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DELSY—Dubna ELectron SYnchrotron at JINR

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Abstract

The project DELSY is under development at JINR. It is based on an accelerator facility presented to JINR by the Institute for Nuclear and High Energy Physics (NIKHEF, Amsterdam): linear accelerator MEA and electron storage ring. Analysis has shown that it would be possible to build in Dubna a universal light source with unique characteristics consisting of the following components: a complex of Free Electron Lasers (FEL) covering continuously the wavelength range from far-infrared (150 μm) down to ultraviolet (150 nm), the DELSY storage ring and a vacuum VUV/soft X-ray FEL with minimal wavelength down to 5 nm—SASE (Self Amplified Spontaneous Emission) FEL. After complete commissioning of the DELSY facility, we will have a unique light source covering continuously the wavelength range from 1 mm down to a fraction of Angstrom. It is important that a significant fraction of the spectrum (from 1 mm down to 5 nm) will be covered by FELs providing extremely high brilliance of the output radiation.

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The construction of the DELSY facility will be proceeded in three phases:

- Phase I consists of assembling of the linac and the construction of a complex of FELs covering the spectrum continuously from far infrared down to ultraviolet (of about 150 nm).
- Phase II will be accomplished with the commissioning of the storage ring DELSY.
- Complete commissioning of the DELSY project will take place after finishing Phase III—construction of an X-ray FEL [1]. This phase is considered as the ultimate goal of the project.

Recently, the conceptual design of the unique injector to form and accelerate short bunches in LINAC-800 has been developed. Two-storeyed gallery for linac sections and modulators in length of 200 m are almost completed for the mounting of equipment. The first four sections of linac have been mounted at the ground floor of gallery in the end of 2003. The layout of the linac-800 and the

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DELSY storage ring in the existed buildings at JINR is shown in Fig. 1.

Phase I: The linear accelerator MEA transferred with the NIKHEF facility will be used for two purposes: electron injection into the DELSY ring (phase II) and pumping of free electron lasers. The last one covers a wide spectrum from far infrared down to ultraviolet of about 150 nm (Table 1).

The key element of a free electron laser is an undulator (or wiggler). There are two popular undulator configurations: helical and planar. The technology of planar undulators construction is much better developed, and they are widely used in almost all operating FELs. In the DELSY FELS, we plan to use in the beginning planar undulators.

The driving beam for a FEL accelerated in the DELSY linac will have parameters (Table 2) sufficient for driving the FEL oscillators of infrared and optical wavelength range. The proper field distribution and application of a coil with opposite field direction at the injector exit allows to form the beam with a required emittance. Evolution of the beam parameters from the gun up to the first section exit shows an efficient bunch formation. SHB is a cavity of the quarter of the wave length with a gap of 1 cm and voltage amplitude of 100 kV. After SHB, the electrons pass the drift section of 2.3 m length where the bunch length reduces up to 5 mm.

The drift section is followed by standing wave acceleration section (bunch compressor—BC), which has the length of 4λ at the frequency of 2856 MHz. If the acceleration field amplitude is of 25 MV/m, the bunch length diminishes in BC up to 2–3 mm and the peak current reaches the value of 100 A. At 40 MV/m, one can obtain 1–2 mm and 500 A, correspondingly.

Another critical requirement is formation of the bunch with the small emittance. For this purpose, we have chosen a formation scheme with longitudinal magnetic field and the gun cathode placed outside the field.

The linac injector consists of electron gun, acceleration tube, subharmonic prebuncher and standing wave acceleration section (buncher). The principle of the injector scheme is similar to that

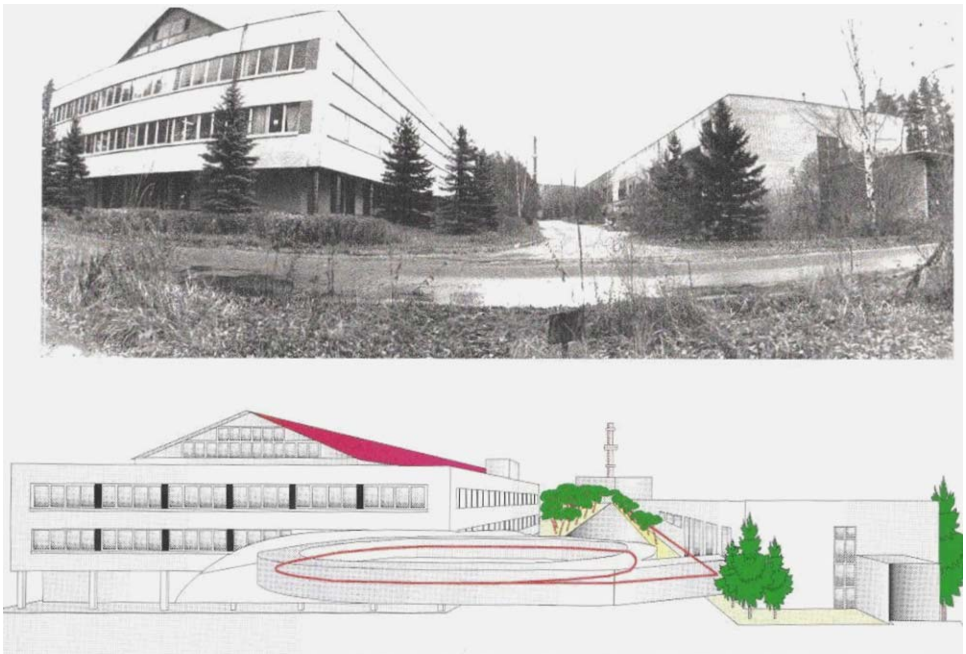

Fig. 1. The layout of the linac-800 and the DELSY storage ring in the existed buildings (two-storeyed gallery is in the right side).

Table 1
Summary of FEL radiation properties in Phase 1

Parameter	FIR	G1	G2	G3	G4
Radiation wavelength (μm)	150–1000	20–150	5–30	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	

The notations G1–G4 refer to the FEL oscillators, and FIR stands for the far-infrared coherent source.

Table 2
Electron beam parameter list for the DELSY project

Electron beam parameter	FEL1	FEL2	FEL3	FEL4
Energy (MeV)	30–60	30–70	50–110	120–280
Bunch charge (nC)	1	1	1	1
Peak current (A)	50–70	50–70	50–70	150–250
Bunch length (rms) (mm)	2.4	2.4	2.4	0.5–0.8
Normalized emittance (rms) (mm mrad)	30	30	30	30
Energy spread (rms) (keV)	150	150	150	450–750
Micropulse repetition rate (MHz)		19.8/39.7/59.5		
Macropulse duration (μs)	5–10	5–10	5–10	5–10
Repetition rate (Hz)	1–100	1–100	1–100	1–100

described in Ref. [2]. The gun has grid electrode and generates short bunches of the duration of 0.5 ns and bunched beam current up to 4 A.

Phase II—storage ring: Phase II will be accomplished with commisioning of the storage ring. The DELSY storage ring (Table 3) is designed using an upgraded equipment of the AmPS storage ring. The energy will be increased up to 1.2 GeV (with respect to 0.9 GeV at AmPS). The optics of the DELSY storage ring is characterized by its two-fold symmetry. Every quadrant consists of the MBA structure: two halves of straight sections and two periodic cells [3,4]. The periodic cell consists of two dipoles and three quadrupoles. The matching cell contains two dipoles and provides zero dispersion in the straight section. The storage ring has four strait sections to accommodate accelerator equipment and insertion devices. One of the strait section is intended for a 10 T superconducting wiggler (wavelength shifter) and one for undulator with 150 periods and a magnetic field of 0.75 T. The wiggler will influence many aspects of beam dynamics: linear motion, dynamics aperture, emittance, damping times, etc. The problem is rather serious for the DELSY machine

Table 3
Main parameters of the DELSY ring

Full energy (GeV)	1.2
Injection energy (GeV)	0.8
Circumference (m)	136.04
Bending radius (m)	3.3
Betatron tunes (h/v)	9.44/3.42
Momentum compaction factor	5.03×10^{-3}
Natural chromaticity (h/v)	$-22.2/-12.6$
Injection current (mA)	10
Stored electron current (mA)	300
Horizontal emittance (nm)	11.4
RF frequency (MHz)	476
Harmonic number	216
Energy loss per turn (keV)	55.7

because the energy of the electron beam is small while the wiggler's magnetic fields is strong.

The beta functions in a very strong wiggler must be small enough to avoid emittance increase and minimise the optics distortions with the wiggler on. In our case, they are $\beta_x = 1.05\,\text{m}$ and $\beta_y = 2.80\,\text{m}$. The vertical beta function in the centre of the undulator is small to provide the tolerable lifetime limited by the residual gas scattering. It was accepted to be $\beta_x = 14.55\,\text{m}$ and $\beta_y = 0.98\,\text{m}$.

Influence of both wiggler and undulator insertion devices on the linear optics is rather limited and does not decrease essentially the dynamic aperture. The influence of the 10 T wiggler can be recovered by applying local and global linear optics corrections [5]. When the linear lattice is cured well, the reduction of dynamics aperture with the wiggler and undulator on is not big. The emittance increases by a factor of 1.78 for the regime when both insertion devices are switched on. The main requirement for the wiggler design is to decrease focussing coming from the sextupolar field of the wiggler.

The synchrotron radiation from the dipole magnets and inserting devices of DELSY (Fig. 2) has rather high intensity and extends from IR up to soft X-ray region. It provides a wide research program in different fields of science and technology.

The injection energy for DELSY is 0.8 GeV, while operation is at 1.2 GeV. This imposes strong constraints on the DELSY dynamic aperture. The solution with two sextupole families was found that solves the problem. The closed orbit correction can be provided with existing correctors of AmPS ring.

Phase III—X-ray FEL: Linac-800, which is an upgraded version of MEA, allows realizing a unique project of FEL facility with radiation generation in VUV and soft X-ray wave length range. The scheme of this FEL will be similar to the one, which is used in SASE FEL at DESY [1].

- DELSY storage ring SR source based on the magnetic elements of AmPS belongs to the third generation.
- Machine optics is designed in a way to install at least one very strong wiggler with 10 T magnetic field and one undulator.

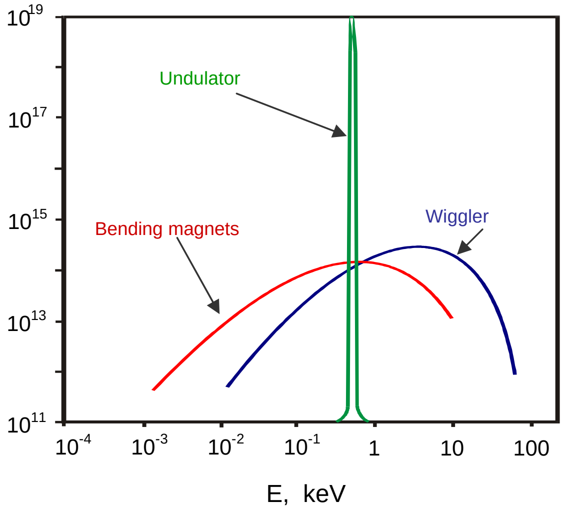

Fig. 2. Synchrotron radiation brightness of the DELSY ring (photon/(s mm^2 mrad 0.1% b.w.).

- The dynamic aperture is big enough to provide effective injection and good lifetime during the operation with the insertion devices on.
- The scheme of the closed orbit correction allows the correctors from AmPS to be used.
- The mounting on linac-800 has been started in the existed building at JINR.
- Competition of Phase I of the project allows to construct a set of FELs for a wide range of applications.
- Further development of the facility (Phase III) will consist of X-ray FEL construction based on 800 MeV linac.

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