Review of
Scientific Instruments

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Cite as: Review of Scientific Instruments **63**, 761 (1992); https://doi.org/10.1063/1.1142655

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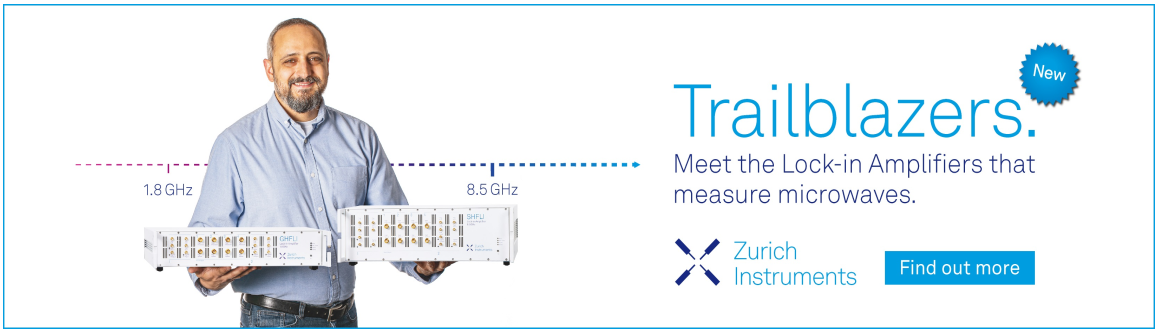

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Low-emittance synchrotron radiation source TNK for technology (radiation spectra and beam lines)

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(Presented on 16 July 1991)

The 1–2-GeV synchrotron radiation (SR) source TNK is expected to be a heart of the new Zelenograd Technological Research Center (Moscow). TNK is intended to solve submicrometer technology problems, create the base for industrial realization of advanced x-ray lithography, and to perform various x-ray structural studies within 0.2–2000 Å. The important characteristics of the facility, the features of the radiation from bending magnets and insertion devices, and SR beamline designs are described.

I. INTRODUCTION

Since 1985 at the INP (Novosibirsk) the dedicated storage ring synchrotron radiation (SR) source TNK has been under construction for the Moscow region.[1] The magnetic lattice of the storage ring was optimized for obtaining intense photon fluxes of high brightness from both the bending magnets and the insertion devices (ID).[2]

Besides the main ring, the facility includes a linac injector (80–100 MeV), a small storage ring booster (450 MeV), two transfer lines, and 39 SR beam lines.

Now that the buildings at the construction site near Moscow are almost complete, the bulk of the equipment for all the systems including ID and beam lines is ready or is being fabricated in Novosibirsk, and we expect the start of commissioning to be in 1992.

II. ACCELERATOR PERFORMANCE

The ring with the parameters that are given in Table I has six mirror symmetrical cells and 12 straight sections, three of which are intended for injection and rf equipment, and in the rest of the ring there are two superconducting wigglers, two undulators, and five multipole wigglers (Fig. 1).

TABLE I. Summary of the main parameters of the ring.

Nominal energy	1.5 GeV
Peak energy	1.9 GeV
Maximum current, multibunch	300 mA
Circumference	115.73 m
Natural horizontal emittance	2.7×10^{-6} cm rad
Number of cells	6
Number of straight sections:	
dispersive, 3 m long	6
nondispersive, 2 m long	6
Betatron tunes: horizontal/vertical	7.73/7.74
Chromaticities: horizontal/vertical	$-25/-23$
rf frequency	181.3 MHz
Harmonic number	70
Bunch length, 2.35σ ($U_{\rm rf}=400$ keV)	4.4 cm
Magnetic field: main/soft edge	1.02/0.255 T
Energy loss per turn, without ID	88.3 keV
Touschek lifetime, multibunch, 1% coupling	5 h
SR pulse duration	0.13 ns

The magnetic lattice of the ring was optimized to achieve a low horizontal emittance and optimal spatial and angular sizes of the electron beam at the radiation azimuth. In the straight sections for undulators (U sections) the betatron functions are large enough to obtain a low divergent electron beam. High-field superconducting wigglers are located in the dispersion-free straight sections (W sections) and do not distort the horizontal emittance.

The storage ring will accommodate 20 x-ray lithography stations on the bending magnets' beam lines; five x-ray lithography stations on the multipole wigglers' beam lines; ten analytical stations on the hard SR beam lines from two superconducting wigglers for express x-ray topography, energy-dispersive diffractometry, extended x-ray-absorption fine structure analysis, x-ray fluorescent trace-element analysis, etc.; two analytical stations on the beam lines of the undulator radiation for researches of dry and low temperature processes, photoelectron spectroscopy, atomic spectroscopy, etc.

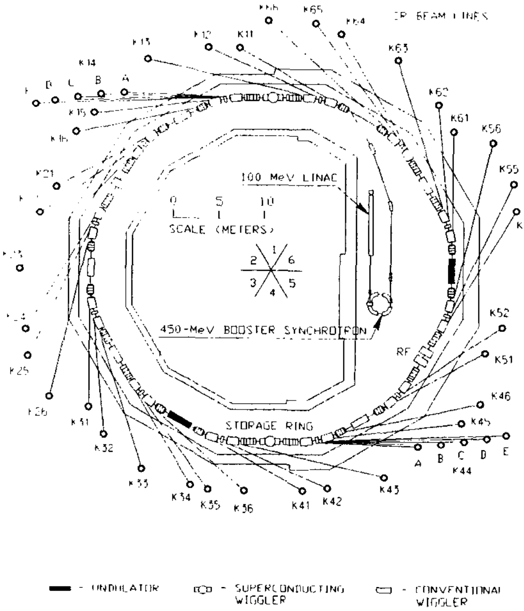

FIG. 1. The general plan view of the TNK facility.

TABLE II. Some parameters of the electron beam at the radiation points [$E = 1.6$ GeV, $\epsilon_x = 3.1\times10^{-6}$ cm rad, 1% coupling, relative energy spread $(\sigma_\epsilon/E) = 6.1\times10^{-4}$].

Point	β_x (cm)	β_z (cm)	η_x (cm)	σ_x (mm)	$\sigma_{x'}$ (mrad)	σ_z (mm)	$\sigma_{z'}$ (mrad)
U section	1600	792	80	0.86	0.04	0.05	0.006
Beam 5°20′	150	390	24	0.26	0.16	0.03	0.03
Beam 17°	60	220	10	0.15	0.26	0.03	0.02
W section	610	25	0	0.43	0.07	0.01	0.02
Beam 5°20′ (symm)	95	360	5	0.17	0.25	0.03	0.03
Beam 17° (symm)	120	200	25	0.25	0.17	0.02	0.03

III. MAJOR PROPERTIES OF THE SOURCE

There are three different sets of radiation points at the TNK: in the bending magnets, and in U and W straight sections. For one-half cell that includes two bending magnets we have two beam lines (one for each magnet) marked 5°20′ and 17° (the angle is counted off from the previous straight section); and this is the case for the symmetrical half-cell.

The values of the lattice functions, rms dimensions, and divergencies of the electron beam at the radiation points are shown in Table II.

There is the possibility of reducing the horizontal emittance by a factor of 3 by means of two 1.5-m-long superconducting wigglers with a 4.5-T magnetic field that can be installed in the nondispersive straight sections.

IV. INSERTION DEVICES

The 1–2-GeV electrons are optimal for obtaining bright undulator radiation in the soft x-ray and vuv ranges. Two electromagnetic undulators (U) with 12 11-cm periods and magnetic-field amplitude $H_{\max} = 0.65$ T will be installed in the U sections.[3] The intensity of the undulator photon beam integrated over all angles is shown in Fig. 2, so one can see a useful flux enhancement as compared with a conventional beam line (horizontal opening angle is a few mrad) in the chosen range of wavelengths.

Multipole wigglers[3] (MW) are intended for providing lithography stations with intense beams in the 5–40-Å wavelength range. For lithography, a radiation power distribution with good homogeneity across the sample is required. In our case, a relative spread $\Delta P/P \leqslant 5\%$ of the radiation power absorbed in the center of the sample and its edge was taken into consideration. From this requirement the main design parameters of the MW was obtained: period length $\lambda_0 = 24$ cm and maximum strength of magnetic field $H_{\max} = 1$ T. Five MW are planned to be positioned in both the W straight sections (seven-period wigglers) and the U straight sections (five-period wigglers).

For experiments in the short-wavelength region two superconducting wigglers (SCW) are planned to be used.[4] They will be inserted in the W straight sections and do not disturb the horizontal emittance. The critical wavelength for $E = 1.6$ GeV and $H_{\max} = 8$ T will be $\lambda_c = 0.9$ Å. To eliminate the second source (very important for experiments with high spatial resolution) we have a five-pole scheme. Each outer pole is split into two parts: a long one with low field to suppress the second source and a short one with a field that should be enough to compensate the orbit deflection in the high-field center of the wiggler.

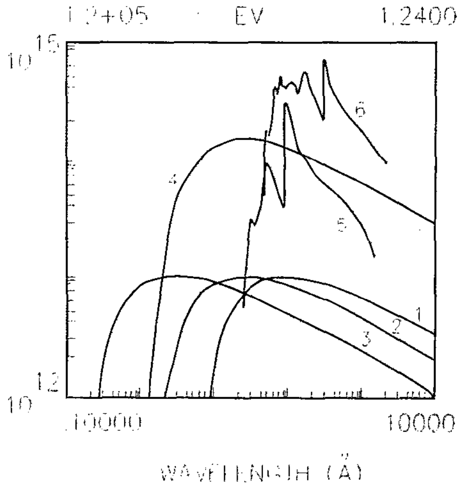

FIG. 2. Photon flux (photons/s/0.1% BW) for soft edge of the bending magnet (1), the main part of the bending magnet (2), superconducting wiggler (3), multipole (7 poles) wiggler (4), and undulator with K parameter equal to 1 (5) and equal to 3 (6). The electron-beam parameters are: $E = 1.6$ GeV and $I = 0.3$ A.

In Table III the basic parameters of the ID for TNK are summarized.

In Fig. 2 the vertically integrated intensity for a 1-mrad horizontal opening angle (for an undulator integrated over all angles) is shown. Figure 3 gives the same but for the radiation brightness (on-axis brightness in the case of an undulator).

V. BEAM LINES

There are two kinds of beam lines[5] at the ring (see Fig. 1): ten beam lines K14 (A, B, C, D, E) and K44 (A, B, C, D, E) are intended for superconducting wigglers in the 0.2–5-Å wavelength range and the 29 remaining will be used for the radiation from the bending magnets, multipole wigglers, and undulators in the 5–2000-Å interval. One beam line (K25) is designed to measure the electron-beam parameters.

TABLE III. General parameters of the insertion devices.

Parameter	SCW	U	MW1	MW2
Period (cm)	31	11	24	24
Total length (cm)	100	131	133	182
Period number	1	12	5	7
Peak field (T)	8	0.65	1	1
Pole gap (cm)	3	3.2	3.2	3.2
Wavelength:				
critical (Å)	0.9	11.2	7.3	7.3
first harmonic (Å)	···	60–1300	···	···
Undulator factor K	230	6.7	22.4	22.4
Horizontal divergency $(2K/\gamma)$ (mrad)	2×74	4.3	14.3	14.3

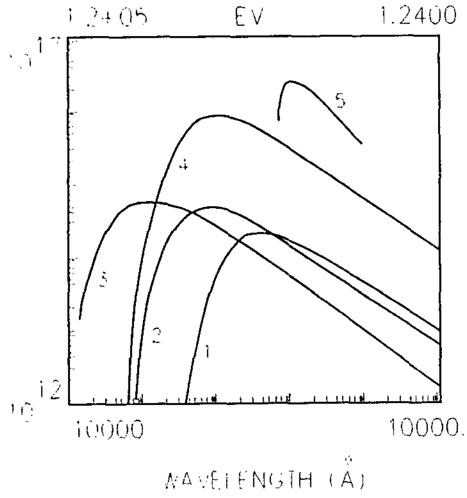

FIG. 3. Brightness (photons/s/mm^{-2}/mrad^{-2}/0.1% BW) of various radiation sources. Notations and electron parameters are the same as in Fig. 2.

The radiation from each superconducting wiggler is split into five beam lines by a radiation absorber installed at the front end. The horizontal angular aperture of each beam line is $2\Delta\theta = 3.6$ mrad. All the beam lines are identical in design and elements, but different in length (from 15 to 35 m) (Fig. 4). To protect the ring and beam line components in the case of vacuum failure, the ring and the beam lines are separated by three Be foils, each of 200 μm thickness. One more Be foil separates the station from a beam line. Two radiation W-Cu shutters are used for the shielding of the personnel from the bremsstrahlung and showers due to the particle losses in the ring. In addition, lead collimators are placed near the shutter and a lead absorber is located behind the experimental station. Each beam line has a luminophor position monitor for SR beam matching. The ion pumps provide a pressure in the beam lines within 10^{-4}–10^{-5} Pa.

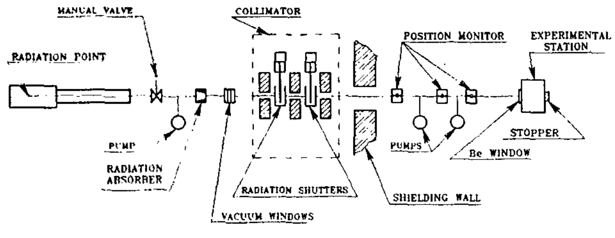

FIG. 4. Layout of the hard x-ray beam line.

Figure 5 presents the layout of a bending magnet beam line. The differential pumping provides a pressure at the ring end of 10^{-8} Pa while the pressure at the exposure chamber end is 10^{-5} Pa. To protect the vacuum inside the ring in the case of emergency there are a manual valve and pneumatic valves with a closing time of less than 2 s at a beam line. The vacuum detection gauges along the beam line trigger the fast valve, which closes in about 15–20 ms. The vacuum acoustic delay line provides a delay in the propagation for 40–50 ms. The beam line with 15 m total length can be baked out at 350 °C. The propagation of the photons along the beam lines can be controlled by luminophor position monitors. The beam lines are separated from the exposure chamber by a vacuum window that consists of a 28-μm-thick Be foil, a capton foil of 8 μm thickness, and a Si membrane of 2-μm thickness. The gap between the capton foil and the Si membrane is filled with helium at atmospheric pressure. All the beam lines have the same front end from the port to the shielding wall. This first part of the beam line includes all elements necessary to protect the vacuum inside the storage ring and to shield the researchers. The maximum horizontal opening angle is about 4.2 mrad.

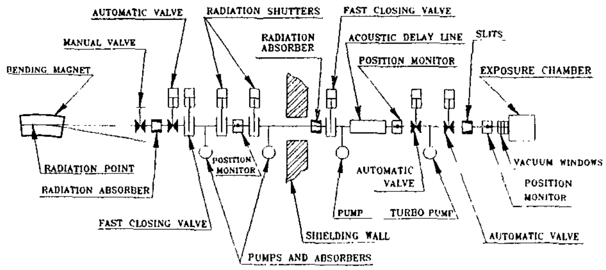

FIG. 5. Layout of the lithographic beam line.

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[5] V. V. Anashin *et al.*, in Proceedings of the 9th USSR National Conference on Synchrotron Radiation Utilization, 1990, Moscow, Nucl. Instrum. Methods (in press).