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New Ideas for Compact Electron Storage Rings

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1. Introduction

As storage ring based light sources pursue as low emittance as possible down to the diffraction limited number by adopting as many bending magnets and quadrupoles as possible per cell, the number of sextupole magnets also grows not only to correct chromaticity generated by quadrupoles but also to secure a sufficiently large dynamic aperture. Major light sources in the world in the sub-rad emittance range typically have about 6-8 sextupole families [1]. As a result, the circumference of a multi-bend achromatic lattice storage ring with very low emittance is typically very long but the resulting dynamic aperture is still small in those cases in spite of many sextupole magnets.

This paper presents two new ideas to realize a rather compact electron storage ring with low emittance. The first idea is to install no sextupole at all and suppress the head-tail instability by using the bunch-by-bunch transverse feedback kicker system. This way, the size of a multi-bend lattice storage ring can diminish substantially and there are other advantages including large dynamic aperture. The second idea is to use non-metallic materials, such as ceramic or glass, for the vacuum chamber to lower the instability-causing impedance substantially compared to metallic chambers. This will weaken the head-tail instability and greatly help suppression of the instability by the bunch-by-bunch feedback kicker system. This paper introduces these ideas and explains the motivations behind the ideas.

2. Suppression of Head-Tail Instability by Using Bunch-by-Bunch Feedback Kicker

The bunch-by-bunch transverse feedback kicker system has long been used as an important tool to suppress transverse instabilities. This paper proposes to use an appropriate transverse feedback kicker system to suppress the head-tail instability with no installed sextupole magnet at all. The purpose is to design and construct a simple linear lattice storage ring with minor non-linearity coming from multipole magnet errors and insertion devices. The advantage of this scheme is obviously to achieve low beam emittance in a rather small ring circumference and save the construction cost. Another valuable advantage would be the consequential large dynamic aperture, which can enable injection with no orbit bump. This would significantly improve the operation quality of the light source.

There are certainly potential problems of this scheme. The most important one is the risk of betatron resonance crossing due to large chromatic tune spread coming from absence of sextupole magnets. This tune spread should be assured not to cause betatron resonance and consequential beam loss. Fortunately, absence of sextupole magnets significantly weakens third order resonances to such a low level that they can be practically harmless, and the large tune spread mentioned above would strongly act against any potential transverse instability.

2.1 Strategy

If the relative length of an electron bunch with respect to the impedance, defined as $x = \omega_r \sigma / Q$ where ω_r is the impedance resonant frequency, σ is the electron bunch length and Q is the quality factor of the impedance, is sufficiently small, the two-particle model of Sacherer [2] is a good approximation enough to describe the head-tail instability. An important result of the model is shown in Table 1, where ξ denotes the storage ring chromaticity.

Table 1: Head-tail Instability Modes and Chromaticity

Mode		$\xi > 0$	$\xi < 0$
Dipole Mode	Above Transition	Damped	Unstable
	Below Transition	Unstable	Damped
Higher Modes	Above Transition	Unstable	Damped
	Below Transition	Damped	Unstable

As we consider only the above-transition electron rings, the ring chromaticity is negative without sextupole magnets and only the lowest dipole mode would be excited. Being a rigid body mode fortunately, this dipole mode can be suppressed by a typical narrowband bunch-by-bunch transverse feedback kicker system that is widely used to suppress multi-bunch transverse instabilities. Figure 2 below shows the schematic figure of the dipole mode and two higher modes of the head-tail instability.

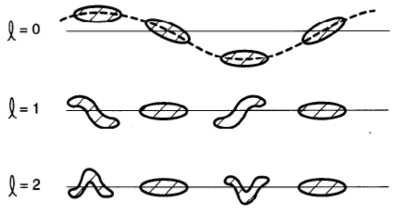

Fig. 1. Modes of the head-tail instability. The *l*=0 is the dipole mode and *l*=1 and *l*=2 are the next higher modes. [3]

This suppression of the head-tail instability through the transverse bunch-by-bunch feedback kicker system is often used at a proton synchrotron as can be seen from the Main Ring of J-Parc [4]. Thanks to modern technology, the transverse bunch-by-bunch feedback has been developed to such a level to be able to suppress complicated single bunch instabilities.

2.2 Large Dynamic Aperture and Injection with No Orbit Bump

Under the scheme of this paper, the light source lattice is virtually a linear lattice. The only non-linearity comes from multipole errors in dipole magnets and quadrupole magnets and insertion devices. Consequently, the dynamic aperture would be very large regardless of momentum deviations and this helps not only longer lifetime but also much easier injection. The large dynamic aperture can lift the constraint put on injection by dynamic aperture. Then, injection into the storage ring can be performed without the familiar bumped orbit, if physical space is large enough to allow the large horizontal betatron amplitude increased by the absence of orbit bump, and this would make top-up injection entirely harmless for users.

3. Use of Non-metal Materials for Vacuum Chamber

For efficient suppression of the head-tail instability through the bunch-by-bunch feedback system, the growth rate should be as small as possible. The two-particle model evaluates the growth rate of the head-tail instability as:

$$\tau^{-1} = \frac{e^2}{2\pi}\frac{N\xi\hat{z}}{p_0\eta}\left(\frac{W_0}{C}\right). \tag{3}$$

where N is the number of electrons in a bunch, $\hat{z}$ is bunch length, η is the slippage factor, p_0 is the nominal momentum of electron beam, and W_0/C is the wake per unit length along the storage ring. Hence, the wake force should be small enough. In other words, the (broadband) impedance of the vacuum chamber should be small enough. For this purpose, this paper proposes using non-metallic materials, such as ceramic or glass, for the low impedance of the storage ring vacuum chamber. These materials can maintain vacuum and have relatively high melting points (melting point of glass products is around 1500℃ and that of ceramics is higher).

With these materials, the image current would not flow on the chamber wall and both the longitudinal and transverse impedance of the vacuum chamber would be significantly small except possible resonances, as can be seen in the figure below. The resonances can be significantly weakened by thin metallization that is applied to the inside of such walls to avoid accumulation of static charges [5]. Such elements as the RF cavity that cannot be made of non-metallic materials should be grounded separately to avoid accumulation of image charges.

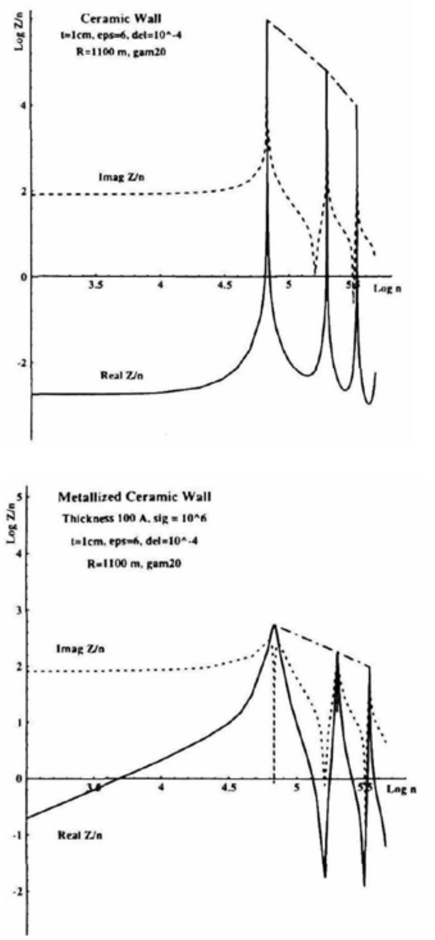

Fig. 2. Z/n versus n for a ceramic wall, with metallization (up) and without metallization (down) [6]. Resonances of the ceramic wall impedance are suppressed by metallization.

4. Summary

Using the transverse bunch-by-bunch feedback kicker system to suppress the head-tail instability and using such non-metal materials as ceramic and glass to have low impedance may make not only a compact but also an (broad) impedance-free electron storage ring.

REFERENCES

[1] See, e.g., V. P. Suller, Status of the DIAMOND light source project, Proceedings of the 8th European Particle Accelerator Conference, Paris, France, Jun. 2002.
[2] F.J Sacherer, Transverse Bunched Beam Instabilities, CERN, Geneva, Switzerland, Rep. CERN/PS/BR76-21, 1976.
[3] A. W. Chao, Physics of collective Beam Instabilities in High Energy Accelerators, John Wiley & Sons, Inc., 1993.
[4] Y. H. Chin et al., Head-tail instabilities observed at J-PARC MR and their using a feedback syste, Proceedings of the 9th Annual Meeting of Particle Accelerator Society of Japan, Osaka, Japan, Aug. 2012, pp. 97-101.
[5] B. A. Zotter and S. A. Kheifets, Impedances and Wakes in High Energy Particle Accelerators, World Scientific Publishing Co., 1998