Harmonics Beams Characterization Using the Knife-Edge Technique

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Abstract: Using the knife-edge method we have measured HHG beams sizes in the VUV and calculated their divergences, showing that they have similar spatial characteristics to synchrotron beams at the same spectral region.
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Introduction

Brazil is building Sirius[1], its fourth generation synchrotron, and simultaneously planning the shutdown of the Brazilian Synchrotron Light Laboratory (LNLS), a second generation machine and the only synchrotron facility in Latin America. In this upgrade, the synchrotron users' community will be left with a gap in the 10-100 nm spectral region due to the emission characteristics of the new ring, whose emission spectrum is shifted to higher energies. To provide a light source in this spectral gap we have set a program using High Harmonics Generation, with the added benefit of higher temporal resolution when compared to tens of picoseconds usual synchrotron pulses.

By HHG we are currently generating harmonics in the 70-30 nm range (11th to 19th harmonic), and here we describe the characterization these radiation beams using the knife-edge method to verify their similarity to synchrotron generated ones.

Experimental Setup

Harmonics in the 70-38 nm range (11th to 19th harmonics) were generated from 785 nm, 650 µJ, 25 fs pulses at 4 kHz repetition rate (Femtolasers Femtopower Compact Pro HR/HP). The laser pulses were focused, by a f=50 cm lens, on a stainless steel 2.5 mm gas nozzle through which Argon flowed at a 90 mbar pressure, where the harmonics were generated, placed inside a vacuum chamber with a background pressure under 10^{-6} mbar. The fundamental wavelength is filtered out by self-sustaining 150 nm aluminum filters, and the harmonics are separated by a VUV monochromator (McPherson 234/302) and detected by a scintillator and a photomultiplier, as shown in Figure 1. To determine the harmonics beams sizes and divergences, they were assumed to be TEM_{00} Gaussian beams, and two knife edges (KE1 and KE2) were mounted inside the vacuum chamber on vacuum compatible displacement stages with computer controlled actuators (Newport NSA12V6), at 65 and 221 mm from the nozzle, as indicated in Figure 1. The monochromator entrance slit is 820 mm away from the second knife-edge, and its aperture was set at 2 mm, larger than the beams at its position. The exit slit was also set at 2 mm aperture.

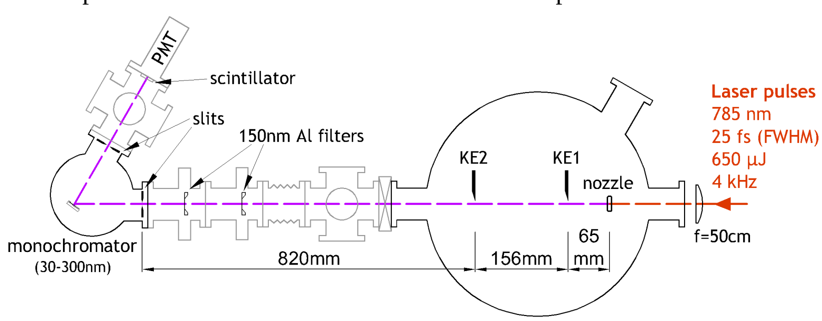

Figure 1. Scheme of the experimental setup in which the harmonics beams were generated and measured.

An initial spectrum was taken, with 0.5 mm monochromator slits, to determine the harmonics wavelengths peaks positions at which the knife-edge measurements would be made (11th harmonic at 69 nm, 13th at 58 nm, 15th at 50 nm, 17th at 44 nm and 19th at 39 nm). The knife-edge measurements were then done, with 2 mm slits, reading the PMT signal in a lock-in amplifier synchronized by the pulses. The obtained data was then fitted by:

$$f = amp\frac{1}{2}\left\{1+erf\left[\frac{\sqrt{2}}{w}(x-x_0)\right]\right\}+bg \qquad (1)$$

where w is the beam spot size defined in the usual way (radial distance where the intensity drops to $1/e^2$ of the peak), x_0 is the peak position, *amp* is the function amplitude and *bg* is the background. The measured values of w at the KE1 and KE2 positions, w_1 and w_2 respectively, were used to calculate the beam divergence, harmonic beamwaist position relative to KE1 and beamwaist size for each harmonic. Two measurements were done for each harmonic and the values obtained are the average of the measurements.

Results

Figure 2 presents the 2 knife-edges measurements for the 15th harmonic (50 nm), with the spot sizes obtained from fittings by eq. (1). From these values the beam divergence $\theta_0=(w_2-w_1)/d$ is immediately obtained, with d=156 mm being the distance between KE1 and KE2. The harmonics divergences are shown in Figure 3a. Knowing w_1 and w_2 values and positions, and using the beam propagation law $w(z)=w_0[1+(z/z_0)^2]^{1/2}$, where z is the position relative to the beamwaist and z_0 is the beam confocal parameter, it is possible to calculate the beamwaist position relative to KE1, l_1, and its size w_0, and the results are shown in Figure 3b and 3c, respectively, as a function of the harmonics wavelengths.

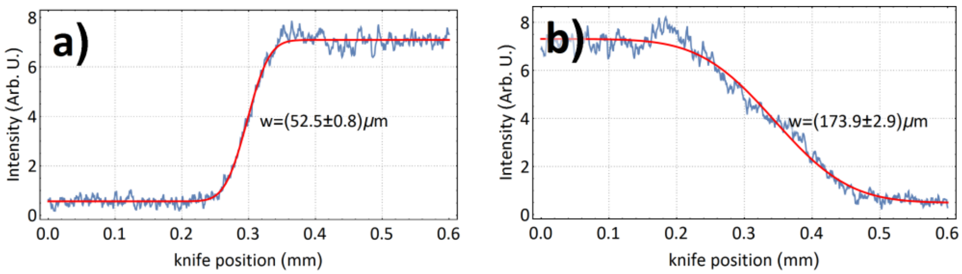

Figure 2. Knife-edge traces measured at a) KE1 and b) KE2 positions, for the 15th Harmonic (50.0 nm). The spot sizes obtained from the fittings by eq. (1), in red, are shown.

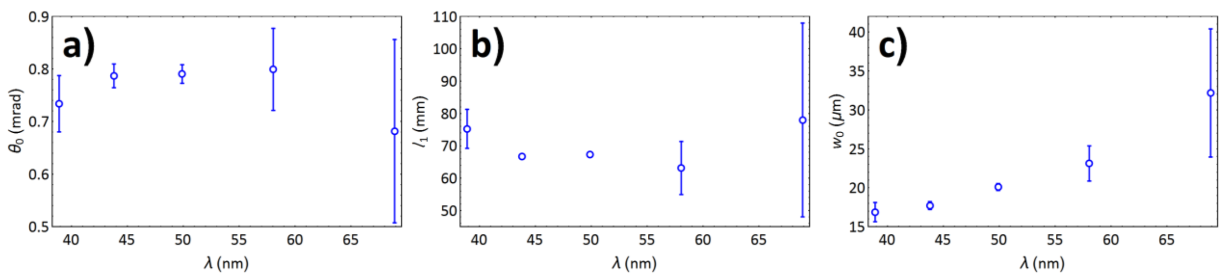

Figure 3. a) divergence, b) distance between beamwaist position and KE1, and c) beamwaist size for the generated harmonics.

Although there is a wavelength dependence, the results depicted in Figure 3a (beam divergence) and 3b (beamwaist position relative to the KE1) show that the harmonics beams divergences are close to 800 μrad and the beamwaists are situated close to the nozzle position (65 mm). Figure 3 shows that the beamwaist size is reduced as the harmonic order grows (wavelength decreases), meaning that, as the harmonic order increases its generation is more confined to higher intensities regions, as expected.

Conclusions

We have generated and characterized harmonics beams from 39 to 69 nm, in a first attempt to fill the gap from 10 to 100 nm that is predicted exist in the new Brazilian synchrotron, Sirius. Our analysis revealed that the diameter and divergence of the HHG beams generated in our setup are similar to those commonly observed in synchrotron beams in the VUV-EUV spectrum, which usually have ~100 μm diameters at the sample and divergences around 1 mrad.

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References

[1] "Synchrotron sources accelerate," Nature Photonics 9, 281-281 (2015).