PROTOTYPE OF THE S-BAND BUNCHER FOR THE VEPP-5 PREINJECTOR

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INTRODUCTION

The buncher system of the VEPP-5 preinjector consists of two subharmonic cavities at operating frequency of 180 MHz (the 16-th subharmonic of the operating frequency f_o = 2856 MHz), S-band buncher, and the first accelerating structure with the operating frequency of 2856 MHz [1].

Numerical simulations of the buncher system shows that space charge factor has a great influence on the beam dynamics, and interaction between the bunch and RF channel units is of a complicated character. Under these circumstances the buncher system should provide an ability to tune its elements during the system setup.

A possible variant of the S-band buncher with the operating frequency of 2856 MHz is presented in the paper. It is our belief that this buncher can provide the system's adaptability and required bunch parameters at the input of the first accelerating structure. The couplers of the accelerating structure which have already been produced are used as main elements of the buncher, that allowed us to decrease the manufacturing time and total cost of the whole system.

BUNCHER DESIGN

The S-band buncher was designed as a three-coupled cavity structure. The input coupler of the buncher is connected with the RF power source (5045 klystron) through the SLED system and the 25 dB directional coupler [1]. The buncher is coupled with the rectangular waveguide by the inductive iris.

The interaction between the electrons and electromagnetic field occurs within the first and third resonators (accelerating cavities) of the buncher. The second resonator (coaxial cavity) is used as a connecting cavity between them. The general layout of the S-band buncher is shown in Fig.1.

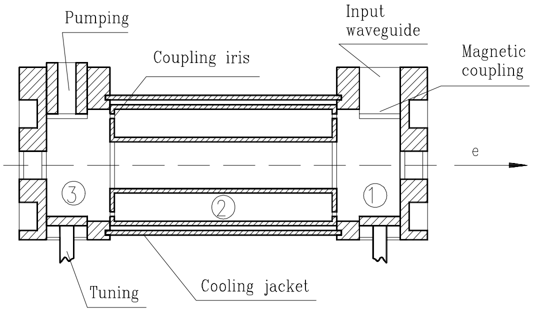

Fig. 1: The S-band buncher.

Geometrical parameters of the buncher cavities are listed in Table 1.

Table 1

D_1,mm	L_1,mm	d_2,mm	D_2,mm	L_2,mm	D_3,mm	L_3,mm
83	34	32	85	102	83	34

Here D_i, L_i (i=1,3) are the diameters and lengths of the first and third cavities;

d_2, D_2, L_2 are the internal diameter, the external diameter, and the length of the coaxial cavity.

The buncher operates at 2856 MHz. The operational mode, which corresponds to the operating frequency, provides the equality of the field phases in both accelerating resonators. Centers of the accelerating cavities are 14.6 cm distant from one another (see Tab.1).

Thus the interaction of the 200 keV electrons ($v \approx 0.7c$) with the electromagnetic field occurs in equal phases for both accelerating cavities.

The first and the third cavities have the tuner, designed as a plunger (see Fig.1). The resonant frequencies of the accelerating cavities may be changed by changing the plunger position, by this means a new ratio of field amplitudes can be set.

The standard couplers from the accelerating structure are used as accelerating cavities (the first and third cavities, Fig.1). Such a design after the minor changes provides RF power input, vacuum pumping, and possibility to tune the resonant frequencies of the both cavities. Each of the accelerating cavities is a high quality copper resonator operating at E_{010} fundamental mode.

The second resonator was designed as a coaxial cavity operating at TEM_{012} mode with two field variations along the axis. It couples accelerating cavities with one another. This resonator was made of 12X18H special stainless steel with low conductivity within S-band, that allowed us to decrease the transient process characteristic time down to 0.2 μs and therefore increase its stability to external factors (i.e. RF pulse instability, temperature regime, etc.). It should be noted that RF power level according to the preinjector project is more than enough for the buncher operating, so low quality does not reduce the bunching efficiency.

BASIC EQUATIONS AND COMPUTER SIMULATION

The equivalent circuit of the buncher is shown in Fig.2.

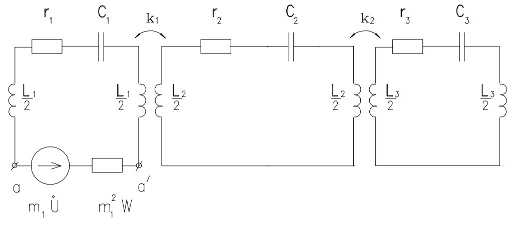

Fig. 2: Electric circuit representation of the buncher.

The first cavity is connected with the power transmission waveguide by an iris, which is represented in Fig.2 as a transformer with transformer ratio *m*. In terms of our model the value of *m* may be expressed by coupling coefficient β between the first cavity and input waveguide by the following equation: $\beta = \frac{m^2 Z_0}{r_1}$, where Z_0 is the rectangular waveguide characteristic impedance.

Let us consider that the circuit is driven by a harmonic signal: $\mathbf{U} = U_0 e^{i2\pi ft}$, where $U_0 = const$ (steady-state regime). In this case we can write:

$$\begin{cases} \left(1-\frac{f_1^2}{f^2}-i\frac{f_1}{f}\frac{1+\beta_1}{Q_1}\right)X_1-\frac{k_1}{2}X_2 = \frac{U_0}{i2\pi f}\sqrt{\frac{2\pi f_1\beta}{Q_1 Z_0}} \\ -\frac{k_1}{2}X_1+\left(1-\frac{f_2^2}{f^2}-i\frac{f_2}{f}\frac{1}{Q_2}\right)X_2-\frac{k_2}{2}X_3 = 0 \\ -\frac{k_2}{2}X_2+\left(1-\frac{f_3^2}{f^2}-i\frac{f_3}{f}\frac{1}{Q_3}\right)X_3 = 0, \end{cases} \quad (1.1)$$

where $X_n = J_n\sqrt{L_n}$, J_n is the current in the n-th oscillation circuit cell;

f_n, Q_n are the resonant frequency and quality factor of the n-th cavity;

k_n is the coupling coefficient between the n-th and (n+1)-th cavities;

f is the drive frequency.

The incident wave power P_{in} at the buncher input is connected with the equivalent generator voltage U_0 by the following equation:

$$P_{in} = \frac{U_0^* U_0}{8Z_0}, \quad (1.2)$$

so we can deduce the electromagnetic field energy W_n $(n = 1,2,3)$ stored in each cavity from the system (1.1):

$$W_n = \frac{1}{2}X_n^* X_n. \quad (1.3)$$

The accelerating voltage in the first and third cavity is:

$$U_n = X_n\sqrt{2\pi f_n \frac{R_{sh}}{Q_n}}, \quad \text{n=1,3}, \quad (1.4)$$

where R_{sh} is the cavity shunt impedance for the space harmonic with phase velocity $v = 0.7c$ (that corresponds to the speed of 200 keV electrons).

The reflection coefficient of the buncher may be found directly from the matrix composed from the coefficients of system (1.1):

$$\Gamma = -1 - 2i\frac{f_1}{f}\frac{\beta}{Q_1}\frac{\Delta'}{\Delta}, \quad (1.5)$$

where Δ is the determinant of the matrix (1.1); Δ' is the determinant of the same matrix without the first row and first column.

We can estimate how the field amplitudes in the accelerating cavities depend on electrotechnical parameters of the system. Let us consider the solution of the system (1.1), which corresponds to the normal mode with the lowest resonant frequency for the case $\beta = 0$ (free oscillations) to estimate the dependence of the field amplitudes in accelerating cavities, from the system parameters. In this case we can obtain:

$$\frac{X_1}{X_3} = \frac{k_1}{k_2}\frac{\left(1-\frac{f_1^2}{f_0^2}-i\frac{f_1}{f_0}\frac{1}{Q_1}\right)}{\left(1-\frac{f_3^2}{f_0^2}-i\frac{f_3}{f_0}\frac{1}{Q_3}\right)}. \quad (1.6)$$

From (1.6) we can see, that if the resonant frequencies of the first and third cavities are the same ($f_1 = f_3$), and their Q-factors are sufficiently high (i.e. $\frac{1}{Q_1} << 1$ and $\frac{1}{Q_3} << 1$), the ratio of the field amplitudes in accelerating cavities is determined only by their coupling coefficients with the coaxial cavity:

$$X_1 = \frac{k_1}{k_2}X_3. \quad (1.7)$$

If we change the resonant frequencies of the first and third cavities by the value of Δf and $-\frac{k_1}{k_2}\Delta f$ correspondingly, the resonant frequency of the buncher f_0 remains the same (that can be shown either from Eqs. (1.1) or from Boltzmann/Ehrenfest theorem), and the ratio of the fields will be equal to:

$$\frac{X_1}{X_3} = \frac{k_1}{k_2}\frac{1-\frac{f_3^2}{f_0^2}+2\frac{k_1}{k_2}\frac{\Delta f}{f_0}}{1-\frac{f_1^2}{f_0^2}-2\frac{\Delta f}{f_0}}. \quad (1.8)$$

It is also followed from (1.1) that if the all three cavity resonant frequencies are the same, the following equation holds:

$$1-\frac{f_{1,3}^2}{f_0^2} = \sqrt{\frac{k_1^2+k_2^3}{2}}. \quad (1.9)$$

Let us define: $\Delta_f \equiv \frac{\Delta f}{f_0}$, $\gamma \equiv 1-\frac{f_{1,3}^2}{f_0^2} = \sqrt{\frac{k_1^2+k_2^2}{2}}$.

In this terms the equation (1.6) can be written as:

$$\frac{X_1}{X_3} = \frac{k_1}{k_2}\frac{\gamma+2\frac{k_1}{k_2}\Delta_f}{\gamma-2\Delta_f}, \quad (1.10)$$

and for the coaxial cavity:

$$\frac{X_2}{X_1} = \frac{2}{k_2}\left(\gamma+\frac{k_1}{k_2}2\Delta_f\right). \quad (1.11)$$

From equations (1.1) − (1.11) we can make the following important conclusions:

a) Any desired ratio of the field amplitudes in the accelerating cavities can be obtained by choosing the proper coupling coefficients.

b) This ratio may be changed by varying the resonant frequencies of the accelerating cavities, so that the structure resonant frequency remains the same.

c) Sensitivity of the field amplitudes in the accelerating cavities to their resonant frequency changing depends mainly on the absolute value of the coupling coefficient between the cavities.

After extended simulations the following parameters of the buncher elements were chosen (see Table 2):

Table 2

f_1, MHz	Q_1	k_1	f_2,MHz	Q_2	k_2	f_3,MHz	Q_3
2872	7000	0.012	2864	950	0.006	2872	7000

The initial ratio of the accelerating fields has been chosen of 1/2 (that corresponds to $\frac{k_1}{k_2} = 2$) and may be changed during the buncher setup.

The exact electromagnetic field axial distribution was calculated by SLANS code [1] for each of the cavities individually. The absolute value of the electromagnetic field was obtained by the energy stored in each cavity, determined by Eqs. (1.1) and (1.3). A phase shift between the field amplitudes in the cavities is determined by Eqs. (1.1) and is equal to:

$$\Delta\phi = \frac{\arg(X_1)}{\arg(X_3)}. \qquad (1.12)$$

The numerical simulations shown that for the parameters listed in Tab.2 $\Delta\phi \approx 1$ (i.e. the oscillations in the both cavities are of the same phase, and an additional phase shift due to a finite quality of the cavities is practically zero).

The field distribution along the buncher axis for different parameters of its elements is shown in Fig. 3.

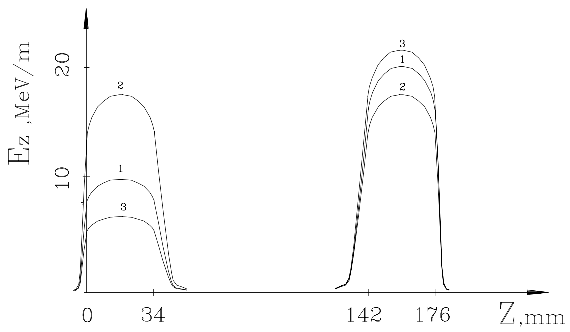

Fig. 3: Axial field distributions.

It should be noted that the described method allows us to measure fields on the structure axis with a high enough accuracy, because the coupling slots are located near the shell and do not disturb the axial fields.

TRANSIENT PROCESS IN THE BUNCHER

All equation listed above are valid only for the case when the amplitude of the input RF pulse changes during a time interval much longer than the transient time of the buncher. The buncher transient process must be considered because the RF pulse duration after the SLED system is 0.5 μs, that is a value of the same order as the buncher transient time.

Transient regime of buncher operation was simulated by the VIT 032 special computer code, developed by one of the authors [2]. That program was intended for simulations of the RF process in the whole preinjector system (SLED system, accelerating structure, buncher system etc.), as well as ion its individual elements. The brief explanation of the code algorithm as well as the calculation results is presented below.

Results of simulations carried out by VIT 030 code [3] are presented in Fig.4.

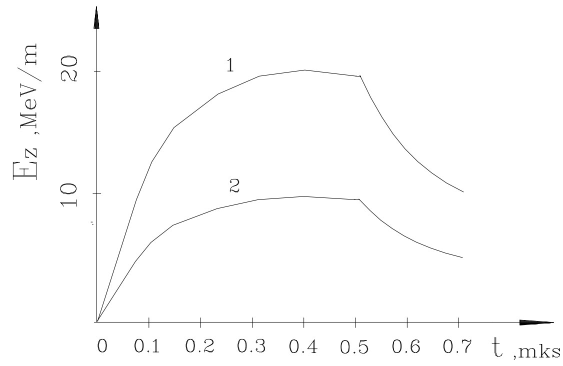

Fig. 4: Time dependencies of the filed amplitude.

CONCLUSIONS

By now a prototype of the buncher, presented in the paper, has been manufactured. Measurements carried out are in a good agreement with simulation results. A new version of the buncher, which will allow us to control not only an amplitude, but also phase ratio in accelerating cavities is under development now. It may be done in a transient regime by varying the coupling cavity parameters, according to Eq. (1.1).

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