OPERATION FEATURES OF VEPP-5 PREINJECTOR RF-BUNCHER WITH "LONG–TIME" BEAM

V. M. Pavlov, BINP, Novosibirsk, Russia

Abstract

RF buncher of VEPP-5 preinjector consists of four coupling cavities. The complete formation of short separated bunches from originally continuous beam take place within buncher. This train induces long-wave wake voltage that added to a generator voltage. So if we are bunching the long beam, the resulting train of bunches will have a significant variation of bunch parameters along the train.

The features of RF-buncher operation with long beam are presented in this paper.

1 INTRODUCTION

Usually for bunching of originally continuous beam single gap cavity (like klystron buncher) is used. Such cavity gives only increment of particle's velocity. The particles which pass through the cavity have no time to be bunched. The finally formation of short separated bunches occurs into special drift tube. Therefore the continuous beam of particles doesn't induce the additional wake-voltage into cavity. And as a result the process of bunching determined by external generator voltage only, independently of initial beam current duration.

The RF-buncher of VEPP-5 preinjector [1] consists of four coupling cavities (see Fig. 1c) and has the next performance attributes:

working frequency	$f = 2856.45$ MHz,
quality factor	$Q_0 = 3350$,
coupling factor	$\beta_C = 1.31$,
effective shunt impedance	$R_{sh} = 0.389$ MOhm

for electron's input energy 200 kV ($\beta_0 = v_0 / c = 0.695$).

The complete formation of short separated bunches from originally continuous beam occurs within the buncher (see Fig. 1a). It gives an opportunity to place RF buncher as close to the first accelerating section as it possible without any additional drift tube.

In contrast to the single gap cavity, in downstream part of our buncher we have completely grouped beam. It induces the long-wave wakefield of the same frequency. This field adds to already existing one in the cavity. Then the subsequent particles will bunch in the field with another amplitude and phase. So when the beam pass through a buncher the transient process take place in it. As a result at the buncher output "head" and "tail" of long-time beam will have different bunch density, and it is even more important, a different output phase of grouped bunches.

On the other hand, the bunched beam will induce a wakefield in the first accelerating section as well. But this field, induced by next portion of beam, will at each time moment leave from upstream part of section with accelerating structure's group velocity. So on an upstream part of accelerating section always there will be identical conditions for reception of next bunches, which determined by the incoming RF field only and not depend

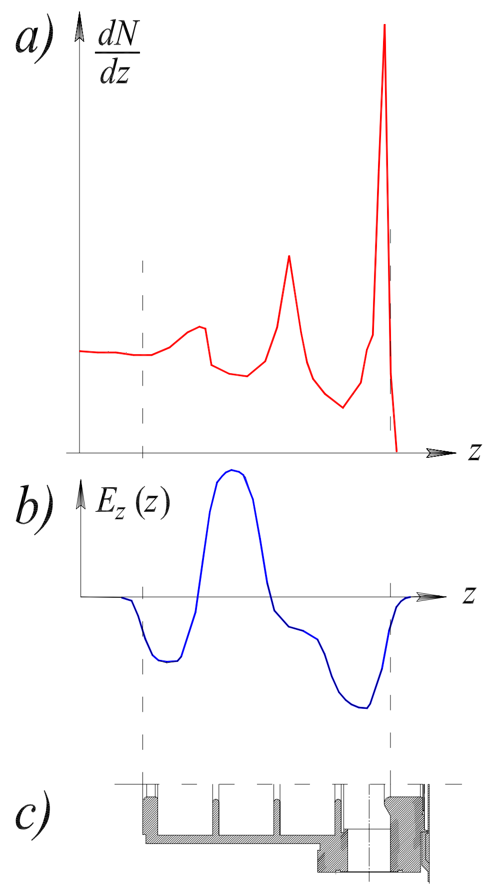

Figure 1: RF-buncher of VEPP-5 preinjector:
a) z-dependence of bunching beam density,
b) $E_z(z)$ distribution on the axis,
c) design of RF-buncher.

from a beam current. As the consequence, bunches of long beam, enter to accelerating structure at different phase. It affects bunch energy gain, output energy spectrum and capture factor.

2 TRANSIENT EQUATION

Express the real voltage of cavity in terms of the phasor representation:

$$V_C(t) = \mathrm{Re}\left\langle \tilde{V}_C(t)\cdot e^{j\omega t}\right\rangle, \qquad \tilde{V}_C(t) = \left|\tilde{V}_C(t)\right|\cdot e^{j\varphi_C(t)}$$

For ballistic "pencil" bunching beam the current density phasor representation is

$$\vec{J}(\vec{r},t) = \vec{z}^{\,0}\cdot\frac{\delta(r^2)}{\pi}\cdot\mathrm{Re}\left\langle \tilde{I}(\vec{r},t)\cdot e^{j\omega t}\right\rangle \equiv$$
$$\equiv \vec{z}^{\,0}\cdot\delta^2(\vec{r}_\perp)\cdot\mathrm{Re}\left\langle \tilde{I}(\vec{r},t)\cdot e^{j\omega t}\right\rangle .$$

Then in Slowly Varying Envelop Approximation (SVEA) hypotheses the time domain voltage $\tilde{V}_C(t)$ on the resonant frequency $\omega = \omega_0$ satisfies [2]:

$$\frac{d\tilde{V}_C}{d\tau} + \tilde{V}_C = \frac{2\cdot\sqrt{\beta_C\cdot R_{sh}\cdot P_F}}{1+\beta_C}\cdot e^{j\varphi_{gen}} - \frac{I_0\cdot R_{sh}}{1+\beta_C}\cdot W(\tilde{V}_C)$$

where

$\tau = \frac{\omega_0}{2Q_L}\cdot t$ - is time measured in units of filling time,

$Q_L = \frac{Q_0}{1+\beta_C}$ - loaded quality factor,

$P_{gen}(\tau)$-forward-coming power in the input waveguide,

$\varphi_{gen}(\tau)$ - its phase,

$I_0(\tau) = q(\tau)\cdot f \equiv \frac{q(\tau)\omega}{2\pi}$ - average beam current.

As distinct from standard equation of transient there is the bunching factor $W(\tilde{V}_C)$:

$$W(\tilde{V}_C) = \frac{\int_0^L dz\left\{e_z(z)\cdot\frac{1}{N}\sum_{n=1}^{N}\exp[-\varphi(t_{0n},z)]\right\}}{w^*},$$

where

$w = \int_0^L dz\, e_z(\vec{r},z)\cdot e^{j\omega\frac{z}{v_0}}$, but

$e(z) = \frac{E_z(z)}{\left|\int_{-L/2}^{L/2} E_z(z)\cdot e^{-j\frac{2\pi z}{\beta_0\lambda}}dz\right|}$ - normalised distribution of axis electric field, $\beta_0 = v_0/c$.

The equations for the longitudinal motion of *n*-th single particle are:

$$\begin{cases} \frac{d\varphi_n}{d\xi} = \frac{2\pi}{\beta_n(\xi)}, \quad n = 1,2,\ldots N; \qquad \varphi_n(0) = \frac{2\pi}{N}\cdot(n-1), \\ \frac{d\beta_n}{d\xi} \approx \frac{G(\tau,\xi)}{\beta_n\gamma_n^3}\cdot\cos[\varphi_a(\tau)+\varphi_n(\xi)], \qquad \beta_n(0) = \beta_0, \end{cases}$$

where $\xi = z/\lambda$,

$$G(\tau,\xi) = \frac{e\cdot\left|\tilde{V}_C(\tau)\right|}{m_0c^2}\cdot\frac{E_z(\xi)}{\left|\int_{-L/2}^{L/2}E_z(\xi)\cdot e^{-j\frac{2\pi}{\beta_0}}d\xi\right|}.$$

In steady-sate regime

$$\tilde{V}_C = \frac{2\cdot\sqrt{\beta\cdot R_{sh}\cdot P_F}}{1+\beta_C}\cdot e^{j\varphi_{gen}} - \frac{I_0\cdot R_{sh}}{1+\beta_C}\cdot W(V_C).$$

If velocity of bunching particles is constant, then the group-factor will depend on shape of input current only. For the constant input current the group-factor $W = 0$ and grouping process depends on RF power of generator only. But if we have the ideal bunched input beam (one charge q per period only) then $W = 1$.

It is clear that for continuous input current the group-factor depends on amplitude of voltage in the cavity only

$$W(\tilde{V}_C) = W\left(\left|\tilde{V}_C\right|\right)\cdot e^{j\varphi_C}.$$

In Fig. 2 the amplitude and phase of group-factor $W\left(\left|\tilde{V}_C\right|\right) \equiv W(P_0)$ are shown. P_0 in Fig.2 is equivalent of input power. And the amplitude of cavity voltage is

$$\left|\tilde{V}_C\right| = \frac{2\cdot\sqrt{\beta_C\cdot R_{sh}\cdot P_0}}{1+\beta_C}.$$

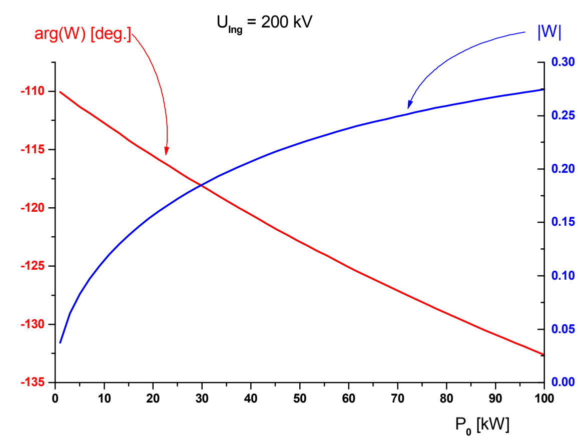

Figure 2: The dependence of amplitude and phase of group-factor upon the input power.

The example of calculation:

Input energy $U_{Ing} = 200$ kV,

Pulse current per period $I_0 = 1.5$ A,

Pulse duration $\tau_B = 250$ ns.

These parameters are very close to the normal LUE200 operation conditions [3]. In Fig. 3 the dependencies of amplitude and phase of cavity voltage upon the incoming power are sown at the end of the beam current pulse. In other words the "head" of current pulse forming in cavity voltage V_0 according to input power of generator P_0, but the "tail" of current pulse forming in new cavity voltage V_{New} with phase shift $\Delta\varphi$.

In Fig. 4 the output current density histogram of "head" and "tail" current pulse are sown.

The dynamics of bunched particles depends strongly from accepting accelerating section. And these results one can consider as initial data for further particle dynamic calculations.

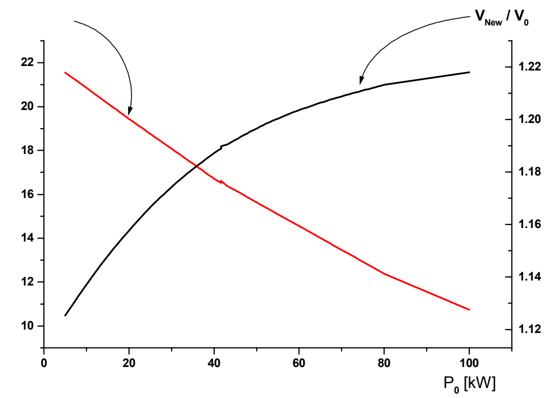

Figure 3: The amplitude and phase of cavity voltage versus input power.

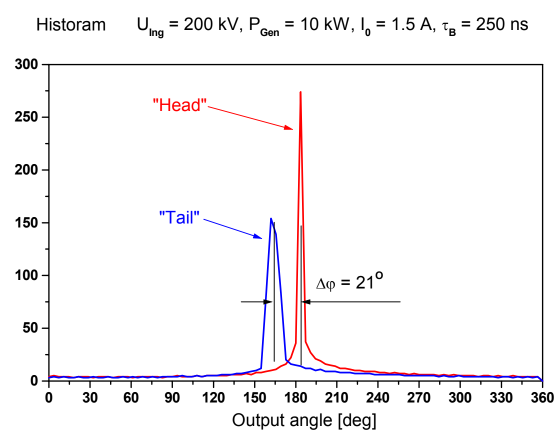

Figure 4: Output bunch density histograms for "head" and "tail" of the long pulse.

3 REFERENCES

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