# Low $\alpha_p$ Mode Study of the BEPCⅡ

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**Abstract** BEPCⅡ, the upgrading project of the Beijing Electron-Positron Collider (BEPC), has been designed with a luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$ at the t-charm energy regime. To increase the operating luminosity of the BEPCⅡ, a low momentum compaction factor collision mode has been studied. At the same time, the dynamic aperture of this mode has been calculated since it may not be enough as a result of the sextupole strength increasing. The corresponding luminosity of this mode is calculated through beam-beam simulations.

**Key words** momentum compaction factor, lattice, dynamic aperture

## 1 Introduction

BEPCⅡ is an upgrading project of the Beijing Electron-Positron Collider (BEPC), in which a new inner ring will be installed inside the old one. The BEPC has a 4-folder symmetrical structure, consisting of the IR/RF, the arc and the injection regions.

The double-ring geometric structure of the BEPCⅡ makes each ring not to be a 4-folder symmetrical structure, though a symmetry still exists between the electron and positron rings. Based on several design criteria, a geometric design which satisfies both collision and synchrotron radiation modes requirements is done[1]. The emittance and tunes for the collision mode can be changed easily. The lattice offers a good dynamic aperture even with ±0.6% energy spread. The main parameters of BEPCⅡ collision mode are listed in Table 1.

There are several measures to increase the operating luminosity of BEPCII, such as increasing the bunch number, moving the horizontal working points to 6.51, and decreasing the bunch length. To decrease the bunch length, we can increase the voltage of the rf cavity. But at the design value of the machine parameters, it is impossible to increase the rf voltage higher than 1.5MV. However, under the microwave instability threshold, one possible way to decrease the bunch length is to decrease the momentum compaction factor.

Table 1. Main parameters of BEPCⅡ collision mode.

| | |
|---|---|
| Energy/GeV | 1.89 |
| Circumference/m | 237.531 |
| RF voltage/MV | 1.5 |
| Beam current/A | 0.91 |
| Momentum compaction factor | 0.0235 |
| Bunch length/cm | 1.5 |
| Beta-function at IP($x/y$)/m | 1/0.015 |
| Luminosity/($\text{cm}^{-2}\cdot\text{s}^{-1}$) | $1.0\times10^{33}$ |

In the following sections we will introduce the criteria which should be abided during the matching of the low $\alpha_p$ mode, the matching result, tracking result of the dynamic aperture and the luminosity calculated from the beam-beam simulations.

## 2 Matching of low $\alpha_p$ mode

### 2.1 Matching of BEPC

As BEPC has a 4-folder symmetrical structure, it is easy to match the K values of quadrupoles to get

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a low $\alpha_p$ mode. The results are listed in Table 2.

Table 2. Comparation with original values (BEPC).

| BEPC | Operating value | Matching value |
|---|---|---|
| Momentum compact | 0.0427 | 0.0284 |
| Working points($x/y$) | 5.81/6.79 | 5.89/6.52 |

## 2.2 Matching criteria

According to the existing lattice design, there are several criteria during the matching process: the horizontal working point is limited between 6.51 and 6.53, and the vertical working point is limited between 5.55 and 5.59; the dispersion should be 0 in the RF and injection regions; the horizontal beta function at the injection point should be greater than 20 meters, the horizontal and vertical beta function at the rf cavity should be around 10 meters, and the horizontal beta function at the injecting kicker should be around 10 meters; the horizontal phase advance between the two kickers in the outer ring should be π strictly.

According to the existing lattice, all of the components' positions and lengths are fixed in the electron and positron rings. The strength of the dipoles is fixed too. That is to say, we can only change the values of the strengths of quadrupoles to reduce the momentum compaction factor. At the same time, it is necessary to optimize the strengths of the sextupoles to get a reasonable dynamic aperture.

The strength of the superconducting quadrupole in the interaction region is fixed. There are 17 quadrupoles (Q1—Q17) in each quadrant of each ring. Due to the existing lattice, their polarities are fixed too, except for Q2 to Q4 whose polarities can be changed. The minimum and maximum K values are −1.6 and +1.6 respectively. Q1 is divided into Q1a and Q1b, which are special dual aperture quadrupoles. For Q1a and Q1b the gradients in the inner and outer rings are equal. The K value of Q1a is set as 1. The K value of Q1b should change between 0.6 and 0.81.

The momentum compaction factor is defined as:

$$\frac{\Delta C}{C}=\alpha_p\frac{\Delta p}{p_0}\ , \tag{1}$$

where $C$ is the circumference of the storage ring, $p_0$ the momentum of the synchrotron particle, $\Delta p$ the momentum deviation from the synchrotron particle, and $\Delta C$ the circumference deviation due to $\Delta p/p$.

By a series of deduction, we get another formula for the momentum compaction factor:

$$\alpha_p=\frac{1}{C}\oint\frac{D(s)}{\rho}\mathrm{d}s\ . \tag{2}$$

Here $D(s)$ is the dispersion function at every point along the whole ring.

We can see that to decrease the momentum compaction factor, the most straight and effective way is to decrease the dispersion function.

## 2.3 Matching result

If the K values of all the quadrupoles are adjusted together, we can not get a convergent result. So several quadrupoles' K values are fixed and the others' are adjustable.

By now, we can compress the momentum compaction factor from 0.0235 to 0.0188 using MAD[2]. The convergence is good. The results are listed in Table 3.

Table 3. Comparation with original values (BEPCⅡ).

| BEPCⅡ | Original value | Matching value |
|---|---|---|
| Momentum compact | 0.0235 | 0.0188 |
| Working points($x/y$) | 6.53/5.58 | 6.53/5.58 |

As Fig. 1 shows, all of the twiss parameters can fulfill the matching criteria.

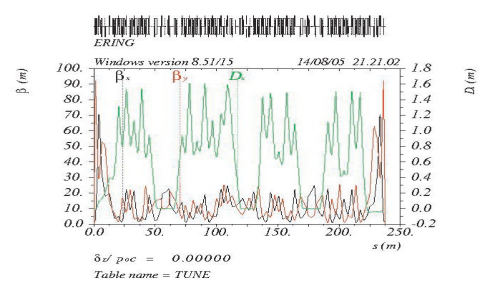


Fig. 1. BEPCⅡ ERING TWISS parameters.

## 2.4 Chromaticity correction and dynamic aperture

Nine sextupoles in each arc region are used to correct the chromaticity from negative values to 1. They are divided into 5 families of defocusing sextupoles (SD) and 4 families of focusing sextupoles (SF). The families of sextuples are set as SD1, SF1, SD2, SF2, SD3, SF3, SD4, SF4, and SD5 from the IP to the injection region in the southern half ring and from the injection region to the RF region in the northern half ring. Their strengths are −1.15, 2.72, −13.4, 9.97, −11.8, 3.72, −8.66, 3.47, and −6.19, respectively.

A sufficient dynamic aperture is necessary, either for efficient beam injection or long beam life time. Tracking for 1024 turns with 10 seeds using SAD[3], the dynamic aperture with all magnets errors is obtained, as shown in Fig. 2.

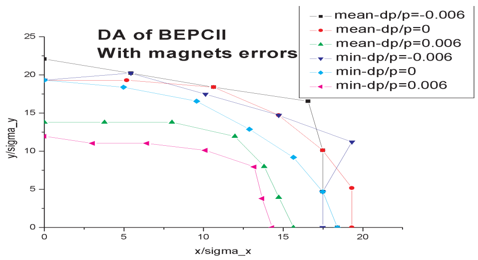


Fig. 2. Dynamic aperture with all errors.

Within the momentum deviation range of ±0.7%, the beta functions change less than 40% and the tunes change about 0.5%, as shown in Fig. 3.

Using Zhang's code[4], the luminosity for the low $\alpha_p$ mode is calculated to be $5.3\times10^{32}\text{cm}^{-2}\cdot\text{s}^{-1}$ after two transverse damping times.

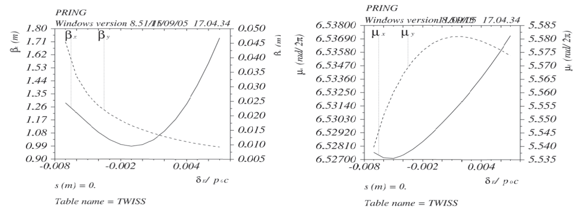


Fig. 3. Beta and tunes vs deltap.

## 3 Conclusion

A low $\alpha_p$ collision mode for BEPCII has been developed. The momentum compaction factor has been reduced from 0.0235 to 0.0188. The dynamic aperture is acceptable and the working points is selected concerning the beam-beam issues. The momentum compaction factor is expected to be reduced to 0.017 through detailed work in the near future and the dynamic aperture should be optimized.

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# BEPCⅡ小动量压缩因子模式研究

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**摘要**　BEPCⅡ 是BEPC的升级工程, 它被设计工作在亮度为$10^{33}\text{cm}^{-2}\cdot\text{s}^{-1}$的τ-charm能区. 为了提高BEPCⅡ的运行亮度, 研究了BEPCⅡ 对撞模式的小动量压缩因子模式. 同时优化了这个模式下的动力学孔径和模拟计算了这个模式的亮度.

**关键词**　动量压缩因子　磁聚焦结构　动力学孔径

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