BEAM DYNAMICS OPTIMIZATION AND FUTURE PLANS FOR LUE-200 LINAC UPGRADE

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Abstract

The Intense Resonance Neutron Source (IREN) is now in test exploitation and further development in JINR [1-3]. The linear electron accelerator LUE-200 is used to generate intense fluxes of resonant photo-neutrons. Linac should deliver up to 200 MeV electron beam with 1 A or more current in 200 ns pulses. It consists of electron source, LEBT including buncher and two main accelerating sections. One of the sections was commissioned in 2007 and operated before 2016 when the second section installation was started. Test runs of the first section shows that beam loading influence to the output beam parameters very sufficiently and beam energy after first section decreases from planned 55-60 MeV up to 35 MeV. The buncher doesn't provide efficient beam bunching also and beam recapturing by the main section is not high enough. Dynamics of the electron beam for travelling wave S-band linac LUE-200 was studied by numerical simulation. The report shows results of the beam dynamics simulation and optimization taking into account beam loading. Parameters for the new more effective buncher and first results of such buncher development are also shown.

INTRODUCTION

LUE-200 is conventional travelling wave linac with Disk-Loaded Waveguide (DLW) operating on $2\pi/3$ mode; group velocity is equal to 0.02c. It's prototype was developed as injection linac for electron-positron collider VEPP and its exploitation in G.I. Budker Nuclear Physics Institute of RAS was started in 2015 after long time construction and tuning. It consist of five regular sections providing 450 MeV electrons with ~400 mA of pulse current. But VEPP injector should generate very short pulses consisting of <10 bunches. LUE-200 should accelerate more intensive beams (1 A of pulse current or more) with beam pulse duration up to 400 ns. It highly influences the beam loading and leads to sufficient decrease of electrons energy along the bunch: transient process influences the parameters of approximately 50 bunches. Four-cell standing wave buncher (operating on $4\pi/3$ mode, [4]) is the second problem. In the buncher coupling between the cells and RF power load is not enough for 1 A beam acceleration. It leads to non-effective beam bunching and capturing of the beam by the regular section falls down. Beam energy spread also grows. Let us try to correctly simulate the beam dynamics in LUE-200 taking into account beam loading and to propose some ideas to improve the beam bunching and to reduce beam loading influence.

LUE-200 LINAC CONSTRUCTION AND CHARACTERISTICS

The general view and scheme of LUE-200 are shown in Figure 1. Linac consists of two electrode E-gun (200 keV), LEBT including short 4-cells buncher with focusing solenoid, two regular sections and HEBT but the second section was installed in 2015 only as it was noted above. First regular section consists of 85 DLW accelerating cells (297 cm length, resonant frequency of 2856 MHz), operates on $2\pi/3$ mode and have magnetic coupling on the axis only and low group velocity equal to 0.02c. The focusing is realized by means of solenoid providing B=0.028 T on the axis. The focusing is effective and transverse current loses are not observed. RF feed of the section is provided by a high power klystron with SLED (RF power amplifying coefficient is ~4). It was planned to use the SLAC 5045 klystron with pulse power up to 65 MW but now 18 MW Thomson TH 2129 is used. Note that about 1 MW of RF power is separated by directional coupler to feed the buncher. Less power leads to lower output energy that was projected and beam loading influence is more sufficient in this case. Nevertheless new modulator and 50 MW klystron are now been tested. Typical beam energy spectrums are presented in Figure 2; the output energy vs. beam current is also shown.

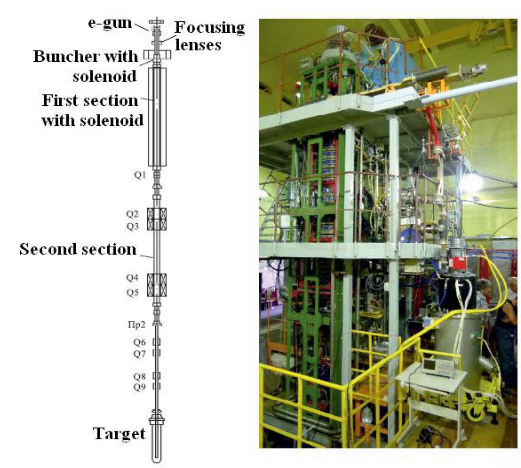

Figure 1: The general scheme (left, not in scale, Q1-Q9 are matching quadrupoles) and photo of LUE-200.

BEAM DYNAMICS IN BUNCHER

As it was noted above, the used buncher of LUE-200 can not provide effective beam bunching because of too

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high current in linac. It is illustrated in Figure 3 in which beam dynamics simulation results are presented. Beam dynamics simulation was done using BEAMDULAC-BL code which was developed in MEPhI for simulations taking into account beam loading and Coulomb field self-consistently [5].

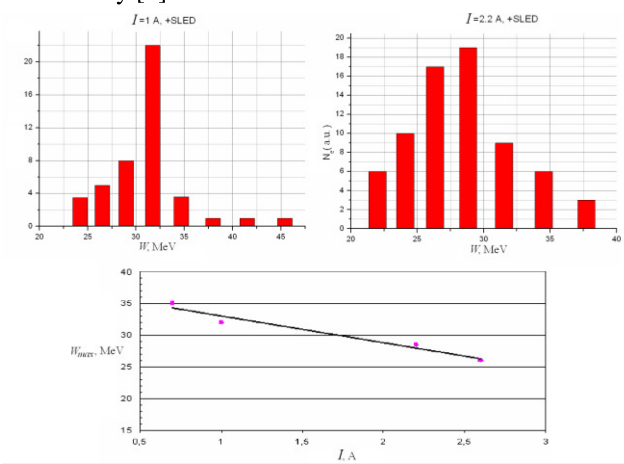

Figure 2: Typical measured beam energy spectrums (top) for LUE-200 and output energy vs. beam current.

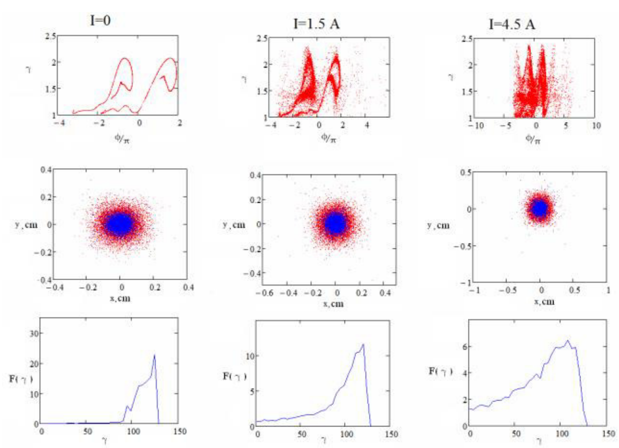

Figure 3: Beam dynamics simulation results for LUE-200 buncher for different currents: beam on (γ, φ) phase plane (top), beam cross-section and energy spectrum after regular section (bottom). The capturing coefficient for the regular section doesn't exceed 50-60 %. Here and next all initial values are plotted by red points and lines, output – by blue.

It was shown by simulation that bunch with I>1 A will be effectively captured by the regular section if its phase size will be ~π/2 and energy is equal to 2.5±1 MeV. It is clear from figure that operating buncher doesn't provide these parameters and its replacement is recommended. Note that the simulation was done for nominal RF power in buncher value of 1 MW not taking into account that coupler was developed for 400 mA of beam current and can have not enough coupling coefficient for 1 A beam. The power of klystron was taken equal to 45 kW (maximal RF field amplitude on the axis of the regular section E_0~600 kV/cm).

BEAM DYNAMICS IN REGULAR SECTION

Beam dynamics was also simulated for regular section. Three field models were studied: maximal RF field amplitude on the axis of the regular section ~360 kV/cm (18 MW from klystron and ~80 MW after SLED, this is the operating mode at present); ~600 kV/cm (45 MW from klystron is now under commissioning); ~900 kV/cm (65 MW from klystron, projected power). It was shown that both beam loading and non-effective beam bunching seriously influences the beam dynamics. Transient process of the beam energy stabilization is very long (about 15 ns or 50 bunches) due to very low coupling coefficient and group velocity for the regular section. Such effects are clear from Figure 4 which shows bunch-to-bunch dynamics simulation results for E_0=360 kV/cm: peak and averaged bunch energies fall down from 60 to 35 MeV and from 50 to 30 MeV correspondingly. Current transmission coefficient of 70 % is observed but it was proposed that 1 MW is really loaded into buncher and the beam loading influence in buncher is not sufficient. It is not more than 50 % in real and beam loading influence will be less there. Peak and averaged bunch energies fall down from 100 to 57 MeV and from 77 to 46 MeV correspondingly for E_0=600 kV/cm; from 105 to 57 MeV and from 145 to 65 MeV correspondingly for E_0=900 kV/cm. That illustrates dominating effect of beam loading to the beam dynamics clearly. Note that necessary for effective photo-neutrons production energy of 50-60 (100 after two regular sections) MeV will be achieved after 45 MW klystron commissioning but transient process will still influence the beam energy and spectrum.

The SLED characteristics also influence the beam dynamics. SLED was developed for short bunch acceleration as it was provided in VEPP injector. The pulse after SLED have serious drop, it is about 40 % for 500 ns RF pulses. Such drop also influences the beam dynamics very seriously. This case is illustrated in Figure 4f for first 100 bunches in the pulse.

NEW BUNCHER

It was proposed to replace operating buncher by new one which will specially developed for high (>1 A) beam current bunching and will provide the phase size ~π/2 and bunch energy ~2.5±1 MeV which are necessary for effective recapturing by the regular section. Such buncher can be based on the short DLW travelling wave section operating on 2π/3 mode. It can consist of 7 accelerating sells (see Fig. 5). Four of them will have growing from 0.6 to 0.9 phase velocities β_{ph} and RF field amplitude for effective beam bunching. The 1st and the 7th cells will also be RF couplers. Maximal RF field amplitude on the axis ~240 kV/cm is enough for effective bunching as it is clear from Figure 6. Beam parameters after buncher are shown for two cases: for "ideal" field distribution which was optimized by numerical simulations of the beam dynamics (RF field amplitude grows form $0.5 \cdot E_{max}$ in the 1st cell to E_{max} in the 5th) and for "real" distribution for

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simulated and tuned CST model of the new buncher (see Fig. 5). The results are very close; the current transmission coefficient is equal to 79 % in the first case and to 81 % in the second. It is clear that proposed buncher can provide the bunch phase size and energy necessary for effective recapturing by the regular section.

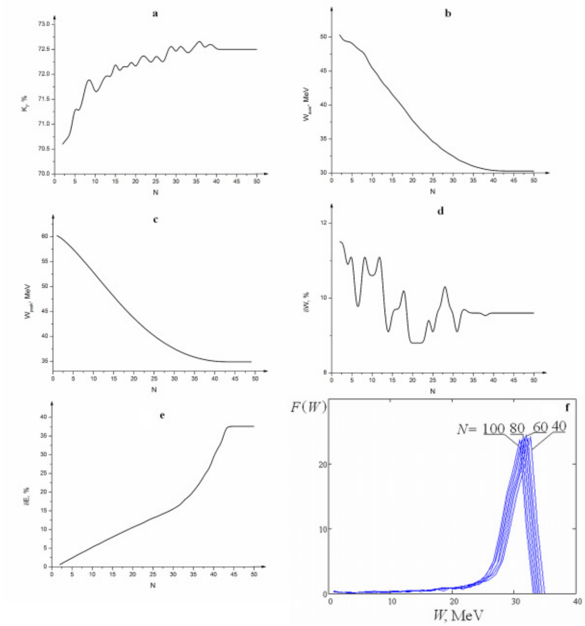

Figure 4: Beam dynamics simulation results for regular section of the LUE-200: current transmission coefficient (a), averaged (b) and peak (c) bunch energies, energy spread ±δW on half-width of spectrum (d) and RF field amplitude drop in the last section cells compared to unloaded mode vs. the bunch number in the pulse (e). The energy spectrums drop vs. the bunch number (f). Maximal RF field amplitude 360 kV/cm on axis.

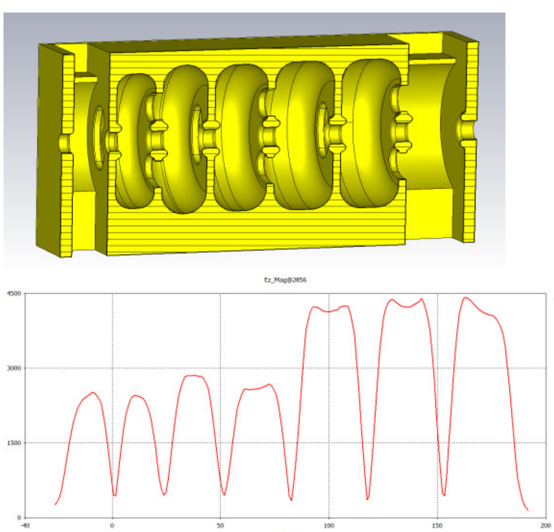

Figure 5: CST model of new 7-cell travelling wave DLW buncher and RF field amplitude distribution in cells.

CONCLUSION

Beam dynamics simulation results for LUE-200 linac are presented. Dominating effect of beam loading to the beam dynamics was shown due to long transient process caused by low coupling and group velocity in the regular section. It was also shown that the buncher operating at present can not provide the effective beam bunching. Efficiency of LUE-200 can be grown after the commissioning of 45 - 50 MW klystron which in under processing now. New more effective buncher was also proposed. The phase matching between the buncher and the regular section is also useful for beam quality growth.

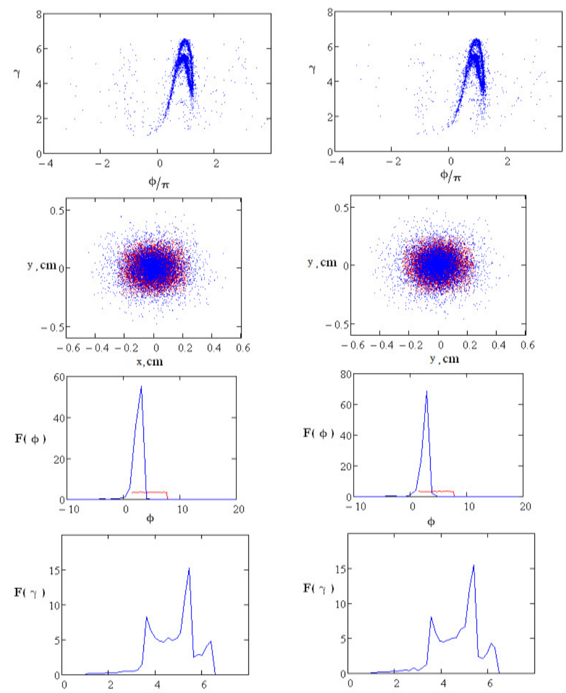

Figure 6: Beam dynamics simulation results for new buncher (top-to-bottom): beam on (γ, φ) phase plane (top), beam cross-section, phase and energy spectrums after buncher. “Ideal” (left) and simulated RF field distributions are studied.

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