Simulations of the Dependence of Harmonic Radiation on Undulator Parameters*

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WEP074

* This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Abstract

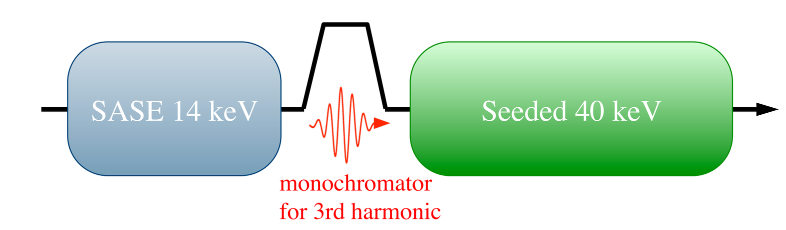
The flux and bandwidth of radiation produced at harmonics of the fundamental are very sensitive to the undulator parameter, and thus the beam energy or undulator period. We look at high-energy XFELs with parameters relevant to the MaRIE FEL design. Both SASE and seeded FELs are considered.

Nominal Parameters (based on MaRIE FEL)

Electron Beam:
- 12 GeV energy, 1.2 MeV energy spread
- 3 kA peak current
- 0.2 micron emittance
- 15 m beta function

Undulators:
- 15 mm, 18 mm, and 20 mm period
- 3.6 m long sections
- either 1.2 m or 0.9 m breaks between sections
- resonant at either 14 keV or 40 keV

Focus of study



Assume idealized self-seeding stage
- produce low-bandwidth seed at 40 keV
- amplify as fundamental, or 3rd harmonic from lower photon energy

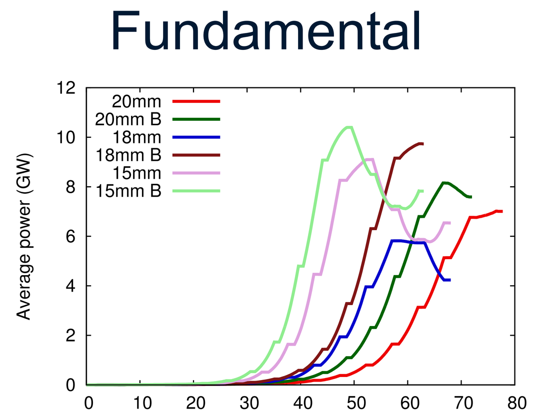
Amplify to, or past, saturation
- focus on nonlinear 3rd harmonic
- look at output power, spectrum, and total length of beamline

Simulations use GENESIS

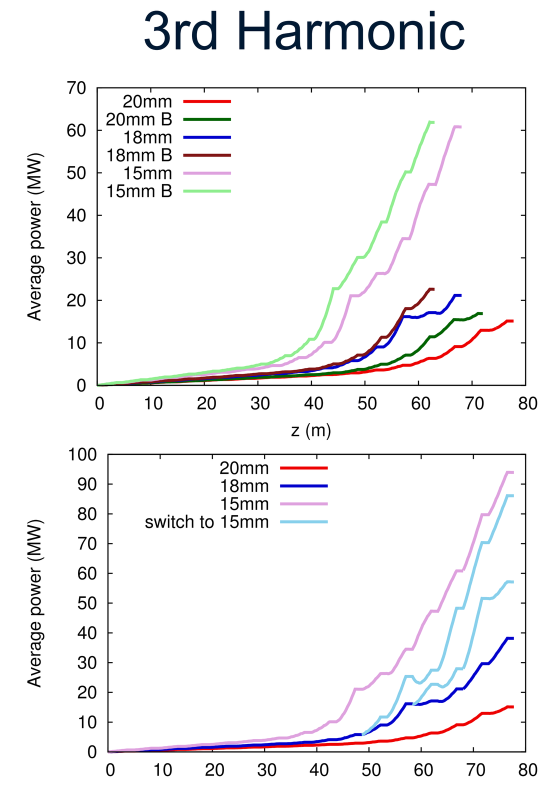
Output power is sensitive to undulator design

Vary undulator period and separation between undulator sections

Fundamental



3rd Harmonic



'B' indicates shorter breaks between undulators (higher fill fraction)

Changing to more advanced undulators near the end can recover good performance

- Start from 100 kW input power at 40 keV
- Saturated power at 40 keV fundamental sensitive to fill fraction
- Power at harmonic mostly depends on undulator period
  - related to rms undulator parameter a_u

Period	a_u	P_3/P_1 (ideal)
20 mm	0.81	0.69%
18 mm	0.92	0.88%
15mm	1.10	1.16%

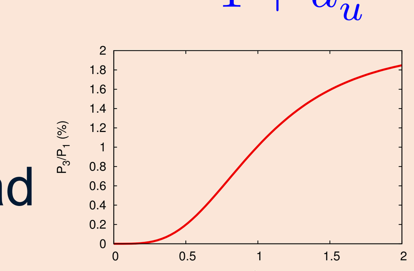
For fundamental of 14 keV:
- less sensitive to choice of undulator
- undulator parameter a_u ranges from 2.0 to 2.4

PPM undulator: 18 mm period allows ~5 mm gap
SC undulator: 15 mm period allows ~9 mm gap

Harmonic sensitive to undulator parameter a_u
- ignoring "3D" effects, scales at saturation as (see Saldin et al, PRSTAB 9, 2006):

$$\frac{P_3}{P_1} \simeq 0.094 \, \frac{J_1(3\xi) - J_2(3\xi)}{J_0(\xi) - J_1(\xi)}\,, \qquad \xi \equiv \frac{a_u^2/2}{1+a_u^2}$$

- scaling more drastic when emittance and energy spread important



Alternatives are limited:

Amplify 40 keV as linear 3rd harmonic of 14 keV?
- gain length from simulations is not any shorter
  - emittance and energy spread too large
- saturates at lower power

Linear harmonic amplification of 120 keV?
- no linear gain for these parameters

Afterburner
- switch to aggressive undulator technology only for last few gain lengths

Fresh-slice, fresh-bunch, or multi-bunch methods to return to lower energy spread
- during self-seeding and/or afterwards

Conclusions

Undulator parameter very important for harmonic radiation
- either push on undulator technology or raise beam energy (14 GeV?)
- in-vacuum or superconducting undulators

Note *relative* bandwidth not going to improve when using nonlinear harmonic
- wakefields, microbunching not considered here – could spoil spectrum

Selected References

MaRIE:
J.W. Lewellen et al., FEL 2015 paper MOP062.
GENESIS:
S. Reiche, Nucl. Instrum. Meth. A 429 (1999) 243.
Harmonic radiation:
R. Bonifacio, L. De Salvo and P. Pierini, NIMA 293 (1990) 627.
E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, PRSTAB 9, 030702 (2006)
E.A. Schneidmiller and M.V. Yurkov, PRSTAB 15, 080702 (2012).