CAVITY BPM FOR 1300 MHZ CRYOMODULES*

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Abstract

A cavity BPM (beam position monitor) for 1300 MHz cryomodules is under development by FAR-TECH, Inc. The BPM is capacitively loaded in order to fit in a small volume, and uses a novel coupling scheme which further cuts down on space requirements. We discuss status of the fabrication, and eventual plan to test the diagnostic at the ANL Wakefield Accelerator facility.

INTRODUCTION

1300 MHz cryomodules of the type developed for ILC and related projects place stringent requirements on the BPM system. The BPM must have a large bore (78 mm) and resolve a 1 micron beam offset. In addition, it must withstand the stresses of being cooled to cryogenic temperatures without adverse structural or RF de-tuning effects. The device shares the vacuum envelope with a superconducting RF cavity, and must undergo acid etch and cleaning steps consistent with that environment. The geometry must be such as to allow cleaning solutions to properly drain out of the structure. Several groups have constructed such BPM systems, including at DESY [1] and at FNAL [2]. The DESY system uses four magnetic-coupled loops that result in large external coupling of the cavity mode, where the signals are combined with hybrid couplers outside of the cryostat. The FNAL-developed systems represent a more traditional cavity BPM design that satisfy the cleaning requirement by either using coupling slots filled with dielectric, or similar co-axial feedthroughs.

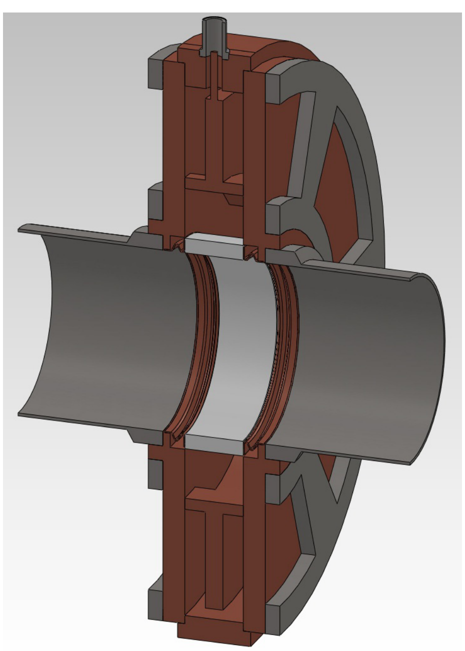

Figure 1: A cross-section of the BPM.

*Work supported by DOE Office of High Energy Physics, DOE-SBIR #DE-SC0004498

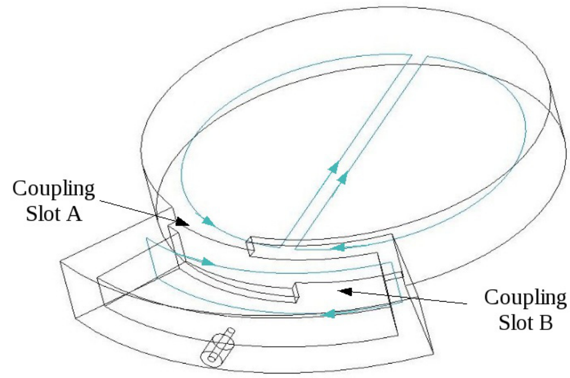

Figure 2: The coupling scheme used to select the cavity dipole mode.

The BPM design being developed by FAR-TECH uses a dielectric ring as a barrier that separates the beam tube region from the rest of the BPM cavity and out-coupling network. The capacitive loading effect of the dielectric helps to make the cavity smaller in radius, and the ring, together with its mounting system, allows for drainage of cleaning solutions. Together with the coupler network described below, the cavity body fits in only a 1 inch longitudinal space plus two 0.75 inch thick end walls.

The BPM is being designed to operate with the dipole mode at 1425 MHz, and the fundamental, or monopole mode at 1175, such that both signals can be down-converted to 125 MHz.

RF AND MECHANICAL DESIGN

The Coupling Scheme

Figure 2 shows the coupling scheme used to select the dipole mode. The magnetic field of the cavity mode is shown in light blue, and two coupling slots are staggered both in longitude (along z) and in azimuthal placement. The coupler can be thought of as a shorted co-axial transmission line, with a typical magnetic field pattern also shown in the Figure. The magnetic field vectors on both sides of each slot are in alignment for a dipole mode, which can easily create an external Q in the 500-600 range. Such strong coupling is required for the BPM in order to distinguish individual bunches within the ILC bunch train. By symmetry, coupling to the fundamental mode is suppressed.

This coupler topology allows for a very compact BPM, where the couplers take no additional longitudinal space beyond what's needed by the cavity itself. Also, despite the large coupling, the cavity mode is not perturbed very much, which makes it possible to locate only two such couplers 90 degrees to one another rather than four couplers spaced at 90 degree increments. RF network analyzer measurements have demonstrated that it's

ISBN 978-3-95450-115-1

possible to have >40 dB of isolation between the two ports. This was accomplished by placing some small perturbations within the cavity that help to establish the near-degeneracy condition between the two orthogonal dipole modes.

The design of a system not having 4-way symmetry introduces complications into the RF design, and these will be discussed further in this paper.

Engineering of the Bellows Subsystem

In order to allow for differential thermal expansion between the dielectric and metallic parts of the BPM, the ceramic is suspended by two bellows-like copper-nickel sheet metal shims. The structure must be able to withstand braze temperatures >1000°C, and cryogentic cool-down to 1.8°K. Figure 3 shows a stress analysis arising from the projected component strain with the model showing a peak stress of 50 ksi. The number of cooling cycles the assembly must withstand are limited, and we believe the stress levels will not cause component failure.

Due to the long lead times associated with fabricating the ceramic and copper-nickel assembly, we have initiated production of these components.

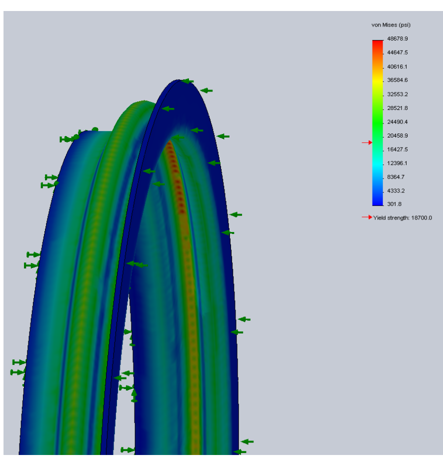

Figure 3: Stress-strain calculation of the bellows shim.

Monopole Coupler and Symmetrization

Although the dipole couplers do not distort the cavity dipole modes very much, some corrections must be made to the structure with the help of HFSS [4] simulations. The most obvious effect is that the X coupler shifts the Y-mode off-axis and likewise for the Y coupler. This can be corrected by pulling the cavity and couplers off-axis relative to beamline center.

The dipole couplers also cause a more subtle effect by slightly rotating the electromagnetic field pattern about the port axis. This causes a response similar to a beam crossing the cavity non-parallel to the axis, which creates a signal at quadrature phase. In principle, this can be remedied by rotating the entire cavity, but a more elegant solution is to include tuning perturbations designed to minimize the effect. Figure 4 shows a set of four perturbations designed to achieve this effect. The perturbations at the 11 and 5 o'clock positions rotate the modes (of both polarizations), while the ones near 7 and 2 o'clock compensate for the frequency shift of the first two.

Figure 4 also shows the coupler for the fundamental mode which serves to extract the phase reference and bunch charge information needed for signal processing. This coupler extends nearly 180 degrees around the cavity, and has two coupling slots both located on the near side of the cavity as shown in that Figure.

Although the cavity RF design is close to completion, two potential problems must be understood. First, the system with all three couplers does not sufficiently isolate the dipole ports from the fundamental mode. This will be discussed in the next section dealing with time-dependent analysis. Second, the fundamental mode coupler does not yet have the required strong coupling to the cavity mode, and opening up the coupling slots will require re-tuning the rest of the cavity.

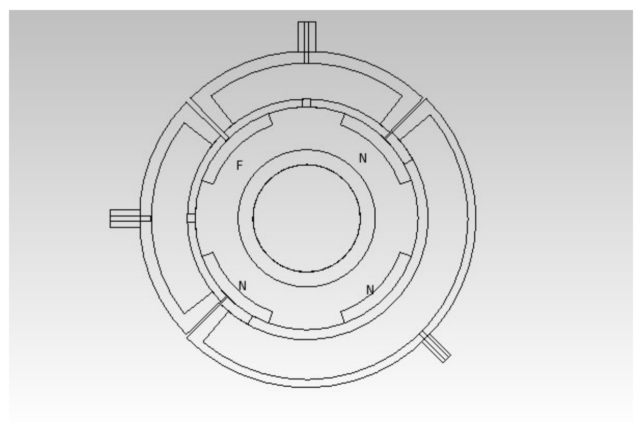

Figure 4: Perturbations placed on the near side (N) and the far side (F) of the cavity to compensate for mode asymmetry.

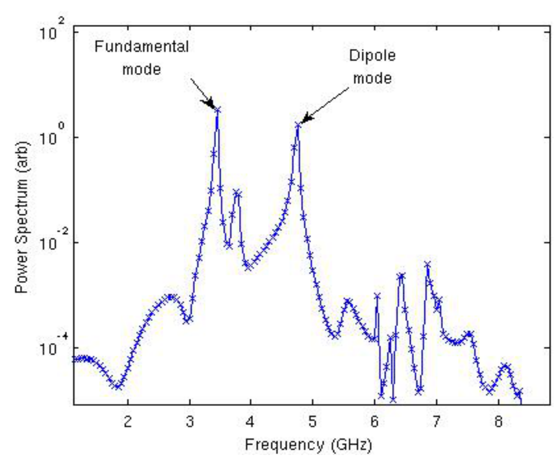

Figure 5: Power spectrum of time-dependent simulation using the code T3P.

Time-Dependent Simulation

The spectral analysis discussed above is very labor-intensive because the cavity must be tuned to a near-degenerate condition before evaluation of the various line integrals needed to assess mode distortion and rotation. A time-dependent analysis can simulate the RF field evolution in the system regardless of any particular state of tune, and therefore relies on fewer assumptions. We used the T3P [3] component of the ACE3P group of codes, which was used to simulate the wake-field from a bunch propagating along a straight line through the cavity, and the out-coupling of that wake into the output ports. Figure 5 is a Fourier transform of the first 20 ns of a dipole port output signal. In this design, the dipole coupler is not sufficiently symmetrized to reject the fundamental mode, and there is a significant peak at 3.45 GHz, as well as a lesser peak at 3.8 GHz corresponding to a coupler resonance.

Time-dependent analysis can also evaluate wake impedances coupled to ports that are away from any structure resonance. In future work, we plan to use digital signal processing techniques to simulate the effect filtering the signal spectrum such as to admit only the desired working mode.

C-BAND BPM DESIGN

We have also assembled an RF model at C-band, with the dipole mode at 4.8 GHz and the monopole mode at 3.45 GHz. This design is considerably simpler than the L-band design because it uses no dielectric loading and is not required to work inside of a cryomodule. The beam pipe is 1.35" in diameter, which can satisfy installation requirement at many accelerator laboratories. The higher frequency allows enhanced sensitivity down to 1 µm resolution for bunches with <100 pC charge.

BEAM TEST

A pair of BPM cavities and processing electronics will be constructed and installed at the Argonne Wakefield Accelerator (AWA) facility where they will undergo testing. The BPM's will remain at AWA where they will be used to measure beam positions before and after the wakefield test region.

The BPM will also be tested at liquid nitrogen temperature. This test will be conducted without a beam, and will be performed for the purpose of testing how much the RF properties change between the room and cryogenic temperature states.

CONCLUSION

We have performed the bulk of the RF design for a compact large-bore BPM that is compatible with 1300 MHz cryomodules. Fabrication of some key components has started. The departure from a 4-way symmetrized design simplifies mechanical fabrication and reduces the size, but introduces significant complication in the RF design.

ACKNOWLEDGEMENT

We would like to thank the Advanced Computing Department at SLAC National Laboratory for their support in using the ACE3P codes. We are also thankful to Dr. Wei Gai and the AWA team for help with the planning of the beam test.

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ISBN 978-3-95450-115-1