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NEW SOURCE FOR BENDING MAGNET BEAM LINES AT ULTRA-LOW-EMITTANCE RING

M. Abbaslou†1, M. Sedaghatizadeh[1], F. Saeidi[2], J. Rahighi[2], S. Dastan[2]
[1]Department of Physics, Khaje Nasir Toosi University of Technology, Tehran, Iran
[2]Iranian Light Source Facility (ILSF), Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

Abstract

The Iranian light source facility (ILSF) is a 3 GeV 3rd synchrotron radiation laboratory in the basic design phase. The Storage Ring (SR) is based on a five-bend achromat (5BA) lattice, providing low horizontal emittance of 0.27 nm.rad. Due to the ILSF storage ring straight section limits, the use of short length wigglers for hard X -ray generation is recommended. This paper describes the magnetic design and optimization of the 3-pole wiggler for ILSF. The 3D modeling and flux calculations have been carried out by the Radia and SRW Codes, respectively.

INTRODUCTION

The Iranian Light Source Facility (ILSF) is a new synchrotron radiation light source in the Middle East, with 400 mA stored beam current operating in top-up mode. The circumference of the storage ring (SR) is 528 m and the horizontal electron beam emittance is 0.27 nm.rad. The ILSF storage ring is based on a five-bend achromat (5BA) lattice. The main parameters of the lattice including the bending magnet specification and beam sizes are listed in Table 1.

The more number of bending magnets per cell, the lower magnet field and then the smaller emittance of lattice, but it is however in conflict with the hard X-ray demand from bending magnets source (BM). The critical energy of 3.35keV of these dipoles would be useful for several experiments in the soft X-ray regions but it is not applicable for hard X-ray experiments. In order to avoid this limitation, the ILSF team has proposed two solutions of utilizing super-bend magnets and short insertion devices. For the ILSF, these solutions would be superior to additional insertion devices. The first solution, the SR lattice in the presence of the super-bend magnet and detailed magnetic design, have been described in Refs.[1] and [2], respectively. In the second solution, a short insertion device would be applied adjust to the dipole magnets as a new source in each super-period of the ring which would be presented in this article.

Table 1: Main ILSF Storage Ring Parameters

Parameter	Unit	Value
Energy	GeV	3
Maximum beam current	mA	400
Lattice structure	-	5BA
Number of super period	-	20
Natural emittance	nm.rad	0.27
Length of straight Section	m	7.021
Beam size at straight section x/y	μm/μm	69/3
Beam size before central dipole x/y	μm/μm	12/4
Natural energy spread	-	6.98×10^{-4}
Natural energy loss per Turn	keV	433.9
Dipole field	T	0.56
Radiation power from di poles @ 400 mA	kW	214.390
Radiation integral, I_1	m	9.63×10^{-2}
Radiation integral, I_2	1/m	3.56×10^{-1}
Radiation integral, I_3	$1/m^2$	2.02×10^{-2}
Radiation integral, I_4	1/m	-1.35×10^{-1}
Radiation integral, I_5	1/m	1.01×10^{-5}
Beta function at straight section ($\beta x/\beta y$)	m/m	17.787/ 3.294

The photon flux of the 3PW and bending magnet have been shown in Fig. 1. The figure is directly produced by the SRW code.[3] The 3PW flux spectrum is the same as the BM it just has shifted to higher energies. This dipole source is inadequate for the hard X-ray beam lines for energies above 10 keV. Hence, the 3PW can be an acceptable source instead of the ILSF low field dipole magnet.

The 3PW is designed as a source for hard X-rays beam lines such as powder diffraction and macromolecular crystallography, which the required flux and energy are 10^{12} Ph/s and 6-30 keV, respectively.

The lack of straight sections is a significant issue in the ILSF machine, since there will be totally 17 free straight sections for insertion devices (IDs).

† minaabbaslou@mail.kntu.ac.ir

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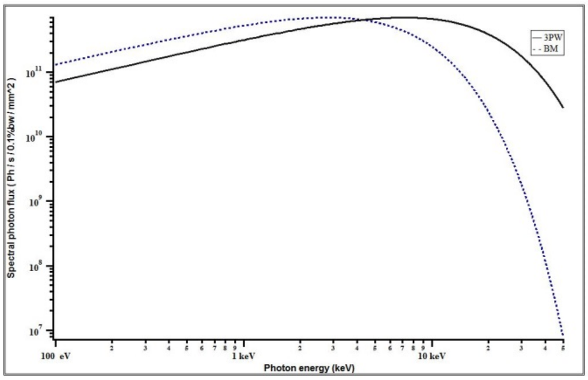

Figure 1: Photon flux generated by a 400 mA, 3 GeV electron beam for 0.56 T bending magnet (dotted black) and 1.5 T 3PW (dark blue). (Fan angle = ± K/γ = 0.005).

The 3PW provides high capacity, serving up to 20 beam lines in the ILSF storage ring, while their fabrication cost is lower than long IDs and dipole magnets. Because of the smaller electron beam spot size, the super bends make available higher flux density than an ID, which is desirable from a scientific point of view. The total radiation power of the 3PW beam line is significantly smaller than the ID beam line, which results to save energy. Therefore, the 3PW magnet is chosen as a new dipole source instead of the ILSF lattice central low-field dipole. Hence, in this paper, ILSF has investigated this short wiggler in the SR lattice. The 3PW will be placed adjust the central dipole of the cell as shown in Fig. 2.

The girder of the central dipole magnet is individual to place the 3PW or the super bend magnet easily in the lattice. Since the space between the central dipole (BE2) and the sextupole magnet, is limited to 48 cm, the length of the 3PW selected 25 cm considering the vacuum equipment's.

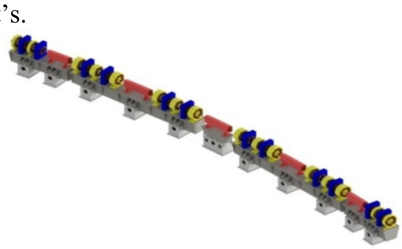

Figure 2: The arrangement of the magnets in one su-per-period of the ILSF storage ring lattice. The blue, red, and yellow colors demonstrate dipole, quadru-pole and sex-tupole magnets, respectively.

MAGNETIC DESIGN

The users are proposed to have flux of 10^{12} Ph/s, beam of 0.01−10 mm^2 and energy of 6-30 keV for several beam lines. It seems the magnetic field higher than 1.5 T could satisfy the users' requirement for dipole sources.

A hybrid structure with side magnets, permendur center pole and low carbon steel end poles has been chosen for the new dipole source insertion device. Soft iron poles are significantly cheaper than permendur but produce slightly lower field. The NdFeB permanent magnet (with Br=1.18 T and intrinsic coercive force of 1400 kA/m) is utilized to produce a magnetic field and to get the highest possible peak flux density it was chosen the Vanadium Permendur material with equal amount of Co and Fe and about 2% V. The material has a saturation magnetization of 2.35 T compared to 2.1 T for pure Fe.

Figure 3 shows a view of the designed 3PW in simple and wedge models by RADIA code[4], respectively. The peak magnetic field differences in both cases are not so much. So, the simple design is chosen by mechanical considerations.

Vertical magnetic flux density is displayed in Fig. 4 at the gap of 26 mm whose peak field is 1.47 T at the center of the gap.

The beam dynamic requirements determine ± 6 mm horizontal Good Field Region (GFR) that is based on the SR lattice and is a result of the dimensions of magnet blocks. Additionally, the desired transverse roll-off specifies the magnetic field uniformity along the transverse of insertion devices. More uniform transverse roll-off function results in the stability of the beam; thereby the undesirable magnetic multipoles integral distribution will be diminished.

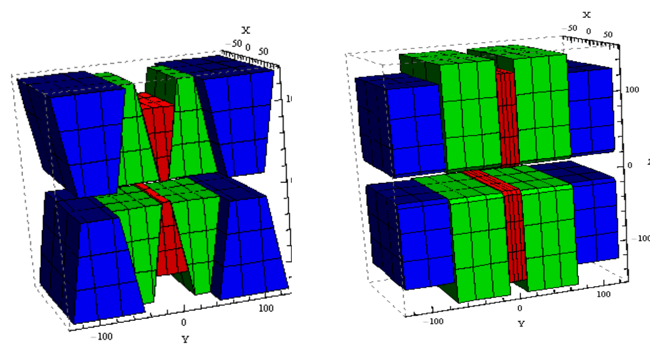

Figure 3: Magnetic structure of the 1.5T simple & symmetric wedged pole 3PW.

Calculated transverse roll-off of the wiggler is shown in Fig. 5 The magnetic field deviation from the central field is less than 1% in the GFR.

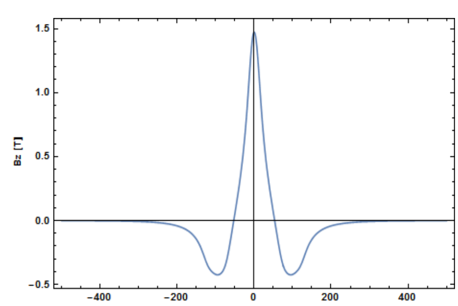

Figure 4: Vertical component of the magnetic flux density Bz at the centre of the gap.

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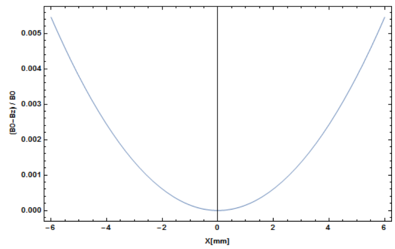

Figure 5: The transverse roll-off of the designed 3PW for gap of 26 mm. (Field homogeneity map: |Bz(0)-Bz(x) / Bz(0)|).

Figure 6 shows the primary mechanical design of an array with aluminium fixation parts. There is a 5 mm chamfer at the corners of magnet blocks due to the mechanical clamping and the reduction of magnetic fields [5].

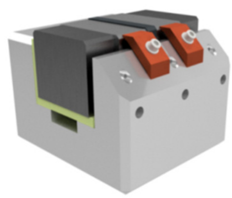

Figure 6: The mechanical structure of an array of the ILSF 3PW.

FIRST AND SECOND FIELD INTEGRALS

The period of the wiggler, on axis maximum flux density, and the transverse roll-off depend on the thickness, height, and the width of the magnet, respectively.

Although the primary block dimensions of IDs are determined by the required good field region (GFR= 6 mm) and transverse roll-off, the effects of magnetic field on beam dynamics of electron should be reduced by the field integrals and blocks sizes.

In order to achieve null first and second field integrals, the 3PW blocks dimensions have to be optimized. The selected merit function is the summations of squares of the first and second field integrals (Eq.1).

$$I = \left(\frac{e}{\gamma m_0 c}\int B_z dy\right)^2 + \left(\frac{e}{\gamma m_0 c}\iint B_z dy' dy\right)^2 \qquad (1)$$

Where e and m_0 are charge and rest mass of an electron, γ is the relative energy (E/E0) and c is the velocity of light.

The magnetic field effect of an ID on the exit angle and position of the electron beam is evaluated by the first and second field integrals, respectively that must be decreased to zero [6]. The main optimized parameters of the ILSF 3PW are listed in Table 2.

Figure 7 shows horizontal angle (first field integral) and Fig. 8 shows trajectory (second field integral) of the electron in the optimized wiggler along Y axis where the electron is travelling. The maximum opening angle is 6.6 m·rad.

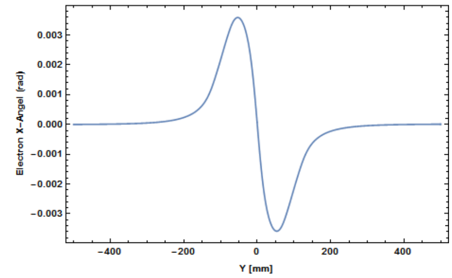

Figure 7: Horizontal angle along the 3PW at the centre of the gap.

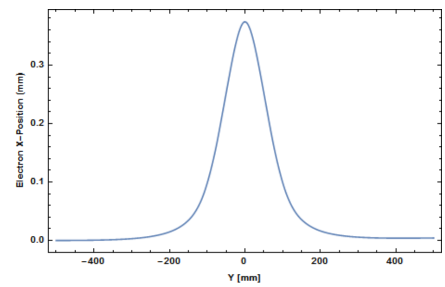

Figure 8: Horizontal trajectory of electron along the 3PW at the centre of the gap.

Table 2: Results of the Magnetic Design of the ILSF Three-pole Wiggler

Parameter	Unit	Value
Peak field on axis (Bz)	T	1.47
The deflection parameter, [K]	-	33.61
Minimum gap	mm	26
Total length	mm	250
Pole material	-	Vanadium Permendur
PM material	-	NdFeB
Remanent field	T	1.18
Total number of full-size Poles	-	6
Total number of full-size PM block	-	4
Main PM block dimensions	mm^3	140x60x135
Main pole dimensions	mm^3	140x20x120
Side pole dimensions	mm^3	125x55x110.5
First field integral	T.m	8.4×10^{-5}
Second field integral	$T.m^2$	4×10^{-5}
Force at 26 mm gap	N	3658.05

CONCLUSION

Due to the ILSF storage ring straight section limits, the needs of users to X-ray radiation, short length wigglers for hard X -ray generation is recommended. The first 3PW for the ILSF has been designed magnetically and mechanically. This magnetic design will be used for construction of a prototype model of a 3PW for hard x-ray application and we hope to report it in future conferences.

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