EFFECT OF MIRROR-TILT ON THE MODE-STRUCTURE IN AN FEL OSCILLATOR

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Abstract

In a hole-coupled FEL oscillator the out-coupled power depends strongly on the resonator configuration and the mirror alignment. Using three-dimensional simulations (GENESIS+OPC), the effect of mirror tilt on out-coupled power is investigated for different resonator configurations and for different radiation wavelengths. For the concentric configuration the out-coupled power decreases monotonically with increasing tilt. For the confocal, this power can actually be higher at some optimal tilt; however, this introduces non-Gaussian, non-axisymmetric modes, which may be undesirable from the user point-of-view. This process of mirror tilt affects the radiation mode profile and the out-coupled power and may be a serious issue for X-FEL oscillators.

INTRODUCTION

In a free-electron laser (FEL) oscillator the out-coupled power depends strongly on the mode configuration at the out-coupling mirror, which in turn depends on the resonator configuration. Stability analysis for a symmetric FEL oscillator was carried out in Ref. 1, where it was found that the FEL interaction changes the resonator stability, so that the exactly concentric and exactly confocal configurations are now stable. However, the concentric is preferred because the mode in this case is close to Gaussian, and hence gives more out-coupled power, whereas in the confocal case substantially non-Gaussian modes can develop. Subsequently [2] the study was extended to asymmetric resonators both analytically and with simulations. The previous work considers no mis-alignment between the two reflecting mirrors which is far from reality. In actual experiments we expect that mirrors will have some mis-alignment, though small, and this could affect the stability of the FEL oscillator. In next section we use three-dimensional simulations to study the effect of tilting the outcoupling mirror on the mode structure of the radiation, for the confocal and concentric configurations and at different wavelengths. We end with a summary and conclusions.

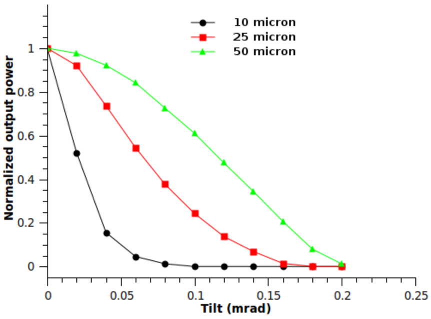
THREE-DIMENSIONAL SIMULATIONS

We performed time-independent FEL oscillator simulations with the codes GENESIS [3], which simulates the FEL interaction, and OPC [4], which handles transport of the radiation in the optical cavity. Typical parameters used in the simulation are give in Table 1.

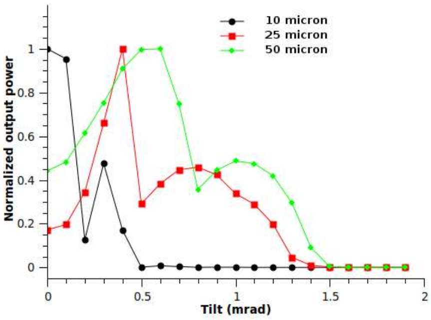
Table 1: Parameters used in the simulation.

Parameter	Value
Undulator parameter (a_u)	0.637
Undulator length (L)	2 m
Undulator period (λ_u)	5 cm
Normalized emittance (ϵ_n)	20π mm-mrad
Beam radius (r_b)	0.595 mm
Beam energy (E)	30.3, 19, 13.4 MeV
Beam current (I)	100 A
Optical wavelength (λ)	10, 25, 50 μm
Initial optical power	1 MW
Hole radius	4 mm
Radius of curvature of mirrors	6.15 m
Radius of cross-section of mirrors	23 mm
Separation between the mirrors	6.15, 12.3 m
Number of test particles	1024
Number of radial grid points	256

The effect of tilting the mirror was studied at three different wavelengths 10, 25, 50 μm, and for both, the confocal as well as the concentric configuration. The mirror was tilted equally in x and y. Figure 1 shows the normalized output power as a function of tilt of the out-coupling mirror. For the concentric case, Fig. 1(a), the power decreases monotonically and rapidly with the tilt angle for all wavelengths. It drops faster at lower wavelengths, but for tilts over around 0.2 mrad, there is no lasing at any wavelength. For the confocal case, Fig. 1(b), the situation is more interesting. There is actually an optimal tilt at which the out-coupled power is maximum - this is 0.5 mrad at 50 μm, and 0.4 mrad at 25 μm. This observation is consistent with results from the CLIO FEL in France [5]. At a wavelength 10 μm the power is maximum at zero tilt, but the curve is still non-monotonic, and there is a secondary maximum at a tilt of 0.3 mrad. It is also evident that the confocal configuration is more robust to mirror tilt compared to the concentric. To understand this behaviour better, we looked at the mode contour on the out-coupling mirror for different cavity configurations (Fig. 2). For the concentric configuration, Figs. 2(a) to 2(f) show that tilting the outcoupling mirror displaces the radiation beam off-centre. The displacement increases with increasing tilt, and hence the power drops monotonically. Though this behaviour is seen at all wavelengths, the displacement is greater at shorter wavelengths, which explains why the power drops faster at these wavelengths. The mode itself remains largely axisymmetric, though some hint of asymmetry can be seen. For the confocal case, Figs. 2(g) to 2(l), the behaviour is very different. For zero tilt, the mode is axisymmetric



(a)



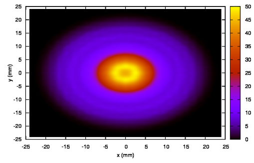
(b)

Figure 1: Normalized output power (a) for concentric case (b) for confocal case.

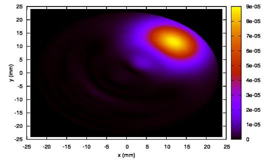
though non-Gaussian (as seen in Ref. 1). With tilt, unlike in the concentric case, the beam is no longer displaced off-centre, but the distribution is highly non-axisymmetric, and is still non-Gaussian. Most of the power is concentrated in small lobes. Recalling that the hole size in these simulations is 4 mm, it is not surprising that, at some values of the mirror tilt, there may actually be more power coupled out. However, it is evident that this power is in non-Gaussian, non-axisymmetric, modes, which may not be conducive for experiments.

CONCLUSION

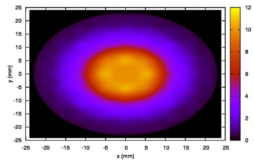
Using GENESIS+OPC we have shown the effect of mirror tilt on the mode structure, for the confocal and concentric configurations, at different wavelengths. For the concentric configuration the power decreases monotonically with increase in mirror tilt, and the mode is largely axisymmetric. The confocal case behaves very differently. There is an optimal tilt, corresponding to maximum outcoupled power; however the mode is highly asymmetric and non-Gaussian in this case. It is important to note that at lower wavelengths the output power simply drops with increasing tilt, in both concentric as well as confocal configurations, indicating that this issue of mirror tilt, which affects the radiation mode profile and the out-coupled power, can be a serious one for X-FEL oscillators.



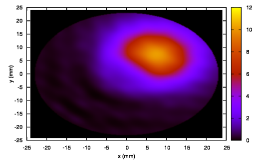
(a) 10 μm, concentric, 0 mrad tilt



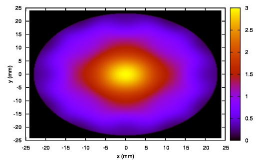
(b) 10 μm, concentric, 0.1 mrad



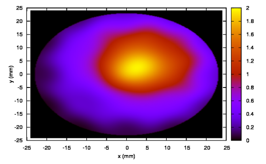
(c) 25 μm, concentric, 0 mrad tilt



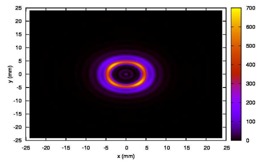
(d) 25 μm, concentric, 0.1 mrad



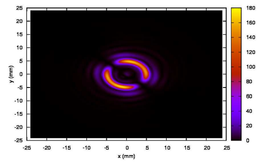
(e) 50 μm, concentric, 0 mrad tilt



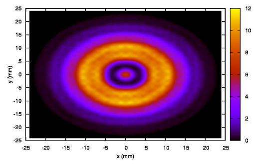
(f) 50 μm, concentric, 0.1 mrad



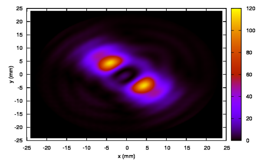
(g) 10 μm, confocal, 0 mrad tilt



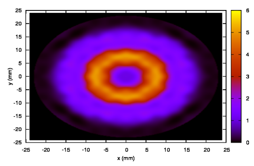
(h) 10 μm, confocal, 0.4 mrad tilt



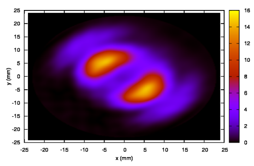
(i) 25 μm, confocal, 0 mrad tilt



(j) 25 μm, confocal, 0.4 mrad tilt



(k) 50 μm, confocal, 0 mrad tilt



(l) 50 μm, confocal, 0.5 mrad tilt

Figure 2: Contour of mode profile on out-coupling mirror.

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