MULTI-POINT CAVITY EXCITATION

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ABSTRACT

To simplify the solution to transfer and input of high rf power in the accelerating system it is proposed to excite a cavity at several points by independent loops and power generation systems, the rf power being then summed directly in the accelerating cavity. The theoretical and experimental study of this excitation has been carried out for development of an RF system for the project "Supercyclotron"[1] with the RF power to be about 20 MW per cavity.

1. ONE-LOOP CAVITY EXCITATION.

When one deals with a high power level, it is important to minimize the power of the wave reflected from the excitation system, i.e. good matching of the loop and the excitation circuit. Let us represent the cavity and the excitation system as a system of coupled circuits (Fig.1).

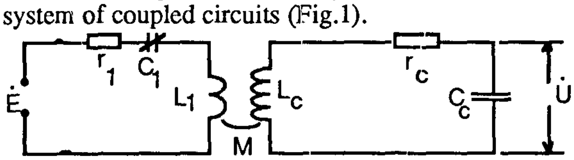

Fig. 1. RF system as the coupled circuit system.

Then the matching conditions are written as

$$x_1+x_C=0\ , \qquad (1a)$$

$$r_1+r_C=Z_o\ , \qquad (1b)$$

where r_1, x_1 are the natural active and reactive resistances of the loop, r_C, x_C are the activ and reactive components of the cavity impedance coupled into the power supply circuit, Z_o is the wave resistance of the coupling feeder. If $r_1 \ll r_C$, which is practically always so, then

$$r_C=Z_o\ , \qquad (2a)$$

$$x_1=-x_C=2\Delta f Q Z_o/f\ . \qquad (2b)$$

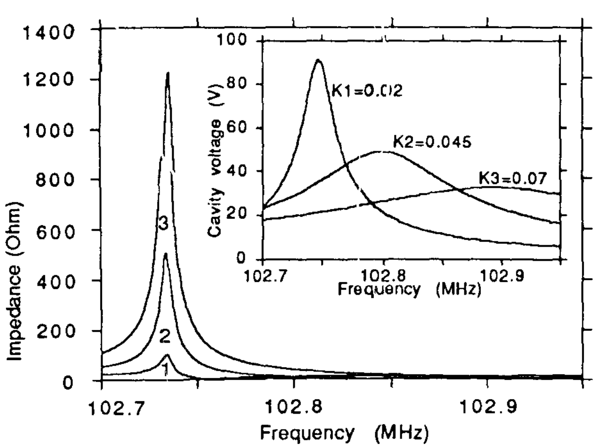

Fig. 2a. Coupling loop resonance characteristics.

Eq.1a is realized by connecting the compensating capacitor C_1 in series with the coupling loop inductor L_1 (Fig.1). Eq.1b can be realized by changing the interaction between the excitation system and the cavity.

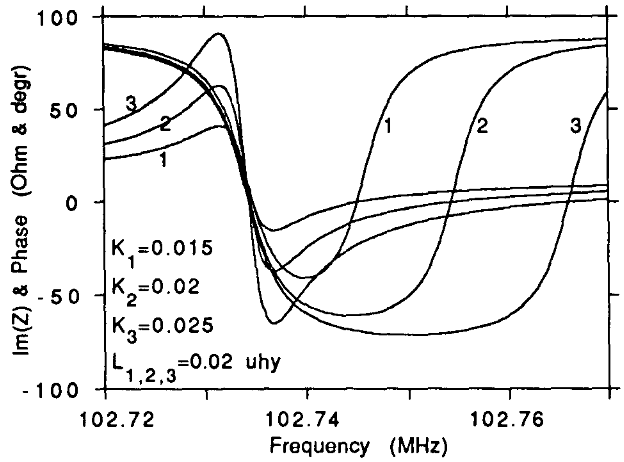

Fig. 2b. Reactance & Phase of coupling loop.

Theoretical analysis of the matching conditions was provided by means of the PSpice program.[2] Let's represent the scheme without compensating capacitor. On Fig.2a,b there are typical frequency functions of the cavity voltage and the coupling loop resonance characteristics at different coupling coefficient values. There are the cavity quality factor fall because of the increasing of the coupling system influence and the impedance grew coupled from the cavity for the generator.

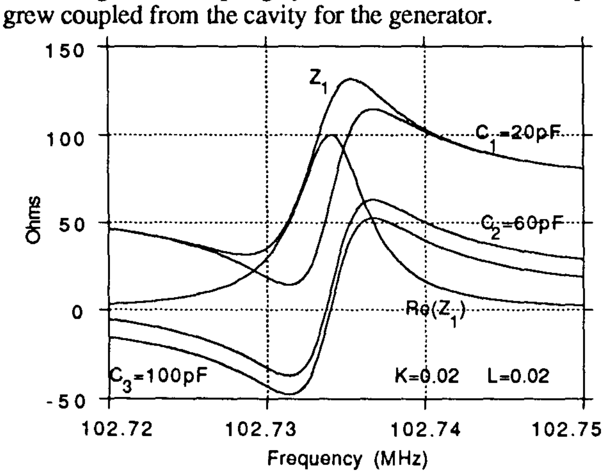

Fig. 3. Compensation of coupling system inductance.

At the presence of the compensating capacitor C_1 there is an additional parameter allowing to change coupling system characteristics. The frequency dependences of the excitation system reflecting the influence of the C_1 value - step by step compensation of the system inductance at the resonance frequency, are represented on Fig. 3.

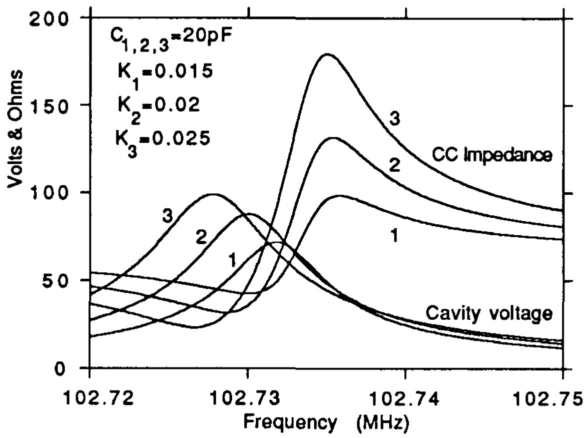

Fig. 4a.

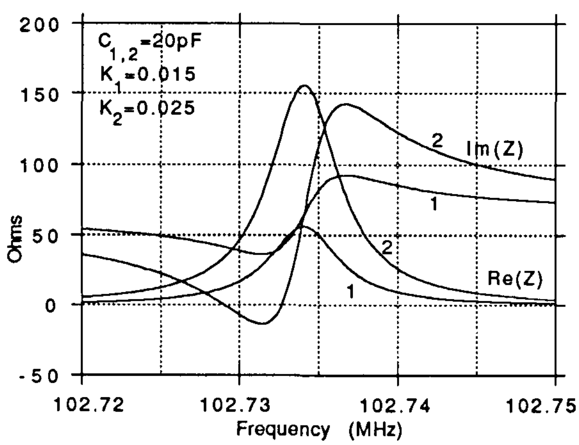

Fig. 4b. Exciting circuit frequency characteristics.

Now, the behavior of the exciting circuit frequency characteristics at the coupling change is shown on Fig.4a,b. Figure 5 demonstrates the principle of the coupling system tuning on the activ resistance 50 Ohm.

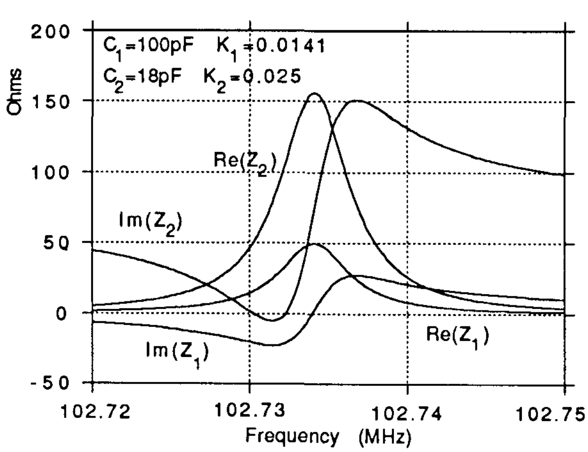

Fig. 5. Coupling system tuning.

Changing the coupling with the cavity and the compensating capacitor value it is possible to achieve the matching on different frequencies. It may be useful when the cavity frequency tune without its geometry change is needed.

The experimental unit for this study is a model of the "Supercyclotron" accelerating cavity 1/4 of full size[3-4]) with a system of excitation loops, an rf generator with five independent outputs and a measuring system for rf parameters. The loop assembly includes the loop itself and 50-Ohm section of a feeder connected to the loop. To neutralise internal inductance of the loop, a polycylindrical variable capacitor is connected in series with the internal conductor of the feeder. The loop assembly can rotate round the axis, which allows one to change the coupling of the excitation system with the cavity. The zero angle α of loop rotation corresponds to the minimal coupling with the cavity.

In Fig.6 there are typical frequency functions of the activ and reactiv resistances measured at the connector of the coupling system. The functions are measured for different loop rotation angles, which changes the value of the coupled impedance from the cavity. The capacitance of the compensating capacitor is constant C_1=5.1. It is measured in relative units (turns of the capacitor tuning screw).

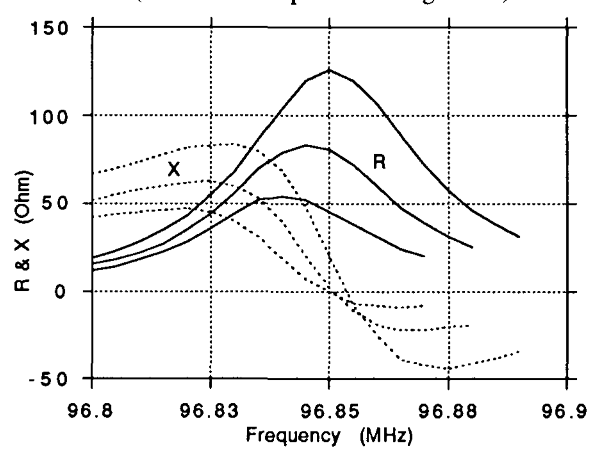

Fig. 6. Active & reactive resistances of coupling loop.

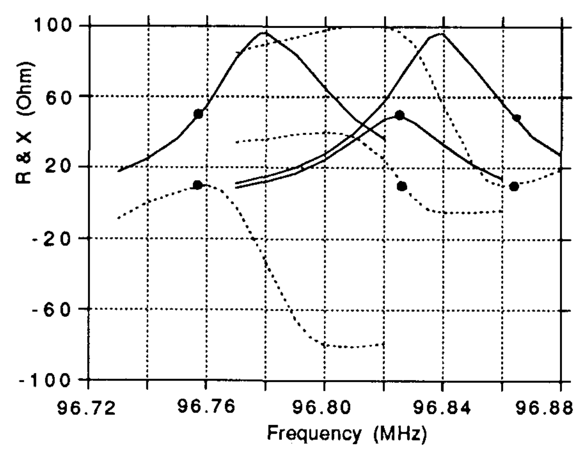

Fig. 7. Active & reactive resistances of coupling loop matched with cavity.

The system was tuned to matching by means of a vector voltmeter and a reflectometer which allowed us to check amplitudes of the incident and reflected waves in the excitation circuit and their phase difference. Tuning the compensating capacitor and the coupling with the cavity, we set the reflected wave voltage to a minimum and the phase difference to zero, which corresponded to Eq.2.

In Fig.7 there is the family of curves, each of them corresponding to the matching regime for a certain frequency at different C_l and α. The matching points are highlighted.

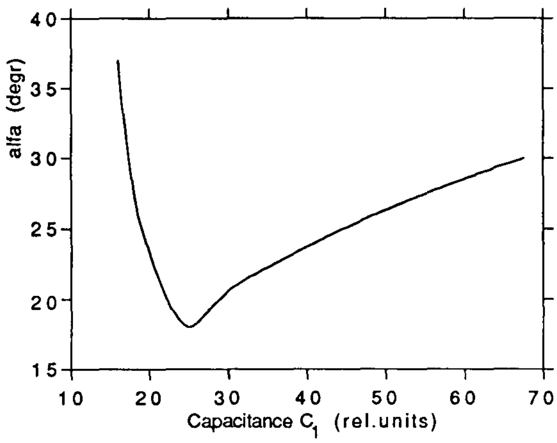

Fig. 8. Angle of loop vs compensating capacity.

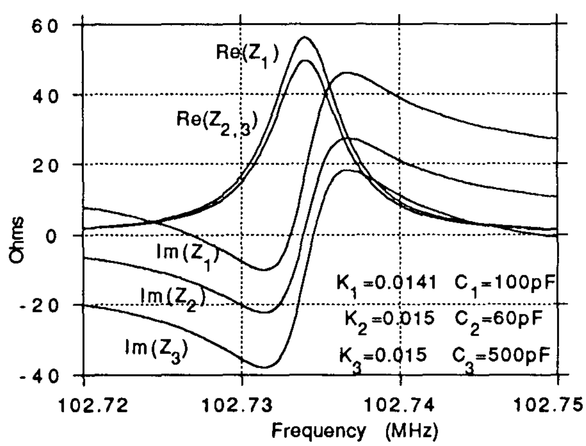

Fig. 9. Capacitance variation at the same coupling factor.

A specific feature of cavity excitation using a compensated coupling loop is that for one rotation angle α there are two values of the capacitance C_l which allow matching. On Fig.8 the experimental curve of the angle α rotation versus compensating capacitor value C_l and on Fig.9 the theoretical analysis of this effect are represented.

The explanation is as follows. At the moment when the value $C_l=C_O$ corresponds to the angle α we have an exact resonance, i.e. $x_{Cres}=x_{Lres}$, and C_l compensates only for the internal inductance of the coupling loop. If $C_l<C_O$, the loop inductance is compensated for by detuning the cavity, so that to couple an additional capacitance C_{res}. If $C_l>C_O$, an additional inductance L_{res} is coupled to compensate for the excess capacitance C_l. This is how the mechanism of the matching frequency "detuning" is determined. However, shifting the frequency in this or that direction we also change the coupled active resistance. So we have to change the interaction with the cavity, i.e. the angle α, to satisfy Eq.2a. Thus, each point of the curve in Fig.9 corresponds to a resonant characteristic in Fig.8. The frequency shift of the matching moment depends on the loop area and the compensating capacitor parameters.

Thus, one can choose the matching moment for the cavity and the excitation system in a rather wide frequency range. If Eq.2 are satisfied, the magnitude of the transfer coefficient is

$$|\dot{K}| = \frac{|\dot{U}|}{|\dot{E}|} = \frac{1}{\omega C_c \sqrt{r_c Z_0}} \qquad (3)$$

i.e. the voltage in the cavity is independent of the coupling system parameters and depends only on the cavity itself. In agreement with this, we experimentally obtained the shift of the resonant characteristic of the voltage as large as six bandwidths of the cavity model without its amplitude reduction.

2. MULTI-LOOP CAVITY EXCITATION.

To find the excitation loop area satisfying Eq.2a, we shall make use of the fact that the loop dimensions are very small as compared with the cavity dimensions and the wave length, so H=const within the loop and

$$S = \frac{\sqrt{2 r_c P}}{\omega_0 \mu_0 H \sin(\alpha)} \qquad (4)$$

where S is the loop area, P is the power applied to the cavity, α is the angle of the loop plane with the lines of the magnetic field H counted off from the position of the minimal interaction between the excitation system and the cavity.

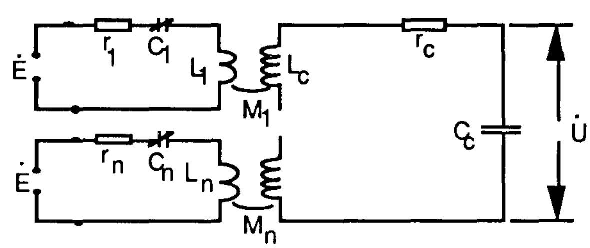

Fig.10. Simplyfied diagram of multi-loop cavity excitation.

If we have N similar loops (Fig.10), each matched to the excitation circuit at 90^O and assume that the power applied to the cavity is uniformly distributed over all excitation circuits then the rotation angle of each loop must be

$$\alpha=\arcsin(1/N^{1/2}) \qquad (5)$$

for Eq.2 to be satisfied in the case of simultaneous excitation of the cavity by all loops.

Those results were got also using PSpice. On Fig.11,12 two-loop and three-loop excitation correspondently are represented.

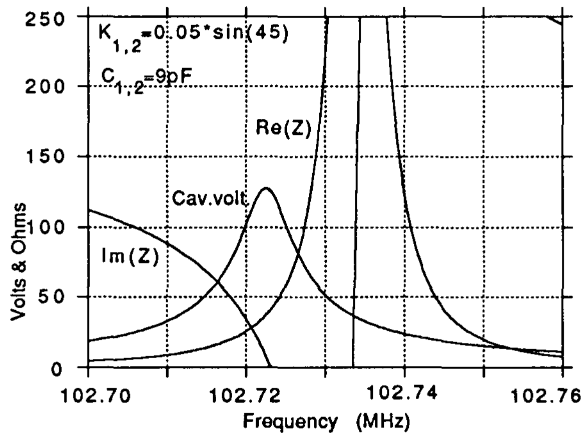

Fig. 11. Two-loop excitation.

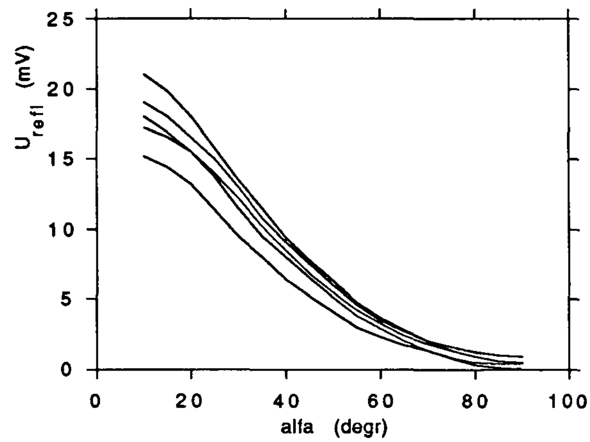

Fig. 13. Reflected wave vs loop angle.

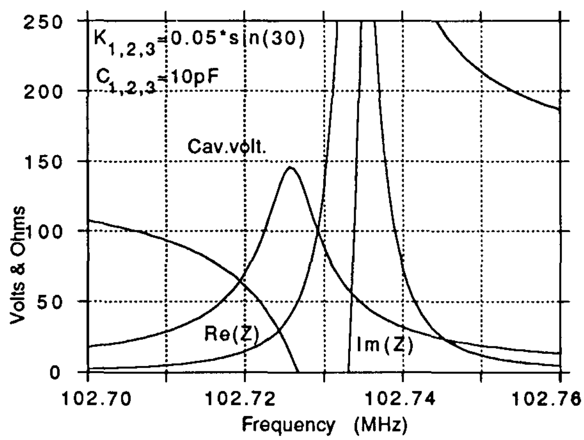

Fig. 12. Three-loop excitation.

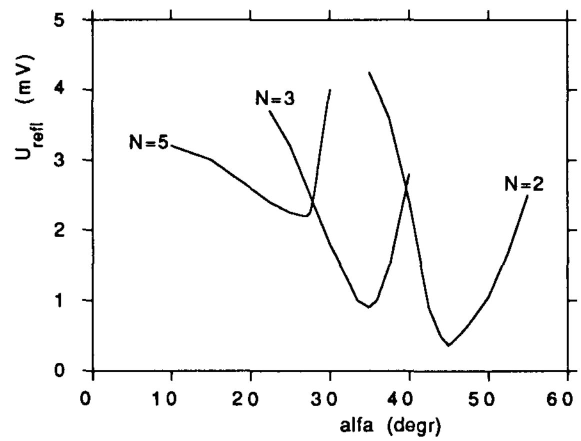

Fig. 14. Reflected wave vs angle of loops.

Showing the dependence of the reflected wave amplitude on the loop rotation angle, the experiment curves in Fig.13 characterize the results of tuning the matching of each of the five excitation channels. The non-identity of the excitation channels is seen to be 3 kHz in frequency and 5% in the reflection coefficient.

If we install several loops in the cavity, the dependence of the reflected wave amplitude on the simultaneous rotation of all loops will be as in Fig.14. The resonant voltage maximum is also shifted over the angle according to Eq.3. The tuning criterion was the maximal running wave factor in all excitation circuits. The fact that the running wave factor worsens as the number of loops increases is due to growing difficulty in tuning. Our investigations showed that the summed resonant voltage in excitation of the cavity by each loop separatly differs by 5% from the voltage in excitation by the five loops used together.

3. REFERENCES.

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4) Glazov, A.A. and Zaplatin, E.N. JINR, 9-80-46, Dubna, 1980.