Modelling of MgB_2 Conductors for Low Field Coils and Feeders for Future Fusion Energy Reactors

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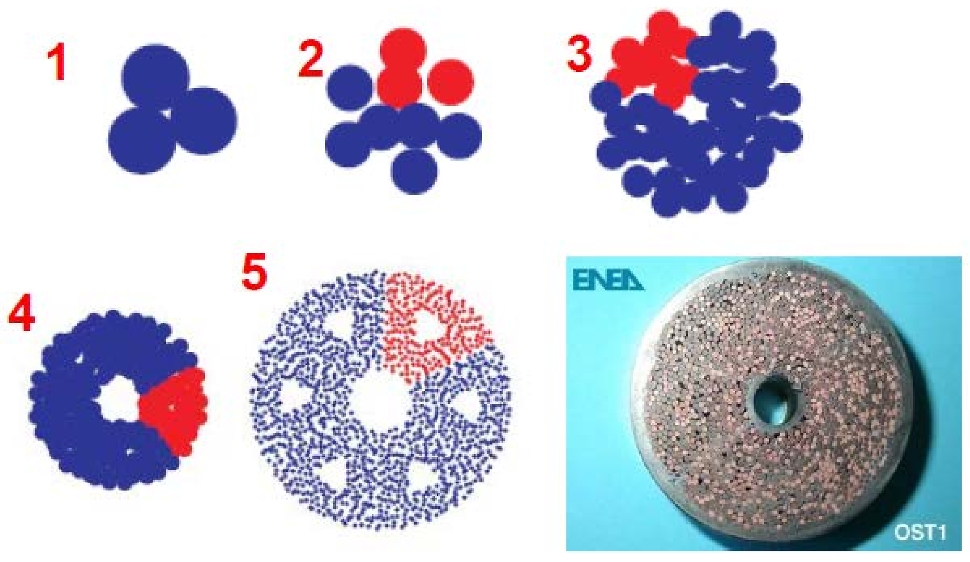
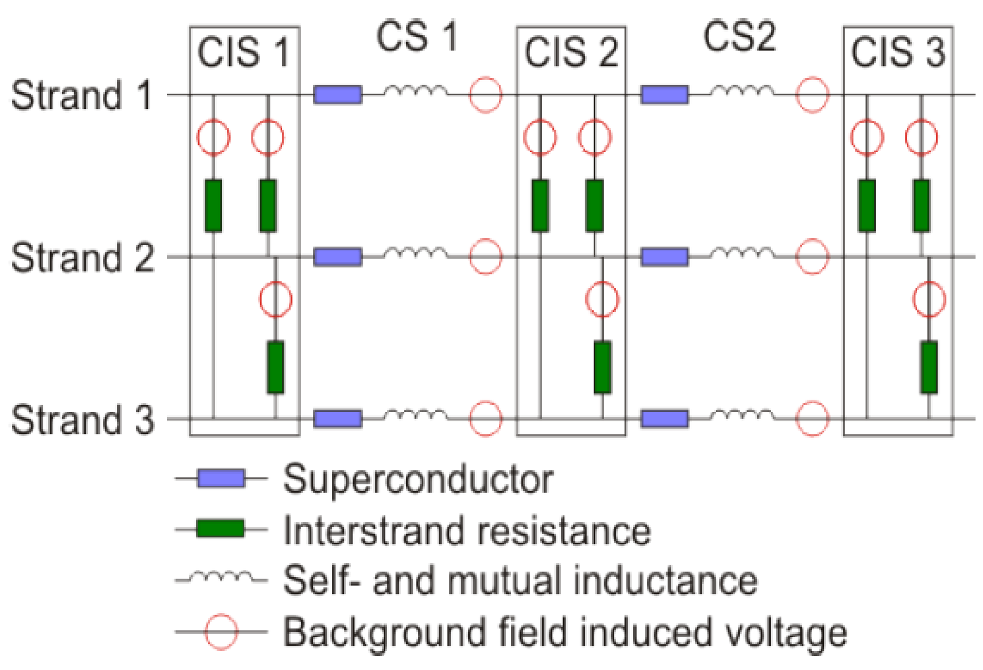
Introduction

A CabToday NbTi is the undisputed superconductor for use in the Poloidal Field coils (PF), Correction Coil (CC), graded Toroidal Field (TF) coils and Feeders of a fusion machine. However, a major advantage of MgB_2 is its higher operating temperature and larger temperature margin. The larger temperature margin allows cost reduction of the cryogenic system and improvement of reliability.
le-In-Conduit Conductor (CICC) concept is adopted with a strand cable pattern designed for minimum inter-strand coupling loss to limit the heat load and maximum strand mechanical support to avoid degradation from thermal and electromagnetic stress. The lead for the design and eventual test is a full-size MgB2 PF conductor.
The prospective to use state of the art MgB_2 strands for the PF and CC superconductors of a fusion device is analyzed with the code JackPot-ACDC. The strand critical parameters for second-generation multi-filamentary HyperTech MgB_2 strand with a diameter of 0.83 mm serve as a critical input for the analysis of the computed conductor performance. The predicted MgB_2 PF CICC performance is compared with the requirement of the present ITER PF design with maximum operating current of 45 kA and nominal peak field of 6 T.

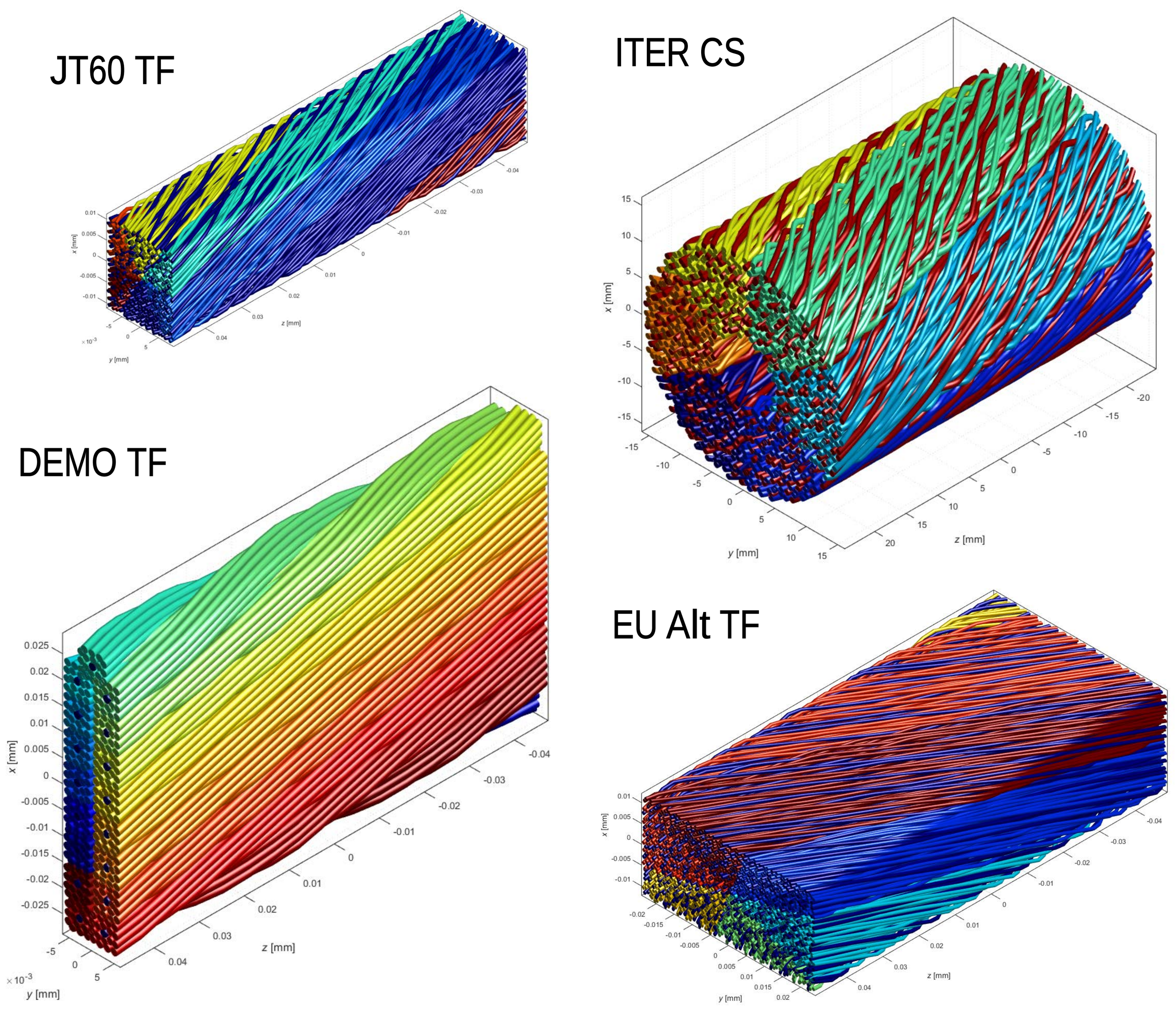
JackPot AC/DC: CICC modeling

Cable-In-Conduit Conductors (CICCs) are made by hundreds of superconductive strands twisted and compacted together around a spiral into a stainless steel jacket. The code JackPot AC/DC is able to reproduce the complete geometry of a CICC and it calculates all the trajectories of all the strands (>1000).



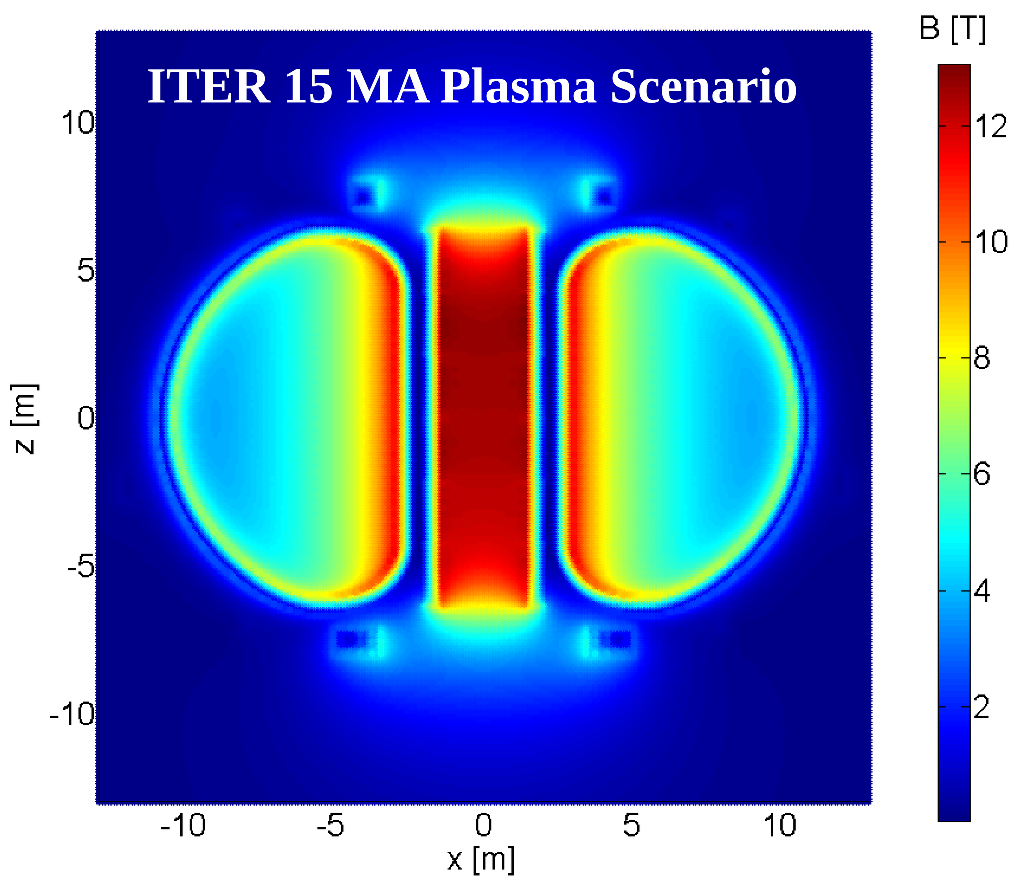


JackPot creates a network of superconductor and resistive elements, whereby it calculates mutual inductances, contact resistances and coupling with the background field and self-field; all the quantities are obtained from geometry and experiments, thus there are not free parameters in the model.



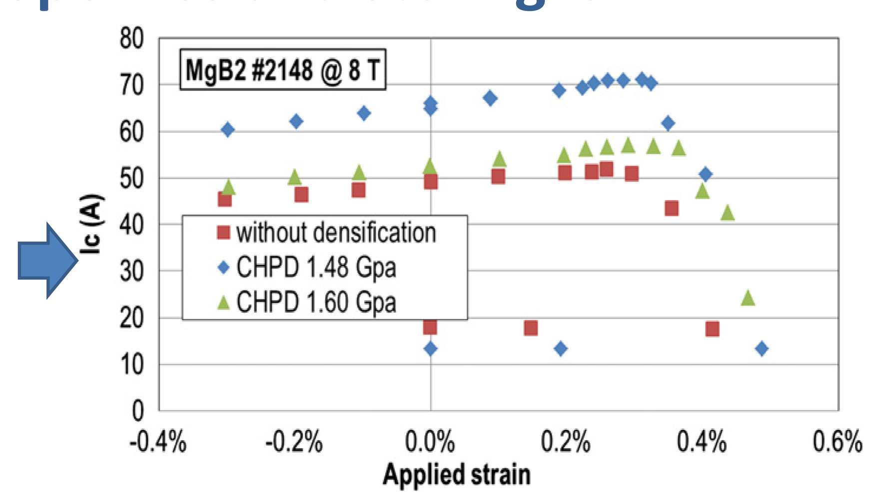
JackPot AC/DC: Coil Modeling

JackPot is able to model the tokamak structure and to calculate the magnetic field in every point. The coil routine starts from the real structure and dimensions of the magnets, it reproduces the winding pack of every pancake and using the plasma scenario current distribution it calculates the magnetic field during the plasma scenario. This routine is not only able to model the ITER magnets, but it is adaptable to different coil configurations and scenarios.



MgB_2 Strand properties and scaling law

Strain measurements on the HyperTech's strand: the Irreversibility limit for the tensile stress ≈ +0.3 / +0.4 %

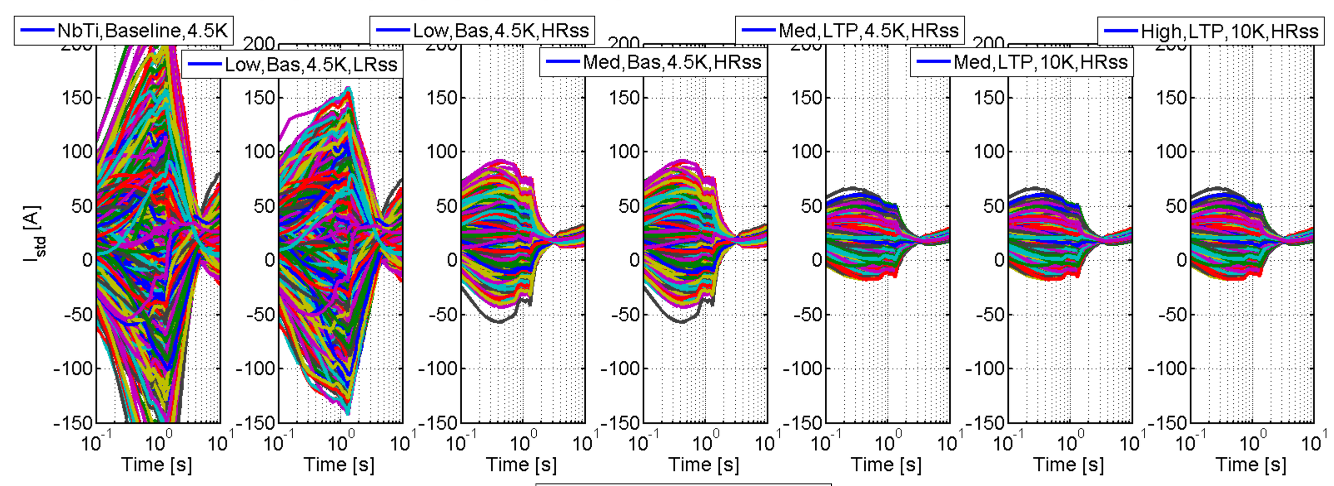


The MgB2 scaling law is define using the Kramer-Dew-Hughes model of grain boundary pinning, adapted for the Hyperech's strand:

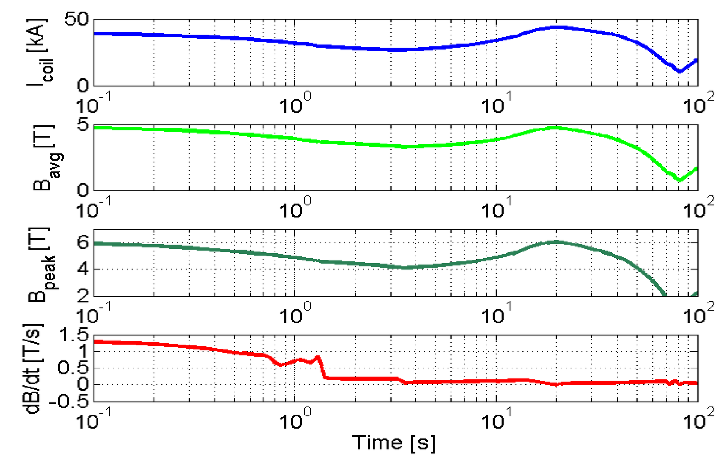
$$J_c(B) = F_m \frac{\left[1 - \frac{B}{B_{\rho=0}}\right]^2}{\sqrt{B_{\rho=0} \cdot B}} \left(\frac{p_{SC} \cdot p(B) - p_c}{1 - p_c}\right)^\alpha$$

JackPot AC/DC - MgB_2 PF Coil - 15 MA Plasma Scenario

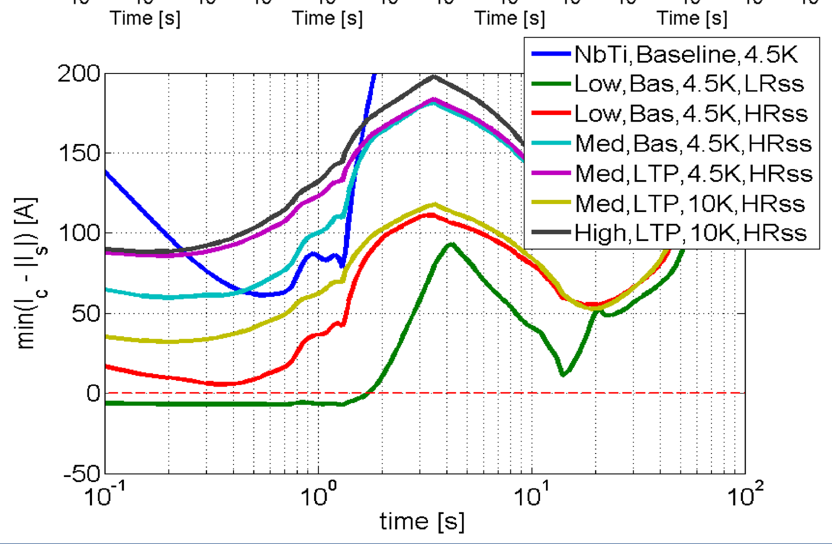
Boundary Conditions			
	Low, Baseline, 4.5K, LRss	Medium, Baseline, 4.5K, HRss	High, LTP, 10K, HRss
Type of strand	Low(C1)	Medium	High
# SC strands	1440	1440	1440
Pattern	3_{Sc}x4x4x5x6	3_{Sc}x4x4x5x6	3_{Sc}x4x4x5x6
Twist pitch $[mm]$	Baseline 45/85/145/250/450	Baseline 45/85/145/250/450	LTP 110/118/126/140/352
T_{op} $[K]$	4.5	4.5	10
IS - resistivity ρ_{ss} $[\mu\Omega/m^2]$	$30 * 10^{-6}$	$159 * 10^{-6}$	$159 * 10^{-6}$



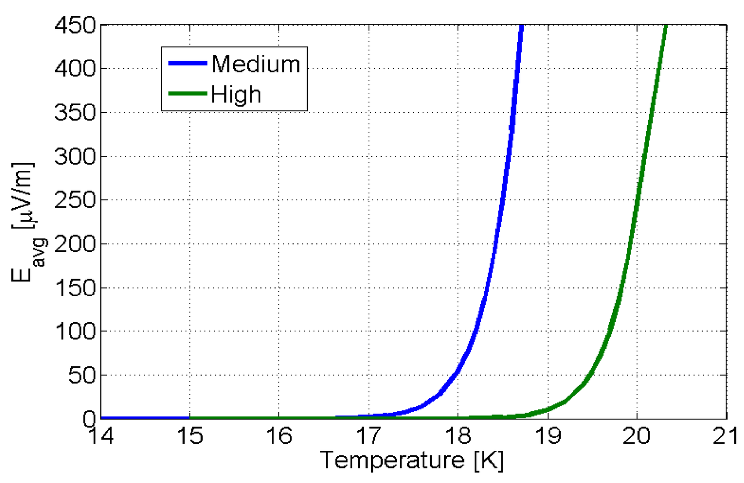
Transport and coupling current during the first 10s of the 15MA plasma scenario at different boundary conditions



15 MA Plasma scenario conditions



Current margin comparisons between MgB_2 CICCs and $NbTi$



T_{cs} simulation of Medium and High MgB_2 strands at $B = 5\,T, I = 45\,kA$

Conclusions

- MgB_2 has an high adaptability to a larger spread of temperatures than $NbTi$, keeping high performance over 15 K in most demanding PF coil.
- For lower field coils (PF, CC) and feeders the operating temperature could be up to 20 K.
- AC Loss reduction choosing the cable scheme optimization, LTP (Long Twist Pitch) has lower losses than the ITER Baseline.