Some Undulator and Beamline Comments
Pertinent to the Topics of WG 7
MAG - 9 Mar 10

This is a particular undulator approach of possible interest to seeded-FEL operation in all traditional polarization modes: horizontal (HP), vertical (VP), and variably inclined-plane (IP) linear, as well as left (CPL) and right (CPR) circular, excluding radial and azimuthal.

In present configurations linacs can be a substantial cost in the construction of an FEL facility and minimizing that cost must be considered. Linac length, and energy can be reduced by either/both **reducing undulator period length ($\lambda_u$) and/or increasing the harmonic number (i) of the radiation in the final radiator of the highest photon-energy beamline**, assuming fixed spectral coverage (in wavelength $\lambda$) and K-range used for tunability as follows from the resonance equation

$$\lambda = \frac{\lambda_u}{2i\gamma^2}\left(1+\frac{K^2}{2}\right) \quad for\ planar, or \quad \lambda = \frac{\lambda_u}{2\gamma^2}\left(1+K^2\right) \quad for\ helical\,.$$

**To what extent higher harmonics in all polarization modes are desirable, or not, is a science/user issue. To what extent they are, or can be made, useful, or removed, is an FEL physics question.**

As evidenced at this Workshop, there is currently considerable effort to reduce $\lambda_u$ and this is invariably tied (through K) to how small the magnetic and vacuum gaps can be made. **Smallness of gap involves both physics and engineering issues**, namely and respectively, beam-wall interactions that affect the beam (via wakefield, roughness, geometric variations, etc.) and beam effects on the wall (heating, radiation, etc.).

Distinct from these issues is the manner in which the several polarization states are "assembled" in the final radiator. Conventionally this has been accomplished in a single magnetic ID of which there are a great many examples [Refs]. However, an early alternative, which presumes the presence of a monochromator, has been the crossed undulator [Refs] with one or more undulator pairs [Ref], separated by an electron path-lengthening modulator, with polarization in the paired undulator orthogonal with respect to the other. Although the pairs are traditionally **(simple) planar**, they can also be **(simple) helical** [Ref]. In either case the several linear (HP, VP, IP) and circular (CPL, CPR) states can be produced. **If planar IDs are used higher harmonics, including circular, are produced**, if desired, whereas **helical IDs would not produce any higher harmonics, on-axis,** if desired; this feature of higher harmonics either being present or not is unique to this particular scheme. Further, the modulator provides a means of **polarization switching at, say, 100 Hz, which is much higher than what would be possible by mechanical array motions (APPLE, DELTA, etc.) or electrical coil variations (SC case)**. Unlike the case with SASE FELs [Ref], **the use of crossed-undulators in seeded FELs is expected to produce high degree-of-polarization [Ref]; this is also an FEL physics question for continued study.**

Practical considerations of crossed undulators include the following. Assuming minimum K values of $K_{min}$ = 1 and $1/\sqrt{2}$ for planar vs helical IDs, respectively, a 3:1 tuning range results in maximum K values $K_{max} = \sqrt{5}$ = 2.2 and $\sqrt{7/2}$ = 1.8, respectively. It should be noted that planar undulators might allow better pumping and access for magnetic measurements. Also, a clean, low steering-residual modulator must be designed [Ref]. Further, depending on how the undulators are paired, and excited, some **thought must be given to the impact of, and remedy for, longitudinal source point variation**.

As mentioned at this Workshop, non-conventional undulators may also be of interest. These might include, for example, $CO_2$ laser [Ref], microwave [Ref] undulators, etc.

There are also some general beamline considerations. One is that **beamlines can alter orthogonal polarizations in terms of relative E-field amplitudes and phasing** which is especially true at lower photon energies, say < 60 eV or so [Ref], which means that substantial changes can occur between polarization at the source and that presented to the user; this will/may necessitate appropriate changes at the ID source, in the beamline, or by the end user. Compensation of beamline effects for CP & IP polarizations at the source in the case of an APPLE II have been implemented [Ref], for example. Another, obvious, consideration is the provision for full polarimetric characterization of the radiation after the beamline.