USE OF WAVEGUIDE AND BEAM PIPE PROBES AS BEAM POSITION AND TILT MONITORING DIAGNOSTICS WITH SUPERCONDUCTING DEFLECTING CAVITIES*

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Abstract

Waveguide and beam pipe field probes associated with a superconducting deflecting cavity are explored as beam position and tilt monitoring diagnostics. The superconducting deflecting cavity will be used for the Short-pulse X-rays (SPX) in the Advanced Photon Source (APS) Upgrade project. Microwave Studio will be used to simulate the techniques of detecting the fields excited by the beam passing through the cavity and determining how close the beam is on electrical center.

INTRODUCTION

The superconducting deflecting cavity will be used for the SPX in the APS Upgrade project (APS-U). A single-cell cavity was designed and evaluated, which consists of the SPX deflecting cavity, fundamental power coupler (FPC), high order mode coupler (HOM) and low order mode coupler (LOM) [1], see Figure 1. Four single-cell cavities are grouped in a single cryomodule.

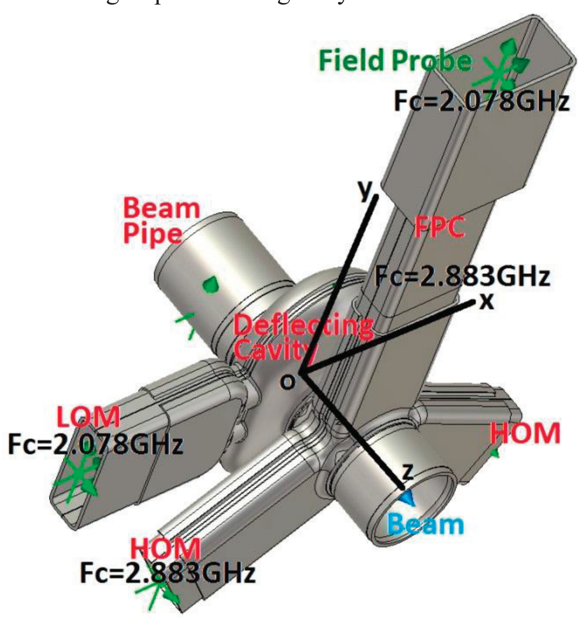

Figure 1: SPX superconducting single-cell deflecting cavity and the associated waveguides. Fc is the cut-off frequency.

Two cryomodules will precisely produce and exactly reverse a vertical / longitudinal beam tilt at the entry and exit of the SPX zone. The beam will restore its regular orbit to minimize the impact on other APS users. It is essential to measure the very small amounts of beam vertical offset and tilt.

Misalignment of the deflecting cavities will change the beam loading and the rf generator requirement. It is necessary to determine how close the beam is to the cavity electrical center.

When the beam crosses the deflecting cavity gap of Figure 1 with vertical offset y or/and tilted angle θ, the deflecting dipole mode TM_{120} in a rectangle cavity (or TM_{110} in a circular cavity) will be induced [2]. This dipole mode is proportional to to the beam vertical position.

The X-band cavity BPM has higher sensitivity for beam vertical offset. However, it is difficult to damp the lower modes in the cavity. Taking advantage of the deflecting cavity is a good choice.

Because the deflecting cavity only deflects the beam vertically, this paper will focus on the sensitivity of various probes to vertical beam position and tilt.

Microwave Studio [3] will be used to simulate the techniques of detecting the fields excited by the beam passing through the cavity without an rf generator. The probes are setup in the cavity, waveguides, and beam pipe, as shown in Figure 2.

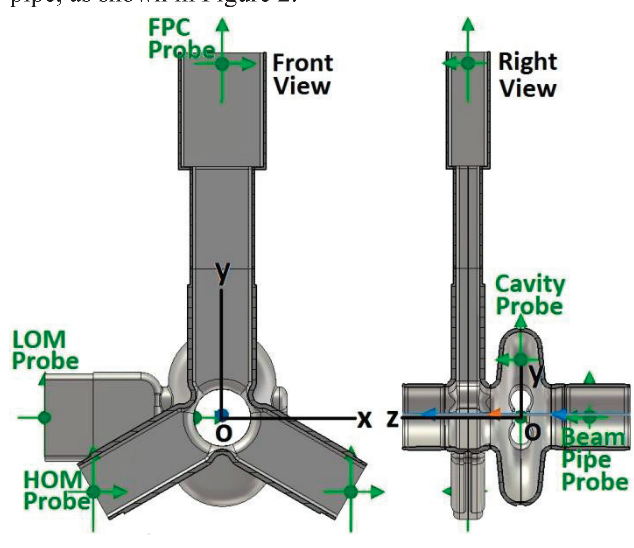

Figure 2: Distribution of the field probes.

The beam is launched at different vertical offsets (y = ±2 mm, ±1 mm, 0 mm) while there is no rf generator. The numerical studies assume the beam as a 1-nC Gaussian bunch with the rms bunch length of 10.05 mm.

The probes in the cavity, waveguides, and beam pipe associated with the superconducting deflecting cavity will detect the local fields excited by the beam. The results are used to evaluate the probes' suitability as beam position and tilt monitoring diagnostics.

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FIELDS INSIDE THE DEFLECTING CAVITY

The spectrums of the electric fields at the probe inside the SPX deflecting cavity are shown in Figure 3. The frequencies of monopole and dipole modes are 2.282 GHz and 2.844 GHz, respectively. The dipole mode is proportional to the beam vertical position.

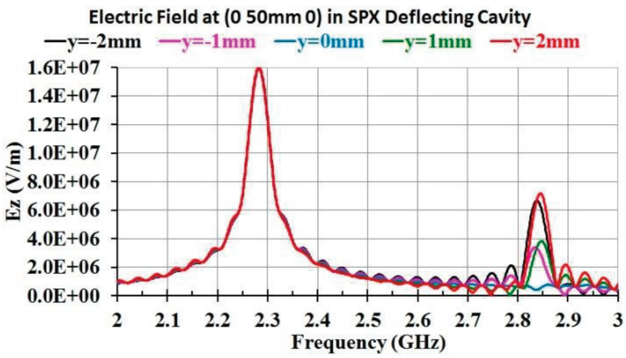

Figure 3: Electric field spectra for different vertical beam positions at the probe inside the deflecting cavity.

Figure 4 shows the electric field patterns of the dipole mode in the planes including the deflecting cavity probe. This mode corresponds with TM_{120} in a rectangle cavity or TM_{110} in a circular cavity.

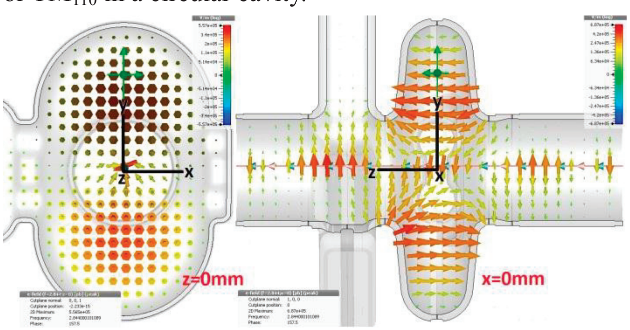

Figure 4: Electric fields at frequency 2.844 GHz for beam y = 2 mm on the planes of z = 0 mm (left) and x = 0 mm (right).

The simulated dipole mode frequency of 2.844 GHz was a little different from the designed frequency of 2.815 GHz in SPX-U [1]. It was caused by the tiny differences in the simulation environment such as waveguides length and boundary condition.

The field probes inside the deflecting cavity display response proportional to the beam vertical offset. This mode was expected to be coupled to the waveguides and measured as vertical position / tilt monitor.

FIELDS IN THE WAVEGUIDES

The probes were set up in the LOM, HOM, and FPC waveguides. Figures 5 – 7 show the spectra of the electric fields at those probes, respectively. Unfortunately, the waveguide probes present no obvious response directly proportional to the beam vertical position, even though they showed some sensitivity to the vertical beam position at specific frequencies.

In the LOM waveguide, the dipole mode would be coupled out if the LOM waveguide were rotated 90° and deviated from the symmetry axis of the deflecting cavity [2]. But the monopole mode was deliberately coupled out, and the dipole mode was rejected at the LOM probe due to the waveguide selectivity.

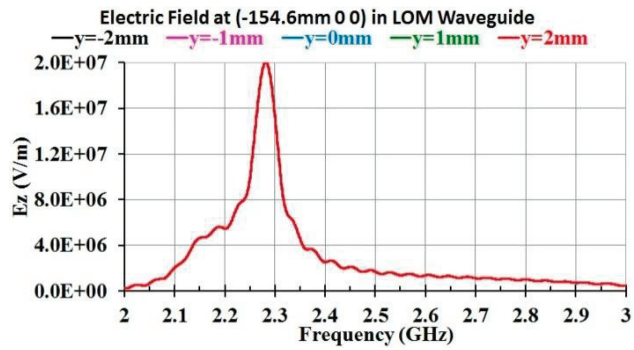

Figure 5: Electric field spectra for different vertical beam positions at the probe in the LOM waveguide.

In the HOM and FPC waveguides, the deflecting dipole mode at frequency 2.844 GHz is beyond the waveguide cut-off frequency of 2.883 GHz by design, to attain correct coupling. The mode is attenuated in the beam pipe and the HOM and FPC waveguides. However, it cannot propagate far in the HOM and FPC waveguides. Even worse, the mode is contaminated by the HOM waveguide mode at frequency 2.949 GHz and by the FPC waveguide mode at frequency 2.968 GHz. The dipole mode in the HOM and FPC waveguides shows limited sensitivity to the beam vertical position.

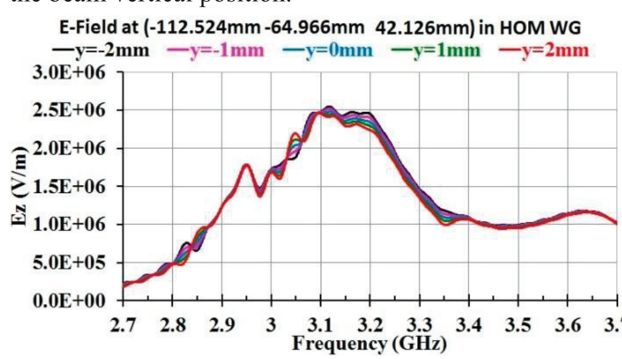

Figure 6: Electric field spectra for different vertical beam positions at the probe in the HOM waveguide.

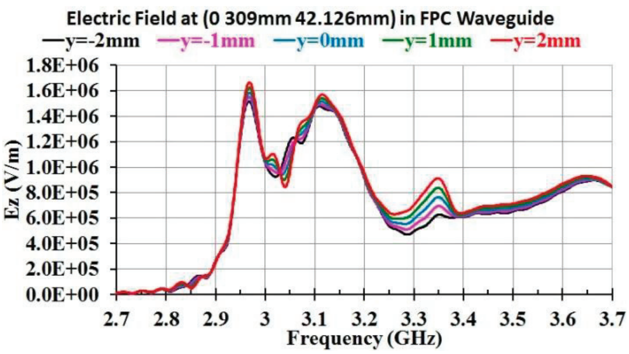

Figure 7: Electric field spectra for different vertical beam positions at the probe in the FPC waveguide.

Figure 8 shows the electric field patterns of the FPC waveguide mode in the planes including the FPC waveguide probe.

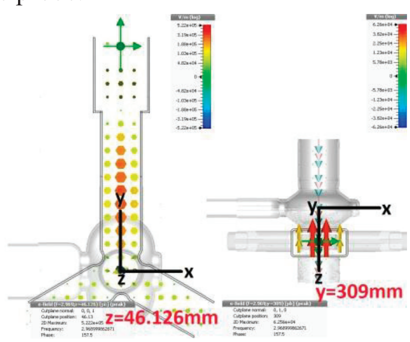

Figure 8: Electric fields at frequency 2.969 GHz for beam y = 2 mm on the planes of z = 46.126 mm (left) and y = 309 mm (right), at the FPC waveguide probe location.

FIELDS IN THE BEAM PIPE

Figure 9 shows the spectra of the electric fields at the probe in the beam pipe. The deflecting dipole mode TM_{120} leaks into the beam pipe and shows linear sensitivity to the vertical beam position with the probe oriented in the same horizontal plane as the beam. The beam pipe probe shows response that is proportional to the vertical beam position and can be used as a beam position and tilt monitoring diagnostic.

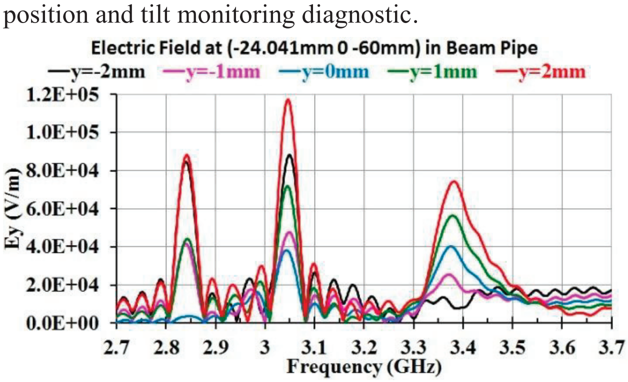

Figure 9: Electric field spectra for different vertical beam positions with a beam pipe probe oriented in the same horizontal plane as the beam.

Figure 10 shows the electric field patterns of the dipole mode near the beam pipe probe.

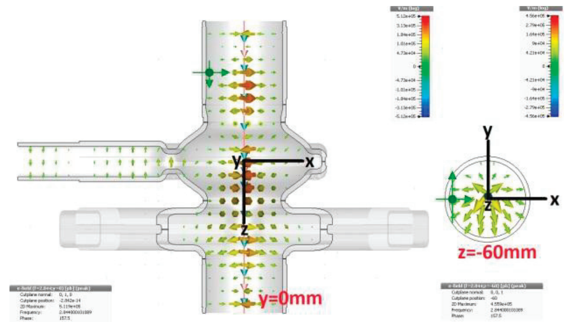

Figure 10: Electric fields at frequency 2.844 GHz for beam y = 2 mm on the planes of y = 0 mm (left) and z = -60 mm (right), where the beam pipe probe was located.

SUMMARY

Using a beam launched at different vertical positions and passing through the SPX deflecting cavity, the electric and magnetic fields excited by the beam were simulated without an rf generator.

The deflecting dipole mode (2.844 GHz) leaked from the superconducting cavity into the LOM, HOM, and FPC waveguides and beam pipe. However, the LOM coupling scheme selectively coupled the LOM waveguide only to monopole mode but suppressed the dipole mode. The dipole mode attenuated in the HOM and FPC waveguides because its frequency was beyond the HOM and FPC waveguide cut-off frequency (2.883 GHz). The dipole mode was very close to the dominant HOM and FPC waveguide modes and was contaminated by them.

The probes installed on the same horizontal plane with the beam in the beam pipe were sensitive to the beam vertical position. The signals from the beam pipe probes were proportional to the beam vertical positions. The beam pipe probes can be used to vertically align the deflecting cavity and as beam position and tilt monitoring diagnostics.

The stretched wire measurement will be performed and compared to the simulation without an rf generator. Simulations will also be run when the beam passes through the SPX cavity with an rf generator.

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