A GIRDER-FREE MAGNET SUPPORT SYSTEM DESIGN

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Abstract

Magnet support systems for the new light sources are required to satisfy several rigorous performance specifications. The support system must be rigid so that its static deflection under its own weight and the combined weight of the magnets is small and repeatable. For vibration stability the lowest natural frequency of the magnet-support assembly should be greater than 50 Hz. To meet thermal stability requirements it is desirable to minimize bending deformations of the support system when subjected to temperature changes. In addition, the magnet support system should be easy to transport, easy to align, and cost effective. Altogether these requirements are difficult to satisfy, especially if the main structural component of the support system is a girder of length greater than 3 meters.

In this paper we propose a magnet support system design consisting of column-type supports joined by removable C-channel beams. The column-type supports provide a superior stability performance without compromising the alignment capability. Analysis results are presented to characterize the performance of this support system.

INTRODUCTION

The storage ring (SR) magnets of new high-brightness light sources have stringent mechanical alignment and stability requirements. The magnets are usually grouped together for assembly on girders in such a way that the stricter specifications apply to magnets on the same girder whereas the specifications for the girders are substantially relaxed. Table 1 shows the alignment and stability specifications for the NSLS-II storage ring magnets [1].

Table 1: NSLS-II Alignment and Stability Specifications in X (horizontal) and Y (vertical) Directions.

Specifications	Alignment (μm)		Stability (nm)	
	Δ X	ΔY	Δ X	ΔY
Magnets	30	30	150	25
Girders	100	100	600	70

Magnets are usually assembled on long girders (in 3–7 m range) outside the SR tunnel. This allows advanced preparation of magnet-girder assemblies as well as use of better techniques for magnet alignment such as the vibrating wire method. Long girders support the weight of the magnets primarily by bending (flexural) deformations which are not conducive to magnet alignment. Bending vibration modes and thermal bending deformations also work against meeting the magnet stability specifications. This is illustrated below for a simple box-beam girder.

A BOX-BEAM GIRDER

A steel box-beam girder of 0.5 m height, 0.5 m width and 0.04 m wall thickness (inset of Figure 1) is analysed for deflection under its self-weight and the weight of the magnets. The weight of the magnets is approximated by doubling the weight density of steel. The deflection for simply-supported boundary conditions is calculated both by a flexural beam equation and by 3-D Ansys analysis that includes shear and compression deformations. As shown in Fig. 1, the gravity loads are resisted primarily by shear and compression deformations for span-to-height ratio R of < 3. For R > 7, the loads are resisted mainly by bending deformations which increase as R^4. As a comparison, the measured gravity deflection of a 5 m long (R = ~ 10) NSLS-II girder was 117 μm, and had a scatter of ~ 15 μm (half of the alignment tolerance) because of friction at the support points.

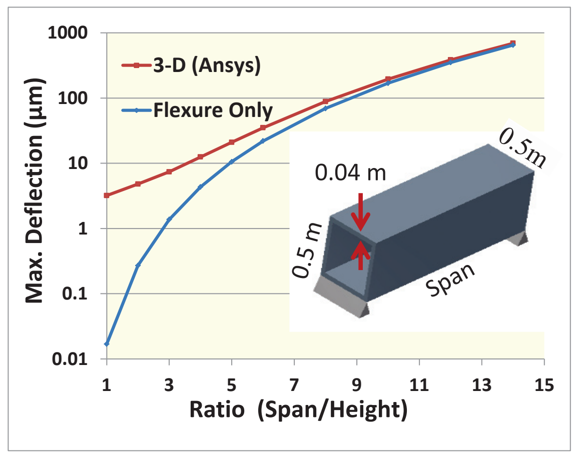


Figure 1: Gravity deflection of a box-beam girder under its self-weight and weight of the magnets versus R (Span/Height).

The box-beam girder can also be used for an insight into its mechanical stability. A natural frequency of > 50 Hz in bending (or torsion) mode is commonly used for the magnet-girder assembly to ensure that the vibration stability specifications are met for the ambient ground motion. Thermal bending deformations are induced in the girder when the girder's expansion or contraction due to change in the tunnel-air temperature is constrained. Because of thermal inertia, a girder typically experiences only a fraction (~ 10%) of the change in the tunnel air temperature. Thermal bending also occurs due to diurnal expansion/contraction of the floor.

The first natural frequency in bending mode and thermal bending (for 1° C change in girder temperature) of the box-beam girder are plotted in Fig. 2. The weight of the magnets is again included approximately by doubling the weight density of steel. As can be seen the natural frequency decreases as $1/R^2$ whereas the thermal bending deformation increases as R^2. A natural frequency of > 50 Hz is obtained for R < 9. Assuming that the stability specifications of Table 1 also apply to thermal stability (effectively 2.5 µm/ °C), R for this beam needs to be ~ 1.

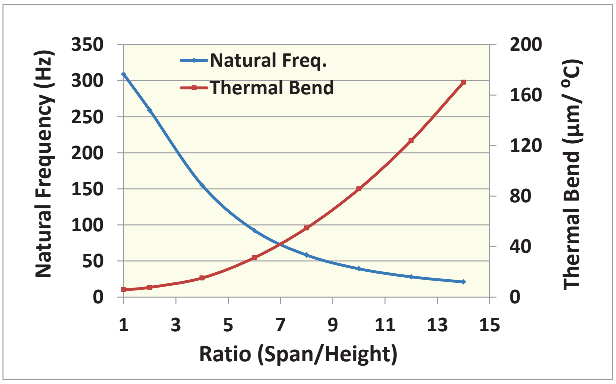
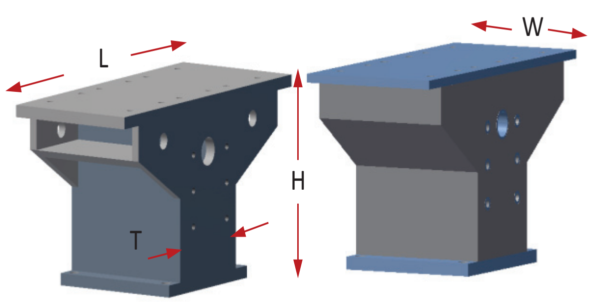


Figure 2: Natural frequencies and thermal bending deformation of a box-beam girder versus R (Span/Height).

GIRDER-FREE SUPPORT SYSTEM

From the example above it is clear that bending deformations of the girder make it difficult to meet the alignment and stability specifications. Special measures, such as profiling, damping pads [1] and locking system [2], are often introduced to meet the specifications. We propose a magnet support system based on hammerhead columns (Fig. 3) which minimize bending deformations. A hammerhead column can be constructed either as a welded steel structure (Fig. 3-a) or as a solid reinforced concrete (RC) structure (Fig. 3-b). RC hammerhead piers are commonly used for bridge construction where they are designed to carry a large fraction of loads in shear and compression.

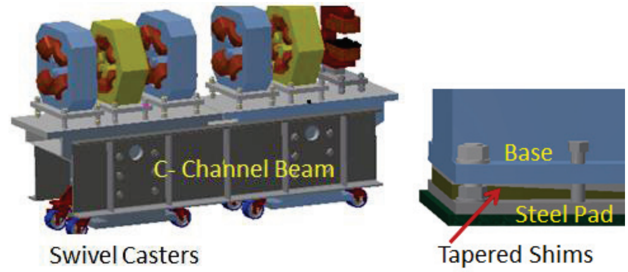


(a) (b)

Figure 3: Hammerhead support columns – (a) welded steel construction, (b) from reinforced concrete with steel plates. Dimensions used in analyses are H = 0.8 m, L = 1.5 m, W = 0.65 m, and T = 0.5 m.

Basic dimensions of the hammerhead columns, used for analyses in the following sections, are shown in Fig. 3. Both the steel and RC hammerhead columns weigh in the range of 1400–1500 kg. For the RC hammerhead a combined density of 2500 kg/m^3 and Young's modulus of 30 GPa are used in the analyses. The length L of the top plate can be increased if the T dimension is increased proportionately to achieve the same performance. Because of their simple construction and manageable dimensions these hammerhead columns are cost-effective and easy to fabricate.

ASSEMBLY, TRANSPORTATION AND ALIGNMENT



(a) (b)

Figure 4: (a) An assembly with two hammerhead columns, removable c-channel beams and spring- loaded swivel casters, (b) tapered shims between the hammerhead base and grouted steel pad.

Two or more hammerhead columns can be used to replace a girder of the same length for the assembly and alignment of magnets, vacuum chamber and other ancillary components. The hammerheads columns are joined by removable C-channel beams (Fig. 4-a). Spring-loaded swivel casters are attached for transportation and load sharing. After transportation into the SR tunnel a precise alignment over pre-grouted steel pads is performed either for the entire assembly or for each hammerhead assembly. In the latter case simple pusher-type alignment mechanisms can be used since the weight of the entire hammerhead assembly is comparatively small (~ 3000 kg) and there is no cross-talk between the two assemblies. Tapered shims (Fig. 4-b) can be used between the base and the grouted pad for better mechanical stability and to help automate the alignment process. For subsequent global alignment of the SR, the use of a smoothing technique [3] can be used to reduce the number of hammerhead assemblies to be aligned.

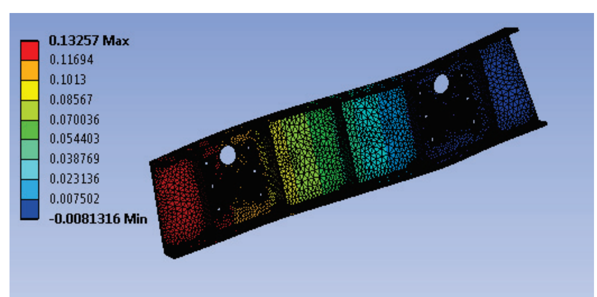


Figure 5: Deflection of C-channel beams subjected to the weight of a hammerhead assembly is 0.14 mm.

The C-channel beams are approximately 0.13 m in width and 0.6 m in height, weighing approximately 270 kg. These dimensions for the C-channel beams ensure that the relative displacement between the two hammerhead assemblies is a small fraction of 1 mm even if they are accidentally subjected to the full load of one hammerhead assembly (see Fig. 5). The maximum effective stress in the beams is less than 50 MPa as compared to 200 MPa yield strength of structural steel.

ANALYSIS OF PERFORMANCE

Ansys finite element analyses were carried out for magnet assemblies on both steel and RC hammerheads. The results for gravity deflection, modal analysis and thermal stability are described below.

Gravity Deflection

Gravity deflection of a steel hammerhead column under its self-weight and weight of the magnets is depicted in Fig. 6. The maximum and minimum deflections of the magnets on a steel hammerhead column are 5 µm and 4 µm, respectively, resulting in a misalignment of only 1 µm. A similar misalignment (0.7 µm) was obtained for an RC hammerhead column. These values are more than an order of magnitude smaller than those measured for NSLS-II steel girders. High-precision alignment of the magnets is simpler when the effect of gravity deflection is negligible.

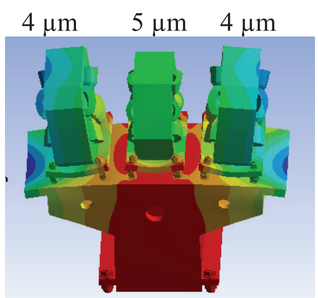
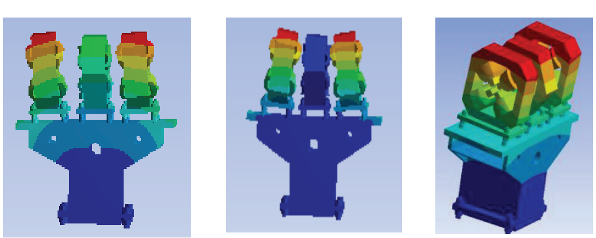


Figure 6: Gravity deflections for a steel hammerhead – magnets assembly.

Modal Analysis

Natural frequencies for the first four lowest modes of a steel hammerhead - magnets assembly were calculated as 70.3 Hz, 94.3 Hz, 100.8 Hz and 102.7 Hz. In the 1^{st}, 2^{nd} and 4^{th} modes all motions are along the beam direction. In the 1^{st} mode (Fig, 7) the hammerhead column itself bends at the base whereas in the 2^{nd} and 4^{th} modes the magnets move with respect to the column. These modes are not relevant for the stability of the magnets. In only the 3^{rd} mode at 100.8 Hz, the column bends in the transverse-to-beam direction and is subject to the mechanical stability criterion of natural frequency > 50 Hz.



1^{st} Mode 2^{nd} Mode 3^{rd} Mode

Figure 7: First three modes of a steel hammerhead - magnets assembly (natural frequencies of 70.3 Hz, 94.3 Hz and 100.8 Hz).

For the RC hammerhead assembly the first four natural frequencies are 59.3 Hz, 77.5 Hz, 97.87 Hz and 102.0 Hz. The transverse motion of the column occurs in the 2^{nd} mode at 77.5 Hz. This is expected to be close to the actual natural frequency because of a single-unit construction of the column and because the stiffness uncertainty of bolted connections is mitigated by tightening the bolts against tapered shims.

Thermal Stability

A transient analysis was performed for a tunnel air temperature change of ± 0.1° C at 1 hour cycle. As expected, the temperature change in the steel hammerhead column and the magnets is only 10% of the change in air temperature because of thermal inertia. Thermal deformation of the hammerhead-magnets assembly under the induced thermal gradients, which are maximum at time = 1,260 seconds, is shown in Fig. 8. Magnet misalignment due to the thermal gradient is only 9 nm which is a fraction of the stability specification of 25 nm. The corresponding misalignment in the RC hammerhead – magnets assembly is 10 nm. It should be noted that the thermal stability of hammerhead columns is immune to SR floor's diurnal expansion/contraction and counter-measures such as viscoelastic pads [1] are not required.

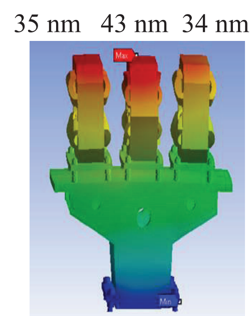


Figure 8: Thermal deformations in a steel hammerhead – magnets assembly due to tunnel air temperature change.

CONCLUSIONS

Bending deformations in girder-based magnet support system are detrimental to meeting the stringent mechanical alignment and stability specifications of the magnets of new storage rings. Such deformations are minimized in a support system based on hammerhead columns. These columns are joined with removable C-channel beams only during assembly and transportation. High-precision alignment is simplified in the proposed design because gravity deflections are reduced by more than an order of magnitude. This support system meets all vibration and thermal stability specifications by a substantial margin.

REFERENCES

[1] S. Sharma, et al, "Optimization of magnet stability and alignment for NSLS-II", *in Proc. PAC11, NY, USA.*

[2] P-L Sung, et al, "Vibration measurements for the Girders with Multi-Stage Adjustable Dampers in TPS Storage Ring, *in Proc. MEDSI2012*, Oxford, UK.

[3] C-Y Yu et al, "The Application of Smoothing in NSLS-II", *paper to be presented at IWAA2016,* Grenoble, France.