NEW SCHEME OF TWO BEAM ACCELERATOR DRIVER BASED ON LINEAR INDUCTION ACCELERATOR*

A.V. Elzhov, A.A. Kaminsky, A.K. Kaminsky, V.I. Kazacha, E.A. Perelstein, S.N. Sedykh, A.P. Sergeev,
Joint Institute for Nuclear Research, 141980, Dubna, Russia

Abstract

A new scheme of two beam accelerator (TBA) driver based on a linear induction accelerator is suggested in this work The electron beam bunching occurs at a rather low initial energy ~1 MeV. The bunched beam is accelerated in the .accompanying enhanced synchronous microwave that provides the steady longitudinal beam bunching along the whole driver. There is no total microwave power extraction anywhere in the driver. A beam-loaded waveguide (initially corrugated and regular further) is used along the driver. The planned test experiment based on JINR LIA-3000 should yield the possibility of studying the bunching, microwave generation, beam propagation and twofold microwave extraction.

INTRODUCTION

The Two Beam Accelerator (TBA) drivers based on a linear induction accelerator (LIA) were discussed in [1], [2], [3], [4]. In these schemes the driver electron beam moves through alternating discrete row of microwave generators (free electron lasers (FEL), relativistic klystrons, etc.) and reaccelerator sections. The microwave power is totally extracted from the driver after every generation section. The continuous microwave power extraction along the whole driver length was designed in CLIC [5]. The beam dynamics in TBA with continuous microwave power extraction was studied in [6].

A new scheme of TBA driver based on a linear induction accelerator was suggested in [7]. The scheme is quite uniform and has the following characteristic properties: a) the electron beam bunching occurs at a rather low initial energy; b) the bunched beam is accelerated in the accompanying of the microwave that provides the steady longitudinal beam bunching along the whole driver; c) there is no total microwave power extraction anywhere in the driver; d) a waveguide is used along the driver.

The driver consists of an injector, buncher and long (a few hundreds meters) row of separate LIA sections producing the external accelerating electric field and partitioned by transition chambers. The injector produces the initial electron beam with energy 1 through 2 MeV and current 0.5 through 1 kA. For beam bunching a travelling wave tube (TWT) working in the amplification mode may be used. Then the electron bunches continue moving in the LIA in accompaniment of the amplified in the TWT microwave and are accelerated in the LIA electric field. The microwave power extraction from the driver occurs only in the transition chambers. The system attains the steady state at first few tens meters where the bunch energy increases up to the level of ~ 10 MeV. Then the spatial region of quasi-stationary microwave generation begins where the total power, that the accelerating field inserts into the beam, transforms into the microwave power. The scheme provides the microwave phase and amplitude stability. The phase stability can be obtained at the expense of quasi-continuity of the system. Due to the bunched beam acceleration it is not necessary to have a high (~ 10 MeV) initial electron beam energy.

1 SIMULATION OF ACCELERATION OF ELECTRON BUNCHES ACCOMPANIED BY ELECTROMAGNETIC WAVE IN EXTERNAL ELECTRIC FIELD

We have three characteristic regions of the driver: 1) the bunching region with using of TWT and without acceleration, 2) transition region with a beam acceleration, and 3) quasi-stationary beam propagation region.

As it was shown in [8], one can obtain the electron beam bunching in a TWT at a rather short length ~ 50 cm, for example for the following electron beam and E_{01} type microwave parameters: electron beam energy ~ 2.2 MeV, electron current inside TWT I_b ~ 500 A, electron beam radius ~ 0.5 cm, microwave frequency $f_0 = 17 \cdot 10^9$ Hz (λ~1.76 cm), initial microwave power in TWT ~ 10 kW, output microwave power in TWT at the acceleration region entrance ~ 13 MW.

Without accompanying microwave, the debunching process will immediately occur at the distance of few tens centimeters from the buncher output. The simulation showed that the electron bunches could be transported through the distance ~ 10 m if the bunch movement is accompanied by the microwave amplified in the TWT. The most encouraging situation is that when the moving

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after the TWT output bunches are simultaneously accompanied by a part of the amplified microwave and accelerated in the external electric field inside a corrugated waveguide.

The distinctive feature of the TWT calculations in our case is the large electron beam loading of the waveguide. It conduces to essential alteration of the microwave phase velocity and to the change of the wave-particle synchronism condition. For example, the calculated dependence of the microwave amplitude a_{max} value on the unloaded phase velocity β_{ph} for the electron beam parameters mentioned above is shown in Fig.1.

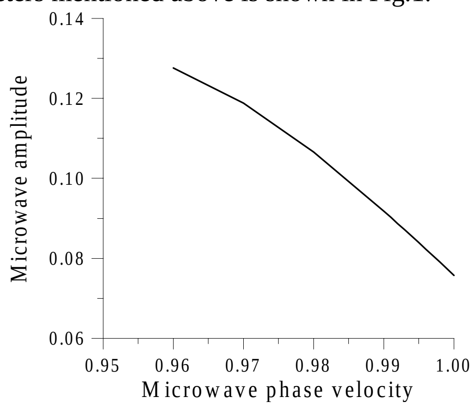

Figure 1: Dependence of the microwave amplitude a_{max} on the unloaded waveguide phase velocity β_{ph} .

One can see from this figure that when the β_{ph} value increases, the a_{max} value decreases. Availability of the amplifying effect when $\beta_{ph} > \beta_{\|}$ (the longitudinal beam velocity) is connected with the beam bunching process in a TWT which decreases β_{ph} value down to a such value when the synchronism is established and the energy transfer from the electron beam to the microwave takes place. This effect allows us to use a smooth waveguide with $\beta_{ph} \approx 1$ in LIA sections. One can also see from Fig.2 that the electron beam bunching parameter B increases with increasing of the β_{ph} value.

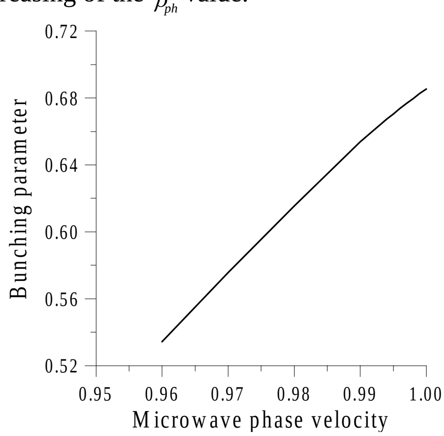

Figure 2: Dependence of the bunching parameter on the unloaded waveguide phase velocity β_{ph}.

In [7] three sets of calculations corresponding to different variants of driver geometry were carried out. The first one was accomplished for the case when the external electric field and the attenuation spatial coefficient (corresponding to the microwave power extraction) had been continuously distributed along the driver. The second set of calculations was performed for the more realistic driver with a discrete structure of LIA consisting of separate induction sections partitioned by transition chambers. The lengths of the induction sections and transition chambers were chosen to be l_s = 50 cm and (l_t = 25 cm) respectively. The microwave extraction was being switched on only in the transition chambers, and the electric field E_a was equal to 1.5 MV/m inside the accelerating sections. In the third set of calculations for the same lengths of the accelerating sections and the transition chambers the accelerating voltage of every section (750 kV) was concentrated only on the gap 7.5 cm long located at the beginning of every section.

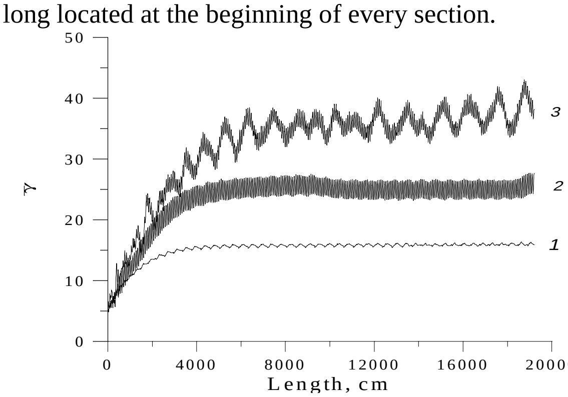

Figure 3: The electron mean energy versus the distance for: 1 - continuously distributed driver parameters; 2 - discrete periodic cells, 3 - discrete cells with narrow accelerating gaps.

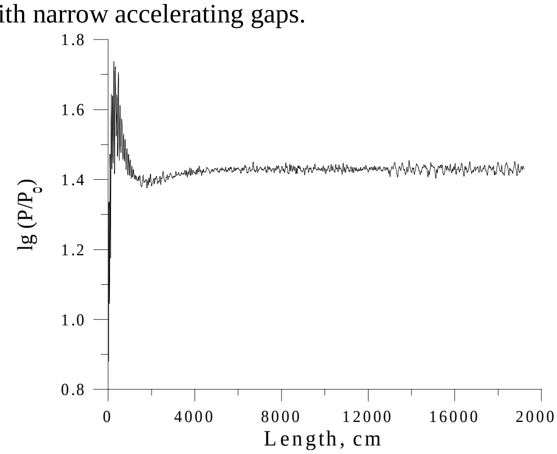

Figure 4: The microwave power versus the distance for continuously distributed driver parameters.

Fig. 3 shows the calculated dependence of the bunch mean energy $\bar{\gamma}$ on the distance ($z = 0$ corresponds to the TWT output) for the whole three sets of calculations. The dependencies of the microwave power and the bunching parameter B on the distance are shown in the Fig. 4 and Fig. 5. One can see from these figures, the quasi-steady state of the system is achieved at the distance ~ 40 m. The extracted microwave power in the quasi-steady state is equal to ~ 333 MW. The mean steady state bunch energy

~ 7.5 MeV. And at last we have the high value of the bunching parameter $B \cong 0.9$ in the quasi-steady state. The electron phase space picture (see Fig. 6) shows that the initial bunch breaks down on two main bunches being at the phase shift $\Delta\psi \cong 2\pi$ one from another.

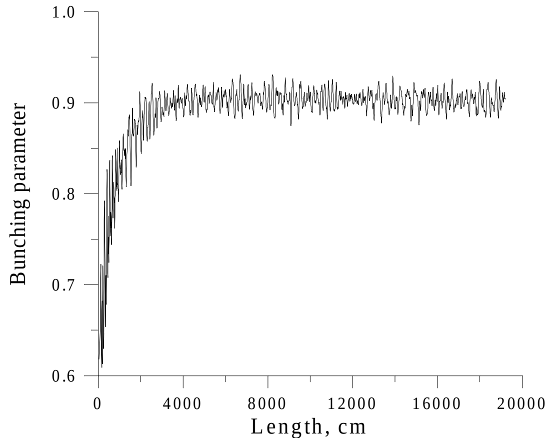

Figure 5: The bunching parameter versus the distance for continuously distributed driver parameters.

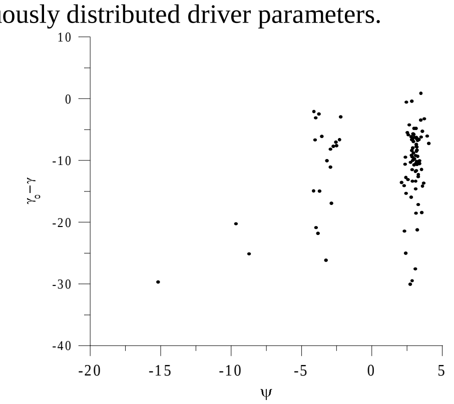

Figure 6: The typical electron phase space picture at the distance of 100 m for continuously distributed driver parameters.

So the external electric field puts into the electron beam the power equal to ~ 500 MW/m which transforms into the microwave power in the steady state. The investigation of solution stability revealed the existence of the steady state solution up to error values $\delta I/I \cong \pm 10\%$ in the electron beam current.

2 TEST FACILITY

Series of test experiments are planned at JINR to study the scheme mentioned above. The scheme of the experimental setup based on the existing LIA-3000 facility is shown in Fig. 7. It consists of the injector and two reaccelerating sections. At the injector output the electron beam energy is about 800 keV and the current is equal to 200 A. The input microwave power is about of 10 kW with the wave length of 8 mm. Each reaccelerating section is 130 cm long and gives the energy gain of 360 keV. The microwave extraction and reacceleration voltage in this scheme are both located in the narrow gaps between accelerating sections each few centimeters long.

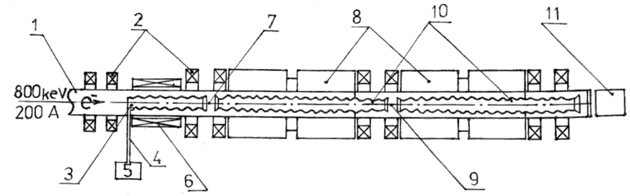

Figure 7: The experimental setup scheme on the base of LIA-3000: 1) injector exit; 2) magnetic field coils; 3) travelling wave tube; 4) waveguide; 5) magnetron; 6) magnetic solenoid; 7) first accelerating gap; 8) linear induction accelerating sections; 9) second accelerating gap; 10) corrugated waveguide; 11) diagnostic chamber.

The fulfilled simulation of the beam propagation, acceleration and microwave extraction for the real LIA-3000 parameters gives that the extracted microwave power should amount by approximately 10-15 MW per gap. The obtained spatial evolution of the bunch mean energy is presented in Fig. 8. Two rapid increases in the energy exactly correspond to the accelerating gaps. From the figures one can see that the travelling electron beam maintain rather high bunching parameter, while the beam energy rises from 0.8 to 1.3 MeV.

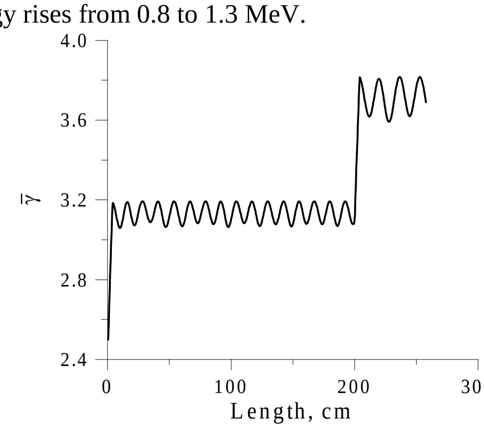

Figure 8: The electron mean energy versus the distance for LIA-3000 parameters.

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