SPACE-TIME COMPRESSION OF ATOM BEAM IN THE DISTANCE ANALYSIS OF PLANETS SURFACES

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INTRODUCTION

The intensive ion and neutral atom beams can be used in the remote analysis of a planet surface of Solar system [1,2]. To obtain high intensity beam ion linear accelerator with space-time compression is proposed. It allows to form on the removed target a high density pulse of neutral atoms and the reflected value sufficient for registration [1,2]. It is technically feasible to obtain the beam compression factor not less than 100 of a distance from 200 km up to 2000 km. It provides reliable registration of a return signal with the help of detectors established on space station [4].

The paper is to describe the theoretical questions of technical realization energy modulation of ion beam pulse The requirements to power and phase parameters of a high-frequency source are determined.

MODULATION OF AN ACCELERATING WAVE AMPLITUDE IN THE RESONATOR

The method of the equivalent circuits give an analytical expressions for the dependence of voltage on a the resonator gap vs time with excitation by generator or beam [3]. The expression for the voltage on the resonator

$$U_{ã}(t)=\left[\frac{2\sqrt{\beta Z_{ø}P_n}}{\alpha(1+\beta)}+2\frac{\sqrt{\beta Z_{ø}P_{n+1}}-\sqrt{\beta Z_{ø}P_n}}{\alpha(1+\beta)}\frac{t-t_{nã}}{t_{(n+1)ã}-t_{nã}}\right]\times$$
$$\times\left[\frac{\sin(\omega_{ã}t+\psi_0+\varphi_0-\varphi_1)}{\sqrt{1+(2Q_í(\omega_{ã}/\omega_0-\alpha))^2}}+\frac{\sin(\omega_{ã}t+\psi_0-\varphi_0-\varphi_2)}{\sqrt{1+(2Q_í(\omega_{ã}/\omega_0+\alpha))^2}}\right]-$$
$$-\frac{4Q_í\sqrt{\beta Z_{ø}}(\sqrt{P_{n+1}}+\sqrt{P_n})}{\alpha\omega_0(1+\beta)(t_{(n+1)ã}-t_{nã})}\times$$
$$\times\left[\frac{\sin(\omega_{ã}t+\psi_0+\varphi_0-2\varphi_1)}{1+(2Q_í(\omega_{ã}/\omega_0-\alpha))^2}+\frac{\sin(\omega_{ã}t+\psi_0-\varphi_0-2\varphi_2)}{1+(2Q_í(\omega_{ã}/\omega_0+\alpha))^2}\right]+$$
$$+\exp(-\frac{\omega_0 t}{2Q_í})\left\{\sum_{m=1}^{n}\exp(\frac{\omega_0 t_{mã}}{2Q_í})\frac{4Q_í\sqrt{\beta Z_{ø}}(\sqrt{P_{m+1}}+\sqrt{P_m})}{\alpha\omega_0(1+\beta)(t_{(m+1)ã}-t_{mã})}\times\right.$$
$$\times\left[\frac{\sin(\alpha\omega_0 t+(\omega_{ã}-\alpha\omega_0)t_{mã}+\psi_0+\varphi_0-2\varphi_1)}{1+(2Q_í(\omega_{ã}/\omega_0-\alpha))^2}-\right.$$
$$\left.-\frac{\sin(\alpha\omega_0 t-(\omega_{ã}+\alpha\omega_0)t_{mã}-\psi_0+\varphi_0+2\varphi_2)}{1+(2Q_í(\omega_{ã}/\omega_0+\alpha))^2}\right]-$$
$$-\sum_{m=1}^{n}\exp(\frac{\omega_0 t_{(m+1)ã}}{2Q_í})\frac{4Q_í\sqrt{\beta Z_{ø}}(\sqrt{P_{m+1}}+\sqrt{P_m})}{\alpha\omega_0(1+\beta)(t_{(m+1)ã}-t_{mã})}\times$$
$$\times\left[\frac{\sin(\alpha\omega_0 t+(\omega_{ã}-\alpha\omega_0)t_{(m+1)ã}+\psi_0+\varphi_0-2\varphi_1)}{1+(2Q_í(\omega_{ã}/\omega_0-\alpha))^2}-\right.$$
$$\left.-\frac{\sin(\alpha\omega_0 t-(\omega_{ã}+\alpha\omega_0)t_{(m+1)ã}-\psi_0+\varphi_0+2\varphi_2)}{1+(2Q_í(\omega_{ã}/\omega_0+\alpha))^2}\right]-$$
$$-\exp(\frac{\omega_0 t_{1ã}}{2Q_í})\frac{2\sqrt{\beta Z_{ø}P_1}}{\alpha\omega_0(1+\beta)}\times \qquad (1)$$
$$\times\left[\frac{\sin(\alpha\omega_0 t+(\omega_{ã}-\alpha\omega_0)t_{1ã}+\psi_0+\varphi_0-\varphi_1)}{\sqrt{1+(2Q_í(\omega_{ã}/\omega_0-\alpha))^2}}-\right.$$
$$\left.\left.-\frac{\sin(\alpha\omega_0 t-(\omega_{ã}+\alpha\omega_0)t_{1ã}-\psi_0+\varphi_0+\varphi_2)}{\sqrt{1+(2Q_í(\omega_{ã}/\omega_0+\alpha))^2}}\right]\right\},$$

gap created by the generator is as follow:

where: $\varphi_0=\mathrm{arctg}(1/2\alpha Q_í)$;

$\varphi_1=\mathrm{arctg}(2Q_í(\omega_{ã}/\omega_0-\alpha))$;

$\varphi_2=\mathrm{arctg}(2Q_í(\omega_{ã}/\omega_0+\alpha))$;

$\alpha=\sqrt{1-(2Q_i)^{-2}}$;

n - number of bunch.

The voltage on the resonator gap created by beam current can be writing as:

$U_n(t)=0$, with $0<t<t_{1n}-t_2/2$;

$$U_n(t)=\frac{Z_{ø}}{2\alpha(1+\beta)}\left\{\sum_{k=0}^{\infty}I_{ê}\left[\frac{\sin(k\omega_{ï}t+\psi_k+\varphi_0-\varphi_{1k})}{\sqrt{1+(2Q_í(k\omega_{ï}/\omega_0-\alpha))^2}}+\right.\right.$$
$$\left.+\frac{\sin(k\omega_{ï}t+\psi_k-\varphi_0+\varphi_{2k})}{\sqrt{1+(2Q_í(k\omega_{ï}/\omega_0+\alpha))^2}}\right]-\exp\left[-\frac{\omega_0(t-t_{1ï}+t_2/2)}{2Q_í}\right]\times$$
$$\times\sum_{k=0}^{\infty}I_{ê}\left[\frac{\sin(\alpha\omega_0 t+(k\omega_{ï}-\alpha\omega_0)(t_{1ï}-t_2/2)+\psi_k+\varphi_0-\varphi_{1k})}{\sqrt{1+(2Q_í(k\omega_{ï}/\omega_0-\alpha))^2}}-\right.$$
$$\left.\left.-\frac{\sin(\alpha\omega_0 t-(k\omega_{ï}+\alpha\omega_0)(t_{1ï}-t_2/2)-\psi_k+\varphi_0+\varphi_{2k})}{\sqrt{1+(2Q_í(k\omega_{ï}/\omega_0+\alpha))^2}}\right]\right\},$$

for $t_{1n}-t_2/2<t<t_{2n}$;

$$U_n(t)=\frac{Z_{ø}}{2\alpha(1+\beta)}\left\{\exp\left[-\frac{\omega_0(t-t_{2ï})}{2Q_í}\right]\sum_{k=0}^{\infty}I_{ê}\times\right.$$
$$\times\left[\frac{\sin(\alpha\omega_0 t+(k\omega_{ï}-\alpha\omega_0)t_{2ï}+\psi_k+\varphi_0-\varphi_{1k})}{\sqrt{1+(2Q_í(k\omega_{ï}/\omega_0-\alpha))^2}}-\right.$$
$$\left.-\frac{\sin(\alpha\omega_0 t-(k\omega_{ï}+\alpha\omega_0)t_{2ï}-\psi_k+\varphi_0+\varphi_{2k})}{\sqrt{1+(2Q_í(k\omega_{ï}/\omega_0+\alpha))^2}}\right]-$$
$$-\exp\left[-\frac{\omega_0(t-t_{1ï}+t_2/2)}{2Q_í}\right]\sum_{k=0}^{\infty}I_{ê}\times \qquad (2)$$

$$\times\left[\frac{\sin(\alpha\omega_0 t+(k\omega_{ï}-\alpha\omega_0)(t_{1ï}-t_2/2)+\psi_k+\varphi_0-\varphi_{1k})}{\sqrt{1+(2Q_{í}\,(k\omega_{ï}/\omega_0-\alpha))^2}}-\right.$$

$$\left.-\frac{\sin(\alpha\omega_0 t-(k\omega_{ï}+\alpha\omega_0)(t_{1ï}-t_2/2)-\psi_k+\varphi_0+\varphi_{2k})}{\sqrt{1+(2Q_{í}\,(k\omega_{ï}/\omega_0+\alpha))^2}}\right]\Bigg\},$$

With $t_{2n} \le t$,

Where: $\varphi_{1ê} = \mathrm{arctg}(2Q_{í}\,(k\omega_{ï}/\omega_0-\alpha));$

$$\varphi_{2ê} = \mathrm{arctg}(2Q_{í}\,(k\omega_{ï}/\omega_0+\alpha));$$

$$t_1=\begin{cases}\Delta\varphi_{Ï}/\varpi_{Ï}\,, & \Delta\varphi_{Ï}\le\varpi_{Ï}\,D/v;\\ D/v, & \Delta\varphi_{Ï}\ge\varpi_{Ï}\,D/v;\end{cases}$$

D - the resonator gap width;

v - speed of the particles in the resonator gap;

$2t_2$ - current pulse duration (on the basis);

Q_0 - unlouded Q-factor

Z - shunt impedance

To joint influence of the generator and beam the voltage will be equal to the sum of voltages U_r(t) and $U_n(t)$. The beam is represented as the regular charged bunches following one after another with the frequencies f_r and having the phase extent $\Delta\varphi_n$. The pulse current of beam is equal 1. To provide linear dependence of voltage on resonator gap with time it is needed to choose resonator coupling coefficient, initial power level and following power increasing.

The dependence of the resonator gap voltage on time for various phases of bunches and generator frequency deviation are submitted in Fig. 1 and Fig. 2.

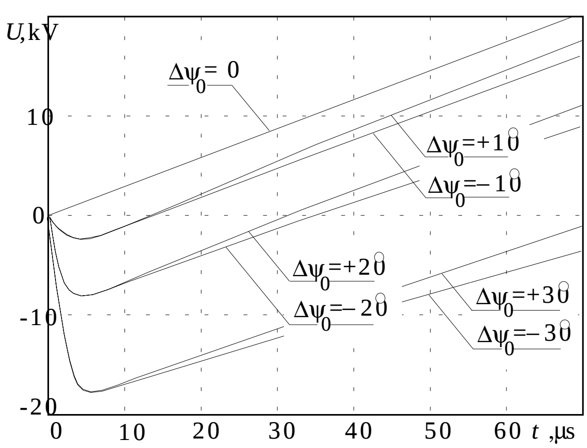

Figure 1: Resonator gap voltage dependence on time with various bunch phases.

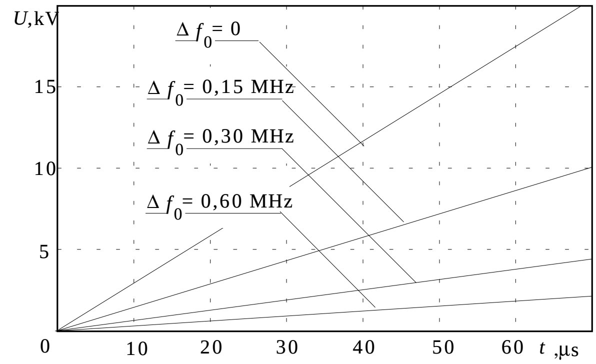

Figure 2: The resonator gap voltage v.s. with various generator frequency deviation.

From the data, given in these figures 1 and 2, it is clear, that the deviation from linear dependence is observed only during first 5-8 μs and voltage all time remains accelerating.

AMPLITUDE-PHASE MODULATION OF A GENERATOR WAVE

Let us assume that resonator with Q-factor Q_0 and coupling coefficient k are fed from generator with microvawe power P_0. The strength of a field emitted from the resonator will be:

$$E_{èçë} = -\alpha_0 E_0 (1-e^{-t/\tau}), \qquad (3)$$

E_0 - electric field of generator;

α_0 = 2k/ (1 + k);

$\tau = Q_0/\pi f_0$ (1 + k) - constant transient in resonators.

After the moment of time t = t_0 falling on the resonator microwave changes on amplitude and phase. For the moment of time t = t_0 + Δt the field emitted from the resonator field will consist of:

$$E_1^\bullet = \mathrm{Re}\,E_1^\bullet + j\,\mathrm{Im}\,E_1^\bullet, \qquad (4)$$

Where:

$$\mathrm{Re}\,E_1^\bullet = -\alpha_0 E_0 (1-e^{-t_0/\tau})e^{-\Delta t/\tau} - \alpha_0 E_1 \cos\Delta\varphi_1 (1-e^{-\Delta t/\tau});$$

$$\mathrm{Im}\,E_1^\bullet = -\alpha_0 E_1 \sin\Delta\varphi_1 (1-e^{-\Delta t/\tau});$$

$\Delta\varphi_1$ - phase changing during a period Δt; $E_1 = E_0\,(K_{p1})^{1/2}$ - strength of RF wave falling on the resonator during an interval of time (t_0, t_0 + Δt); $K_{p1}=P_0/P_1$; P_1 - RF power from generator in a period (t_0, t_0 + Δt). For the moment of time t = t_0 + Δt we shall have the expression for field emitted from resonator wave:

$$E_2^\bullet = \mathrm{Re}\,E_2^\bullet + j\,\mathrm{Im}\,E_2^\bullet; \qquad (5)$$

$$\mathrm{Re}\,E_2^\bullet = -\alpha_0 E_0 (1-e^{-t_0/\tau})e^{-2\Delta t/\tau} - \alpha_0 E_1 \cos\Delta\varphi_1 (1-e^{-\Delta t/\tau})e^{-\Delta t/\tau} -$$

$$-\alpha_0 E_2 \cos(\Delta\varphi_1+\Delta\varphi_2)(1-e^{-\Delta t/\tau});$$

$$\mathrm{Im}\,E_2^\bullet = -\alpha_0 E_1 \sin\Delta\varphi_1 (1-e^{-\Delta t/\tau})e^{-\Delta t/\tau} - \alpha_0 E_2 \sin(\Delta\varphi_1+\Delta\varphi_2)(1-e^{-\Delta t/\tau});$$

$E_2 = E_0 (K_{p2})^{1/2}$.

For the time moments t = t_0 + nΔt, where n = 1,2..., we shall have:

$$P_{èçë} = P_0 e^{-2(t-t_0)/\tau}\alpha_0^2 (A^2+B^2); \qquad (6)$$

$$\mathrm{tg}\varphi_{\mathrm{p}} = B/A;$$

where: $A = (1 - e^{-t_0/\tau}) + \sum_{n=1}^{N} \sqrt{K_{\mathrm{P}n}} (1 - e^{-t_0/\tau}) e^{-n\Delta t/\tau} \cos \sum_{i=1}^{n} \Delta\varphi_i;$

$$B = \sum_{n=1}^{N} \sqrt{K_{\mathrm{P}n}} (1 - e^{-\Delta t/\tau}) e^{-n\Delta t/\tau} \sin \sum_{i=1}^{n} \Delta\varphi_i;$$

φ_p- phase of the resonator field at the time moment $t = t_0 + n\Delta t$.

To obtain increasing of particles energy it is needed to change phase in resonators of linac. As show the calculations, it is necessary to make instant phase change of generator RF wave to ψ_0, and then smoothly change a phase with speed $d\varphi/dt = d\varphi_p/dt$. At the moment of time $t = t_0$, the power of a falling wave also will change by step to P.

The results of calculations of Ψ_0 and P/P_0 vs $\tau(d\varphi/dt)$ are submitted in Fig 3. If the changes of power do not exceed (1-2)% value $\tau(d\varphi/dt)$ will be less than 10.

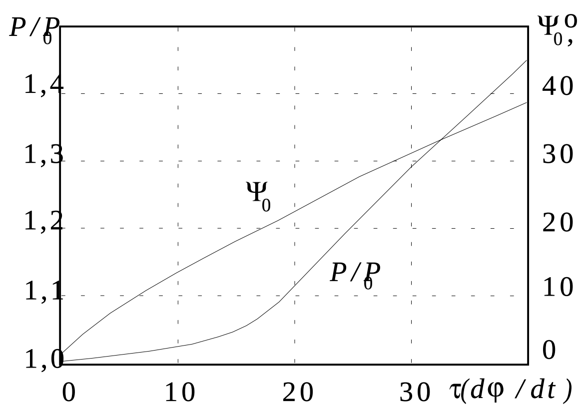

Figure 3: Dependence Ψ_0 and P/P_0 v.s. τ ($d\varphi/dt$).

CONCLUSION

The received results allow to proceed directly to technical realization of the prototype of system of a complex of space basing for the purposes of sounding of a surface of planets of Solar system.

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