COARSE AND FINE TUNERS FOR THE CERN PS 40 MHZ BUNCHER CAVITY

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Abstract

A 40 MHz cavity has been constructed at CERN as part of the PS upgrade program for injection into LHC. To compensate for the variable capacitive power coupling and mechanical tolerance during fabrication, a coarse tuner has been envisaged to correct the resonant frequency of the PS 40 MHz cavity. This consists of a shorted loop inside the cavity and by rotating the loop, the magnetic coupling to the cavity can be varied and hence a coarse tuning is obtained. The coarse tuner can not be changed when the cavity is in vacuum. The fine tuner is to compensate for slow variation of resonant frequency of the cavity due to temperature and pressure variation. The tuner employs a variable capacitor as the tuning element. It is connected to a loop inside the cavity via a ceramic window and a rigid transmission line of suitable length. The desired tuning range of the coarse tuner is 1% and the fine tuner is 0.5 %. The coarse tuner has been designed and tested at TRIUMF on a full scale wooden model of the CERN cavity. The fine tuner was designed using PSPICE with the same loop as the coarse tuner. This tuner has been constructed at CERN and also installed in the cavity. Excellent agreement was found between the predicted and the measured tuning ranges of both the tuners on the 40 MHz CERN cavity.

1 INTRODUCTION

A 40 MHz cavity has been built at CERN for LHC injection. The cavity has been recently installed in the PS and a nominal gap voltage of 300 kV has been attained [1]. The cavity is equipped with inductively coupled tuners to provide coarse and fine tuning. A coarse tuner is required to compensate for the mechanical tolerance during fabrication and the capacitive loading of the power coupler. The fine tuner is in the form of a mechanical servo tuner for correcting the slow varying frequency change of the 40 MHz cavity due to temperature and pressure variation. The coarse tuner was designed at TRIUMF on a full scale copper lined wooden model of the CERN cavity [2]. The fine tuner was designed with PSPICE and built at CERN.

2 THEORY

The de-tuning of a resonant cavity with a coupled loop is outlined in the following section. In figure 1, the resonant cavity is represented in a series equivalent circuit, where L_2 and C_2 are the equivalent inductance and the capacitance of a resonant cavity and r_2 is the series equivalent resistance. If L_1 is the self inductance of the loop coupled to the cavity and Z_l is a load terminating the loop, as shown in figure 1, then the impedance coupled to the cavity [3], is given by

$Z_c = (\omega M)^2 /(Z_l + j\omega L_1)$

where M = mutual inductance and is related to the coupling coefficient k by : $M = k\sqrt{L_1 L_2}$

The resonant frequency ω_c and quality factor Q_c of the coupled circuit is given by

$\omega_c = 1/\sqrt{L_{eff}C_2}$ and $Q_c = \omega_c L_{eff}/ r_2$

where $L_{eff} = L_2(1- k^2/(1+ Z_l/ j\omega L_1))$

This equation becomes the basis of the tuners discussed in this paper.

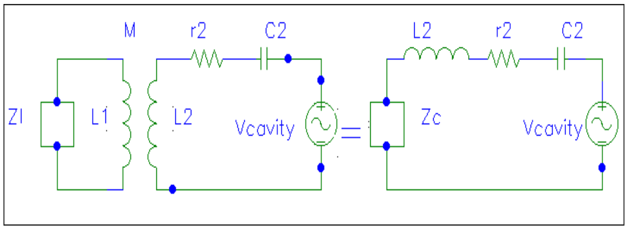

Figure 1: Equivalent circuit of cavity-loop coupled system.

case 1: when $Z_l = 0$ i.e. the loop L_1 is short circuited
$L_{eff} = L_2(1-k^2)$

case 2: when $Z_l = \infty$ i.e. the loop is open circuited
$L_{eff} = L_2$

If Δf is the frequency shift from open loop to short-circuited loop
then $\Delta f /f = 1/2\ k^2$

It can be also shown that $\Delta Q/Q = k^2$
where ΔQ is the change in Q value from open loop to short-circuited loop

case 3: If $Z_l = -j\omega L_1$ (i.e. the loop is terminated with a capacitance whose value $C = 1/\omega^2 L_1$) then the cavity resonance is destroyed due to series resonance of C and L1. This case must be avoided for any tuner design. It is obvious that a short circuited loop increases the resonant frequency of the cavity and decreases Q of the cavity.

3 COARSE TUNER

A short circuited loop placed inside the magnetic field of 40 MHz cavity de-tunes the cavity resonant frequency.

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If the loop with an area A is located at a radius r_o inside the cavity, the mutual inductance $M=\mu_0 A/(2\pi\, r_o)$
where $\mu_o=4\pi.10^{-7}$ henry/m
Hence $k=\mu_0 A/(2\pi\, r_o)/\sqrt{(L_1 L_2)}$
Since Δf is proportional to k^2, for a given cavity and loop position, Δf can be maximized by increasing the loop area or decreasing the self inductance. The position of the loop inside the CERN cavity was optimized with MAFIA.

Table 1: Measurements of $L_{self,}$ Δf and ΔQ for different types of loops.

Type of loop	Loop Area cm^2	Lself µH	Δ f kHz	ΔQ %
circular loop, 34cm ϕ 2.1 mm ϕ tube	907	1.16	152	16.2
circular loop, 34cm ϕ 6.35 mm ϕ tube	907	0.870	194	8.5
octagonal loop 30 cm mean ϕ 33 mm ϕ tube	710	0.48	240	7.0
rectangular loop, 25.4 mm width strip	1100	0.79	285	10.5

Different loops were installed on the TRIUMF wooden model at the same position as mentioned above and self inductance, Δf and ΔQ were measured. Table 1 shows the results of such measurements. The loop was shorted and rotated to produce variable coupling. The variation of cavity resonant frequency and Q with loop rotated through 90 degree is shown in figure 2. 90 degree represents maximum coupling and 0 degree represents minimum coupling of magnetic flux.

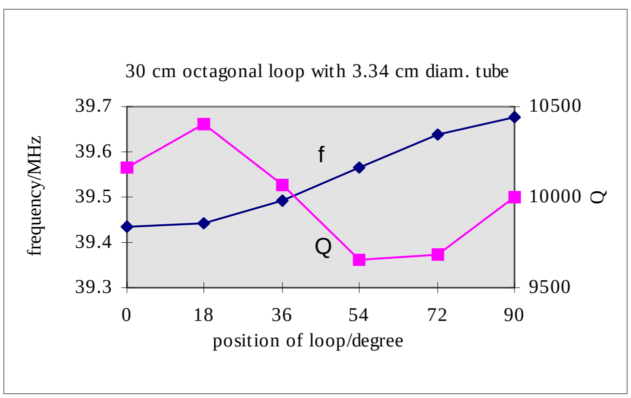

Figure 2: Variation of f and Q with coupling coefficient k

A circular loop was easier to construct than a rectangular loop and gave better mechanical stability. A circular loop of 30.5 cm diameter was constructed at CERN from a copper tube with an outer diameter 3.34 cm and was installed on the CERN cavity. It was estimated to have a self inductance of 0.44 µH and produce Δf of 0.62 % and ΔQ of 11 % for the CERN cavity. Measurement showed that with minimum coupling, the resonant frequency and Q was 39.051 MHz and 19200 respectively. With maximum coupling of the loop, the resonant frequency of the cavity changed to 39.358 MHz and Q changed to 16300. Hence frequency de-tuning was 0.78 % with a loss of Q of 15 %. This showed an excellent agreement between the measured and the expected values of the de-tuning and Q .

4 SERVO TUNER

Instead of shorting the loop inside the cavity as in the case of the coarse tuner, if a variable reactance is connected to the loop, a fine tuner can be obtained. A transmission line with suitable length and a variable capacitor forms the reactance. Figure 3 shows such a scheme of a servo tuner which has been employed for the CERN 40 MHz cavity. The rigid transmission line is 650 mm long with a characteristic impedance of 120 Ω. The loop is the similar to the one used for the coarse tuner. The ceramic window uses an existing CERN window

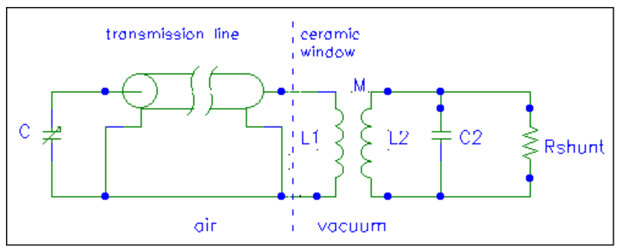

Figure 3 : Schematic of servo tuner.

which had to be modified to withstand high voltages. The variable capacitor is a COMET CV7W 300F/90 whose capacitance varies from 20 pF to 300 pF. PSPICE was used to evaluate the performance of this servo tuner [4]. Voltages at the ceramic window, and capacitor, and the associated circulating currents were calculated with a cavity gap voltage of 300 kV and is shown in figures 4 and 5. The cavity parameters are L_2=0.132 µH, C_2=121.3 pF, Rshunt=640 kΩ, Q=19400 and f=39.76 MHz. The frequency offset is 170 kHz when the capacitor is 300 pF and the tuning range is 160 kHz as the capacitor is varied from 300 pF to 20 pF. The maximum voltage across the capacitor is 55 kV. Since the voltage gradient on the air side of the window is > 30 kV/cm, the window and the rigid transmission line are pressurized to cope with the high electric gradient. The detail design and fabrication of the servo tuner was implemented at CERN on the basis of the design outlined in this section. Measurements on the servo tuner is shown in figure 6. The tuning range is large, and it has been limited by mechanical stops to use only the range where the Q is high and the window voltage is low.

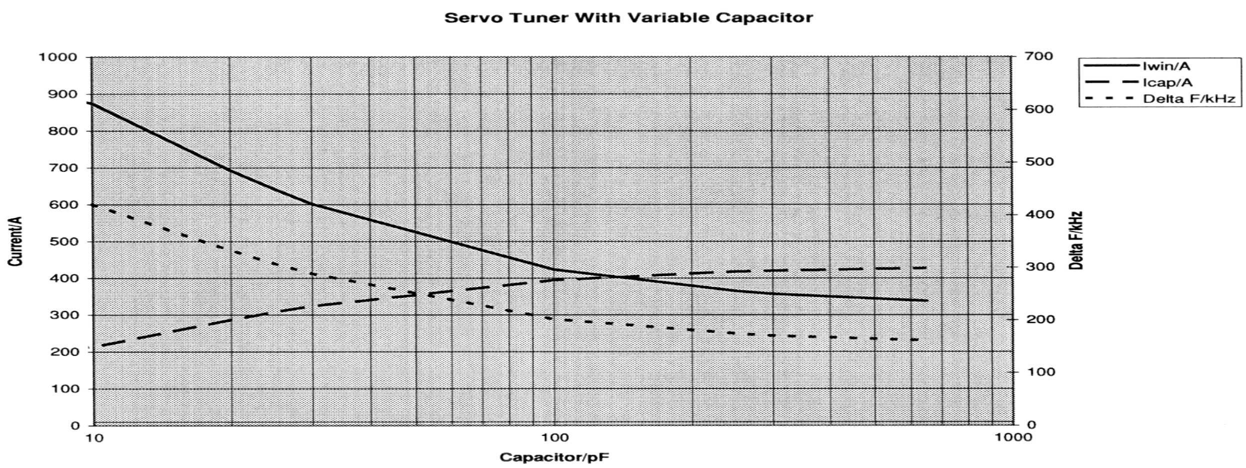

Figure 4: Current and Δf with capacitance variation

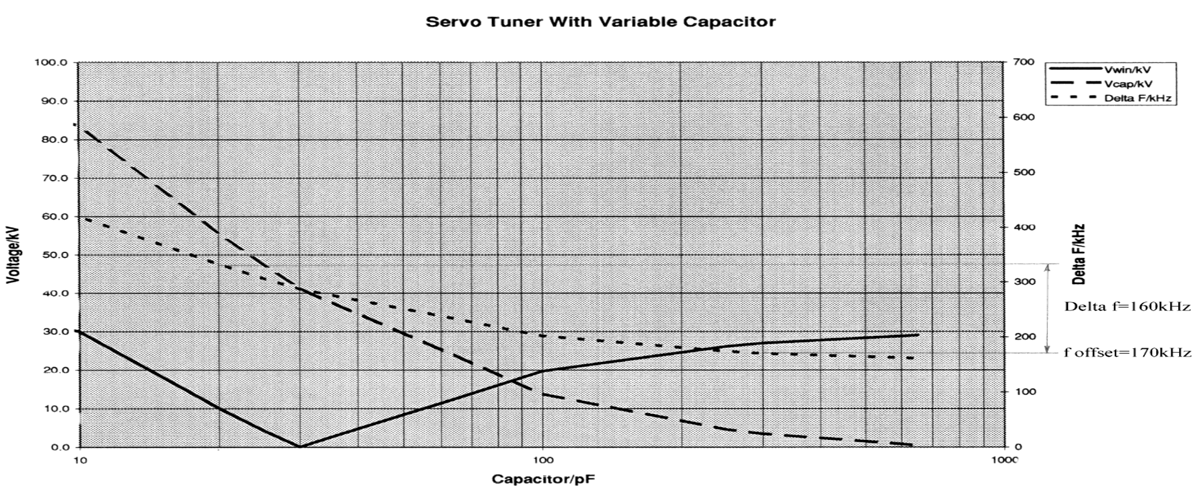

Figure5. Voltage and Δf with capacitance variation.

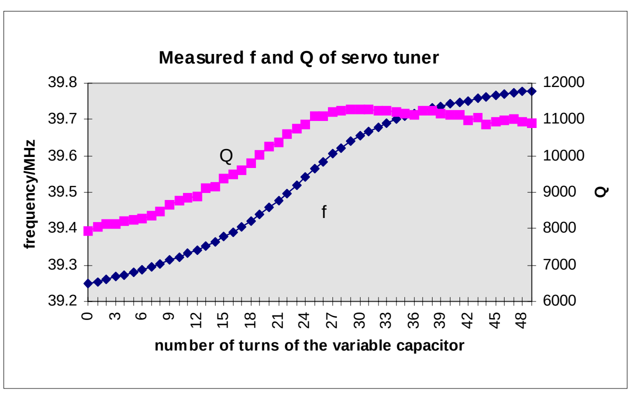

Figure 6. Resonant frequency and Q of the cavity with capacitance variation of the servo tuner.

5 ACKNOWLEDGMENTS

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REFERENCES

[1] E. Jensen, R. Garoby, E. Grier (CERN), A. K. Mitra, R.L. Poirier (TRIUMF), “The PS 40 MHz Bunching Cavity”, these Proceedings.

[2] E. Jensen, R. Hohbach, A.K. Mitra, R.L. Poirier, “Higher order mode damping of the CERN PS 40 MHz cavity” , Proc. Of the 5th EPAC Conference, Sitges, 1996.

[3] R.M. Hutcheon, “Modeling Studies of PETRA II Cavity Frequency Tuner: A Comparison of Resonant/Non-Resonant Perpendicular Biased External Ferrite Loaded Tuning Lines”, HERA-TM-23

[4] A. K. Mitra, “ Servo Tuner for 40 MHz Cavity”, PS/RF Note 96-20, 17 July 1996.