DEVELOPMENT AND TESTING OF CARBON FIBER COMPOSITE CHAMBER SUPPORTS FOR NSLS-II*

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Abstract

The NSLS-II Synchrotron Light Source, a 3 GeV electron storage ring currently under contruction at Brookhaven National Laboratory is expected to provide exceptional orbit stability in order to fully utilize the very small emittance of the electron beam. In order to realize this, the beam position monitor (BPM) pick up electrodes which are part of the orbit feedback system must have a high degree of mechanical and thermal stability. In the baseline design, this would have been accomplished by using flexible Invar plates to support the multi-pole vacuum chambers at the positions where the BPM pick up electrodes are mounted. However, it was later discovered that the close proximity of the Invar supports to the adjacent multi-pole magnets had an adverse affect on the magnetic fields. To mitigate this issue, we propose the use of carbon fiber composite in place of Invar as a low CTE (coefficient of thermal expansion) material. Here we show the design, devlopment and testing of thermally stable composite supports capable of sub-micron thermal stability.

INTRODUCTION

The baseline design for the NSLS-II multipole girder sections consist of an array of multi-pole and corrector magnets mounted on rigid steel girders with the vacuum chambers suspended on a set of mechanical supports. The center support located at roughly the midpoint of the chamber is rigid in all three directions while the two end supports which are located directly beneath the BPM (beam position monitor) pick up electrodes at either end of the chamber must be flexible in the longitudinal direction to allow for chamber expansion during bake out. In addition, they must be sufficiently rigid in the vertical and horizontal direction to allow for chamber adjustment during survey and alignment. The end supports are also required to be thermally stable in the vertical direction. The focus of this paper will be the design and testing of these end supports.

REQUIREMENTS

The mechanical requirements for the chamber end supports are quite challenging. The specification for thermal stability of the BPM pickups are ±200nm in the vertical direction given that the storage ring tunnel air temperature stability will be maintained within ±0.1°C cycling with a time period of one hour which is required for the thermal stability of the magnet-girder assemblies [1]. One component of this is attributed to the 0.78m high steel girder which is estimated to be ±100nm. This imposes ±100nm of thermal stability on the end supports which are 0.42m high, implying the material chosen for the supports must have a CTE<2.4ppm/°C.

The vacuum chambers will be baked to a temperature of 130°C and in the most extreme case where the chamber length is 2.5m between supports, we expect roughly 3mm of motion at each end due to chamber expansion. The supports must have adequate flexibility in the longitudinal direction to absorb this motion.

Finally, the chambers will be aligned on the girder assemblies using removable adjustment fixtures that temporarily bolt to the supports. The support must have sufficient stiffness in the horizontal and vertical direction in order to absorb the loads of a slightly deformed chamber.

MECHANICAL DESIGN

In order to satisfy the above requirements, a structure consisting of pair of thin (2mm) Invar plates which spans the width of the chamber was chosen as the baseline design (Fig 1). Invar has a CTE of 1.3 ppm/°C and sufficient stiffness (E=140 GPa) such that chamber alignment would not be a concern. Thin plates would have sufficient flexibility to absorb chamber motion during bake out without yielding. In principal, this design satisfies all of the mechanical requirements, however it was discovered that the high iron content of Invar dramatically skewed the fields of the adjacent focusing magnets. Several design options were considered to mitigate this problem but ultimately a thin carbon fiber/epoxy composite plate of similar geometry to that of

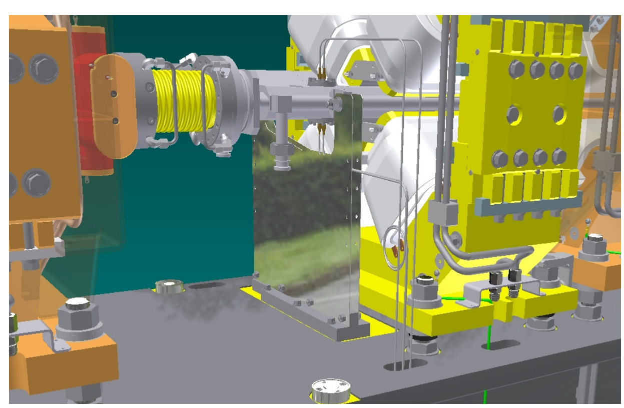

Figure 1: Preliminary design of Invar multi-pole chamber support located beneath BPM pickup electrodes.

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the Invar design was chosen (Fig 4a). Carbon fiber composites can be engineered to optimize mechanical properties and has the added benefit in this application of having no effect on the magnetic field quality. Prototype samples were procured from three vendors with the additional requirement of being capable of sustaining 10^8 rads of radiation with no significant degradation of the mechanical properties.

MEASURING THERMAL STABILITY

The most critical specification for the chamber supports is the thermal stability which is also the most difficult to measure. Similar work was performed on a high stability BPM support in which the thermal stability of a 1.2m structure was characterized using a laser interferometer capable of 10nm resolution [2]. To measure the carbon fiber prototypes, a test configuration consisting of a pair of sample composite plates mounted to a rigid base was placed in an environmental room where the ambient temperature could be precisely controlled. A Renishaw RLE-20 laser interferometer [3] was mounted to the base and a retro-reflective target mirror mounted to the top of the sample. An evacuated beam pipe consisting of a 40mm tube with optical windows was placed in the beam path to minimize the effects of barometric changes (Fig. 2).

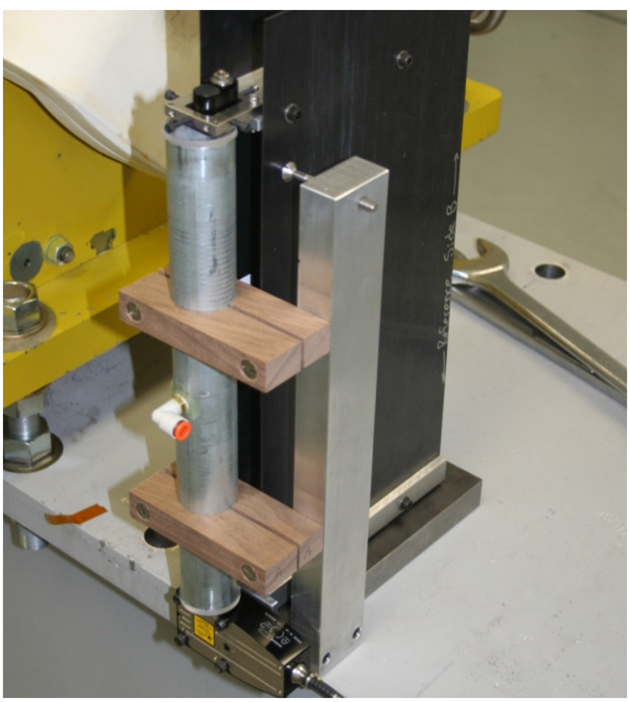

Figure 2: Thermal stability test showing laser interferometer, evacuated beam pipe and reflective target mounted to a pair of carbon fiber sample plates.

Data was collected over 16 hour intervals for each set of vendor samples. The temperature of the environmental room was set to cycle at ±0.1°C with a period of one hour. Of the three samples tested, all met the thermal stability requirement of ±100nm by at least a factor of 2, however the thermal stability of sample #3 was exceptional at ±25nm (Fig. 3).

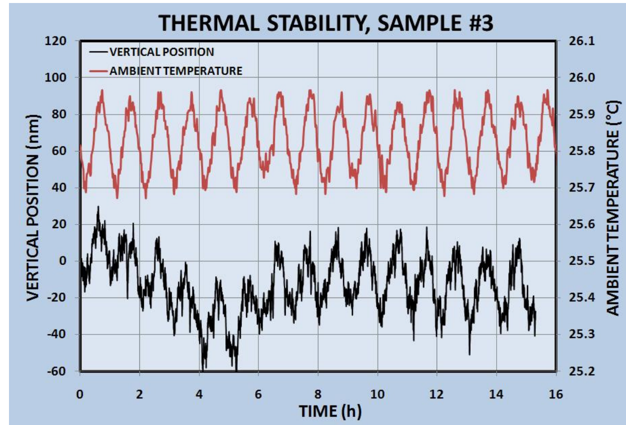

Figure 3: Plot of thermal stability over 16 hours of carbon fiber sample #3.

TESTING MATERIAL STRENGTH

Composite materials are typically anisotropic, meaning that their material properties are dependent upon direction. In the case of the vacuum chamber support design, an important consideration was its ability to remain un-deformed when under load during chamber alignment. We expect in some instances that the chambers could require up to 200 lbs of force in order to bring them into position during survey and alignment. To facilitate this, a special adjustment fixture was designed which bolts directly to the supports (Fig. 4b). A simple test was conducted whereby a chamber was mounted on the supports and positioned with the adjusting fixture. Chamber position was verified via laser tracking survey equipment and fiducial targets on the BPM flanges. The chamber was then clamped in position with the locking hardware on the support, the adjustment fixtures were removed and the chamber was then re-surveyed. This test revealed there was no measureable change in position that would result if the supports had deformed under load.

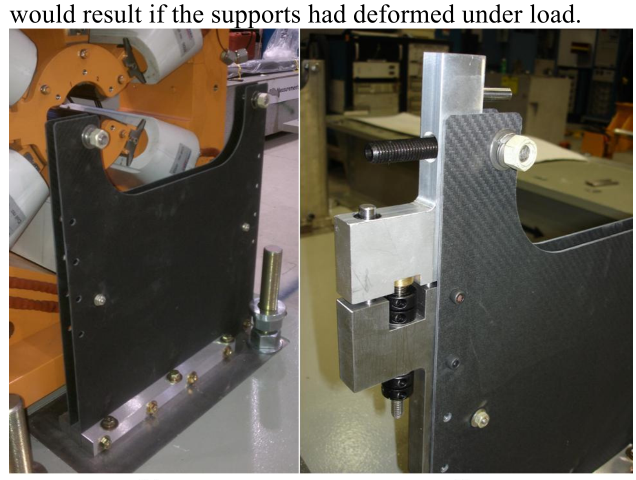

Figure 4: a) Production chamber support. b) Chamber adjustment fixture.

TESTING RADIATION HARDNESS

In order to meet the radiation hardness requirement, vendors used epoxies such as PEEK and SE 84LV [4] which are known to be radiation resistant. The initial concern was that radiation damage to the epoxy would impact the mechanical properties of the composite structure. To test this, five sets of test coupon from two vendors were produced, four of which were place in the Cobalt 60 gamma ray source at Brookhaven. This source produces 1.25 Mev gamma rays at a rate of 0.3 MRads per hour. One set of samples was removed from the source every ten days and its stiffness modulus was measured using a clamped cantilevered beam setup. An Omega LCFD-5 load cell was used to measure the load as the coupon was deflected with a micrometer adjustment translation stage. Figure 5 shows a plot of the stiffness modulus as a function of dose rate for each vendor. We can conclude from this test that there is no discernable degradation of stiffness resulting from radiation exposure.

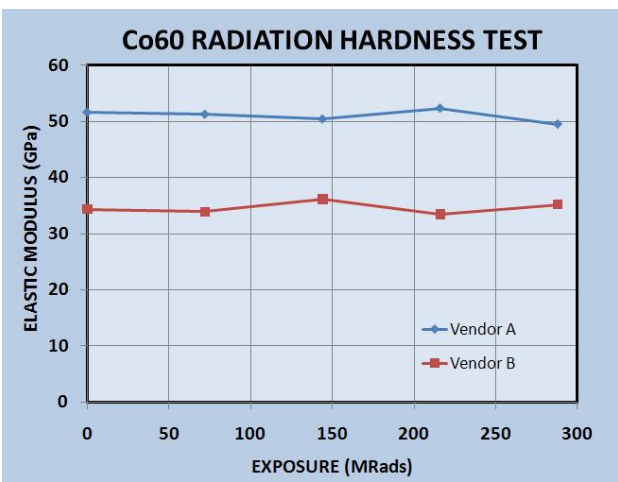

Figure 5: Plot of elastic modulus vs. exposure to Co60 gamma ray source for two vendor samples.

SUMMARY

The use of carbon fiber composite material as an alternative to Invar for chamber supports effectively mitigates the issue of magnetic field distortion. We have also shown that carbon fiber composites can be engineered to achieve exceptional thermal stability, in this case equal to or better than that of Invar. The prototype supports tested have sufficient stiffness to bear the loads induced from chamber adjustments during survey and alignment. Finally, choosing a radiation resistant epoxy as part of the composite layup yields an end product that should survive in the harsh radiation environment expected in the NSLS-II storage ring.

ACKNOWLEGEMENTS

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