

Upgrading the RF Cavity for U-70 Accelerator

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Abstract

This paper presents the results on the experimental investigation of the U-70 RF cavity with additional short circuit loops in the RF magnetic field. These loops introduce a negative inductance impedance into the RF cavity circuit and decrease the equivalent value of cavity inductance by about a factor of 10. This method allows at a low cost 5-fold increase the capacity of the accelerating gap for the U-70 cavity operating with the booster injection complex. The technique of measuring the ferrite-dominated cavity parameters is described.

1 INTRODUCTION

When a point charge crosses an empty cavity, it leaves behind a voltage V_{b0} . The point charge itself is decelerated by $V_{b0}/2$ {fundamental theorem of beam loading [1]}. The voltage V_{b0} developed across the capacitance C_g is related to the beam charge q by:

$$V_{b0} = \frac{q}{C_g}, \quad (1)$$

Where C_g is equivalent capacitance of the cavity gap. We can see that the decelerating voltage reduces when C_g is increased.

The U-70 RF system was worked out to operate with the injector - linac at 100 GeV energy. A wide RF range was 2.6-6.1 MHz. For the new U-70 injector booster the wide RF range decreased and now it is 5.5-6.1 MHz. This fact and method of changing the parameters in RF ferrite dominated cavity [2] allow one to increase the capacitance of the cavity gap.

2 STATUS OF U-70 CAVITY PARAMETERS

The U-70 accelerating system consists of 40 (10 kV each) cavities. The wide RF range is 5.5-6.1 MHz. The harmonic number is 30. Figure 1 shows the equivalent circuit {Terminology is the one used by F. Pedersen [3]}. The cavity is represented as a simple R_s, L, C_g resonator. The amplifier output impedance, transformed to the cavity gap, is included into R_s as well as the cavity losses. The RF and the beam amplifier are modeled as ideal current generators. V_g is the peak RF voltage across the cavity gap. For the cavity resonant frequency $f_0 = 5.5$ MHz { $f_0 = 1/(2\pi\sqrt{LC_g})$ } the U-70 cavity parameters are:

$C_g \simeq 200$ pF, $L \simeq 4.2$ μ H, $R_s \simeq 7$ k Ω , the quality factor for $V_g = 10$ kV is $Q_0 \simeq 50$, the total power dissipation in the resonator is $P \simeq 7$ kW and the mean power per unit length is $P_{mean} \simeq 5.5$ kW.

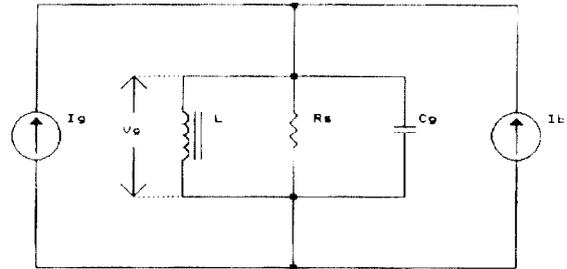


Fig.1 Equivalent circuit of the resonator

3 U-70 CAVITY WITH LOOPS

Method [2] was used to increase capacitance of accelerating gap. The equivalent inductance of the cavity with loops is:

$$L' = \mu_e(1 - K^2)L_0, \quad (2)$$

where L_0 is the value of the air-cored inductance, μ_e is the value of the effective permeability of the air and ferrite, K is the coupling coefficient. The experimentally measured value for L_0 is $L_0 \simeq 0.2$ μ H. Experimental values for μ_e of the U-70 cavity at the maximum and minimum of magnetic bias fields are $\mu_{e\ min} \simeq 12.2$ and $\mu_{e\ max} \simeq 75$ accordingly.

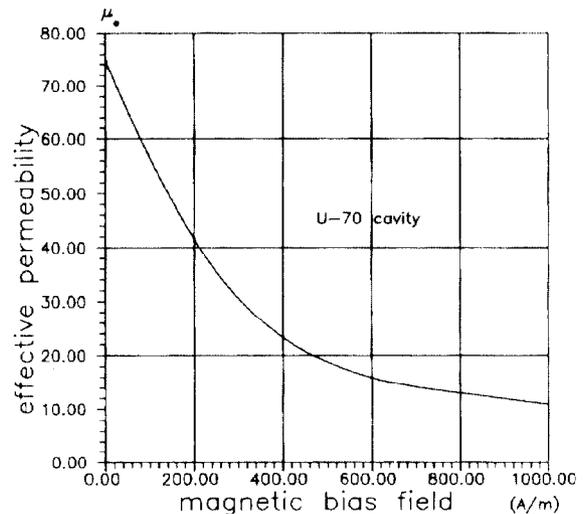


Fig.2 Plot of μ_e against magnetic bias field.

The plot of μ_e against magnetic bias field for 300NN type of ferrite is shown in Fig.2.

Design of the loop in the U-70 cavity: the material is copper, the transverse section is rectangular with sizes $A = 7.5$ mm and $B = 2$ mm {the perimeter is $p_l = 2(A + B) = 19$ mm}, the length in each half of the cavity is $s_l = 1.3$ m.

3.1 Coupling coefficient

Experimental values for K of the U-70 cavity can be found:

$$K = \sqrt{1 - f_0^2 / f_0'^2}, \quad (3)$$

where f_0 is the cavity resonance frequency without loops and f_0' is the cavity resonance frequency with loops at the equal bias fields. Figure 3 shows that the coupling coefficient changes with variations of the effective permeability.

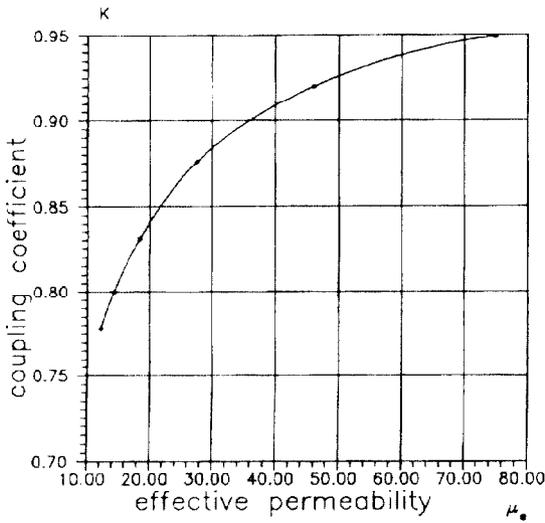


Fig.3 Evolution of the coupling coefficient

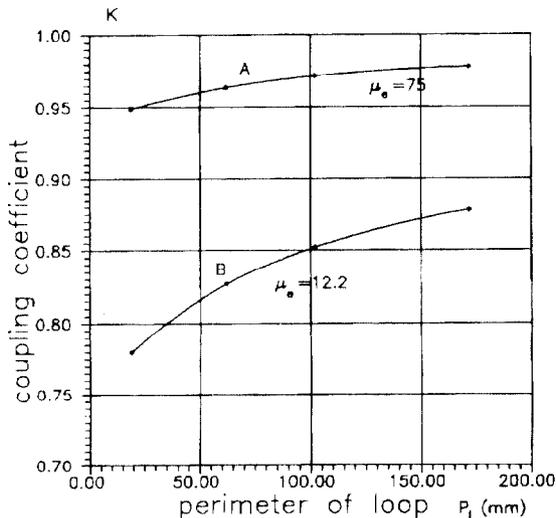


Fig.4 Coupling coefficient as function of perimeter

We can change the value of the coupling coefficient, for this we can change, for example, the value of the perimeter (p_l). The coupling coefficient dependence on the design of the loop is as:

$$K \propto \frac{1}{\sqrt{\alpha_1 s_l (\alpha_2 l g \frac{\alpha_3 s_l}{p_l} - \theta)}}, \quad (4)$$

where $\alpha_1, \alpha_2, \alpha_3, \theta$ are the coefficients from [4]. A graph of K against p_l is shown in Fig.4: (A) minimum of magnetic bias field, (B) maximum of magnetic bias field.

3.2 Range of frequency

The range of frequency over which the system can be tuned is given by the change in μ_e value. In the cavity with loops the range of frequency is:

$$\eta' = \sqrt{\frac{(1 - K_{\mu_e \max}^2) \mu_{e \max}}{(1 - K_{\mu_e \min}^2) \mu_{e \min}}}, \quad (5)$$

where $\mu_{e \max}$ is the maximum value of the effective permeability of the air and ferrite at the minimum bias field, and $\mu_{e \min}$ is the minimum value of the effective permeability at the maximum bias field, $K_{\mu_{e \max}}$ is the maximum value of the coupling coefficient at the minimum bias field, and $K_{\mu_{e \min}}$ is the minimum value of the coupling coefficient at the maximum bias field.

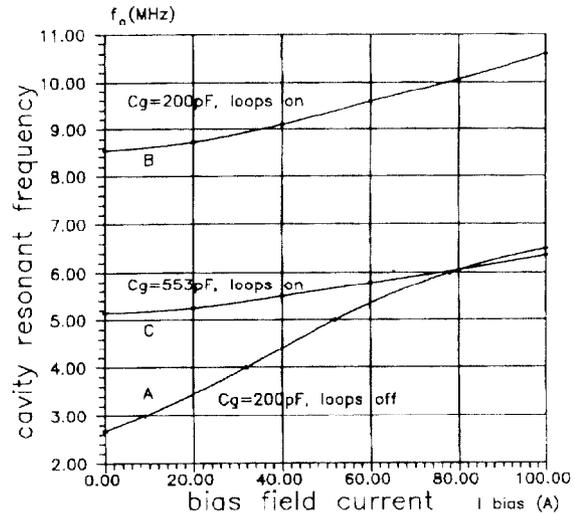


Fig.5 Cavity resonant frequency as function of the bias field current

Figure 5 shows the cavity resonant frequency as function of the bias field current: (A) curve is status of U-70 cavity without loops, (B) curve is when the loops are inserted into the cavity, (C) curve is for the cavity with inserted loops and the capacitance of the accelerating gap increased.

3.3 Cavity shunt impedance

The value of cavity shunt impedance was measured on the test cavity with using two methods. In first method the

resonant frequency and quality of the cavity were measured then the shunt impedance (R_s) was calculated. The measured parameters for resonant frequency $f_0 = 5.5$ MHz are listed in table 1.

Table 1

cavity	$C_g(pF)$	Q	$R_s(k\Omega)$
without loops	200	50	7,20
with loops	553	110	5,75

The beam simulation as in [5] is used in second method. Measured shunt impedance for resonant frequency $f_0 = 5.5$ MHz are listed in table 2.

Table 2

cavity	$C_g(pF)$	$R_s(k\Omega)$
without loops	200	6,90
with loops	553	5,23

The experiments used the design of the loops described above. From the tables one can see that the shunt impedance for the same resonant frequency decreases in the cavity with loops against the cavity without loops.

3.4 Power dissipation

The power dissipation will be added from dissipation in the ferrite $P_{ferrite}$ and loops P_{loops} .

$$P' = P_{ferrite} + P_{loops} \quad (6)$$

For the resonant frequency $f_0 = 5.5$ MHz, the shunt impedance $R_s \simeq 5.5$ k Ω the power dissipation in the cavity with loops is $P' \simeq 9$ kW at the peak RF voltage $V_g = 10$ kV. Where dissipation in the ferrite is $P_{ferrite} \simeq 7$ kW and dissipation in loops is $P_{loops} \simeq 2$ kW.

4 CONCLUSIONS

Briefly, the results of the work are:

- decrease of the equivalent value of the cavity inductance by about a factor of 10,
- increase of the equivalent value of the cavity capacitance for the main frequency by about a factor of 2.7,
- increase of the equivalent value of the cavity capacitance for high harmonics of the beam by about a factor of 5,
- decrease of the shunt impedance of the cavity by about 20%,
- increase of the cavity quality by about a factor of 2.2,
- decrease of the frequency range by about a factor of 2 for the old range magnetic bias field ($f_0 = 5.15 \div 6.36$ MHz),
- the cost of design is very low.

One cavity with loops was tested also for the high beam intensity and we could see some decrease the transient beam loading effect of the accelerating cavity due to the transition energy.

5 REFERENCES

1. P.B. Wilson, "Transient beam loading in electron-positron storage rings", CERN ISR-TH/78-23 (1978).
2. O.P. Lebedev, "The second life of ferrite dominated cavities", these proceedings.
3. F. Pedersen, "Beam loading effects in the CERN PS Booster", IEEE Trans. Nuc. Sci., NS-22, 1975, p.1906.
4. H.B. Dwight, and F.W. Grover, "Some series formulas for mutual inductance of solenoids", EIE, Vol.56, p.347, March 1937.
5. Q.A. Kerns, H.W. Miller, IEEE Trans. Nucl. Sci. NS-24, No3, p.1704, 1977.