A Perpendicular AC Biased Ferrite Tuned Cavity for the TRIUMF Kaon Factory Booster Synchrotron

R.L. Poirier, T.A. Enegren and C. Haddock, TRIUMF
I. Enchevich, Sofia University, Bulgaria

Abstract

The rf cavity for the Booster Synchrotron requires a frequency swing of 46 MHz to 61 MHz at a repetition rate of 50 Hz. This will be accomplished using a tuner containing yttrium garnet ferrite where the bias field is perpendicular to the rf magnetic field. Conventional methods use parallel biased NiZn ferrite. Yttrium garnet ferrite possess a high electric quality factor and when operated in saturation also possess a high magnetic quality factor. However the ac magnetizing circuit is much more complicated and special care must be taken to minimize the induced eddy current losses when designing the tuner. A dc biased prototype cavity was constructed and tested at Los Alamos. As part of the project definition study for the proposed KAON factory, this cavity has now been almost entirely rebuilt at TRIUMF with a completely redesigned tuner for ac bias operation. Measurements and test results will be reported.

Introduction

A cross section view of the ac biased ferrite tuned cavity is shown in figure 1. The power tetrode is capacitively coupled to the accelerating cavity. The ferrite tuner is located on the beam axis. A toroidal magnet surrounds six yttrium garnet ferrite rings establishing a bias field in the longitudinal direction which is perpendicular to the azimuthal rf magnetic field. Beryllium oxide (BeO) cooling spacers are placed between the ferrite rings and conduct heat from the rings to a copper cooling jacket at the outer radius. A cross section view of the ferrite tuner is shown in figure 2. The return yoke for the magnetic field consists of 12 sectors which are held together by an aluminum clamping plate and a set of tie rods. The sector design provides room for the entrance and exit of the stranded cable and further provides easy access for the various water cooling lines. Each sector is made from three rectangular laminated blocks which are tapered by cutting and grinding. The coil consists of twelve turns of cable constructed from 82 strands of #9 heavy formvar insulated magnet wire that surround a copper tube that is water cooled. The voids between the individual strands and the coil turns are vacuum impregnated. The rf components of the ferrite tuner surrounding the ferrite rings is formed by the copper cooling jacket, a tapered inner conductor and two thin rf membrane end walls . The support structure for the rf membranes consists of two stainless steel rings connected by an array of spokes to form a wheel shaped structure. Both the stainless steel rings and the spokes have water cooling channels to remove the heat from the rf membranes.

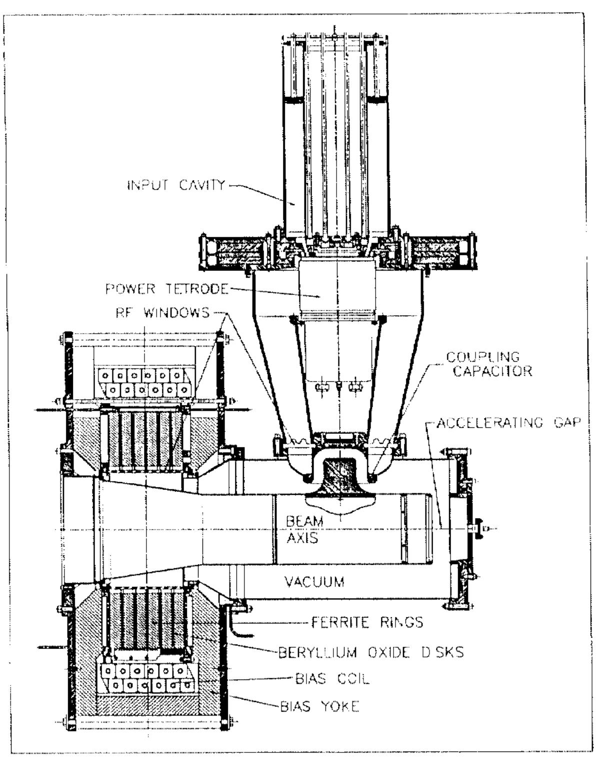

Figure 1: Cross Section View of the AC Biased Ferrite Tuned Cavity.

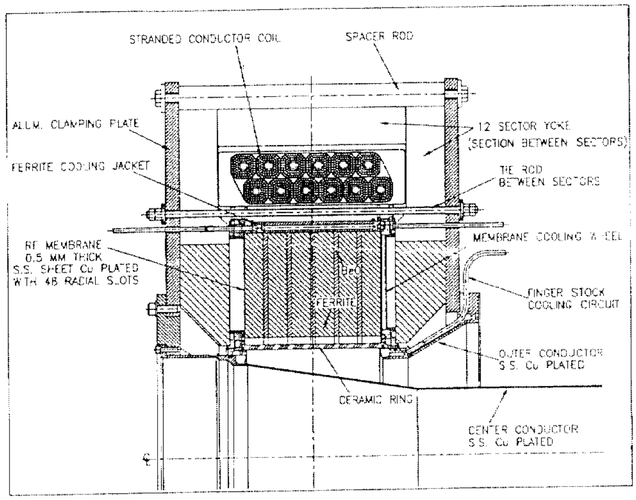

Figure 2: Cross Section View of the AC Biased Tuner.

Eddy current losses

It is desirable that the components that comprise the ferrite tuner be designed such that the induced eddy currents are as small as possible. The inner and outer stainless steel rings of the structure that supports the thin rf membranes are broken at opposite ends of a diameter. Calculations show that this results[1] in a reduction in eddy current losses by a factor of 900 for the outer ring and 80 for the inner ring. Consequently, for our particular dimensions, whenever a complete circular geometry can be broken a significant reduction in eddy current losses can be achieved. The most difficult task was the reduction of eddy current losses in the rf membrane end walls This was

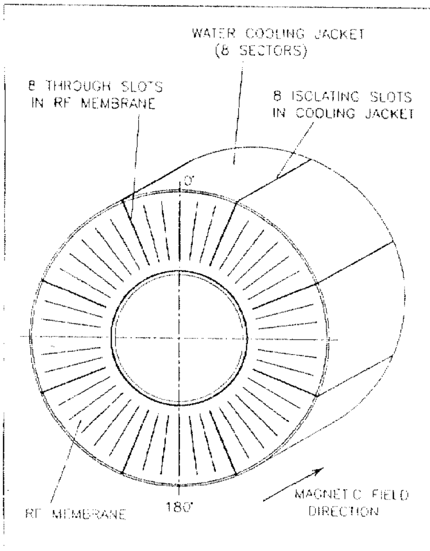

Figure 3: Arrangement of the RF Membrane and the Water Cooling Jacket for the Eddy Current Loss Measurements.

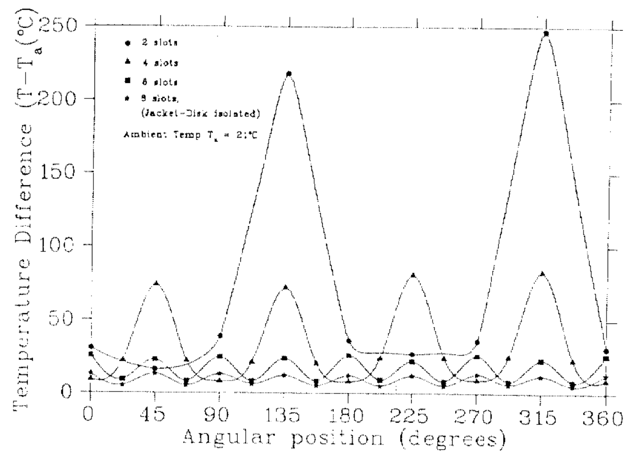

Figure 4: Azimuthal Temperature Rise Distribution at Inner Radius of Radial Slots in the RF Membrane as a Function of their Number with Copper Cooling Jacket.

accomplished by extending 8 of the 48 radial slots in the rf membranes to the outer circumference of the membranes and introducing eight insulating breaks in the water cooling jacket. The through slots and the insulating breaks are aligned with each other as shown in figure 3. In order to maintain the vacuum integrity of the cavity assembly the radial slots cannot be extended into the inner circumference to break the complete circular geometry.

Eddy current losses measurements

The magnet code PE2D was used to evaluate the eddy current losses in the different sections of the tuner cavity. Although the calculated results were quite reasonable, PE2D is only a two dimensional program and can not predict what happens when the sections of the tuner cavity are brought together in a three dimensional configuration. It was necessary to determine the eddy current losses experimentally. The structure shown in figure 3 was introduced into an 50 Hz ac magnetic field with a peak value of .005 tesla. The water cooling jacket is a copper cylinder 600 mm in diameter, 160 mm long and 16mm thick. The rf membranes are constructed from 0.5 mm stainless steel plated with copper to a thickness of 0.013 mm. It was found that measuring the temperature of the surface of the membrane was a very good indication of the eddy current distribution. The through slots in the membrane and the isolating slots in the water cooling jacket were progressively doubled and the temperature distribution around the inner circumference of the rf membrane for the different number of slots is shown in figure 4. The results clearly show that at least a factor of 9 in the reduction of temperature rise can be achieved by increasing the number of slots from 2 to 8. There are two plots shown with 8 slots, one with and one without the water cooling jacket. The effect of the water cooling jacket is to increase the maximum temperature rise by approximately 12 degrees celsius. Figure 5 shows the effect of increasing the water cooling jacket resistive path by replacing the 16 mm copper water jacket with a 1.5 mm stainless steel water cooling jacket. In this case only a factor of 2.5 is gained in going from 2 slots to 8 slots but the temperature rise with 2 slots is already a factor of 5 lower than in the case of 2 slots with the copper cooling jacket. The conclusion from these measurements is that in order to reduce the temperature rise due to eddy current losses a compromise can be made between the number of radial slots and the resistive path of the water cooling jacket. For the continuing prototype work the number of slots in the copper cooling jacket will be kept at eight. Figure 5 also shows the temperature rise measured at the outer edge of the rf membrane. The position of maximum temperature corresponds to the area of maximum eddy currents in the cooling wheel which is thermally connected to the rf membrane. The rf membranes have 6 radial slots between the 8 radial through slots which do not extend into the inner or the outer circumference. To determine what happens to the eddy currents around these slots, a probe with a fixed separation of 2 cm between terminals was used to measure the radial and azimuthal surface potentials on the rf membrane. A vector plot of the eddy current distribution in a one eighth section of the rf membrane is shown in figure 6. The effect of the slots is to split the eddy current coming from the inner circumference at a through slot into three parallel paths and increasing the resistive path by causing the currents to flow outward radially and then back in again. This distribution pattern provides a valuable insight for improving the cooling design.

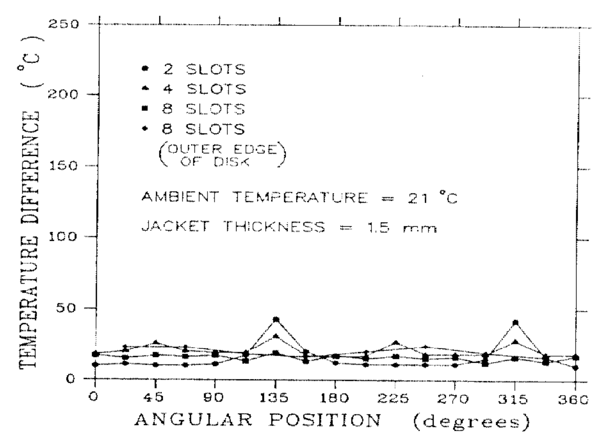

Figure 5: Azimuthal Temperature Rise Distribution at Inner Radius of Radial Slots in the RF Membrane as a Function of their Number with Stainless Steel Jacket. The RF Membrane is Thermally Connected to the Stainless Steel Cooling Wheel which has Complete Radial Slots at 135 Degrees and 315 Degrees.

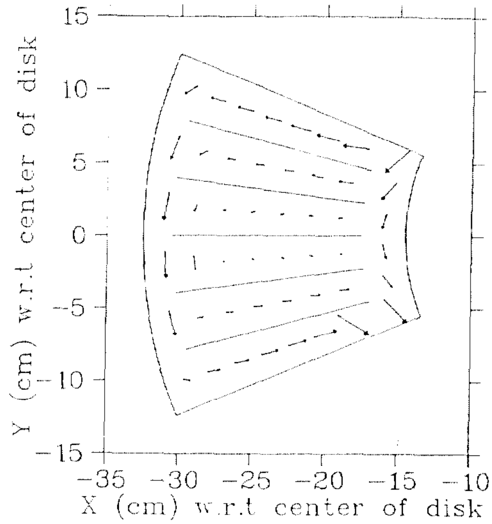

Figure 6: Vector Plot of Eddy Current Distribution in a 1/8 Section of the RF Membrane.

Tuning measurements

The ferrite tuner with 8 through slots in the rf membranes and 8 insulating breaks in the water cooling jacket was reassembled and mounted on the cavity. With the tuner modifications it was now possible to ac bias the tuner to a peak current of 2650 amperes at a repetition rate of 50 Hz without overheating the rf membrane as done previously. The current and voltage waveforms measured at the terminals of the biasing coil are shown in figure 7. The cavity was excited with a network analyzer whose sweep rate was set sufficiently low so that the maximum resonant frequency of the cavity could be measured. A

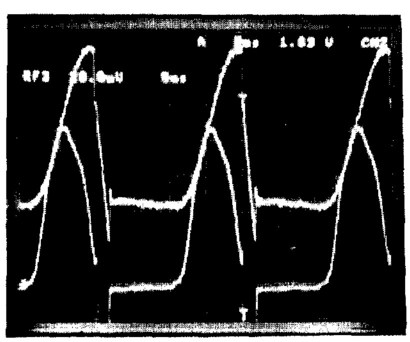

Figure 7: Current (top trace) and Voltage (bottom trace) Waveforms at the Terminals of the Biasing Coil. Current scale 400A/div., Voltage scale 22.5V/div. and time scale 5ms/div.

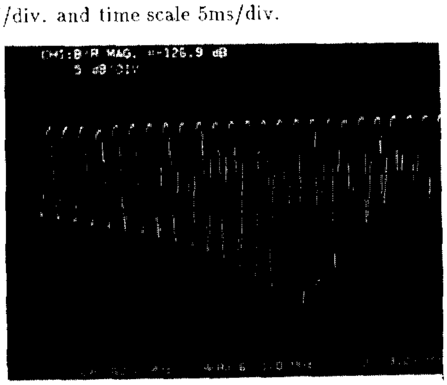

Figure 8: Measurement of the Maximum RF Frequency with a Peak AC Bias Current of 2650 Amperes at a Repetition Rate of 50 Hz.

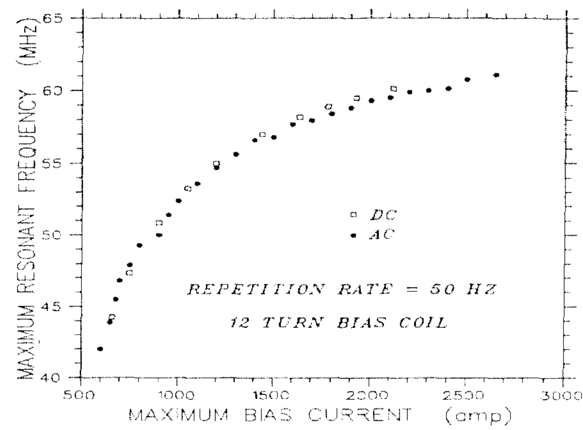

Figure 9: Frequency Tuning Range of the AC Biased Ferrite Tuner.

typical measurement at 61.1 MHz with the peak bias current set at 2650 amperes is shown in figure 8 . A plot of the resonant frequency of the cavity as a function of ac and dc bias current is shown in figure 9 . The close agreement between dc and ac biasing is very encouraging, indicating that the influence on the bias field by the eddy current magnetic fields is minimal. During these measurements the power supply was not regulating properly and therefore the measurements at the lower value of biasing currents are not as accurate as the measurements at the higher biasing currents. This also meant that the shape of the biasing curve was not always constant and could account for the fact that the curve is not as smooth as expected. However the experimental measurements confirmed the theoretical prediction[2] that a peak current of 2650 amperes is sufficient to allow the cavity to resonate at 61.1 MHz.

Acknowledgement

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References

[1] C. Haddock et al, "Design of an AC Magnetic Biasing Circuit for the Kaon Factory Booster RF Cavity", 11th International Conference on Magnet Technology, Tsukuba City, Japan, Sept 1989.

[2] R. L. Poirier et al., "Parallel Bias vs Perpendicular Bias of a Ferrite Tuned Cavity for the TRIUMF Kaon Factory Booster Ring", European Particle Accelerator Conference,Italy, p 1321 (1988).