A SECOND HARMONIC IN FERRITE DOMINATED CAVITY OF U-70

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Abstract

Results of experimental test of a modernized U-70 cavity are presented. The cavity was reconstructed from fundamental to the second-harmonic one at the same geometry and type of a ferrite. The increase of tunable resonant frequency is achieved by inclusion of additional loops in RF magnetic field. The inductance of cavity was reduced by an order of magnitude with the loop design experimentally found. Our method of modernization proves to be very inexpensive.

1 INTRODUCTION

The U-70 accelerator cavity was initially designed to operate with the 100 MeV injector linac and fundamental frequency range of f_1= (2.6 - 6.1) MHz. When the 1.3 GeV injector Booster was put in action, this range has decreased to f_1= (5.5 - 6.1) MHz. The gap of frequency from 2.6 to 5.5 MHz has ceased to be used. In 1994, all the 40 (10 kV each) cavities were modernized [1]. The accelerating gap capacitance was increased by about a factor of 5, while the cavity capacitance - by more than 2.7 times, so as to decrease transient beam loading of U-70 cavity at high beam intensity [2]. The result was achieved at the expense of reducing the cavity inductance by about a factor 10 with the additional loops included in RF magnetic field [3]. A modified cavity of U-70 is shown schematically in Fig.1.

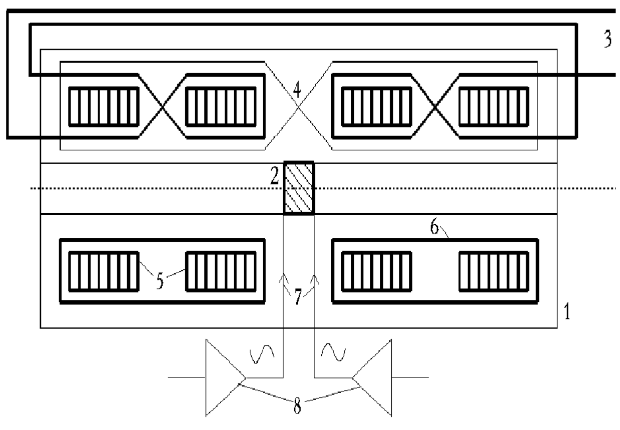

Figure: 1 A modified cavity of U-70.

Here is: 1 - wall, 2 - accelerating gap, 3 - bias field winding, 4 - loop in the figure-of-eight mode, 5 - ferrite, 6 - additional loops, 7 - transmission line, 8 - power amplifier.

2 EXPERIMENTAL STUDY OF CAVITY

During experimental studies of cavity [1], at the certain design of additional loops, a shift of the cavity RF range enabling to operate at the second harmonic f_2 = (11 - 12.2) MHz was achieved. Contrary to the previous step [1], additional copper loops with a rectangular cross section sized of 50×1 mm^2 were used. The loop length was set to 1.3 m in each half-resonator. The final tuning of the frequency range was carried out by changing a capacitor in the accelerating gap. The equivalent circuit of U-70 resonator additional loops is shown in Fig.2.

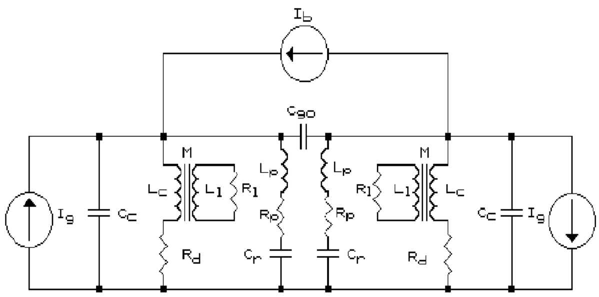

Figure: 2 The equivalent circuit of U-70 resonator with additional loops

The resonator is described by two coupled symmetric resonant circuits: L_c, C_c - inductance and capacitance of a half-resonator, L_l - loop inductance, R_l - resistance of losses in the loop, M - mutual inductance, R_d - resistance of losses in ferrite, amplifier output impedance included, C_{g0} - capacitance of accelerating gap, C_r - total capacitance of tube and additional capacitors connecting accelerating gap to transmission line, L_p - inductance of transmission line, R_p - resistance of losses in transmission line. The beam and RF amplifier are modeled as ideal current generators I_b and I_g, accordingly.

The inductance of a half-resonator under condition of $\omega L_l >> R_l$ can be written as:

$$L^1_c = (1- K^2)L_c \qquad (1)$$

where $K=M/(L_c L_l)^{1/2}$ is coupling coefficient between the cavity and additional loops. Experimental value of the coupling coefficient can be determined from measurement of two resonant frequencies: a frequency of the cavity without the loops f, and a frequency of the cavity with the loops f^1 at the same magnetic bias field. Then

$$K= (1- f^2/f^{1\,2})^{1/2}. \qquad (2)$$

Fig.3 shows the dependence of coupling coefficient K against effective magnetic permeability μ_e of the cavity.

The magnetic bias field changes from maximum to minimum.

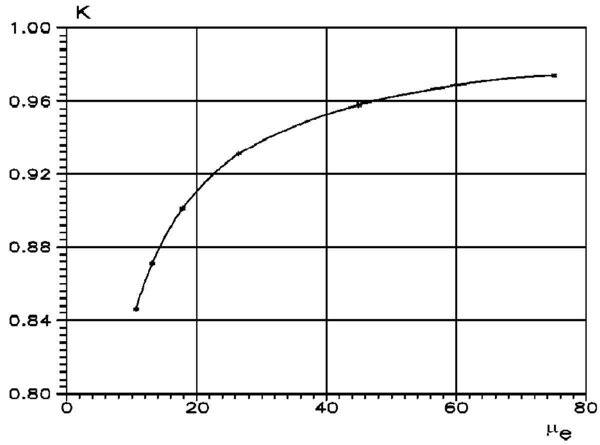

Figure: 3 Evolution of the coupling coefficient.

For our cavity design, the transmission line is 0.5 m in length and has a large inductance L_p. In the future design the inductance should be reduced. Equivalent circuit of the second-harmonic resonator reduced to its accelerating gap with the L_p is shown in Fig.4.

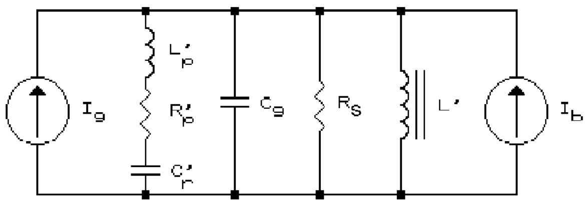

Figure: 4 Equivalent circuit of the 2nd-harmonic resonator.

Here is: C_g, L^1 are equivalent capacitance and inductance of the resonator, R_s is shunt resistance which includes losses in ferrite, additional loops and amplifier output impedance, L^1_p is equivalent inductance of transmission line, R^1_p is equivalent resistance of transmission line, C^1_r is equivalent capacitance of tubes and additional capacitors.

Parameters of the cavity were measured by various techniques. To measure capacitance C_g and inductance L^1, the cavity transmission lines were disconnected, and the capacitor of a known capacitance was added to the accelerating gap. The cavity was excited with a wire simulating the beam [4]. Resonant frequencies were measured at the same magnetic bias field, and then C_g and L^1 were calculated.

For a low-level signal the shunt resistance was evaluated with the "wire" technique. Final measurement of the loss resistance was made via excitation of the cavity by a power amplifier up to voltage of V_g =10 kV in the accelerating gap. Quality factor Q of the cavity and the shunt impedance were defined. For the operating frequency range from 10.9 to 12.5 MHz the quality factor Q was changed from 43 to 35, and shunt impedance R_s - from 3.1 to 2.4 kOhm.

Equivalent inductance of the transmission line L^1_p was defined. The frequency of a harmful cavity HOM resonance at 34.8 MHz was detected during the testing. It was caused by design elements L^1_p, C^1_r, C_g. The quality factor of cavity HOM resonance was lower than 5. Cures against such a resonance are well known [5].

Parameters of cavity at f_2 = 11 MHz for the bias field current I_f = 19 A were as follows: C_g = 125 pF, L^1 = 1 μH, C^1_r = 70 pF, L^1_p = 0.5 μH, R_s = 3 kOhm.

Fig.5 shows (1) the RF range for main frequency of a U-70 cavity after modification, (2) and the second harmonic in a test cavity at the same bias field current.

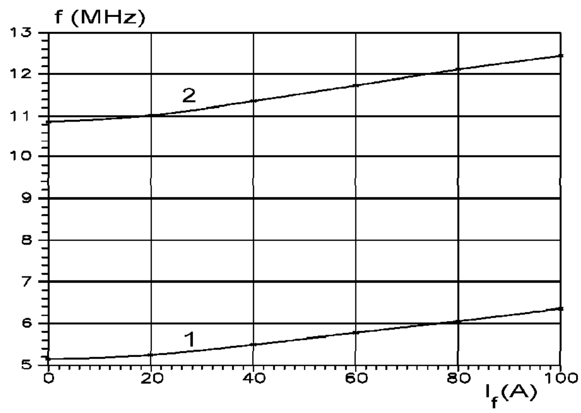

Figure: 5 Cavity resonant frequency versus of the bias field current.

For the peak RF voltage V_g = 10 kV across the accelerating gap, power dissipation of the second-harmonic cavity was 21 kW at maximum. 90% of this power was lost in the ferrite of 300NN type which was chosen to operate in frequency range of (2.6-6.1) MHz [6]. Given the same voltage across the accelerating gap, power dissipation in the fundamental cavity is 10 kW at maximum. At V_g = 7 kV, the second-harmonic cavity would work without changes in the air cooling system design.

CONCLUSIONS

- It is shown how to make the second-harmonic resonator of the existing U-70 cavities.
- Expenses of such a cavity modernization are reduced to minimum.
- The experience achieved can be used to modernize the RF cavities employed in other accelerators.

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