LINEAR ACCELERATOR LINAC-800 OF THE DELSY PROJECT

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Abstract

In the report the modernization of electron linear accelerator MEA (Medium Energy Accelerator) is discussed. The goal of the work is to create on the base of MEA a complex of free electron lasers overlaying a range of radiation waves from infrared to ultraviolet. Status of the work is reported.

THE DELSY PROJECT

The DELSY (Dubna Electron Synchrotron) project is being under development at the JINR, Dubna, Russia [1]. It is based on an accelerator facility presented to JINR by the NIKHEF, Amsterdam. The construction of the DELSY facility will proceed in three phases. Phase I will be accomplished with the construction of a complex of FEL covering continuously the spectrum from far infrared down to ultraviolet [2]. Phase II will be accomplished with commissioning of the storage ring DELSY. The optics of the DELSY storage ring is characterized by its 2-fold symmetry, low horizontal emittance (11.4 nm), low-beta section at the wiggler location and section for miniundulator. Synchrotron radiation from the dipole magnets with critical photon energy up to 1.16 keV has rather high intensity in both ultraviolet and infrared regions. This radiation can be used in photoelectron microscopy, time-resolved fluorescent studies of biological objects, in absorption spectroscopy, metrology and photometry. Hard X-ray radiation from wiggler can be used for researches on VUV luminescence of crystal and pumping of VUV-lasers, time-resolved Moessbauer spectroscopy, EXAFS spectroscopy, DANES, DAFS. Phase III of the project is construction of an X-ray FEL. Recent studies have shown that the DELSY complex has a reliable potential for upgrading into a fourth-generation SR light source.

Phase I

Phase I will be accomplished with the construction of a complex of free electron lasers covering continuously the spectrum from far infrared down to ultraviolet (of about 150 nm). The far-infrared coherent source will cover continuously the submillimeter wavelength range. Realization of this phase will not require a significant modification of the JINR infrastructure. In Table 1 we present a summary of the radiation properties from coherent radiation sources being planned to build in Phase I. Notations G1-G4 refer to the FEL oscillators, and FIR stands for the far-infrared coherent source.

Table 1: Summary of radiation properties from coherent radiation sources in Phase I.

	FIR	G1	G2	G3	G4
Radiation wavelength, [μm]	150-1000	20-150	50-30	1-6	0.15-1.2
Peak output power, [MW]	10-100	1-5	1-5	3-15	10-20
Micropulse energy, [μJ]	500	50-200	25-100	25-100	50-100
Micropulse duration (FWHM),[ps]	5-10	10-30	10	10	3-5
Spectrum bandwidth (FWHM),[%]		0.2-0.4	0.6	0.6	0.6
Micropulse repetition rate, [MHz]			19.8/ 39.7/ 59.5		
Macropulse duration, [μs]			5-10		
Repetition rate, [Hz]			1-100		
Average output power (max.), [W]	10-50		0.2-1		

ACCELERATOR LINAC-800

The electron beam with necessary parameters for the Free Electron Laser will be generated with the electron linac, which is a modified version of the Medium Energy Accelerator (MEA) transferred to JINR from NIKHEF[3]. The energy of electrons at the linac exit is 800 MeV and peak current of 30-60 A, with subharmonic buncher of the frequency of 476 MHz, a buncher at the frequency of 2856 MHz and 24 acceleration sections, which are combined in 14 acceleration stations (A00 – A13).

To operate FEL, one needs an injector with a special subharmonic prebuncher. Such an injector has to be developed at JINR.

MEA Injector

To start the linac operation and test its condition, we plan to use the MEA injector consisting of an electron gun, chopper, prebuncher and buncher [4].

The electron gun (Table 2) has a dispenser thermocathode with the diameter of 8 mm. Its heater current is 15 A at the heater filament voltage of 12 V. The cathode lifetime is of the order of 20 thousand hours. The gun optics elements contain Pirce electrode at the cathode potential, control electrode and acceleration tube, which has 15 diaphragms forming homogeneous acceleration field. Linear potential distribution along the tube is provided with the divider, the voltage between two neighbour diaphragms is of the order of 30 kV. One can "close" the gun by applying the voltage of –150 V between the cathode and control electrode. The gun is operated in a pulsed mode by applying voltage pulses of +6 kV amplitude between the cathode and control electrode.

Table 2: The electron gun parameters

Scheme	Triode
Type of cathode: Diameter, [mm] Heater: voltage, [V] current, [A]	Dispenser 8 0-12 0-15
Electron energy, [keV]	400
Peak current, [A]	0.45
Cathode current stability	$1.5 \cdot 10^{-3}$
Beam diameter, [mm]	1.5
Normalized emittance (1σ), [π·mm·mrad]	8

Buncher

The MEA buncher system (Table 3) contains three elements, and the first of them is the chopper.

Table 3: The buncher system

Chopper	Scheme	RF-cavity (TM_{110})
	Frequency, [MHz]	2856
	Amplitude of transverse deflection, [mm]	16
	Drift space Length, [cm]	50
	Quality factor (unloaded)	4000
	Transmission efficiency, %	20
	Peak RF power input,[kW]	3.0
Prebuncher	Scheme	RF-cavity (TM_{010})
	Frequency, [MHz]	2856
	Mode	2π/3
	Peak electric field at the gap center, [kV/cm]	10.3
	Bunch phase length at the prebuncher exit: at 10 mA current at 20 mA current	 6° 10°
	Distance between chopper collimator and the buncher entrance, [cm]	98.7
	Distance between prebuncher exit and the buncher entrance, [cm]	132.7
Buncher	Frequency, [MHz]	2856
	Mode	2π/3
	Number of cavities	38
	Shunt impedance, [MΩ/m]	51.2 – 55.1
	Length at 24° C, cm]	127.77
	Bunch phase length at the buncher exit: at 10 mA current at 20 mA current	 ≤ 1° ≤ 2°
	Electron energy, [MeV]	6

It is a deflector cavity of S-band type with collimator. The peak RF power consumed by the chopper is of 3 kW.

The prebuncher cavity is installed just after the chopper cavity. It is fed with RF of 2 kW power from klystron of the first acceleration section through attenuator and phase shifter.

The buncher is actually the short acceleration section of the accelerator structure. The bunch phase length at the buncher exit is of 6°. Its structure is supplied with RF power of 2 MW from the first klystron. The RF power is transmitted from the buncher exit through phase shifter to the first acceleration section.

Acceleration Sections

The MEA linac contains acceleration waveguide sections of six types. They are similar in mechanical features, but differ in RF-parameters (Table 4). Each section contains eleven uniform 2π/3-mode segments. The numbering of the sections is done with the alphanumeric identifiers, in which first letter symbol (A or B) means the way of RF-feeder connection to the section: symbol A indicates that the feeder is connected to the top of the section, the symbol B – to the bottom. The last symbols (one or two) mean the type of the section.

Table 4: The parameters of acceleration sections

Type of section	Short	Long
Number of sections	3	18
Number of cells per sections	105	210
Section length, [m]	3.673	7.346
Frequency, [MHz]	2856	
Traveling-wave mode	2π/3	
Acceleration gradient, [MeV/m]	5	
Filling time, [μs]	1.3	
Beam load, [MeV/mA]	2.6	
Shunt impedance, [MΩm]	56.5 - 48	
Aperture: diameter, [mm] thickness, [mm]	32 5.84	

Besides, double letter symbol AA or BB indicates the short section, single letter A, B, C, D – a long section. The short sections have the length of 3.6 m, they are immersed in constant solenoidal magnetic field of the order of 500 Gauss. The long sections of the length of 7.35 m have no magnetic field. All the acceleration sections are combined in acceleration stations that comprise an RF-power source (klystrons with modulators), waveguide, acceleration section and drift section. The drift section is used as a place of disposition of beam diagnostic devices (monitoring of the electron energy, beam current, size, position and emittance).

FEL INJECTOR

Generation of an electron beam with the parameters suitable for feeding of FEL requires significant upgrade of the linac injector. The requirements to the FEL electron beam listed in Table 5 can be satisfied using a subharmonic bunch compressor (SBH) described in Ref.

[5]. It contains in our case (Figure 1) an electron gun, a cavity operating at subharmonic frequency, a drift section and the first acceleration section of the linac.

Table 5: Parameters of electron beam after injection and acceleration in the first linac section

Energy, [MeV]	7
Peak current, [A]	60
Micropulse duration, [ps]	20
Normalized emittance, [mm·mrad]	≤ 30π
Electron energy spread, [%]	< 3

The electron gun has a modulation grid, which provides generation of short electron bunches with the duration of 0.5 ns. The electrons emitted from the dispenser thermocathode are accelerated in the electric field of the

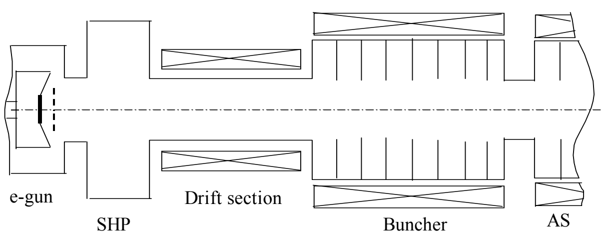

Figure 1: Injector layout.

gun electrodes up to energy of the order of 400 keV and are formed in the injector elements – prebuncher, drift section and acceleration section.

The electron bunch dynamics in the injector can be described as follows. Electron bunches have at the gun exit the length of

$$L_{gun} = \beta_{gun} c \tau_0,$$

where β_{gun} is the ratio of the electron velocity to light speed, τ_0,- the gun micropulse duration. Crossing the SHP cavity, the electron get additional energy

$$\Delta\varepsilon = eV_0 \cdot \sin\Omega t,$$

where V_0 and Ω are the amplitude and frequency of SNP "voltage" ($V_0 = E_{SHP} \cdot L_{SHP}$). We choose $\Omega = \omega_0/6$ and τ_0, equal to one quarter of SHP field oscillation:

$$\tau_0 = ¼(2\pi/\Omega) = 3\pi/\omega_0 \approx 0,5\ ns.$$

If we inject electrons into the SHP cavity as it is shown in Figure 2 the maximal and minimal electron energy values are equal to:

$$E_{max} = e(V_{gun} + V_0) = 400\ keV,$$
$$E_{min} = eV_{gun} = 350\ keV.$$

The electron gun delivers the pulse that enters SHP cavity at the phase of zero cavity field. Therefore, after SHP cavity passing the "head" of the beam contains slow electrons with minimal electron energy E_{min}, and the beam tail move faster in the drift section than the head. As a result, the bunch gets compressed. At the drift section exit we have:

$$l_0 = c\tau_{gun}\beta_{max} - L_0(\beta_{max}/\beta_{min} - 1) = 14.5\ mm.$$

The first linac section has a structure which corresponds to the stable electron velocity $\beta = 0.825$ ($\varepsilon = 400\ keV$). The phase oscillation frequency is very low at chosen parameters (of the order of a few MHz). One can show

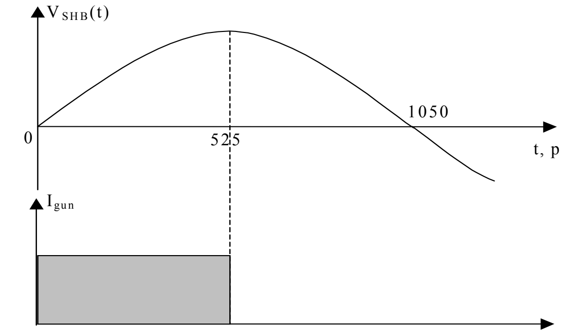

Figure 2: The time dependence of the acceleration voltage of subharmonic prebuncher and electron beam pulse at the gun exit.

that the bunch length at the exit of the section is given by the following formula:

$$l_{final} = l_0 - \gamma^3_{max} \cdot (\beta_{max} - \beta_{min})/\alpha \times (1 - A/(1+A)^{1/2}) -$$
$$- 1/4\alpha \times (2\pi l_0/\lambda)^2 \times 1/(1+A)^{1/2}$$

$\alpha = eE_0/mc^2$, $A = \beta_{min}\gamma_{min}$, $\gamma_{min,max} = (1 - \beta^2_{min,max})^{-1/2}$, E_0 – the acceleration field amplitude in the first linac section. The results of the estimates give us the final value of the electron bunch length:

$$l_{final} = 5.3\ mm.$$

The bunch compaction factor and peak electron current are equal to:

$$k = l_{final}/l_{gun} = 23,$$
$$I_{final} = kI_{gun} = 100\ A.$$

Three first linac sections have focusing solenoids with magnetic field of 500 G. In the FEL injector the most critical position for beam space charge influence is the exit part of the drift section and the entrance part of the first linac section. There $I_{peak} \approx 36\ A$. The value of the solenoid magnetic field has to exceed the level of so-called Brillouin field.

$$B_{Brillouin} \approx 500\ \text{G}.$$

Keeping in mind future development of the injector, we have chosen maximum value of drift section magnetic field equal to 1 kG.

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