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# Project of the Dubna electron synchrotron

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**Abstract**

The project "Dubna Electron Synchrotron" (DELSY) is aimed to construct a synchrotron radiation source of the third generation at the Joint Institute for Nuclear Research. The DELSY synchrotron radiation source will be constructed on the base of the accelerator facility of the Institute for Nuclear Physics and High Energy Physics (NIKHEF), Amsterdam, The Netherlands. This accelerator facility consists of a linear electron accelerator Medium Energy Accelerator (MEA) for an electron energy of 700 MeV and the electron storage ring Amsterdam Pulse Stretcher (AmPS) for the maximum electron energy of 900 MeV at a circulating beam current of 200 mA.

The DELSY storage ring is supposed to be constructed with the use of the AmPS (PAC, Chicago, 1989) storage ring, the focusing system of which will be essentially modified: the ring circumference will be approximately 1.5 times smaller, the electron energy will be increased up to 1.2 GeV and the focusing strength will be enhanced. These measures will allow one to obtain a beam emittance at least ten times smaller which subsequently increases the synchrotron radiation brilliance by several orders of magnitude.

The rigging of the DELSY ring with the insertion devices—the superconducting wiggler with a magnetic field of 10 T and the so-called "vacuum hybrid miniundulator" is the principal feature of the new synchrotron radiation source. Both devices developed by Budker INP, Novosibirsk, will allow one to enrich the characteristics of DELSY as a

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synchrotron radiation source, expanding its radiation spectrum in the region of the hard X-rays and increasing its brilliance up to $3 \times 10^{18}$ photons/s/mm$^2$/mrad$^2$/0.1% b.w.

Now this facility is being dismounted and transferred to JINR. 

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*Keywords:* Synchrotron radiation; Wiggler; Undulator; Free electron laser

## 1. Structure and main parameters of the DELSY facility

The primary formation and acceleration of the electron beam in the "Dubna Electron Synchrotron" (DELSY) facility is done within the MEA linear accelerator where the electrons get an energy of 800 MeV [2] (Table 1). The linac acceleration system consists of 14 acceleration stations, which include RF generators. The electron linac itself contains an injector, buncher, chopper, preliminary energy compressor ("prebuncher"), the second buncher, 23 accelerator sections and an energy spectrum compressor. We plan to install two additional ("spare") accelerator sections to increase the electron energy from 700 up to 800 MeV. The RF power amplifiers are based on pulsed clystrons. The VA938 D clystrons of the Varian company feed accelerator sections A0 and A01, chopper, prebuncher, buncher and acceleration section A. The other sections are fed by TH 2129 clystrons of the Thomson company.

The DELSY storage ring will be assembled with the elements of the AmPS ring (Table 2) [1]. It will be equipped with a superconducting wiggler, which will generate the hard X-ray radiation. SR of a higher brilliance will be obtained by a vacuum miniundulator the magnetic field of which is formed by permanent magnets.

The machine consists of four quadrants; every quadrant includes a straight section for an insertion device. The periodic cell consists of two dipoles and three quadrupoles. The phase advance in the periodic cell is equal to $\mu_x = 0.43{\times}2\pi$, $\mu_y = 0.15{\times}2\pi$. The horizontal phase advance is determined by the condition of

Table 1
The parameters of the MEA linac

| | |
|---|---|
| Length (m) | 200 |
| Electron energy (GeV) | 0.8 |
| Beam current peak (mA) | 60 |
| Average (mA) | 50 |
| Average beam power (kW) | 34 |
| Norm. emittance ($\pi$ mm mrad) | 25 |
| Pulse duration (μs) | 3.5 |
| RF parameters of the acceleration section | |
| RF frequency (GHz) | 2.856 |
| Acceleration rate (MeV/m) | 5–7 |
| Pulse duration (μs) | 0.1–3.5 |
| Cavity power (MW) | 20 |

Table 2
General parameters of the AmPS and DELSY rings

| Electron ring | AmPS | DELSY |
|---|---|---|
| Electron energy (GeV) | 0.9 | 1.2 |
| Injection energy (GeV) | 0.7 | 0.8 |
| Circumference (m) | 211.76 | 140.546 |
| Bending radius (m) | 3.3 | 3.3 |
| Long section length (m) | 32 | 7.2 |
| Short section length (m) | | 5.6 |
| Revolution period (μs) | 0.706 | 0.4685 |
| Horizontal tune | 8.3 | 9.58 |
| Vertical tune | 7.214 | 3.56 |
| Momentum compaction factor | $2.7 \times 10^{-2}$ | $4.8 \times 10^{-3}$ |
| Natural chromaticity (m) | | |
| Horizontal | −9.39 | −21.3 |
| Vertical | −9.51 | −17.5 |
| Injection current (mA) | 10 | 10 |
| Stored electron current (mA) | 250 | 300 |
| Horizontal emittance (nm) | 160 | 11.1 |
| RF frequency (MHz) | 476 | 476 |
| Harmonics number | 336 | 223 |
| Synchrotron tune | 0.031 | 0.007 |
| RF voltage (kV) | 350 | 350 |
| Bunch length, mm | 15 | 8.67 |
| Number of | | 32 |
| Dipoles | 32 | 64 |
| Quadrupoles | 68 | |
| Sextupoles | 32 | 48 |

the horizontal emittance minimization, yet maintaining reasonable natural chromaticity.

The matching cell contains two dipoles and provides zero dispersion in the straight section. The particular values of the beta functions in the straight sections are adjusted by use of a doublet.

The straight section lengths are equal to 7.2 and 5.3 m. One of the two long straight sections is intended to house the wiggler and the first injection kicker while the other houses RF-stations and the second injection kicker. The undulator is placed in one of the shorter straight sections and the injection septum in the other.

The beta functions in a very strong wiggler must be small enough to avoid emittance increase and to minimize optics distortion with the wiggler on. In our case $\beta_x \leqslant 3m$, $\beta_y \leqslant 3m$ [3].

The vertical beta function at the center of the undulator must be small still keeping tolerable lifetime limited by the residual gas scattering. It was accepted that $\beta_x = 14.1m$, $\beta_y = 0.8m$. Lattice functions for the undulator quadrant are shown in Fig. 1.

In another undulator quadrant the injection septum is placed. To relax requirements to its strength, the horizontal beta function at the center of the straight section is big (about 25 m).

For the linear optics and dynamic aperture calculations with the wiggler on the measured multipole components of the 7 T wiggler have been used [3]. The very strong wiggler produces great distortion of the linear optics. To maintain the same tunes with the wiggler on and avoid increasing the number of matching quadrupoles the following procedure of preparation of the linear optics has been applied. Initially, strengths of two quadrupoles in the doublets matching the wiggler section have been modified to maintain the constraint ($\alpha_x = 0$, $\alpha_y = 0$) with the wiggler on as well as with the wiggler off. This prevents beating of the beta functions everywhere outside the wiggler section. The same has been done for the undulator (0.75 T, 150 periods of 2.25 cm), but its effect on machine optics is much weaker. After this the machine tunes change significantly. To bring them back as well as to maintain the required beta

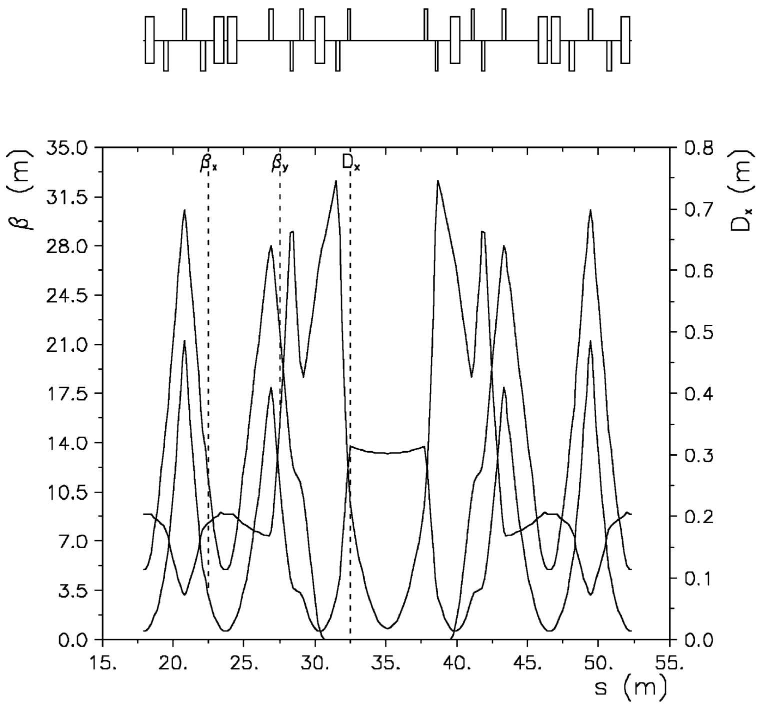


Fig. 1. Lattice functions in the matching cell and the straight section for the undulator.

functions in the straight sections, the "global" matching procedure involving all the matching doublets and three quadrupoles of the matching cell has been applied. As a result, the deviation of the beta functions for the machine with the wiggler on from that with the wiggler off is less than 8%. The lattice functions in the wiggler quadrant with the wiggler on are shown in Fig. 2.

The injection energy for DELSY is 0.8 GeV while operation is at 1.2 GeV. This put strong requirements to the dynamic aperture. The required dynamic aperture in the horizontal plane, expressed by the number $N$ of the standard deviation $\sigma$ with the emittance of the injected beam of 18.3 nm and the emittance of the circulated beam of 4.9 nm at 0.8 GeV must fulfill $N_x > 29$. The dynamic apertures are equal to $74\sigma_x$ and $56\sigma_y$, respectively. It is shown for the machine without errors in Fig. 3.

The dynamic aperture in the horizontal plane is larger when the wiggler is on than when it is off (Fig. 3).A possible explanation is given in the following: the machine optics has a periodicity equal to one in both cases when the wiggler is on and off. However, the bandwidth of the 3D-order resonance decreases when the wiggler is on. Moreover, the tune derivatives with amplitude are smaller when the wiggler is on.

The wiggler with a magnetic field of 7 T does damp, as the computing shows, and correspondingly the beam emittance with the wiggler on is

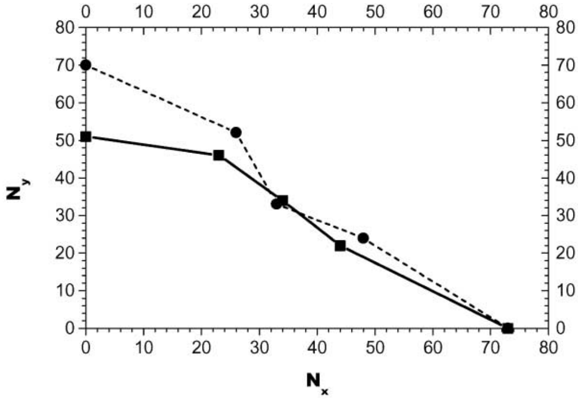


Fig. 3. The dynamic aperture, expressed as a multiple of the standard deviation with the wiggler off (solid line) and on (dotted line).

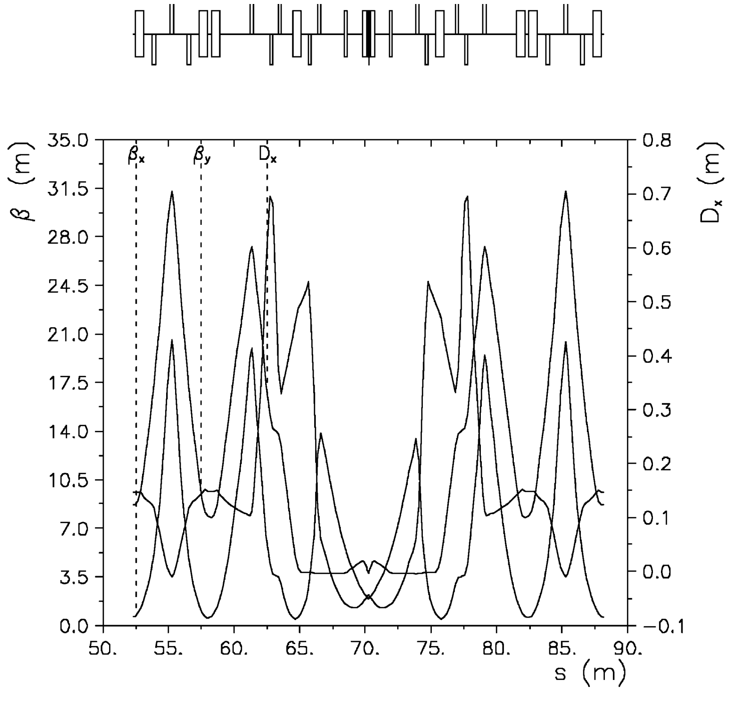


Fig. 2. Lattice functions in the wiggler quadrant (the wiggler is on).

$\varepsilon_x = 10\,\text{nm}$, while with the wiggler off it is $\varepsilon_x = 11\,\text{nm}$.

The maximum electron energy in the DELSY ring is increased up to 1.2 GeV from 0.9 GeV in the AmPS. All these demand to modernize the AmPS dipole magnets. We suggest to decrease the magnet gap from 45 to 38 mm. This measure allows one to increase the dipole magnet field from 0.9 up to 1.2 T keeping the dipole magnet current at the same level as in the AmPS ring. A detailed description of the ring structure is given in Ref. [4].

## 2. Synchrotron radiation

The SR parameters from the DELSY dipole magnets for the electron beam at the current $I = 0.3\,\text{A}$, beam emittance $\varepsilon_x = 10\,\text{nm}$ and $\beta_x/\beta_y = 12.5/1.2\,\text{m}$ are given in Table 3.

The vacuum miniundulator 2.5 m long with 150 periods will allow one to exceed the SR brilliance from the dipole magnets by five orders of magnitude (Table 3). The brilliance level to be achieved with the undulator does correspond to that of the third-generation SR source.

The superconducting wiggler with a magnetic field of 10 T [5] is designed to generate SR with the photon energy in the range of 20–50 keV (Table 3).

## 3. Perspective of DELSY as a fourth-generation SR facility

The linear RF accelerator of DELSY has the potential of reaching an energy up to 1 GeV and average power of tens of kilowatts. It seems to be very attractive to use this accelerator for driving the complex of free electron lasers. FEL oscillators can cover the wavelength range from the far infrared down to ultraviolet, 50–0.2 μm (see Table 4 and Ref. [7]). Also, it is possible to produce shorter-wavelength radiation with the single-pass SASE scheme, similar to the Tesla Test Facility FEL at DESY [6]. At an energy of about 1 GeV the minimal achievable wavelength will be about 5 nm. Tuning the energy of the accelerator will allow one to cover the wavelength range from 5 up to 200 nm. Table 4 gives an estimate of the DELSY SASE FEL parameters. A moderate upgrade of the present facility would allow one to construct the fourth-generation synchrotron light source at DELSY. The upgrade is mainly connected with installation of precise undulators, modification of the injection system of the linear accelerator, and installation of the bunch compressors.

## 4. Conclusions

The construction of the SR source of the third-generation in Dubna will significantly enrich the JINR Research Program. It will enable expansion of experimental studies in condensed matter physics, atomic physics, biology, medicine, chemistry and geology, and development of new technologies based on SR applications. The project realization is of great interest to the scientific community and industrial companies of the JINR Member States.

Table 3
Parameters of SR from the dipole magnets, undulator and superconducting wiggler

| | Dipole magnets | Undulator | Wiggler |
|---|---|---|---|
| Electron energy (GeV) | 1.2 | 1.2 | 1.2 |
| SR critical energy (keV) | 1.16 | | 8.6 |
| Photon energy at first harmonic, (keV) | | 0.58 | |
| SR flux (photons/s mm$^2$ mrad$^2$ 0.1% b.w.) | $7\times10^{12}$ | $8\times10^{16}$ | $2\times10^{13}$ |
| SR brilliance photons/(s mm$^2$ mrad$^2$ 0.1% b.w.) | $2\times10^{14}$ | $3\times10^{18}$ | $4\times10^{14}$ |
| SR power density (W/mrad$^2$) | 2.8 | 310 | 181 |
| SR linear power density (W/mrad) | 2.4 | | 542 |
| SR power (kW) | 16.6 | 0.17 | 6.9 |

Table 4
Parameters of the FEL oscillators and UV/SOFT X-ray SASE FEL at DELSY

| FEL | IR | UV | SASE |
|---|---|---|---|
| Electron beam parameters | | | |
| Energy (MeV) | 10–80 | 150–200 | 300–1000 |
| Peak current (A) | 30–50 | 30–50 | 500–2500 |
| Bunch charge, (nC) | | | 1 |
| Normalized rms emittance ($\pi$ mm mrad) | 20–30 | 20–30 | 2 |
| Micropulse duration (ps) | 10 | 10 | 0.3–1 |
| Bunch separation (ns) | 30–60 | 30–60 | 100 |
| Rms energy spread (%) | 1 | 1 | 0.3–0.1 |
| Number of bunches per train | | | 50 |
| Repetition rate (Hz) | 10–50 | 10–50 | 100 |
| Undulator | | | |
| Length of undulator (m) | 2–3 | 3–4 | 15–20 |
| Period (cm) | 3–4 | 3–5 | 2.8–4 |
| Peak magnetic field (T) | 0.5–0.8 | | 0.5–1 |
| Radiation | | | |
| Wavelength (nm) | 10–1 | 2–0.2 | 5–100 |
| Bandwidth (%) | 0.1–1 | 0.1–1 | 0.5–1 |
| Peak power (GW) | | | 0.3–3 |
| Average power (W) | 0.1–1 | 0.1–1 | 3–10 |
| Peak brilliance (photons/s mrad$^2$ 0.1% b.w.) | | | $10^{29}$–$10^{30}$ |
| Average brilliance (photons/s mrad$^2$ 0.1% b.w.) | | | $10^{21}$–$10^{22}$ |

## References


[1] G. Luickx, J.H.M. Bijeveld, Boer Rookhuizen, et al., PAC, Chicago, 1989.

[2] F.B. Kroes, LINAC96 Conference, Geneva, 22–29 August 1996.

[3] E.B. Levichev, private communication.

[4] I. Titkova, P. Beloshitsky, I. Meshkov, E. Syresin, Magnet lattice of the synchrotron radiation source DELSY, Proceedings of the EPAC'2001, p. 708.

[5] A.V. Grudiev, V.N. Durba, G.N. Kulipanov, et al., Nucl. Instr.and Meth. A 359 (1995) 101.

[6] A VUV free electron laser at the TESLA test facility: conceptual design report. DESY Print TESLA–FEL 95-03, Hamburg, DESY, 1995.

[7] I.N. Meshkov, E.L. Saldin, E.A. Schneidmiller, E.M. Syresin, M.V. Yurkov, Perspective of DELSY for the fourth generation SR facility, Proceedings of the EPAC'2001, p. 660.