BNL--37082

DE86 001179

TUNING THE RF CAVITY BY USING A DETUNING LOOP

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September 1985

Research Supported by the
OFFICE OF BASIC ENERGY SCIENCES
U.S. DEPARTMENT OF ENERGY
WASHINGTON, D.C.

NATIONAL SYNCHROTRON LIGHT SOURCE DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Under Contract No. DE-AC02-76CH00016 with the
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ABSTRACT

The tuning of the RF cavity with a coupling loop connected to a variable capacitor or an open or shorted coaxial line is described. Two kinds of equivalent circuits are described and some of the calculations of Δf and Q vs. capacitance curves are given. At 52 MHz the maximum practical tuning range is about 100 KHz, if the parameters of tuning circuit are chosen properly so that the Q of the accelerating cavity does not decrease to much.

INTRODUCTION

At the NSLS the RF cavities are heavily capacitively loaded quarter wave T.E.M. resonant structures, which are described fully in Ref. 1 and 2. There are many possible methods of tuning the cavity; however, it is more convenient to tune the cavity by using a coupling loop connected with a variable capacitor or a movable coaxial line shorted or open at the end. A ceramic window will provide a vacuum barrier and the use of a coaxial structure eases the problem of water-cooling the loop.

Fig. 1 shows the schematic diagram of the proposed tuning cavity.

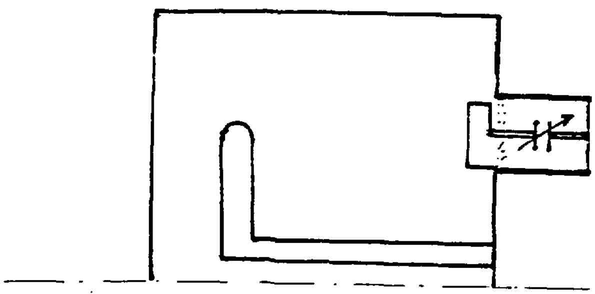

Fig. 1

Theory

The storage energy of the accelerating cavity W is

$$W = \frac{1}{2} C_p V_{gap}^2 = \frac{1}{2} I_p^2 L_p \quad \ldots \qquad (1)$$

where C_p and L_p are the equivalent capacitance and inductance of the accelerating cavity for the fundamental mode.

V_{gap} and I_p are gap voltage and current of the accelerating cavity respectively. The resonance freq. f and Δf can be calculated,

$$f_o = \frac{1}{2\pi\sqrt{L_p C_p}} \quad \ldots \qquad (2)$$

$$\frac{\Delta f}{f_o} = -\frac{1}{2}\frac{\Delta C_p}{C_p} \quad \left(\text{or } \frac{\Delta f}{f_o} = -\frac{1}{2}\frac{\Delta L_p}{L_p}\right)\ldots \qquad (3)$$

Also we can get the relationship between Δf and ΔW,

$$\frac{\Delta f}{f_o} = -\frac{1}{2}\frac{\Delta W}{W} \quad \ldots \qquad (4)$$

where ΔC_p, ΔL_p and ΔW are increments of C_p, L_p and W introduced by the tuning device and f_o denotes the unperturbed freq. of the accelerating cavity (about 52.88 MHz in the case considered).

For the fundamental mode, two kinds of equivalent circuits may be used to calculate the parameters related to cavity tuning.

One of them uses the mutual inductance M, as shown in Fig. 2

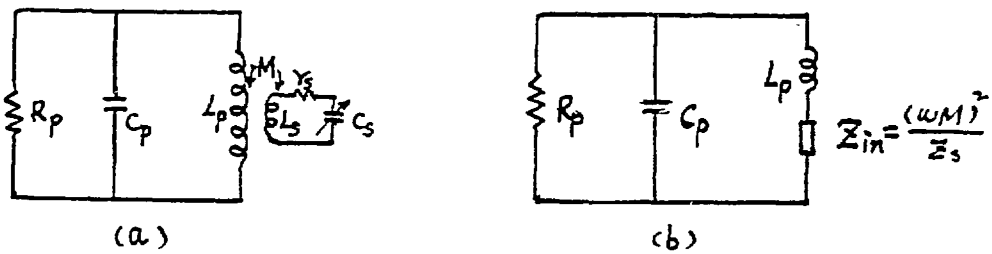

Fig. 2

where C_p, L_p and R denote parameters of the unperturbed cavity. r_s, L_s and C_s denote the resistance, inductance and capacitance of the tuning circuit, respectively. Z_s is the impedance of the tuning circuit, $Z_s = r_s + jwL_s + 1/jwc_s$. Z_{in} denotes the impedance introduced into the accelerating cavity. When C_s or L_s in the tuning circuit is changed, the reactive component of Z_{in} is changed, and the accelerating cavity is detuned.

The other circuit option uses the ideal transformer of ratio n = 13 shown in Fig. 3.

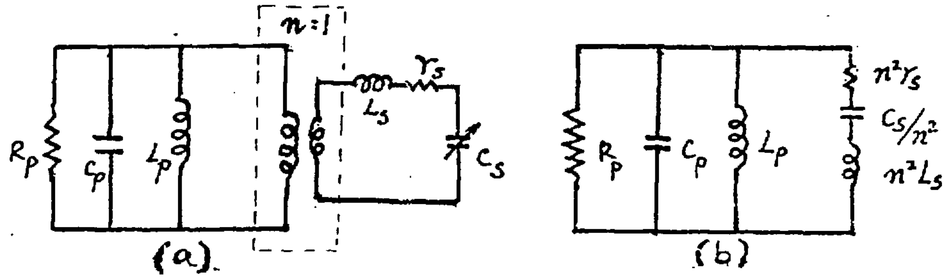

Fig. 3

where n denotes the transformer ratio of the voltage from the gap of theaccelerating cavity to the tuning loop.

In order to tune the accelerating cavity, the proper n or M, L_s and C_s must be chosen to achieve adequate tuning range. The resonant frequency of the tuning circuit, which is formed by C_s and L_s, should be sufficiently far from the RF source or cavity resonant frequency to avoid disturbing modes, as shown in region III in Fig. 4. The tuning characteristic achieved by a variable capacitor c_s are illustrated in Fig. 4.

The regions I and II can be used for tuning the cavity. In the region I, there is $\omega_s = 1/\sqrt{L_s C_s} < \omega_o/\sqrt{2}$ and in the region II, there is $\omega_s > \sqrt{2}\omega_o$. In In region III, two modes exist and Q decreases dramatically so we cannot use this region for tuning the cavity.

In a test system, with n = 13, the range of frequency tuning was as much as 300 KHz (Fig. 4). The theoretical calculations give the same results.

Also, the tuning loop connected with a variable length shorted coaxial line can be used to tune the accelerating cavity. The tuning curve with n = 13 is indicated in Fig. 5. The measured values are basically identical to the theoretical calculation as indicated in Fig. 5.

In every case, mode spectra of the longitudinal E fields in the accelerating gap. were taken by using an E field probe on either side of the gap and an Eton spectrum analyzer with tracking generator. No change in the mode spectra were found with the tuning circuit, in which the $\omega_s < \omega_o/\sqrt{2}$ or $\omega_s > \sqrt{2}\,\omega_o$ conditions were met, as indicated in Fig. 6.

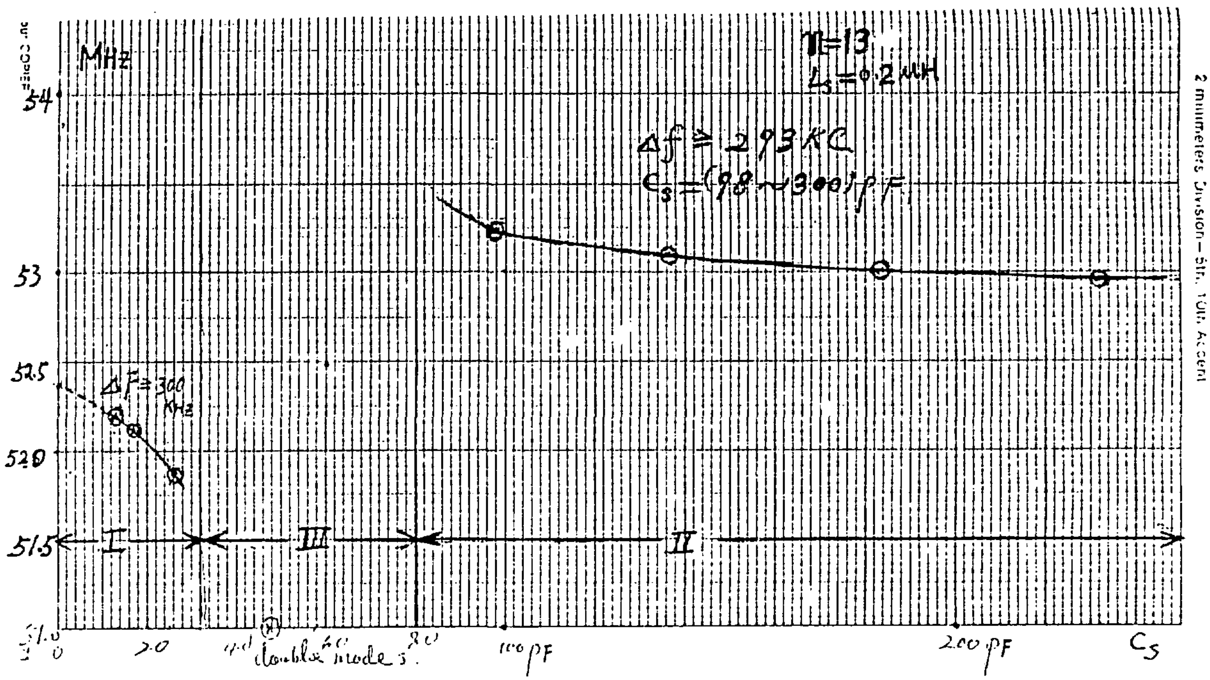
MHz
n=13
Ls=0.2 μH
Δf ≥ 293 KC
Cs=(98~300)pF
ΔF≥300 KHz
54
53
52.5
52.0
51.5
I
III
II
double modes
100 pF
200 pF
Cs
2 millimeters Division

Fig. 4

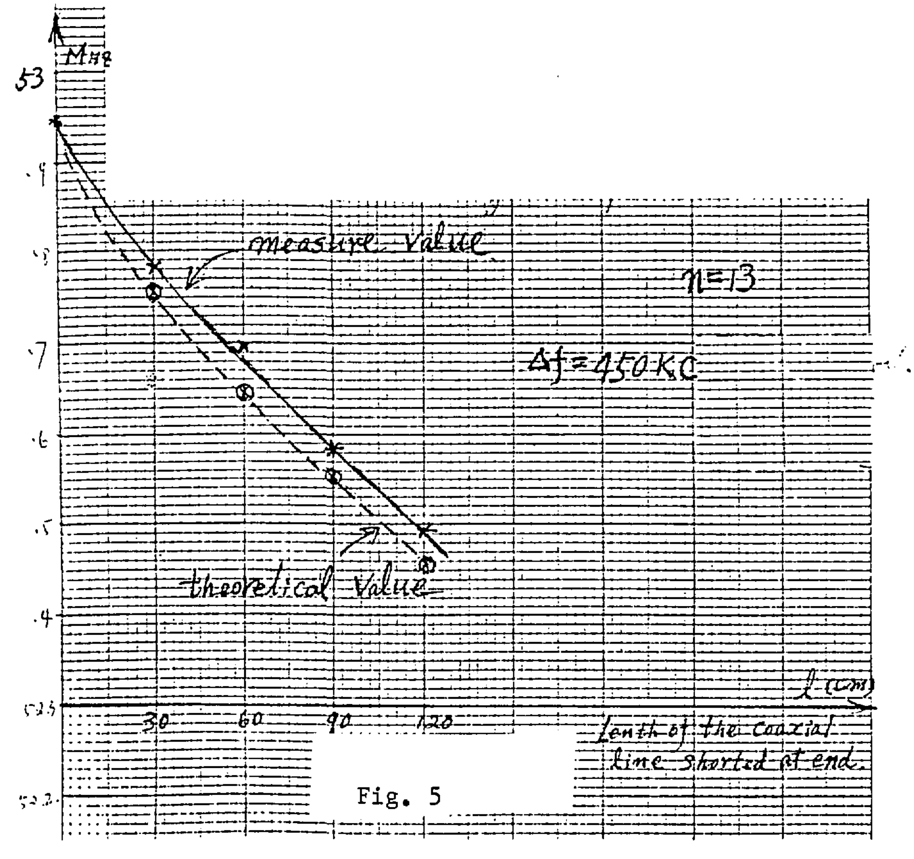
MHz
53
.9
.8
.7
.6
.5
.4
measure value
theoretical value
n=13
Δf=450 KC
30
60
90
120
l (cm)
lenth of the coaxial line shorted at end.

Fig. 5

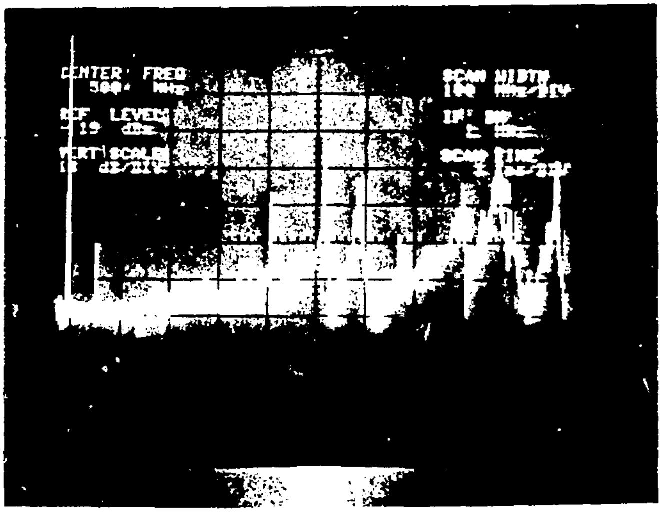

Fig. 6

If this tuning circuit is utilized to tune the accelerating cavity the shunt resistance R of the fundamental mode should be affected. The degree to which R decreases depends on the tuned range of the cavity frequency (Δf), the Q_s of the tuning circuit and the tuning region involved.

Fig. 7 and 8 show the theoretical value of Q and the tuning frequency versus capacitance C_s, when c_p = 25 PF, L_p = 0.3611 pF, $R_p = 10^6 \Omega$, $M = 10^{-2}$ μH, $r_s = 0.1\Omega$ and L_s = 0.1 μH.

According to these results, it is better to use the region I, corresponding $c \leq 40$ PF. The range of the tuning covers up to 50 KHz, which is enough to compensate the beam loading and temperature variations of the resonant cavity. Under this condition, the maximum voltage across the C is about 10 KV.

The Effects of Tuning

The tuning of a cavity will affect its parameters including R_p and geometrie factor of the cavity, GF, which is defined as $GF = R_p/Q_o$, where GF only depends on the geometry of the cavity. It is necessary to measure the f_o, Q_o and GF and to calculate R_p, when the cavity is tuned. If R falls too much, or GF changes too much, (perturbation method is needed to measure GF) the range of tuning is limited by the amount of power fed to the tuning system. Care is also needed in order to avoid introducing high order modes into the cavity system.

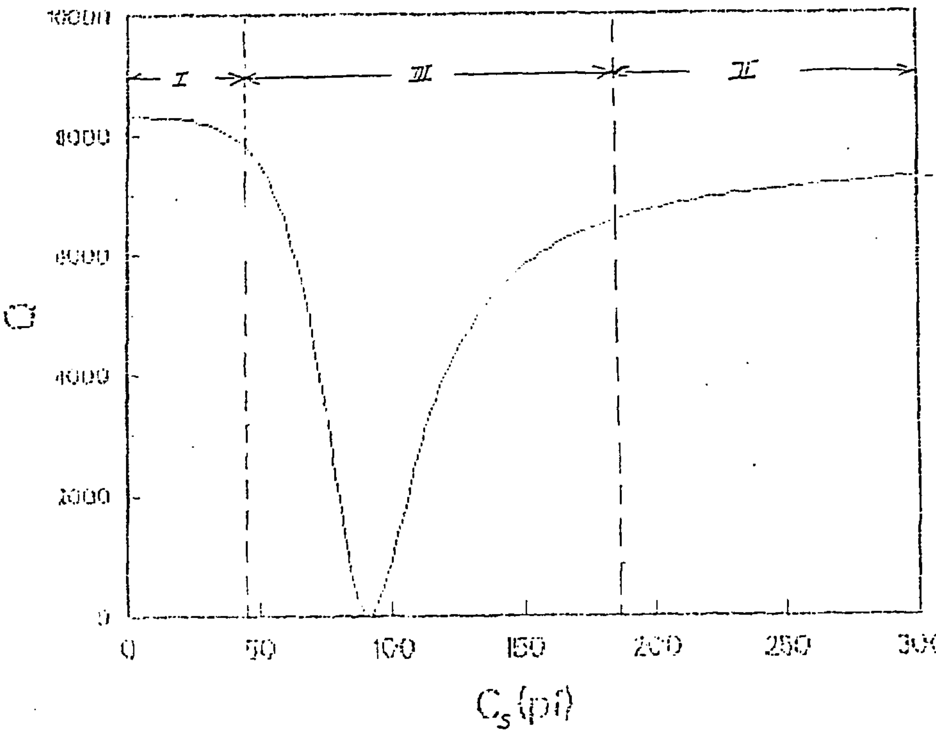
I
III
II
8000
6000
4000
2000
0
Q
0
50
100
150
200
250
300
C_s (pf)

Fig. 7

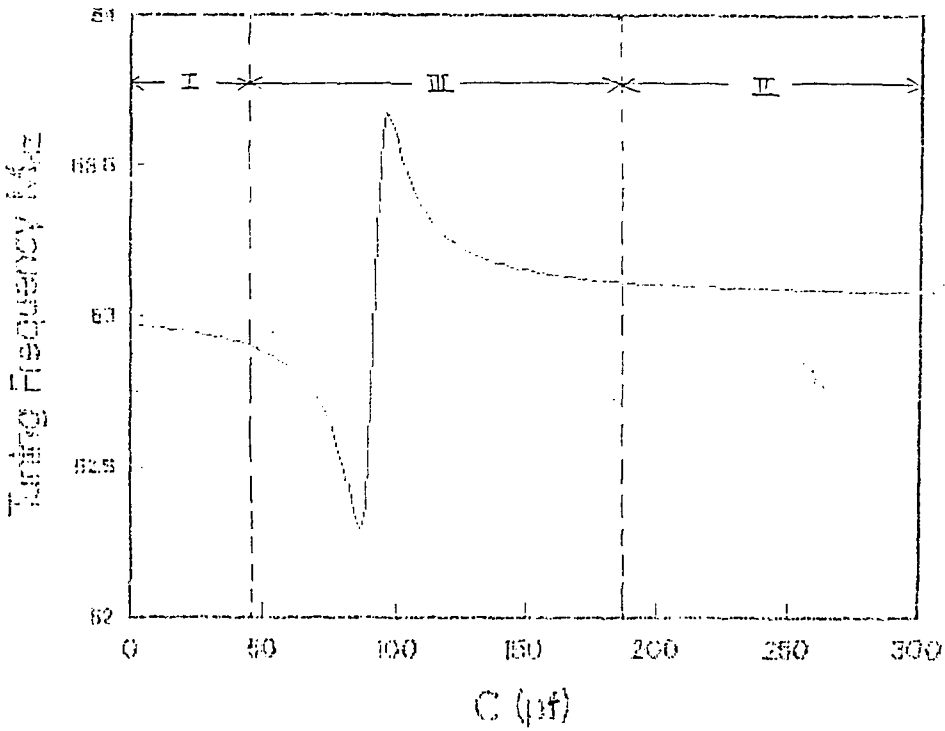
I
III
II
63
62
0
50
100
150
200
250
300
C (pf)

Fig. 8

Possible Tuner Designs

There are several kinds of tuners that can be used for tuning the cavity:

1) A loop with a variable capacitor C.
2) A loop with a movable coaxial line shorted at the end.
3) A loop with a variable length open-ended coaxial line.

Mode Damping

In many storage rings high order modes in the accelerating cavity can give rise to various types of beam instabilities. It is of interest to "damp" or lower the Q value of these higher order modes in order to alleviate such problems. The region III of Figures 4 and 7 is of interest in this regard since it is clear that with a properly designed loop and shorted line arrange so that

$$w_s = \frac{1}{L_s C_s} = w_{hm} \qquad (5)$$

where w_{hm} is the resonant frequency of a given higher order mode, it is possible to leave the Q value of this mode by a large factor.

Conclusion

The design method of tuning a cavity with a coupling loop connected to a variable capacitor (or a movable coaxial line) is evident. The theoretical calculations are basically in agreement with the results of test measurements. The lower the dissipation in the tuning circuit, the better the tuning behavior.

Acknowledgments

The authors wish to express their gratitude to N. Fewell and M. Puglisi for useful discussions and M. Thomas, R. D'Alsace, K. Riker, R. Biscardi, G. Ramirez and H. Ackerman for assistance with the measurement. This work was also supported by Zhejiang University, Hangzhou, Zhejiang, The People's Republic of China.

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