Development of Advanced Superconducting Undulators

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Potential Impact

The newest generation of large FELs, such as LCLS-II, European XFEL and now LCLS-II-HE, enable operations at unprecedented "hard X-ray" levels, thereby increasing the discovery potential and broadening the user base. This is achieved by leveraging the extraordinary advances in SRF technology of the past 20 years, performed under the umbrella of the Tesla and ILC technology development programs. A further step forward, toward even harder X-ray ranges or more compact and less expensive facilities is the upgrade of the undulator sections of the machines by selecting a more advanced technology and utilizing superconductivity.
Third generation synchrotron rings (SR) would also benefit from the use of superconducting undulators (SCUs), while older SR could considerably improve their capabilities by simply swapping insertion devices without investing in costly complete machine upgrades. Innovative plasma-driven machines such as EuPRAXIA can reduce their footprint while significantly increasing operation flexibility by embracing the integration of SCUs.
With regards to high energy physics, the present design of the ILC polarized positron source incorporates superconducting helical undulators [1]. Prototypes have been manufactured [2], however continued development would be extremely beneficial. Moreover, the same technology could be used to upgrade the ILC damping ring wigglers leading to more reliable machine operation [3].
In the short term, developing the technologies required for SCUs is fully synergetic with the R&D roadmap of high field magnets for accelerator applications. SCUs can be a small-scale test bed for the implementation of key technologies related to advanced superconductors such as first- and second-generation HTS.

Status Quo

SCUs are a natural continuation in the evolution of insertion devices. The use of permanent magnets (PMs) has been pushed to the limit by installing the arrays directly in the beam UHV to reduce the gap (In-Vacuum Undulators IVU) and even further by cooling them down to cryogenic temperatures to increase the remanence field (Cryogenic Permanent Magnet Undulators CPMU). In order to further increase the magnetic field of these devices, a jump in technology is required; hence the implementation of superconductivity. Development programs in both the US (ANL, LBNL) [4] and Europe (KIT-NOELL) [5] have shown that SCUs generate a stronger field on axis than comparable permanent magnet-based devices and that the use of superconductivity does not compromise the operation of synchrotron storage rings or FELs. At the moment, for period lengths above 13 mm, SCUs made out of NbTi show a significant improvement in field on axis compared to CPMUs [6] and NbTi SCUs are part of the APS-U upgrade where they will be integrated in several beamlines [7].

Technology roadmap

Planar NbTi SCUs in operation have demonstrated the capability of superconducting technology in terms of achievable magnetic field. Parameters such as a comparable phase error with respect to PM devices and beam transparency have been achieved. The performance of superconducting elliptical devices (producing a polarized light) have also been demonstrated. These are important milestones, however, there is still much room for improvement in terms of superconductor R&D (magnet performance) and cryomodule design (system integration). The implementation of Nb_3Sn [8] and 2G HTS, both in tape form [9] and bulk [10] can drastically improve the magnetic field created by these devices, producing a stronger impact on the performance of future accelerators. Furthermore, the SCUs presently in operation are stand-alone devices; however, on the basis of existing conceptual designs [11], considerable effort should be invested in modular designs that can benefit of the 2 K operation of SRF LINACs and seamlessly integrate in a FEL tunnel.

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