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

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Abstract

In an oscillator free-electron laser (FEL) the power coupled out depends strongly on the mode configuration at the out-coupling mirror. This mode configuration is affected by many parameters such as the resonator configuration, FEL wavelength, etc. In addition, mirror alignment also plays an important role in determining the mode structure. In this paper we use three-dimensional simulations (GENESIS+OPC), to study the effect of mirror tilt on the out-coupled power. We find that mirror-tilt can severely distort the mode, and can introduce non-Gaussian, non-axisymmetric modes. In this regard the confocal configuration is more robust compared to the concentric.

INTRODUCTION

The stability of an oscillator consisting of two spherical mirrors depends on the cavity configuration. The stability of an empty cavity is well understood [1] in terms of the stability diagram in $g_1 - g_2$ space (where $g = 1 - r/d$, where r is the radius of curvature of the mirror, and d the separation between them). Stability of a symmetric oscillator FEL was studied in [2], 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 [3] the study was extended to asymmetric resonators (i.e. $g_1 \neq g_2$), both analytically (using a simple thin-lens model), and with the simulation. The previous work considered no mis-alignment, but in actual experiments we expect that the mirrors will have some mis-alignment, though small, and this could affect the stability of the FEL oscillator. We have studied these issues using the time-independent FEL code GENESIS [4], which simulates the FEL interaction, and OPC [5], which handles transport of the radiation in the optical cavity. Typical parameters used in the simulation are give in Table 1. In next section we show results of tilting the outcoupling mirror on the stability of an oscillator FEL for the confocal and concentric configurations and at different wavelengths. In Section III we explore the change in mode structure as a consequence of changing the size of the out-coupling hole.

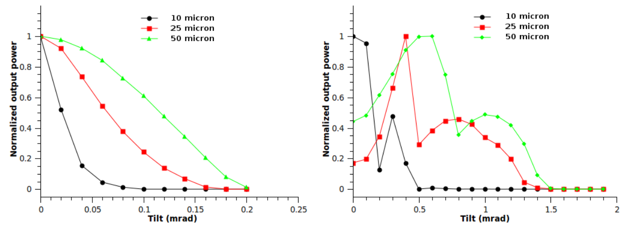
Table 1: Parameters used in the simulation.

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, 50 μm
Initial optical power	1 MW
Hole radius	4 mm
Radius of curvature of mirrors	6.15 m
Radius of cross-sectionof mirrors	23 mm
Separation between the mirrors	6.15, 12.3 m
Number of test particles	1024
Number of radial grid points	256

EFFECT OF MIRROR TILT

The effect of tilting the mirror was studied at three different wavelengths 10, 25 and 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 on 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 acutally 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 [6]. 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(d) show that tilting the outcoupling mirrror 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 largely remains axisymmetric, though some hint of asymmetry can be seen.



(a) (b)

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

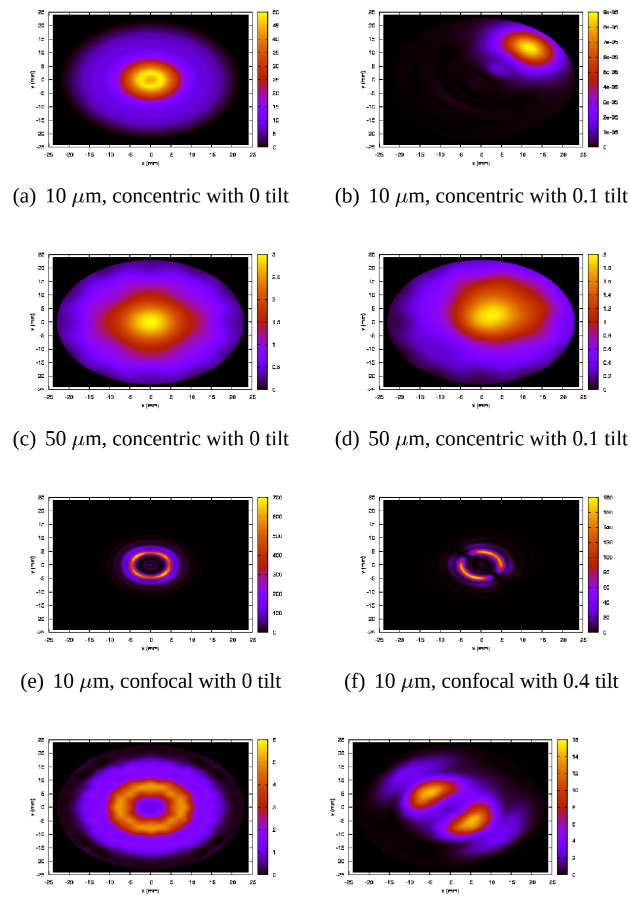
For the confocal case, Figs. 2(e) to 2(h), the behaviour is very different. For zero tilt, the mode is axisymmetric though non-Gaussian (as seen in Ref. 2). With tilt, unlike in the concentric case, the beam is no longer displaced off-centre, but the distribution is highly non-axisymmetric, and is still 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 conducive for experiments.

DEPENDENCE ON HOLE-SIZE

Next we studied the dependence of the out-coupled power as a function of the hole-size for three different cavity configurations. The intensity contour plots on the outcoupling mirror for the concentric configuration (g=-1), Figure 3(c),3(f),3(i),3(l) show that the mode is near-Gaussian for all wavelengths and hole sizes. For the confocal case (g=0), however, Fig 3(a),3(d),3(g),3(j) show that for all wavelengths and hole sizes, the mode remains non-Gaussian, with a minimum at the centre, and would therefore lead to poor out-coupling. Interestingly, for an intermediate cavity geometry, (g=-0.6), similar to that of CLIO, Fig 3(b),3(e),3(h),3(k) show that, at 10 μm, an increase in hole radius results in a higher-order mode that is severly non-Gaussian. However, this does not happen at the longer wavelength of 50 μm. Thus, the intermediate configurations are not recommended, especially at shorter wavelengths.

CONCLUSION

Using GENESIS+OPC, we have studied the effect of a tilt in the out-coupling mirror. We find that tilting the mirror produces a substantial asymmetry in the mode. For the concentric configuration the power decreases monotonically with increase in hole size, but for the confocal case, there is an optimal tilt, corresponding to maximum out-coupled power; however the mode is highly asymmetric and non-Gaussian in this case. This corresponds well with



(a) 10 μm, concentric with 0 tilt (b) 10 μm, concentric with 0.1 tilt

(c) 50 μm, concentric with 0 tilt (d) 50 μm, concentric with 0.1 tilt

(e) 10 μm, confocal with 0 tilt (f) 10 μm, confocal with 0.4 tilt

(g) 50 μm, confocal with 0 tilt (h) 50 μm, confocal with 0.5 tilt

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

some measurements done at the CLIO FEL (albeit at a different wavelength), and we plan to pursue this in future work. We have also explored the variation of the output mode as a function of hole size for three different cavity configuration, and found that with increase in radius of the hole higher-order modes tends to develop for g = -0.6 configuration. The concentric configuration is therefore preferred to the confocal and other configurations.

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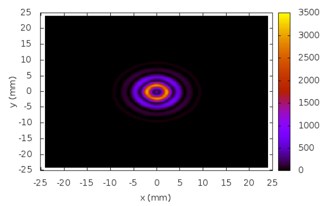
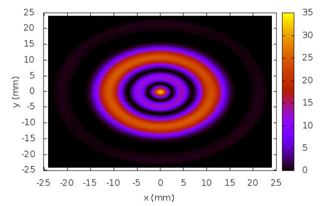
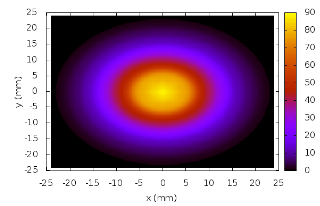


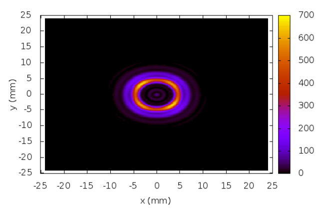
(a) 10 μm, g=0, rhole=1mm



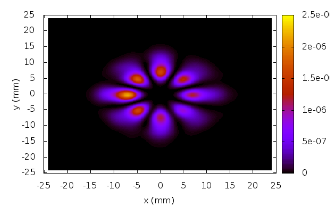
(b) 10 μm, g=-0.6, rhole=1mm



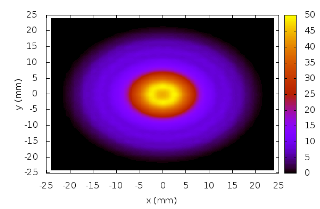
(c) 10 μm, g=-1, rhole=1mm



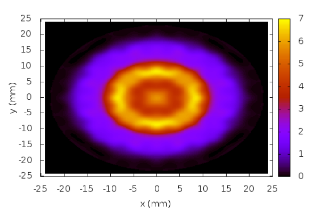
(d) 10 μm, g=0, rhole=4mm



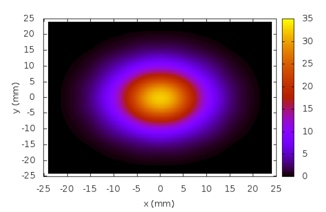
(e) 10 μm, g=0.6, rhole=4mm



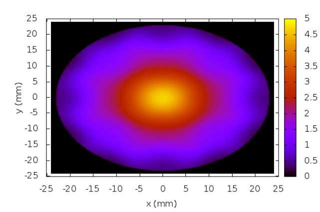
(f) 10 μm, g=-1, rhole=4mm



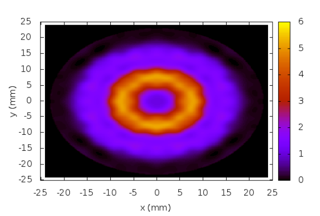
(g) 50 μm, g=0, rhole=1mm



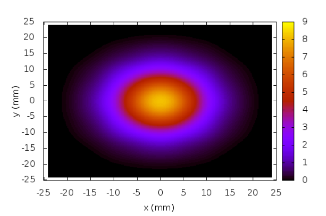
(h) 50 μm, g=-06, rhole=1mm



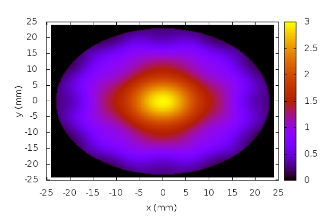
(i) 50 μm, g=1, rhole=1mm



(j) 50 μm, g=0, rhole=4mm



(k) 50 μm, g=-0.6, rhole=4mm



(l) 50 μm, g=-1, rhole=4mm

Figure 3: Contur plot of mode profile on out-coupling mirror.