PARAMETRIC MECHANICAL DESIGN OF NEW INSERTION DEVICES AT THE APS*

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Abstract

Three permanent-magnet, planar, hybrid insertion device (ID) designs have recently been completed at the APS. The periods of these undulators are 2.7 cm, 3.0 cm and 3.5 cm with nominal lengths of 2.4 m. Several design studies were performed for the initial 2.7-cm-period device. Then a parametric solid model for the initial device was developed and value engineered to minimize manufacturing, assembly and tuning costs. The model allowed the very rapid design of subsequent devices of similar periods and allowed commonality of several components of the IDs.

This design family incorporates a low-cost method of pole retention and registration. Poles are secured by screws in two holes tapped into each pole. Pole location is registered by means of two small dowel pins in mating holes reamed into each pole and a "divider" plate common to the poles and magnets. This divider plate is flexible along its length so shimming behind it can be used to accurately change the height of a pair of poles for tuning.

Another feature of the design is modular construction to allow each device to be used full length or shortened to a nominal 2.1 m length for use in APS "canted undulator" sectors.

INTRODUCTION

While most ID beamlines at the APS use the 3.3-cm-period "Undulator A" [1], some applications require other period lengths to optimize the brilliance in a particular energy region or to reach specific K edges in the first harmonic with sufficient brilliance. The 2.7-cm-period device is used for generation of relatively high-energy x-rays with a lowest energy of 7.0 keV in the first harmonic. The 3.0-cm-period device will be used for inelastic x-ray scattering and for biological research with a tuning range from 5.0 keV to 14.5 keV in the first harmonic, which covers the important bromine K edge at 13.5 keV. The 3.5-cm-period device will use SmCo magnets for enhanced radiation resistance, as it will replace a 3.3-cm-period Undulator A in a straight section with the smallest vertical and horizontal apertures in the APS storage ring. Relevant parameters for the three undulators are summarized below:

Magnet Period (cm)	2.7	3.0	3.5
Number of Periods	88 / 78	79 / 69	64 / 56
Minimum Gap (mm)	8.5	10	9
Nominal Length (m)	2.4 / 2.1		
Magnet Material	NdFeB		SmCo
Pole Material	Vanadium Permendur		

THE UNDULATOR DESIGNS

Objectives

The primary goals of the new insertion device design were lower cost, ease of initial assembly, ease of magnetic tuning, compatibility with both types of APS gap separation mechanisms [2, 3, 4], commonality of as many parts as possible and adaptability for use in both full 2.4 m length and in nominal 2.1 m length for the dual-canted-undulator sectors. It was also desirable to be able to quickly design future undulators with periods as short as 2.2 cm. Several design studies were performed for the initial 2.7-cm-period device to investigate the utility and feasibility of key design features. The size and number of magnet assembly modules, the methods of pole and magnet location and retention, methods of changing the height or cant of individual poles for tuning and provisions for conventional magnetic and mechanical shimming were all evaluated.

The Design Process

Early decisions included using a common structural support "strongback" beam for all of the designs, common base plates for all of the designs and the use of five magnet assembly modules of three different lengths for each design. These decisions fixed some of the "hard points" for the design, then a conceptual solid model for the 2.7-cm-period device was designed using ProEngineer Wildfire. The ability to do finite element analysis with the Mechanica application embedded in Wildfire was exploited to optimize the geometry of several of the design components. The parametric associativity of the model was exploited to allow rapid "what-if" changes to the concept.

As this concept evolved, a team of APS and ANL experts in undulator assembly, undulator tuning and precision machining was consulted for value engineering of the concept. This allowed the design to minimize the overall cost of manufacturing, assembling and tuning of the insertion devices. The optimized parametric model allowed very rapid design of the subsequent devices and allowed economies of scale in production of the components common to all of the devices or very similar

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between the devices. The model can be used for devices with periods as short as 2.2 cms.

Key Features of the New Designs

An exploded view of a 2.7-cm-period magnetic structure is shown in Figure 1. For each of the upper and lower halves of the undulator, five of these assemblies are mounted to a structural strongback. This design eliminates pole clamps entirely and secures the poles to the divider plate with screws threaded into tapped holes in the poles. Each pole and each shoulder of the divider plate has a pair of reamed holes for accepting small (1.5 mm diameter) stainless-steel dowel pins to accurately locate each pole relative to the divider plate. The screws used for this device are #3-48 socket-head cap screws of

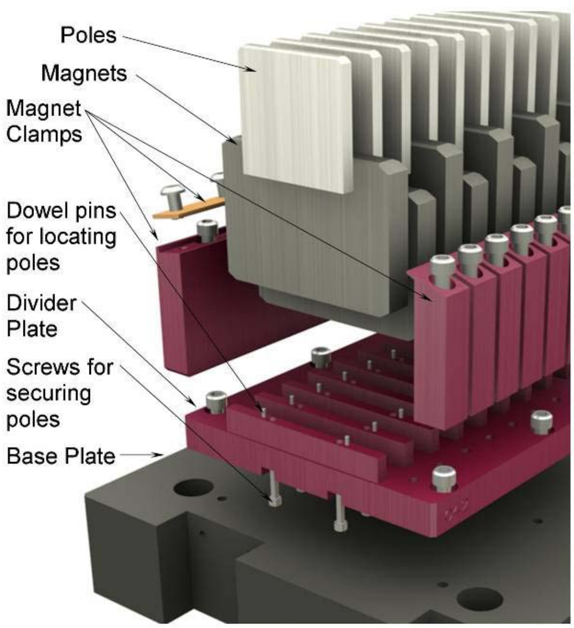

Figure 1: Exploded view of an undulator magnetic structure subassembly.

18-8 stainless steel. They are silver plated to provide a consistent level of friction for repeatable pole clamping force at a given tightening torque. An electronically controlled screwdriver is used to tighten the screws very accurately to 10 in-lbs (1.1 N-m).

Once the poles are assembled to the divider plates, the divider plates and base plates are mounted to the strongback. Precise alignment and spacing of poles is maintained between the five separate divider plates as they are installed. Then the continuous magnet clamps are installed, followed by the individual magnet clamps.

The divider plate is designed to be flexible in bending in the beam direction, while the base plate is very stiff. This is so that pole height (and therefore field strength) can be adjusted by shimming between the divider plate and the base plate, and/or between the base plate and the strongback, depending on how local an adjustment is required. The geometry of the divider plate is also optimized for minimal manufacturing cost, ease of magnet installation and removal, and minimum variation in deflection (from magnetic attraction of the poles) between the pole locations. A finite element analysis of deflection for one of the small divider plates for the end modules is shown in Figure 2.

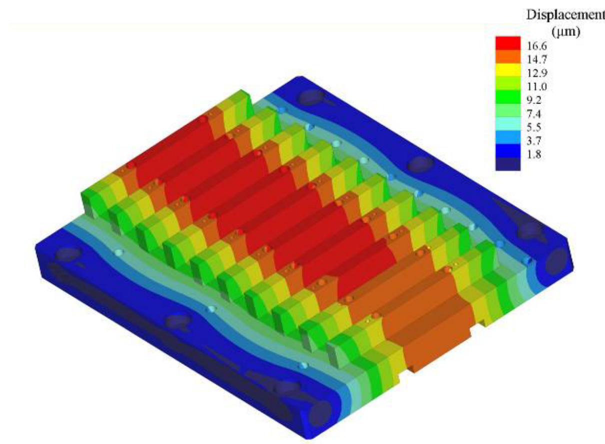

Figure 2: Finite element analysis results for deflection of a divider plate.

A finite element analysis of stress in one of the magnet clamps is shown in Figure 3. For this part, the geometry and material selection is optimized to prevent damage to the magnet while adequately securing it.

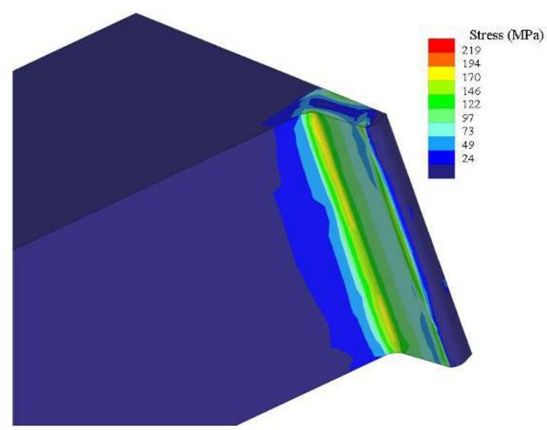

Figure 3: Finite element analysis results for stress in one magnet clamp.

A unique feature of the design is the modular construction, which allows each device to be used at the nominal 2.4 m full length or shortened to a nominal 2.1 m length. Each magnet structure consists of five modules. The two on either end are each a nominal 150 mm length and can be readily removed to shorten an undulator. The shorter length is needed for use in the APS dual-canted-undulator sectors, where two IDs are used in a common straight section to provide two radiation sources with a small angular separation between them.

LIMITATIONS TO FULL PARAMETRIC DESIGN

This project has been a productive use of solid-modeling and finite element analysis capabilities, and the generation of a mechanical design for a new undulator of a similar period can literally be done in less than a week. But that work is not quite as simple as changing several design parameters. The divider plates can be readily altered for the number and size of the pole supports, their spacing and the clearance holes in them. But some complications include the fact that the magnetic design and modeling is still distinct from the mechanical design and modeling. Some of the design considerations for the second design required further iterations of magnetic analysis, so the two design processes were not simply sequential. An additional complication is the fact that the finite element analysis of some components is unique to a given period and needs to be done before they can be finalized. This could be further integrated for a larger scale design project, though.

A final complication is that, while a common size of dowel pin is used for locating of all undulator poles, for each of the three different periods a different size screw is used for retention of the poles. The analysis of the screws and the internal threads in the poles cannot be readily done in Mechanica as implemented in Wildfire 1.0 (but can be done in Wildfire 2.0). Since we did not feel comfortable enough using published mechanical properties of annealed vanadium permendur for analysis of the pole threads, the screw sizes and tightening torques were, in fact, verified experimentally. But we now have design criteria for four different pole screw sizes (#2-56, #3-48, #4-40 and #6-32) as appropriate for the pole sizes and forces in future designs.

CONCLUSIONS AND STATUS

This design project has been extremely successful in producing cost-effective planar, hybrid undulators. There is a high level of accuracy in the machining of the poles and the divider plates, but the incremental cost of this accuracy for parts machined with automated machining centers is trivial and results in ease of assembly, ease of tuning and high magnetic field quality. Magnetic measurement and tuning were accomplished rapidly due to the high accuracy of the undulator components and of the assembled undulators.

A single 2.7-cm-period undulator and two 3.0-cm-period undulators have now been assembled, tuned and installed at the APS. All the components for building three more 3.0-cm-period undulators have been produced, and those undulators will be assembled shortly. The next 3.0-cm-period device will be built without the end modules so it can be used in a dual-canted undulator application. The components for the 3.5-cm-period undulator are currently being produced, and it will be assembled and tuned in late 2005. Two of the 3.0-cm-period devices and the 3.5-cm-period device will be installed in December of 2005.

A 2.2-cm-period device is being considered for the next design. An upgrade to the current design, which allows positive retention of large iron magnetic shims used for tuning, is in progress. The magnetic measurement results for the first three undulators are summarized below.

Magnet Period (cm)	2.7	3.0	3.0
Number of Periods	88	79	79
Measured Gap (mm)	10.5	11.0	11.0
Length (m)	2.4		
Max. Field, B_{peak} (T)	.722	.758	.756
Max. Field, B_{eff} (T)	.707	.741	.739
Deflection Parameter, K_{eff}	1.784	2.076	2.070
rms Phase Errors (°)	3.97	4.07	4.16

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