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A NOVEL ATTEMPT TO DEVELOP A LINEAR POLARIZATION ADJUSTABLE UNDULATOR BASED ON MAGNETIC FORCE COMPENSATION TECHNOLOGY *

W. Zhang†, Y. Zhu, Shanghai Institute of Applied Physics, CAS, Shanghai, China

Abstract

A linear polarization adjustable undulator is proposed in this paper. This undulator can reach 1.5T magnetic peak field with a period length 68mm and magnet length 4m. By adding two repulsive magnet arrays beside centre array the magnetic force between girders can be reduced from 70kN to near zero. Such an approach can result in a significant reduction of the undulator volume, simplification of the strong back design and fabrication. By means of rotating through the centre of undulator we can achieve magnetic field from vertical orientation to horizontal orientation. The linear polarization of radiation can be adjusted between zero and 90 degree.

INTRODUCTION

In majority of linear polarized PM undulators operating in synchrotrons and FELs, magnetic field strength is controlled by varying the gap between magnet arrays by moving arrays in vertical plane. Usually, arrays are mounted using rails on C-shape strong back. The C-shape enables lateral access to magnetic field region. Because of magnetic forces between arrays are very strong and required precision for the gap control is very high, the strong back structures must be extremely rigid. To provide such rigidity, these structures are usually built with massive and heavy components. As a result, gap varying undulators are very large, heavy and quite expensive.

There are three different method have been developed to cancel the attractive force [1-5]. One is the mechanical system composed of a number of springs having different lengths and coefficients attached to the both sides of the main magnets, which was applied to an in-vacuum wiggler developed at Synchrotron SOLEIL and SSRF for CLS. Spring-8 suggested that adding magnetic system composed of two rows of magnet array generating a repulsive force attached to the both sides of the main magnets. None of them led to a reduction in undulator dimensions or noticeable simplification of the undulator mechanical system. APS used a custom-designed conical spring system for the dynamic compensation of the undulator magnetic forces and achieved vertically polarized radiation in one 3.4-meter-long undulator prototype [6]. Such an approach resulted in a significant reduction of the undulator volume, simplification of the strong back design and fabrication but needed dozens spring tuning and calibration work.

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† email address : zhangwei3@sinap.ac.cn

Table 1: U68 Specifications

Periodic Length	68 mm
Length/Segment	4.0 m
Number of Periods	58
Maximum Field	1.5 T
Minimum Gap	7.2 mm
Nominal Gap	7.5 mm
Maximum Gap	80 mm
Magnet Material	NdFeB
Magnet Structure	PPM
Beam Deformation	Less than 10μm

In this paper we propose a relative compact undulator design based on Spring-8 suggestion that using repulsive magnet arrays method. Thanks to the magnetic force cancellation for all gap range 7.2-80 mm we design a very compact and thin aluminum alloy girder 80mm thickness as magnet array base beam. The deformation of the beam is just from gravity-induced deformation which is stable 5μm as the magnetic gap changes. The C-shape strong back can be simplified and the whole undulator can be weight loss less than 2t. The undulator mechanical system designed can be rotated around the centre axis. We can achieve magnetic field from vertical orientation to horizontal orientation. The linear polarization of radiation can be adjusted between zero and 90 degree.

CRITICAL DESIGN FEATURES

This U68 has 58 periods with period length 68 mm corresponds to six standard Halbach-type magnet arrays which consist of two centre magnet arrays provided the magnetic field 1.5T and four magnet arrays beside the centre arrays above and below to produce repulsive force. The specification of the undulator is list in Table 1.

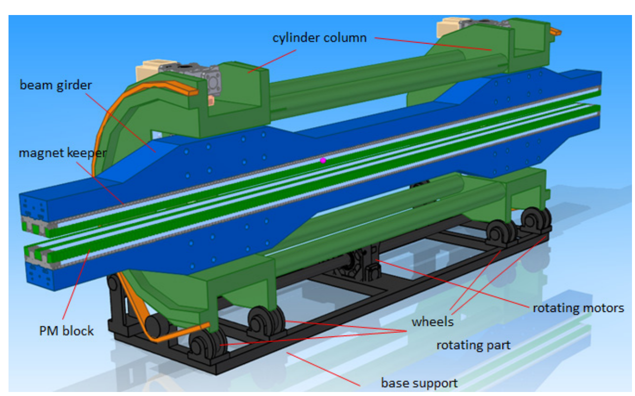

Figure 1: Overview of undulator structure: (1) –cylinder column; (2) -permanent magnet blocks soldered to aluminum keepers (3); (4) – beam girder ;(5) – base support

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and wheels (6); (7) –rotating parts and chain; (8) –servo motors.

The undulator frame is a welded steel structure consists of two semicircular cylinders and five joint rods. The center of two cylinders is designed to coincide with magnetic axis. Supported on one base plate though a set of wheels the undulator can be revolved on magnetic axis, shown in Figure 1.

There are two motors used for gap change. The gap should be adjusted with an accuracy of less than 2µm level. And one motor have to be used for rotating: linear polarization adjustment from horizontal to vertical.

MAGNETIC DESIGN

The magnetic fields for U68 were calculated by RADIA [7]. The usual halbach configuration is adopted. The centre blocks are chosen 45mm ×35mm (width ×height) section with two side mounting cuts, see Fig. 2. The remanence of the NdFeB magnet with grade N40SH is supposed to be 1.28T. At the minimum gap 7.2mm, the effective magnetic field can reach 1.5T, see Fig. 3. The magnetic force between upper and down centre magnet arrays is about 70kN. Therefore additional repulsive force magnet arrays are designed on both sides of centre arrays. After the magnetic force compensation the magnetic force between upper and down arrays can be reduced to zero for all gaps, see Fig. 4.

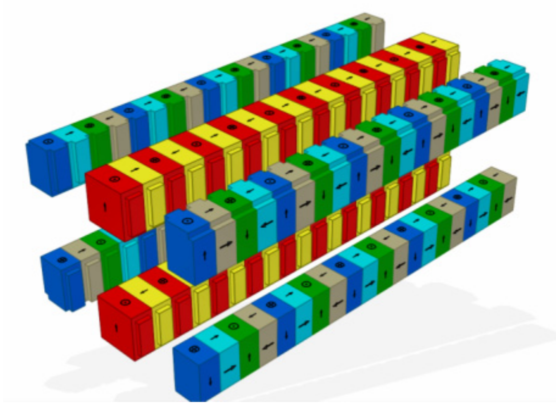

Figure 2: Layout of U68 magnet arrays model.

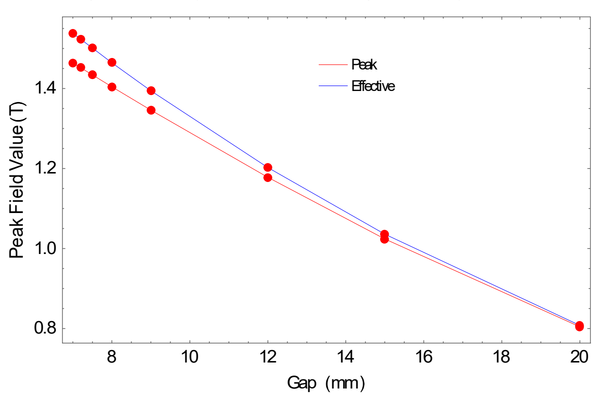

Figure 3: The effective peak field values vs gaps.

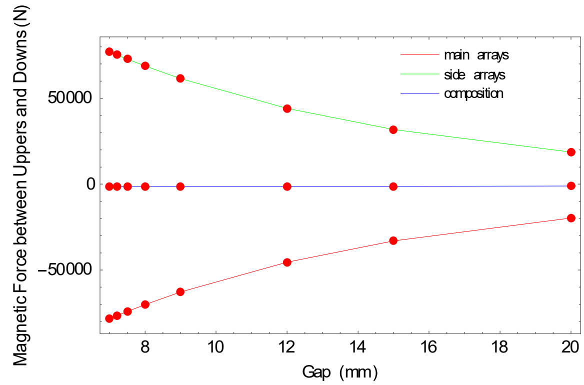

Figure 4: The magnetic force for different gaps: red represents for centre magnet arrays attractive force, green represents for repulsive force from side magnet arrays, blue line acts as composition of forces.

STRUCTURE

Figure 5 shows a closer view of magnetic structure details. Magnets are mounted to module keepers, made of aluminum alloy to match the thermal expansion characteristics of the beams. Each magnet keeper mounts three magnets together and be fixed to beams which allow for magnetic tuning by keeper height adjustment and rearrangement technique based on flipping and swapping keepers. Keepers are precisely located along the beam direction by pins to maintain precise periodic spacing.

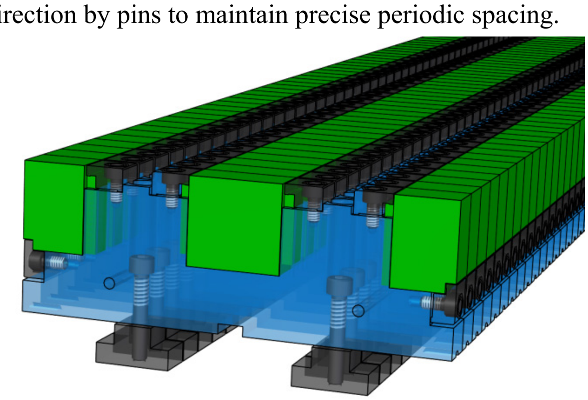

Figure 5: Magnet keeper configuration.

The magnetic attractive force between the top and bottom magnetic structures is very tiny in this undulator. In horizontal polarization mode the constant gravitational force acts gap variation in the same direction as the magnetic force for the top beam, but is opposite for the lower beam. In vertical polarization mode only the magnetic force acts gap variation. To weightless and ensure the rigidity of beams is very critical in mechanical design. Figure 6 shows the simulation results of upper and down beam in horizontal polarization mode. The maximum deformation is about 5.2µm for each beam mostly origin from beam gravity and have the same direction. The gap variation along the undulator is not to exist. And in vertical polarization mode the gap variation is inconsiderable also is shown in Fig. 7. Most of the deformation is in

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gravity direction perpendicular to gap direction, nearly same for two beams.

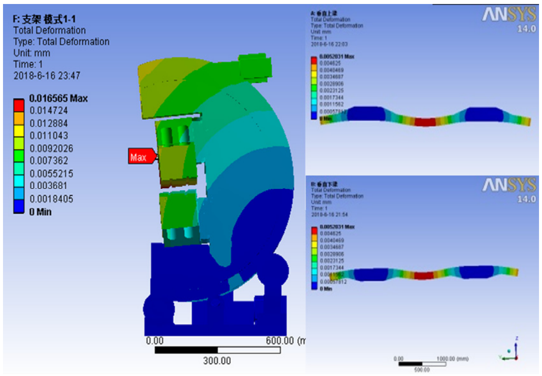

Figure 6: FEM analysis of upper beam deformation (left) and down beam deformation (right) in horizontal polarization mode.

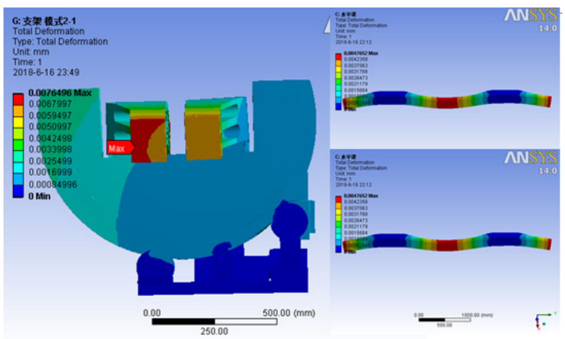

Figure 7: FEM analysis of beam deformation in vertical polarization mode: most of the deformation is in gravity direction perpendicular to gap direction, nearly same for two beams.

Table 2: U68 Beam Deformation Calculation

	Conventional		Proposed
Material	Al.	C.ST	Al
Width (mm)	150	150	150
Length (mm)	4	4	4
Heigth (mm)	600	400	80
Magnetic Force (kN)	70	70	0.2
Weight (kN)	10	19	1
Deformation			
Magnetic force (µm)	11	11	<1
Gravity (µm)	2	3	5
Top beam (µm)	13	14	5
Low beam (µm)	-10	-8	5
Gap Variation	22	22	5

Table 2 gives an approximate calculation with two-point support model for 4 meter undulator 70kN magnetic force load. To satisfy the beam deformation less than 10µm level, the single beam height should more than 600mm for aluminum alloy, or 400mm for carbon steel. In the case of conventional undulator, the supporting structure is formed by strong-back made of steel base plate and two large aluminum or steel beams supporting magnet arrays. The whole structure is approximately more than 2.0 m high, 1m wide, 4.0 m long and has approximately weight of more than 8000 kg. However, in our proposed the whole structure can be much more compact: 1.0 m high, 0.6m wide and weight reduction less than 2000 kg.

CONCLUSIONS

This paper proposes the design of a linear polarization adjustable undulator based on magnetic force cancellation method. Compared to usually designs in FELs this design gives a much more reduction of beam girder height due to magnetic force load cancellation, thence we can weightless the whole mechanical structure and support to less than 25%. With a rotary mechanism design the linear polarization radiation can be adjusted that gives a great convenience for undulator design and is very attractive for facility photon users.

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