An Alternative Conductor Design for the K-DEMO Toroidal Field Coils

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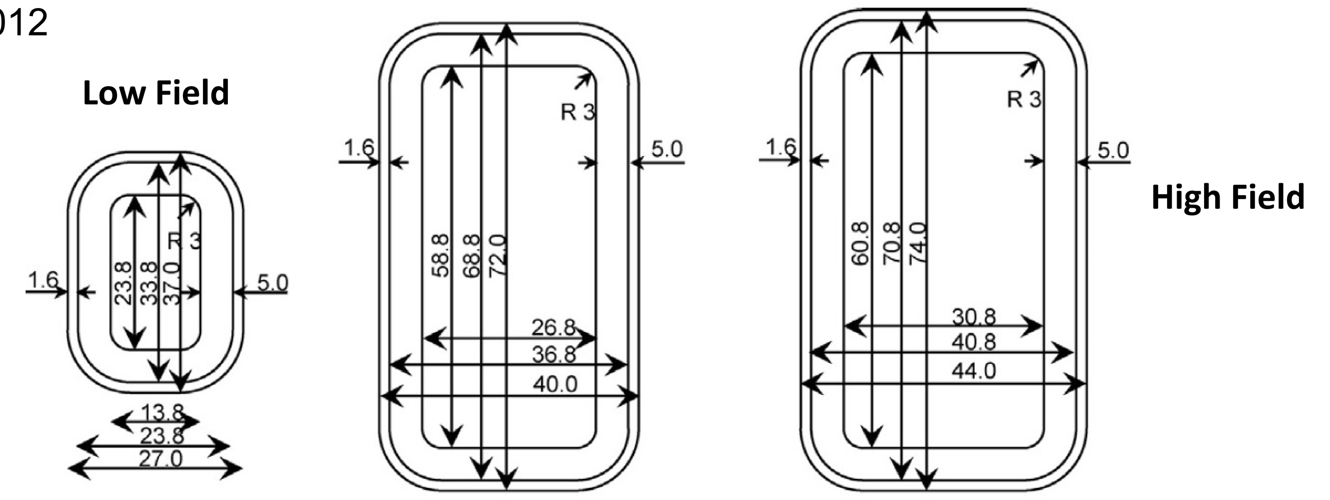
Abstract : The conceptual design for the superconducting coils of the K-DEMO tokamak has been proposed and continues to be updated. The toroidal field coils rely on Nb_3Sn technology with new generation high J_c strand. The design is that of a cable-in-conduit conductor (CICC) consisting of multistage Nb_3Sn cable inside a rectangular stainless steel jacket. There are huge Lorentz forces on the cable due to the large currents and magnetic field. A large aspect ratio for the rectangular conductor is proposed to reduce the accumulative pressure on the cable strands. Further increases in the aspect ratio would be advantageous. However, manufacturing such a conductor in a conventional way would be difficult as compaction of a cable to extreme aspect ratios damages the strands. To overcome this limitation, an alternate cable design for the conductor is proposed. The perceived advantages and expected difficulties and required complications of the design are discussed.

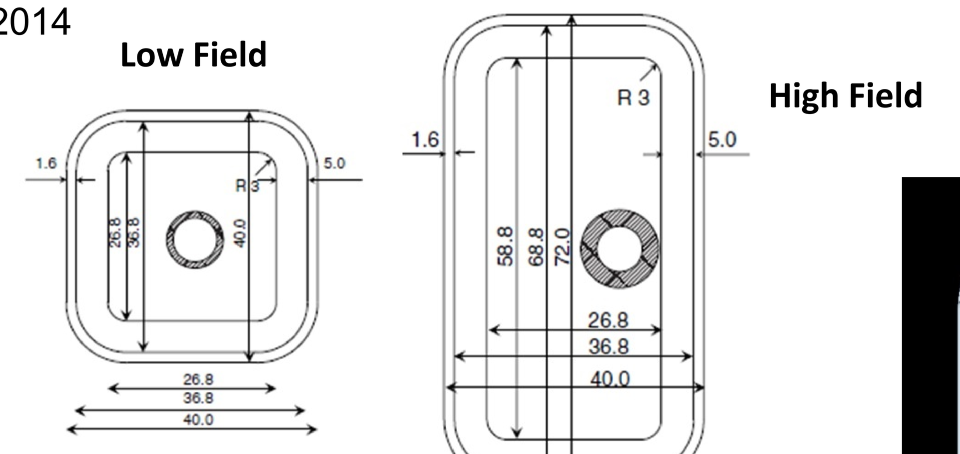
1. Introduction

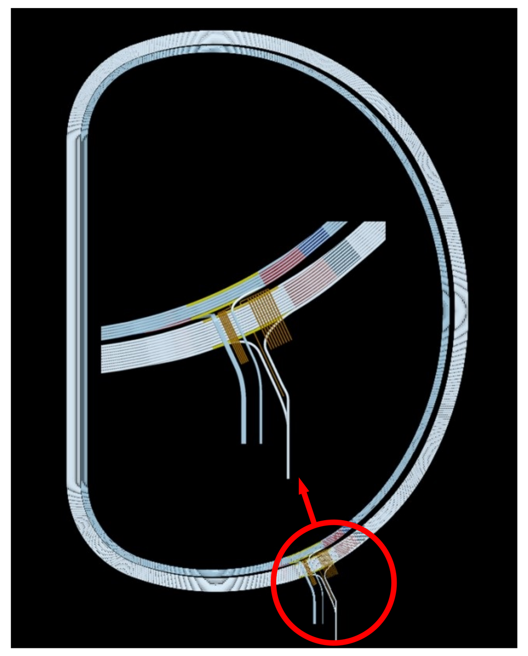
◆ **Evolution of the K-DEMO TF coil conductor design**

- 2012



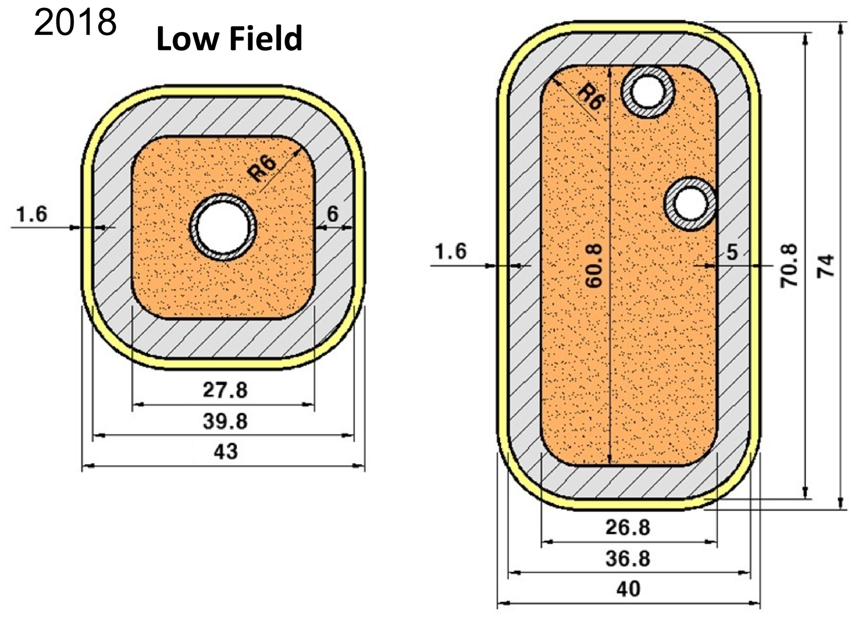
- 2014





K-DEMO TF coil

- 2018

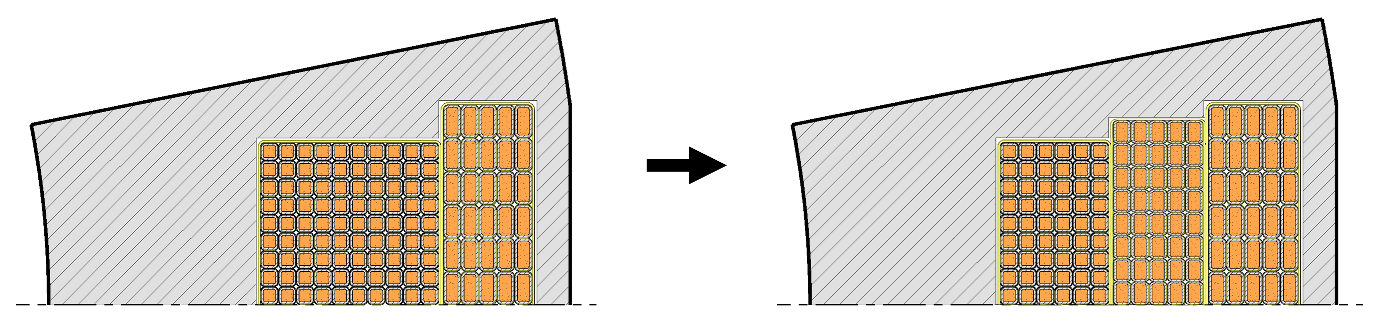


◆ **Current K-DEMO TF coil conductor specifications**

Characteristic	Low Field	High Field
Number of Nb_3Sn (SC) strands	360	1800
Number of Cu strands	402	0
Cable pattern	((2SC + 2Cu) × 5 × 6 + 7Cu) × 6 + CS	3SC × 4 × 5 × 6 × 5 + 2 CS
Nominal current (kA)	65.52	
Cooling Spiral (CS) dimensions (mm)	5 (inner diameter) / 8 (outer diameter)	
Strand diameter (mm)	0.82	
Nb_3Sn current density @ 12 T, 4.2 K (A/mm²)	> 2600	
Nb_3Sn strand Cu/non-Cu ratio	1.0	

2. Further Design Considerations

◆ **Addition of a middle field winding pack**



K-DEMO TF coil in-board leg cross section

◆ **Issues**

- Proposed mid field CICC outer dimensions: 36.0 mm × 50.0 mm
- Maintain overall TF coil dimensions and space for joints, leads & feedthroughs
- Larger CICC aspect ratios advantageous with respect to Lorentz force mitigation
- CICC void fraction needs to remain low for good CICC performance

3. Alternative CICC Cable Design

◆ **Strategy**

- Allow for limited increases of the aspect ratio in the high field CICC
- Use conventional cabling methods (without having to rely on Rutherford type cabling)
- Prevent excessive cable deformation that may lead to strand damage

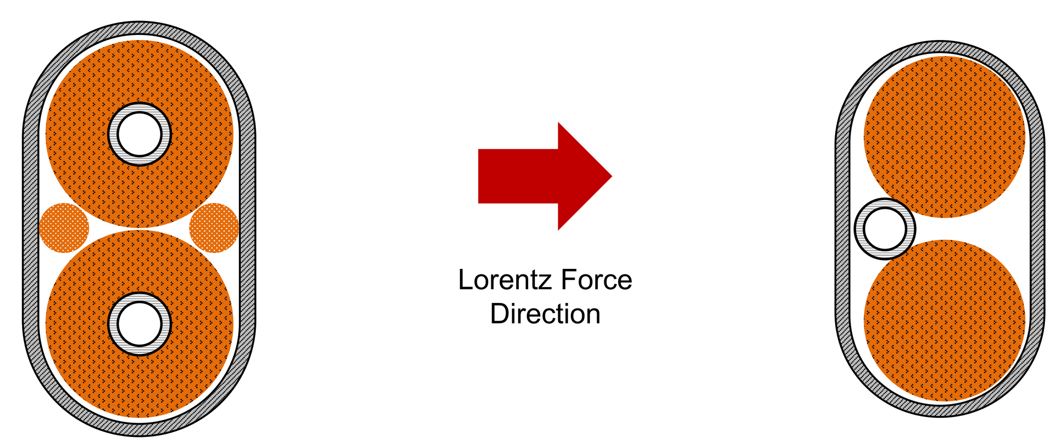
◆ **Proposed solution**

- Divide single CICC cable into 2 subcables (bi-cable)
- Appropriate for CICC cable aspect ratios from 2:1 to 5:1
- Less cable deformation per subcable with respect to single cable design

◆ **Expected disadvantages**

- Full transposition of cable strands not possible
- Higher AC losses and diminished current sharing than single cable design
- Racetrack shaped initial jacket cross section before compaction and shaping

1) ITER like twist pitch bi-cable **2) Long twist pitch bi-cable**



(3SC × 3 × 4 × 5 × 5 + CS) × 2 + (3Cu × 3 × 4) × 2
45 – 85 – 125 – 245 – 435
With subcable wraps

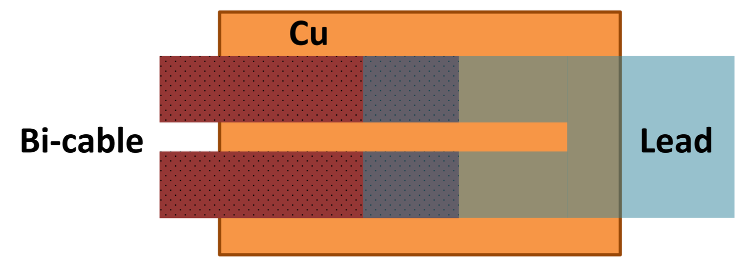
(3SC × 3 × 4 × 5 × 5) × 2 + CS
120 – 140 – 170 – 200 – 230
No subcable wraps

4. Cable Joint Interface

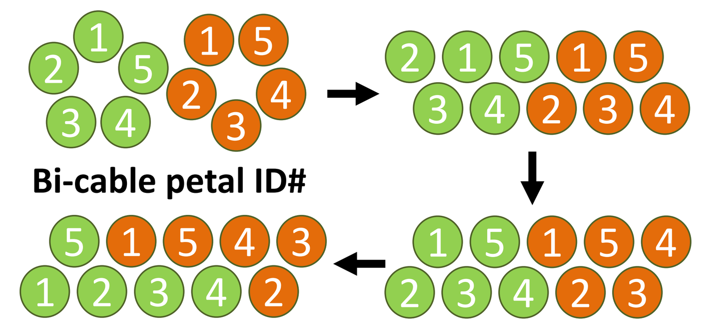
◆ **Resolving the bi-cable to single joint connection**

- Current balancing between subcables
- Single joint for a single CICC
- Current balanced joints or combining the 2 subcables into a single cable near the joint

1) Long lead joint



2) Rutherford cable conversion



5. Future Plans

◆ **Short Term**

- Finalize cable design
- Produce Cu dummy prototypes
- Destructive examination of dummy CICC samples for strand damage and void fraction measurements
- Investigation of CICC jacketing approaches

◆ **Long Term**

- Design rectangular Nb_3Sn CICC samples with standard ITER cable material using same strategy
- Produce equivalent Nb_3Sn CICC samples as those of ITER TF or CS CICC
- Perform low temperature performance testing of Nb_3Sn CICC samples at ITER conditions (SULTAN testing)
- Produce long length jacketed CICC samples

SPC SULTAN Facility
at PSI in Villigen, Switzerland

6. References

[1] K. Kim *et al.*, "A preliminary conceptual design study for Korean fusion DEMO reactor," *Fusion Eng. Design*, vol. 88, no. 6-8, pp. 488-491, October 2013.
[2] K. Kim *et al.*, "Conceptual design study of the K-DEMO magnet system," *Fusion Eng. Design*, vol. 96-97, pp. 281-285, October 2015.
[3] H. W. Kim *et al.*, "Design updates of magnet system for Korean fusion demonstration reactor, K-DEMO," *Fusion Eng. Design*, vol. 146, Part A, pp. 1086-1090, September 2019.
[4] A. della Corte *et al.*, "Successful performances of the EU-AltTF sample, a large size Nb_3Sn cable-in-conduit conductor with rectangular geometry," *Supercond. Sci. Technol.*, vol. 23, no. 4, Apr. 2010, Art. no. 045028.
[5] P. Bruzzone *et al.*, "Test results of two European ITER TF conductor samples in SULTAN," *IEEE Trans. Appl. Supercond.*, vol. 18, no. 2 , pp. 1088-1091, June 2008.
[6] L. Muzzi *et al.*, "Design, Manufacture, and Test of an 80 kA-Class Nb_3Sn Cable-In-Conduit Conductor With Rectangular Geometry and Distributed Pressure Relief Channels," *IEEE Trans. Appl. Supercond.*, vol. 27, no. 4, June 2017, Art. no. 4800206.

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