Commissioning and First Tests of the New Standing Wave 10 MeV Electron Accelerator

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EB systems designed and made by CORAD Ltd or in a collaboration with CORAD Ltd:

Company	Location	Energy MeV	Power kW	Technology	Accelerator manufacturer	Year
POLICOR Ltd	St. Petersburg, Russia	8	5	Sterilization, crosslinking	NIIEFA	1992
LEIDI Radiation Technology Co.	Guanghan, Sichuan, China	8	5	Crosslinking, semiconductors irradiation	NIIEFA	1996
Electron Nord	Borre, France	6-10	5	Sterilization	NIIEFA & CORAD	2000
RAD Ltd	St. Petersburg, Russia	8 8	5 10	Sterilization, crosslinking of shrinkable items	NIIEFA CORAD	2004 2010
Karpov Institute	Obninsk, Russia	10	10	Crosslinking of shrinkable items	CORAD	2005
VINAGAMMA	Ho Chi Minh City, Vietnam	10	15	Food irradiation	CORAD	2011
Russian medical biophysical center	Moscow, Russia	10	10	Sterilization	CORAD	2012
Ural Federal University	Ekaterinburg, Russia	10	10	Sterilization	CORAD	2013

CORAD Ltd is producing radiation facilities with linacs since 1992

CORAD Ltd used linacs made
by Efremov institute (NIIEFA)
on the basis of magnetrons at first.

Since 2005 we made linacs ourselves
on the basis of klystron TH2173F but we
used accelerating structure made by NIIEFA

CORAD's linacs features:

- High efficiency due to using solid-state modulators for klystron and electron gun

-Continuous control of electron energy, beam current and scanning length during electron beam processing

-Beam extraction system allows irradiating opposite sides of boxes during one pass.

New 10 MeV linac design was started on 2014 in cooperation with MEPhI team:

-Average beam power up to 20 kW;

-Variable energy range from 7.5 to 10 MeV;

-High RF and electrical efficiencies;

-Narrow beam energy spectrum;

-Low accelerated beam loses.

We tried to realize the following statements in our new linac design:

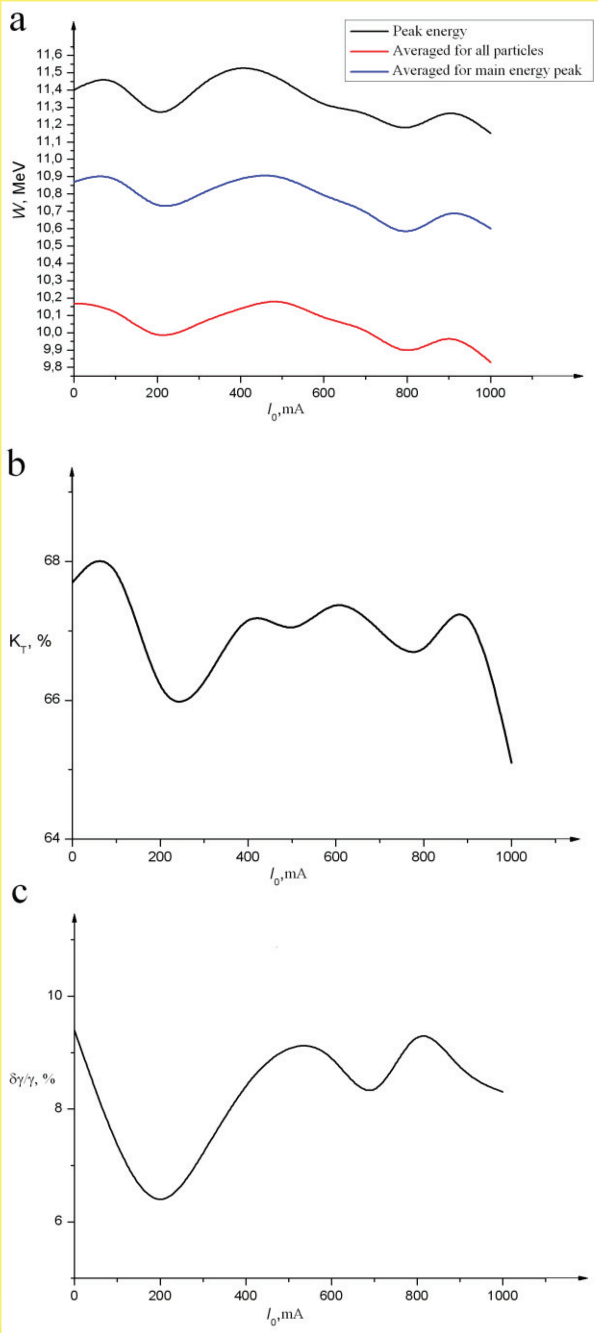
-*The accelerating structure should have high coupling coefficient for maximal RF pulse power usage efficiency;*
-*The gentle buncher should be used to provide high capturing coefficient and narrow energy spectrum for all output energies;*
- *Traditional three-electrode E-gun should provide up to 400-450 mA of pulse beam current to reach 300-320 mA of accelerated beam;*
-*The conventional biperiodical accelerating structure (BAS) based on Disk Loaded Waveguide (DLW) was used;*
-*Operating frequency 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.*

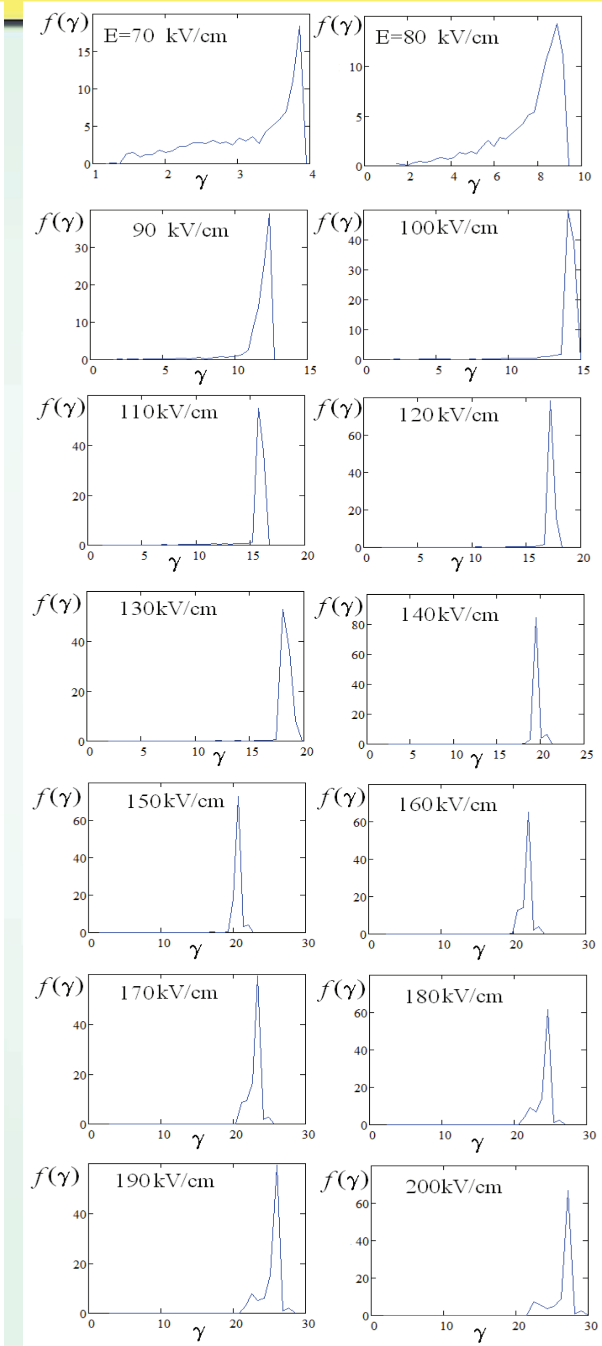
Beam Dynamics

Was simulated by BEAMDULAC-BL 3D code designed at MEPhI for simulations with beam loading and Coulomb field effects taken into account self-consistently.

Beam output parameters vs. RF field amplitude

E_{max}, kV/cm	Most probably energy, MeV	Average energy, MeV	Output beam current, mA	K_T, %	$\delta\gamma/\gamma$ 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





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 and 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.

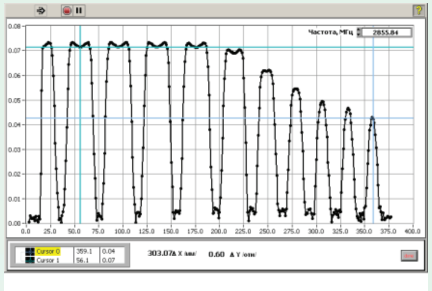
Electrodynamics:

The conventional DLW-based BAS was used in linac and the following electrodynamics characteristics were obtained after optimization: resonant frequency is 2856 MHz, coupling coefficient > 10 % (this value was one of the projected parameters to limit the RF filling time), simulated 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.

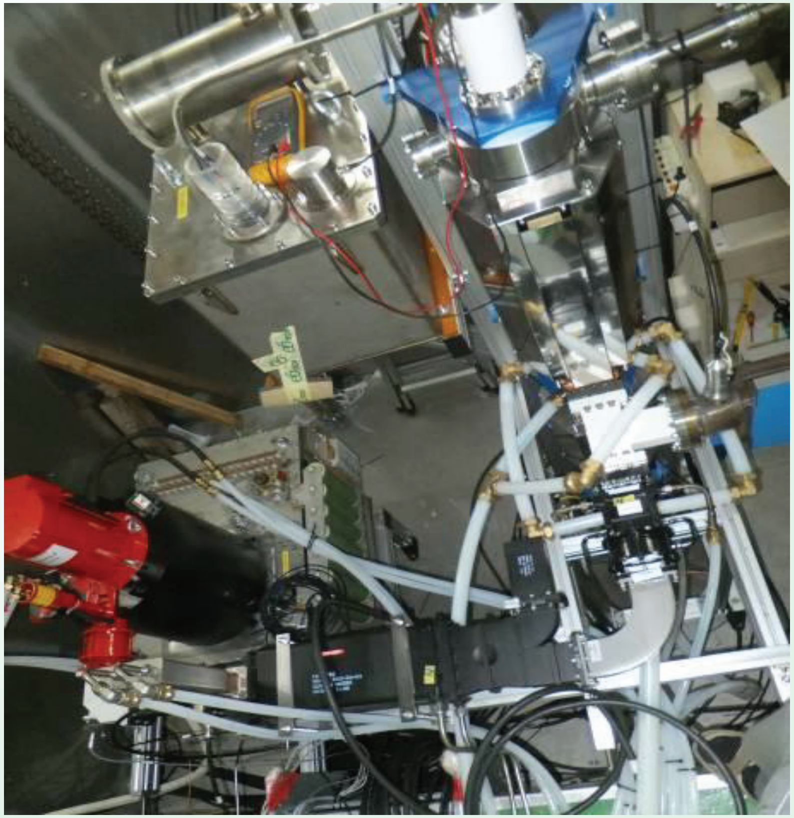
Traditional RF power coupler was simulated and tuned. The coupler is highly over-coupled with the structure (ρ≈4) because of the high beam pulse current. The additional auxiliary rectangular waveguide was added to the coupler cell for RF field distribution symmetrization.

The accelerating cell shape was optimized to minimize multipactor discharge problem using MultP-M code.

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



The first new accelerator was manufactured, assembled and successfully tested at EB Tech Company site in Daejeon, Korea. Control system and some other accelerator components were made by EB Tech. The first accelerated beam was generated on September, 2015. The beam energy was measured by ISO/ASTM 51649:2005(E) Standard.



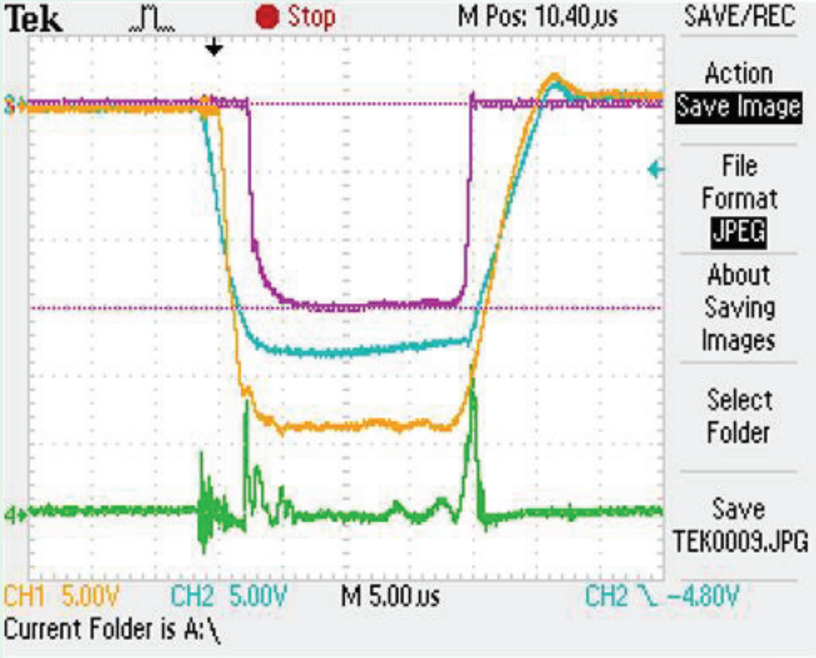
Comparison between sections with different coupling coefficients

The new section with high coupling coefficient tested at EB TECH:

Pink – beam pulse on the beam stop,

Yellow – klystron voltage, Blue – electron gun voltage, Green – reflected wave.

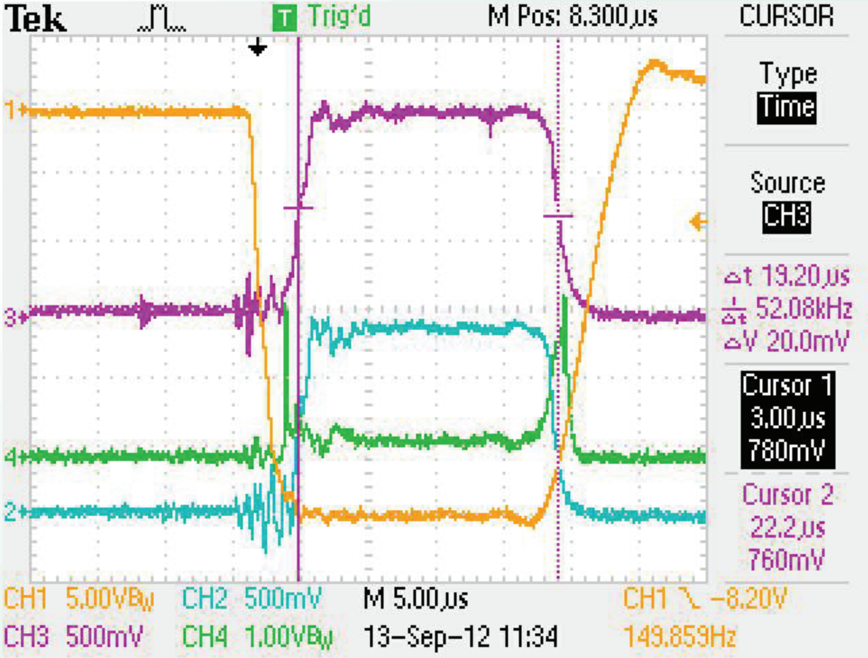
Beam pulse width = 85% of klystron pulse width.



Previously used section with low coupling coefficient tested at VINAGAMMA:

Pink & Blue – beam pulses, Yellow – klystron voltage, Green –reflected wave.

Beam pulse width = 77% of klystron pulse width.



Beam dynamics simulation results, experimental data and linac RF efficiency

		Output energy W, MeV							Power, kW				
	E_{RF}, kV/cm	Peak	Avg.	Avg. for main peak	I_{out}, mA	K_T, %	N_{main}, %	$\delta\gamma/\gamma$, %	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**

All simulations were done for initial beam current 450 mA and all experimental data are presented for the beam output current of 320 mA.

The second linac was manufactured for ACCENTR Ltd. Company and installed at “Rodniki” Industrial Park, Ivanovo Region on September, 2016 is under commissioning at present

Thank You for Attention!