新博士紹介

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Title: Coherent synchrotron radiation and microwave instability in electron storage rings

1. Introduction

Coherent synchrotron radiation（CSR）has become a hot topic in accelerator physics over the last decade. It plays an important role in the single-bunch instabilities existing in both storage rings and linacs where high current and/or short bunch length are preferred. In storage rings, it may leads to bunch lengthening and even microwave instability. In linacs, it may cause unwanted emittance growth and microbunching in linac-based FEL light sources.

In the range of wavelengths comparable to or longer than the bunch length, the synchrotron radiation fields emitted by different particles in the bunch may interfere with each other and become coherent. Consequently, the radiation power at the relevant frequencies may be proportional to the square of the number of particles in the bunch. In modern electron storage rings, a singe bunch may contains electrons in the order of 10^9 or higher. In this case, the coherence may lead to a very large enhancement factor in the radiation power spectrum. CSR can be a primary obstacle to achieving ultra-short bunch length, ultra-low emittance, or ultra-high luminosity in modern storage rings. During the design of the SuperKEKB[1], it was found that the beam instability caused by CSR was so significant in the high-current option[2,3], which is one of the important factors of the change to the present nano-beam scheme[4]. Due to the facts of small emittance, high intensity and low Tousheck lifetime in the main rings, a damping ring（DR）was proposed for improving the beam injection of positron beam to the main ring[5]. Since the bending radius of the main dipoles in the DR is around 3 meters, there is also a concern about the CSR induced instability in the SuperKEKB DR.

2. Code development for calculation of CSR impedance

To calculate the longitudinal CSR impedance for a beam moving along a curved chamber, a new code, named CSRZ[6,7], was developed using finite difference method originated by T. Agoh and K. Yokoya[2,8]. It solves the parabolic equation in the frequency domain in a curvilinear coordinate system. The chamber considered has uniform rectangular cross-section along the beam trajectory. The curvature of the beam orbit is assumed to be an arbitrary function of the distance along the orbit. This assumption indicates the most significant feature of CSRZ. It allows CSRZ to investigate the CSR interference between consecutive bending magnets, even coherent wiggler or undulator radiation.

The code CSRZ was used to investigate the properties of CSR impedance of a single or a series of bending magnets. The calculation results indicate that the shielding effect due to outer chamber wall can be well explained by a simple optical approximation model at high frequencies. The CSR fields reflected by the outer wall may interfere with each other along a series of bending magnets and lead to sharp narrow peaks in the CSR impedance[6].

3. Analytical calculation of coherent wiggler radiation

An analytic method originated by Y.H. Chin[9] was available to calculate the longitudinal impedance due to coherent wiggler radiation（CWR）with rectangular chamber. The method used dyadic Green functions in electromagnetic theory and was rigorous for the case of straight chamber. Substantial alterations were, however, required in Chin's discussion in order to make it applicable to calculate the imaginary part of CWR impedance. Therefore we re-derived the theory and did find the full expressions for CWR fields and impedance. Due to chamber shielding, the CWR impedance exhibits narrow peaks at frequencies satisfying the resonant conditions, which were not seen in the theory for CWR in free space. The analytic work also provided excellent benchmarking to the CSRZ code.

4. Microwave instability in the SuperKEKB damping ring

CSR fields generated by a bunched beam passing through a

series of bending magnets may interfere each other due to the reflection at the outer chamber wall. This kind of multi-bend interference causes sharp peaks and long-range tail in the CSR impedance and wake potentials, respectively. Using CSRZ, we calculated the longitudinal CSR impedance in the SuperKEKB positron damping ring. It was found that multi-bend interference enhances the CSR fields within a distance comparable to the bunch length, which is typically in the order of several millimeters. A simple instability analysis was performed and it suggested that multi-bend interference might play a role in the single-bunch instabilities of small electron/positron rings. This peculiar microwave instability was proved by particle tracking simulations[10].

5. Summary of my thesis work

A numerical code has been developed to calculate longitudinal CSR impedance. Through my work done in the last three years, I have contributed to the SuperKEKB project in better understanding CSR induced beam instabilities in the positron damping ring. The eigenfunction expansion method was studied in detail and was found to be an excellent method for solving the CWR problem with shielding of rectangular chamber. CSR is the dominant source of impedances causing microwave instability in the SuperKEKB positron damping ring.

6. Future work

Fortunately, I was hired by KEK as a postdoctoral researcher since December, 2011. For the future researches, I want to continue my studies on CSR theory, CSR effects on beam dynamics and CSR related experiments in both storage rings and linacs. CSR in the projects at KEK, such as SuperKEKB and ERL light source is mostly interesting to me.

Space-charge and beam-beam interaction are the next two topics I want to study. Space-charge effect appears in J-PARC rings, injection system of SuperKEKB, and cERL[11]. Beam-beam is always important in KEKB and SuperKEKB. My experiences in the last several years also make it possible for me to work on impedance related collective effects.

THz light source is a hot topic in recent years. This topic is related to CSR. Actually CSR can be a candidate of THz light source. One of my interests is to searching for new schemes of THz light sources.

References

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