Characteristics and Properties of Synchrotron Radiation: Free Electron Lasers and Coherence

G. Margaritondo
Faculté des Sciences de Base, Ecole Polytechnique Fédérale de Lausanne

Coherence is one of the important properties of synchrotron radiation. This is particularly relevant for x-rays, since their short wavelengths make it difficult to achieve high levels of coherence. The difficulty is present both for longitudinal coherence and for lateral coherence. Longitudinal (time) coherence requires indeed a small relative bandwidth of wavelengths, $\Delta\lambda/\lambda$, hard to obtain when λ is small. Lateral (spatial) coherence requires instead a large "coherent power", defined by λ^2 divided by the source size and by the angular divergence. Here again, small wavelengths limit the coherence level.

Synchrotron sources do overcome these obstacles. Bending magnets and wigglers emit broad bandwidths, thus their longitudinal coherence is limited. But the emission is very strong, so one can use monochromators to decrease $\Delta\lambda$, tolerating the corresponding flux decrease. Undulators have naturally narrow bandwidths, which can also be decreased by monochromators.

As to lateral coherence, the size of synchrotron sources is defined by the transverse dimension of the emitting electron beam, and is typically very small. And the angular divergence is made small by relativity.

The high lateral coherence is particularly important for imaging applications. In fact, it activates contrast mechanisms related to the phase of the x-ray waves, whereas conventional radiology only exploits their intensity. The results can be very spectacular, in particular those in x-ray microscopy, as illustrated by those achieved in Trieste under the leadership of Giuliana Tromba.

Coherence makes synchrotron sources reminiscent of lasers, in particular when considered together with their powerful emission. But one should not assume that they are lasers, since the emission mechanism is different. However, there exist now x-ray sources that exploit an optical amplification phenomenon somewhat similar to that of a laser: the so-called "free electron lasers" (FEL).

The optical amplification of an FEL is caused by the coordinated emission of the electrons in an electron bunch passing through an undulator. When the bunch enters the undulators, some of its electrons start emitting x-ray waves. These waves travel with the bunch and interact with its electrons pushing them towards periodic "slices", with a periodicity equal to the wavelength. The electrons so microbunched emit additional x-ray waves in a coordinated fashion, producing optical amplification.

The mechanism was originally proposed by John Madey for infrared emission and by Claudio Pellegrini and others for x-rays. But at short wavelengths very delicate and vulnerable to perturbations. So, so it took many decades to be realized for x-rays. But it new produces outstanding x-ray beams at a number of facilities, such as the FERMI FEL in Trieste.

X-ray FEL's achieve unprecedented levels of intensity and coherence. They sharply improve the performance of experiments with respect to standard x-ray sources, in particular in the domain of microscopy and imaging. And open the door to entirely new experiments, like "one-shot" crystallography. In particular, the so-called "seeded" FEL's like FERMI make it possible to activate optical phenomena beyond the first order of quantum electrodynamics, extending their exciting research opportunities from the visible to the x-ray spectral range