INFRARED EXTRACTION CHAMBER FOR THE NSLS-II STORAGE RING*

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Abstract

The short- and long-range wakepotentials have been studied for the design of the infrared (IR) extraction chamber with large full aperture: *67mm* vertical and *134mm* horizontal. The IR-chamber will be installed within a *2.6m* long wide-gap bending magnet with *25m* bend radius. Due to the large bend radius it is difficult to separate the light from the electron trajectory. The required parameters of the collected IR radiation at the extraction mirror are *~50mrad* horizontal and *~25mrad* vertical (full radiation opening angles). If the extraction mirror is seen by the beam, resonant modes are generated in the chamber. In this paper, we present the detailed calculated impedance for the design of the far-IR chamber, and show that placing the extraction mirror in the proper position eliminates the resonances. In this case, the impedance reduces to that of a simple tapered structure, which is acceptable in regard to its impact on the electron beam.

INTRODUCTION

The intrinsic infrared brightness of most storage ring sources is determined by the circulating beam current. This is certainly the case for the low-emittance electron beam of the NSLS-II storage ring, and the goal of *500 mA* beam current is very attractive from the standpoint of infrared performance. The ring is designed for an extremely stable beam; an important characteristic for the standard rapid-scan interferometric techniques employed in most infrared spectroscopies.

The *3GeV* NSLS-II storage ring has a 30 cell (15 super-period) double-bend achromatic (DBA) lattice [1]. Here we focus on the synchrotron radiation produced within the bending magnets. The dipole magnets have a bending radius of $\rho=25m$ and are *2.6m* long. Fifty-four of sixty dipole magnets have a vertical gap of *35mm*. The regular vacuum chamber in these magnets has an elliptical cross section. Its inner dimensions are *2a=76mm* full width and *2b=25mm* full height.

Large full angular collection ($2\text{x}\theta_{rms}$) of *~50mrad* horizontal and *~25mrad* vertical is required to extract radiation far-IR wavelength region.

$$\theta_{rms} = \left(\frac{3\lambda}{4\pi\rho}\right)^{1/3}$$

A study of the NSLS-II dipole design indicates that a horizontal extraction of *50mrad* is achievable (plus an additional *5mrad* on the "negative side", useful for collecting edge radiation). This is based on an infrared extraction where the second dipole in a DBA cell is used in order to stay clear of insertion device beamlines (Fig. 1). The large bending radius makes extraction increasingly difficult as one continues toward the second half of a dipole, giving rise to the *50mrad* horizontal collection limit.

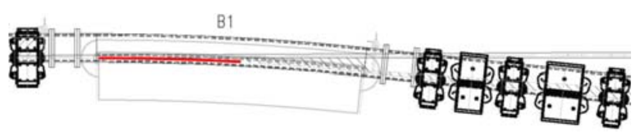

Figure 1: Second dipole magnet in the NSLS-II DBA 30 lattice. Red line indicates the candidate IR source orbit segment. Approximately *50mrad* of horizontal collection appears feasible, including the zero-degree segment for edge radiation.

FAR-IR VACUUM CHAMBER

The wave length of synchrotron radiation which can be extracted from a bending magnet is limited due to geometric dimensions of the regular vacuum chamber [2].

$$\lambda \approx 2\sqrt{\frac{b^3}{\rho}},$$

where ρ is the bending radius and b is the vertical half-gap of the chamber. A vertical chamber dimension of *2b=25mm* limits the vertical collection to approximately θ_{rms}=17mrad (the value can be varied from *12mrad* up to *20mrad* due to the large source depth). While this is adequate for mid-infrared spectroscopy as used in chemical imaging, it limits the performance for far-infrared spectroscopy due to the relatively large angles into which this radiation is emitted.

The vertical and horizontal aperture of the standard chamber has to be increased to achieve the required extraction angles. A special chamber with a full aperture of *67mm* vertical, *134mm* horizontal and a special trapezoidal slot extended vertically up to 79mm high are required to collect radiation within the required extraction angles (Fig. 2). Since the IR-chamber has larger elliptical shape than the regular vacuum chamber, smooth tapered transitions are applied to minimize the contribution to the longitudinal and transverse broad-band impedance. Effect of the taper angle on the wakepotential and impedance in this structure will be discussed later in this paper. As a first step, the taper length is taken to be *300mm* at the beginning of the structure and *100mm* at the end of the structure. Tapers do not extend beyond the dipole magnet

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length and if necessary the taper length can be increased inside the dipole magnet to further reduce the broad – band impedance.

Long-Range Wakepotential

To direct the collected emission into the output port, the extraction mirror of 78mm high (copper color, *5mm* thick) is first modeled at the end of the trapezoid slot, *30mm* from the beam trajectory as shown in Fig. 2a (zoomed part). The mirror must be located close to the electron beam to collect the IR emission. Separation of the radiation from the electron beam is made more difficult due to the large bending radius of the NSLS-II dipoles.

The narrow-band impedance computations using the electromagnetic simulator GdfidL [3] are shown in Figure 2b. The real part of the longitudinal impedance is presented for the IR-chamber with (wine color) and without mirror (purple color). Resonant modes are generated in the chamber by the passing beam if the extraction mirror is in place. The mirror is seen by the beam and generated modes are trapped in a small pocket between the tapered transition and the mirror. These modes can cause coupled bunch instability and heating of the chamber wall.

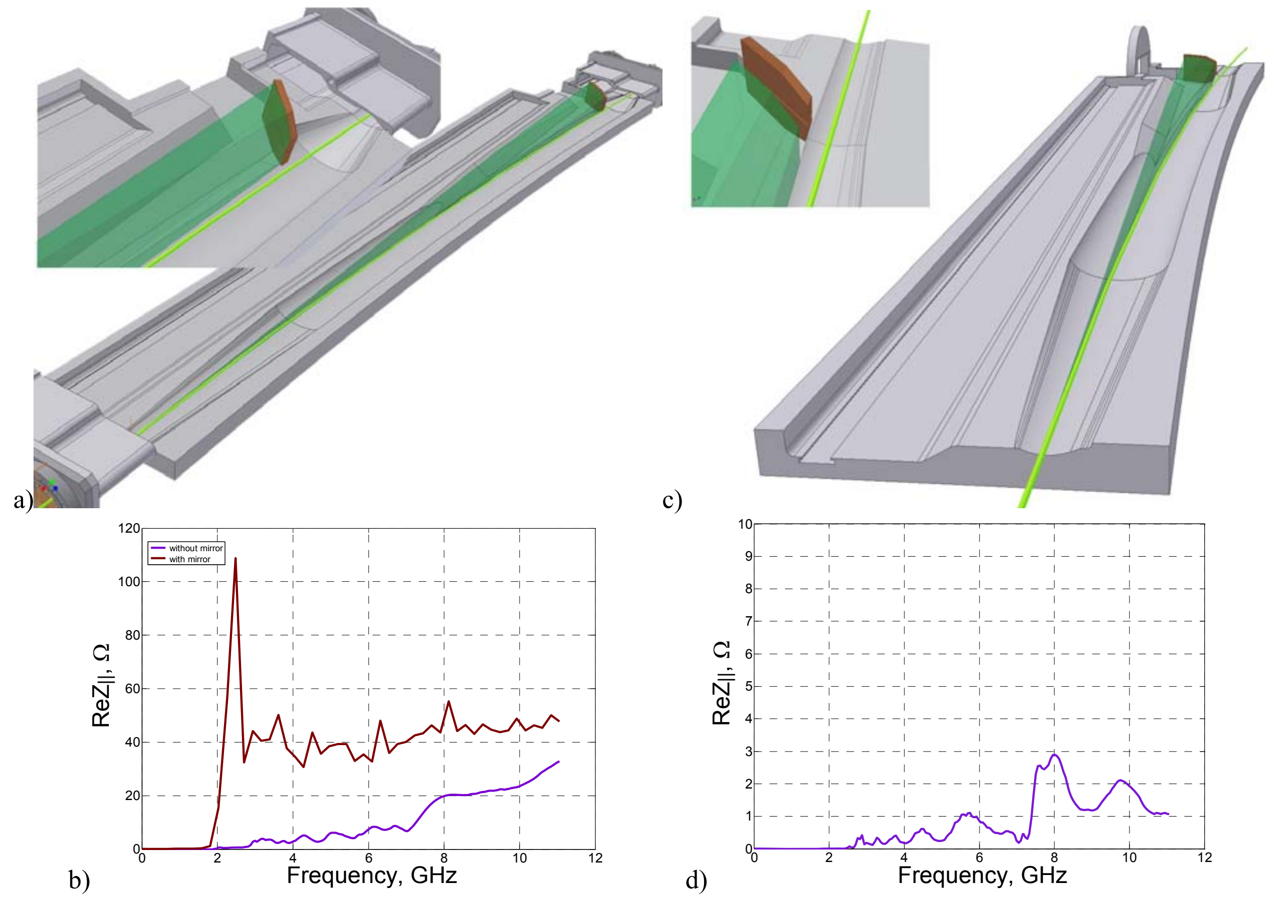

Figure 2: Preliminary design of the infrared extraction chamber for the dipole magnet with a large gap. The green line represents the electron beam and the green shaded region represents the IR radiation. a) Design of the IR chamber with a mirror in front of the tapered transition. b) Real part of the longitudinal impedance. Wine line and the purple line are calculations with and without extraction mirror inside the chamber (presented in Fig. 2a) respectively. c) Design of the infrared extraction chamber with the mirror at a point right after the widened cross-section has tapered back down to the regular dimensions. Mirror is located inside the regular vacuum chamber behind the tapered transition. d) Real part of the longitudinal impedance for the design of the IR chamber with the extraction mirror presented in Fig. 2c.

To avoid generation of resonant modes inside the chamber, we studied several variants of mirror positions while maintaining the required extraction angles. One of the variants is shown in Fig. 2c. To avoid producing a pocket behind the mirror, we located the mirror at a point right after the widened cross-section had tapered back down to the regular dimensions. In this case, the extraction mirror is hidden behind the tapered transition in the region of the antechamber slot. This design eliminated the problem of resonant modes due to the mirror, as can be seen from the real part of the longitudinal impedance presented in Figure 2d. The impedance of the complex IR-chamber was reduced down to the impedance of just a tapered structure.

Short-Range Wakepotential

To estimate the short range wake (broad-band impedance) of the IR chamber, we consider a simplified model. The full height and the full width of the tapered chamber are taken to be the same as for the real structure, *67mm* and *134mm*, respectively. Smooth tapered transitions, each *180mm* long, are located at both ends of the chamber. The shorter taper length here is taken for reducing computational time. We modeled narrow and trapezoid slots, where the extraction mirror will be located. The trapezoid slot extends vertically away from the structure as shown in Figure 3c.

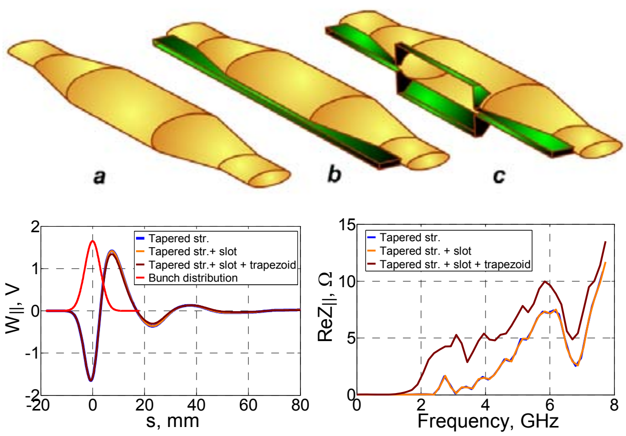

Figure 3: Simplified model of IR-extraction chamber. a) Tapered elliptic chamber. b) Tapered elliptic chamber with narrow slot. c) Tapered elliptic chamber with narrow slot and trapezoidal slot. **Left Bottom:** The longitudinal short-range wakepotential for a 3mm Gaussian bunch. **Right Bottom:** The real part of the longitudinal impedance.

Computations of the longitudinal wakepotential for a $\sigma_s=3mm$ rms bunch length show that narrow and trapezoid slots do not significantly affect the short-range wakepotential and hence the loss factor. The narrow-band impedance due to tapered transitions is similar to the impedance of the actual geometry with the extraction mirror at the proper location (Fig. 2d). The amplitude of the resonant peaks in the simplified geometry is slightly higher due to shorter taper length.

This analysis concentrated on verifying results obtained for the actual geometry, which is a more complex geometry. As a first step we eliminated the resonant modes (narrow-band impedance) due to the extraction mirror and used the simplified models for analysis of the short-range wakepotential. The next step is to estimate the short-range wakepotential for the actual design geometry.

The simplified model with a *180mm* taper length has a loss factor of $\kappa_{loss}=0.84V/pC$. This is a pretty large value per component to be compared with other elements computed for a *3mm* bunch length [1]. It needs to be reduced to minimize its impact on the total impedance of the ring. One of the options is to increase the taper length of the structure. For the tapered elliptical chamber and bunch length $\sigma_s=3mm$ we found the loss factor is inversely proportional to the square of the taper length ($\kappa_{loss} \propto 1/L^2_{Taper}$). Since we are not limited in space inside the dipole magnet, tapered transitions of the far-IR chamber have been increased up to $L_{Taper}=530mm$.

Results for the actual geometry of far-IR chamber are presented in Table 1. Longitudinal and dipole wakepotentials, $W_{||}(s)$, $W_{Dx}(s)$, have been calculated for a 3mm-Gaussian bunch. The loss factor, as we expected, dropped down to the value of $\kappa_{loss}=0.084V/pC$. The horizontal dipole kick factor is $\kappa_{Dx}=5.1V/pC/m$.

Four far-IR chambers will be installed in the ring. The vertical impedance of this geometry must also be small since it will be installed in a region where the vertical beta function is large $\beta_y \approx 25$m [4]. The vertical kick factor for the actual design geometry needs to be simulated. We would expect that the vertical kick factor will have sufficiently low value for $\sigma_s=3mm$ with the lengthened tapered transitions.

Table 1: Summary of Data for the Actual Geometry of far-IR Chamber with $L_{Taper}=530mm$ ($\sigma_s=3mm$).

	κ_{loss} V/pC	$\left(\frac{\mathrm{Im} Z_{\|}}{n}\right)_0$, Ω	κ_{Dx} V/pC/m
Far-IR Chamber	0.084	0.7x10^{-3}	5

CONCLUSION

Design of the far-IR chamber for the NSLS-II storage ring has been discussed. It has low-impedance contribution and can be used inside the dipole magnet with a large aperture of *90mm* for extraction of synchrotron light out to the mm-wavelength region. The mirror optic integrated successfully into the far-IR chamber construction without effect on the narrow- and broad-band impedances.

We thank D. Robin and F. Sannibale for discussion of the results of impedance studies for the IR-extraction chambers for CIRCE [5].

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