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Abstract

Tuning of an RF cavity with a moving loop inside the cavity is described. The formula to calculate the main parameters Δf and Q of the cavity are given. The results of these tests are presented. The advantages of this method are analyzed.

Introduction

There are many possible methods to tune the accelerating cavity at the NSLS. Some of them are described in Reference 1, 2, and 3. However, there are many advantages to tuning the cavity by using a moving loop. This loop should penetrate into an area of strong magnetic field in the cavity and ideally at the magnetic field maximum, as indicated in Figure 1.

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Figure 1

Theory

For the fundamental mode, the equivalent circuit in Figure 2 may be used to calculate the main parameters of the tuning system shown in Figure 1.

Where C_p , L_p , and R_p are the equivalent capacitance, inductance and shunt resistance of the accelerating cavity which are approximately 25 pF, 0.36 μ H and 2 M Ω respectively. L_s and R_s are the equivalent inductance and resistance of the tuning loop. N is the ideal transformer ratio between the tuning loop and the accelerating cavity.

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Figure 2

Figure 3 is the equivalent circuit of Figure 2, and is more convenient for calculating the parameters of the tuning cavity.

Figure 3

According to Figure 3 we can get

$$\Delta f = \frac{1}{2\pi} \left(\frac{1}{\sqrt{L \cdot C_p}} - \frac{1}{\sqrt{L_p \cdot C_p}} \right) \text{ where } L = \frac{L_p \cdot L_{ps}}{L_p + L_{ps}}$$

$$Q = \omega C_p R \text{ where } R = (R_p \cdot R_{ps}) / (R_p + R_{ps})$$

$$R_{ps} = \frac{K}{R_i}, \quad L_{ps} = \frac{K}{\omega^2 L_i}$$

$$\text{Here } R_i = N^2 R_s, \quad L_i = N^2 L_s, \quad K = R_i^2 + \omega^2 L_i^2.$$

$$N = \frac{\int S_1 B dS}{\int S_2 B dS}$$

Where S_1 is the cavity area and S_2 the loop area

The tuning range Δf and Q of the tuning cavity depend on the transformer ratio N and parameters of the tuning loop L_s and R_s respectively.

Practical Loop Tests

In order to test the theory, three loops of identical coupling area (28.5 sq. inches) and different cross sections and hence different self-inductance were constructed and inserted into a magnetic field region at the outer wall of the test cavity near to the shortest end. The resultant frequency shifts were measured and conferred with theory. The results are given in Table 1 below.

TABLE 1

Loop Cross Section	Loop #1 0.081" dia.	Loop #2 0.310" dia.	Loop #3 rectangular 1.5"x.063"
Calculated Resistance, R_s	0.169 Ω	0.0432 Ω	0.031 Ω
Calculated Inductance, L_s	0.476 μH	0.321 μH	0.224 μH
Calculated Q Value	17600	17800	17700
Calculated Loop Current	81.3 A	150.3 A	165 A
Calculated Frequency Shift	38.6 KHz	57.2 KHz	82.0 KHz
Measured Frequency Shift	35 KHz	54 KHz	74 KHz

Table 1 Parameters and Measurement of Three Test Loops

The calculated N value for these loops was 23 and it can be seen from Table 1 that since the unloaded Q value was 18000, the maximum reduction in Q value, for Loop #1, was less than three percent. There is good agreement between the calculated and measured frequency shifts. In every case, the measured frequency shift was less than the calculated value. This is due to electric field coupling which gives rise to a reduction in cavity frequency and thus counteracts the increase in frequency obtained by magnetic coupling.

We built a test loop as shown in Figure 4 and calculated the parameters of this loop. Its self-inductance L_s is about 0.12 μH and its RF resistance R_s is about 0.01 Ω at a frequency of 50 MHz.

$$H = 7.5 \text{ cm}, W = 6.2 \text{ cm}$$

$$L = 15 \text{ cm}, T = .2 \text{ cm}$$

Figure 4

Using the formula and the parameters of the tuning loop shown above, the main parameters of the tuning system shown in Figure 5 may be calculated.

We put this tuning loop into the RF cavity shown in Figure 5 and changed the depth of penetration of the loop. The tuning curve we measured is shown in Figure 6. When the tuning loop penetrates three inches into the cavity detuning is 43 KHz. The calculated value of detuning for this penetration depth is 50 KHz.

Figure 5

Figure 6

Under normal operating conditions, the gap voltage in the rf cavity is 282 kV, then according to calculations, the maximum current in the tuning loop is about 181 A. This current does not pass through the RF spring contact. Also, the calculated maximum losses in the loop are about 328 W. When the Q_0 of the tuning cavity is about 18000, the Q_0 changes three percent due to tuning losses.

Final Loop Tuner Design

For the final loop tuner, a 3/8" diameter copper pipe was used to form the coupling loop. The mechanical configuration of this loop is shown in Figure 7. The maximum area of this loop was 36 sq. inches. The calculated frequency shift for a loop penetration of 5" is 52 KHz and the measured tuning range versus loop penetration is shown in Figure 8. Since the self-inductance, L_s , of the final loop of 0.356 μ H is greater than that of the test loop, the tuning range for the same depth of penetration is less. In order to achieve a tuning range of about 45 KHz, the loop penetration has to be slightly greater than 5".

Figure 7

Figure 8

Now we consider the current passing through the RF spring contact. Even if the wall of the cavity has been slotted for tuning, most of the current at the wall near the slot will flow around the slot, as indicated in Figure 9. Only a small amount of wall current will pass through the RF spring, since we can make the slot as narrow as possible.

Figure 9

The tuning loop also behaves like a probe placed in the electric field in the cavity. It also perturbs the local magnetic field and this, together with the electric field perturbation, causes current to flow along the tuner support stem. This current will pass through the RF spring contact and thus the bellows used for a vacuum seal is protected from heating by the induced current, that would flow through it if the spring ring was not used. It can be shown that an asymmetrically supported loop placed at a suitable location on the cavity end wall opposite to the gap results in close to zero current flowing along the support stem.

In many storage rings, the beam can excite high order modes in the accelerating cavities, which can give rise to various types of beam instabilities. When the depth of penetration of the loop into the cavity is increased, not only the main mode is effected by the tuning loop, but also some of the high order modes.

The effect on these higher order modes is essentially the same as for the fundamental mode. That is, the resonant frequencies are changed, but the modes are not damped. There is no evidence of any new modes being introduced by the addition of the loop tuner into the cavity as can be seen in Figure 10 (a) and (b).

(a) without tuner

(b) with maximum tuner penetrations

Figure 10. Cavity Frequency Spectra.

Conclusion

This method of tuning a RF cavity has been used for existing cavities at the NSLS. At the operating frequency of 50 MHz, the tuning range is about 50 KHz. This cavity tuning system works well.

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References

1. K. Batchelor, J. Galayda, and R. Hawrylak, RF Cavity Design for the NSLS, IEEE Trans. on Nucl. Sci., Vol. NS-28, No. 3, June 1981.
2. N. Fewell and W. Zhou, High Order Mode Damping in the NSLS. Accelerating RF Cavities by Use of Damping Antennae. 1985 Particle Accelerator Conference, Vancouver, BC.
3. Y.M. Wang, J. Keane, and K. Batchelor, Tuning the RF Cavity by Using a Detuning Loop. BNL 37082, September 1985.
4. K. Batchelor, Y.M. Wang, and J. Keane, Electric and Magnetic Field Perturbation by a Tuning Loop in a RF Cavity. To be published.

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