The Ninth International Conference on Synchrotron Radiation Instrumentation
May 28 – June 2, 2006, DAEGU, EXCO, KOREA

FEA of Magnetic Loads on MAX II 46.6mm EPU Girders

Dave Caletka, Alex Deyhim, Dave Waterman, Jonathan Hunter-Dunn*, K. Ingvar Blomqvist**

Advanced Design Consulting USA, 126 Ridge Road, P.O. Box 187, Lansing, NY 14882, USA
** MAX-Lab, SE-22100, Lund, Sweden*
***Consultant*

Abstract. A finite element analysis of the magnetic loads was performed on the girders supporting the magnet assemblies for the MAX II 46.6mm EPU. The analysis focused on the following concerns; off center vertical support with respect to vertical magnetic loads resulting in unwelcome transverse girder deflections; an increase in attractive transverse magnetic loads (vertical mode of operation); and assembly complexity and maintenance. In this publication we will review the FEA assumptions, boundary conditions, and the final results. The FEA data will then be compared with the actual measurement of the system after fabrication and magnet installation.

Keywords: Insertion Devices, Magnets, modeling, finite element analysis, EPU

PACS: 02.70.Dc, 41.60.-m

INTRODUCTION

An extensive finite element analysis was undertaken as part of the design of an EPU for Max-Lab. This is a two meter, Apple II device capable of producing inclined and helically polarized light with inclination angles of ±90° Its period is 46.6 mm, minimum gap is 14 mm and it covers the energy range from 500 eV to 2000 eV. In planar mode its rms phase error is specified as <3°. A strict limit on the device's weight introduced additional challenges.

To meet such these requirements the deflections of the structure must be carefully controlled. A finite element analysis of the effects of magnetic loads on the magnet arrays was critical in meeting the specifications.

DISCUSSION

The critical element of the mechanical design proved to be the girder and sliders to which the magnet assemblies are mounted. Therefore, although the entire undulator frame was modeled, only this critical portion of the structure will be discussed.

The stiffness of the sub-girder bearing race contact elements was estimated according to bearing rigidity calculations presented in the INA design guide. A conservative nominal preload of 3000 lbs (per bearing set) was applied to the bearings through the use of multiple load steps. The initial load step solved for contact interference at the bearings in order to generate the preload. Deformations from this preloaded state were subtracted from subsequent load steps (application of magnetic loads) as these deformations would be eliminated during shimming. Coupled nodes were employed to connect the vertical bearings to the base girder at positions corresponding to the mounting bolts. Longitudinal placement of the vertical bearings and gap drive lead screws was "optimal" at 0.22L from the girder ends, where L is the total length of the girder assembly. The restraints for the gap drive lead screws were located on the top, solid area of the main girder and centered over the magnet array. The modulus of the RUE 35D vertical bearing blocks was adjusted so as to account for bearing stiffness published in the INA catalog. The magnetic loads were applied as pressures on the magnet assemblies in directions appropriate for the load conditions considered.

Note that the size of, and non-linearities associated with, the 3D finite element models required considerable computational resources and run times in excess of 20 hrs.

A model, showing vertical displacement contours under a vertical load of 16 kN, is shown in Figure 1. The cross-section of the main girder, the four sets of crossed-roller bearings, and the two sub-girders that carry the magnet arrays can be seen in the lower left-hand portion of the figure.

A design goal of <10 µm deflection was set as part of the phase error budget. Magnetic forces were calculated in Radia[1] in the two planar modes and in 45° inclined and circular modes. Deflections produced by three load conditions were evaluated: vertical load between upper and lower magnet assemblies; transverse load between the upper

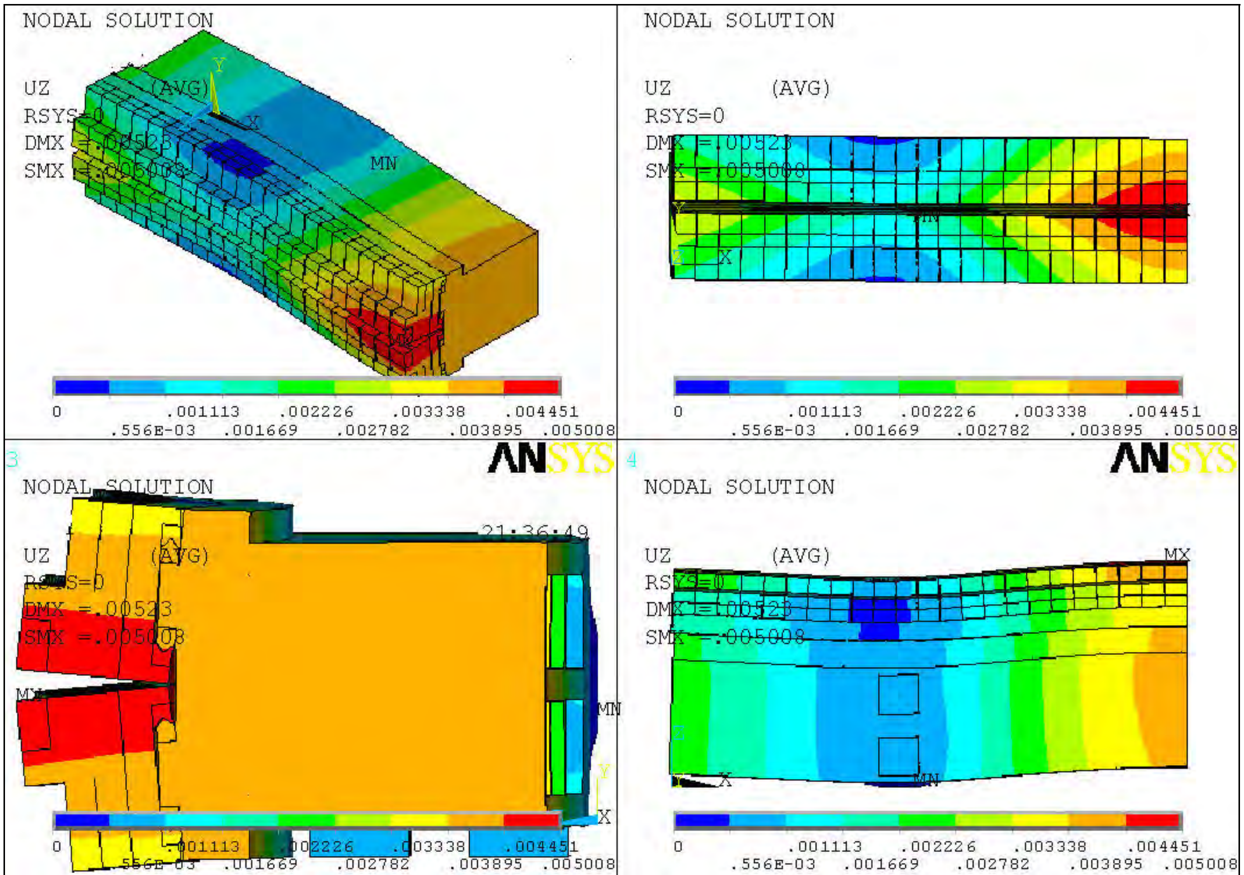

Figure 1: Displacement contours in horizontal mode at minimum gap.

and lower magnet assemblies; and the transverse load between adjacent magnet subassemblies. The last of these proved to be the most difficult to reduce.

When operated at minimum gap in vertical mode the load acting between adjacent magnet arrays was found to be 10.3 kN. Results from the model using this load condition are seen in Figure 2.

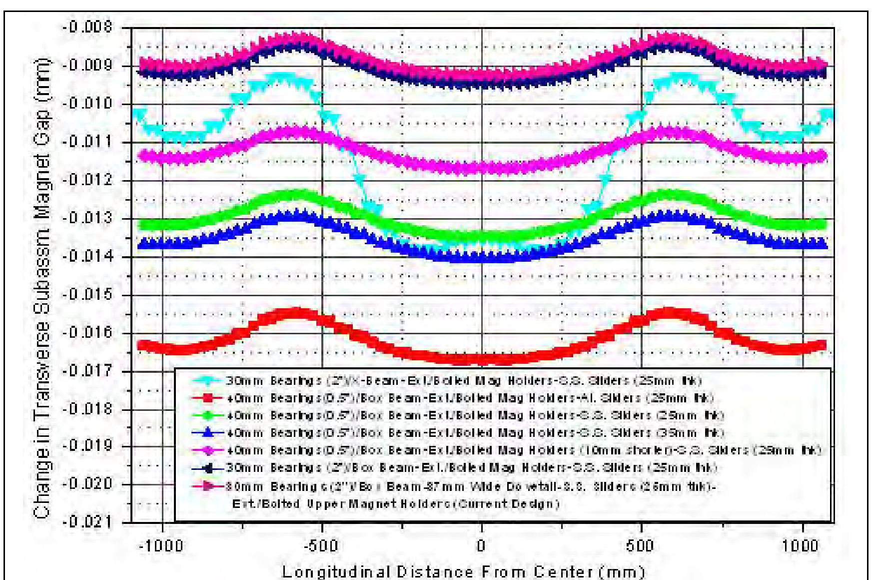

Figure 2: Change in the gap between adjacent magnet arrays at minimum gap in vertical mode.

The main girder was originally designed as a casting with diagonal cross bracing. This resulted in considerable longitudinal variation in the transverse magnetic gap, as shown by the light-blue triangles in the figure. A box beam design proved to be much more rigid, reducing the gap between adjacent magnet arrays from ~4.5µ to ~1µ. All other curves in the figure use this structure.

The effects of bearing size (40mm vs. 30mm), slider material (Al. vs. Stainless), slider thickness and bearing spacing (2” vs. 0.5”) are also shown in the figure. Of these the change to stainless for the longitudinal sub-girders was the most beneficial.

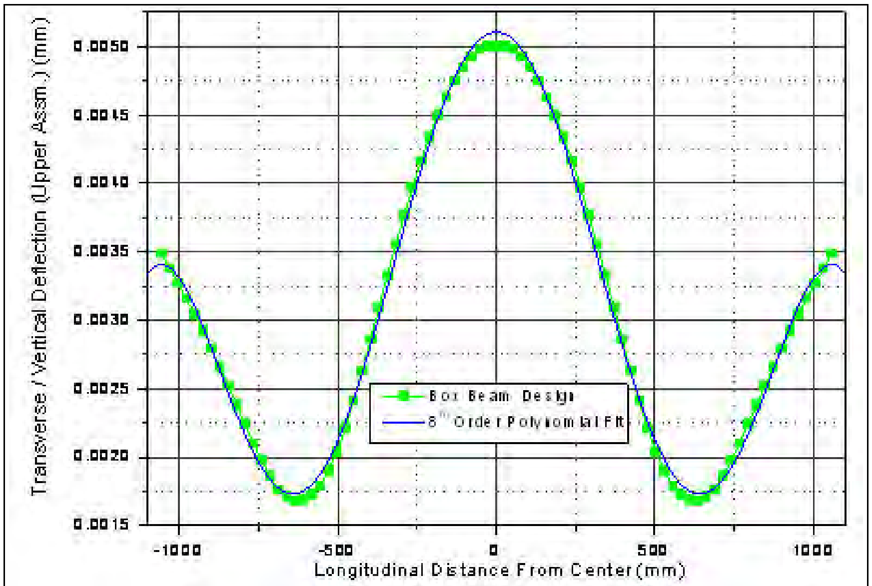

Figure 3: Vertical displacement of magnets at minimum gap in horizontal mode.

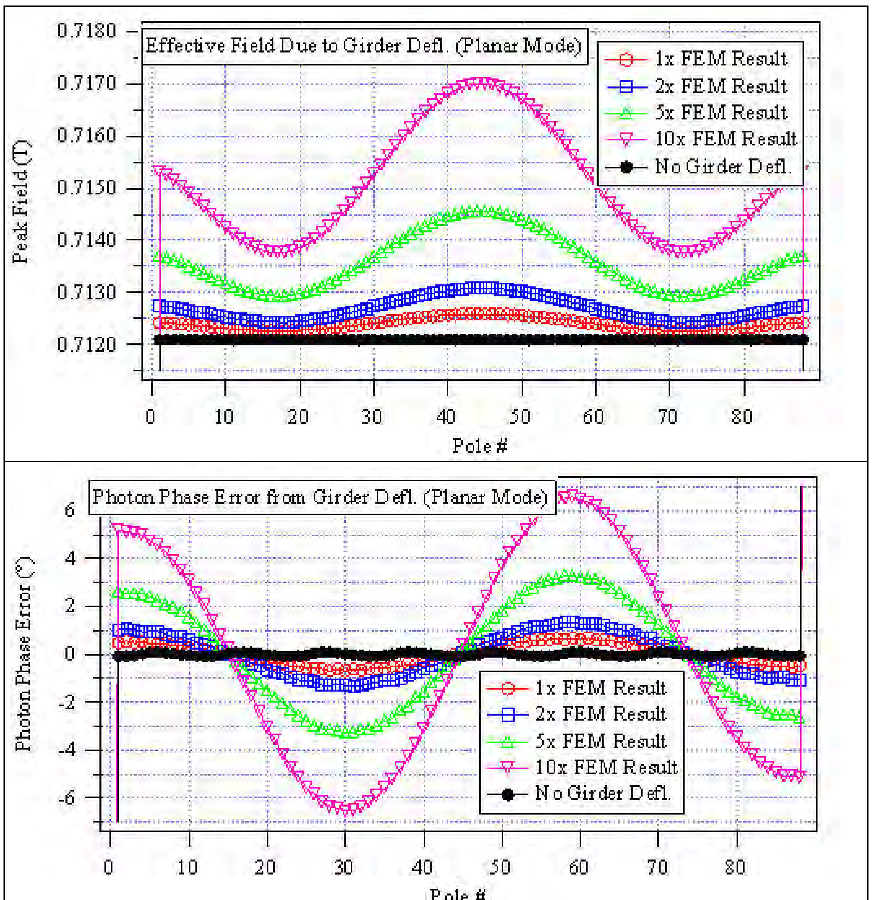

Figure 4: Effective field (top) and resulting phase error (bottom) produced by the girder deflections in horizontal mode at minimum gap.

Another design parameter that was explored was the fastening of the magnet holders to the sub-girder. A dovetail with gib-screws is used for this purpose. Increasing the size of the dovetail and an additional bolt through the magnet holders directly into the sub-girder were considered. Maximizing the width of the dovetail was shown to provide a slight benefit.

As a result of the modeling the final design used cast, aluminum girders with stainless sub-girders supported by widely-spaced cross-roller bearings. The calculated deflections were then used to predict the structure's effect on phase error.

As an example, the vertical displacement of the magnets, at minimum gap in horizontal mode, is shown in Figure 3. An 8^{th} order polynomial was fit to the displacement curve (a 4^{th} order polynomial failed to adequately reproduce the deformed shape of the girder, although the effect on calculated phase angle error was seen to be negligible). This functional representation of the deflected girder shape was then utilized in B2E[2] to modify the idealized magnetic field of the EPU and investigate the effects on the photon phase angle error and radiation spectra. This was done for several magnitudes of the calculated displacement function ranging from 1X the finite element result to 10X the finite element result. The effects on the effective vertical field and the photon phase error are presented in Figure 4.

The effects of the girder deformations on the radiation spectrum is shown for the 1^{st} five (odd) harmonics in Figure 5. As can be seen, girder deflections as high as two to five times those predicted by the finite element simulations have minor effects on the magnitude and energy level of the harmonics presented.

CONCLUSIONS

The only magnetic loading condition which required multiple design iterations in order to meet the +/-10µ spec was the attractive transverse load experienced when operated at minimum gap and a phase of 23.3mm, i.e., vertical mode. The following design features were adopted as a result of the analysis: stainless steel has been used for the sub-girders; the transverse spacing of the longitudinal bearings was increased from 0.5” to 2” and the dovetail width was increased from 30mm to 87mm in order to reduce reaction loads; the magnet holders were redesigned to increase moment arm; the cross section of the cast aluminum beam was optimized to reduce longitudinal variability of deflections

Results from the simulations indicate that the current design meets the deflection criteria for all magnetic load conditions.

Note that in order to maintain a photon phase angle error of less than 2° rms in planar mode, the maximum allowable girder deflection, based on the calculated deflected shape, could have been specified as high as 20+µ, providing a 4-5X safety factor.

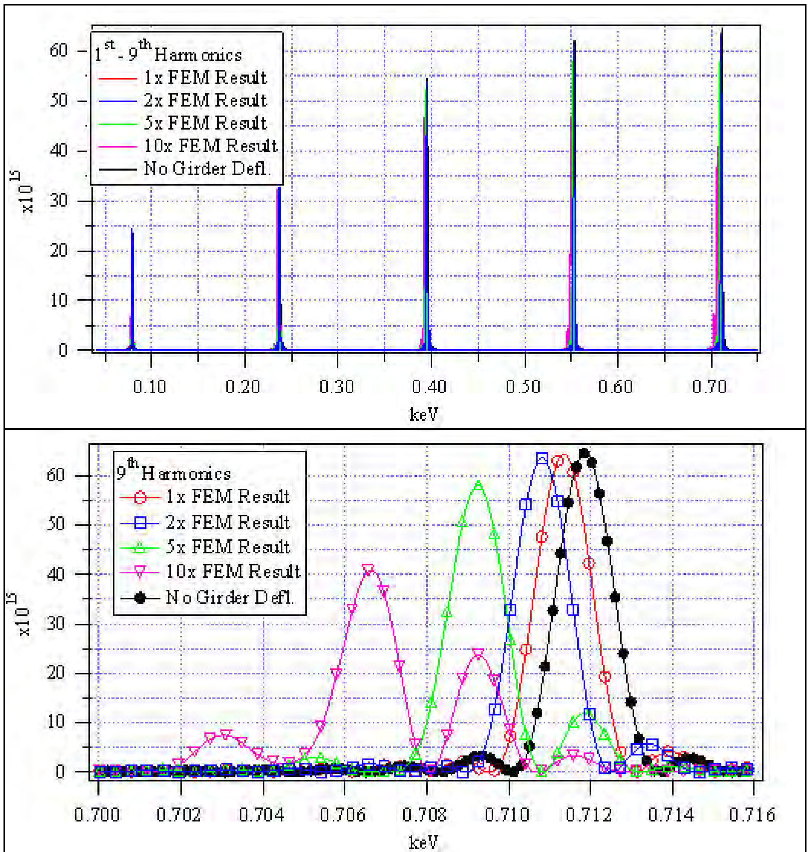

Figure 5: The effect of girder deformation on the energy spectrum of the EPU in horizontal mode is shown (top). The effect is greater on higher harmonics. The ninth harmonic is also shown (bottom).

ACKNOWLEDGMENTS

REFERENCES

[1] Radia was written at the ESRF by Pascal Elleaume and Oleg Chubar and can be obtained from http://www.esrf.fr
[2] B2E was written at the ESRF by Pascal Elleaume and can be obtained from http://www.esrf.fr