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FIRST EXPERIMENTS WITH SR FROM THE 75 KG SUPERCONDUCTING WIGGLER ON THE VEPP-2M STORAGE RING

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The 75 kG superconducting wiggler design is described. A special sweeping orbit regime provides irradiation of the large area on the plate in X-ray lithography experiments.

The 75 kG superconducting wiggler was installed on the VEPP-2M storage ring straight section in autumn, 1984 (fig. 1). The main reason for the wiggler incorporation is the luminosity enhancement due to enlarged horizontal emittance of the beam [1].

The wiggler design is shown in figs. 2 and 3, its parameters are listed in table 1. The lower and upper poles of the dipoles are housed in two separated helium vessels which are joined with an accuracy of ± 50 μm to form the block of superconducting magnets. The inner vacuum chamber kept under nitrogen temperature is placed in the middle of the SC magnet block with a spacing of 1.5 mm. The replacement and assembly of the SC magnets can be performed with the storage ring vacuum retained. The doubled helium vessel with the dipoles is fixed to the nitrogen tank via the leaf supports, and the tank is hung on the support arms mounted on the outer shell base. The support type employed

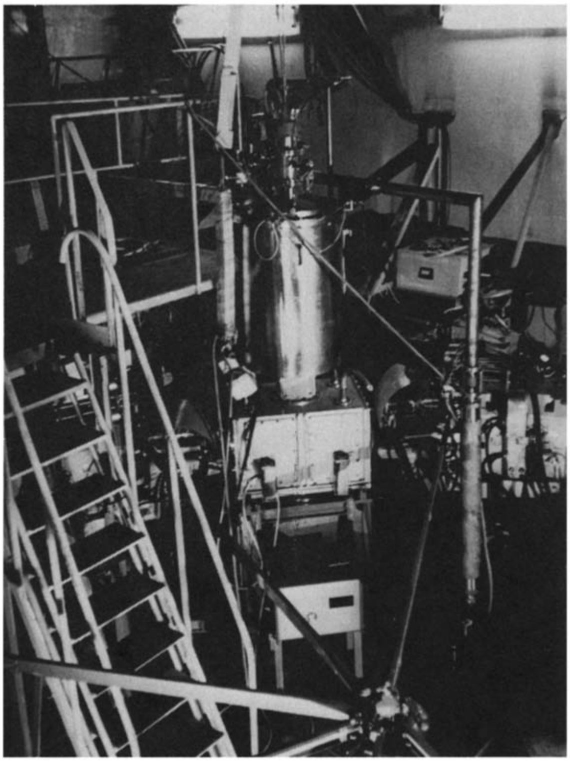

Fig. 1. Photo of the 75 kG wiggler.

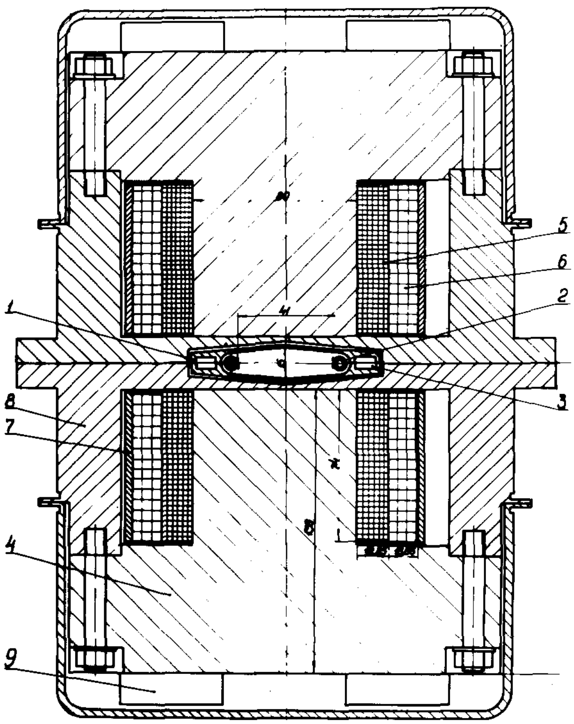

Fig. 2. Vertical cross-section of the superconducting wiggler magnet for VEPP-2M. 1 – vacuum chamber, 2 – cooled absorber for synchrotron radiation, 3 – liquid nitrogen, 4 – iron core, 5 – inner winding section, 6 – outer winding section, 7 – wire binding, 8 – stainless steel helium vessel, 9 – shunt resistors.

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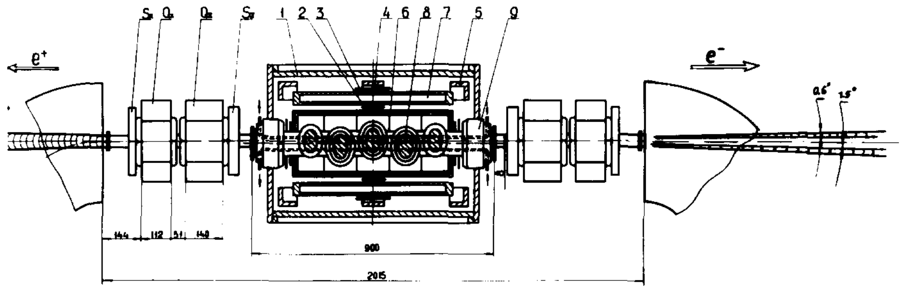

Fig. 3. VEPP-2M straight section with the superconducting wiggler magnet. Q_x and Q_z are quadrupole lenses, S_x and S_z are sextupole correctors, 1 – stray flux yoke and housing, 2 and 3 – leaf supports, 4 and 5 – arm supports, 6 – helium vessel, 7 – nitrogen vessel, 8 – inner vacuum chamber, 9 – assembly of heat insulation and absorber feedthrough. Synchrotron radiation lines are shown schematically.

provides for the stable position of the SC magnet block with respect to the median plane in cooling and against the magnetic forces. The construction is housed in the removable vacuum-tight housing serving also as a stray flux yoke.

For the independent supply of the central and side dipoles three feedthroughs are used. The liquid helium is supplied by the separate dewar tank of 145 l capacity similarly to the one mentioned in ref. [2].

Half of the synchrotron radiation power generated by the wiggler does not escape the inner vacuum chamber thus requiring special cooled absorbers for synchrotron radiation to be developed. The absorbers are made of copper tubes with inner diameters of 4 mm and wall thicknesses of 1 mm. They are mounted on both sides of the vacuum chamber on thin heat-insulating clamps (fig. 3).

To these tubes the absorber plates are brazed on the sides exposed to radiation which have the vertical catcher grooves 3 mm deep and 2 mm wide for reduction of the reflected synchrotron radiation that heats the nitrogen-cooled vacuum chamber. The mixture $H_2O + C_2H_5OH$ is used as a cooling agent. With the flow stopped for a long time it can freeze below −60°C causing only elastic deformations in the absorber copper tubes. The wiggler radiation (WR) is used for experiments performed in parallel with the colliding beams experiment. WR spectral distributions (from one pole) are shown in fig. 4. Their maxima are shifted to short wavelengths as compared with SR from VEPP-2M bending magnet. The appearance of such a bright source increases the experimental possibilities for the X-ray lithography and microscopy.

Two WR beam lines transport the radiation to experimental stations located at a distance of 12 m from the radiation point. As a result the vertical size of the WR beam is approximately 12 mm. In some cases for the X-ray lithography experiment a comparatively large square (40×40 mm^2, 80×80 mm^2) should be irradiated.

The X-ray mask-wafer vertical scanning is the common solution to this problem. This method used on the X-ray lithography beam line from the VEPP-2M bending magnet [3] is unsuitable for multilayer X-ray lithography where high precision (not worse than 0.05 μm) in the alignment process is required. Another proposed solution is the SR beam scanning by the rocking reflecting mirror [4]. However, difficulties connected with the spectral variations in the reflected SR beam and carbon pollution of the mirror surface seem to be difficult to overcome.

Sometimes the vertical beam size expansion may be effective if the source is installed in the region of the β-function's minimum. The increasing of the vertical size up to the horizontal size does not degrade the X-ray lithography spatial resolution and leads in this case to the comparatively large electron beam angular spread $\sigma_{z'} = \sqrt{\varepsilon_x \beta_x} / \beta_z$. Such vertical beam size magnification in many cases is impossible for a beam with a Gaussian density distribution due to the limitation of the vacuum chamber aperture where β_z has a maximum.

To avoid this beam loss effect the stochastic excita-

Table 1
Design parameters of the superconducting wiggler magnet on VEPP-2M

Maximum field on the beam orbit	75 kG
Number of superconducting dipoles	5 = 3 + 2
SC dipole length along beam orbit	12.0 cm
Pole gap in the dipoles	2.65 cm
Vertical aperture of the vacuum chamber	1.50 cm
Horizontal aperture of the vacuum chamber	4.2 cm
Maximum orbit displacement in the wiggler	1.6 cm
Total length of magnetic field	58 cm
Maximum bending angle in the wiggler	±168 mrad
Supply current for central and side dipoles	200, 220 A
Maximum energy stored in the wiggler	150 kJ

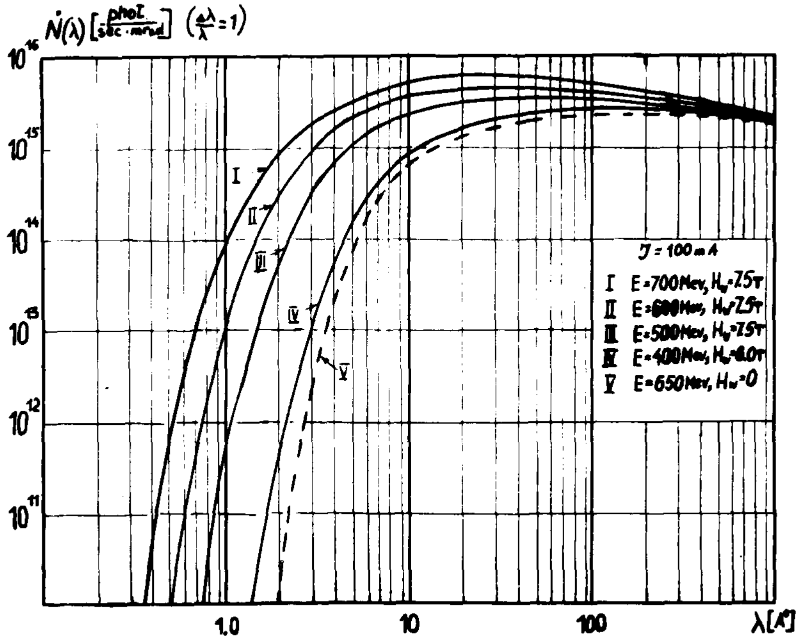

Fig. 4. WR spectral distributions.

tion of the betatron oscillations may be realized which results in much shorter tails of the beam distribution function [5]. The stochastic regime of the excitation appears due to periodic crossing of the nonlinear resonance of vertical betatron oscillations. If the resonance excitation on the frequency $f_z = f_0(n - \nu_z)$ has the modulation frequency f_m and Δf-deviation, then under special conditions [5] the excitation becomes stochastic and the diffusion of particles inside the excited beam is possible up to amplitudes Δa_z depending on the frequency deviation only: $\Delta a_z = (\Delta f/(f_0 \partial\nu_z/\partial a_z^2)^{1/2}$. This leads to the right-angle density distribution of the beam and results in decreasing of the aperture limitation.

Having considered these possibilities we chose another method of beam scanning [6]. The wiggler location in the section with β_z minimum permits the tilting of the orbit in the wiggler by a considerably large angle ($z' = \pm 3.5$ mrad) with a comparatively small orbit displacement in the bending magnet (smaller than 1 mm). In addition, the proximity of the operating point to the integer resonance ($\nu_x = 3.06$, $\nu_z = 3.09$) facilitates the orbit correction.

To realize the fast orbit correction a magnetic corrector was installed in the VEPP-2M straight section. The

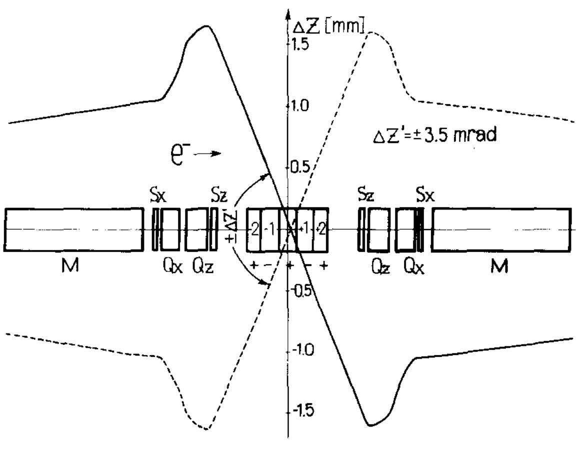

Fig. 5. The vertical orbit displacement in the VEPP-2M straight section.

Table 2
Beam parameters with the wiggler field off and on

	Wiggler field H_w		Unit
	0 kG	75 kG	
Energy E	510	510	MeV
β_z	3	3	cm
Emittance coupling ratio, $x = (\varepsilon_z/\varepsilon_x)^{1/2}$	0.1	0.1	
Horizontal emittance, $\varepsilon_x \times 10^5$	1.08	5.0	cm rad
R.m.s. beam sizes at the radiation point			
σ_z	7	14	μm
σ_x	270	590	μm
Beam lifetime due to EIS 100 mA $(\Delta E/E)_{max} = 0.5\%$	178	2000	s

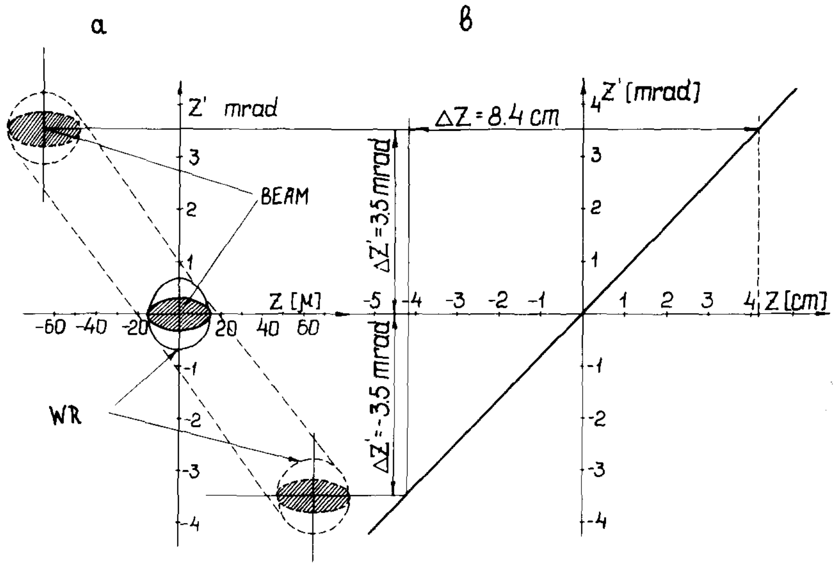

Fig. 6. Phase diagram: a – the radiation point, b – the experimental station point.

horizontal magnetic field in the corrector follows the saw-tooth law with frequencies from 1 to 30 Hz. As a result the orbit is sweeping (fig. 5) and WR is scanning synchronously (fig. 6). The amplitude of the sweeping is chosen large enough to avoid irradiation of the plates from the turning points and, consequently to avoid nonuniformities of the WR beam.

Significant orbit distortions and beam passing through regions with the sextupole fields lead to the radial–vertical betatron coupling. The measured vertical beam emittance increase during the sweeping orbit regime gives the value $\varepsilon_z(\Delta z\ \max)/\varepsilon_z(\Delta z = 0) = 1.2$. It is negligible compared with the radial beam size and consequently does not degrade the spatial X-ray lithography resolution.

The PMMA resist on the 80 mm ∅ plate was exposed by WR in the sweeping orbit regime. The 6 s exposure time was taken with the 40 mA current in VEPP-2M ($H_w = 70$ kG, WR was passed through two 1 μm Al filters) and illumination uniformity was not worse than 5% over the whole plate surface.

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