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A CONCEPT OF A UNIVERSAL SUPERCONDUCTING UNDULATOR*

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Abstract

Tiny round electron beams of free-electron lasers and relatively new diffraction-limited storage rings make possible the utilization of electromagnetic helical undulators based on double-helical windings. It has long been understood that a coaxial pair of double-helical windings can generate helical as well as planar magnetic fields [1]. Such a coil structure can potentially be realized with superconducting windings, thus forming the concept of a universal superconducting undulator (Universal SCU). An example of a possible universal SCU for the recently suggested Advanced Photon Source (APS) multi-bend achromat storage ring is given in this paper. The results of the magnetic simulation together with initial design considerations are presented.

INTRODUCTION

It is recognized that circularly polarized radiation is very useful in a broad range of scientific disciplines, including solid state physics, chemistry, biology, and medicine [2]. Such radiation can be generated by permanent magnet or electromagnetic polarizing undulators, as reviewed in [2].

Within possible schemes of polarizing electromagnetic undulators, there is the concept of a universal double-helical undulator, originally suggested in [1] and mentioned in [2].

This paper describes a further development of the idea of a universal double-helical undulator – a universal superconducting undulator. The results of the magnetic modeling of such a device are described in this paper. Initial design considerations are also presented.

UNIVERSAL DOUBLE-HELICAL UNDULATOR

The idea of using two overlapped and coaxial helical undulators for generation of both planar and elliptically polarized radiation was originally described in [1]. The suggested scheme is presented in Fig.1, which is copied from [1]. In this scheme, there are two helical structures noted as 1 and 2 in Fig. 1. Each structure forms a helical undulator made of a pair of currents flowing in opposite directions and shifted by a half-period. Thus, the currents 3 and 4 form an internal helical undulator structure while the currents 5 and 6 form an outer helical structure. Both internal and outer helical undulators have the same period length *l* but opposite helicities. Such a double-helical electromagnetic structure was analysed by the authors of [1]. It was shown that if one of helical undulators was powered, a circular polarized magnetic field was generated. When both undulator coils are powered, a planar magnetic field is generated, provided that the inner and the outer undulator coils create the same field amplitude.

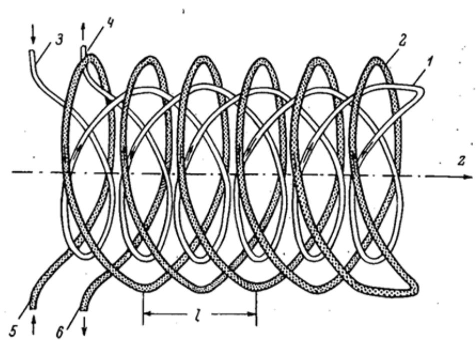

Figure 1: Universal double–helical undulator [1].

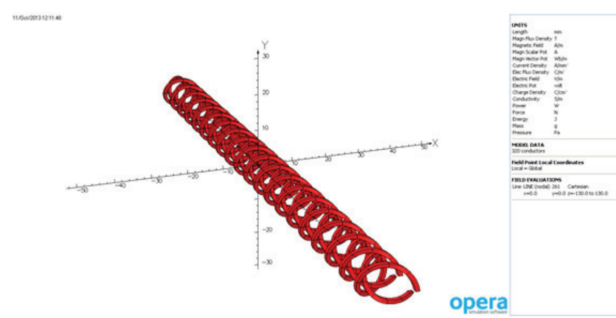

Figure 2: Model of a double-helical structure in OPERA 3d.

This scheme has been simulated by the author in OPERA 3d as shown in Fig. 2. It is found that the magnetic field configuration is as listed in Table 1.

Table 1: Field in Universal Double-Helical Undulator

Inner coil current	Outer coil current	Field configuration
+ I_1	0	Helical
0	+ I_2	Helical (opposite helicity)
+I_1	+I_2	Planar vertical
-I_1	+I_2	Planar horizontal

The simulation confirmed that such a structure can generate both planar and helical magnetic fields.

UNIVERSAL SUPERCONDUCTING UNDULATOR

A universal superconducting undulator is a universal double-helical undulator with the coils wound with a

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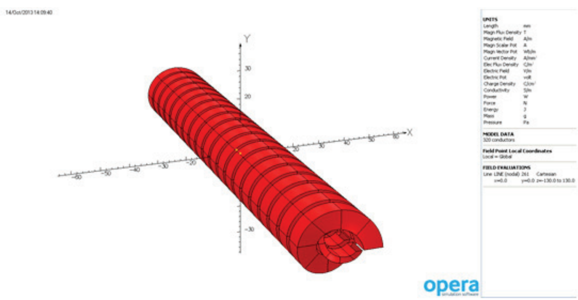

Figure 3: Universal SCU in OPERA 3d.

superconducting wire. Due to the high current density achievable in modern NbTi and Nb_3Sn superconductors, it is expected that a Universal SCU could generate on axis a magnetic field in a 1-T range. To check this, a 3d model of such a structure was created and simulated in OPERA 3d, Fig. 3. No magnetic material was used in the model. The dimensions for the model were chosen to be suitable for the Advance Photon Source (APS) multi-bend achromat upgrade, Table 2.

Table 2: Dimensions of the Universal SCU Magnetic Model

Parameter	Inner coil	Outer coil
Superconductor	NbTi	NbTi
Period length, mm	16	16
Winding bore, mm	6	11
Winding cross-section (horizontal × vertical), mm × mm	6 × 2	6 × 6

The goal of the simulation was to find the maximum achievable magnetic field on undulator axis for the coils wound with an NbTi superconductor, assuming that the conductor operates at an 80-% level of a short sample critical current density.

The results of the simulation are summarized in Table 3.

Table 3: Magnetic Field in the Simulated Universal SCU

Inner coil current density, A/mm2	Outer coil current density, A/mm2	Field configuration
795.6	0	Helical: B_y = 0.68 T, B_x = 0.68 T
0	1184.5	Helical (opposite helicity): B_y = 0.68 T, B_x = 0.68 T
795.6	1184.5	Planar vertical: B_y = 1.36 T, B_x = 0
-795.6	1184.5	Planar horizontal: B_y = 0 T, B_x = 1.36 T

The magnetic simulation predicts that a very reasonable magnetic field, about 0.7 T in a helical mode and about 1.4 T in a planar mode, can be achieved. One can also notice that in a planar mode the field is twice the value of the field in a helical mode.

INITIAL DESIGN CONSIDERATIONS

Beam Vacuum Chamber Geometry

A Universal SCU utilizes helical windings and therefore naturally accommodates a round beam vacuum chamber. Such round beam chambers are available in a free electron laser (FEL) and are becoming possible in a storage ring with a multi-bend achromat (MBA) lattice. In the case of a beam chamber with a rectangular aperture of about 5-10 mm in the vertical plane and 40-50 mm in the horizontal plane, the helical coil diameters are becoming too large and are therefore resulting in a very small magnetic field on the undulator axis.

Magnetic Structure

An example of a helical SCU undulator developed for the International Linear Collider project is described in [3-4]. As explained above, in the Universal SCU there are two concentric helical magnets. This introduces the necessity of finding a very compact scheme for winding the internal helical structure, including its ends. The winding scheme developed in [4] that uses radial loops for making U-turns in the coil ends, should therefore be significantly modified for a Universal SCU. A novel design is currently being developed at the APS.

The possibility of operating a Universal SCU in a switching mode when direction of polarization can be changed at a frequency above, say, 10 Hz, is another attractive feature of this device. A helical electrical winding is known to have a low inductance [5]. For instance, a helical winding with a period length of 16 mm and a winding diameter of 6 mm has an inductance of only 0.01 µH per period. As a result, a fast switching operation of an electromagnetic helical undulator is possible, and a switching rate of 25 Hz was demonstrated [6]. For a Universal SCU, a limit for a switching rate is likely to come from a superconductor maximum current ramp rate. This requires special consideration.

Cooling Scheme

The superconducting coils of the Universal SCU can be cooled directly or indirectly with cryogen (with liquid helium in cases when low temperature superconductors are used), or conduction cooled. In the former case, a liquid helium (LHe) circuit could be of a closed type as implemented in a planar SCU [7]. Another possibility is to use a powerful cryoplant to supply LHe for the undulator cooling. Such a scheme is likely to be suitable for an FEL with a superconducting linac that itself requires cryoplant. An option of utilizing a cryoplant has the advantage of choosing the cooling scheme with direct cooling of superconducting coils.

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It should be noted that in Universal SCU, a closed geometry of helical coil prevents access to the beam chamber along its length unlike in a planar SCU. As a result, heat deposited by the electron beam onto the beam chamber can only be intercepted at the beam chamber ends, or in the gaps between superconducting magnet sections. Initial thermal calculations at the APS suggest that for a storage ring application where the beam heating is in the range of 5 W/m, the beam chamber should ideally be a low conductivity copper tube with a wall thickness not less than 1 mm, and the heat should be intercepted every 1 m to avoid overheating of the beam chamber by the electron beam.

CONCLUSION

A Universal SCU is a universal double-helical SCU wound with a superconducting wire. The magnetic simulation suggests that a very reasonable magnetic field of about 0.7 T in a helical mode and 1.4 T in a planar mode can be achieved, making such an undulator interesting for electron storage rings with a multi–bend achromat lattice, as well as for FELs.

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