TWO-BEAM INDUCTION LINEAR COLLIDER

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Abstract

A new scheme of electron-positron linear collider is presented in this report. The collider is a combination of a linear induction accelerator and a multi-cavity buncher of a klystron. Very strong electric fields are excited by a driving e-beam into the buncher cavities. This fields are used to accelerate the main electron or positron beam. Thus an energy of the driving electron beam is converted into an energy of the main beam. The driving beam energy is recovered by induction electric fields of the LIA.

1 INTRODUCTION

Two projects of electron-positron collider, CLIC at CERN and NLC at SLAC, assume to use two-beam method of acceleration [1, 2]. In the both projects the high energy electron (or positron) beam and the driving electron beam are accelerated in different accelerators. The RF power is generated by the driving e-beam when it passes special electrodynamic structures. Then this power is fed to the accelerating section of the main accelerator.

Recently JINR (Dubna) and BINP (Protvino) have perform R&D a wide aperture variant of a VLEPP klystron. It was the 14 GHz klystron with the 11 cavities of the buncher and 0.7λ (15 mm) aperture [3]. The operating E_{01} mode was the cut-off for this diameter of the drift tubes but the asymmetric H_{11} mode was not the cut-off. Therefore a self-excitation of the klystron takes place on operating 14 GHz and higher frequencies [3]. The excitation process is as the mode competition process and new mode types appeared when we suppressed the existent parasitic modes. To suppress all parasitic oscillations we used a method of a distributed suppression of the parasitic waves by drift tubes which was made as RF absorbers [3].

Another feature of the multi-cavity buncher of the klystron have been observed. It is very strong electric fields excited in final buncher cavities. When klystron was operating in the self-excitation regime and we could not control the output power the electric discharge in the final buncher cavities took place. The calculated electric field on the buncher axis exceed 100 M/m. This fact allows one to accelerate charged particles of the main beam into an electrodynamic structure similar the klystron buncher.

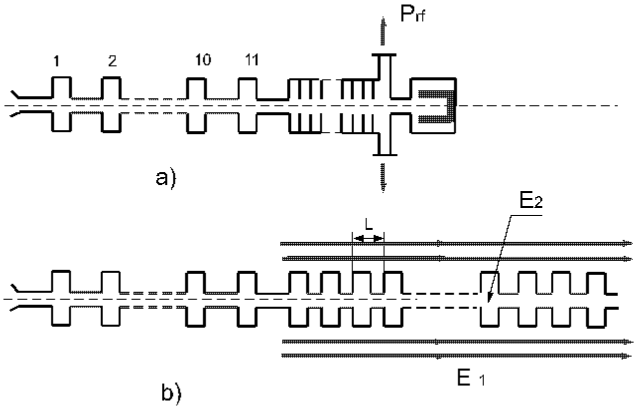


Figure 1: a)–Scheme of a multi-cavity klystron, b)–Scheme of a Two-beam Induction Linac

2 DESIGN OF ELECTRODYNAMIC STRUCTURE

Schemes of the multi-cavity klystron and two-beam accelerator are shown on Fig. 1. In the klystron the bunched electron beam passes an output travelling-wave structure where the kinetic energy of electrons is converted into the energy of RF oscillation. Output RF power is fed to the accelerating structure of the main accelerator.

In the two-beam accelerator the bunched electron beam is injected into electrodynamic structure contained the row of cavities and drift tubes with RF absorbing insertions (See Fig. 2) [4, 5]. When the driving electron beam passes this cavities, it induces high voltage, high frequency electric field. The main beam is accelerated by this induced field.

Detuning of the cavities relative to the first harmonic of the bunched driving beam is chosen in such way that the loaded cavities act as bunchers for the electron bunches, thus providing longitudinal stability. Loaded resonators have almost pure inductive impedance on the bunches frequency, so the phase of induced voltage is close to $\pi/2$ and bunches pass the cavities at almost zero phase of the RF field.

Energy loss of the driving electron beam is recovered during its acceleration in the induction electric field. Synchronism for the main beam is provided by an appropriate change of the cavity spacing.

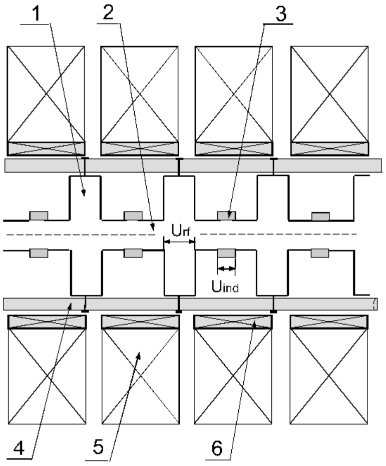


Figure 2: Scheme of an electrodynamic structure of the Two-beam Induction Linac. Here: 1–rf cavity, 2–drift tube, 3–rf absorbing insertion, 4–ceramic tube, 5–induction core, 6–focusing system.

3 CONDITION OF SYNCHRONISM FOR THE MAIN BEAM

The phase difference of the voltage induced in the n-th and n+1-th cavities is

$$\Delta\varphi_d = 2\pi\frac{L}{\beta_d\lambda}$$

where $\beta_d = v_d/c$ is relative velocity of driving beam electrons. The transit time of main beam particles for one period L of the structure is equal to $\Delta t = L/v_m$ corresponding to

$$\Delta\varphi_m = 2\pi\frac{L}{\beta_m\lambda}$$

The synchronism condition takes place when [4, 5]

$$\Delta\varphi_d \pm \Delta\varphi_m = \pm 2\pi k$$

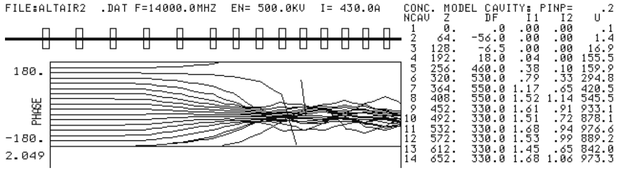
$$\frac{1}{\beta_d} \pm \frac{1}{\beta_m} = \pm k\frac{\lambda}{L}$$

where k is integer. The synchronism is possible when the driving electron and main beam particles move in opposite direction. In this case

$$\frac{1}{\beta_d} + \frac{1}{\beta_m} = k\frac{\lambda}{L}$$

4 LONGITUDINAL STABILITY OF THE DRIVING ELECTRON BEAM

The bunching of electrons in the electrodynamic structure of the two-beam linear collider is provided by the RF field similar the multi-cavity klystron buncher. The possibility of an existence of the stabilized bunches in this structure is demonstrated on Fig. 3, where the phase trajectories of electrons of the 500 keV, 430 A driving beam are shown. Such bunched electron beam excites in the 14 GHz cavities of the two-beam accelerating structure the RF voltage equal about of 1 MV (See Fig. 3)



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                                                           1     0.      .0  .00  .00    .1
                                                           2    64.   -56.0  .00  .00   1.4
                                                           3   128.    -6.5  .00  .00  16.9
                                                           4   192.    18.0  .04  .00 155.5
                                                           5   256.   460.0  .38  .10 159.9
                                                           6   320.   530.0  .79  .33 294.8
                                                           7   364.   550.0 1.17  .65 420.5
                                                           8   408.   550.0 1.52 1.14 545.5
                                                           9   452.   330.0 1.61  .91 933.1
                                                          10   492.   330.0 1.51  .72 878.1
                                                          11   532.   330.0 1.68  .94 976.6
                                                          12   572.   330.0 1.53  .99 889.2
                                                          13   612.   330.0 1.45  .65 842.0
                                                          14   652.   330.0 1.68 1.06 973.3
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Figure 3: Results of computer calculations of the phase trajectories of electrons in the electrodynamic structure of the two beam accelerator and rf voltage excited by e-beam in cavities (right column – $U_{(kV)}$).

The average accelerating gradient depends on the number of cavities per meter. To calculation of the phase trajectories we have used the ”Diskly V3.5” computer program, which have been developed by Budker BINP (Protvino, Novosibirsk) for the calculation of the multi-beam powerful klystrons.

5 EXCITATION OF THE ACCELERATING FIELDS

Maximal accelerating gradient of the two-beam accelerator is defined by shunt impedance of unloaded cavities and achieved at a small value of the main beam current. At high intensity of the main beam, when the efficiency of the energy conversion from the driving beam to the main beam is close to 1.0, the voltage excited in cavity is equal to:

$$U = 2(1-\eta)\frac{R_0 I_d}{\sqrt{1+\xi^2}}$$

where η - efficiency of conversion the driving beam energy into the energy of the main beam., R_0 - shunt impedance of the cavity, I_d - average current of the driving beam, $\xi = Q(2\Delta f/f)$ - relative detuning of the cavity. The efficiency of the energy conversion is equal to

$$\eta = \frac{I_d}{I_m\sqrt{1+\xi^2}}$$

and I_m is average current of the main beam. These equalities are consequence of the balance of the power:

$$P_d = P_m + P_{loss}$$

where P_d - average power of the driving beam which is spent to excite the cavity, P_m - average power which is taken to accelerate the main beam, P_{loss} - power lost in the cavity.

The average accelerating gradient,$E = U/L$, of accelerating structure with cylindrical cavities which have period

$$L = \lambda(\beta_d^{-1} + \beta_m^{-1})^{-1}$$

is equal to:

$$E = \frac{1-\eta}{\sqrt{1+\xi^2}} \frac{\rho_0 I_d}{\pi\delta} \Psi$$

where $\rho_0 = \sqrt{\mu_0 \varepsilon_0} = 120\pi$ - wave-forming resistance of free space, δ – skin-layer and

$$\Psi = (\frac{1}{\beta_d} \pm \frac{1}{\beta_m} + \frac{h}{L}\frac{2\pi}{j_{01}})^{-1}$$

where h– accelerating gap, j_{01} – first root of the Bessel function.

The average deaccelerating gradient of this structure for driving electrons is recouped by the average induction field:

$$E_{ind} = \frac{E}{\sqrt{1+\xi^2}}$$

For accelerating structure based on copper cavities

$$E \simeq 310^7 \frac{1-\eta}{\sqrt{1+\xi^2}} \frac{I_d}{\sqrt{\lambda}} \Psi$$

Let the average driving beam current be equal to 500 A, the wave length be equal to 0.02 m and the relative detuning be equal to ξ = 100. If the conversion efficiency of the driving beam energy into the main beam energy is equal to 70 % the average accelerating gradient will be equal to 100 MV/m. For superconducting accelerating structure of two-beam accelerator shunt impedance is equal to some ten GΩ, so there aren't any problem to excite the very high accelerating gradient. The balance of the powers of the primary and secondary beams gives the following value of the average accelerating gradient for particles of the main beam:

$$E = E_{ind} \frac{I_d}{I_m}$$

where E_{ind} - electric field of the LIA. In this case the induction electric field can be reduced down 10-100 kV/m and a transistor type of LIA modulators can be successful used. Such modulators are much cheaper and more reliable than RF station of the conventional linear colliders. Maximal accelerating gradient of the superconducting two-beam accelerator is determined by critical fields of superconducting cavities.

ACKNOWLEDGEMENTS

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