FUNCTIONING OF LINEAR INDUCTION ACCELERATOR OF ELECTRONS LIA-30 IN THE MODE OF SIMULTANEOUS FORMING AND ACCELERATION OF 2 - 3 HIGH-CURRENT RELATIVISTIC ELECTRON BEAMS

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The carried out experimental investigations of LIA-30 accelerator injection system as well as the new data on standard operation modes testing in bremsstrahlung pulse generation made it possible to take a new view of electrophysical processes taking place in the accelerating track. In spite of success achieved in searching for optimal acceleration conditions – namely, limitation of edge steepness and amplitude of injection current pulses, definition of the program of forming voltage pulses that accelerate electrons etc. – there still remains to acute the task of decreasing lateral oscillations of high-current relativistic electron beam along the track as a whole and especially in cathode-anode gap where the influence of longitudinal magnetic field irregularities is most evident. When the magnetic field is limited in the track what is related to technical potentialities, the oscillations decrease in the injection system equipped with a two-beam cathode. Moreover, this process of electron beam acceleration becomes more stable even under conditions of parameter changes in the accelerator subsystem operation.
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1 INTRODUCTION

The 36-module pulse high-current high-energy electron accelerator with inductors based on radial lines LIA-30 (~40 MeV, ~100 kA, ~20 ns) has been operating in RFNC-VNIIEF since 1987 [1].

The module structure permits to expect realization of a large number of operation modes of accelerator through a change of high-voltage electrodes contained in an accelerating track, and variation of delays of voltage switching on the outputs of inductors of either module group [2]. At a stage of physical accelerator start-up there were conducted experiments with different modifications of the injection system where the number of enabled modules was changing [3]. In doing so for currents of the electron beam of 50…170 kA the injection energy varied in the range of 2.5 ÷ 7 MeV. Further the beam was captured by the accelerating system composed of one type inductor units with 0.43m aperture of drift tubes (see fig.1), inside which solenoids of the leading magnetic longitudinal field were placed. On the outer diameter the tubes were separated from the inductor water insulation by high-voltage insulators of 0.75 m diameter. The diameter of the corresponding cylinder cavity of injector units (N 1÷4) was 1.40 m.

At presence of a very strong outer magnet field the motion of the high-current electron beam (EB) is determined by the longitudinal component of a pulsed electric field E_Z [4].

Rough estimates and experiments with a real beam in the available accelerating track with $E_Z \le 3$ MV/m proved inefficiency of acceleration and propagation of the electron beam with the current $I_m > 100$ kA along the whole accelerator length equaling ~26 m. Deceleration of EB with steep edges $\Delta I/\Delta t$ ~20 kA/ns led to appearance of high-frequency electromagnetic fields in drift tube cavities followed by modulation of the beam itself. In Fig. 2 shown are the experimentally registered changes of the electric potential $U_{15}(t)$ near the accelerating gap of the 15-th inductor unit synchronized with the transmitted beam current $i_{EB}(t)$. The unit itself was disconnected from the charging voltage. The period of registered oscillations T ~ 4 ns was close to the doubled travel time along the unit length $2t_{unit} = 4{,}2$ ns. In the subsequent units the oscillation amplitude grew, thickness of hollow EB increased, electrons began to scatter onto the accelerating track walls what pointed to the longitudinal EB modulation over density similar to that shown schematically as dash electron trajectories in Fig. 1.

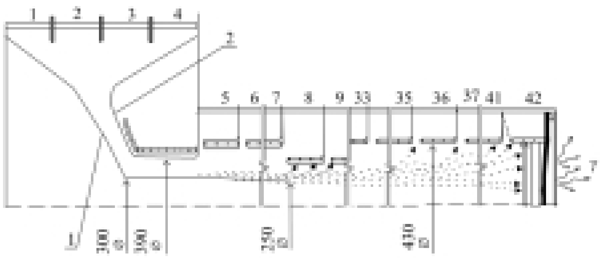

Fig. 1. Constructive scheme LIA-30 with diode current Im ~170 kA.

An urge for EB modulation on the first section is presence of electrons with phase velocity v less than the velocity of light c, delayed from the main relativistic electron stream in the course of acceleration.

Collision of scattered electrons with molecules of residual gases in accelerator track at P >$2{\cdot}10^{-2}$ Pa caused plasma formations that bridge units' accelerating gaps. Loading of units with proper currents (~100 kA) through plasma broke the acceleration process at a greater degree. The presence of azimuth irregularity of electron leakages led to randomness of the following processes, as a result, hollowness of high-current EB was broken, and on beam autograph/imprint on the outlet there was registered a spot significantly degraded in density that completely filled the aperture of the accelerator exit window.

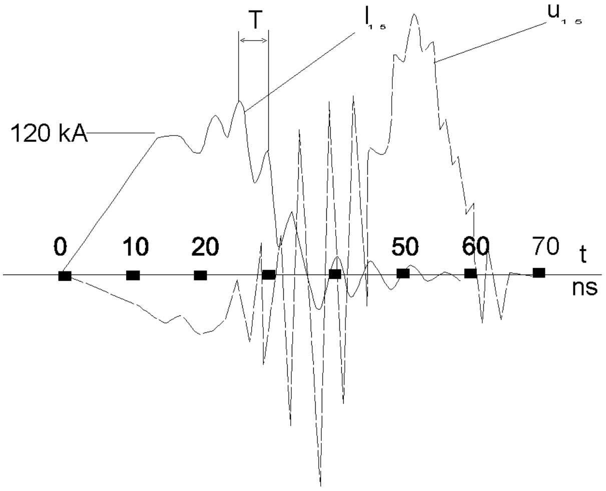

Fig. 2. Pulsed beam current and induced potential.

Similar effects of beam electron scattering and partial short-circuiting of accelerating units were observed also in other cases: at local attenuation of longitudinal magnetic field B_Z or shift of electron beam or its part in the radial direction during failure of B_Z and E_Z forming systems, for example, at solenoid breakdowns or untimely unauthorized start-ups of controlled radial line switches.

Functioning of LIA-30 at small currents with I ~70 kA with the steepness $\Delta I/\Delta t$ ~4 kA/ns on the pulse edge allowed to reach a sufficiently stable acceleration and output parameters. However, a desire to get high currents and, in this connection, realization of some additional accelerator capabilities remained unsatisfied.

2 SPECIFIC FEATURES OF MAGNET INSULATION OF HIGH-CURRENT EB

There were conducted additional studies of high-current EB forming in different injection systems.

Firstly, there became clear the problems of magnet insulation between cone parts of cathode support 1 and anode electrode 2 at 150 mm diameter of the cathode tube and amplitude B_Z <0.5 T on the accelerator axis. In spite of experimental matching of cathode profile and field line configuration of anode solenoid edge magnetic field, one could not fully avoid leakages appearing on the diameter >∅210 mm at realization of cathode emitters with diameters not less than 150 mm. Individual azimuth electron leakages were captivated by the accelerating system in parallel with the main beam and violated the total system equilibrium. The problem was partially solved by installing metal absorbing diaphragms in the accelerating track on the way of leakages, however, diaphragms themselves also could cause electromagnet fields disturbance during high-current electron beam formation. Also leakages were diminished through enlargement of the gap between electrodes provided that a completely cylindrical cathode support was employed. However, in doing so, losses of power supplied to diode grew, and duration of injected current pulse increased.

Secondly, a significant problem was B_Z pulsation on unit junctions when moving from the axis to solenoid wraps on the azimuth of their electric lead locations. Especially it was notable in the cross-section of the 4-5-th units where the leads of extended and more power-consuming anode solenoid were located. Formation of electron streams existing in this region was accompanied by redistribution of their azimuth density.

3 EXPERIMENTAL RESULTS

In connection with circumstances listed there we have studied the electron beam injection with a two-emitter cathode. The second point emitter with a medium diameter of 243 mm was coaxial with the main annular emitter of ~135 mm diameter (see Fig. 3) and with a height ~0.4 m. Thus, it was supposed to raise in such a way the total injection current and to provide electromagnetic fields for the internal beam that were more homogeneous in azimuth in the region of its formation. As measuring instruments there were used inductive current sensors on sections of spiral lines [5], color film dosimeters (CFD) of IP/2,2 type, point luminescent γ-radiation dosimeters.

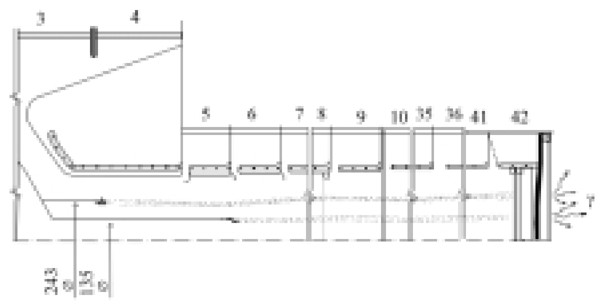

Fig. 3. Constructive scheme of LIA-30 with two-emitter cathode for injection of currents Im ~140 kA.

Fig. 4 shows a negative image of the transversal autograph of two co-axial cylinder beams obtained on the axis distance ~1.7m from the main cathode and demonstrating graphically a two-beam injection.

As was expected, as a result of diode gap shunting by the external beam the electron leakages on the diameter >210mm disappeared, due to this fact the autograph/imprint was shown cut from the sides in Fig. 4. The impedance of a double cathode turned out to be greater than the impedance of a single cathode of ~243 mm diameter.

In Fig. 4 points O and O’ are centers of accelerator axis and emitters circles, inscribed in the annular beams traces. Lines L-P and N-V are of horizontal and vertical orientation. Eight annular contours of ~45 mm diameter limited the azimuth sections of electron beams in directions L, V, P, N; within whose limits in positive image units there was determined an average density J of CFD autographs/imprints exposure.

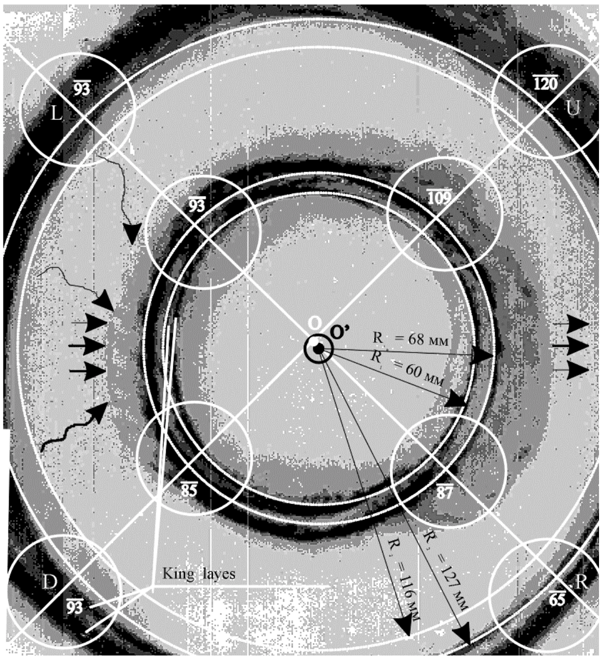

Fig. 4. Transverse autograph beam in eighth accelerators unit.

According to simple calculations the average density value $J=(\Sigma J_i)/4$ in four azimuth directions was 75 and 70 relative units for internal and external beams, respectively, and showed some defocusing of the external electron beam. Relative average declinations from the average values $\Sigma\Delta J_i/\Sigma J_i$ were 13% and 17%, respectively, i.e. the internal electron beam was more symmetrical than the external one. A thorough image analysis showed dynamics of beams interaction according to which the external beam, first of all, "stood in the gap" of electromagnetic fields irregularities and contributed to the integrity of annual internal electron beam. The autograph demonstrated correlation of limits of images comprising layers and relative simplicity of development of the process of formation and initial beam acceleration in spite of integral overlapping of their prompt profiles. Registering of their propagating/passing currents pointed to the absence of the evident traces of the 3-rd or 4-th beams that could be possible on the subsequent accelerating voltage half-waves.

As a result one managed to fulfil injection of the beam increased by the current up to I_m ~140 kA and to propagate/conduct it from I_m ~110 kA to the 34-th module what by 6 modules exceeded transporting of the electron beam corresponding by current with a single cathode injection system. The total level of dose fields around the accelerating track decreased due to electron leakages onto the walls registered by point integral dosimeters.

4 CONCLUSION

As a result of additional beam formation the total cross-section of the electron stream increased, what spoke for expediency of this property use for generating bremsstrahlung radiation (BR) with a spot increased in diameter on the accelerator output. To conduct the electron beam to the accelerator target (cross-section N 42), it was necessary to diminish the amplitude of the total current up to the highness of common values I_{mm} ~75 kA. The used additional emitter represented a metal tube of ∅250 mm diameter [6]. A separation from the main cathode emitter location allowed one to perform simultaneously a two-pulsed mode of electron beam generation and bremsstrahlung pulses with regulated time delay between pulses [2]. Thus, the external beam accompanied the main internal one not along the whole length of its passing but through 24 units. However, an average level of doses registered at the distance of S = 1 m from the target increased by 20 % as compared to the mode in the absence of the additional emitter. Bremsstrahlung spot diameter on 0.5 level from the maximum dose and at a distance of 1m from the target increased from 0.5 m to 0.7 m.

Also, it turned out possible to accelerate simultaneously 3 beams at specific relations of cathode diameters.

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