LOW OUTPUT-IMPEDANCE RF SYSTEM FOR HEAVY BEAM LOADING IN PROTON SYNCHROTRON

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Abstract

The instability, which is caused by beam induced current, occurs without effective compensation in a high intensity proton synchrotron. The very low output-impedance RF system is required for this compensation. A grounded cathode scheme, having a feedback loop between plate and grid, can provide such system. The model system has been tested using the Eimac 3CW40,000H3 triode as a final tube. By choosing the appropriate resonant frequencies, the output-impedance is obtained as 30-80 ohms and the voltage gain 6-10 over the frequency range of 2.5-8.5 MHz.

1 INTRODUCTION

In a high intensity proton synchrotron, the wall current induced by the beam in an RF cavity can not be ignored against the drive current which is supplied by RF power supply and the instability occurs without proper compensation. The contribution of this beam is called a beam loading, and many analyses are investigated to avoid it. The stability of the RF system including the beam was evaluated by using the relative beam loading Y, which is the ratio of the beam current to the unloaded generator current [1]. It is implied that the small value of Y is required for stability, and the very low output-impedance RF system realises that value of Y.

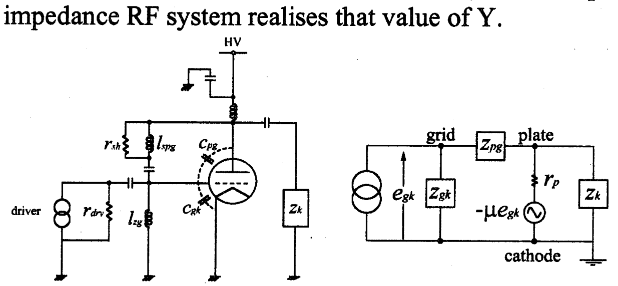

Fig. 1 Grounded cathode scheme having dual resonant circuits and the equivalent circuit.

As the system, the grounded cathode scheme, having dual resonant circuits, is able to realise a high voltage gain and the low output-impedance comparable to the cathode-follower scheme, which is well known by the low output-impedance characteristic. The one resonant circuit comprises a parallel tuned circuit between grid and cathode, and the other a feedback loop between plate and grid. Fig. 1 shows this scheme.

The output-impedance (Z_o) in the grounded cathode scheme can be expressed by

$$Z_o = \left(\frac{1}{z_{pg} + z_{gk}} + \frac{1+\mu\beta}{r_p} + \frac{1}{z_k} \right)^{-1} , \tag{1}$$

with

$$\beta = \frac{z_{gk}}{z_{pg} + z_{gk}} .$$

Where μ is the amplification factor, r_p the plate resistance of the tube, z_k the load impedance, z_{pg} the grid-plate impedance which is composed of r_{sh}, l_{spg} and c_{pg}, and z_{gk} the grid-cathode impedance which is composed of r_{drv}, l_{zg} and c_{gk}. The main term in the bracket of Eq. (1) is the second one, and then the output-impedance is approximated by

$$Z_o \approx \frac{r_p}{1+\mu\beta} . \tag{2}$$

Here, the lead inductance (l_k) in the cathode circuit in following is neglected.

l_k in Fig. 2 gives a significant contribution to the output-impedance. Eq. (1) or Eq. (2) is then modified to include the impedance between cathode and ground (z_l) that comprises l_k and the bypass capacitor (c_k) at the filament power in Fig. 2. The output-impedance including the contribution of z_l is approximately given by

$$\frac{r_p}{1+\mu\beta} + z_l \left(\frac{z_{pg} + z_{gg}}{z_{gg}} \right) . \tag{3}$$

Where, z_{gg} is the impedance between grid and ground which is composed of r_{drv}, l_{in}, l_{zg} and c_{zg}. Comparing to Eq. (2), the z_l multiplied by $(z_{pg} + z_{gg}) / z_{gg}$ increases the output-impedance.

2 SYSTEM SETUP

Fig. 2 shows the schematic views of the model RF system for the grounded cathode scheme, which has dual resonant circuits. The Eimac triode (3CW40,000H3) is used as the final tube. The dc-bias power supply feeds a bias current to keep the ferrite-loaded cavity at resonance. The relation of the resonant frequency versus bias current was measured over the frequency range of 2.5-8.5 MHz. The maximum frequency is restricted by the current limitation of the bias power-supply. The plate voltage for the tube is 6.3 KV and the quiescent current is 5.4 A. A

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Pearson model 150 monitors the cavity input current. The z_{pg} comprises a parallel resonant circuit with l_{spg}, r_{sh}, a plate-grid capacitance (c_{pg}) and stray capacitance (c_{st}) of l_{spg}, and the z_{gk} with l_{zg}, r_{drv}, a grid-cathode capacitance (c_{gk}) and stray capacitance (c_{zg}) of l_{zg}. The resonant frequencies of z_{pg} and z_{gk} are set near to the lowest frequency of the frequency range. The parameters are summarised in Table 1.

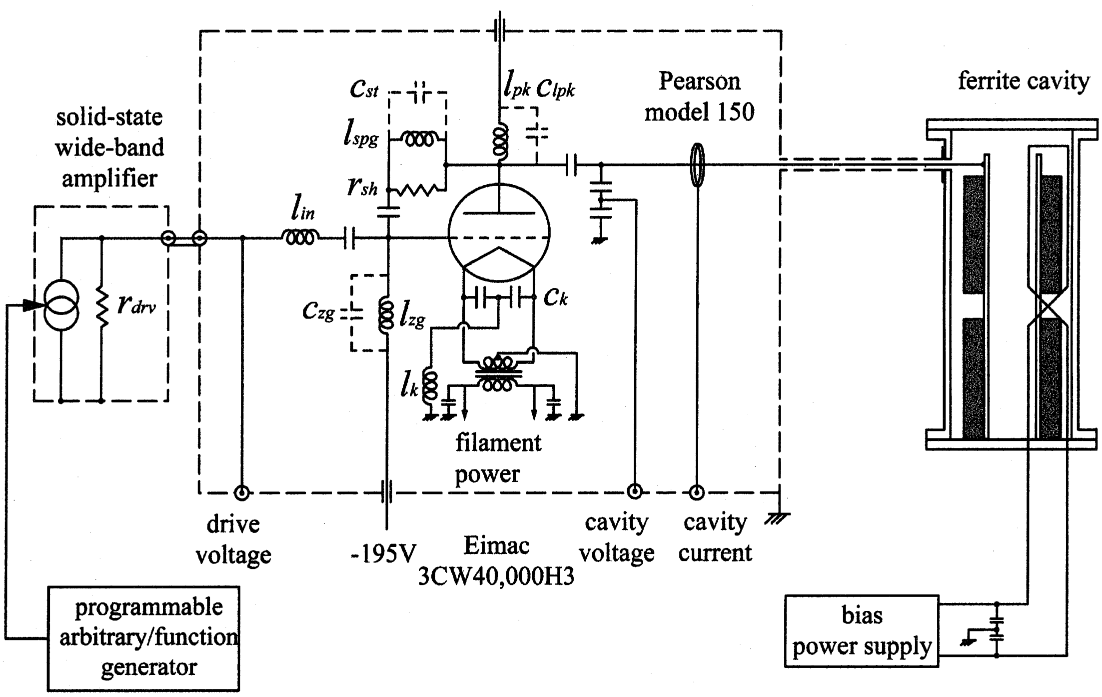

Fig. 2 Model RF system for the grounded cathode scheme, which has dual resonant circuits.

Table 1 Parameters of the model RF system.

μ		18
r_p	(Ω)	310
c_{gk}	(pF)	75.7
c_{pg}	(pF)	50.8
l_{zg}	(μH)	41.3
c_{zg}	(pF)	27.5
r_{drv}	(Ω)	50
l_{spg}	(μH)	50.7
r_{sh}	(Ω)	428
c_{st}	(pF)	28.5
c_k	(nF)	120
l_k	(μH)	0.3
l_{in}	(μH)	0.5
cavity gap capacitance c_{gap}	(pF)	273
cavity inductance l_{cav}	(μH)	1.3-15
cavity shunt resistance r_{cav}	(Ω)	500

3 EXPERIMENTAL RESULTS

3.1 Output-impedance

A Hewlett Packard 4195A network/spectrum analyser is used to measure the output-impedance. The probe is connected to the output terminal of RF system. As the output-impedance is dependent on the β in Eq. (1), various measurements for the shunt resistor (r_{drv}) of 50, 150, and 300 Ω are performed. The measurements and calculations at the resonant cavity frequency are compared in Fig. 3.

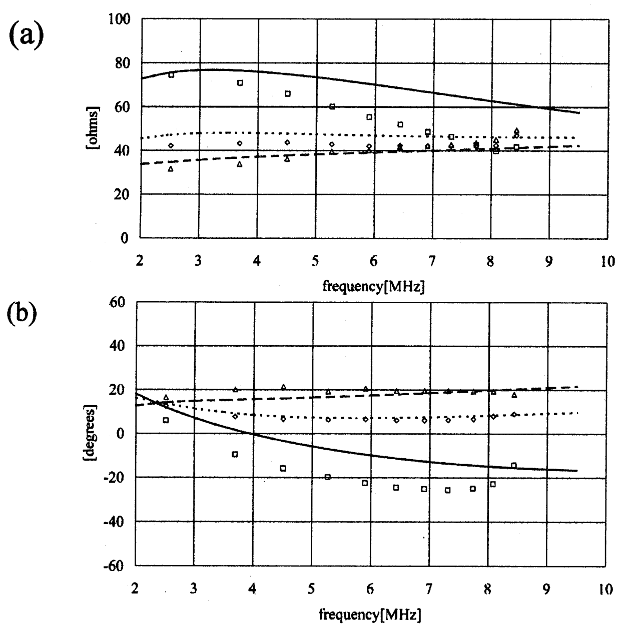

Fig. 3 Output-impedance of the grounded cathode scheme at the shunt resistor (r_{drv}) of 50 (square), 150 (lozenge), and 300 (triangle) Ω; (a) magnitude and (b) phase. Measurements are compared to calculations denoted by solid, dotted and dashed lines, respectively.

For r_{drv} of 300 Ω, Absolute value of the first term in Eq. (3) and $(z_{pg} + z_{gg}) / z_{gg}$, which is the coefficient of z_l, are 36.8-34.7 Ω and 2.53-1.53 over the frequency range of 2-10 MHz, respectively. Therefor, the second term in Eq. (3) occupies 20-60 percent of output-impedance.

3.2 Voltage gain

Fig. 4 shows the voltage gain of the driver to the cavity gap under the gap voltage of 530-820 V. At a higher frequency, the gain decreases with frequency due to l_{in} that is the lead inductance of input terminal of RF system in Fig. 2.

In the calculations, a peaking structure can be seen. It is explained mainly in terms of the series resonance, which is composed of the l_{in} + l_k and the plate-grid capacitance, where the capacitance becomes $(1+\mu)$-times larger by the Miller effect. Because it is surmised that the cavity shunt resistance (r_{cav}) decreases with frequency gradually, there is no peaking structure in the measurement.

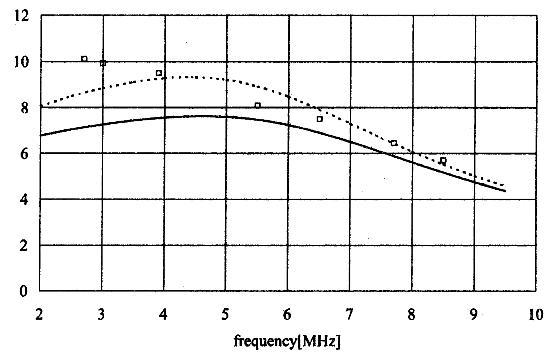

Fig. 4 Voltage gain of the driver to the cavity gap. Square shows the measurements under the gap voltage of 530-820 V. The solid and dotted lines show the calculations at 500 and 1500 Ω of r_{cav}, respectively.

4 DISCUSSION AND CONCLUSIONS

Low impedance RF system with high voltage gain was tested in the frequency range of 2.5-8.5 MHz. The model system comprises a 1 KW solid-state amplifier and a 40 KW triode as a final amplifier. The grounded cathode scheme, having dual resonant circuits, can provide the very low output-impedance RF system. Consequently, the output-impedance is obtained as 30-80 ohms and the voltage gain 6-10.

We have studies with much higher power tube for future applications. The triode whose maximum plate dissipation is 240 kW is used as a final amplifier. As the expectation, the output-impedance is 21-27 ohms and the voltage gain is 25-60 over the frequency range of 2.7-6.2 MHz. Regarding output-impedance, it is comparable with that obtained by cathode-follower beam buncher in the Proton Storage Ring [2].

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