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Status of the AC Perpendicular Biased Ferrite Tuned Cavity Development Program at TRIUMF

R. L. Poirier and I. B. Enchevich

TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., V6T 2A3

ABSTRACT

The rf cavity for the Booster Synchrotron requires a frequency swing from 46 MHz to 61 MHz at a repetition rate of 50 Hz and a maximum accelerating voltage of 62.5 kV. These parameters have been achieved [1], [2] on a prototype cavity at TRIUMF using yttrium garnet ferrites rather than the conventional parallel biased NiZn ferrites. The results of the tests performed on the prototype cavity as well as some of the problems encountered and their solutions, will be reported.

INTRODUCTION

The accelerating cavity is a quarter wavelength resonator foreshortened by the ferrite material at the shorted end of the cavity which is used for tuning purposes. A cross section view of the ac bias ferrite tuned cavity is shown in figure 1. The tuner consists of six yttrium garnet ferrite rings with beryllium oxide (BeO) cooling spacers placed between the rings to conduct the heat dissipated in the ferrite to a water cooling jacket at the outer radius. A toroidal magnet surrounds the coil and the ferrite rings, establishing a variable bias field in the longitudinal direction which is perpendicular to the azimuthal rf magnetic field. The return yoke for the magnetic field consists of 12 sectors which are held together by two aluminum clamping plates and a set of tie rods. The rf conducting surface of the ferrite cavity surrounding the ferrite rings is formed by the water cooling jacket, a tapered inner conductor and two thin rf walls with radial slots. The radial slots were necessary to reduce the eddy current losses and to allow the biasing field to easily penetrate the rf walls to improve the response of the tuner. The combiner sums the power from 12 solid state rf driver units which have been especially built with a short group delay for implementing fast rf feedback. High order modes are damped by a special cavity near the accelerating gap.

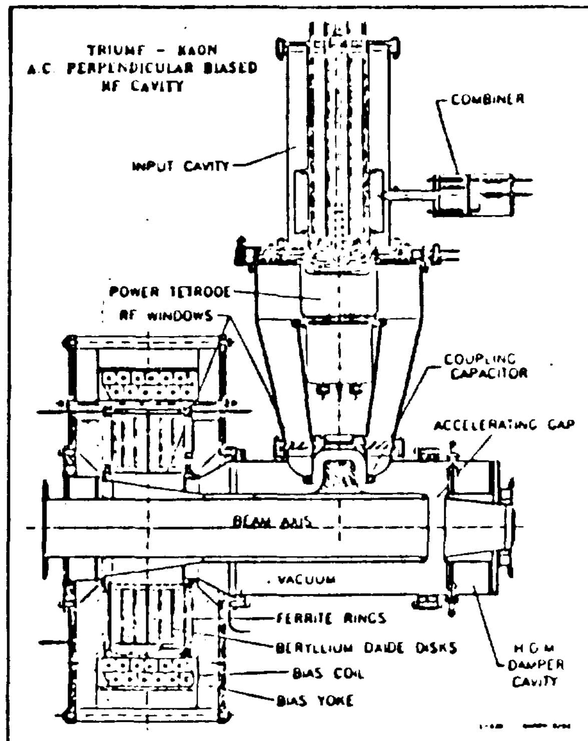

Figure 1. Cross-section of the ac biased ferrite tuned cavity.

EDDY CURRENT

If special care is not taken to minimize eddy current losses in the walls, the dissipative power would be excessive and the magnetic fields set up by the eddy currents would disturb the magnetic fields being applied. To minimize this effect in the rf membrane walls which the magnetic flux passes through, radial slots were introduced. Eddy currents in the rf walls are determined by the electromotive forces induced by the axially symmetric variable magnetic flux, the impedance of the different sections and the connection between them. The equivalent diagram used to simulate eddy currents in the rf wall shown in figure 2 represents one-eight of the rf wall (i.e. a sector) and each sector is sub-

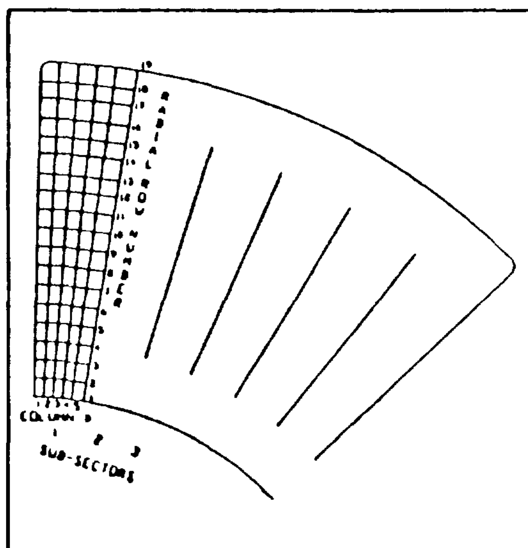

Figure 2. Representation of 45 degree sector by cells.

divided into six sub-sectors. The calculation of the currents was based on Faraday's and Kirchoff's laws using the values of the differential emf into the cell sub-sectors of the walls and their cooling structure, taking into account only the active resistivity of the cells and their galvanic coupling.

The circuit analysis program PSpice [3] was used with the boundary conditions determined by the geometry. To map experimentally the eddy currents induced in the rf wall by the magnetic field, it was placed inside the magnetizing coil (without return yoke) and the cell's current was determined by measuring the radial and axial voltages across a cell. The amplitude and the direction of the surface currents were determined from these measurements. Different configurations of slots and materials were modeled for minimizing eddy currents. Thermocouple temperature probes were also used to measure the temperature distribution on the surface of the rf wall due to eddy currents. Figure 3 is the predicted power loss distribution due to radial, azimuthal and axial currents in sub-sectors 1, 2 & 3 using the 3D simulation, which agree well with the measured temperature distribution. Although it is difficult to compare the results directly, the places where maximal temperatures are measured coincide with the places of maximum predicted power level.

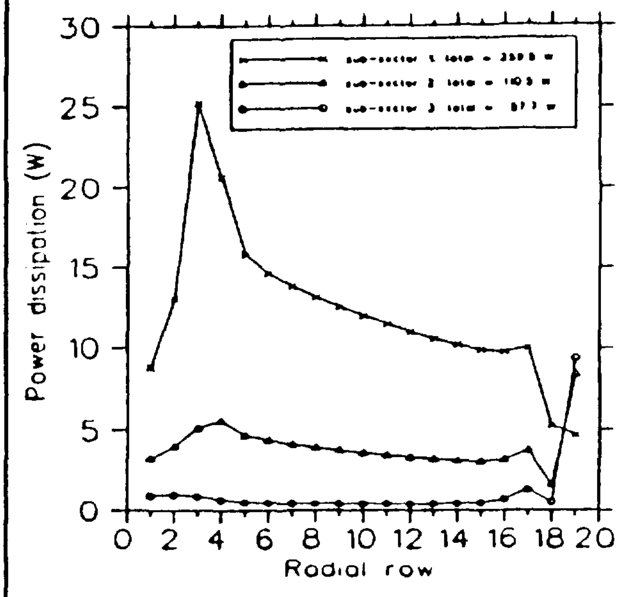

Figure 3 Predicted power loss distribution due to radial, azimuthal and axial currents in sub-sector 1,2 and 3 from 3D simulation

MAGNETIC FIELD MEASUREMENTS

Axial magnetic field measurements were done using a calibrated Hall probe [4]. The magnetic induction field biasing the ferrite was measured on the outside surface of the cavity via a hole drilled through the return yoke. Figure 4 shows the surface induction and the biasing current during a 20 ms period of modulation. Maximum induction on the surface of the rf wall was measured to be 0.19 T for a current of 2520 A. Some hysteresis behavior occurs since the induction does not follow the current drop to zero.

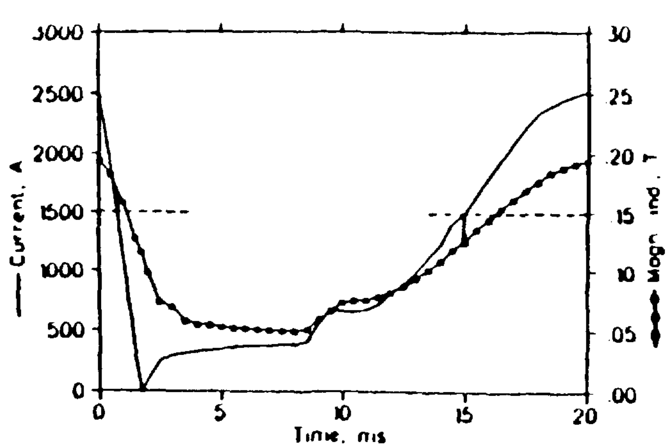

Figure 4. Surface induction and biasing current for the 20 ms modulation period.

From a Fourier Analysis of the above results the discrete frequency response between the biasing current and the magnetic induction were obtained. The axial distribution of the induced field was measured showing a maximum field of 0.11 T at the centre of the tuner assembly, which is approximately half the value of the induced field at the surface of the rf wall.

RF CONDITIONING

RF conditioning was done under dc bias conditions. Only after 14 hours of continuous conditioning was it possible to punch through multipactoring, followed by days of further conditioning in cw and pulsed mode to reach a stable operating condition. During the conditioning, a strong multipactoring discharge was observed in the vicinity of the narrow throat section in the outer conductor where the rf membrane makes fingerstock connection to the outer conductor. The area of discharge was easily identified on the centre conductor and was painted with aquadag to prevent further multipactoring discharge in that area. This made rf conditioning through multipactoring much easier and within one half hour it is now possible to achieve stable rf voltage on the gap either in cw or pulsed mode operation.

HIGH POWER AC BIAS OPERATION

RF conditioning had to be repeated again under ac bias conditions, but when preceded by dc bias conditioning in cw rf mode the conditioning was fairly quick. A well synchronized rf control system to insure that the rf is switched on and off at the proper time and that the frequency program and the ferrite bias program are synchronized was designed and installed. Figure 5 and figure 6 represents the success of our development program over the last few years reaching an accelerating voltage of 65 Kv at a repetition rate of 50 Hz and a frequency range of 46 MHz to 61 MHz.

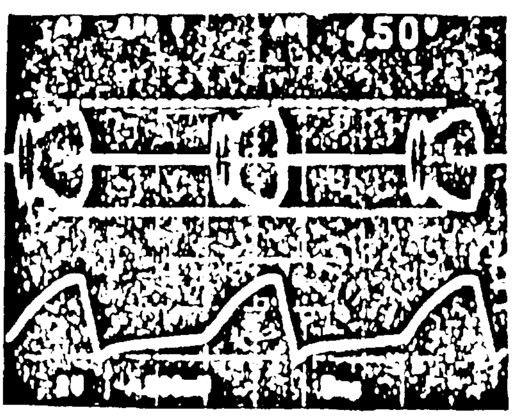

Figure 5 High power operation of the ac perpendicular biased tuner cavity Top trace is the gap voltage (65 kV max.) and the bottom trace is the output signal from the ferrite bias power supply

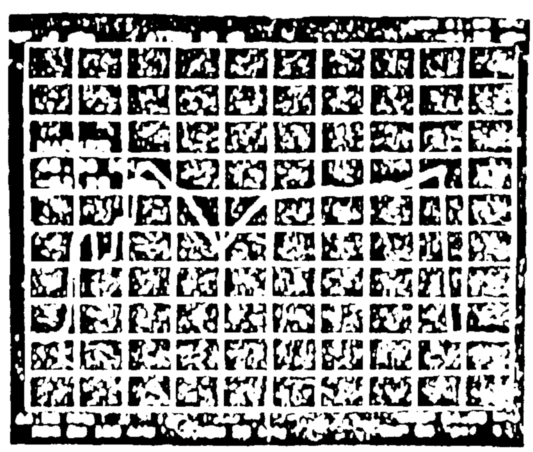

Figure 6 Spectrum analyzer measurement showing frequency swing from 46 MHz to 61 MHz

FERRITE COOLING

In order to have proper cooling of the ferrite it is necessary to have good thermal contact between the ferrite rings and the BeO spacers and between the BeO spacers and the cooling jacket. Thermal distribution measurements showed that only about half of the heat dissipated in the ferrite is being removed through the cooling jacket and the other half is being removed through the rf membrane walls. This confirmed our suspicion that the thermal contact between the BeO spacers and the water cooling jacket is not adequate. An improved water cooling jacket design is presently being fabricated and will be installed later for testing. During the thermal flow measurements it was observed that as the temperature of the ferrite increased while reaching thermal equilibrium, the frequency also increased (figure 7). This is in agreement with the characteristics of the ferrite material which decreases in saturation magnetization as the temperature is increased. This gives a lower effective permeability causing the frequency to increase as observed.

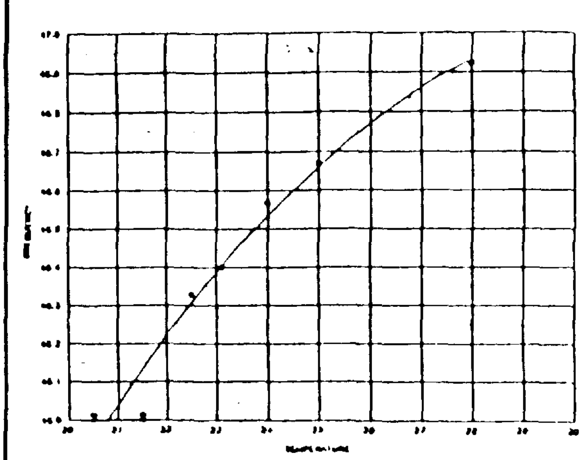

Figure 7. Tuner resonance frequency drift as a function of temperature

RF CONTROLS

The pertinent specifications of the rf system for rf controls are a maximum dF/dt of 3.5 MHz/ms, a maximum dF/dI of 0.03 MHz/A, a maximum dI/dt of 311 Amps/ms and a cavity Q variation from 2200 at 46.1 MHz to 3600 at 61.1 MHz. The frequency response of the ferrite tuned cavity to small signal modulation of the ferrite bias power supply was measured using a HP Control Analyzer and the results plotted in figure 8. Curve fitting of the results to pole/zero polynomial resulted in a pole at 300 Hz due to eddy currents on the end rf membrane walls of the ferrite tuner, a pole at 6 KHz due to the Q of the cavity and a zero at 800 Hz due to the extra inductance created by the radial slots. The above results show that the effect of the slotted rf membrane walls can be neglected in control compensation.

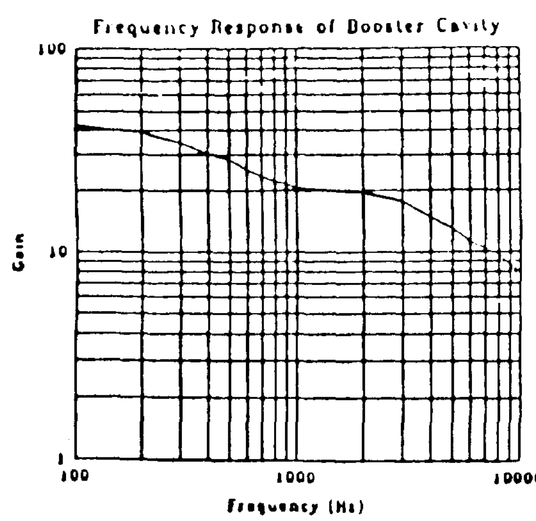

Figure 8. Frequency response of the ferrite tuner to small signal modulation of the ferrite bias power supply

CONCLUSION

To the best of our knowledge this is the first fast (50 Hz) ac perpendicular biased yttrium garnet ferrite tuner that has been operated over such a large frequency range at high rf power levels. Hopefully in the future, ac perpendicular biased tuners will become as popular as the now well established parallel biased NiZn ferrite tuners.

References

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