COMMISSIONING AND FIRST TESTS OF THE NEW STANDING WAVE 10 MEV ELECTRON ACCELERATOR

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Abstract

A new linear electron accelerator for industrial applications was developed by the joint team of CORAD and MEPhI. It is based on conventional biperiodical accelerating structure for energy range from 7.5 to 10 MeV and beam power up to 20 kW. 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 and obtain high efficiency. The first two accelerators with the new structure have been installed and tested.

INTRODUCTION

A number of commercial S-band 10 MeV linacs for industrial applications are nowadays available on the market. These linacs are developed and produced by MEVEX, GETINGE, NUCTECH and Wuxi El Pont companies and can provide 15-30 kW of beam power . New industrial linac for average beam power up to 20 kW and variable energy range from 7.5 to 10 MeV was developed in 2014-15 by the joint team of CORAD and MEPhI. New linac has high electrical efficiency, narrow beam energy spectrum, provide 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 first two new accelerators have been produced and installed at EB-Tech Company site in Daejeon, Republic of Korea, and for company ACCENTR in “Rodniki” Industrial Park, Ivanovo Region, Russia. In this article we will briefly report the main results of linac development, manufacturing and testing.

THE LINAC GENERAL LAYOUT AND BEAM DYNAMICS

The traditional three-electrode E-gun was used for injection. It should 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 with 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 was realized using such idea. It also leads to the beam loading effect decrease.

Beam dynamics simulation was done using BEAMDULAC-BL code developed at MEPhI for simulations with beam loading and Coulomb field effects taken into account self-consistently [1]. Beam dynamics optimization was directed to obtain effective beam bunching for all energy range of 7.5-10 MeV and to achieve low beam energy spread. It was proposed to use a gentle buncher for these aims. 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. The bunching part consists of of 6 accelerating cell with variable length. The average field in the accelerating cells should be equal to 160 kV/cm for the effective beam bunching and acceleration up to 11 MeV. Maximal on-axis RF field amplitude will be equal to 210 kV/cm in this case. One of the middle cells is used as RF power coupler.

Four short ~20 cm focusing magnetic coils are used for beam focusing, three of the coils were installed before coupler and one after it. Magnetic field of 30 mT on the linac axis is necessary for effective beam focusing.

Some main beam dynamics simulation results are presented in Table 1: E_{RF} is averaged field into accelerating cells, kV/cm; I_{out} is output current, mA; K_T is current transmission coefficient, %; N_{main} is the part of electrons in the main beam energy distribution peak, %; $\delta\gamma/\gamma$ is the energy spread on the energy distribution peak base; η, % is RF efficiency. Experimental data was defined for the first linac, which was commissioned on Sep. 2015 at EB-Tech Company site. All experimental data are presented for the beam output current of 320 mA. 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 65-70 % 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 vs. E_{max} (or vs. W_{max}) for constant current. But it increases with the 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 for simulation only.

ISBN 978-3-95450-181-6

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

		Output energy W, MeV							Power, kW				
	E_{RF}, kV/cm	Peak	Avg.	Avg. for main peak	I_{out}, mA	K_T, %	N_{main}, %	δγ/γ, %	Wall loses	Beam	Beam loses	Total	η, %
Simulation	70.0	1.93	1.59	1.60	110	24.4	-	±3.6	380	180	800	1360	13.2
	80.0	4.44	3.46	3.86	157	34.9	~ 25	±9.0	490	540	660	1690	32.0
	90.0	6.19	5.39	5.91	198	44.0	~ 40	±7.5	620	1070	490	1980	54.0
	100.0	7.05	6.76	7.20	217	48.2	~ 46	±4.6	770	1470	430	2670	55.1
	110.0	7.86	7.74	7.94	234	51.9	~ 49	±4.9	930	1800	370	3100	58.1
	120.0	8.61	8.39	8.68	256	56.8	~ 55	±4.8	1110	2150	300	3560	60.4
	130.0	9.03	9.09	9.28	275	61.2	~ 60	±4.9	1300	2500	240	4040	61.9
	140.0	9.73	9.75	9.89	293	65.2	~ 64	±3.8	1500	2860	200	4560	62.7
	150.0	10.34	10.32	10.45	306	67.9	~ 66	±3.4	1730	3160	170	5080	62.2
	160.0	11.04	10.91	11.02	320	71.2	~ 71	±3.4	2000	3500	150	5650	61.9
	170.0	11.71	11.42	11.62	326	73.4	~ 73	±4.9	2220	3720	130	6090	61.1
	180.0	12.33	12.10	12.22	316	70.3	~ 67	±5.0	2500	3820	90	6430	59.4
	190.0	13.00	12.73	12.83	306	68.0	~ 65	±6.6	2780	3900	90	6770	57.6
	200.0	13.58	13.25	13.43	294	65.3	~ 62	±5.2	3080	3900	100	7080	55.1
Experiment		**9.57**	**8.68**		**320**	**~ 55**	**~ 55**					**4600**	**60.4**

ACCELERATING STRUCTURE RF POWER SYSTEM

As it was noted above, the conventional DLW-based BAS was used in linac. The coupling cell length and diaphragm thickness were chosen constant along the structure including periods of the gentle buncher.

Traditional RF power coupler was simulated and tuned. The coupler is highly over-coupled with the structure (ρ≈4) because of the high beam pulse current. The additional auxiliary rectangular waveguide was 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 Figure 1) 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 is 2856 MHz, coupling coefficient > 10 % (this value was one of the projected parameters to limit the RF filling time), Q-factor is 16600, effective shunt impedance is 82.5 MOhm/m and maximal overvoltage on the surface is 3.6 (it is observed on the diaphragm bevels).

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.

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

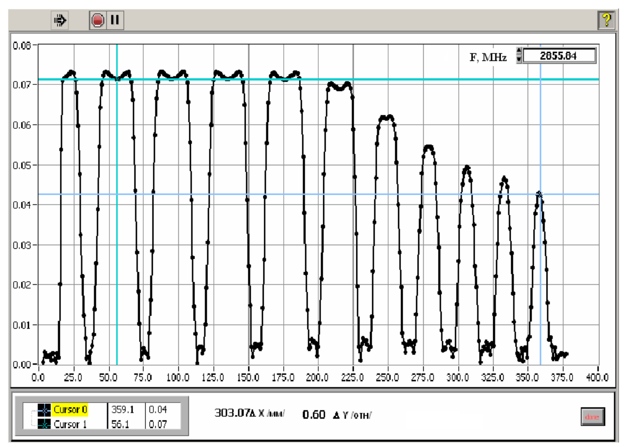

Figure 1: Measured RF field distribution in buncher and first regular cells, the amplitude deviation doesn't exceed 5 % from the simulations.

LINACS COMMISIONINGS

The first new accelerator was manufactured, assembled and successfully tested at EB Tech Company site in Daejeon, Korea (see Figure 2). Two solid-state modulators were manufactured by CORAD Ltd. to feed both klystron and electron gun.

Control system and some other accelerator components were made by EB Tech. The first accelerated beam was generated on September, 2015 [4].

The beam energy was measured by ISO/ASTM 51649:2005(E) Standard [3]. Experimental data is also presented in the Table 1. The beam energy and pulse beam power have very good correlation to simulated values. The RF efficiency is ~60.4 % and this value correlates with the simulation dates very well too. We

ISBN 978-3-95450-181-6

also confirm the achieved high total linac electrical efficiency. 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 standing wave S-band RF linac.

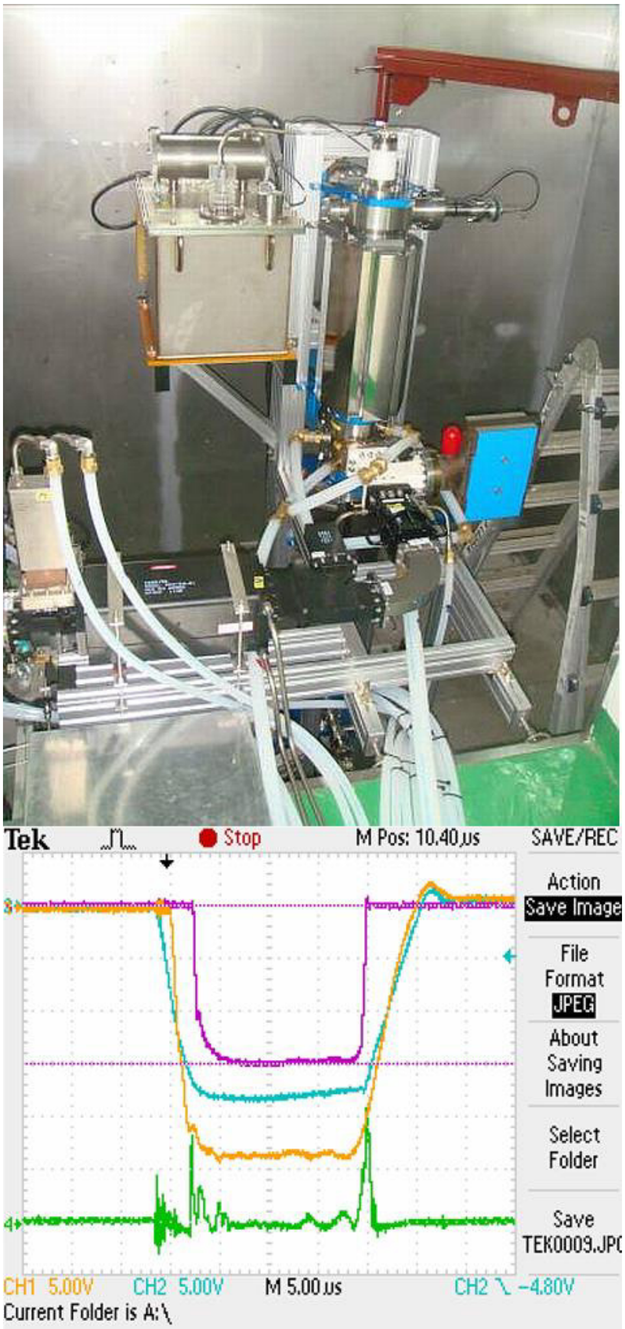

Figure 2: Photo of the assembled linac (it is installed vertically over the conveyer) at EB Tech Company site in Daejeon, Korea and experimental curves for klystron voltage pulse (yellow), E-gun pulse (cyan), beam pulse (magenta) and reflected RF wave (green).

The second linac was manufactured for ACCENTR Ltd. Company and installed at “Rodniki” Industrial Park, Ivanovo Region on September, 2016. Unlike the first linac, such accelerator has horizontally conveyor as it can be seen from Figure 3. Such linac is under commissioning at present. It will used for sterilization of medical disposable products.

Figure 3: Photo of installed linac at ACCENTR Ltd. Company site, the beam scanner is clearly seen in the right side of the photo.

CONCLUSION

The new 10 MeV linear electron accelerator for industrial applications was successfully developed by the joint team of CORAD and MEPhI. The first two accelerators have been manufactured, installed at EB-Tech Company site in Daejeon, Republic of Korea, and at “Rodniki” Industrial Park, Ivanovo Region, Russia, and successfully tested. After minor engineering enhancements and specifications corrections such linac can be produced in a series.

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ISBN 978-3-95450-181-6