# Superconducting Undulators for Positron Sources

D. Arbelaez, S.O. Prestemon, X. Wang (1)

(1) Lawrence Berkeley National Laboratory, Berkeley, CA 94720, darbelaez@lbl.gov, soprestemon@lbl.gov, xrwang@lbl.gov

Positron beams are required for future linear colliders such as ILC. Polarized positron beams can be produced through the pair-production process using circularly polarized photons. These can be generated when a high energy electron beam travels through a helical undulator. This process has been previously demonstrated in [1] using a short period pulsed helical undulator. Future facilities can profit from the development of high performance superconducting undulators. For example, the short period and high field afforded by advanced undulator technologies can reduce the required electron energy to produce photons in the 1 – 20 MeV range that is desirable for positron production. Furthermore, advanced undulator technologies will also lead to shorter undulator lengths, thus reducing the overall cost. Some developments have already taken place for development of NbTi helical undulators for ILC [2-3]. This technology can be taken further by using higher performing superconductors such as $Nb_3Sn$ and high temperature superconductors such as REBCO conductors. A number of challenges must be addressed to reach the highest performance possible given the current state of conductors. Below, we review the current state of superconducting undulator R&D, discuss the possible use of different superconductors, and lay out a conceptual plan to achieve these goals.

There has been a rapid development in superconducting undulator technology over the past two decades. The application of these undulators has primarily been for synchrotron radiation facilities, although, as mentioned above, some work has also been done towards positron production for linear colliders [2-3]. There are currently a number of NbTi undulators operating at synchrotron radiation facilities at the Advanced Photon Source (APS) in Argonne National Laboratory (ANL) in the USA [4-5] and at the ANKA storage ring in Germany [6]. Work on $Nb_3Sn$ undulators has taken place at LBNL over approximately the past decade [7-8]. This work culminated in the successful fabrication and test of a 1.5 m long prototype planar undulator [9]. There is a current project at ANL to fabricate and install two operating $Nb_3Sn$ planar undulator segments in the APS [10]. The next step in higher field performance is in using HTS conductors which have the potential to achieve the highest engineering current densities of currently available conductors. High current density operation of YBCO planar undulators has been demonstrated at ANL in [11] on a short undulator prototype.

Circularly polarized photons are desired since they can be used to produce polarized positrons. Superconducting undulators in a bifilar helical geometry are ideal for the production of circularly polarized photons. These undulators are composed of two helical winding packs which are shifted along the undulator length by half of the period length. The coils are powered in opposite directions, which produces a magnetic field with constant strength that rotates periodically along the length of the device. This configuration also has the advantage that, due to the constant acceleration of the electrons, a larger tuning range is provided when compared to planar devices. NbTi bifilar helical undulators have been previously produced as part of an R&D program towards positron production at the Rutherford Appleton Laboratory in the UK [2-3]. One NbTi bifilar helical undulator was also developed and is currently operating at the APS [12]. A focus on developing $Nb_3Sn$ and REBCO bifilar helical undulators is the next step in pushing the performance boundaries for these devices.

There are a number of issues that must be resolved in order to demonstrate the feasibility of using these undulators in a facility. For planar $Nb_3Sn$ undulators it has been previously demonstrated that issues such as distortion due to reaction, difficulties with quench protection, and conductor stability due to high current density operation can be overcome on a full length device [9]. However, the bifilar helical geometry presents a new challenge, especially with respect to geometric errors and distortion due to the high temperature heat treatment. These challenges would be addressed through fabrication and testing of short and medium length prototypes.

REBCO materials have the potential to provide even higher current densities than $Nb_3Sn$ conductors. The critical current density of REBCO is orders of magnitude higher than that of other traditionally used superconductors, when operating at low temperature (near 4.2 K). For practical use, REBCO conductors are manufactured in the form of a tape with a thin layer of the superconductor deposited on a substrate material, which is then encapsulated in a stabilizing material. This leads to a reduced effective superconductor cross-section which reduces the average current density in the conductor. Until recently, the average current density of REBCO conductors was not yet competitive when compared the low temperature superconductors NbTi and $Nb_3Sn$. However, recent advances have led to significant increases in the average current density of these conductors. These include: (1) a reduction in the thickness of the substrate material, (2) an increase in the thickness of the deposited REBCO layer, and (3) significant increases in the critical current density of the superconductor, for example, through enhanced pinning by Zr doping [13].

REBCO bifilar helical undulators have the advantage that there is no heat treatment required. Their high thermal stability, when compared to LTS conductors, also leads to the possibility that these magnets could be training free. However, there are a number of challenges related to field quality, quench protection, and winding geometry. In order for this technology to be viable for accelerators, several technological advances must be made. These include: the development of winding methods that allow for current "turn-around" or fabrication of low resistance joints, development of quench detection and protection methods, understanding of current distribution within the tapes and the effect on field quality, and development of impregnation procedures that avoid damage / delamination of tapes.

As part of a proposed program, initial work will focus on building short $Nb_3Sn$ and REBCO bifilar helical undulator prototypes (<0.2 m) in order to develop fabrication methods and to understand issues related to quench protection for both technologies. This would be followed by medium length prototypes (~0.5 m) which will be long enough to identify and correct issues related to field quality. Once the required field quality can be achieved, full length prototypes (~1.5 m) would be fabricated and tested. Finally, in order for this technology to be deemed for operation in a facility, a full operational system should also be designed and tested. This includes the cryostat with multiple undulator segments, the alignment features for the undulators segments and the overall cryostat, and additional "cold" components such as quadrupole magnets and beam positon monitors.

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