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EFFECT OF THE ELECTRON BEAM EMITTANCE ON THE ILSF RADIATION OF SOURCES AND THE BEAMLINE DESIGN

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Abstract

In this paper the effect of emittance on the relevant issues of the synchrotron radiation sources, optics and beamline design for two values of emittance, ε_x=3.278 and 0.937 nm.rad, suggested for the Iranian Light Source Facility lattice design, have been discussed. The effect of spot size and divergence of the electron beam, and strength of the bending magnet field, have been considered in the calculations. The results show that reducing of emittance, increases the brilliance of the undulator by factor 5, and decrease the foot print on the optical elements and spot size of photon beam on the sample by a factor of about 2.

INTRODUCTION

For a variety of experiments especially when we are facing with lower spot size and divergence and high flux, users need higher brilliance. The optics part of the beamline has its limitation for optimizing of these values. So one of the best ways, is to reduce the emittance. The brilliance increases by reducing the emittance and the spot size of the beam. Especially because the Iranian Light Source Facility (ILSF), 3 GeV machine and 400 mA electron current, is designed to be used for the next decades [1] and due to the trend of the experiments to smaller sample size [2], the reduction of emittance would be very useful for the ILSF users. Cutting the photon beam by slit for reducing the spot size in the sample position reduces the photon flux, so it is not an appropriate way to decrease the spot size. In addition decreasing of the emittance improves the quality of light, such as increasing of resolving power or having smaller and more qualified optical elements. In the following effect of the electron emittance on the size, divergence and brilliance of the photon beam in the Bending Magnet (BM) and Insertion Devices (ID) have been investigated. Calculation and ray-tracing to find out role of emittance on the beamline design also have been performed.

SOURCE OF BEAMLINE

Source Size and Divergence

The spot size (σ_r) and divergence (σ'_r) of the photon beam at the source is derived from the reference [3] for BM of ILSF and and a typical ID. Total spot size ($\sum_{x(y)}$) and divergence ($\sum'_{x(y)}$) by considering the spot size ($\sigma_{x(y)}$) and divergence ($\sigma'_{x(y)}$) of the electron beam and analytical formula [4] could be calculated in both x and y directions.

Table 1: Total spot size and divergence of the beam in BM source for both values of emittance in high (1.42 T) and low (0.72 T) filed for E=1 keV and 1.5 mrad acceptance angle.

ε_x(nm.rad)	0.937	3.278
B(T) (E_c (KeV))	0.72 (4.3)	1.42 (8.5)
$\sigma_x \times \sigma_y$ (μm^2)	26.27 × 15.13	46.6 × 25.13
$\sigma'_x \times \sigma'_y$ (μrad^2)	44.1 × 0.67	87.6 × 1.37
$\sum_x \times \sum_y$ (μm^2)	26.27 × 15.13	46.6 × 25.13
$\sum'_x \times \sum'_y$ (μrad^2)	1500× 175	1500 × 230

For BM and for E=1 keV (and not far from Ec) $\sum x(y) \sim \sigma x(y)$. So, the total spot size of the photon beam is also reduced by reduction of emittance by a factor of about 1.75. Because of $\sigma' x(y) << \sigma' r$ the dominant effect on $\sum' x(y)$ comes from the BM field not from the emittance. In the case of an undulator, the wavelength of radiation and the insertion device length are two important factors that determine the size and divergence of the photon beam. For two lengths of insertion device and two photon energies, E= 1, 10 keV total spot size and divergence of the beam have been calculated and gathered in Table 2.

The total horizontal beam size is limited by the electron beam in the whole energy range. It is reduced by 1/2.7 in the emittance 0.937 nm.rad compared to the 3.278 nm.rad.

Table 2: Total spot size and divergence of the beam in undulator source for both values of emittance for two length=2, 6 mand for E=1, 10 keV.

ε_x (nm.rad)		0.937		3.278	
$\sigma_{,x} \times \sigma_y$ (μm^2)		57.87 × 3.25		156.18 × 6.85	
$\sigma'_{,x} \times \sigma'_y$ (μrad^2)		28.45 × 2.87		37.07 × 4.77	
E (KeV)		1	10	1	10
L=2 m	$\sum_x \times \sum_y$ (μm^2)	57.15 × 5.23	57.01 × 3.50	156.23 × 7.98	156.2 × 6.97
	$\sum'_{,x} \times \sum'_y$ (μrad^2)	37.33 × 24.34	29.45 × 8.16	44.26 × 24.64	37.85 × 9.01
L=6 m	$\sum_x \times \sum_y$ (μm^2)	57.41 × 7.60	57.04 × 3.91	156.33 × 9.70	156.20 × 7.19
	$\sum'_{,x} \times \sum'_y$ (μrad^2)	31.88 × 14.67	28.81 × 5.38	39.77 × 15.16	37.35 × 6.59

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The total vertical beam size is mainly determined by the diffraction limit at low energies (E< 3000 eV), so it is depend on undulator characteristics and photon energy. But at E> 3000 eV the vertical total beam size is determined by the electron beam. The source divergence is also energy dependent because of the diffraction limit. Horizontal divergence is diffraction limited only at low energies, so it is limited by the electron horizontal divergence above ~3000 eV. In the vertical plane, the source divergence is diffraction limited at the whole energy range.

Brilliance

Brilliance of a source is a very important parameter of the photon sources in synchrotron facilities. It is defined as a photon flux divided by cross section of spot size and divergence of the electron beam in 0.1% of photon band width.

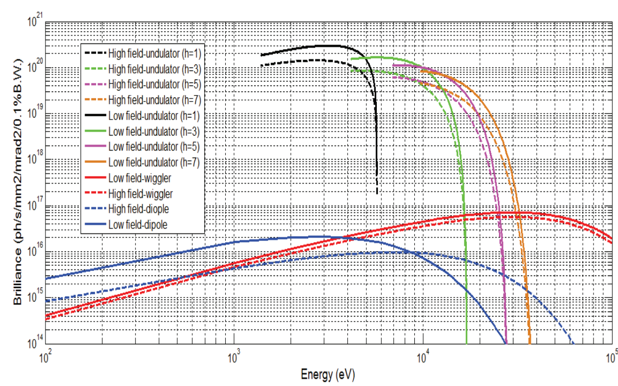

Figure 1: brilliance of BM, undulator and wiggler for high emittance=3.278 nm.rad (solid line) and low emittance=0.937 nm.rad (dash line) by SPECTRA [5].

Figure 1 shows the results of the four first odd harmonics of undulator in both values of emittance (gap=16 mm, λ_p=15 mm, N=153, B=1.08 T, K=1.5251, L=2.3 m.). characteristics of The brilliance for each harmonic and around the highest brilliance is increased by a factor of about 5 in low emittance case, which can be an important factor for users. In the wiggler case (K=18.8, λ=48 mm, N=30, gap=14 mm) the reduction of emittance only increases the brilliance by a factor about 1.5 in the maximum brilliance range, which does not make important factor for users. For the bending magnet by simultaneously reducing of the emittance and the magnetic field strength, the brilliance shifts up (by a factor about 3) just in low energies (E<10 keV).

BEAMLINE

In the beamline, effect of the emittance on the Foot Print (FP) on the on the optical elements, the monochromator resolving power, spot size of the beam in some places in the beamline especially at slits or sample position have been investigated by SHADOW code [6]. The calculations have been performed for a typical soft and hard x-ray beamline, Fig. 2 and Fig. 3.

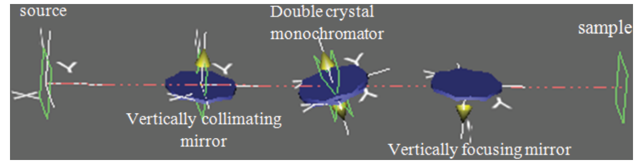

Figure 2: A typical hard x-ray powder diffraction beamline [7] (by Shadow code).

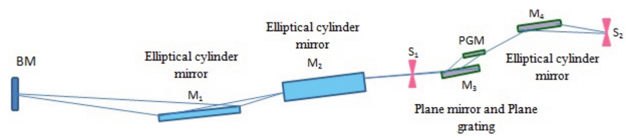

Figure 3: A typical soft x-ray Microscopy beamline.

For soft x-ray beamline, the demagnification of the KB system in horizontal and vertical plane are supposed to be 1/7 and 1/3 respectively. The photon beam properties at the undulator source and the focal plane of the KB mirror is summarized in Table 3. As it can be seen from Table 3, in the same demagnification, spot size on the focal plane in the both directions is reduced, depend on the emitted photon beam characteristics. In the undulator case, the horizontal and vertical size of the photon beam in the mirror's focal plane come down by more than half compared with the emittance 3.278 nm.rad.

Table 3: The spot size at the undulator source and at the focal plane of KB mirrors.

ε_x (nm.rad)	0.937 nm.rad	3.278 nm.rad
Spot size at the source (H×V) μm^2	140 × 12	371 × 24
Spot size at the focal plane of KB mirror (H×V) μm^2	19.4 × 4	53 × 8

The energy resulotion (ΔE) of widely used monochromators of the soft x-ray beamlines have been studied for the two cases of the emittance. There are two important types of grating monochromators in the soft x-ray regime [3]. In the first type, the vertical divergence of the photon beam is reduced by the use of a vertical collimating mirror upstream of the monochromator. By a linear undulator with length about 4.3 m, and above mentioned kind of the monochromators, there is almost no change in the resolving power in the both emittance values because of the same vertical divergence of the photon beam in each emittance approximately. In the second type, an entrance slit upstream of the monochromator is employed to improve the resolution. When the emittance changes from 3.278 nm.rad to 0.937 nm.rad, the resolution is decreased due to decreasing the vertical photon beam size. The rate of resolution reduction also depend on energy and an undulator length, in the higher energies and a shorter undulator length, the

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effect of the reduction of emittance in the resolution is more significant because of determination of the vertical photon beam by the electron beam.

Table 4: The specifications for photon beam in a hard x-ray (powder diffraction) beamline. The source of radiation is considered dipole and undulator (K=1.3114, λ_p=1.8 cm, B=0.78 T, L=2.3 m, N=127, gap=10 m).

	(ε_x=0.937 nm.rad)	**(ε_x=3.278 nm.rad)**
	BM	
Source size (μm^2)	62×35	110×60
Source divergence ($mrad^2$)	1.500×0.196	1.500×0.283
FP on the mirrors (cm^2)	97.05×2.24	142×2.24
FP on the crystals (cm^2)	1.18×2.90	1.70×2.90
Size at the sample (μm^2)	66×35	110×60
Divergence at sample ($mrad^2$)	1.500×0.193	1.500×0.283
Resolution (ΔE/E)	1.04	1.04
	undulator	
Source size (μm^2)	139×7	368×17
Source divergence (μrad^2)	42×24	90×25
FP on the mirrors (cm^2)	12.50×0.06	12.9×0.14
FP on the crystals (cm^2)	0.14×0.08	0.15×0.18
size at the sample (μm^2)	139×7	368×17
Divergence at sample ($mrad^2$)	44×25	99×25
Resolution (ΔE/E)	1.04	1.05

When the source is dipole, the main difference between the low and high field storage ring in view of powder diffraction beamline is the foot print at the optical elements. For instance, the foot print is reduced from 98 cm to 142 cm at the mirrors. However higher heatload at the optical elements becomes more challengeable. For the undulator source, significant difference is in the spot size of photon beam at the source and sample. Therefore by decreasing the size of the electron beam, we will have small photon source and small spot size at sample for same beamline optics design and same demagnification.

CONCLUSION

As a summary the effect of machine emittance on the brilliance of bending magnet and insertion device sources, optics of the beamline in two values of suggested emittance (3.278 and 0.937 nm-rad) for ILSF have been investigated. It has been found that the brilliance of the undulator source is increased by a factor of 5 for all the harmonics in low emittance case, while for wiggler there is no important changes. For bending magnet, due to using lower magnetic field strength in low emittance case, the critical energy and the range of high photon flux shifts to lower energy and brilliance shift up just in E<10 keV. So, it is suggested to change the design such that lower emittance is derived for high magnetic field which has been done in some recent planned synchrotrons. The foot print on the optical elements and spot size of photon beam is reduced by reduction of emittance that has its advantages on the beamline construction and expenses and also for users. Finally by listing some of the wide used experiments and explaining the role of emittance on doing these experimental techniques, we have discussed that ILSF user's community for their future researches need to the smallest value for emittance that is possible from the machine design.

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