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Common Coil Dipole for High Field Magnet Design and R&D

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The principle thrust of magnet R&D for the next generation high energy hadron collider is developing and demonstrating magnet designs for building higher field magnets in large volume in industry at a lower cost. All accelerators to date have been built on the strength of the cosine theta magnet designs using NbTi and, more recently, Nb_3Sn Low Temperature Superconductors (LTS). These magnet designs are being extended to reach higher fields. Based on a significant body of experience, the cost of carrying out large-scale production based on this design as well as the challenges in obtaining higher fields both in terms of budget and turn-around-time can be estimated. With the next collider several decades away, a case can be made that this time should be used in demonstrating alternate designs that have potential to produce higher field magnets in industry at a lower cost while meeting the field quality requirements of high energy colliders. There is also a need to include a strong R&D component in the program which facilitates testing and demonstration of new conductors and new technologies in a relatively shorter time frame and at a cost much smaller than building a magnet.

The common coil design [1] is a conductor-friendly block coil design with simple ends that have a large bend radius. The bend radius is determined by the separation between the two apertures of the collider rather than the aperture itself. The common coil design easily accommodates high field, brittle conductors or those cables that require large bend radii. The large bend radii in the common coil geometry allows both "Wind & React" and "React & Wind" technologies. The common coil design is a technically superior solution for high field magnets because the coils are primarily stacked vertically and move as a unit against the large horizontal Lorentz forces. This largely eliminates the internal strain on the conductor at or near the end region of the superconducting coils when the two sides of the coil move apart under Lorentz forces – a very different situation as compared to that in the conventional block coil or cosine theta dipole designs. As compared to the conventional block coil designs, the common coil block coil design eliminates almost all of the hard-way bends (or ends requiring long length). The only remaining hard-way bends are in the small pole coils and some designs practically eliminate the hard-way bends in those as well.

The common coil design facilitates a modular geometry which is particularly attractive for hybrid (HTS/LTS) magnet designs which require combining coils made with different types of conductors. In addition, the common coil design also offers easier vertical segmentation that is ideally suitable for hybrid coil dipole designs. Such magnets use coil modules made with made different conductors (Nb_3Sn, NbTi and HTS). In addition, the design provides natural and easier stress management. These features are applicable for both R&D magnets and for large-scale production magnets.

In addition to allowing versatility in conductors and technologies, the common coil design is also one of the most likely candidates to provide lower cost large scale production of high field 2-in-1 collider dipoles with good technical performance. Lower cost in large volume industrial manufacturing is expected because the common coil design would allow less expensive and more reliable production techniques due to 1) its simpler racetrack coil geometry; 2) half the number of coils required (as the same coils are shared between two apertures), and 3) the geometry requires a smaller volume of structural material.

The common coil dipole design was used in an earlier proposal for the Very Large Hadron Collider (VLHC) in the US [2]. The common coil design has also been used [3] in the present proposal of the Super proton-proton Collider (SppC) in China and is one of the designs under consideration for the proposed Future Circular Collider by CIMET [4].

Several institutes including LBNL [5], BNL [6], FNAL [7], IHEP [3] and CERN collaborators at CIEMAT [4] have carried out significant design studies on common coil magnets. Magnets based on the common coil dipole design have been successfully built at LBNL, BNL, FNAL, IHEP and other institutions with a variety of superconductors such as NbTi, Nb_3Sn, Bi-2212, ReBCO and Iron Based Superconductors (IBS). The very first test magnet based on this design at LBNL (RT1) reached short sample with almost no quenches [8]. Similar results were obtained at many other institutions including at BNL [9]. Further tests also showed that the change in pre-stress causes no degradation in performance. A common coil Nb_3Sn dipole (RD3) built using the "Wind & React" technology reached 14.7 T at LBNL [5]. At BNL a "React & Wind" Nb_3Sn dipole DCC017 [6] was built with essentially no vertical and horizontal pre-stress and it reached over 10 T, its computed short sample limit. FNAL [7] and IHEP [10] have also built and tested magnets based on this design. Despite many successes and even though FNAL built and tested an accelerator type field quality common coil dipole, demonstration of a fully optimized, high quality, high field common coil design with reasonable aperture and good technical performance remains to be done.

Hybrid magnets based on the common coil design have also been built and tested. Some examples of hybrid common coil dipole include a 3.7 T dipole at BNL with Bi-2212 and Nb_3Sn Rutherford cables [11] at BNL, a 10.7 T dipole at 4.2 K with Nb_3Sn and NbTi cables at IHEP [10], a 8.7 T dipole at BNL with ReBCO tape in a perpendicular direction to the primary field and Nb_3Sn cable in collaboration with Particle Beam Lasers, Inc. [12], and a 12.3 T dipole at BNL with ReBCO tape in primary field parallel direction and Nb_3Sn cable [13]. Higher field hybrid common coil dipoles under construction include 13-14 T with CORC® cable and Nb_3Sn cable under a collaboration between the Advanced Conductor Technologies, LLC and BNL [14], and HTS (ReBCO or IBS) at IHEP [15]. A common feature of all these dipoles is easy and better optimized segmentation between coils made with a different conductor.

The common coil design also offers an alternate path for building high field magnets with systematic and/or innovative R&D in a rapid-turn-around and lower-cost flexible R&D program for a variety of superconductors and technologies in a modular fashion [16]. Common coil dipoles, such as DCC017 built at BNL [6] with a large opening, allows new racetrack coil modules to be inserted and tested as an integral part of the high field magnet without requiring any disassembly and re-assembly of the magnet [12]. This, however, requires a larger amount of conductor for 2-in-1 magnet unless the insert coil can tolerate a tighter bend radius and is tested in one aperture only [13]. The design allows the same racetrack coil modules (or adding or replacing only some) to make either a higher field, smaller aperture dipole or a larger aperture, lower field dipole - as was done, for example at LBNL between RD3b and RD3c common coil dipole [5].

The common coil geometry provides an alternate design to the conventional cosine theta dipoles. It allows a wider range of conductor and magnet technologies. It also facilitates a low-cost, rapid-turn-around design and R&D program. Therefore, it should be a part of a long-term R&D program of developing high field magnets for high energy hadron colliders.

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