PSI-XFEL SENSITIVITY TO BEAM MAIN PARAMETERS AND UNDULATOR FOCUSING

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Abstract

The study of radiation saturation length and saturation power sensitivity to beam main parameters (emittance, energy spread and peak current) at the entrance of the undulator section of PSI-XFEL project is presented. The comparative analysis of the SASE FEL performance with external and natural focusing in undulator section is given.

INTRODUCTION

The PSI-XFEL project [1,2] is aimed to obtain the high brightness coherent radiation in the 0.1-7 nm wavelength range. After injector, the beam is accelerated to the maximum energy of 5.8 GeV. Two bunch compressor sections are foreseen to compress the bunch rms length down to 8.8 μm. The compressed electron beam with 2.7 kA peak current is delivered at different energies 2.1, 3.4 and 5.8 GeV to three undulator sections Athos, Porthos and Aramis to produce SASE FEL (Fig.1). In addition the High Gain Harmonic Generation (HGHG) D'Artagnan beamline at electron energies of 2.1–3.4 GeV seeded with 12nm wavelength external laser is planned.

Aramis undulator will produce linearly polarized FEL radiation with wavelengths starting of 0.1 nm to 0.7nm utilizing electron beam with the energy that can be varied up to 5.8 GeV. Porthos and Athos undulators' radiation fundamental wavelengths are also tuneable within the range of 0.7 – 7.0 nm. They can produce radiation with both linear and circular polarization. The undulator systems should be compact (~70 m) to fit the area anticipated for the construction of the PSI- XFEL facility. In this paper the calculations are based on bunch charge 0.2 nC and 0.4 nm normalized beam emittance, which can be expected from start-end simulations. The undulator sections with different undulator K values (Table 1) are composed of the similar cells with the undulator segment length of 4m and FODO period length of 9.4 m.

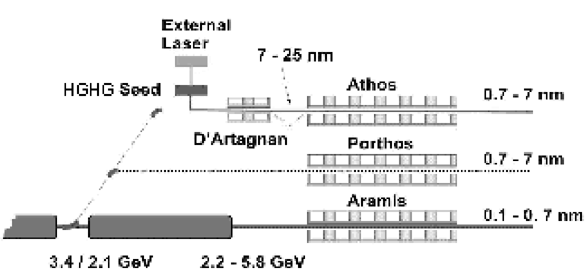

Figure 1: Schematic layout of PSI-XFEL undulator lines.

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The main design parameters of the PSI XFEL project are presented in Table 1.

Table 1: PSI-XFEL main design parameters

	Aramis	Porthos	Athos
Beam Energy [Gev]	5.8	2.1/3.4	2.1/3.4
Wavelength (nm)	0.1-0.7	0.7-2.8 /1.8-7	0.7-2.8 /1.8-7
Undulator K Value	1.2	1-3.2	1-3.2
Period [mm]	15	40	40
Undulator type	Planar/invac.	APPLE II	APPLEII

Two three-dimensional simulation codes SIMPLEX [3] and GENESIS [4] have been applied to study the FEL performance sensitivity to beam main parameters and injection jitter. The SASE FEL performance without external focusing in undulator beamline is studied.

FEL SENSITIVITY TO BEAM PARAMETERS

In the real accelerator the beam main parameters (emittance, energy spread and peak current) differ from the design values due to various types of machine components imperfections. The tolerable beam main parameters budget is an important issue of the facility design study to provide the reliable facility operation. In this section we present the results of our study for the SASE FEL performance sensitivity (saturation length L_{st} and saturation power P_{st}) to beam main parameters in Athos, Porthos and Aramis undulator sections. Fig.2 presents the SASE FEL power growth curve for beam design parameters in Aramis undulator section. At radiation wavelength of 0.1 nm, the saturation length is 60.4m and the saturation power is 6.15 GW.

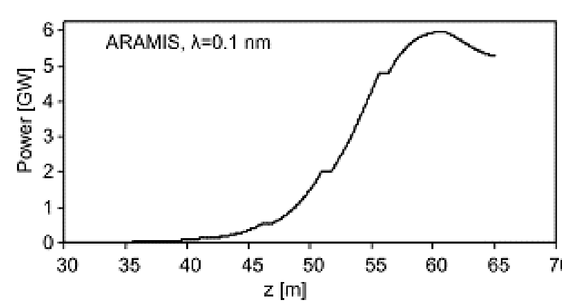

Figure 2: The Aramis SASE FEL power growth curve for beam design parameters.

By means of the SIMPLEX and GENESIS simulations we investigated the behavior of the FEL performance parameters (saturation length and saturation power) when the electron beam normalized emittance varies from 0.36 to 0.8mm-mrad. In Figure 3 the dependence of saturation length and power on electron beam emittance for Aramis are presented. It turned out that saturation length increases by 75% and saturation power decreases by about 75% compared with the design values for Aramis (Fig. 3).

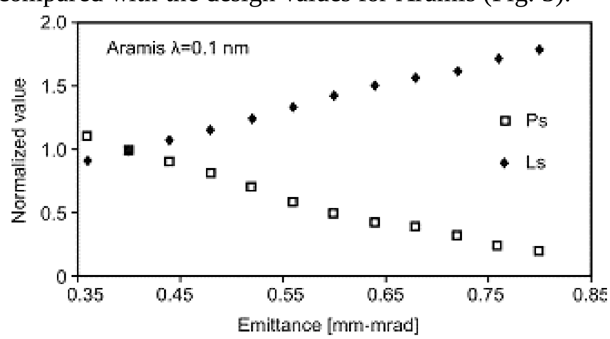

Figure 3: The normalized saturation length (Ls) and power (Ps) dependence on the beam emittance.

The complete results for Aramis, Porthos and Athos undulators are presented in Table 2. The pictures for all the three SASE chains are similar.

Table 2: Change of saturation length and power when emittance varies from 0.36 to 0.8mm-mrad

Undulator	Wavelength [nm]	Sat. Power decrease(%)	Sat. Length increase(%)
Aramis	0.1	75	75
Porthos	0.7	47	77
	2.5	37	60
Athos	1.8	45	75
	6.5	50	55

Saturation length and saturation power dependence on the energy spread have been investigated in the energy deviation range from 0.3 to 1 MeV. For Aramis the saturation power decreases with the increase of energy spread to ~20% of its initial value and saturation length remains about the same.

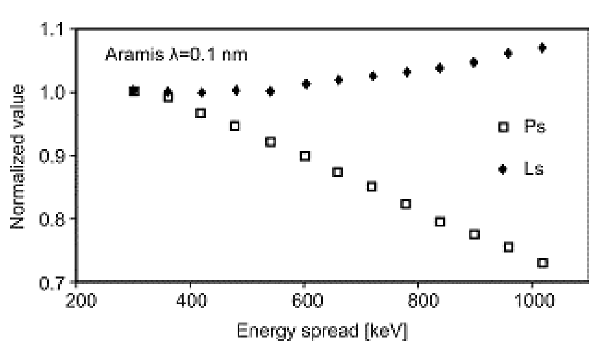

Figure 4: Normalized saturation length (Ls) and power (Ps) dependence on the beam energy spread.

In Figure 4 the behaviour of saturation length and power when energy spread varies is presented. For Porthos and Athos the behaviours are similar.

The simulation results for Aramis, Porthos and Athos undulators sections are summarized in Table 3.

Table 3: Change of saturation length and power when energy spread varies from 0.3 to 1 MeV

Undulator	Wavelength [nm]	Sat. Power decrease(%)	Sat. Length increase(%)
Aramis	0.1	30	5
Porthos	0.7	20	7
	2.5	10	4
Athos	1.8	30	10
	6.5	25	4

Saturation length and power dependence on the peak current for Aramis is shown in Fig. 5. Bunch charge was kept the same, equal to 0.2 nC. With decrease of beam peak current from 2.7 to 1.8 kA saturation length grows by 35% while saturation power decreases by about 50%. For all the undulators the dependence of saturation length and power to the beam peak current is similar.

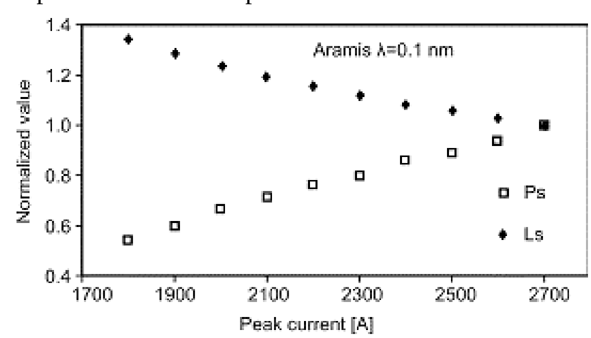

Figure 5: Normalized saturation length (Ls) and power (Ps) dependence on the beam peak current.

The simulation results for all the three undulators are presented in Table 4.

Table 4: Change of saturation length and power when beam peak current varies from 2.7 to 1.8 kA

Undulator	Wavelength [nm]	Sat. Power decrease(%)	Sat. Length increase(%)
Aramis	0.1	50	35
Porthos	0.7	44	35
	2.5	45	28
Athos	1.8	45	30
	6.5	50	30

THE EFFECTS OF INJECTION JITTER

The off-axis electron beam (injection jitter) injected into the undulator section performs the coherent betatron oscillations in external focusing lattice. The SASE process is degraded due to violation of the resonant condition and debunching effect. Fig. 6 shows the power growth curves in Aramis undulator for the beam centroid initial offsets ranging from 0 to 3σ in 0.5σ step, where σ is the injected beam rms transverse size (23nm).

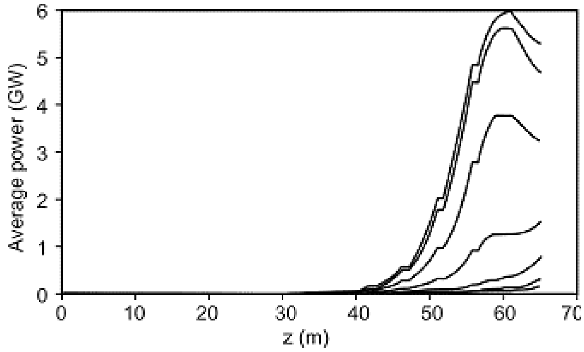

Figure 6: Power growth curves for the beam centroid initial offsets ranging from 0 to 3σ.

As is seen from Fig. 7, with the increase of the beam initial offsets radiation peak power and growth rate diminish rapidly. For one sigma beam initial offset the peak power is reduced by about 40%.

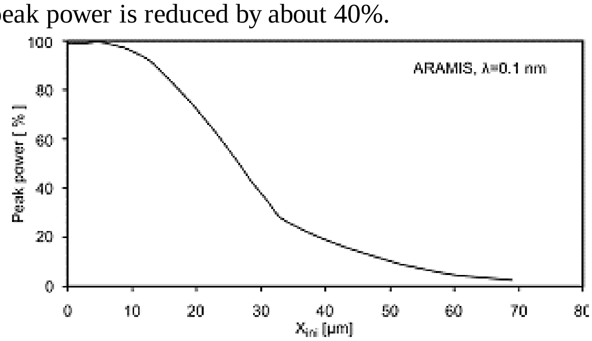

Figure 7: Radiation peak power reduction due to initial spatial offset in Aramis undulator.

SASE FEL PERFORMANCE WITHOUT EXTERNAL FOCUSING

The study of the FEL performance with switching off the external quadrupole focusing in undulator section has special interest to study the misalignment effects caused by quadrupoles. In the commissioning stage, if all quadrupoles are turned off, only so called natural focusing by the undulator field takes place and one gets very interesting results for FEL radiation. In that case the results are worse than the results for the design lattice when quadrupoles misalignment are not taken into account. Note, that the FEL process has a strong sensitivity to quadrupole alignment which can degrade the FEL performance if the tolerance of a few microns are not met. Figure 8 presents the horizontal and vertical beta variations along the Aramis beamline without external focusing.

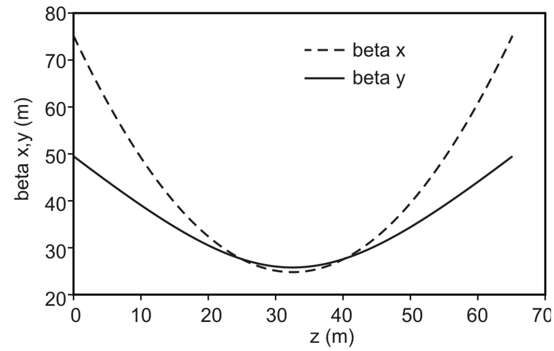

Figure 8: The horizontal and vertical beta functions in Aramis undulator line.

Genesis and SIMPLEX simulations for FEL performance without the external quadrupoles compared to the design value indicate that for Aramis operating at the 0.1 nm wavelength the saturation length remains the same while the saturation power decreases by about 40-50 %. The simulation results for Athos, Porthos and Aramis without external focusing are presented in Table 5.

Table 5**:** SASE FEL performance without quadrupoles

FEL	Wavelength[nm]	P_{max}	L_{sat}
Aramis	0.1	0.52	0.98
Porthos	0.7	0.51	1.06
	2.5	0.88	1.23
Athos	1.8	0.73	1.10
	6.5	0.97	1.12

CONCLUSIONS

PSI XFEL SASE simulations have been done using computer codes SIMPLEX and Genesis.

- The saturation length and power sensitivity to beam main parameters -emittance, energy spread and peak current - for all the three XFEL undulators are studied.
- The injection jitter impact for Aramis is studied that results in 40% radiation power reduction for one sigma initial beam offset.
- Comparative analysis of the FEL performance with and without external focusing is performed. The reduction of radiation power by 40-50% is predicted without the external focusing in comparison with the ideal design FODO lattice arrangement.

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