advantage of the low losses at high magnetization fields and still maintain a reasonable permeability range it is necessary to perpendicularly bias the ferrite so that the effective permeability varies as a function of B/H [8]. NiZn ferrite is not suited for perpendicular biasing because of their usual high saturation magnetization characteristic (3200 gauss for the NiZn ferrite used at Fermilab) and if a large permeability range is required (with moderate magnetic Q's) it is necessary to operate in the parallel biased mode so that the effective

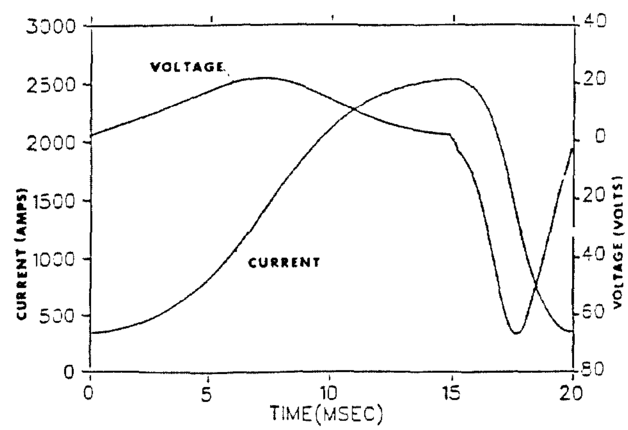

Figure 5: Operating parameters for one cycle of the power supply for parallel bias

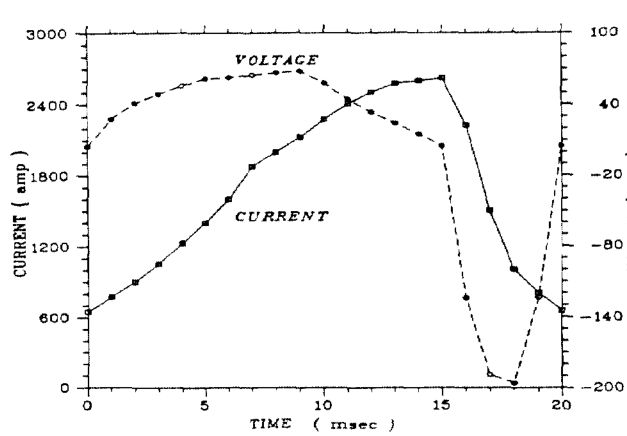

Figure 6: Operating parameters for one cycle of the power supply perpendicular bias

permeability varies as a function of the rate of change of the B-H curve[8]. The electric Q of NiZn ferrite is also low (10...100) which limits the voltage that can be applied. Microwave ferrites on the other hand exhibit high electric Q's (>1000) and are available with low saturation magnetization characteristics (<600 gauss). In the perpendicular bias mode the designer is still faced with a smaller permeability range. However the higher magnetic and electric Q's allow more energy to be stored in the ferrite material to compensate for the smaller permeability range and permits the same required frequency tuning range to be maintained. To allow the coupling of sufficient energy into the ferrite material the design of the RF cavity must therefore be different from the parallel biased ferrite cavity design.

Non-linear effects in Ferrite Material

"Dynamic loss effect" and "high loss effect" of ferrite materials in an rf field are two rf loss mechanisms which have been observed and documented[9,10,11,12] at other laboratories. Dynamic loss effect occurs at any level of rf excitation but only at relatively low values of bias field. High loss effect occurs at any value of bias field but only at high levels of rf excitation. In the perpendicularly biased mode the bias field is always high(near saturation) and therefore there are no instabilities introduced by dynamic loss effect. High loss effect has not been observed in the work done by LAMPF[2] with perpendicularly biased microwave ferrites at power densities as high as 1.4 W/cm^3. High loss effect occurs only if the frequency is constant and is therefore not present during the normal cycling operation of the booster ring. However during commissioning and troubleshooting it would be desirable to operate at a fixed frequency and therefore high loss effect must be investigated.

Beam Related Parameters

During operation of the booster ring it is necessary to compensate for beam loading by detuning the rf cavity. The amount of detuning is directly proportional to the number of accelerating gaps[13] . The single-gap perpendicularly biased cavity design reduces the number of gaps by a factor of two. It is also possible to increase the gap voltage high enough to reduce the number of cavities from 12 to 9 to further reduce the detuning requirements. Minimizing the number of cavities by maximizing the voltage per cavity also reduces the coupled bunch beam instabilities[14].

Conclusions

It would appear that there are very strong arguments to continue development work on perpendicularly biased microwave ferrites for the Kaon Factory booster ring cavity with particular attention to ac biasing techniques and cavity geometry. As a result of a TRIUMF/LAMPF collaboration set up last year the LAMPF booster cavity will be shipped to TRIUMF in June which is about the same time we expect delivery of an ac bias power supply. An ac yoke and solenoid will be designed and manufactured, and the coaxial structure surrounding the ferrite rings will be modified to allow ac biasing of the ferrite rings.

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References

[1] R.L. Poirier and T.A. Enegren, "Status of RF Development Work on a Ferrite Tuned Amplifier Cavity for the TRIUMF Kaon Factory", IEEE Particle Accelerator Conference, Washington, D.C. p 1499. (1987).

[2] W.R. Smythe et al., "RF Cavities with Transversely biased Ferrite Tuning", IEEE Particle Accelerator Conference, Vancouver B.C., p 2951. (1985)

[3] Carl C. Friedrichs et al., "Test Results of the Los Alamos Ferrite Tuned RF Cavity", IEEE Particle Accelerator Conference, Washington, D.C., p 1896. (1987).

[4] M.J. Browman et al., "Testing URMEL-3D by Modeling a Ferrite Tuned RF Cavity", IEEE Particle Accelerator Conference, Washington, D.C., p 1898. (1987).

[5] T. Enegren and R.L. Poirier, "Analysis of Booster Amplifier Designs, Proc. Int. Workshop on Hadron Facility Technology", Los Alamos, New Mexico FEB 22-27, 1988.

[6] S.J. Mai, "An AC Bias Power Supply for Parallel Biasing Ferrite Rings in an RF Cavity for the TRIUMF Kaon Factory Booster Ring", TRIUMF internal notes.

[7] I. Enchevich, "An AC Bias Power Supply for Perpendicularly Biasing Ferrite Rings in an RF Cavity for the TRIUMF Kaon Factory Booster Ring", TRIUMF internal notes.

[8] W.R. Smythe, "Reducing Ferrite Tuner Power Loss by Bias Field Rotation", IEEE Trans. on Nucl. Sci., Vol. NS-30 No. 4 p. 2173, 1983.

[9] J.E. Griffin, "A Review of Some Dynamic Loss Properties of Ni-Zn Accelerator RF System Ferrite", IEEE Trans. on Nucl. Sci. Vol. NS-26 No. 3, p. 3965, 1979.

[10] Q. A. Kerns and B.R. Sandberg, "The RF Testing Program AT NAL", IEEE Trans. on Nucl. Sci., NS-18 p. 244, 1971.

[11] G. Rakowsky and A. Tranis, "Nonlinear Effects in 'Linear' Ferrites at High RF Fields", IEEE Trans. on Nucl. Sci., Vol. NS-16 No. 3 p. 543, 1969.

[12] C. Arnaud et al., "Finding Out about Ferrites", Cern Courier 12 No. 11 p. 364 (1971).

[13] F. Pedersen (CERN), "Beam Loading Aspects of TRIUMF Kaon Factory RF Systems", TRIUMF internal report TRI-DN-85-15.

[14] R.Baartman, "Coupled Bunch Instabilities in Kaon Factory Synchrotrons", LA-11130-C, Proc. Int. Workshop on Hadron Facility Technology, Los Alamos, New Mexico, p. 210, (1987).