BEAM DYNAMICS IN NEW 10 MEV HIGH-POWER ELECTRON LINAC FOR INDUSTRIAL APPLICATION

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Abstract

Beam dynamics simulation in electron gun, bunching and accelerating cells of new 10 MeV high-power electron linac was fulfilled with the help of developed at MEPhI SUMA [1] and BEAMDULAC-BL [2] codes. Three-electrode electron gun was used to obtain up to 400-450 mA of pulse beam current which is necessary to produce 300 mA of the accelerated beam. Precise gun simulation was conducted to satisfy all necessary output beams characteristics, such as profile, energy spectrum, phase space size etc. Some additional calculation was conducted to provide wide range of gun output beam parameters which will be used for subsequent accelerator modification. The conventional biperiodical accelerating structure (BAS) based on disk loaded waveguide (DLW) was used in linac. Beam dynamics optimization was pointed to obtain effective beam bunching for all energy range and to achieve narrow energy spectrum. Simulation results shows that linac provides effective beam bunching and acceleration for wide bands of beam currents and energies.

ELECTRON GUN SIMULATION

PIC code SUMA was used for beam dynamics simulation in the electron gun. The traditional three-electrode gun with cathode-grid voltage 1-1.3 kV, emission current 0.5-0.7 A, cathode-anode voltage 50 kV was investigated. Fig. 1 shows computer simulation result for cathode-grid voltage 1 kV and emission current 0.7 A.

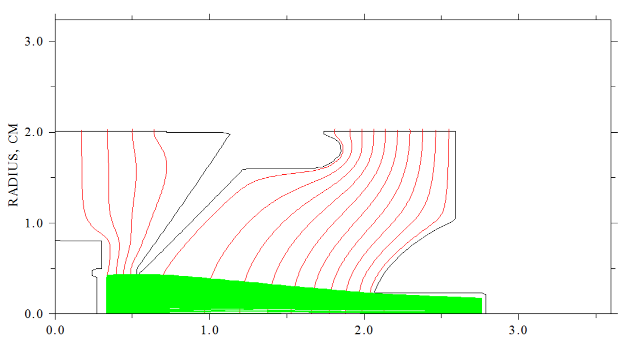

Figure 1: Electron trajectories (green lines), electric field equipotential lines (red lines) and boundary (black lines).

Output energy spread is 1.2% and transverse emittance 2.5 cm·mrad.

For code testing some experiments were conducted. Beam envelope was measured by collimated diaphragm current collector on different distance from gun anode. Fig.2 shows beam envelope dependence on anode distance for different gun currents and cathode – anode voltage is 20 kV, greed - anode microperveance is 0.078. SUMA simulation results for this case are presented in Fig. 3.

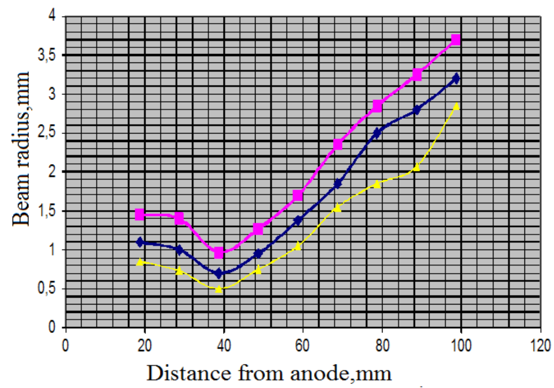

Figure 2: Beam envelope for different current values: red-0.222 A, blue-0.19 A, yellow-0.16 A, cathode-anode voltage 20 kV.

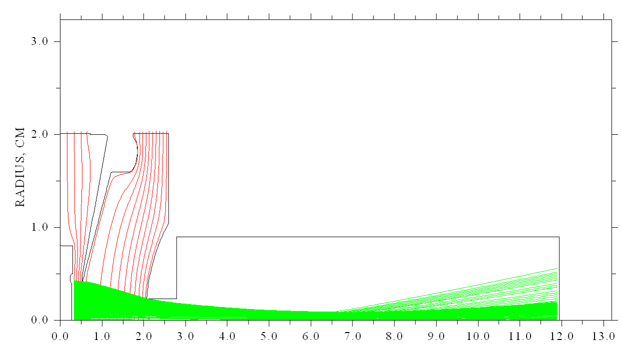

Figure 3: Electron trajectories (green lines), electric field equipotential lines (red lines) and boundary (black lines). Current value -0.222 A.

We obtain a good experimental and calculated results agreement for the beam emittance equals 2.42 cm·mrad and taking into account that distance between cathode and anode equals 25 mm.

For further accelerator modification program it might be necessary to increase output beam diameter from 2 to 3.5 – 4.0 mm or even more. For this purpose some new gun modifications were fulfilled. The main aim was to obtain necessary result with a few changes as possible. First step in this way is to increase the anode hole. Output beam radius rises due to potential sage on the anode hole. Fig. 4 shows beam profile for anode hole radius equals 3 mm (initial value 2.25 mm).

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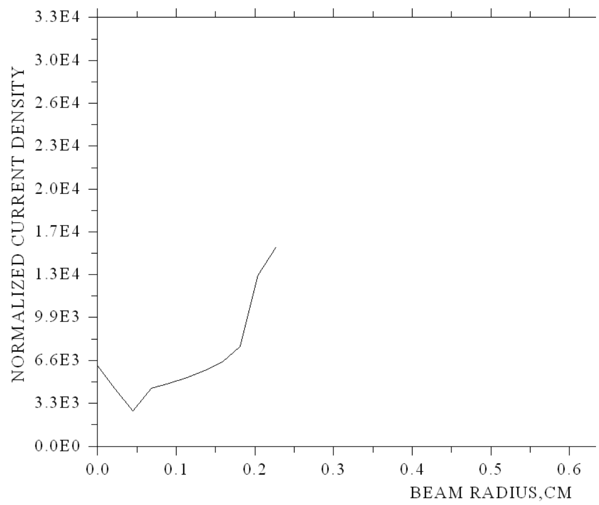

Figure 4: Beam profile.

Another way to increase the beam radius is to straighten equipotential lines in greed – anode gap. Easiest way to do this is to remove anode flange. Electron trajectories for this case are shown in Fig. 5.

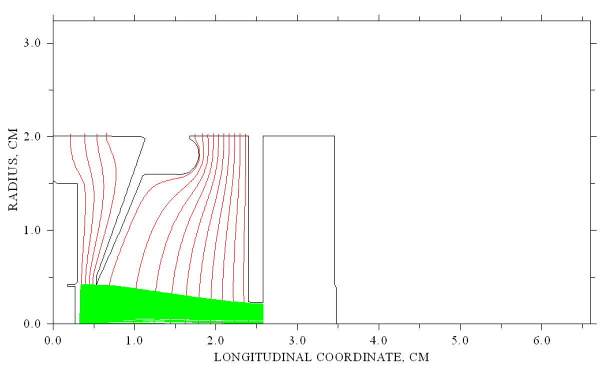

Figure 5: Electron trajectories (green lines), electric field equipotential lines (red lines) and boundary (black lines).

Beam profile is practically the same as at Fig. 4, but emittance decreased to 1.56 см·мрад. If we increase anode gap to 3 mm in last case we obtain emittance 1.26 см·мрад and low energy spread 500 eV. This results seems quite reasonable for further accelerating structure simulation.

ACCELERATING STRUCTURE OPTIMIZATION

Beam dynamics simulation was done using BEAMDULAC-BL code developed at MEPhI for simulations taking into account the beam loading and the Coulomb field effects self-consistently [2]. Beam dynamics optimization was pointed to obtain effective beam bunching for all energy range and to achieve narrow energy spectrum. Both requirements were met using sixperiod gentle buncher proposed. The phase velocities v_{ph} and RF field amplitudes are rising for effective beam bunching. The linac consists of 28 accelerating and 27 coupling cells, its total length is 143 cm. Maximal on-axis RF field amplitude was chosen about 200 kV/cm, it is enough for effective bunching and acceleration up to 13 MeV. One of the middle cells is used as RF power coupler.

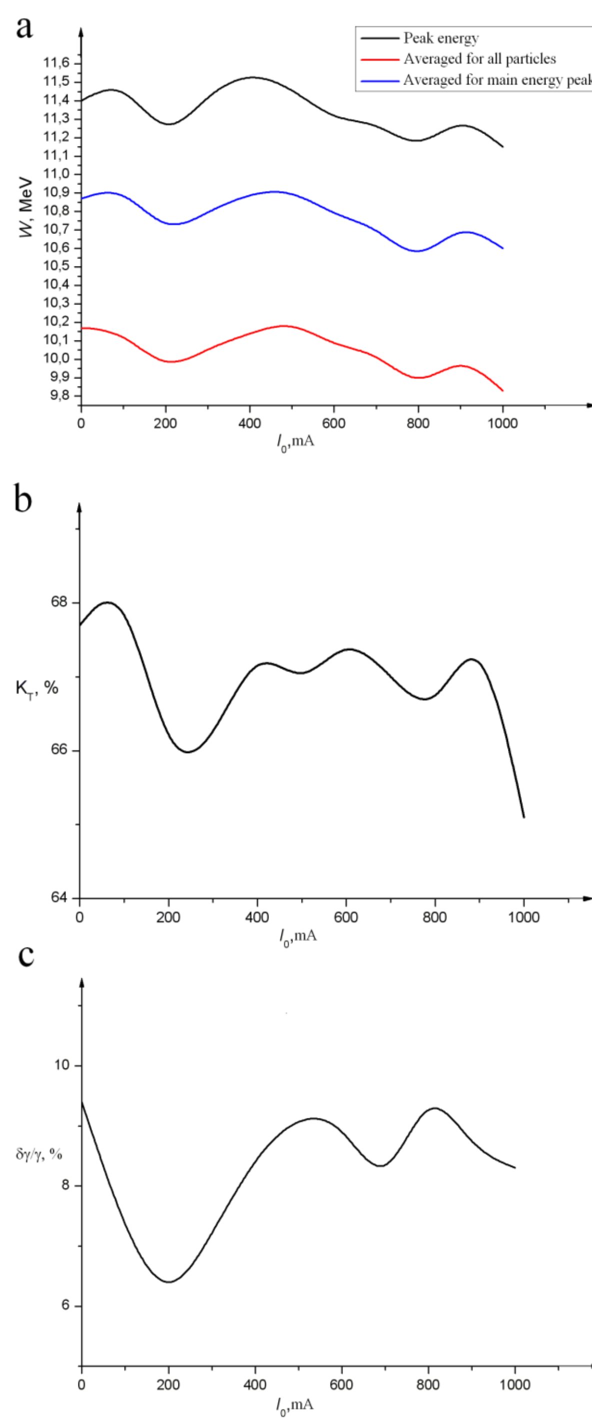

Figure 6: Output beam energy W (a), current transmission coefficient K_T (b) and output energy spectrum measured for full width δγ/γ on the distribution base (c) vs. injection current for E_{max}=160 kV/cm.

Short (~20 cm) focusing magnetic coils are used for beam focusing. Finally three coils were installed before coupler and one after it. Magnetic field of 30 mT on the

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linac axis is necessary for the effective beam focusing. Some main beam dynamics simulation results are presented in Figure 6. It is clear that linac provides effective beam bunching and acceleration for wide bands of beam currents and energies. The current transmission coefficient is not lower than 65 % for all operating modes [3]. It was shown that chosen accelerating structure gives very high quality beam in wide band of energies from 7 to 12 MeV (see Fig. 7 and Table 1). The energy spread measured for total width of the main peak of electron energy distribution is not higher than ± 5 %.

Table 1: Beam Output Parameters vs. RF Field Amplitude

E_{max}, kV/cm	Most probably energy, MeV	Average energy, MeV	Output beam current, mA	K_T, %	δγ/γ on the distribution base, %
70	1.93	1.60	110	24.4	± 3.6
80	4.44	3.86	157	34.9	± 9.0
90	6.19	5.91	198	44.0	± 7.5
100	7.05	7.20	217	48.2	± 4.6
110	7.86	7.94	234	51.9	± 4.9
120	8.61	8.68	256	56.8	± 4.8
130	9.03	9.28	275	61.2	± 4.9
140	9.73	9.89	293	65.2	± 3.8
150	10.34	10.45	306	67.9	± 3.4
160	11.04	11.02	320	71.2	± 3.4
170	11.71	11.62	326	73.4	± 4.9
180	12.33	12.22	316	70.3	± 5.0
190	13.00	12.83	306	68.0	± 6.6
200	13.58	13.43	294	65.3	± 5.2

CONCLUSION

Beam dynamics simulation results in electron gun, bunching and accelerating cells of new 10 MeV high-power electron linac were discussed. It was shown than used three-electrode gun can be effective used to generate high-quality beams having different beam sizes and low energy spread and transverse emittance. It was also shown that accelerating structure with gentle buncher and solenoid focusing can accelerate beams in wide energy band 7-13 MeV with low output energy spread < ± 5 %. Such section was manufactured and commissioned [3] and the base beam dynamics simulations results were confirmed.

REFERENCES

[1] V.I. Rashchikov, Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations, 10 (18), 50 -53 (1990).
[2] T.V. Bondarenko, E.S. Masunov, S.M. Polozov, Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations, 6 (88), 114-118 (2013).
[3] M.I. Demsky, S.M. Polozov, V.I. Rashchikov et al., Proc. of IPAC'16, pp. 1794-1796.

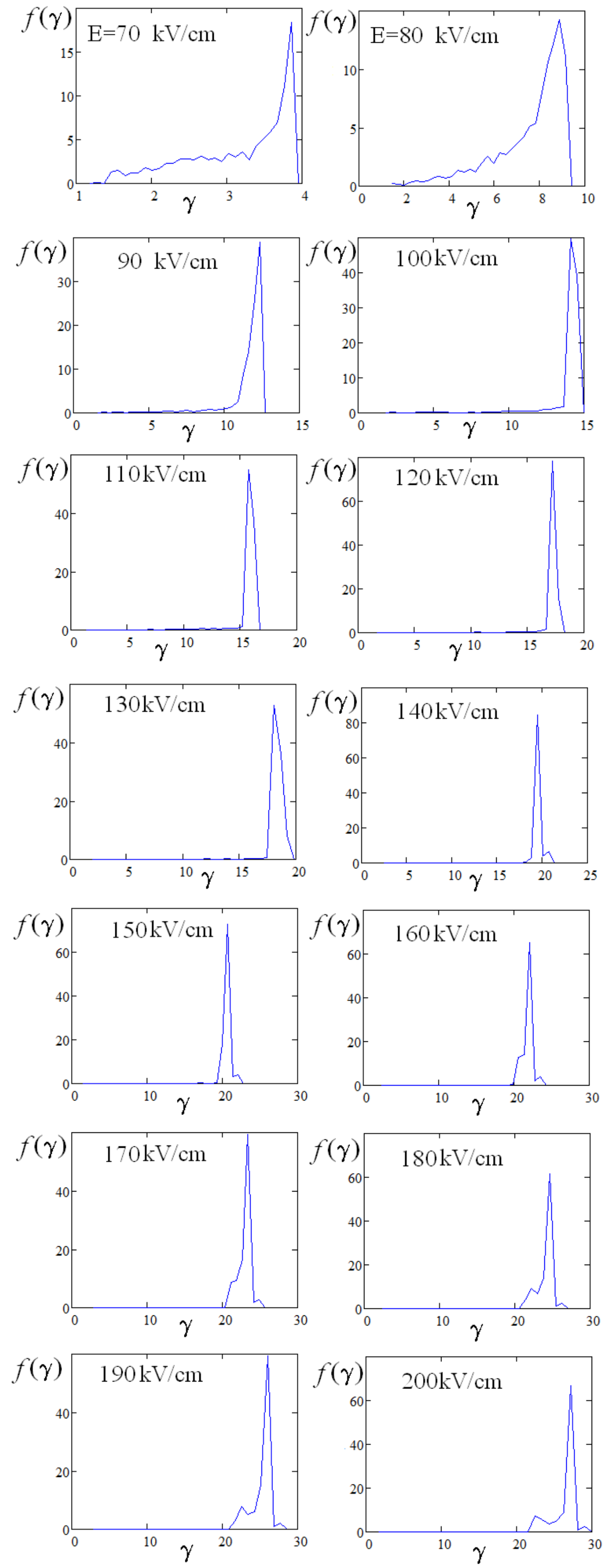

Figure 7: The energy spread measured for total width of the main peak of electron energy distribution vs. RF field amplitude in the range of 70-200 kV/cm.

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