STUDY OF TWO CAVITIES ACCELERATING MODULE AT SR SOURCE SIBERIA-2

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Abstract

SR source Siberia-2 RF system includes an accelerating module consisting of two 181 MHz cavities powered by one amplifier. Some problem occurred now is the accelerating voltage instability under high beam currents conditions. The phase shift between the voltages at cavities causes the asymmetry in beam loading and detuning of cavities. To study the performances of accelerating module, the analytical description has been developed. The whole system can be characterized by seven parameters. These base parameters give the relations of voltages and currents in system. Measurements determine the real values of the base parameters. Set of non linear equations received can be reduced to the voltages and currents in system as the functions of beam current and energy. The results can be applied to injection and ramping in Siberia-2.

ANALYTICAL DESCRIPTION

Accelerating Cavity with Beam

Accelerating cavity with beam can be described by four parameters (see Fig. 1): cavity impedance Z, reflectivity Γ at any cross section of feeder and two coefficients k and m for the same cross section.

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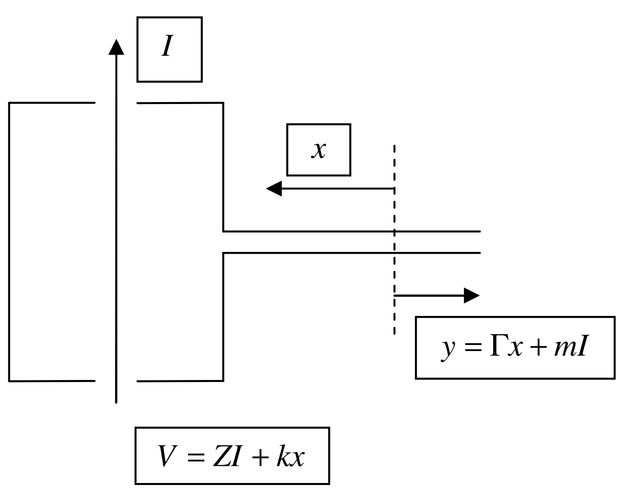

Figure 1: Accelerating cavity with beam (I - the main harmonic of the beam current, V - complex amplitude of accelerating voltage, x and y - complex amplitudes of normalized waves in feeder).

The energy conservation requirements for any beam current harmonic I and any wave x from generator give the relations:

$$4|m| = k\,,$$
$$-2|m|^2 = \frac{|Z|^2}{R_{sh}} + \operatorname{Re} Z\,, \tag{1}$$
$$-2m^*\Gamma = k\left(\frac{Z^*}{R_{sh}} + \frac{1}{2}\right),$$

where R_{sh} is the shunt impedance of the cavity.

For two fields exited in cavity by beam and by generator, Lorenzt lemma gives additional to (1) relation:

$$-4m = k\,. \tag{2}$$

The expression for impedance Z can bee written in conventional form:

$$Z = -\frac{R_{sh}}{1 + g + i\eta}\,, \tag{3}$$

where g is the cavity coupling with feeder and η is the cavity detuning. The system (1), (2) and (3) can be reduced to expressions for coefficients k and m:

$$k = \frac{k_0}{|k_0|}\sqrt{8R_{sh}g}\,\frac{1}{1 + g + i\eta}\,,$$
$$m = \frac{m_0}{|m_0|}\sqrt{\frac{R_{sh}g}{2}}\,\frac{1}{1 + g + i\eta}\,.$$

The phase factors

$$\frac{k_0}{|k_0|} = -\frac{m_0}{|m_0|}$$

depend on position of equivalent representation cross section in feeder.

Simpler cavity description (see Fig. 2) can be reached by using the beam loading parameter

$$M = \frac{IR_{sh}}{V}\,. \tag{4}$$

It can be seen that real part of this parameter

$$\operatorname{Re} M = \frac{\frac{\operatorname{Re} IV^*}{2}}{\frac{|V|^2}{2R_{sh}}} = \frac{P_{beam}}{P_{walls}}$$

and imaginary part $\operatorname{Im} M$ presents the cavity detuning by beam. At Fig. 2,

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$$k_b = \frac{k_0}{|k_0|}\frac{1}{1+g+i\eta+M}\sqrt{8R_{sh}g}\ ,$$
$$\Gamma_b = -\frac{k_0}{|k_0|}\frac{m_0}{|m_0|}\frac{g-1-i\eta-M}{1+g+i\eta+M} \qquad (5)$$

and feeder current

$$I_f = V\sqrt{\frac{1}{4Z_0R_{sh}g}}\frac{|k_0|}{k_0}(1+g+i\eta+M)\left(1+\frac{k_0}{|k_0|}\frac{m_0}{|m_0|}\frac{g-1-i\eta-M}{1+g+i\eta+M}\right).$$

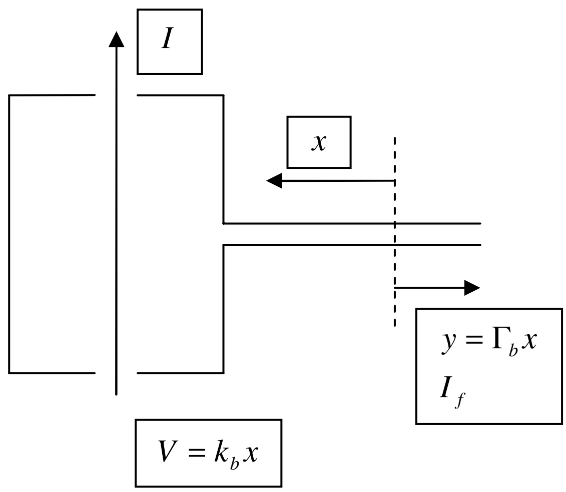

Figure 2: Accelerating cavity with beam.

To control the total cavity detuning by tuner (η) and by beam ($\operatorname{Im} M$), the phase Ψ' of accelerating voltage V to feeder current I_f is used. For feeder cross section with $\frac{k_0}{|k_0|} = e^{i\xi_0}$, the relation between accelerating voltage and feeder current is given by

$$I_f = V\sqrt{\frac{1}{Z_0R_{sh}g}}\cos\xi_o(1+\operatorname{Re} M)(1-itg\Psi'). \qquad (6)$$

Two Cavities Accelerating Module

Two cavities accelerating module consists of two cavities powered by one generator (see Fig. 3). Rectangular waveguide from generator is splitting on two coaxial feeders. Cavities are spaced along the beam orbit at RF wave length. Cavities differ by input power loops orientations – the loop in cavity number 2 is turned opposite the loop orientation in cavity 1. This difference is compensated in module construction by length of coaxial feeders. The feeder to cavity number 1 is half RF wave length longer then the feeder to the cavity 2.

For analytical system description, the formalism of normalized waves and scattering matrix can be used. At Fig. 3, the coaxial feeder cross sections 2 and 4 correspond to arrangements of loops for feeder current measurements. The cross section 3 is symmetrical to cross section 2 with respect to the rectangular waveguide. As it was mentioned above, the section 4 must be distant from section 3 half RF wave length to compensate the different input power loops orientation in cavities.

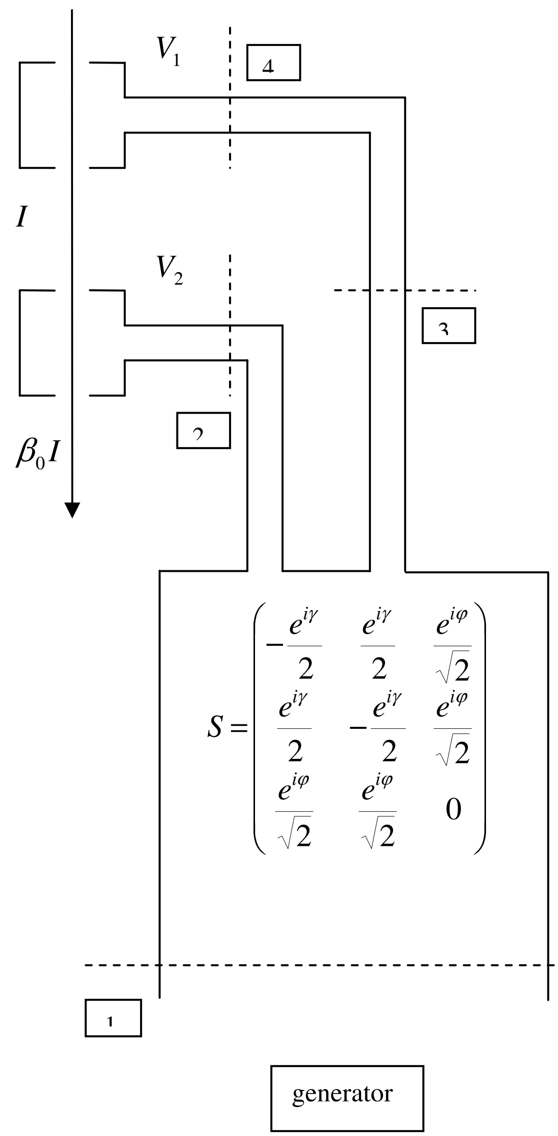

Figure 3: Two cavities accelerating module (I and $\beta_0 I$ - the main harmonic of beam current at cavities).

The cross sections 1, 2 and 3 bound the part of system that can be represented as symmetrical six-pole with scattering matrix S (see Fig. 3). The crucial parameter of two cavities module concerned is the phase factor $e^{i\gamma}$.

In system including two cavities, all expressions for one cavity must be written with index. So, the expression (6) must by written as

$$I_{f1} = V_1\sqrt{\frac{1}{Z_0R_{sh1}g_1}}\cos\xi_{o1}(1+\operatorname{Re} M_1)(1-itg\Psi_1'),$$

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$$I_{f2} = -V_2 \sqrt{\frac{1}{Z_0 R_{sh2} g_2}} \cos\xi_{o2} (1 + \mathrm{Re} M_2)(1 - itg\Psi_2').$$

These expressions give the feeder currents in cross sections 4 and 2 respectively.

Within the frame of the scattering matrix formalism, the set of equations can be received for the normalized waves in the two cavities module. This set gives the ratio of the accelerating voltage complex amplitudes V_1 and V_2 at cavities:

$$\frac{V_1}{V_2} = \frac{\sqrt{R_{sh1} g_1}}{\sqrt{R_{sh2} g_2}} \cdot \frac{g_2 \dfrac{\cos\frac{\gamma}{2}}{\cos\xi_{02}} - i(1 + \mathrm{Re} M_2)\left(1 - i\tan\Psi_2'\right)\sin\left(\xi_{02} + \frac{\gamma}{2}\right)}{g_1 \dfrac{\cos\left(\frac{\gamma}{2} - h\right)}{\cos\xi_{01}} - i(1 + \mathrm{Re} M_1)\left(1 - i\tan\Psi_1'\right)\sin\left(\xi_{01} + \frac{\gamma}{2} - h\right)}.$$

The right side of the equality above contains the construction errors ξ_{01} and ξ_{02} of the feeder current measuring loops positions and the error h of the coaxial feeder length from section 3 to section 4 (see Fig. 3). If these errors can be assumed to be negligible the role of the dominant module parameter γ is evident. For the case $\cos(\gamma/2) = 0$, the ratio of voltages at cavities is changing with beam loading and cavities detuning but the ratio of feeder currents remains constant. For the other case $\sin(\gamma/2) = 0$, the ratio of the voltages at cavities remains constant but the ratio of feeder currents is changing.

MEASUREMENTS AND CALCULATIONS

Experimental Study of Module Parameters

The two cavities module can be characterized definitely by seven parameters: cavities shunt impedances R_{shi} and couplings g_i ($i = 1,2$), construction errors ξ_{0i}, h and the dominant parameter of system γ. These parameters are evaluated from experimental functions without the beam

$$I_{f1} = V_1 \sqrt{\frac{1}{Z_0 R_{sh1} g_1}} \cos\xi_{o1} (1 - itg\Psi_1'),$$

$$I_{f2} = -V_2 \sqrt{\frac{1}{Z_0 R_{sh2} g_2}} \cos\xi_{o2} (1 - itg\Psi_2'),$$

$$\frac{V_1}{V_2} = \frac{\sqrt{R_{sh1} g_1}}{\sqrt{R_{sh2} g_2}} \cdot \frac{g_2 \dfrac{\cos\frac{\gamma}{2}}{\cos\xi_{02}} - i\left(1 - i\tan\Psi_2'\right)\sin\left(\xi_{02} + \frac{\gamma}{2}\right)}{g_1 \dfrac{\cos\left(\frac{\gamma}{2} - h\right)}{\cos\xi_{01}} - i\left(1 - i\tan\Psi_1'\right)\sin\left(\xi_{01} + \frac{\gamma}{2} - h\right)}.$$

The Accelerating Voltage Stabilized Mode

In this mode, the total accelerating voltage of two cavities module is stabilized to any desirable value V_o in phase and amplitude:

$$V_1 + \beta_0^* V_2 = V_0.$$

To calculate complex amplitudes V_1 and V_2, this linear equality can be considered as the first equation. As the second equation, the essential non linear equality for ratio V_1/V_2 in the two cavities module is used (see above). For example, the typical results of calculations are presented in Table1. It is seen that the ratio of voltages at cavities is changing with the beam storage.

Table 1: Injection at Siberia-2 (total voltage at two cavities module 200 kV, $\Psi_1 = \Psi_2 = -78^0$)

I_b, A	$\lvert V_1 \rvert$, kV	$\lvert V_2 \rvert$, kV	$\arg(V_1/\beta_0^* V_2)$
0.00	87	114	4.74^0
0.02	98	102	4.53^0
0.04	108	93	4.35^0
0.06	116	85	4.18^0
0.08	123	78	4.05^0
0.10	129	71	3.93^0
0.012	135	66	3.84^0
0.014	140	60	3.76^0

To compensate the disproportion of voltages at cavities, the different detuning of cavities is introduced (Tab. 2).

Table 2: Injection at Siberia-2 (total voltage at two cavities module 200 kV, $\Psi_1 = -78^0$, $\Psi_2 = -75^0$)

I_b, A	$\lvert V_1 \rvert$, kV	$\lvert V_2 \rvert$, kV	$\arg(V_1/\beta_0^* V_2)$
0.00	77	123	2.52^0
0.02	83	117	2.30^0
0.04	88	112	2.18^0
0.06	92	108	2.08^0
0.08	96	104	1.98^0
0.10	99	101	1.90^0
0.012	102	98	1.82^0
0.014	104	96	1.76^0

CONCLUSIONS

- Analytical description developed can be used efficiently for cavities based complex accelerating RF systems.
- At Siberia-2, the two cavities module is characterized definitely by seven parameters. These parameters are evaluated experimentally.
- Analytical description and calculations reveal features of two cavities module modes.
- Two cavities module is exploited successfully at Sberia-2.

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