

STATUS OF RF DEVELOPMENT WORK ON A FERRITE TUNED AMPLIFIER CAVITY FOR THE TRIUMF KAON FACTORY

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Summary

Of the five synchrotron rings in the proposed TRIUMF KAON factory, the Booster ring to accelerate the proton beam from 440 MeV to 3 GeV has the most demanding rf requirements, primarily because of the relatively large frequency swing of 46.1 MHz to 61.1 MHz at a high repetition rate of 50 Hz. In the current reference design, the Booster lattice has twelve 3.9 m drift spaces with 2.5 m in each drift space available for installation of rf cavities to provide a required effective acceleration voltage of up to 600 kV per turn i.e. 50 kV per cavity. Design and development studies of a suitable cavity-amplifier system are in progress. For the initial reference design a system based on the one used in the Fermilab booster synchrotron has been chosen. That is, a double-gap drift-tube cavity with parallel-biased ferrite tuners and excited with a directly coupled Eimac Y567B tetrode. Design procedures used to meet the tuning and voltage requirements within the various mechanical and other constraints such as tube to gap voltage ratio, ferrite power density and available space will be discussed along with results from cold model tests.

Introduction

The rf requirements for the TRIUMF KAON Factory are the most demanding in the Booster ring where a frequency swing of 46.1 MHz to 61.1 MHz at a repetition rate of 50 Hz and a total acceleration voltage of 600 kV per turn are specified. Since there is provision for 12 straight sections in the lattice for rf cavity installation, each cavity must provide an accelerating voltage of 50 kV. The initial cavity design that is under consideration is based on that used for the Fermilab booster synchrotron. The basic rf cavity consists of a double gap drift tube structure with frequency tuning provided by parallel biased ferrite tuners. Rf power is coupled directly into the cavity from an Eimac Y567B tetrode as illustrated in Fig. 1.

The cavity design is subject to the following constraints:

- (1) The minimum diameter of the inner conductor is limited to 15 cm to accommodate the beam.
- (2) The maximum allowable voltage swing on the plate of the tetrode is 22 kV. To achieve a required accelerating gap voltage of 25 kV, the tube to gap voltage ratio must be  $>1.14$ .
- (3) Ideally one would like to have a  $180^\circ$  drift tube length; however with a  $140^\circ$  drift tube length the accelerating voltage is still 94% ( $\sin 70^\circ$ ) of the gap voltage. A  $140^\circ$  drift

tube for a Booster ring radius of 34.11 m and and a harmonic number of 45 gives a drift tube length of 1.85 m.

- (4) The combination of available drift space in the ring and maximum drift tube length limits the accelerating gap to a maximum of 10 cm. This in turn fixes the minimum gap capacity.

The only parameters left that can be varied are the characteristic impedances ( $Z_0$ ) and corresponding lengths of the sections of transmission lines which make up the accelerating cavity. The value of these parameters must be chosen to provide the proper impedance match for the tube and the ferrite tuner while staying within the above limitations.

The design of the ferrite tuner is also subject to several constraints

- (1) To prevent excessive temperature rise in the ferrite material the power density averaged over a synchrotron cycle should be less than  $1 \text{ W/cm}^3$
- (2) The electrical length of the ferrite stem must be less than  $45^\circ$  to provide a uniform power density distribution.
- (3) The cross sectional area perpendicular to the rf magnetic field must be large enough to limit the rf magnetic field to less than 50 G.
- (4) The permeability range and Q's at  $\mu_{\max}$  and  $\mu_{\min}$ , respectively must be compromised to stay within the power capability of the rf amplifier.
- (5) Beam loading on the cavity requires that the upper frequency limit be increased from 61.1 MHz to 62.8 MHz.
- (6) The physical arrangement of the desired volume of ferrite must provide the proper impedance match for the cavity and the tube for the chosen permeability range.

Bringing together the accelerating cavity, the tube and the ferrite tuner to form the ferrite tuned amplifier-cavity system reveals another limitation on the design, namely the impedance of the structure connecting the tuner to the accelerating cavity limits the maximum frequency range of the tuner and must be as low as possible in order to reach the high end of the frequency range of 62.8 MHz.

Cavity Design

The power tube is connected directly to the accelerating cavity and therefore its output capacity becomes part of the accelerating cavity. Because of its physical size and coaxial structure, the tube is conveniently connected to the accelerating cavity via a system of coaxial structures. The effect is that the 60 pF output capacity of the tube is transformed to an effective capacity of 200 pF at the high end of the frequency range and therefore loads down the cavity much more than initially expected making it more difficult to reach the high end of the frequency range.

A model of a conceptual design of an accelerating rf cavity based on the Fermilab booster design and staying within the limitations of the cavity design constraints was constructed from copper-covered card-

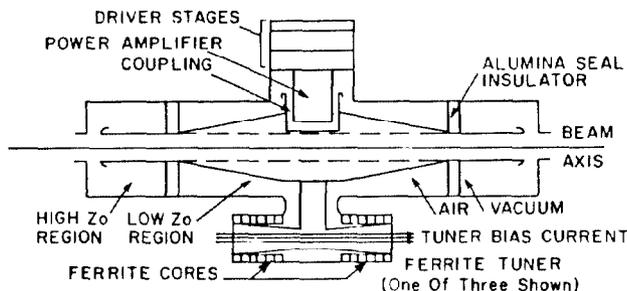


Fig. 1. Modified Fermilab booster cavity.

board cylinders. It was necessary to increase the diameter of the connecting structure from the original diameter of 5.4 cm in the Fermilab design to 31.1 cm to reach the high end of the frequency range of 62.8 MHz.

Because it is very difficult to calculate with any accuracy the rf fields and the impedance transformations at the "T" junction where the ferrite tuner stems meet, the modelling also includes three air dielectric tuners constructed from copper covered cylinders to simulate the impedance of the ferrite tuners as shown in Fig. 2. The measurements are plotted in Fig. 3 which shows that at 46.1 MHz the required length of the tuner stem is 67 cm, which for a  $Z_0$  of 40  $\Omega$  produces

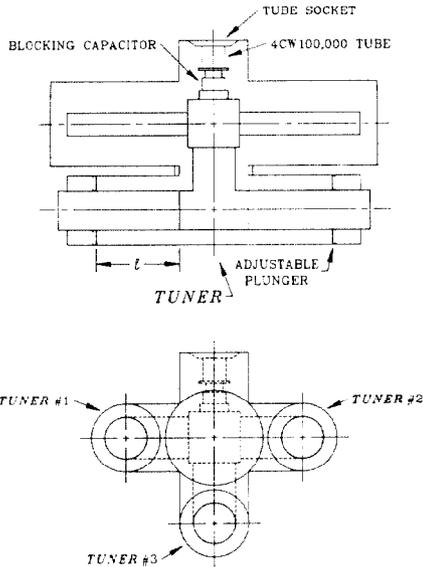


Fig. 2. RF model of accelerating cavity including air dielectric tuners to simulate the ferrite tuners.

an inductive impedance of  $+j 32 \Omega$  and for 62.8 MHz the required length of the tuner is 14.8 cm which for a  $Z_0$  of 40.0  $\Omega$  produces an inductive impedance of  $+j 7.8 \Omega$ .

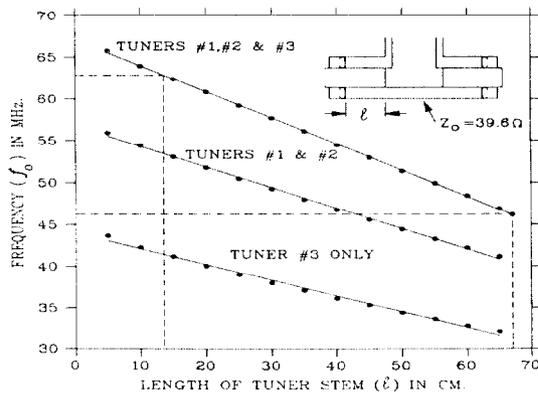


Fig. 3. Length of tuner stem versus resonant frequency of the rf cavity system.

From these measurements we conclude that the air dielectric tuners must be replaced with ferrite tuners such that the impedance of each ferrite tuner stem varies from  $+j 7.8 \Omega$  to  $+j 32 \Omega$  as the frequency is changed from 62.8 MHz to 46.1 MHz.

### Ferrite Tuner Design

A large number of tests and calculations have been performed on ferrite rings obtained from Fermilab.<sup>1</sup> The ferrite tuners will use the conventional mechanical design which consists of a number of ferrite rings sandwiched between metallic plates that are water cooled to remove heat. The resulting structure is a ferrite loaded coaxial transmission line with the ferrite material only partially filling the annular volume between the inner and outer conductor.

The tuner was initially analyzed using the modified transmission line equations in which the assumption is made that the metallic spacers shield the ferrite material from the electric field. Hence the velocity factor calculation of the loaded transmission line considered only the permeability of the ferrite material.<sup>2,3</sup> The velocity factor is given by the following expression.

$$H = \left[ 1 + \delta \mu_{\Delta} \ln D_3/D_2 / \ln D_2/D_1 \right]^{1/2}$$

- where  $\delta$  = the fraction of the cavity filled by the ferrite in the axial direction  
 $\mu_{\Delta}$  = the incremental permeability of the ferrite material  
 $D_3$  = the outer diameter of the ferrite ring  
 $D_2$  = the inner diameter of the ferrite ring  
 $D_1$  = the inner diameter of the tuner

The velocity factor is used to determine the characteristic impedance of the loaded transmission line and the input impedance of the tuner is calculated using conventional transmission line analysis.

A tuner structure was analyzed using the modified transmission line equations and compared with SUPERFISH calculations. The results at two different frequencies are shown in Fig. 4. There is good agreement between the two methods when the radial length of ferrite is relatively small. However as the ferrite outer diameter increases a good agreement no longer exists. This can be explained by the fact that as the ferrite outer diameter increases (for a fixed ferrite inner diameter) the tuner behaves more like a radial transmission line to the point where the axial transmission line equations no longer apply. Also as the frequency increases the axial electrical length of the tuner increases and the linear equations for inductance and capacitance per unit length, which are used to derive the velocity factor, no longer apply. This led to the investigation of radial transmission line equations for calculating the impedance of the ferrite rings. It was found that the analysis using a combination of radial and axial transmission line equations<sup>1</sup> agrees with SUPERFISH calculations to within 0.1%.

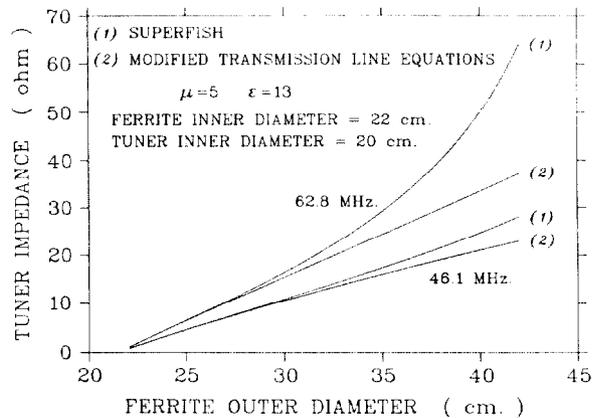


Fig. 4. Comparison of modified transmission line equations with SUPERFISH.

An important advantage of being able to analyze the ferrite tuner using radial and axial transmission line equations instead of SUPERFISH is that the effect of changes in the characteristics of the tuner is more easily determined.

Two possible physical configurations and E field distribution of a tuner stem which meet the design criteria for the ferrite tuner are shown in Fig. 4.

The impedance at point A of the partially loaded transmission line is calculated using a combination of radial and axial transmission line equations. A minimum  $\mu$  of 1.5 is set by the maximum bias fields that can be reasonably produced and a maximum  $\mu$  of 8.0 is set by the minimum value of Q that can be used to keep the power dissipation within the power limits of the tube. SUPERFISH is then used to determine the H field distribution in the ferrite material and hence the magnetic stored energy can be calculated. Assuming a Q of 300 at 46.1 MHz and 600 at 62.8 MHz and using the respective voltages from the proposed RF voltage program, the power density and total power dissipated in the ferrite can be calculated for both configurations. The advantage of the 4 ring configuration is that the power dissipated is more uniformly distributed making more efficient use of the volume of ferrite.

### Conclusions

The four ring configuration shown in Fig. 5 will be used as the reference tuner design and the new reference design for the ferrite tuned amplifier cavity is shown in Fig. 6.

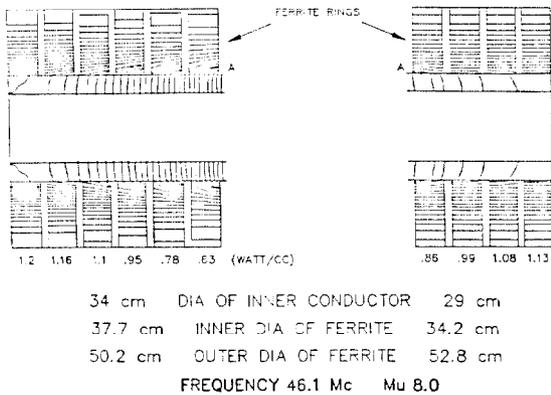


Fig. 5. Physical configuration and H-field distribution of two possible tuner designs.

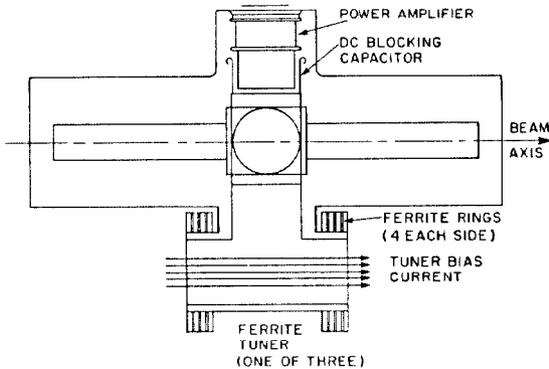


Fig. 6. New reference design for the ferrite tuner amplifier cavity for the TRIUMF KAON factory.

Presently a full power prototype of the new reference design is being designed with air dielectric tuners to allow testing of the amplifier cavity.

### Acknowledgement

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### References

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