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RF DESIGN OF NORMAL CONDUCTING DEFLECTING STRUCTURES FOR THE ADVANCED PHOTON SOURCE [*]

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Abstract

Use of normal conducting deflecting structures for production of short x-ray pulses is now under consideration at Argonne's Advanced Photon Source (APS). The structures have to produce up to 4 MV maximum deflection per pair of structures with a 1 kHz repetition rate. At the same time, the structures should not cause deterioration of beam properties in the APS ring. Following these requirements, we proposed 2815 MHz standing wave deflecting structures with heavy wakefield damping. In this paper we discuss design considerations and present our current design.

INTRODUCTION

Synchrotron light generated in electron storage rings has a typical pulse length of several tens of picoseconds, determined by the electron bunch length. Several approaches have been developed to shorten the x-ray pulse. One of the methods proposed by Zholents' [1] uses two deflecting cavities. Possible application of these methods to APS is discussed in [2, 3, 4, 5, 6]. Both superconducing and normal conducting deflectors were considered. We will discuss design of a normal conducting deflector operating at kHz repetition rate. With this repetition rate it would match the typical repetition rate of lasers used for pump-probe experiments.

The reason rf cavities are suggested for the beam manipulation is that the method requires a chirp of transverse momenta along the roughly 1 cm electron bunch length. A field oscillating with GHz frequencies in high Q cavities provides a practical solution for that. Until this time, most rf deflectors were built for particle separation and time-resolved beam diagnostics in linear accelerators (e.g., the LOLA cavities at SLAC [7]). Unlike these structures, a deflector for a low emittance storage ring has to have impedance that fits within the ring's impedance budget, i.e., it should not decrease thresholds for longitudinal and transverse beam instabilities. An example of such deflector is a super-conducting crab cavity for KEKB and SuperKEKB [8, 9]. We consider for APS a compact, S-band high gradient normal conducting deflector with heavy wakefield suppression.

DEFLECTING CAVITY DESIGN

Below we describe a possible technical realization of compact 2815 MHz deflecting cavities that produce 2 MV maximum deflection if fed with less then 3 MW of rf power. Beam dynamics in APS sets strict requirements on damping of of low-order-modes (LOM) and high-order-modes (HOM) in the cavity [10]. We found that the best way to address these requirements was to use a pair of cavities instead of one long cavity. This way two cavities will be used for initial kick and two for kick that compensates distortion in electron motion generated in the first pair of structures. While working on this structure we employed many technological solutions developed for S-band and X-band traveling wave and standing wave structures [11].

Design Considerations

The design is determined by specifications of existing rf power sources, the need for heavy damping of parasitic cavity modes, the high average power losses expected in the cavity, and the requirement to maximize the space available for the users' insertion device. The operating frequency of the deflector is the 8th harmonic of the APS ring RF frequency [10]. For this design we chose power and repetition rate similar to that of a commercially available klystron [12]. This klystron can produce 25 MW of power at 1 kHz repetition rate and pulse length 2 μs. The structure has to have high shunt impedance and same time large beam aperture ($>$ 20mm radius) [13]. The large beam aperture is required to reduce unwanted interaction of the structure with the beam and to ensure the cavity is not struck by synchrotron radiation produced elsewhere in the ring. To satisfy these we used π-phase advance standing wave deflecting structure operating at the first deflecting mode. From our experience, for robust operation of a high gradient structure the surface electric field must be below 100 MV/m (for $\sim$ μs - long pulses), and pulsed heating has to be below 100° C [14]. Pulse heating is the increase of the copper surface temperature during the rf pulse. Pulse heating depends on the local surface magnetic field and pulse width, but is independent of the structure's cooling system. Pulse heating sets the limit on maximum surface magnetic field for S-band structures to 0.4 MA/m for 2 μs pulses. High gradient operation and kHz repetition rate results in relatively high average power deposited in the structure, i.e., a few kilowatt per cell. This puts stringent requirements on both the cooling system of the structure and the cavity geometry. The deflectors should not lower the beam instability thresholds in APS, so the higher- and lower-order modes have to be heavily damped.

Structure Design

The structure consists of 3 cells. Power couples to the structure symmetrically by two high power WR284 waveguides connected to the middle cell. For damping of long-range wake fields each cell is loaded by waveguides. The waveguides are designed so the fields of the working mode do not propagate into the broadband loads, but lower- and higher-order modes are heavily loaded. RF properties of

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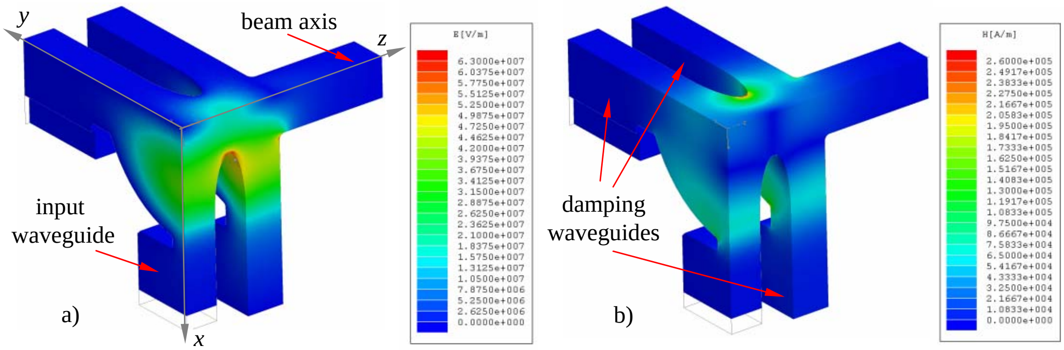

Figure 1: Surface electric a) and surface magnetic b) fields in one-eighth of the 3 cell standing wave deflecting structure. These fields produce 2 MV transverse kick for on-axis bunch with 2.83 MW of rf power fed into the structure by two symmetric waveguides. The waveguide loads that absorb wakefield power are not shown.

Table 1: Main parameters of the deflecting structure.

Working mode frequency	2.815 GHz
Working mode Q	11900
Beam pipe aperture radius	21 mm
Iris radius	22 mm
Phase advance per cell	π
Structure length without beam pipes	111.7 mm
Iris thickness	18 mm
Kick / (Power)$^{1/2}$	1.19 MV/MW$^{1/2}$

the structure were calculated with the commercial 3D finite element code HFSS [15] and are shown in Table 1. Fields in the structure for 2 MV maximum deflection are shown on Fig. 1. The maximum surface electric field in the cell is about 60 MV/m, while the maximum surface magnetic field is about 0.24 MA/m. These values are a good margin below operating values of existing S-band rf guns. We shaped the field on the axis of the deflector so the kick produced by the fields in central cell is almost the same as kick from the fields in each end cell. The transverse magnetic field H_y and transverse electric field E_x on axis of the deflector for 2 MeV maximum kick are shown in Fig. 2. For 2.83 MW of power lost in the structure, a 1 kHz repetition rate, and a pulse width of 2 μs, the heat deposited into the structure will be about 5.7 kW. This heat prompts careful design of cooling system, similar to one done by E. Jongewaard of SLAC for LCLS rf gun [16]. The heat load projected for this two cell gun is 4 kW at 120 Hz repetition rate.

Wakefield Damping

A bunch passing through the deflector excites wakefields that may affect the motion of subsequent bunches which pass through the cavity, leading to beam instabilities that dilute beam emittance and limit the ring current. To prevent such adverse effects, we extract the wakefield energy through waveguides and direct it into matched broadband loads. We expanded the approach discussed in [17] with use of multi-moded ridged waveguide for damping both lower-order modes (frequencies below 2815 MHz) and higher-order modes (frequencies above 2815 MHz).

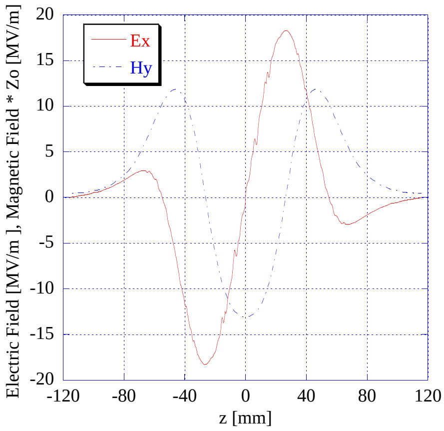

Figure 2: Calculated transverse electric and magnetic fields on axis of the deflector *vs.* z coordinate. These fields produce 2 MeV kick in x direction for relativistic electrons.

APS impedance limitations require that loaded Q's of the most of monopole and dipole modes in the deflector has to be below 200 [10]. At the same time, the shunt impedance of the working mode should be reduced as little as possible. To achieve that we optimized the shape and orientation of the damping waveguides. The geometry of the deflector (as modelled in HFSS) with damping waveguides and LOM-HOM loads is shown in Fig. 3. To verify the wakefield damping we simulated the deflector using GdfidL [18]. The monopole wake and the transverse wake for in the y direction are shown on Fig. 4. The transverse impedance in the x polarization is shown in Fig. 5. We note that only the mode nearest to the operating mode has a relatively high impedance, mostly because of its high Q. Possible mitigations of the effect of this mode on the beam are discussed in [5].

SUMMARY

At publication time we have a base electrical designs of the deflector and work is ongoing on its mechanical design.

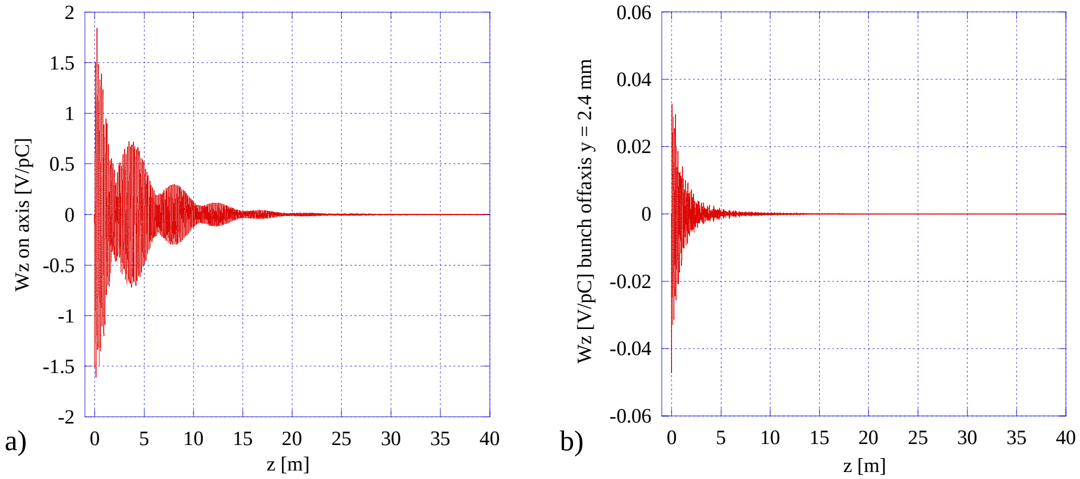

Figure 4: Longitudinal a) and the transverse wake for in the y direction b) *vs.* distance from bunch.

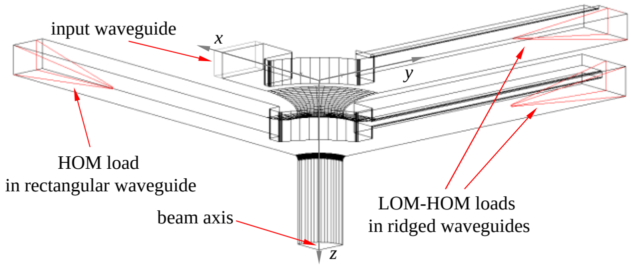

Figure 3: HFSS model of one eighth of the deflector with damping waveguides and higher- and lower-order-mode loads.

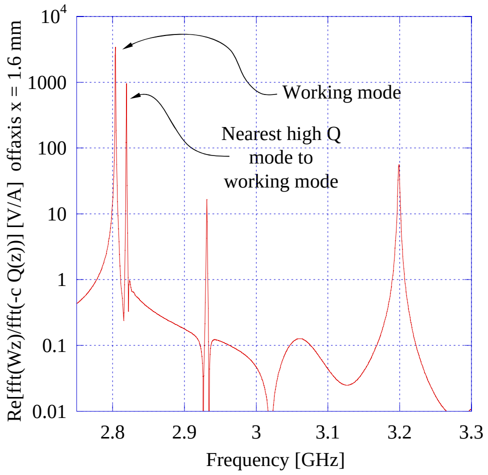

Figure 5: Transverse impedance in the x direction *vs.* frequency.

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