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CONCEPTUAL DESIGN AND ANALYSIS OF A STORAGE RING BEAM POSITION MONITOR FOR THE APS UPGRADE*

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Abstract

A conceptual design has been developed for a radio frequency (rf) pickup-type beam position monitor (BPM) for use in a multi-bend achromat (MBA) storage ring under consideration by the APS Upgrade project (APS-U) [1]. Beam feedback systems are expected to require fourteen rf BPMs per sector with exceptional sensitivity and mechanical stability. Simultaneously, BPM insertion length must be minimized to allow lattice designers the greatest freedom in selecting magnet lengths and locations. Envisioned is a conventional four probe arrangement integrated inside of a pair of rf-shielded bellows for mechanical isolation. Basic aspects of the design are presented along with the results of analyses which establish expected mechanical, electronic, and beam physics-related performance measures.

DESIGN OBJECTIVES

The ultimate goal of the BPM is to generate a set of electronic signals that precisely indicate the arrival time and lateral location of the passing particle beam. Perhaps the most challenging issue is maintaining adequate positional stability in the presence of synchrotron radiation heating of adjacent vacuum chambers, vibrational energy due to water cooling of vacuum chambers and magnets, and rf-induced heating of the BPM itself. The present guidance is that the BPMs should be vibrationally stable to an rms amplitude tolerance of 32 nm horizontally and 56 nm vertically at frequencies between 1 and 1000 Hz. BPM offset values will be established after storage ring systems have stabilized thermally under full-current operation, however the maximum acceptable aggregate of initial and thermally-driven misalignment prior to establishing the offsets has been found to be 500 µm. Once the offsets have been established, the contribution of long-term (thermal) drift to BPM reading error must be no more than 10 µm. Another limitation is available space. The presently envisioned magnet configuration provides a minimum of 125 mm to insert many of the BPMs at required locations.

INTERFACE CONSTRAINTS

There are many constraints that are imposed on the design to ensure that the BPM does not significantly compromise the performance of other technical systems. Foremost among these is that the BPM be compatible with the ultrahigh vacuum environment. Outgassing from internal surfaces must be limited so that average vacuum pressures across the sector can be maintained at a maximum of roughly 2 nTorr during operation. In addition, where BPMs are in close proximity with vacuum chambers coated with non-evaporable getter (NEG) material, the outgassing should not include species such as fluorine or chlorine that are known to cause permanent poisoning of the NEG material or be so excessive that the required thermal activation cannot be accomplished. The assembly should accommodate some degree of misalignment of the flanges on adjacent vacuum chambers. This flange misalignment has been estimated to be no more than 500 µm, a value which sums expected chamber fabrication and alignment tolerances. Also critical is that the BPM should not act to distort fields from the adjacent magnets and should not introduce unacceptable impedance effects on the particle beam. Finally, the BPM should tolerate the radiation environment, thermal-mechanical cycling, and ambient conditions for an expected machine lifetime of 20 years.

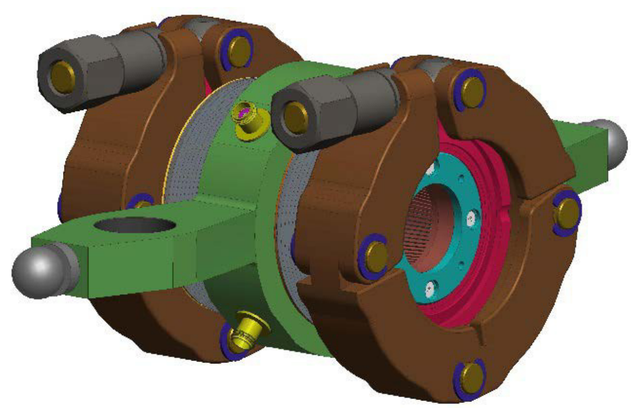

Figure 1: CAD model of BPM assembly.

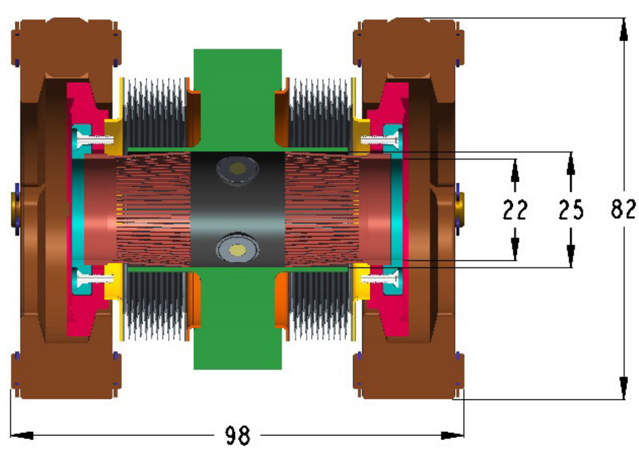

Figure 2: Cross section of BPM assembly.

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DESIGN APPROACH

We seek to address the above requirements with conventional capacitively-coupled button sensors that are inserted into the vacuum using hermetically sealed ceramic-insulated feedthroughs which are welded to a stainless steel block. Buttons of 8 mm diameter are expected to provide sufficient signal. The feedthrough provides a 50 ohm connection from 0 to 20 GHz between the sensor and an external SMA connector. A dielectric filler is used between the feedthrough center conductor and 8.5 mm internal diameter feedthrough housing close to the button to provide good control of the button location and to shunt heat from the center conductor to the body.

The BPM block is rigidly mounted to the magnet baseplate and then flexibly connected on both ends to chain-clampable CF-type vacuum flanges (as sold by VACOM) via a pair of rf-lined stainless steel bellows. The flexible connections serve to decouple the BPM from thermal and vibrational motion on the adjacent vacuum chambers. Edge-welded bellows construction has been selected, instead of forming, to minimize reaction forces under offset. As presently done at the APS, each rf liner consists of a rigid cylinder and a sliding cylindrical array of spring-loaded beryllium-copper fingers [2]. The fingers are 16 mm long, 0.5 mm thick and elastically bent inward for insertion into the rigid portion of the liner so as to provide reliable contact between the two parts under the full range of allowable motion. The gap between fingers is roughly 0.2 mm. Each liner permits a longitudinal offset of +/- 5 mm and a lateral offset of +/- 0.5 mm. Internal mechanical features limit compression of each bellows to the value above. An image of the three-dimensional CAD model and a cross sectional view are shown in Figures 1 and 2, respectively.

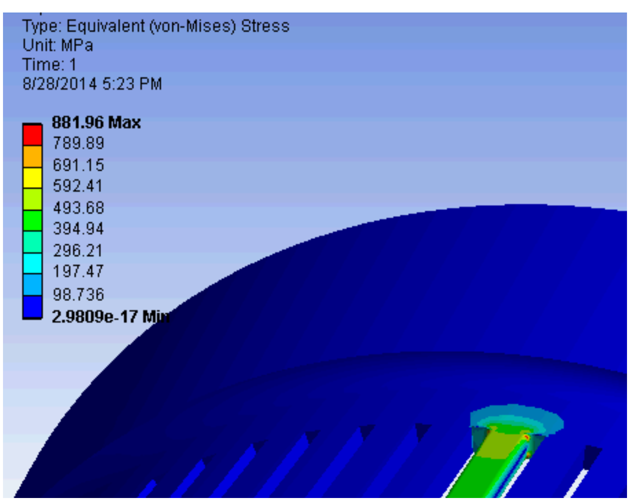

Figure 3: Worst case Von Mises stress.

MECHANICAL ANALYSIS

Finite element analysis has been performed to determine the minimum contact pressure, reaction force, and maximum stress in the flexible portion of the liner during worst-case offset conditions. The results of the stress analysis are shown in Figure 3. The worst case stress, 882 MPa, is comfortably below the yield strength and ultimate tensile strength for half-hard heat-treated material (C17200-TH02). The minimum contact pressure was found to be 0.4 N/mm which is substantially greater than that provided by presently-operational APS bellows liners and greater than published acceptable values for a very similar design [3]. The reaction force under a lateral offset of one of the liners by 0.5 mm was found to be 8 N. Hand calculations based on a simplified set of assumptions have yielded very similar results.

Table 1: Beam-Induced Heat Loads

Location	Material	Power Deposited
Button (each)	SST	0.01 W
Feed-through wall (each)	SST	0.2 W
Center conductor (each)	SST	0.002 W
Flexible liner (each)	BeCu	0.2 W
Rigid liner	SST	0.2 W

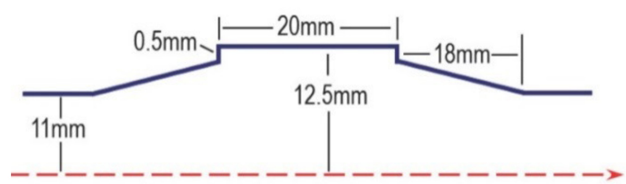

Figure 4: Simplified 2D geometry of the bellows.

ELECROMAGNETIC ANALYSIS

Simulations of the beam-induced microwave environment inside the BPM have been performed and indicate the degree of heating that can be expected from induced surface currents. Table 1 describes the heat loads on the various elements inside the BPM assuming 200 mA current with a 20 mm long bunch length. All heat loads are sufficiently small to be managed with thoughtful thermal design. Total power deposited by the beam in this case was found to be 1.23 W.

Early calculations also indicate that the impedance effects are reasonable owing in part to the smallness of the outward taper and resulting shallow cavity formed by the liner configuration. Wakefield simulations using the full BPM-bellows assembly show quite good agreement with those performed using the simplified geometry shown in Figure 4. This indicates that both the rf finger spacing and gap between the BPM button and housing are small enough to be nearly invisible to the beam. However, these conclusions only hold if there is good rf contact between the fingers and chamber walls, and if the BPM button is well centered. Future work will quantify the tolerances on rf finger and button alignment.

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FUTURE WORK

Performance of the BPM will be critical for successful operation of a future multi-bend achromat at the APS. To ensure this performance we plan to proceed with an iterative design, analysis, and testing program. Because it is increasingly difficult to have beryllium-copper machined owing to safety concerns associated with airborne beryllium, future design iterations will consider the possibility of the use of other materials, perhaps Glidcop [4] or a chromium-copper alloy, for the flexible portion of the liner. In addition, other liner configurations will be considered, including those by which a flexible liner engages the outer surface of a rigid liner as has been done for some other accelerator facilities [5].

Further thermal-mechanical simulations will be performed to optimize design with goals of increasing allowed lateral motion of the bellows, reducing reaction forces under bellows offset, minimizing the risk of bellows liner failure as a result of rf-induced heating, and maximizing the conductance of heat away from critical areas. Additionally, microwave simulations will continue to inform design adaptations that maximize electrical performance of the feedthrough, minimize impedance effects over the full range mechanical offset conditions, and minimize rf-induced heating.

A first set of tests on the mechanical structure is expected to be performed shortly to verify, primarily, vibrational stability and preservation of alignment under displacement of the vacuum flanges expected during operation. These tests will be followed by measurements of the BPM signals under varying offset conditions using a powered wire to simulate the charged particle beam with identical current and frequency characteristics. Ultimately, a test using the APS stored ring is expected to confidently validate the combined set of performance requirements prior to implementation in a new machine.

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[4] Glidcop is a registered trademark name of North American Hoganas, Inc. which refers to a copper alloy that is dispersion-strengthened with aluminium oxide particles.

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