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# LOW EMITTANCE STORAGE RING DESIGN FOR CANDLE PROJECT*

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*Abstract*

The most effective way to increase the brilliance of synchrotron light sources is the reduction of beam emittance. To improve the CANDLE synchrotron light source performance, a new low emittance facility has been designed with the account of the new developments in magnets fabrication technology of last decade. The lattices for the booster and storage rings are re-designed keeping the geometrical layout of the facilities. The new design provides the beam emittance in storage ring below 5nm with sufficient dynamic aperture. This report presents the main design considerations, the linear and non-linear beam dynamics aspects of the modified facility performance.

## INTRODUCTION

The CANDLE synchrotron light source [1] general design was based on full-energy booster with 192 m circumference and 74.9 nm beam emittance and electron storage ring with 216 m circumference and 8.4 nm beam emittance. The booster ring accelerates the electron beam from 100 MeV injector energy to 3 GeV storage ring energy. The storage ring of the accelerator complex is the major facility that provides high brilliance X-ray beams from the bends and insertion devices. The former storage ring design implied the 16 Double-Bend Achromatic (DBA) cells with 4.8 m long straight section in each cell for installation of insertion devices, injection system and radio frequency cavities. Table 1 gives the main parameters of the CANDLE storage ring.

Table 1: Main Parameters of the CANDLE Storage Ring

| Parameter | Value |
|---|---|
| Energy (GeV) | 3 |
| Emittance (nm rad) | 8.458 |
| Circumference (m) | 216 |
| Lattice type | DBA |
| Number of periods | 16 |
| Straight section length (m) | 4.8 |
| Max. betafunction (hor./vert.) (m) | 8.6, 20 |
| Natural chrom. (hor./vert.) | -18.91, -14.86 |
| Betatron tunes (hor./vert.) | 13.2, 4.26 |

To improve the CANDLE facility performance, the new low emittance booster ring has been developed [2] in order to provide a reliable beam dynamics during the injection and facility top-up operation. The booster new design was based on the usage of the compact magnets to improve both the performance and the beam quality. With the new design, the beam emittance at full energy is reduced by factor of 4.

As a next step, the new low emittance storage ring was designed. With moderate magnets parameters it provides about 5 nm of beam emittance with sufficient dynamic aperture of the ring. This paper summarizes the latest modifications of the CANDLE light source booster and storage ring optics, including the nonlinear beam dynamics aspects.

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## LOW EMITTANCE OPERATION MOD

### *Low Emittance Booster*

A new full-energy booster synchrotron was designed for the CANDLE storage ring [2]. The booster will accelerate a beam from injection energy of 100MeV up to full energy 3GeV. The circumference of the booster is 192 m that is compared with the storage ring circumference in the ratio of 8/9 and both booster synchrotron and storage ring are to be built in the same tunnel. To avoid effects of stray fields upon the storage ring, the average distance between the two rings is 3.8 m.

The booster lattice has four-fold super-symmetry with 5m long dispersion free four straight sections for RF, injection, extraction and diagnostics. The lattice is designed with FODO cells which consist of combined-function magnets to reach a small emittance of about 20nm. The main parameters of low emittance booster are presented in Table 2.

Table 2: Low Emittance Booster Main Parameters

| Parameter | Value |
|---|---|
| Injection energy (MeV) | 100 |
| Ejection energy (GeV) | 3 |
| Emittance (nm rad) | 19.54 |
| Circumference (m) | 192 |
| Lattice type | FODO |
| Natural chrom. (hor./vert.) | -19, -14.2 |
| Betatron tunes (hor./vert.) | 13.44, 8.35 |

The basic structure of the booster lattice consists of four arcs, each with 5 m long straight section. The arc has two matching cells and 9 FODO cells, each with two combined-function magnets BF and BD.

It is advantageous to have non-dispersion straight sections, since both the RF-cavity and the injection elements are located in those straights. The non-dispersion straight sections are provided by the missing dipole FODO type matching cells which include two families of quadrupole magnets (QF and QD).

A chromaticity correction is incorporated into the pole profile of the booster dipoles. However, defocusing SD sextupoles are installed after BD in each FODO cell. They will give flexibility in optimizing the chromaticity.

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The main bending magnets of the new booster are combined-function magnets having dipole, quadrupole, and sextupole fields. Such kind of magnets has been already used for SLS [3] and ASP [4].

Figure 1 shows the dynamic aperture of the booster at full energy for relative energy deviations -1%, 0% and +1% at the center of the straight section.

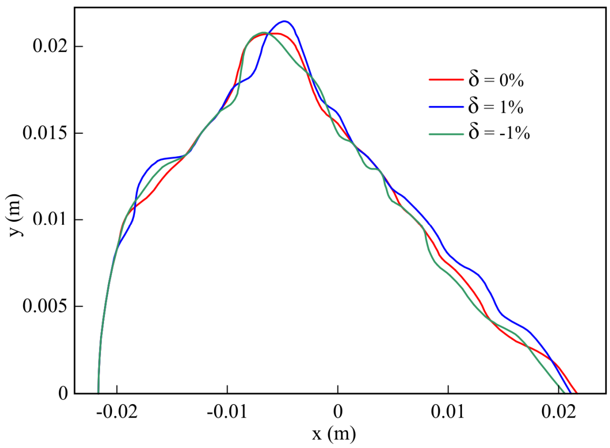


Figure 1: Dynamic aperture of the booster at full energy.

## *Low Emittance Storage Ring*

Detailed study of the linear and non-linear beam dynamics has shown that for low beam emittance storage ring performance with insertion devices the best candidate is the DBA type focusing lattice. Following the new developments at MAX-IV [5,6], for the new low emittance storage ring lattice design the bending magnets with integrated quadrupole and sextupole components and the quadrupole magnets with sextupole components were used . The magnetic structure of the low emittance ring consists of 24 DBA cells with 4.4m long straight sections in each cell. The magnetic layout of new lattice DBA cell is shown in Fig. 2.

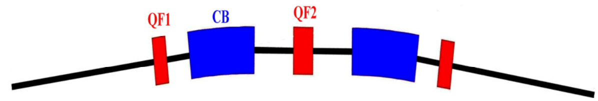


Figure 2: Schematic layout of a low emittance lattice cell (CB-combined dipoles (blue), CF1 and CF2 combined quadrupoles (red)).

The main parameters of the bending and quadrupole magnets for low emittance CANDLE storage ring are shown in Table 3.

Table 3: Main Parameters of Low Emittance Ring's Combined Bending Magnet

| Description | Dipole | QF1 | QF2 |
|---|---|---|---|
| Num. of magnets | 48 | 48 | 24 |
| Bend. angle | $7.5^0$ | - | - |
| Length m | 1 | 0.2 | 0.3 |
| Quad. strength $1/m^2$ | -0.903 | 3.82 | 3.39 |
| Sext. Strength $1/m^3$ | -5.923 | 7.68 | 23.64 |
| Magnet gap mm | 30 | 30 | 30 |

Figure 3 shows the betatron and dispersion functions of the new lattice along the ring one quadrant. The optic functions, dynamic aperture and other parameters optimization have been performed using OPA code [7].

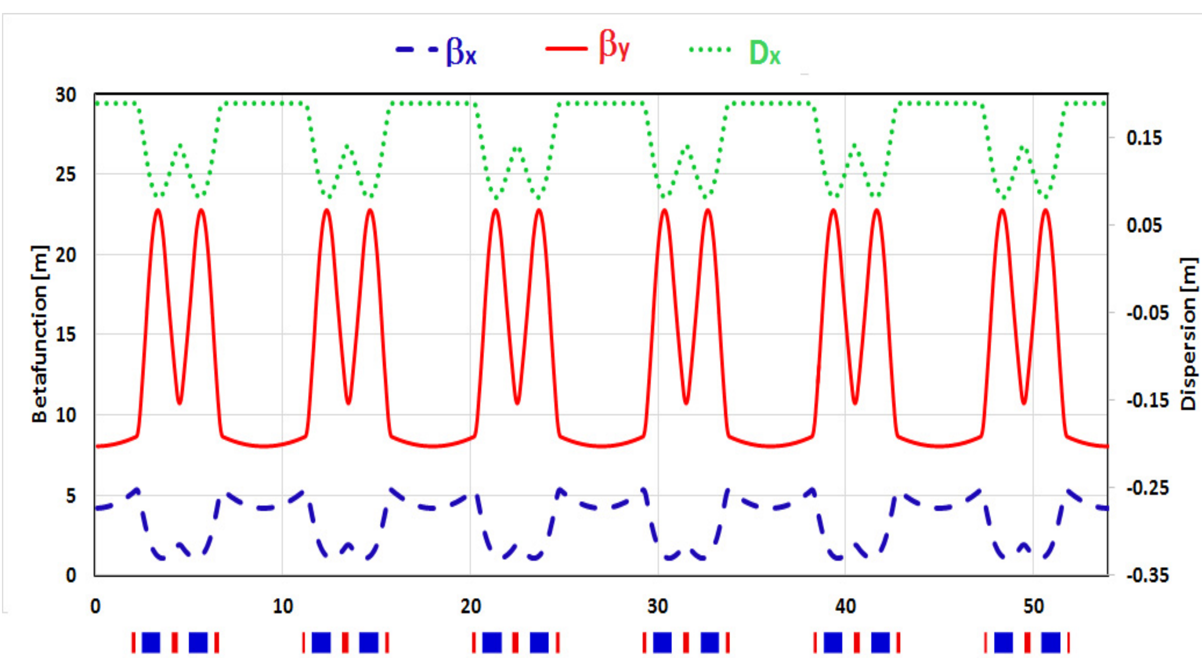


Figure 3: Low emittance storage ring optical functions per one quadrant.

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The key parameters of the new storage ring are given in Table 4.

Table 4: Main Parameters of Low Emittance Ring

| Parameter | Value |
|---|---|
| Energy (GeV) | 3 |
| Emittance (nm rad) | 5.19 |
| Circumference (m) | 216 |
| Lattice type | DBA |
| Number of periods | 24 |
| Straight section length (m) | 4.4 |
| Max. betafunction (hor./vert.) (m) | 5, 22 |
| Natural chrom. (hor./vert.) | -13.64, -24.27 |
| Betatron tunes (hor./vert.) | 14.17, 3.19 |

The betatron functions at the straight section are approximately constant and equal to 5 and 8 m for horizontal and vertical oscillations respectively. The dispersion is about 0.18m. The new lattice provides the horizontal emittance of 5.2 nm.

The integrated sextupole components of (QF2) quadrupole and dipole magnets are used to correct natural chromaticities. The integrated sextupole component of (QF1) quadrupoles is used to enlarge dynamic aperture. Figure 4 shows the 4000 turn's dynamic aperture for relative energy deviations -3%, 0% and +3% at the centre of the straight section (injection point). As it is seen the dynamic aperture is enough large.

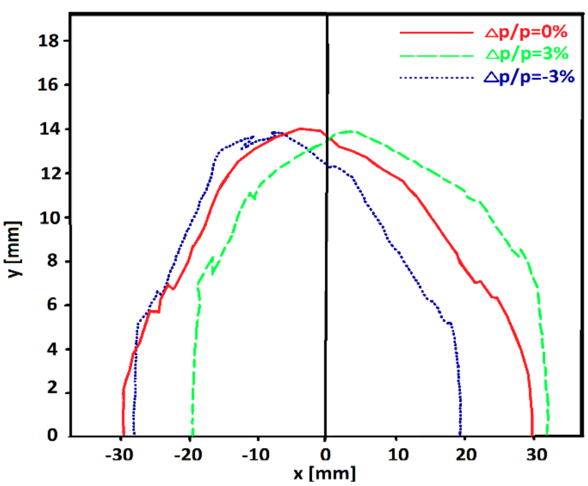
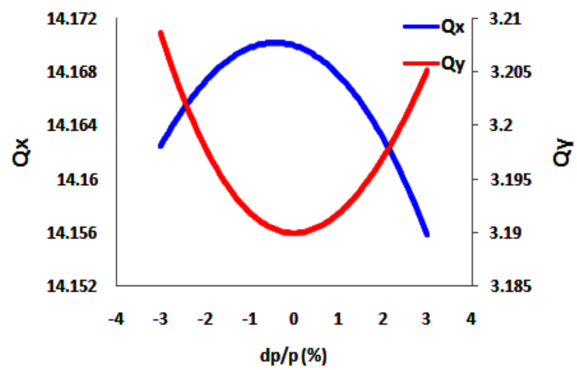
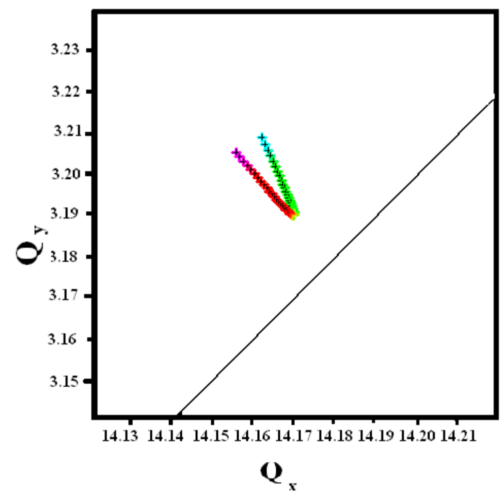



Figure 4: Dynamic aperture of the low emittance ring.

Compared to the original design the working point in the resonance diagram has been shifted from (13.22, 4.26) to (14.17, 3.19). Figure 5 represents the momentum dependence of horizontal and vertical betatron tunes. In Fig. 5 b) up to forth order resonance lines are marked. As it can be seen from plots particles inside the beam do not cross any strong resonance lines in the frequency map within energy relative deviation range of ±3% .




a)




b)

Figure 5: Momentum dependent tunes of the low emittance ring.

## SUMMARY

New low emittance lattice design for the CANDLE storage ring was developed. Compared with the former storage ring design with emittance of 8.45 nm, the new storage ring design provides the horizontal emittance of 5.19 nm with 24 DBA type periods. The new design is based on the combined function magnets and has sufficient horizontal and vertical dynamic apertures.

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