HORIZONTAL EMITTANCE REGULATION AT SIBERIA-2

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Abstract

Synchrotron radiation (SR) brightness is the most valuable parameter of every SR light source. It depends greatly on horizontal emittance of an electron beam. That's why all modern SR light sources have designed emittance of several nanometers. A horizontal emittance of SIBERIA-2 now equals to 98 nm [1]. It can be decreased by two ways. First way is to find another working point (betatron tunes) with lower emittance. Maximal possible current values of existing power supplies must be taken into account. Injection efficiency may become worse because of smaller dynamic aperture (DA) due to stronger sextupoles. Second way is to rebuild magnetic structure keeping the same betatron tunes. Advantages of this method are good injection efficiency and proved energy ramping process. Modification of the magnetic structure may be done at high energy with more stable electron beam. But the second way is not allowed to reach as lower emittance level as in the first way.

Theoretical and practical aspects of these two ways are described in the report. Magnetic structures with dispersion-free straight sections and smooth horizontal dispersion function are presented. Also structure with higher emittance is described in order to reach higher injection efficiency.

INTRODUCTION

Brightness of synchrotron radiation from dedicated SR sources depends strongly on horizontal emittance ε_X of an electron beam. Modern 3rd generation storage rings have ε_X value of about several nanometers. Today SIBERIA-2 storage ring operates with ε_X = 98 nm at 2.5 GeV, so minimization of its value is very actual.

It may be performed by two ways. First way is to find new working point and to change magnetic structure at injection energy 0.45 GeV. Limitations imposed by power supplies (after energy ramping) must be taken into account in this case. Another problem is smaller DA in structures with smaller emittance, so injection efficiency may be decreased. Second way to minimize ε_X consists in reorganization of magnetic structure in old working point at 2.5 GeV after energy ramping. Established processes of injection and energy ramping are advantages of this way. Adjustment of magnetic structure takes place at high energy where stability of electron beam is much higher. But resulting emittance in the second way cannot be so small like in the first one.

NEW WORKING POINTS

ε_X minimization leads to stronger focusing, natural chromaticity growth and as a consequence stronger sextupoles for chromaticity compensation. Nonlinear magnetic fields in sextupole lenses excite resonances which restrict DA. It leads to lower injection efficiency, lower beam lifetime, beam losses during energy ramping. For these reasons magnetic structure in new working points must keep (or improve) machine parameters: injection rate, high stored current, small energy ramping time etc.

SIBERIA-2 structure contains 6 families of quadrupoles (see Fig.1). Lenses F1 and D1 create achromatic bend, F2 determines betatron functions behavior in bending magnets, other lenses in dispersion-free straight section define values of betatron tunes. Sextupoles for chromaticity correction are situated near F1 and D1 quadrupoles. Injection takes place in horizontal plane from inner part of the ring right before F1. Betatron tunes usually equal to $Q_x = 7.77$, $Q_z = 6.70$.

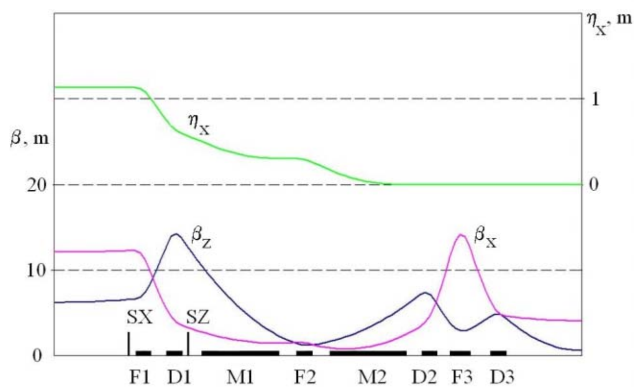

Figure 1: Betatron functions on one-half of the SIBERIA-2 cell (10.34 m = 1/12 of ring circumference). F, D – quadrupoles, M – bending magnets, S – sextupoles.

New magnetic structure may contain achromatic bend or not.

Magnetic Structure with Achromatic Bend

In this case gradients of F1 and D1 must correlate to keep achromatic bend, so emittance is strongly depends on F2 gradient. ε_X minimum value corresponds to F2 gradient 3.6 m^{-2} instead of 2.8 m^{-2} in present structure. New structure has betatron tunes $Q_x = 7.85$, $Q_z = 3.79$ and ε_X = 66 nm (all calculations were made by code OPTICK). DA calculations for injection point demonstrate reduction of available aperture from Ax = 27 mm (present structure, horizontal plane, ±40 mm physical aperture) to Ax = 19 mm in the new structure. We tried to inject beam into this structure and discovered two times less injection efficiency than in the old structure. As one can see later, this working point have not great advantages in comparison with present one. General properties of the structure are presented in Table 1.

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Magnetic Structure without Achromatic Bend

There are fewer limitations for quadrupole gradients in this case. Smaller ε_X may be achieved because of optimal behavior of the betatron functions in bending magnets. Maximum possible power of quadrupoles and sextupoles must be taken into account. Magnetic structure with ε_X = 17 nm and betatron tunes Q_x = 9.71, Q_z = 5.62 was discovered (Fig.2). But phase conditions near injection point are disturbed and normal injection is impossible without serious transformation of the injection system. Dynamic aperture is much less than in the previous structure. Also it is worth noting that this structure is not suitable for high-field wigglers.

General parameters of new SIBERIA-2 structures at 2.5 GeV are presented in Table 1.

Table 1: SIBERIA-2 parameters for old and new magnetic structures

Structure:	**Present**	**New, with achromatic bend**	**New, no achromatic bend**
Betatron tunes, Q_x, Q_z	7.77, 6.70	7.85, 3.79	9.71, 5.62
Natural chromaticities, ξ_x, ξ_z	-17.7 -12.9	-15.5 -11.6	-21.4 -19.7
Horizontal emittance, nm	98	66	17
β_x, β_z at injection point, m	12.1 6.2	12.1 6.0	12.9 6.7
η_x at injection point, m	1.13	0.82	0.54
Momentum compaction	0.0104	0.0083	0.00424
Horizontal DA at injection point, mm	27	19	14

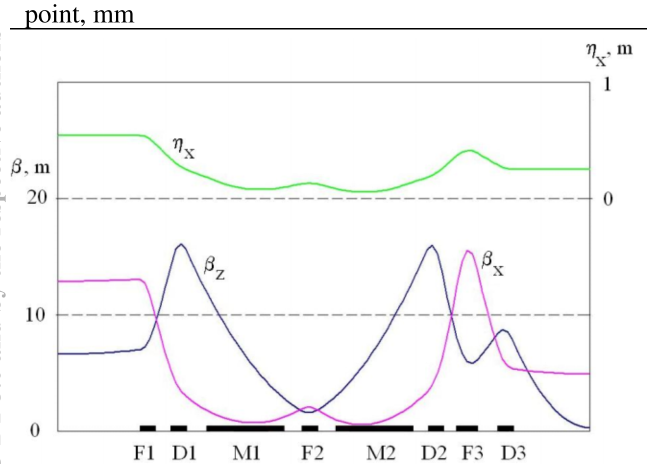

Figure 2: SIBERIA-2 betatron functions in the case of distributed dispersion. F, D – quadrupoles, M – bending magnets.

PRESENT WORKING POINT

In this case emittance decreasing procedure looks completely different. Advantages of this method are stable processes of beam storing at 0.45 GeV and energy ramping up to 2.5 GeV with minimal losses of the beam (2-3%). Structure adjustment takes place at high energy where betatron and synchrotron oscillations' damping is much stronger.

Magnetic Structure with Achromatic Bend

Horizontal emittance in this situation strongly depends on F2 gradient, like in new working point. Minimum ε_X value of 72 nm is achieved when F2 gradient is equal to 3.6 m^{-2}. Optical functions demonstrate behavior similar to Fig.1, excluding smaller dispersion function. General parameters of the structure are presented in Table 2. Structure readjustment experiments were successfully made. Adjustment time was about 1 minute, no beam losses are observed. Beam lifetime was 15% less than in initial structure because of smaller dynamic aperture.

Magnetic Structure without Achromatic Bend

ε_X value of 41 nm can be achieved for structure with distributed dispersion in present working point. Adjustment time was also 1 minute without beam losses. Beam lifetime was 30% less in this case. Structure parameters are presented in Table 2.

Magnetic Structure Enlarged Emittance

Magnetic structure with enlarged emittance value up to 135 nm (for 2.5 GeV) was also tested at injection energy. Record injection efficiency of about 90% was achieved after correction of closed orbit distortions and chromaticity. Beam storing process takes less time because of weaker sextupoles and large dynamic aperture (see Table 2).

Such strategy can be applied to other working points. If low injection efficiency is observed one can find structure with enlarged emittance for given working point and use it at injection energy. After beam storing and energy ramping it will be possible to decrease emittance to minimum possible value. For example, magnetic structure with ε_X = 17 nm may be used now only this way.

CONCLUSIONS

Different methods of the horizontal emittance decreasing at SIBERIA-2 storage ring are described. New magnetic structures for different working points were studied theoretically. Opportunities of the readjustment of SIBERIA-2 magnetic structure were tested experimentally at 2.5 GeV for present working point. Injection into new structure with decreased emittance and new working point was received. Possibility to improve injection efficiency for the structure with enlarged horizontal emittance was demonstrated.

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Table 2: Different SIBERIA-2 structures' parameters for old working point $Q_x = 7.77$, $Q_z = 6.70$ at 2.5 GeV.

Structure:	**Decreased emittance, achromatic bend**	**Decreased emittance, without achromatic bend**	**Enlarged emittance, achromatic bend**
Natural chromaticities, ξ_x, ξ_z	-21.8 -15.6	-16.6 -12.3	-14.4 -11.5
Horizontal emittance, nm	68	41	135
β_x, β_z at injection point, m	14.7 5.7	15.1 5.1	11.7 4.1
η_x at injection point, m	0.81	0.62	1.36
Momentum compaction	0.0083	0.0081	0.0119
Horizontal DA at injection point, mm	20	21	30

REFERENCES

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