FAST FERRITE TUNER FOR THE BNL SYNCHROTRON LIGHT SOURCE*

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Abstract

A new type of ferrite tuner has been tested at the BNL. The ferrite tuner uses garnet slabs partially filling a stripline. One of the important features of the tuner is that the ferrite is perpendicularly biased for operation above FMR, thus reducing the magnetic losses. A unique design was adopted to achieve efficient cooling. The principle of operation of the tuner as well as our preliminary results on tuning a 52 MHz cavity are reported. Optimized conditions under which we demonstrated linear tunability of 80 KHz are described. The tuner's losses and its effect on higher-order modes in the cavity are discussed.

I. INTRODUCTION

Tuning of RF cavities in storage rings is needed to maintain accelerating gap voltage under varying beam load conditions. Conventionally, this has been done using motor-driven capacitive posts or inductive loops. Under conditions of fast injection, the need exists for a different type of tuner in which the mechanical movements of the tuning elements are eliminated. In this paper we report on a Fast Ferrite Tuner (FFT) to be used in the VUV storage ring at the National Synchrotron Light Source.

At the NSLS, the VUV-ring is an electron storage ring dedicated to synchrotron radiation in the UV range and is normally operated at 745 MeV. A single 52 MHz accelerating cavity is used to compensate for the 14.7 KW of synchrotron radiation per ampere of stored beam. This RF cavity requires detuning range of 50 KHz to maintain the correct phase relation between the cavity voltage and the beam current. Currently, a combination of a mechanically driven loop tuner and water temperature variation is used to provide the required detuning. Our objective is to replace these techniques by the ferrite tuner, thus eliminating the beam instabilities associated with certain positions of the mechanical tuner.

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*Work performed under the auspices of the U.S. Department of Energy.
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II. PRINCIPAL OF OPERATION

A. Basic Concept:

A loop-coupled transmission line is used to tune the 52 MHz cavity. The transmission line is partially loaded by ferrite. By changing the bias field, the permeability of the ferrite can be changed. This results in the change in the circulating current in the coupling loop, which in turn changes the magnetic field in the region around the loop. Thus, the ratio of the magnetic to electric stored energy in the cavity is changed with the accompanying change in the cavity's resonant frequency.

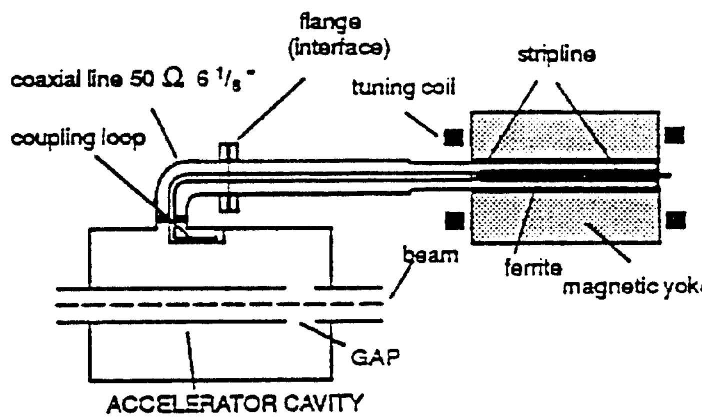

Fig. 1. Configuration for the ferrite tuner and the RF cavity.

B. Material:

Recently, the use of substituted yttrium iron garnet (YIG) has been suggested [1,2]. The choice of such microwave ferrite enjoys the important advantage of custom tailoring the saturation magnetization to the specific application and thus minimizing the bias field requirement. The permeability changes as:

$$\mu = 1 + \frac{4\pi M_s}{H} \quad (1)$$

where $4\pi M_s$ is the saturation magnetization, and H is the dc field inside the ferrite.

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The garnet is biased above saturation and with the dc magnetic field perpendicular to the rf magnetic field. The ferrite is operated above the gyromagnetic resonance in the region where the dissipative part of the permeability, μ'' is low, thus reducing the magnetic losses.

C. Circuit Model:

The ferrite tuner can be modeled as a short-circuited trasmission line whose effective length varies as a function of the bias current, l(I) as shown in Fig. 2.

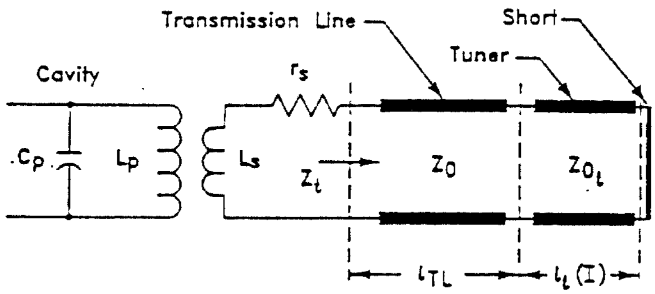


Fig. 2. Transmission line model for the ferrite tuner.

From the tuner equivalent circuit shown in Fig. 3 (a), one can deduce the coupled impedence reflected into the cavity. This is shown in Fig. 3(b).

$$Z_c=\frac{(\omega M)^2}{Z_s+Z_t}=\frac{K_{sp}K_{ps}(\omega L_p)(\omega L_s)}{Z_s+Z_t} \qquad (2)$$

Since the resistive part of Z_s is negligible, then $Z_s = j\omega L_s$.

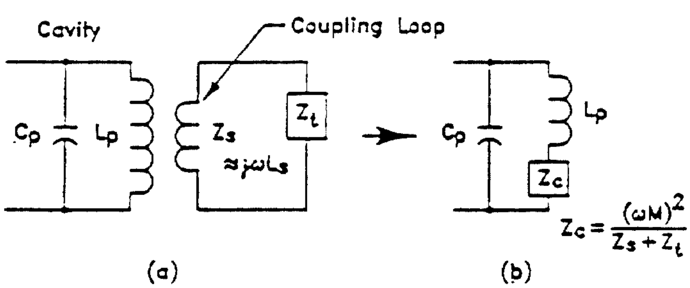


Fig. 3. Equivalent circuits for the tuner and coupling structure.

If we define $K^2 = K_{ps} K_{sp}$, we obtain

$$Z_c=\frac{K^2(\omega L_p)(\omega L_s)}{Z_s+Z_t}=\frac{-K^2 Z_p Z_s}{Z_s+Z_t} \qquad (3)$$

The resonance frequency of the cavity is

$$2\pi f = \frac{1}{\sqrt{L_{eff}C_p}} \quad where \quad L_{eff}=L_p\left[1-\frac{K^2}{1+\frac{Z_t}{Z_s}}\right] \qquad (4)$$

If the capacitance is fixed , then we have

$$\frac{\Delta f}{f}=-\frac{1}{2}\frac{\Delta L_{eff}}{L_{eff}} \qquad (5)$$

Maximum change in the cavity frequency will be between open circuit ($L_{eff}=L_p$) and short circuit ($L_{eff}= L_p [1 - K^2]$). Thus the maximum amount of frequency shift is limited by the degree of coupling, K^2. Our experimental results showed clearly this effect.

III. RESULTS OF PRELIMINARY TUNER TESTING

A. Tunability:

We have optimized the coupling between the tuner and the cavity as well as the length of the connecting transmission line to obtain the required tunability. A length of ℓ = 56.5" gave a linear tuning characteristics as shown in Fig.4. The cavity's frequency is plotted against the tuner biasing current, I. The maximum frequency shift obtained is 78 KHz, which exceeds the design goal of 50 KHz. The voltage standing-wave ratio (VSWR) at the cavity's driving port varied between VSWR = 1.064 at I = 0 A and VSWR = 1.414 at I = 130 A.

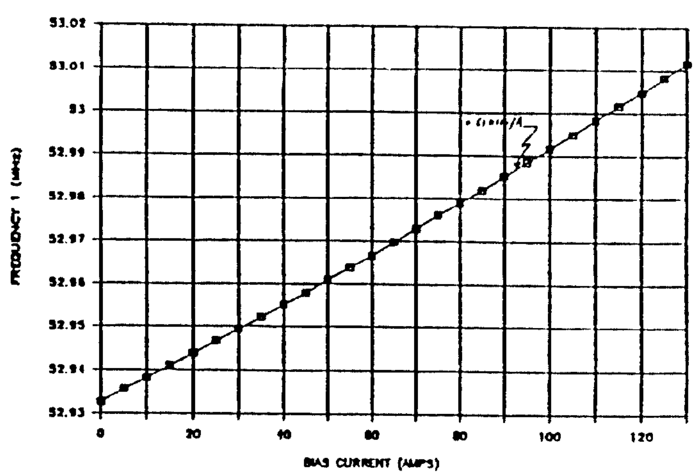


Fig. 4. Tuning characteristics of the FFT.

B. Variation of Tuner Losses:

The Q of the tuner system was measured as a function of the bias current. The results of the measurement are shown in Fig. 5. It can be seen from the figure that Q first increases with bias current up to 30 amperes and then decreases. Since we are biasing the ferrite above FMR, then, as we increase the bias field; μ'' becomes smaller resulting in lower magnetic loss in the ferrite and subsequently higher Q. As for the slight decrease in Q for higher bias currents, we have considered different effects. One possible explaination would be the fact that the tuner effecively becomes a shorter trasmission line as we increase the bias. Thus, for a given voltage at the coupling loop, the electric field in the ferrite increases. This results in the observed increase in losses as manifested by the monotonic decrease in Q.

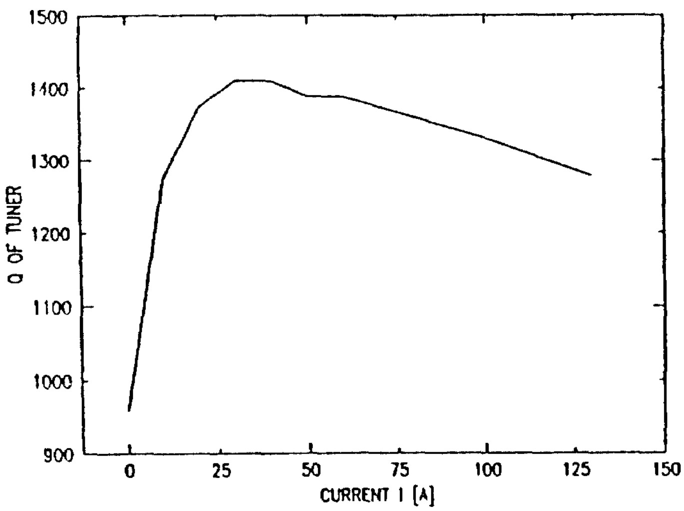
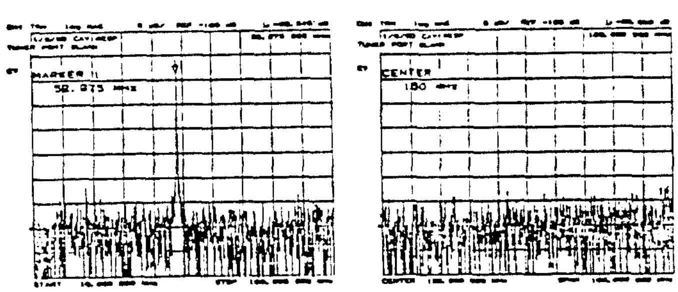


Fig. 5. Variation of the Q of the tuner system.

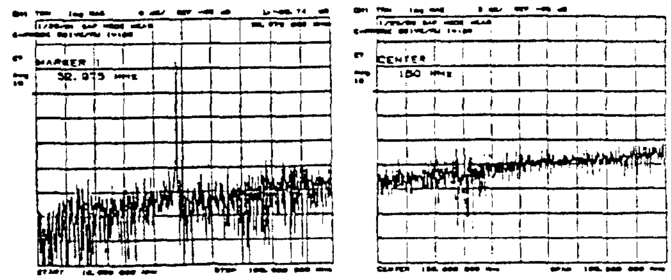
C. *Effect of Tuner on the Cavity's Higher-Order Modes:*

To investigate the effect of the tuner on the excitation of higher-order modes (HOM's) in the VUV-ring cavity, we have analyzed the HOM's induced by the tuner in a replicate study cavity. Specifically, we probed these modes that resulted in a change of field in the accelerating gap. Detailed results of these gap measurements will be reported in a separate publication. Up to 200 MHz there was no observed change in the cavity's response as shown by comparing Fig. 6 (a and b) to Fig. 7 (a and b).



(a) (b)

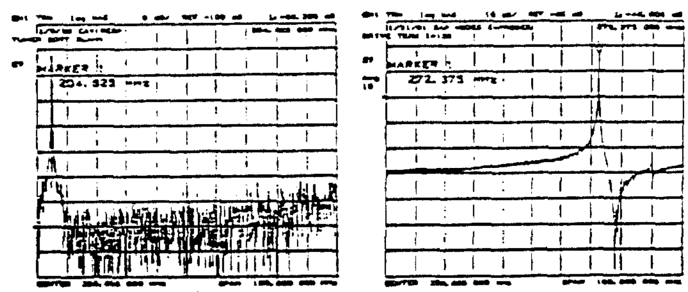
Fig. 6. Cavity response with the tuner port blocked.



(a) (b)

Fig. 7. Cavity response with the tuner coupled to the cavity (I = 130 A).

At higher frequencies, the tuner shifted some of the cavity's HOM's and introduced additional ones. We show in Fig. 8 (a and b) the mode at 272 MHz as an example. Currently, we are studying different approaches to suppress the additional HOM's that are due to the ferrite tuner. This includes the use of a terminated waveguide as a suppressor.



(a) (b)

Fig. 8. Shift in one of the cavity's HOM's due to tuner: (a) tuner port blocked, (b) I = 130 A

IV. CONCLUSIONS

From our preliminary tests on the new ferrite tuner, it is clear that we were able to achieve the design goals concerning the tunability required. The low tuner losses, as demonstrated by the measured high tuner's Q, are credited to the normal bias approach which we use and biasing the ferrite above FMR. The design approach adopted also has the advantage of efficient cooling of the garnet slabs in the stripline configuration.

ACKNOWLEDGEMENT

We wish to acknowledge the technical support of R.D'Alsace and W. Broome.

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