EVALUATION OF COLLECTIVE EFFECTS IN IRANIAN LIGHT SOURCE FACILITY (ILSF) STORAGE RING

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Abstract

ILSF storage ring is based on 5-BA lattice structure and emittance of 270 pm-rad which is optimized to provide high brightness and high flux photons for the users. Because of design features, small radius vacuum pipe and small momentum compaction factor of lattice, it is expected that instabilities emerging from collective effects will affect significantly the beam quality and make it is challenging to reach maximum designed beam current. In this paper, we present an overview of the impact of collective effects upon the performance of the storage ring. Subjects discussed include instability thresholds, Touschek lifetime and intrabeam scattering.

INTRODUCTION

In this paper, we discuss the effect of multi-particle interactions on the electron beam in the ILSF storage ring as described reference [1]. The storage ring has 100 MHz RF and a revolution period of T0=1.76 µs. The calculations will be conducted for 400 mA beam current. According the harmonic number of ring (176) and 80% of filling number, there will be 140 circulating bunch with the charge of 5.032 nC inside the storage ring. We shall estimate instability thresholds using a simplified model of the ring impedance, which has been developed based on impedance calculations performed to-date for ILSF storage ring. In addition to the wakefield effects, we will also discuss calculation of the Touschek lifetime resulting from single scattering, and of the increase in emittance due to intrabeam scattering. We plan to use third-harmonic Landau cavities to increase the bunch length and synchrotron tune spread. Lengthening the bunch raises the longitudinal microwave instability threshold, increases the Touschek lifetime and reduces the effect of intrabeam scattering on the emittance. Increasing the bunch length and synchrotron tune spread improves the effectiveness of positive chromaticity in raising the single and coupled bunch transverse instability thresholds.

IMPEDANCE MODEL

We consider an approximate model of the storage ring impedance. Total impedance of vacuum chamber is the sum of resistance wall and geometric impedance. In order to calculate the resistance wall impedance, we supposed that the storage ring vacuum chamber is composed of 448 m of stainless steel with a vertical half aperture of 10 mm and 20 in-vacuum undulators of copper each with 4 m length and 2.1 mm vertical half-aperture. The thickness of vacuum chamber is 2 mm. Resistance wall impedance of rectangular and elliptical vacuum pipe has been calculated analytically in reference [2]. The longitudinal wall impedance is

$$\frac{Z_{long}^{rw}}{L} = (1 + isign\omega)\frac{Z_0|\omega|\delta_s(\omega)}{4\pi cb}G_0 \qquad (1)$$

where c is the speed of light, µr and σc are the relative permeability and conductivity of the chamber material, respectively; Z0 is the free space impedance; b is the half-aperture. G_0 is form factor which for two different cross sections of ILSF storage ring vacuum chamber is $G_0 \cong 1$.

The longitudinal wall impedance for two cross sections of vacuum chamber is shown in Figure 1.

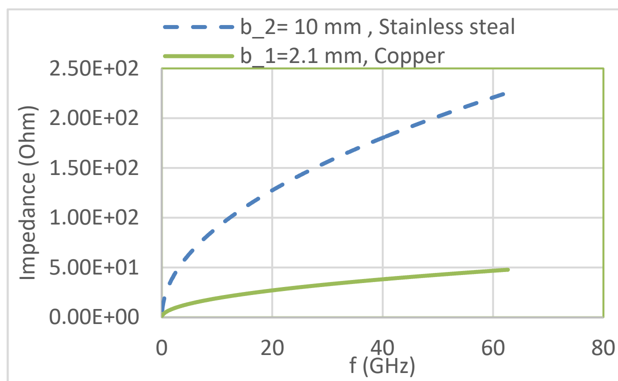

Figure 1: Longitudinal resistance wall impedance for two different cross section of ILSF storage ring. The dashed and solid curves indicate the impedance of Stainless steel and copper part respectively.

The geometric impedance due to cross-section changes in the vacuum vessel is approximated by longitudinal broadband resonators whose parameters are chosen based on numerical impedance calculations we have performed to-date. The numerical geometric impedance calculation already has been done for Beam Position Monitors (BPM), flanges and tapers in the ILSF storage ring. The geometric longitudinal impedance of different part of vacuum chamber approximately given based on Broad Band Resonance (BBR) model.

$$Z_{long} = \frac{R_s}{1+iQ(\frac{\omega}{\omega_r}-\frac{\omega}{\omega_r})^2} \quad (2)$$

The parameters R_s, Q and ω_r are calculated after the fitting BBR model and numerical impedance calculation for different elements in vacuum chamber. Figure 2 shows the geometric impedance based on BBR model. The optimum fitting gives $Q \approx 1$, $R_s = 49\ KOhm$ and $\omega_r = 2\pi \times 27\ GHz$.

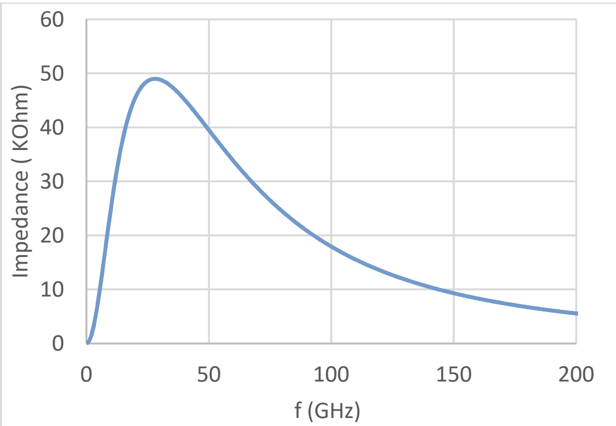

Figure 2: Geometric longitudinal impedance of vacuum chamber based on BBR model.

LONGITUDINAL MICROWAVE INSTABILITY

At very low single-bunch current, the longitudinal density is determined by the equilibrium between radiation damping and quantum fluctuations. As the bunch current increases, the longitudinal charge distribution is modified by the wakefield. Below the threshold of the microwave instability, the energy distribution remains unchanged, and the longitudinal charge distribution is determined by the time-independent solution of the Haissinski equation [3]. In Figure 3, we show the bunch length as a function of a single bunch current calculated based on Haissinski equation.

We also have calculated the bunch length through particle tracking. In Fig. 1, we show the dependence of the bunch length and the energy spread as calculated using the program ELEGANT [4]. The tracking has been done for 100000 particle in 15000 turns.

According to Figure 3, 0.8 mA bunches will suffer negligible increase in energy spread due to the longitudinal microwave instability. In this calculation, we have not considered the effect of landau cavity during the calculations.

We studied the CSR wakefield generated by an electron moving on a circular orbit of radius ρ in the middle of two (perfectly conducting) parallel plates that are separated by a distance 2h. For the CSR wake, the beam dynamics depend only on two dimensionless parameters, the shielding parameter Π and scattering parameter S_{CSR} [5].

$$S = \frac{r_e N_b \rho^{1/3}}{2\pi \nu_s \gamma \sigma_\delta \sigma_z^{4/3}}\ ,\ \Pi = \frac{\sigma_z \rho^{1/2}}{h^{3/2}} \quad (3)$$

Where $N_b . \nu_s . \sigma_\delta$ *and* σ_z are the number of electrons, synchrotron tune, energy spread and bunch length respectively. The threshold associated with CSR is given by

$$(S_{CSR})_{th} = 0.5 + 0.12\Pi \quad (4)$$

Supposing an elliptical vacuum chamber in the arcs with the cross section of (20mm, 13mm), $\rho = 84.04m$ and $h = 13mm$, we find the shielding parameter $\Pi = 36.1399$ and threshold number of electrons in each bunch $N_b = 2.62 \times 10^{10}$. The corresponding threshold current for 140 number of bunches is $I_{th} = 334\ mA$ which is smaller than maximum design current of the ring.

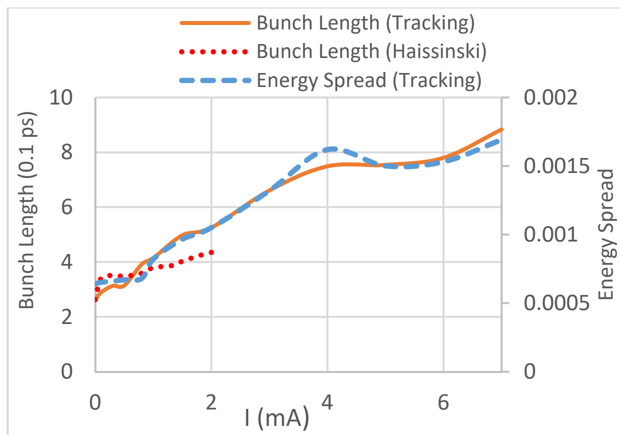

Figure 3: The effect of vacuum chamber impedances on the bunch length and energy spread in different beam currents. The solid and dotted curves show the bunch length through tracking and Haissinski equation.

TRANSVERSE MODE COUPLING INSTABILITY (TMCI)

Small aperture magnets and low gap insertion devices in low emittance storage rings make instabilities excited with resistance wall more important. Transverse mode coupling instability (TMCI) is one of the instabilities which dominantly excited by resistance wall.

The kick factor for a Gaussian bunch pathing through a circular vacuum chamber is defined by [5]

$$k_y = (0.723)\frac{c}{\pi^{\frac{3}{2}} b^3}\sqrt{\frac{Z_0}{\sigma_z \sigma_c}} \quad (5)$$

With b the radius of vacuum chamber, $Z_0 = 377\ \Omega$, σ_c the conductivity and σ_z the bunch length. The TMCI threshold current is given by

$$I_b^{th} \approx 0.7\frac{4\pi c \nu_s (\frac{E}{e})}{C}\frac{1}{\sum_i l_i \beta_{y.i} k_{y.i}} \quad (6)$$

Where C is the circumference of storage ring. In the dominator, the sum is done on the different segments of the lattice. We suppose that the whole ring is composed of

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two parts, the arcs and low gap undulators. The straight sections are filled with 17 low gap undulators. In the multibunche mode, threshold current is $I^{th} = MI_b^{th}$. For 140 bunchs, we find the threshold current about 524 mA where it is larger than the designed current of ring.

TOUSCHECK AND INTRABEAM SCATTERING

The demanding design feature of diffraction limited storage rings, ultra-low emittance and small gap undulator vacuum chambers, causes Touscheck scattering and gas scattering to play a major limitation role for beam lifetime. We calculate the Touscheck lifetime based on Piwinski formalism. By employing Elegant code, a 6-D tracking procedure is conducted to determine the energy acceptance of lattice. The nonlinear synchrotron oscillation due to large second- order momentum compaction factor is included in the energy acceptance calculations. A small vertical ID with 4.1 mm full gap is imposed in the tracking procedure. Fig.4 shows the result of momentum acceptance tracking. Using the result of momentum acceptance tracking, the Touscheck lifetime is calculated. In order to calculate Touscheck lifetime, we assume that 80% of 176 buckets in the ring are filled with 5.032 nC charge per bunch. The Touscheck lifetime for 400 mA beam current in the presence of 17 insertion devices is about 8 h.

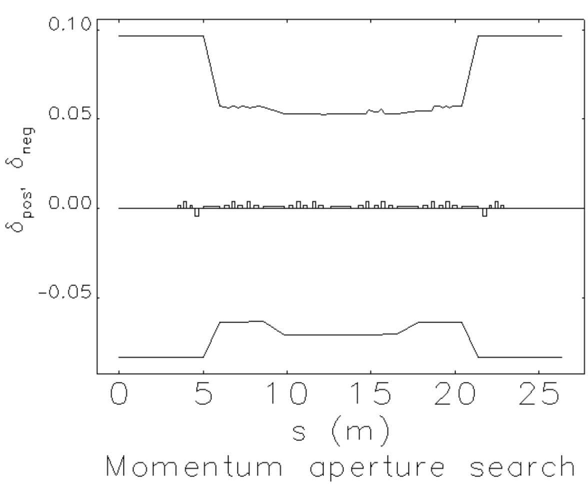

Figure 4: Momentum acceptance tracking for ILSF storage ring. Using the Elegant code, the particles have been tracked for 3000 turns.

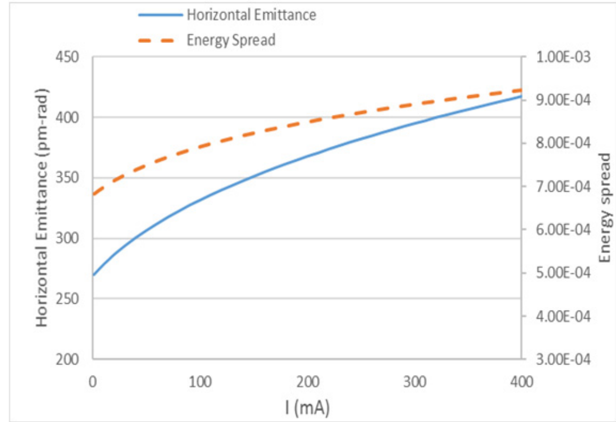

Figure 5: The effect of IBS on equilibrium emittance and energy spread growth in different currents.

Intra beam scattering (IBS) limits the achievable horizontal emittance in the storage rings. By employing 6D tracking code, Elegant, we have calculated the effect of IBS on the emittance and energy spread growth. Fig. 5 shows the variation of emittance and energy spread versus beam current. In the consequence of IBS effect, the zero current emittance (270 pm-rad) increased to 420 pm-rad.

CONCLUSION

In this paper, we investigated the collective effect in ILSF storage ring. We considered an approximate model for longitudinal impedance. It is supposed that the whole impedance of machine is composed of wall impedance and geometric impedance. The geometric impedance of different elements in ring was modeled based on broad-band resonance. The effect of longitudinal impedance on the bunch length and energy spread in different bunch currents has been calculate base on tracking and solving Haissinski equation. In addition, we investigate the effect of Touscheck and intra-beam scattering in the storage ring. It is observed that the IBS has big effect on emittance of the storage ring.

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