A COMPARATIVE STUDY OF LOW ENERGY COMPACT STORAGE RINGS FOR A THOMSON SCATTERING X-RAY SOURCE

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Abstract

A low-energy (<50 MeV) compact storage ring is a basic component of an X-ray source with high average flux based on Thomson scattering. Such ring provides electron bunches with ∼1 nC charge and repetition rate up to 100 MHz for interaction with intense laser pulses. Such ring should provide a small (tens of microns rms) beam radius at interaction point, must have large dynamic aperture, sufficient space for allocation of different elements, such as laser resonator, RF cavity, fast beam injection/extraction systems, beam pick-ups and correctors. In this report, we present the results of comparative study of four versions of storage ring with different structure of lattices.

INTRODUCTION

We consider different variants of low-energy storage ring lattice, which is a part of compact X-ray source based on Thomson backscattering [1, 2]. The energy of the beam injected into the ring is 35–50 MeV, the length of electron bunches is ∼20 ps, the normalized rms emittance is 3–4 mm·mrad. To be able to reach a high intensity of X-ray radiation, the beta functions at the interaction point should be less than 10 cm. While the beam is circulating in a storage ring its emittance is growing and the energy spread occurs due to intrabeam scattering [3] and due to interaction with the laser radiation. To keep the X-ray flux variation small enough, the beam circulating in the ring, is replaced with repletion rate ∼50 Hz.

In [1, 2], we studied a variant of the ring with large dynamic aperture [2], however, the problem of an optimal positioning of the ring elements was not considered there. In this report we compare different options for the ring structure by such characteristics as the dynamic aperture, beta functions at interaction point and emittance growth due to intrabeam scattering.

VARIANTS OF RING LATTICE

We start from lattice [4] which is close to lattice [2], but which allows in a simple way to integrate the optical resonator into the ring by placing interaction point between dipoles (Fig. 1, 2 – RING A). One of the features of the rings for X-ray sources is presence of strong-focusing elements, which results in large values of natural chromaticity (Table 1). In order to compensate natural chromaticity two

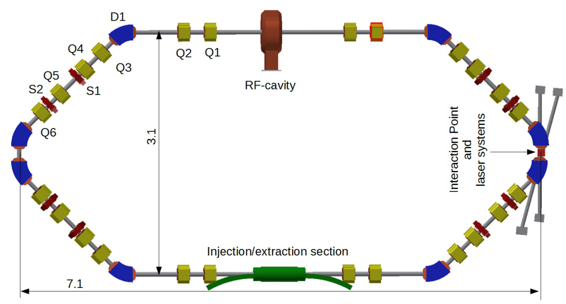

Figure 1: Structure of RING A. Dimensions in meters.

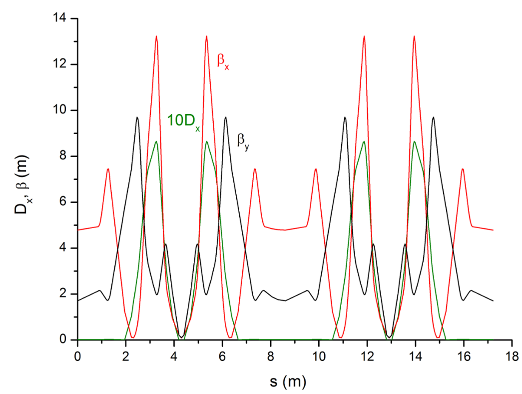

Figure 2: RING A. Horizontal (red curve) and vertical (black curve) beta functions and dispersion (green curve). Calculations were carried out with the MADX code [5].

sextupoles are placed in the sections with nonzero dispersion, (S1, S2 in Fig. 1). Compensation of natural chromaticity was reached by minimizing chromatic invariant [6, 7]. Calculations of dynamic aperture and of beam dynamics were carried out with the MADX PTC code [8]. The ring has a relatively large dynamic aperture (Fig. 9).

In [9, 10] a structure (Fig. 3, 4 – RING B), made of two achromatic bends was proposed. Focusing at the interaction point is done by quadrupoles, placed in close proximity, which allows to minimize beta function at a fairly large dynamical aperture (Fig. 9). The feature of this lattice is high value of the momentum compaction factor (Table 1) which for typical parameters of ring RF system leads to unacceptably large equilibrium bunch length.

The next variant of the structure, which we suggest, has plenty of space for injection/extraction system and RF cav-

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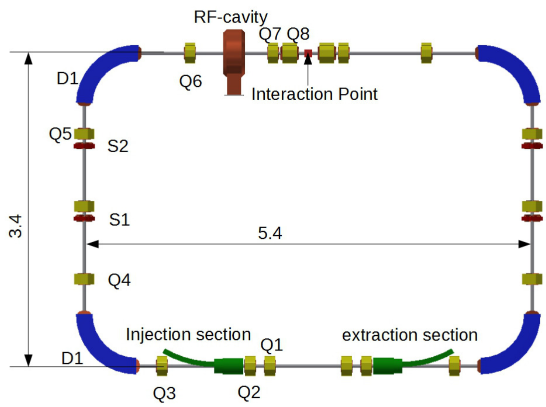

Figure 3: Structure of RING B.

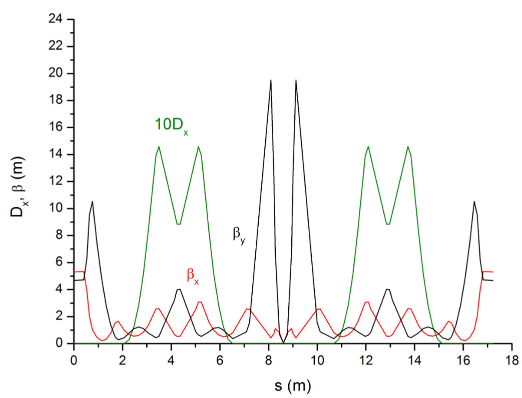

Figure 4: RING B. Horizontal (red curve) and vertical (black curve) beta-functions and dispersion (green curve).

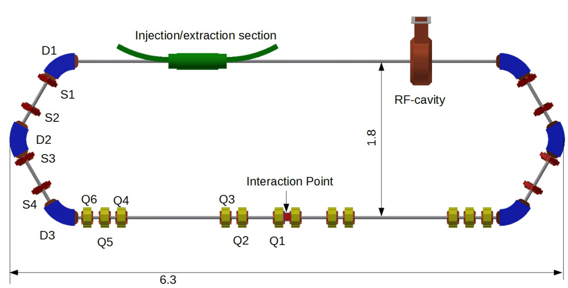

Figure 5: Structure of RING C.

ity and shorter length of the orbit as compared with other variants (Fig. 5, 6 – RING C). The peculiarity of this structure is the absence of quadrupoles in the achromatic bend (Table 1). Beam focusing at the interaction point is done by six quadrupoles. Four sextupoles (S1, S2, S3, S4) installed in the sections with nonzero dispersion compensate natural chromaticity. This structure has a sufficiently large dynamical aperture (Fig. 9), but similar to [9, 10] has a large momentum compaction factor.

After analyzing the given above variants of the rings, we came to a structure, which has enough space for placing injection/extraction systems and RF cavity and low momentum compaction factor (Fig. 7, 8 – RING D). For the compensation of natural chromaticity two sextupoles are placed in the sections with nonzero dispersion (S1, S2 in Fig. 7). The ring has sufficiently large dynamic aperture (Fig. 9) (Table 1).

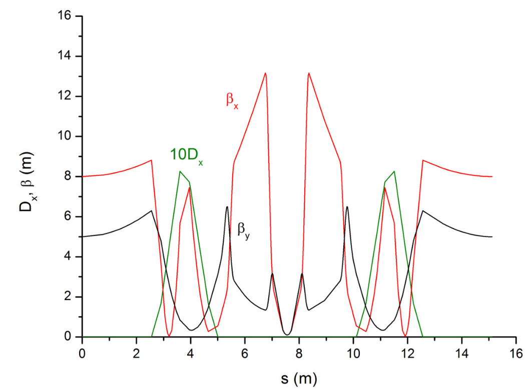

Figure 6: RING C. Horizontal (red curve) and vertical (black curve) beta functions and dispersion (green curve).

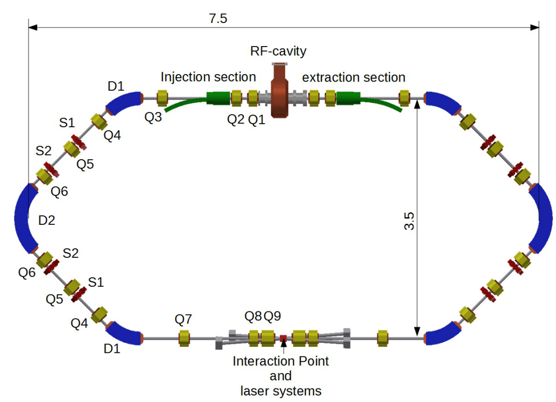

Figure 7: Structure of RING D.

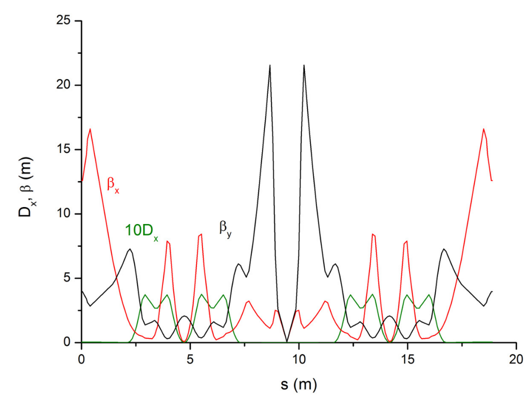

Figure 8: RING D. Horizontal (red curve) and vertical (black curve) beta functions and dispersion (green curve).

For low energy storage ring intrabeam scattering [3] is the major effect leading to unwanted growth of beam emittance. Figure 10 presents emittance growth in 20 ms in the rings A and D for the beam energy 50 MeV and bunch charge 1 nC. Emittance grows more than six times in the course of 20 ms.

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Table 1: Main Characteristics of the Storage Rings Concerned

Ring parameters	Ring A	Ring B	Ring C	Ring D
Length, m	17.2	17.2	15.1	18.9
Betatron tunes	3.22 / 1.71	3.44 / 3.11	2.59 / 1.69	3.78 / 2.16
Beta max x/y, m	13.2 / 9.7	5.3 / 19.5	13.1 / 6.5	16.6 / 21.6
Dispersion max, m	0.87	1.46	0.83	0.38
Beta max x/y in interaction point, m	0.085 / 0.093	0.03 / 0.04	0.1 / 0.1	0.07 / 0.07
Momentum compaction factor	0.013	0.1	0.1	0.023
Natural chromaticity	-12.9 / -11.2	-12.9 / -11.2	-12.7 / -4.6	-9.8 / -11.1
Corrected chromaticity	0.003 / 0.007	0.06 / -0.1	-0.5 / -0.7	0.96 / -1.22
Dispersion max, m	0.87	1.96	0.83	0.38

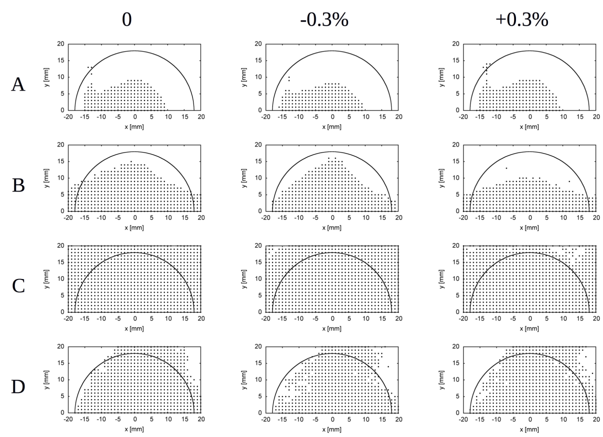

Figure 9: Dynamic apertures of the considered rings for different relative momentum spreads.

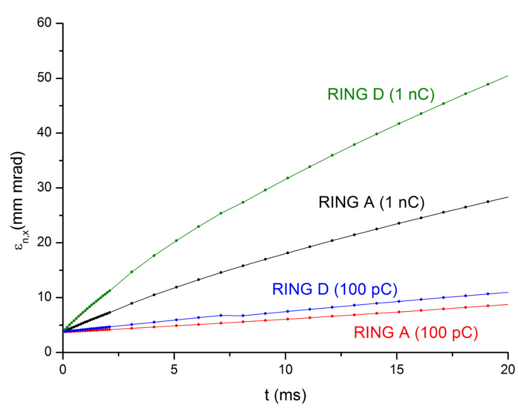

Figure 10: Emittance growth due to intrabeam scattering.

CONCLUSION

We compared four variants of the storage ring structures for Thompson scattering X-ray source. We plan further detailed study for described above variants C and D.

ACKNOWLEDGEMENT

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