NEW 10 MeV HIGH-POWER ELECTRON LINAC FOR INDUSTRIAL APPLICATION

D.S. Basyl, T.V. Bondarenko, M.A. Gusarova, Yu.D. Kliuchevskaia, M.V. Lalayan, S.M. Polozov, V.I. Rashchikov, E.A. Savin,
National Research Nuclear University – Moscow Engineering Physics Institute, Moscow, Russia
M.I. Demsky, A. Eliseev, V. Krotov, D. Trifonov
CORAD Ltd., Saint-Petersburg, Russia
Bumsoo Han, Wongu Kang, Heung Gyu Park
EB TECH Co. Ltd., Daejeon, Korea

Abstract

Joint team of CORAD and MEPhI developed a new industrial accelerating structure for average beam power up to 20 kW and energy range from 7.5 to 10 MeV. The use of modern methods and codes for beam dynamics simulation, raised coupling coefficient and group velocity of SW biperiodic accelerating structure allowed to reach high pulse power utilization level and obtain high efficiency. Gentle buncher provides high capturing coefficient and narrow energy spectrum. The first linear accelerator with this structure was commissioned and tested in collaboration with the EB Tech Company.

INTRODUCTION

MEVEX, GETINGE, NUCTECH and Wuxi El Pont companies successfully made 10 MeV, 15-30 kW S-band linacs for industrial applications and offer these linacs on the present market. The joint team of CORAD and MEPhI develops similar industrial linac for average beam power up to 20 kW and variable energy range from 7.5 to 10 MeV. New linac has high electrical efficiency, narrow beam energy spectrum, provides energy regulation and low accelerated beam loses.

We tried to realize the following statements in our new linac design: the accelerating structure should have high coupling coefficient for maximal RF pulse power usage efficiency; the gentle buncher should be used to provide high capturing coefficient and narrow energy spectrum for all output energies.

The traditional three-electrode E-gun was used fof injection. It should to provide up to 400-450 mA of pulse beam current to reach 300-320 mA of accelerated beam. Injection energy is equal to 50 keV. The conventional biperiodical accelerating structure (BAS) based on Disk loaded Waveguide (DLW) was used in linac. It operates on standing wave and resonant frequency of 2856 MHz. Wide magnetic coupling windows were used to increase the coupling coefficient which leads to low RF transient time and high group velocity. Low (~200 ns) RF filling time can be realized this case and beam loading influence decreases also. Let we briefly discuss the main results of linac development, manufacturing and testing.

BEAM DYNAMICS IN LINAC

Beam dynamics simulation was done using BEAMDULAC-BL code developed at MEPhI for simulations with beam loading and Coulomb field effects self-consistently taken into account [1]. 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 six-period gentle buncher proposed. The phase velocities β_{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 210 kV/cm, it is enough for effective bunching and acceleration up to 11 MeV. One of the middle cells is used as RF power coupler.

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 linac axis is necessary for the effective beam focusing.

Some main beam dynamics simulation results are presented in Table 1 and Figure 1. It is clear that linac provides effective beam bunching and acceleration for wide bands of beam currents and energies. The current transmission coefficient is close to 65 % for all operating modes and output energy spectrum is limited by 10 % (full width on the distribution base). It is clear that RF efficiency η slowly decreases with E_{max} (or with W_{max}) for constant current. But it wills growth vs. beam current growth for constant W_{max}. It should be noted that E-gun provide about ~450 mA of injection current and results for higher beam currents are interesting only for simulation.

ACCELERATING STRUCTURE

The conventional DLW-based BAS was used in linac as it was noted above. The coupling cell length and diaphragm thickness were chosen constant along of the structure. Traditional RF power coupler was simulated and tuned. The coupler is high over-coupled with the structure (ρ≈4) because of the high beam pulse current. The additional auxiliary rectangular waveguide was

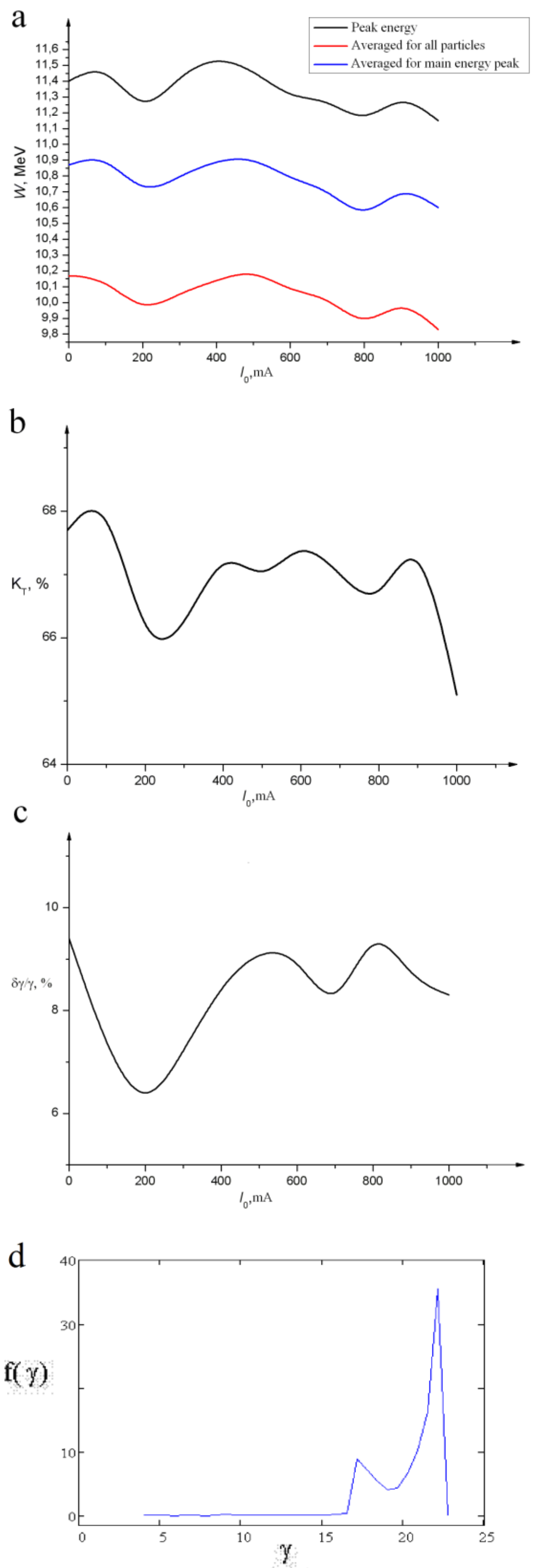

Figure 1: Output beam energy W (a), current transmission coefficient K_T (b) and output energy spectrum measured for full width $\delta\gamma/\gamma$ on the distribution base (c) vs. injection current (E_{max}=200 kV/cm) and typical beam energy spectrum (d) for E_{max}=200 kV/cm.

added to the coupler cell for RF field distribution symmetrization. The main aim of cells optimization was to provide necessary RF field amplitude distribution in buncher (see Fig. 2) with high and constant magnetic coupling coefficient for cells having varying length, shell radius and field. Optimization was successfully done and the following electrodynamics characteristics were obtained: resonant frequency 2856 MHz, coupling coefficient > 10 %, Q-factor 16600, effective shunt impedance 82.5 MOhm/m, and maximal overvoltage on the surface 3.6 (it is observed on the diaphragm tips).

The accelerating cell shape was optimized to minimize multipactor discharge problem. MultP-M code was used for simulation [2].

The measured Q-factor of the manufactured section is equal to 14400.

RF POWER SYSTEM

The klystron TH2173F (Thales Electron Devices) was used for linac RF feeding. It provides up to 5 MW of pulse power for 17 μs RF pulses duration and up to 36 kW of averaged power.

Two solid-state modulators manufactured by CORAD Ltd. feed both klystron and electron gun.

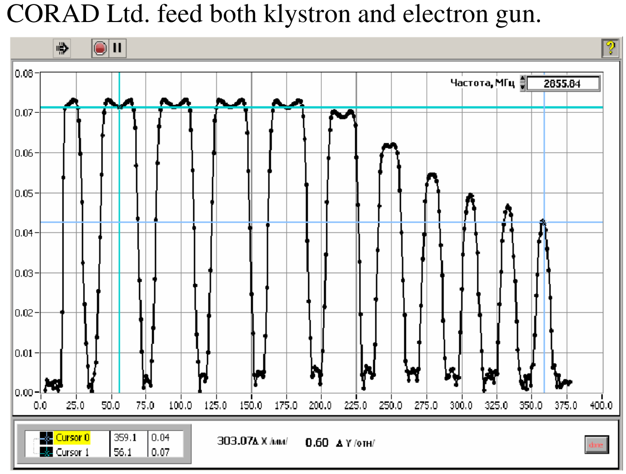

Figure 2: Measured RF field distribution in buncher and first regular cells, the amplitude deviation is not excide of 5 % from the simulated one.

CONCLUSION

The accelerator with new section was assembled and successfully tested at EB Tech Company site in Daejeon (see Figure 3). Control system and some other accelerator components were made by EB Tech.

The beam energy and pulse beam power have very good correlation to simulated values. The beam energy was measured by ISO/ASTM 51649:2005(E) Standard [3]. If we take the most probable energy for definition of the total linac electrical efficiency, latter equals to 19 % for 15 kW beam power and 17.4 % if we take the averaged beam energy value. It is high result for RF linac.

ISBN 978-3-95450-147-2

Table 1: Beam Dynamics Simulation Results and Linac RF Efficiency, I_0=450 mA

E_{max}, kV/cm	Output energy W, MeV			I_{out}, mA	K_T, %	N_{tail}, % (cutoff energy)	$\delta\gamma/\gamma$, %	Power, kW				η, %
	Peak	Avg.	Avg. for main peak					Wall loses	Beam	Beam loses	total	
150.0	9.00	8.38	8.68	255	56.6	5.7 (< 7.0)	7.9	1134	2514	305	4109	61
160.0	9.30	8.58	8.96	268	59.5	5.7 (< 7.3)	8.8	1290	2574	267	4132	62
170.0	9.95	9.11	9.48	273	60.6	6.9 (< 7.6)	7.2	1457	2733	254	4443	62
180.0	10.57	9.63	10.02	281	62.8	8.9 (< 8.5)	7.6	1633	2889	223	4745	61
190.0	10.85	9.84	10.22	287	63.8	8.2 (< 8.5)	7.7	1820	2952	212	4984	60
200.0	11.69	10.61	11.02	302	67.0	6.3 (< 8.5)	8.9	2016	3183	167	5366	59
210.0	12.15	10.98	11.27	297	66.1	5.4 (< 8.5)	9.2	2223	3294	172	5689	58
220.0	13.00	11.76	12.23	312	69.2	3.9 (< 8.5)	9.4	2439	3528	140	6107	58
230.0	13.85	12.44	12.94	315	70.0	1.2 (< 8.5)	9.3	2666	3732	134	6533	57
240.0	13.95	12.51	12.94	315	70.0	1.3 (< 8.5)	9.0	2903	3753	143	6799	55
250.0	14.73	13.16	13.68	322	71.5	1.7 (< 8.5)	8.2	3150	3948	123	7221	55

N_{tail} is part of electrons in the energy tail, η is RF efficiency.

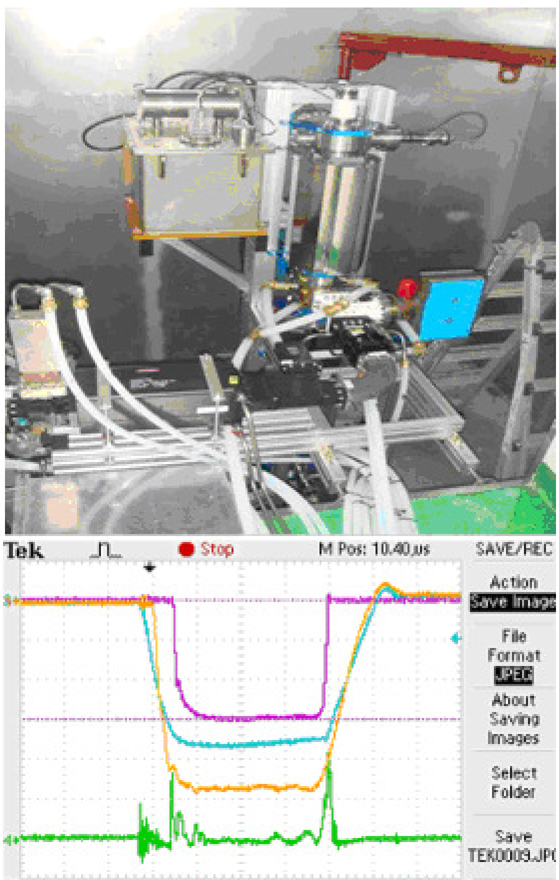

Figure 3: Photo of assembled linac (it is installed vertically over the conveyer) and experimental curves for klystron voltage pulse (yellow), E-gun pulse (cyan), beam pulse (magenta) and reflected RF wave (green).

REFERENCES

[1] T.V. Bondarenko, E.S. Masunov, S.M. Polozov, Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations, 6 (88), 114-118 (2013).

[2] M.A. Gusarova et al., NIM A, 599, 100-105 (2009).

[3] www.iso.org/iso/catalogue_detail.htm?csnumber=39027