Ultra-radiation-transparent Superconducting Detector Magnets for High Energy Physics

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Introduction

At CERN an effort is underway to further develop conceptual designs for FCC-ee [1], i.e. the future circular collider featuring electron-positron collisions. To study the particles emanating from the collision point, a large superconducting detector magnet is needed that bends the trajectory of the particle products and thus allows for characterization.

For the FCC-ee baseline detector, the FCC-ee collaboration has proposed the so-called "IDEA" concept [2,3]. From a magnetic perspective, this concept features a superconducting solenoid that produces magnetic field over the tracker and an iron return yoke that returns the magnetic flux and allows for the tagging of muons [4,5,6]. The space between the solenoid and the return yoke is filled with calorimeters, and to allow particles to reach these calorimeters from the interaction point with minimal losses, the superconducting solenoid and surrounding vacuum vessel has to be as radiation transparent as possible.

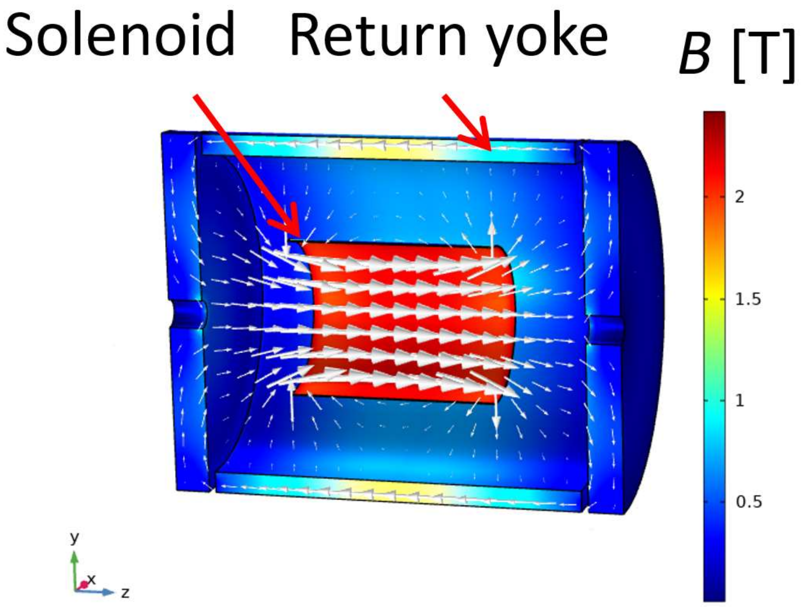

Fig. 1. Magnetic configuration of the FCC-ee IDEA concept [4].

Aluminum-stabilized Nb-Ti conductors

The previously demonstrated concept for making a transparent superconducting detector magnet is to use Nb-Ti Rutherford cables surrounded by aluminum stabilizer with decent mechanical properties [7]. Whereas the ATLAS Central Solenoid features nickel-doped aluminum for a good tradeoff between electrical, thermal, and mechanical properties [7], the Compact Muon Solenoid features a pure aluminum stabilizer for excellent electrical and thermal properties, and an aluminum alloy welded to the sides of the conductor for mechanical reinforcement [8]. In recent years it was shown that these two concepts may be combined leading to the highest yield strength conductor (Fig 2) [9]. For the welding, electron-beam welding and stir-friction welding were investigated (Fig. 2) [9,10]. It is proposed to utilize this conductor to reach maximum achievable particle transparency for FCC-ee.

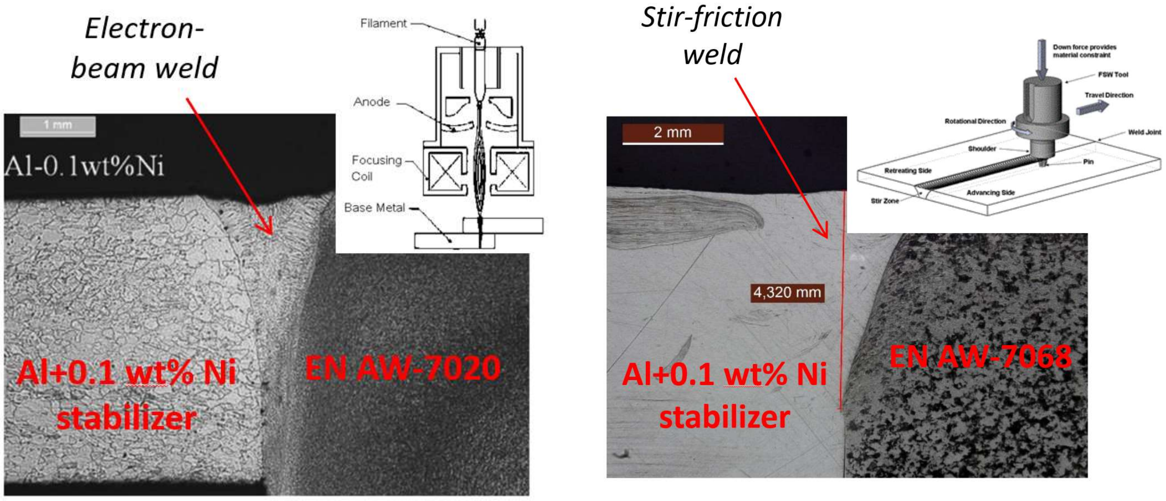

Fig 2. Aluminum-stabilized high-yield stress Nb-Ti conductor concept featuring nickel-doped aluminum and 7000 series aluminum welded to the sides of the conductor [9]. The original concept relied on electron-beam welding , and subsequently the possibility of stir-friction welding has been explored as well [10].

Another important aspect for maximum particle transparency is the vacuum vessel. Mechanical analyses were performed to compare different classical metal based vacuum vessel options, where an aluminum honey-comb structure was found to be the most optimal solution [11].

HTS-based ultra-transparent superconducting solenoids

In addition to the more traditional Nb-Ti-based variant for FCC-ee, we are also exploring the use of high-temperature-superconducting materials for ultra-transparent solenoids. In order to develop this type of magnet further, we are participating in a collaboration with the RWTH Aachen University, Paul Scherrer Institute, and University of Geneva to develop a very innovative and challenging superconducting spectrometer magnet for a detector called AMS-100 [12]. This magnet is to be used in space using radiation-to-space for cooling. The resulting operating temperature of 50 to 60 K requires the use of HTS-based conductors which remain superconducting at significantly higher temperatures than Nb-Ti. Like FCC-ee, AMS-100 requires maximal particle transparency to study highly energetic space particles with minimal losses.

The conceptual development of AMS-100 is of interest for FCC-ee, as both magnets are solenoids and require maximal particle transparency. For FCC-ee the ability to operate at higher operating temperatures would result in less complex and power-consuming cryogenics. This may thus give the potential for cost-reduction over the life-time of the magnet. However, as the quench behaviour of HTS-based magnets is different from LTS-based magnets, studies are needed to develop a thorough understanding.

Ongoing developments and future plans

For the Nb-Ti-based FCC-ee detector magnet we have performed studies in recent years, which include preparation of a preliminary conceptual design of the magnet [4], welding studies for the aluminium-stabilized conductor [10], and mechanical analyses of the vacuum vessel [11]. In the coming years we intend to further refine the designs and engineer how to produce the conductor and the magnet as a whole.

The research for AMS-100 has started last year. Presently we are working towards making a small demonstrator coil. A simulation model is under preparation to study the highly complex transient - and quench behaviour of the controlled-resistance solenoid, and the experimental results of the demonstrator coil are to be used to validate the simulation model. Furthermore, we are looking into the mechanics, fabrication, conductor aspects, and quench behaviour of the full-size AMS-100 coil.

Possibilities for collaboration

We are interested in collaborations featuring synergies towards the development of advanced aluminum-stabilized Nb-Ti and HTS conductors for detector magnets.

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