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Design of DEMO PF Coils

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Abstract

- Proposed Design of EU Demo PF coils is based on EUROfusion 2018 baseline. DEMO PF coils are larger in radius compared to ITER PF coils.
- Conductor is rectangular CICC, forced flow, based on
  - NbTi: 40 % void fraction + no separated cooling channel.
  - Nb_3Sn: 29 % void fraction + separated cooling channel.
- In the proposed work:
  - Electromagnetic analysis on 3-dimensional geometry.
  - Mechanical analysis on 2D axisymmetric geometry.
- In proposed work we compare:
  - Layer winding technique to pancake winding technique.
  - Nb_3Sn conductor to NbTi conductor for PF1 and PF6 coils.
- The WP pack dimensions have increased proportional to increase in current in new baseline.

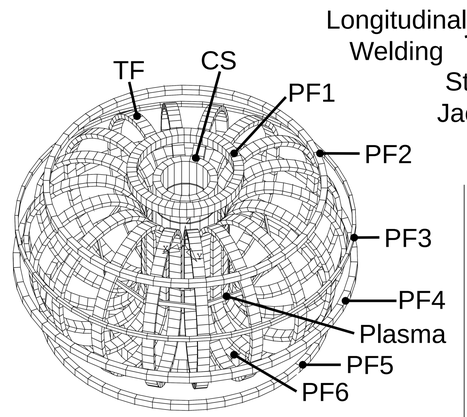
Design Methodology

Electromagnetic Analysis

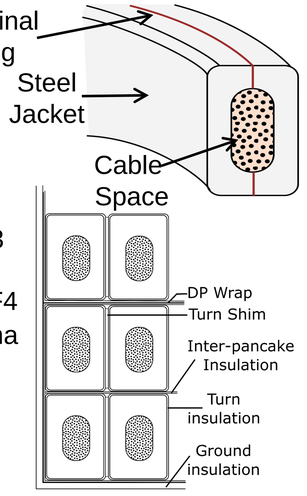
- Full 3-dimensional calculations using M'C (Cryosoft) module. All the coils, as well as, plasma is present.
- 3 Current States: Pre-magnetization (Premag), Start of Flat top (SOF), End of Flat top (EOF) [1].

Mechanical Analysis

- FE simulations are performed on 2D-axisymmetric geometry in ANSYS. Consequently, TF coils are not simulated.
- Cool down from room temperature to 4.5 K.
- Mechanical properties of the winding pack are taken from [2], [3].
- Primary membrane stress (Pm), Primary membrane + Bending stress (Pm+B), and Hoop stress are then calculated.
- Hoop stress limit is determined from Fatigue stress analysis which assumes 20,000 fusion cycles; SS316 LN conductor jacket; 2.0 mm^2 surface crack and 5.0 mm^2 embedded crack in jacket, 240 MPa residual hoop stress from butt joint.



3D geometry for Electromagnetic calculations in M'C.



Conductor layout

**Plasma is modeled as rectangular cross-section coil in center: H=500mm, W=200mm, I_{plasma}=17.86 MA*

Proposed Design

WP Geometry

Coil	Coil radius (m)	WP Height X Width (mm)	Conductor Height X Width (mm)	Cable Height X Width (mm)
PF1	5.40	1002 X 1001	66.4 X 45.3	45.4 X 24.3
PF2	13.84	630 X 523	57.4 X 46.7	39.4 X 28.7
PF3	17.71	740 X 579	56.3 X 42.9	44.3 X 30.9
PF4	17.83	821 X 820	63.1 X 43.3	51.1 X 31.3
PF5	13.77	771 X 770	58.9 X 46.3	40.9 X 28.3
PF6	7.00	1205 X 1205	62.1 X 47.7	41.1 X 26.7

Conductor Layout and EM Parameters

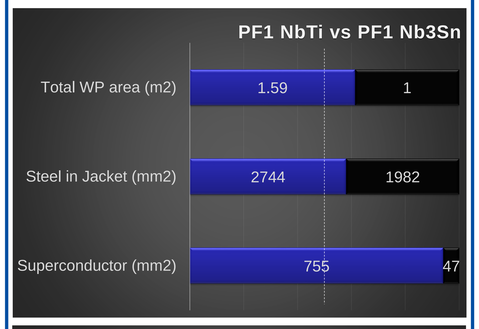
PF1 and PF6 use Nb_3Sn

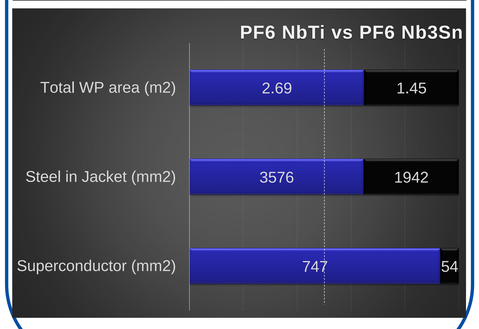
Coil	I_{op} max (MA)	No of turns	No of layers	B_{eff} (T)	Inductance (H)
PF1	16.53	14	20	7.99	1.37
PF2	5.89	10	10	4.68	0.71
PF3	8.47	12	12	5.85	1.94
PF4	12.03	12	17	6.14	3.71
PF5	9.91	12	15	5.43	2.13
PF6	24.03	18	23	9.00	4.00

Stresses in WP

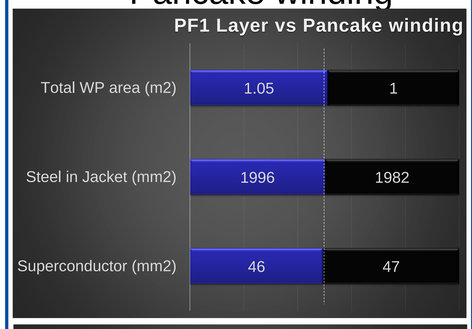
Coil	Max Pm (MPa)	Max Pm+B (MPa)	Max Hoop Stress (MPa)	Max allowable Hoop (MPa)	Plasma cycles until break	Limiting Scenario
PF1	289	323	276	339	36200	Premag
PF2	266	277	267	321	34550	EOF
PF3	219	232	228	267	31183	EOF
PF4	260	293	240	267	27250	Premag
PF5	271	285	271	321	33211	EOF
PF6	284	313	276	339	36400	Premag

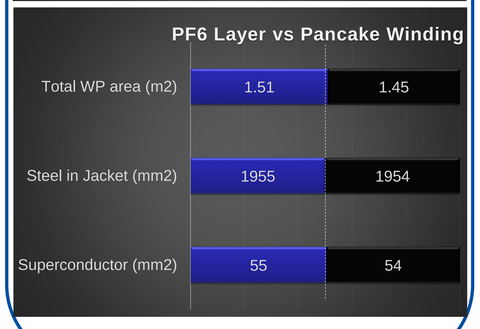
NbTi vs Nb_3Sn





Layer winding vs Pancake winding





Conclusions

- PF coils are pancake-wound unlike previously proposed design. The WP dimensions have also increased proportionally to current.
- The optimized WP dimensions so obtained are mainly driven by magnetic field distributions and mechanical fatigue stress limits.
- The Nb_3Sn based conductors proposed for PF1 and PF6 coils have provision for separated cooling channel and have therefore smaller void fraction (29%) in the remaining cable space as compared to NbTi based conductors (40%) proposed for PF2-PF5 coils which have no separated cooling channel.
- For PF1 and PF6, Nb_3Sn based design makes WP more compact and lighter. NbTi based design makes PF1 and PF6 coils huge and heavy.
- No significant difference in dimensions of WP between the layer-wound and pancake-wound coils.
- A full 3D mechanical analysis and thermal hydraulic analysis is currently being performed.

References

[1] R. Kembleton, https://idm.euro-fusion.org/?uid=2N622S.

[2] F. Nunio *et al.*, https://idm.euro-fusion.org/?uid=2MC8T4.

[3] ITER Structural Material Database, https://user.iter.org/?uid=223BAC.

EUROfusion

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