NEW CONCEPTS FOR REVOLVER UNDULATOR DESIGNS*

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Abstract

Dynamic support of revolver undulator magnet structures presents a challenging mechanical problem. Some designs to date employ a support span connected at its ends to the undulator gap separation mechanism [1]. However, this arrangement is problematic for long undulators operating at small gaps since the gap-dependent distortion of the magnet support span scales approximately with the cube of its length and exponentially with reduction in gap. Other designs have been demonstrated that utilize intermediate connections to a central magnet support span, but require additional stiffening members between that span and the magnet arrays [2]. This arrangement is difficult to implement at the APS because of space constraints imposed by existing beam vacuum chambers. We have developed three revolver undulator concepts that provide an extremely rigid magnet support structure, precise rotational positioning, and wide gap tapering ability. Each of the concepts has advantages and disadvantages. All of the concepts are fully compatible with the existing APS-designed gap separation mechanism, which will greatly simplify testing and implementation. All three of the concepts will be prototyped toward developing a final design to be installed at a number of sectors in conjunction with the APS upgrade.

INTRODUCTION

Implementation of a revolver undulator at the APS is subject to constraints imposed by a desire to preserve existing insertion device conventions including 2.4-m-long undulator length, vacuum chambers with large ante-chambers for NEG pumping, and tapering angles as large as 2 mrad. In addition, it was decided that existing magnet structure and mounting hardware designs would be accommodated by an APS revolver to allow existing magnet sets to be recycled. Achieving these constraints requires simultaneous optimization of undulator rigidity and compactness. Indeed, to match the performance of existing conventional undulators at the APS, the load-dependent deformation of the magnet support plane must be less than 25 µm under 22 kN of magnetic loading. As a result, wholesale adoption of revolver designs developed at other lightsource facilities for use at the APS is precluded; a new or modified scheme is needed. Because of the large contribution revolver undulators are expected to make in the APS Upgrade project presently underway, three independent design efforts have been commissioned. Each preserves the existing APS-designed gap separation mechanism and undulator support frame designs and therefore aims to simply design a new undulator "jaw" that allows automated selection between two distinct magnet structures. However, each relies on a different scheme to satisfy the given constraints and so presents distinct advantages and disadvantages. In this paper, basic features of each of the designs will be presented along with perceived strengths and weaknesses.

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APS REVOLVER CONCEPTS

Concept 1

APS revolver concept 1 is shown in Figure 1. This design utilizes a solid 2.4-m-long aluminum strongback to which a series of radiused aluminum shaft saddles, spaced approximately 100 mm apart, are attached. A 100-mm-diameter, non-rotating, stainless steel shaft is bolted to these saddles with a bronze sleeve bearing placed between each saddle. The rotating magnet support portion of the revolver jaw is formed by a long aluminum block into which an axial circular bore is made. Along one long corner of the block, a series of cuts are made creating a comb-like structure to provide clearance with the shaft saddles. The comb is also cut open at the corner so that the magnet support can be slid lengthwise onto the shaft with the shaft saddles passing though the opening. Rotational drive is provided at both ends with either a pneumatic linear stage and a rack-and-pinion connection or a "Geneva drive" utilizing a geared-down stepping motor.

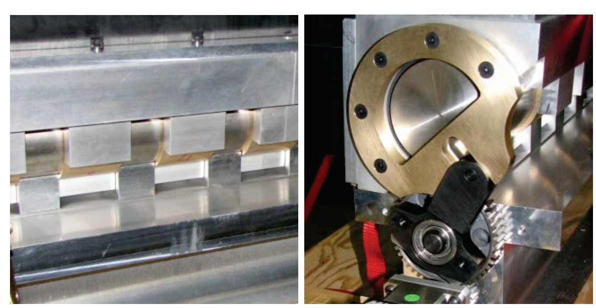

Figure 1: APS revolver concept 1.

Because the revolver jaw is so compact, a high degree of rigidity is achieved with a minimum consumption of vertical space. In addition, only part of the jaw rotates, minimizing the clearance required to rotate magnet structures. Because of the large number and close spacing of the connecting bearings between the non-rotating and rotating halves, the jaw essentially deforms as one body, and there is negligible sagging between the bearings. Finally, because of the simplicity of its construction, the revolver jaw is inexpensive to fabricate, assemble, and maintain.

The design also possesses some challenges. First, proper alignment of the bearings is determined by the precision of the fabrication process, namely the long circular cut that must be made in the rotating block. The continuous depth by which such a cut may be made with required precision is limited. The rotating block for the 2.4-m-long undulator will be made from three sections that will be united into one body by the plates that hold the magnets and pole pieces. Proper clearance between the rotating shaft, bearings, and rotating blocks will be chosen to allow assembly, satisfy required tolerances, and stay within allowable drive torque. A gap between the bearings and the shaft introduces some indeterminacy in the location of the axis of rotation since the subset of bearings that define that axis may change with loading condition. However, it should be noted that the high degree over-constraint provided by the large number of bearings may make the extent of this indeterminacy negligible. Finally, because the rotating and non-rotating portions are so closely packed, there is no room between them to place a drive mechanism, so rotation must be driven at one end or driven in a synchronized manner at both ends. Drive mechanisms will initially be placed on both ends, and during prototyping it will be determined if driving from only one end is sufficient.

Concept 2

Concept 2 for an APS revolver undulator is shown in Figure 2. This design incorporates a non-rotating, double I-beam, stainless steel strongback to which a series of conventional pillow block bearings are fastened. Vertically, the pillow blocks may be adjusted by grinding of a phosphor bronze spacer plate located between the bearing flange and the strongback. The pillow blocks are also adjustable horizontally by use of three “pusher” screws. Each pillow block utilizes a sleeve bearing made of sintered bronze impregnated with radiation-resistant oil. The bearings support a freely rotating stainless steel shaft, 57 mm in diameter, which spans the full length of the undulator. Using precise ID and OD grinding on the bearings and shaft, respectively, the running clearance for the bearings is held to between 13 and 50 microns to limit indeterminacy of the rotation axis. The same grinding processes are used to control circularity of bearing and shaft surfaces to less than 5 microns to ensure that binding does not occur with the small running clearances. Onto the shaft are clamped six two-piece aluminum blocks that are radiused along one corner to provide clearance with the strongback during rotation. Because the blocks are clamped on, there is no need to machine key slots into the shaft, which would introduce internal stresses and compromise the straightness of the shaft. Eight pre-loading devices are used to push between the clamping blocks and the strongback to eliminate any motion of the shaft that may occur inside the bearings as a result of changing magnetic load. The necessity of the pre-loading devices and their number will be determined during prototyping of the design. Finally, two aluminum plates, approximately 25 mm thick, span the series of clamping blocks, providing a uniform surface on which to attach the undulator magnet structure assemblies.

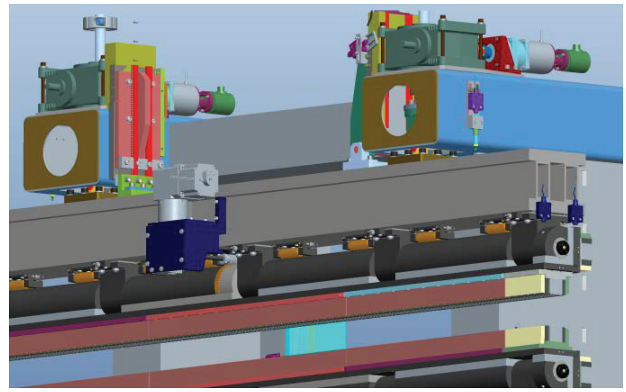

Figure 2: APS revolver concept 2.

The basic scheme of a distributed array of bearings is similar to that successfully utilized in a design developed for SPring-8 [3]. However, by also providing space between the strongback and the rotating portion of the jaw, pre-loading devices and a centrally located drive system are accommodated. The adjustable nature of the pillow block bearings allows the bearings to be precisely aligned so as to minimize friction due to misalignment. In addition, because the bearing positions are adjustable, only a small subset of the components requires rigorous tolerances during fabrication. Finally, the modular nature of the design permits any sub-assembly to be independently redesigned if it is determined to be inadequate during the prototype phase.

The primary disadvantage of revolver concept 2 is cost. Clearly, more parts are required than concept 1. Also, because a considerable amount of the allowed jaw height is consumed by the space between the strongback and the rotating portion of the jaw, the strongback cannot be aluminum, but must be a material with a greater elastic modulus. Further, for concern of magnetic effects and corrosion in load-supporting tapped holes, stainless steel is preferred over common carbon steel. Stainless steel is not only expensive of itself, but additional cost is incurred by needed stress-relieving operations on the post-welded and post-machined strongback, else natural relief of stresses may cause gradual distortion of the magnet-mounting planes.

Concept 3

Concept 3 is depicted in Figure 3 and shares features with a design developed at the ESRF [2]. This design is fundamentally different than concepts 1 and 2 in that the rigid support is provided solely by the rotating portion of the jaw. The magnet support is essentially a single aluminum block, two adjacent sides of which are used for mounting magnet structures. On the opposite two faces

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of the block are mounted four radiused profile rails that travel inside matched trolleys that are fixed to a pair of short box-like supports; these, in turn, attach the jaw to the gap separation mechanism. A single, centrally located, worm gear connection powered by a geared-down stepping motor provides rotation.

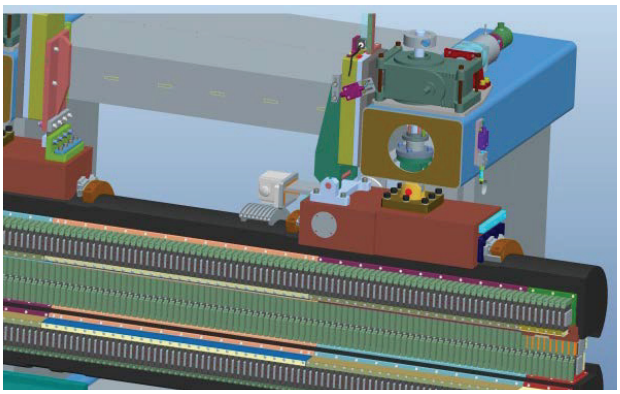

Figure 3: APS revolver concept 3.

Like the others, this approach has distinct advantages and disadvantages. Because all of the required rigidity is provided by the rotating magnet support, no significant distortion of the magnet-mounting planes will result from play in the rotational bearings. In addition, the rotating magnet support has a high degree of torsional rigidity that permits more accurate rotational positioning of the long array of magnets and poles using a single drive location. Furthermore, the magnet support is attached to the gap separation mechanism in four locations which relieves the need somewhat for rigidity in that member. Finally, because of the small number of parts and limited complexity of the design, it is expected to be economical to manufacture.

The primary drawback of this design is that the cross section, and therefore the stiffness, of the rotating magnet support is severely limited by the given space constraints; it cannot be made beyond certain dimensions without an interference occurring between the magnet structures and the insertion device vacuum chamber. Furthermore, unlike schemes incorporating a non-rotating strongback, this member must provide full stiffness in two orthogonal orientations. Finally, like the other designs, the rotation axis is over-constrained because there are more than two rotary bearings. This adds to the loading that each bearing must support, increasing friction. Also, even though gap-dependent distortion of the magnet-mounting surfaces due to play in the bearings is minimized because full rigidity is provided by the rotating member, net motion of the entire rotating magnet support as permitted by bearing play will result in some degree of gap tapering.

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