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A HIGH-Q FERRITE-TUNED CAVITY

by

Lawrence M. Earley, Sandia National Laboratories
Albuquerque, New Mexico, 87185
Henry A. Thiessen, Roger Carlini, and James Potter
Los Alamos National Laboratory, Los Alamos, New Mexico 87545*

Summary

Rapid cycling proton synchrotrons, such as the proposed LAMPF II accelerator, require approximately 10 MV per turn rf with 17% tuning range near 50 MHz. The traditional approach to ferrite-tuned cavities uses a ferrite which is longitudinally biased (rf magnetic field parallel to bias field). This method leads to unacceptably high losses in the ferrite. At Los Alamos, we are developing a cavity with transverse bias to the bias field) making use of the tensor permeability of the ferrite. Initial tests of a small (10-cm-diam) quarter-wave singly re-entrant cavity tuned by several different ferrites indicate that the losses in the ferrite can be made negligible compared with the losses due to the surface resistivity of the copper cavity. Details of the test results will be presented.

Introduction

The use of ferrites in cavity tuning is not a new idea. As early as 1956, several people[1,2,3] had successful experimental results and had developed a theoretical understanding of ferrites in rf fields. These early experiments used ferrites with a bias magnetic field applied perpendicular to the rf magnetic in their cavities. They also tried placing the bias direction along other possible axes of their cavities. All these experiments were carried out at X-band (approx. 10 GHz). In all the cases of applied magnetic field perpendicular to the rf magnetic fields, the applied bias was less than the needed bias to cause the gyro-magnetic resonance. These experimenters were hampered by the poorer quality of the materials they used.

Accelerator cavities have been tuned with ferrites in many laboratories. Some examples are the CERN PS, the Brookhaven AGS, and the rings at Fermilab. In all these facilities, ferrite tuning is achieved by having the applied bias magnetic field parallel to the rf magnetic fields in the cavities. The variation in cavity frequency is achieved by varying the μ of the ferrite by moving along the hysterisis loop of the ferrite.

The many disadvantages of ferrite tuning include: low cavity Q, heating problems in the ferrite, and high maintenance. All of these problems are caused by the high loss most ferrites exhibit in rf cavities. A low loss ferrite-tuned cavity was built for the Los Alamos Proton Storage Ring using a newer ferrite material. The applied bias magnetic field is perpendicular to the rf magnetic fields and the cavity is operated in the region above the gyromagnetic resonance, and selecting the right ferrite, can lead to the condition of a high-Q resonant cavity that can be tuned in frequency over a large range with no appreciable losses in the ferrite.

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A. Perpendicular Bias Magnetic Field Theory

Perpendicular or transverse bias is used in ferrite devices today for a variety of microwave uses.

These devices include isolators, circulators, phase shifters, attenuators, and filters. These devices have their properties derived from the gyromagnetic resonance phenomena.

If we have the condition of a magnetic dipole in a ferrite subjected to a dc magnetic field H and next apply a second magnetic field h, which is both an rf field and perpendicular to the dc field, the rotating vector (H + h) describes a cone. The magnetic moment M moves with a precessional motion around the cone. The condition of gyromagnetic resonance occurs when the rf frequency is synchronized with the precession. The resonance condition occurs at

$$H_o = f/2.8$$

where H_o is the dc magnetic field in oersteds and f is the rf frequency in MHz.

One must remember that under these conditions, the representation of the permeability of the ferrite is a tensor quantity. The permeability tensor was derived by Polder and given by

$$\bar{\mu} = \mu_o \begin{pmatrix} \mu_x & -jk & 0 \\ jk & \mu_y & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

where the dc magnetic field is applied in the z-direction and the material is saturated in the z-direction. The permeability of the ferrite has both a dispersive and a dissipative component and can be written as

$$\mu = \mu' - j\mu''$$

Figure 1 shows a plot of permeability versus applied dc magnetic field. The plot of μ'' is the dissipative component and the greatest loss occurs at an applied field H_{RES} which is the condition for gyromagnetic resonance. The plot of μ_e is the

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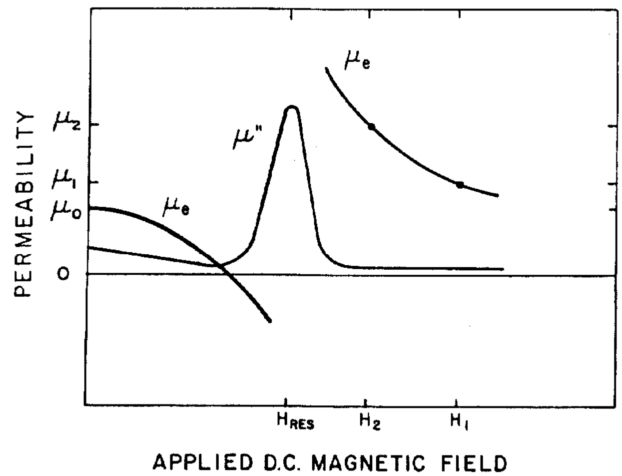

Fig. 1. Plot of permeability versus applied dc magnetic field.

bility μ'. The value of μ_e is varied depending on the relation between the direction of wave propagation in a cavity and the dc magnetic field. The cavity frequency is tuned in the optimum way by varying the dc bias from H_2 to H_1 thus varying the μ_e from μ_2 to μ_1. In the region above resonance, the value of μ is lowest. In selecting ferrite, care should be taken to choose a material that has the lowest μ'' above resonance. Materials with low values (1.5-2.5 oersteds) of ΔH_k (spin-wave line width) should be chosen. Thus, a large variation in μ_e can be reached under a very low loss condition.

B. Prototype Ferrite-Tuned Cavity Experimental Results

A prototype cavity was built near the suggested frequency of 40-50 MHz for the proposed LAMPF II synchrotron. The prototype cavity is shown in Fig. 2. It is a quarter-wave coaxial cavity with ferrite loading on the low-voltage end. The solenoid provides an axial dc magnetic field, while the rf magnetic fields of the cavity are in the θ-direction. The cavity had a resonant frequency of 54 MHz and a Q_o of 2600 with no ferrite loading. The solenoid was capable of providing dc magnetic fields up to 3500 Gauss. Table I shows some of the ferrites that were tested in the prototype cavity. These three ferrites have low values of spin-wave line width.

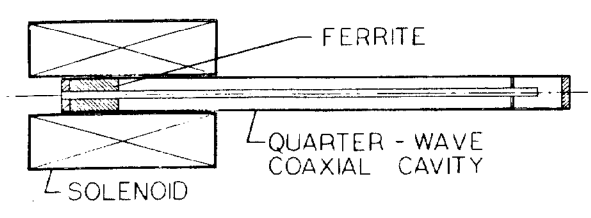

Fig. 2. Drawing of early prototype cavity.

TABLE I

FERRITE	MANUFACTURER	MATERIAL COMPOSITION	SATURATION MAGNETIZATION
TT 1-105	TRANS - TECH	MAGNESIUM FERRITE	1750 G
TT2-111	TRANS-TECH	NICKEL FERRITE	5000 G
CVG-1850	AMPEX	CALCIUM VANADIUM GARNET	1850 G

Experiments were performed with approximately 3.5% ferrite loading by volume. The solenoid had a region of uniform field large enough to handle a ferrite volume of 3.5%. Figure 3 shows the results for all three ferrites with frequency being plotted

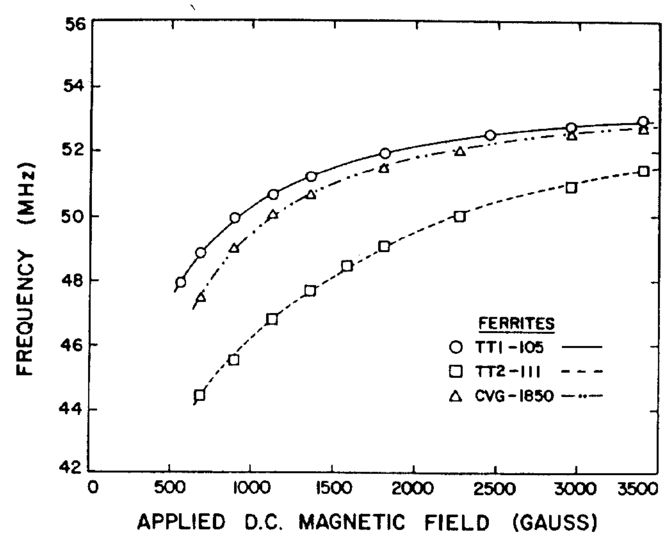

Fig. 3. Results for three ferrites with frequency plotted versus dc magnetic field.

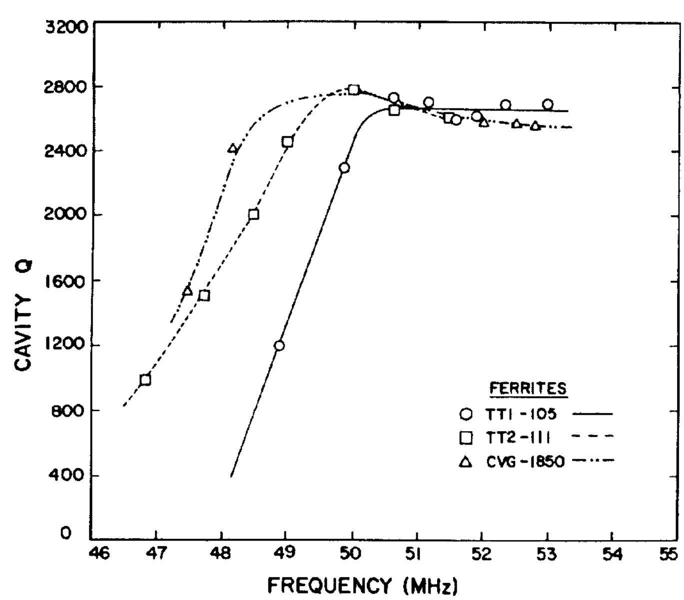

Fig. 4. Results for three ferrites plotted as "Q" versus frequency.

TABLE II. SPECIFICATIONS FOR FULL-POWER PROTOTYPE CAVITY SHOWN IN FIG. 5.

Cavity length = 350.000 cm	Cavity diameter = 100.000 cm
Gap = 10.000 cm	
Frequency	= 55.986 MHz
Normalization Factor (E0=1 MV/M)	A Scale = 45790.8
Stored Energy	= 62.9165 joules
Power dissipation	= 1034969.38 watts
T, TP, TPP, S, SP, SPP = 0.979 0.007	0.001 0.186 0.029 0.000
Q = 21384	Shunt Impedance = 1.69 MOHM/M
Product Z*T**2	ZTT = 1.62 MOHM/M
Magnetic field on outer wall	= 12154.0 amp/M
Maximum electric field on boundary	= 48.528 MV/M

versus dc magnetic field. Figure 4 shows the same materials plotted now with loaded-cavity Q versus frequency. The plots show that 6% tuning range over a region where the ferrite-loaded cavity Q is the same as the unloaded-Q of cavity. Thus, a region of operation can be found where the ferrite losses are negligible in comparison to the losses in the cavity walls. All results are at low power levels.

C. Design of a Full-Power Prototype Ferrite-Tuned Cavity

A full-power protype ferrite-tuned cavity is being designed using SUPERFISH. Some preliminary design parameters are shown in Table II. The cavity is shown in Fig. 5.

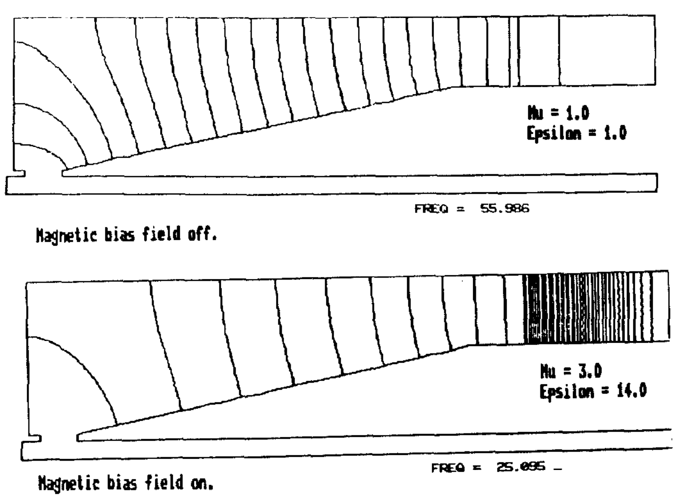

Fig. 5. SUPERFISH design for a full-power prototype.

D. Conclusion

Results for the first ferrite-tuned cavity using transverse bias are very promising. A high Q has been achieved over a large tuning range for several different ferrites. In order to achieve the 17% tuning range needed for LAMPF II, a 10% ferrite volume will be needed. It is reasonable to expect that this tuning range can be reached in the high-Q region. Early SUPERFISH designs show a full-power prototype can be designed with the needed parameters for the LAMPF II system. Medium power tests will be done on the first prototype to 1 kW in the near future.

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