FIRST RESULTS OF SIBERIA-2 STORAGE RING OPERATION WITH 7.5 T SUPERCONDUCTING WIGGLER

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Abstract

7.5 T 19-pole superconducting wiggler has been installed on SIBERIA-2 storage ring in December 2007. First results of an operation of Siberia-2 with the wiggler are described. An influence of the wiggler on betatron tunes, closed orbit, betatron functions and other beam parameters is discussed. Calculated and measured influence on beam parameters is compared.

INTRODUCTION

Dedicated synchrotron radiation (SR) source SIBERIA-2 [1] operates regularly for users since 1999. Working energy of SIBERIA-2 is 2.5 GeV, electron beam current achieved 200 mA. SR users get radiation from bending magnets with 1.7 T field level. In order to extend spectral range and to raise brightness of synchrotron radiation a superconducting wiggler with maximum field 7.5 T was installed in dispersion free straight section of SIBERIA-2 storage ring in December 2007 (Fig.1). The wiggler was designed and fabricated in BINP, Novosibirsk. It will supply 3 beamlines by hard X-rays. The minimum critical wavelength of wiggler radiation is equal to 0.4 Å while this value for bending magnets equals 1.75 Å. 19-poles wiggler will provide powerful spectral flux and brightness of SR. General wiggler parameters and first result of operation of SIBERIA-2 with wiggler are presented below.

Figure 1: Superconducting wiggler on SIBERIA-2 storage ring.

GENERAL WIGGLER PARAMETERS

General features of the wiggler design are presented in Table 1.

Table 1: General parameters of the wiggler

Parameters	Values
Number of poles	19 with main field & 2 with half field
Peak magnetic field	7.5 T
Wiggler field period	164 mm
Gap between upper and lower poles	20.2 mm
Beam aperture (elliptical)	14 mm vertical & 120 mm horizontal
Length	2400 mm
Maximum beam distortion	±23.5 mrad
Power output at 100 mA & 7.5 T	35 kW
Currents of power supplies at 7.5 T	160 – 230 A
Maximum stored energy	500 kJ

The wiggler will show great influence on storage ring parameters. The parameters of SIBERIA-2 with 7.5 T wiggler and without it are shown in Table 2.

Table 2: The parameters of SIBERIA-2 at 2.5 GeV with and without 7.5 T wiggler.

Parameters	Without wiggler	With wiggler 7.5 ▯
Horizontal emittance	98 nm·rad	64.7 nm·rad
Betatron tune shifts, $\Delta\nu_{x,z}$	-	0, 0.05
Radiation loss per turn	685 keV	1041 keV
Orbit compaction factor	0.01036	0.01036
Energy dispersion, σ_E/E	0.000953	0.00133
Damping times: τ_x, τ_z, τ_s	3.15, 3.02, 1.48 ms	2.05, 1.99, 0.98 ms
RF-voltage amplitude	1.2 MV (current value)	1.61 MV (for the same energy acceptance)

WIGGLER TESTING BEFORE INSTALLING ON THE RING

After transportation from BINP the wiggler was assembled and tested outside SIBERIA-2 shielding. A first aim was to reach a design value of magnetic field. The 7.5 T field level was achieved after several quenches. Liquid He consumption was very closed to zero for all field levels. A second aim was to fulfill measurements of magnetic field distribution. First and second integrals of transversal field along the wiggler must be close to zero for correct wiggler operation. In this case wiggler will not distort electron close orbit in the ring. Value of these integrals is regulated by ratio of two power supply currents I1 and I2. First current (I1) feeds internal coils on central poles of the wiggler. External coils on central poles and coils of side poles are supplied by sum of two currents (I1+I2). Magnetic measurements gave relation between I1 and I2 for whole range of the magnetic field (see Fig.2). Obviously, power supply of I2 must be bipolar.

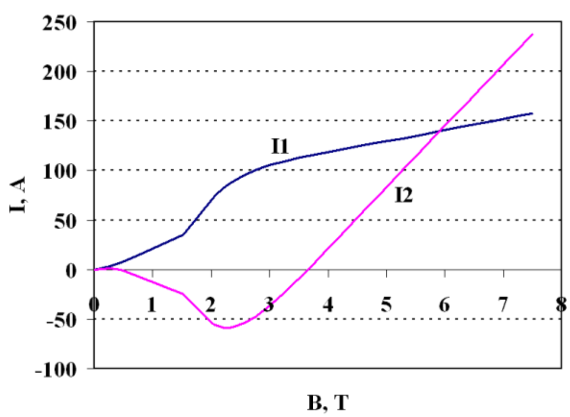

Figure 2: Currents I1 and I2 corresponding to zero field integrals as a function of peak magnetic field B.

At present we have only unipolar power supplies. In order to make measurements between 0.5 T and 3.6 T we must change polarity of I2 power supply by hand. Another property of existing power supplies is low speed of extracting electric energy from the wiggler. We can increase peak field from zero to 7.5 T during 15 minutes, but it takes hours to decrease field from 7.5 T to zero.

WIGGLER PERFORMANCE ON SIBERIA-2 STORAGE RING

Vacuum and cryogenic performance

The wiggler was installed on SIBERIA-2 storage ring with two other parts of vacuum chamber. First part, at an entrance of electron beam, contains additional SR absorber defending the wiggler from radiation of upstream dipole. It also contains ion pump. Second part, at an exit of the beam, contains SR absorber and high diameter bell. No in situ bakeout was done. In spite of this, vacuum level is acceptable for normal storage ring operation; beam lifetime is not determined by vacuum conditions in the wiggler straight section even when wiggler is warm.

Cryogenic conditions are not very well. We observe increasing liquid He consumption exceeding 2 liters per day. Reasons are not fully understood. The consumption doesn't depend on electron beam current.

Vertical aperture

Vertical aperture available for beam was measured by creating beam bump in wiggler straight section. It was found that aperture is equal to approximately 9.6 mm. It's less than design value 14 mm. It may be caused by deformation of copper liner inside wiggler vacuum chamber after several quenches. In any case this value of the aperture doesn't restrict injection efficiency and beam lifetime at working.

Power supplies

Because of unipolar power supplies peak field of the wiggler is limited by value of approximately 3.5 T (see Fig.2). Field integrals were not compensated in the range between 0 and 0.5 T. Large shifts of betatron tunes up to 0.06 at 2.5 GeV were observed in this range. Closed orbit distortion achieved more than 3 mm in horizontal plane at pickup-station azimuths. It means that we can not increase wiggler field from zero level at working energy of SIBERIA-2.

As a result new algorithm of wiggler operation was accepted. At the injection energy (450 MeV) of SIBERIA-2 wiggler peak field is supported at 1.5 T level. This level was not changed during storing of electrons and energy ramping. Then rising of wiggler peak field occurs in order to reach its desirable value. 1.5 T at injection energy approximately corresponds to 7.5 T at working energy if influence of the wiggler on beam parameters is concerned. In this case synchrotron radiation from the wiggler will not heat vacuum chamber inside the wiggler. We found that 1.5 T wiggler has no influence on injection efficiency.

Betatron tune shifts

Betatron tune shifts $\Delta\nu_x$, $\Delta\nu_z$ are given by equations:

$$\Delta\nu_x = 0, \qquad \Delta\nu_z \cong \frac{1}{4\pi}\left(\frac{1}{\rho_w}\right)^2 \frac{L_w}{2} < \beta_z >, \tag{1}$$

where $<\beta>$ - average value of β_z along the wiggler:

$$< \beta > = \beta_0 + \frac{L_w^2}{12\,\beta_0} \tag{2}$$

β_0 is β-function value at the center of wiggler straight section, L_w – wiggler length, $L_w = 0.5 \cdot N \cdot \lambda_w$, ρ_w – minimum bending radius, $\rho_w = \frac{B\rho}{B_0}$, N – wiggler poles number, λ_w – wiggler field period. In our case β_{0z} = 0.6 m, and for injection energy and 1.5 T in wiggler $\Delta\nu_z$ equals 0.063. Observed tune shifts coincide with calculated values with the accuracy of 0.005 (See Fig.3).

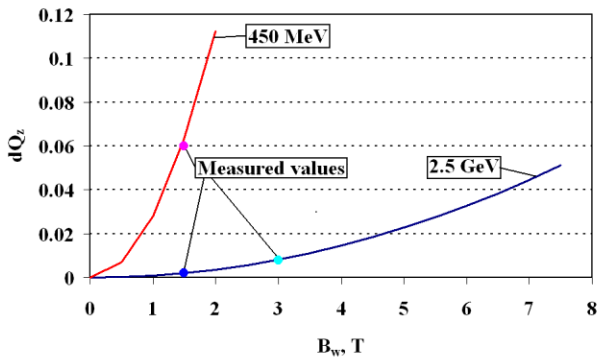

Figure 3: Vertical betatron tune shift as a function of peak wiggler field for two SIBERIA-2 energies. Theory and measured values are shown.

Betatron tune shifts during injection and energy ramping were compensated by two families of quadrupole lenses, that is compensation was global. SIBERIA-2 control system corrects only betatron tunes during energy ramping routine in order to minimize difference between magnetic structures with and without wiggler.

Chromaticity and orbit changes

Except of betatron tunes' changing the wiggler slightly increases natural chromaticity of the ring. At the injection energy and 1.5 T the chromaticity in both planes increased on approximately 0.5 – 1. We should change power of sextupole lenses on 5% in order to get stable injection.

After energy ramping field rising in the wiggler may be done. Duration of this process is determined by high inductivity of wiggler coils. It takes 4 minutes to rise wiggler field from 1.5 T to 3 T. Vertical betatron tune shift at the end of this process was equal to 0.008, in good agreement with (1). Maximum distortion of electron close orbit in horizontal plane was not exceeded 0.5 mm.

Wiggler radiation observation

Radiation from the wiggler was detected by luminofor screen on initial part of wiggler beamline inside SIBERIA-2 shielding (Fig.4). Best value of electron current was 25 mA at 2.5 GeV and 3 T peak field.

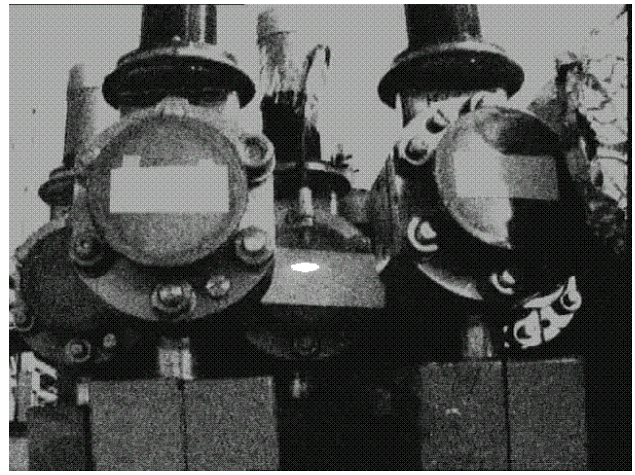

Figure 4: Synchrotron radiation from the wiggler on luminescent screen. 1 mA electron current, 2.5 GeV, 3 T peak field, after stainless steel plate without radiation absorber.

CONCLUSIONS

First radiation from superconducting wiggler was observed on SIBERIA-2 storage ring. An algorithm of electron storing with working wiggler was created and we achieved 25 mA electron current at 2.5 GeV with 3 T peak field in the wiggler. We observed high level of liquid He consumption, so cryostat repair may be needed. Also we need new bipolar power supplies allowing fast current decreasing.

REFERENCES

[1] V.Korchuganov, M.Blokhov, M.Kovalchuk et al. "The status of the Kurchatov center of SR", *Nuclear Instruments and Methods*, A 543 (2005) pp. 14-18.