ELECTRON STORAGE RING FOR THE COMPACT X-RAY SOURCE

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Abstract

Lattice design of a compact storage ring for laser-electron X-ray generator at the energy 45 Mev is discussed. A quasi-monochromatic X-ray radiation is produced in the process of Compton backscattering of laser photons by counter propagating relativistic electrons. Requirements to characteristics of the electron beam and lattice structure are formulated. The basic parameters of the storage ring are listed.

INTRODUCTION

Nowadays the problem of construction of the compact X-ray source with a narrow spectrum is widely discussed [1] – [3]. Quasi monochromatic source is demanded by various applications including medicine, biocrystallography, custom and security, where conventional X-ray tubes are widely used now. However, the X-ray tubes intensity is too low to be monochromatized and tuned to absorption lines of specific chemical elements, which are used as contrast agents. Meanwhile SR research confirmed the effectiveness of application of narrow band X-ray sources in mammography, angiography, terapy and other fields [4]. So Compton scattering X-ray source is expected occupy a niche between robust, non-expensive and compact tubes that provide wide band X-rays and modern storage rings with insertion devices that are capable to provide high power monochromatic X-ray beams but are too expensive and large for practical applications. One of possible approaches to narrow band X-ray source is the usage of the laser beam Compton scattering on relativistic electrons. Compton scattering X-ray generator may be constructed on the basis of picosecond laser, a storage ring and optical resonator [3]. Such generator utilizes multiple interaction of laser radiation stored in optical resonator with electrons, circulating in a storage ring. The effect of laser cooling allows to receive low emittance electron beams [1] which increases efficiency of light-electron interaction and opens new possibilities for electron beam applications.

We propose lattice design of a compact storage ring to realize the scheme mentioned above.

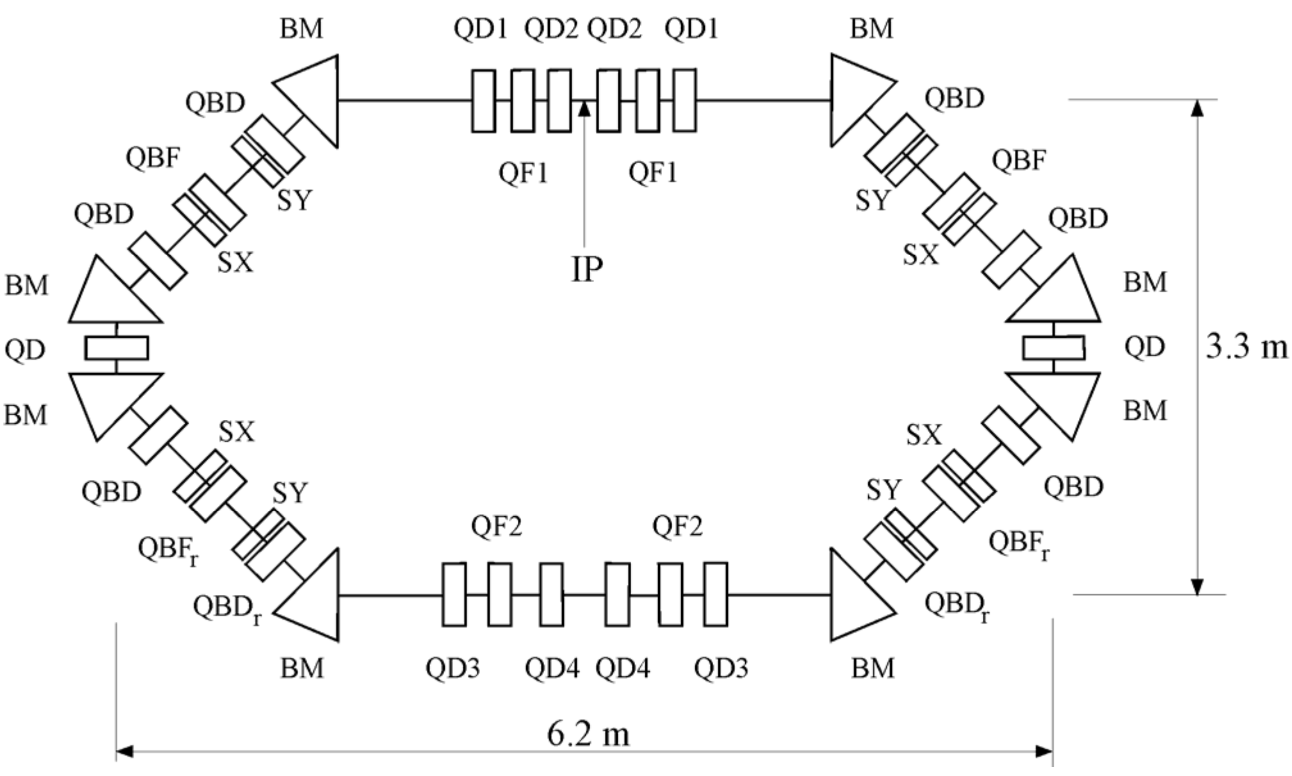

Figure 1: Layout of the storage ring

ELECTRON BEAM PARAMETERS

The balance between the radiation damping and quantum excitation effects during the laser-electron interaction process determines the transverse emittances and relative energy spread of electron beam in the dispersion-free lattice structure [1]:

$$\left(\varepsilon^{n}_{x,z}\right)_{min} = \frac{3}{10}\frac{\lambda_c}{\lambda_L}\beta_{x,z}{}^{*},$$

$$(\sigma_\delta)_{\min} = \left(\frac{\sigma_E}{E}\right)_{\min} = \sqrt{\frac{7}{10}\frac{\lambda_c}{\lambda_L}\gamma},$$

where $\lambda_c = h/mc \approx 2.43\times10^{-12}$ m is the Compton wavelength of the electron, λ_L is the laser wavelength, $\beta_{x,z}{}^{*}$ is the electron beta function (or the depth of focus) in the x or y direction at the laser-electron interaction region, $\gamma = E/mc^2$, E – is the electron energy.

For example, when 45 MeV electrons interact with $\lambda_L \sim 10^{-6}$ m wavelength laser and the depth of focus is $\beta_{x,z}{}^{*} \sim 5$ cm, the relative energy spread is $(\sigma_\delta)_{min} \sim 0.016$ and the normalized transverse emittances are $\left(\varepsilon^{n}_{x,z}\right)_{min} \sim 3\times10^{-8}$ mm·mrad, that corresponds to the rms radius of the electron beam $\sigma_{x,z} = \sqrt{\beta_{x,z}\varepsilon_{x,z}} \sim 3$ μm.

To achieve maximum interaction efficiency the minimal transversal dimensions of the electron and laser beams should be equal in their interaction region (IR). It is important to note that the intrabeam scattering effect can increase the values of transversal beam emittances.

REQUIREMENTS TO THE PARAMETERS OF THE STORAGE RING LATTICE STRUCTURE

To produce high density electron beam in the IR following requirements must be fulfilled in the IR:

- zero value of the dispersion D_x,
- low values of the electron beta functions $\beta_{x,z}{}^{*} \sim 5$ cm (low-β insertion).
- the presence of only one low-β insertion with the high beam density (several low-β insertions with zero dispersion leads to an increase in the nonlinear Coulomb tune shift and magnifies the intrabeam scattering effects).

These requirements and the low degree of a storage ring symmetry inevitably lead to a number of undesirable side effects such as: a) high natural chromaticity, b) high chromatic mismatch of the betatron envelope functions for off-momentum particles, and in particular high-order variations of betatron tune with momentum.

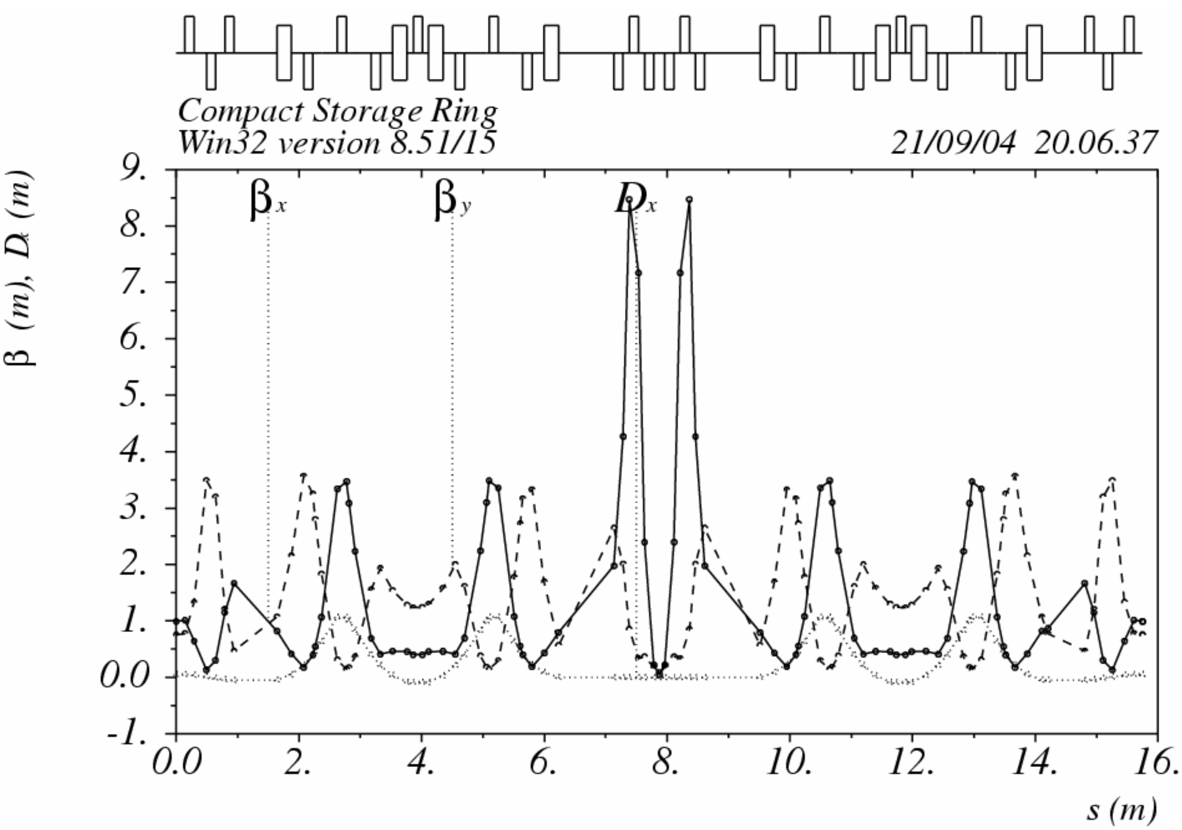

Figure 2: Linear lattice functions of the compact storage ring

STORAGE RING LATTICE STRUCTURE

On the assumption of these conditions, we have proposed the scheme of the storage ring. The layout of the focusing structure elements are shown in fig. 1. It consist of two long straight sections, four bending sections and two short straight sections. Each bending section includes three quadrupole lenses placed between two bending magnets *BM*. This configuration allows to receive zero value of the dispersion function in the long straight section with the interaction point and to solve a problem of natural chromaticity correction.

It is possible to obtain a small enough value of the momentum compaction factor α by fitting of the quadrupole lens strength in the bending sections *QBF* and *QBD*, and short straight sections *QD*, which provides conditions for the electron beam circulation with the required relative energy spread σ_δ=0.016 and relatively low accelerating cavity voltage V=200÷300 kV. To reduce an intrabeam scattering effect it is also possible to make a nonzero dispersion function in the long straight section adjacent with two pairs of quadrupole magnets QBD_r and QBF_r by low retuning of this magnets.

Table 1: Basic parameters of the storage ring

Parameter	Value
Operating energy [MeV]	45
Circumference [m]	15.745
Tunes: horizontal, Q_x vertical, Q_z	 4.35 4.19
Amplitude functions at *IP* [cm]: horizontal, β_x^* vertical, β_z^*	 4.6 8.2
RF voltage amplitude [kV]	300
RF frequency [MHz]	571.2
Harmonic number, q	30
Momentum compaction factor, α	-0.0065
Synchrotron oscillation tune, Q_s	0.0144
Energy acceptance, %	14.5
Natural chromaticity: horizontal, $Q_x^{/}$ vertical, $Q_z^{/}$	 -11.907 -11.023

The reduction of the transversal beam dimensions in the interaction point *IP* is carried out by means of strong quadrupole triplet *QD1*, *QF1*, *QD2*. The length of the straight section free parts is large enough for the location of accelerating cavities and injection system.

The basic parameters of the storage ring are given in table 1. Fig. 2 shows horizontal β_x and vertical β_z amplitude functions and the dispersion function D_x.

CHROMATICITY CORRECTION

To correct natural chromaticity of the storage ring two sextupole families *SX* and *SZ* are proposed. The values of β-functions and the dispersion function at the locations of sextupoles are chosen so as to provide the effective correction with the sufficiently low values of sextupole gradients. The dependence of betatron tunes Q_x and Q_z on relative momentum deviation δ are shown on fig. 3. One can see that for the required energy spread $(\sigma_\delta)_{min}$~0.016 the corresponding tune spread is ΔQ ~0.01. So the effect of nonlinear chromatic terms is rather weak.

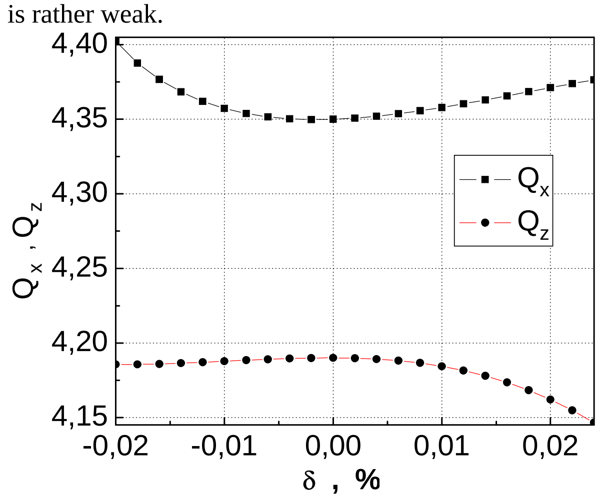

Figure 3: Betatron tunes Q_x and Q_z vs. δ

CONCLUSION

We propose the lattice structure of the electron storage ring for production of high-intensity quasi-monochromatic X-ray radiation based on the backward Compton scattering on relativistic electrons. It also permits to search the process of laser cooling and the effect of intrabeam scattering.

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