FEASIBILITY OF A Nb$_3$Sn UNDULATOR FOR THE ADVANCED PHOTON SOURCE AT ARGONNE NATIONAL LABORATORY

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The Advanced Photon Source (APS) of the Argonne National Laboratory (ANL) commissioned a feasibility study of a 15 mm period, 0.8 T peak-field-on-the-beam (B$_o$), Nb$_3$Sn undulator. Superconducting undulators consist of a beam tube for an electron beam with windings above and below the beam tube that generate a transverse field on the beam that varies in a sinusoidal pattern along the beam. Key features that determine the desired radiation emitted by the electron beam are the peak field value on the beam and the distance between peaks (period). NbTi undulators developed so far and Nb$_3$Sn demonstration undulators have featured an integrated beam tube and winding yoke. This allows the windings to be in close proximity to the beam maximizing B$_o$ at a given current density. Another consequence is that heat generated at the beam tube wall is conducted through the windings. This makes the temperature of the superconductor dependent on the beam parameters and hard to predict, requiring either a large temperature margin in the design and still carries a risk of heat flux induced quenches. A quench will result in a much larger temperature excursion of the beam tube temperature creating an unacceptable risk to the electron beam in the multi-user APS facility. We therefore adopted the concept to thermally separate the beam-tube and winding yokes with a vacuum gap and cool the windings to around 4 K with helium while the beam tube has a separate independent and redundant cooling system with liquid nitrogen. The first stage of a two-stage cryocooler cools liquid nitrogen vessels, whereas the second stage maintains the helium supply. The primary cooling mechanism for the yoke and beam tube is through a longitudinal liquid conduit with secondary cooling of the yoke through transverse ribs connecting to the helium vessel. This concept requires a larger current density in the windings for a given B$_o$, but offers a lower and more stable winding temperature and therefore only small margins to achieve this current density. A limited parameter study has been performed to assess feasibility. With a 7 mm vertical beam aperture and 11 mm between the windings of the upper and lower yoke, a reference $J_{c,\text{non-Cu}}(12 \ T, 4.2 \ K)$ of 1242 A/mm$^2$ is required for a 0.85 K temperature margin when operating at 90% of $I_c$. As reference current densities up to 2000 A/mm$^2$ are considered feasible and routine, and record performance is currently around 3000 A/mm$^2$, a 15 mm period Nb$_3$Sn undulator with B$_o=0.8$ T appears feasible. As there is considerable margin between the required current density for B$_o=0.8$ T and the feasible current density, and the geometry can be optimized as well, designs with slightly shorter periods and higher B$_o$ seem possible too. Several options exist for the assembly of beam tube, windings and yoke. A demonstration experiment to verify feasibility of the mechanical, cryogenic and superconducting aspects is a logical next step.

Fig. Field distribution in the windings in case of a 12 mm gap. A smaller winding gap is possible with correspondingly lower current density and magnetic fields.