4LP1-04

Finite Element Analysis of the mechanical conditions of the Nb_3Sn cable of the 11T dipole magnet during operation

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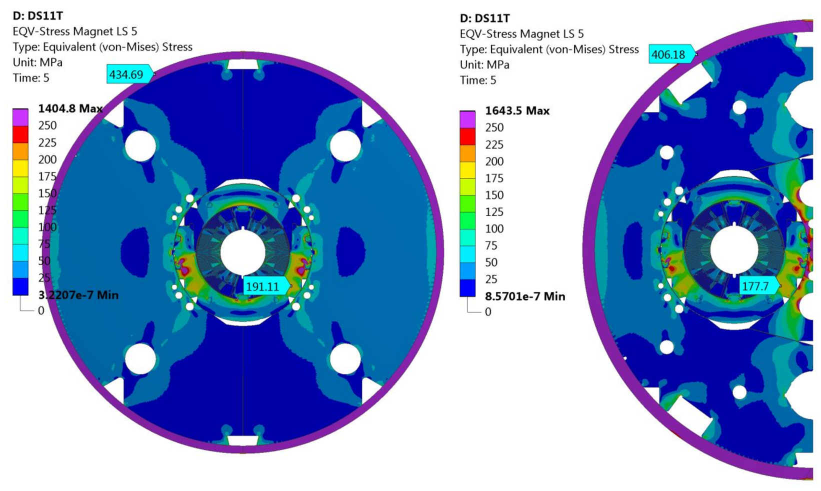
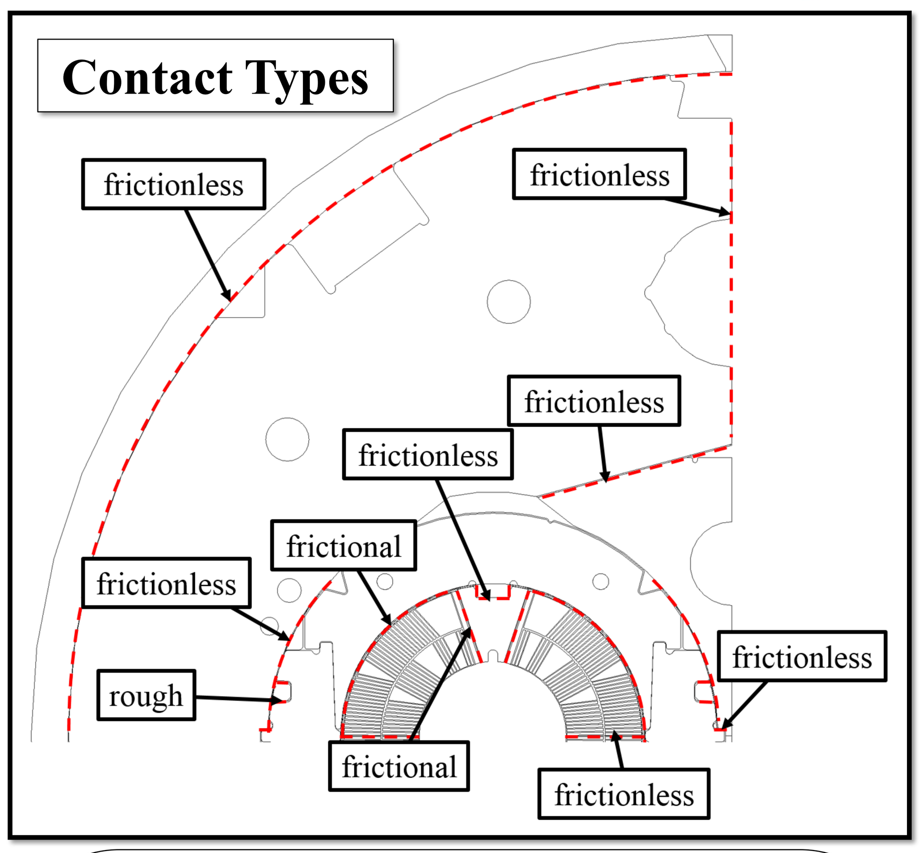
Introduction

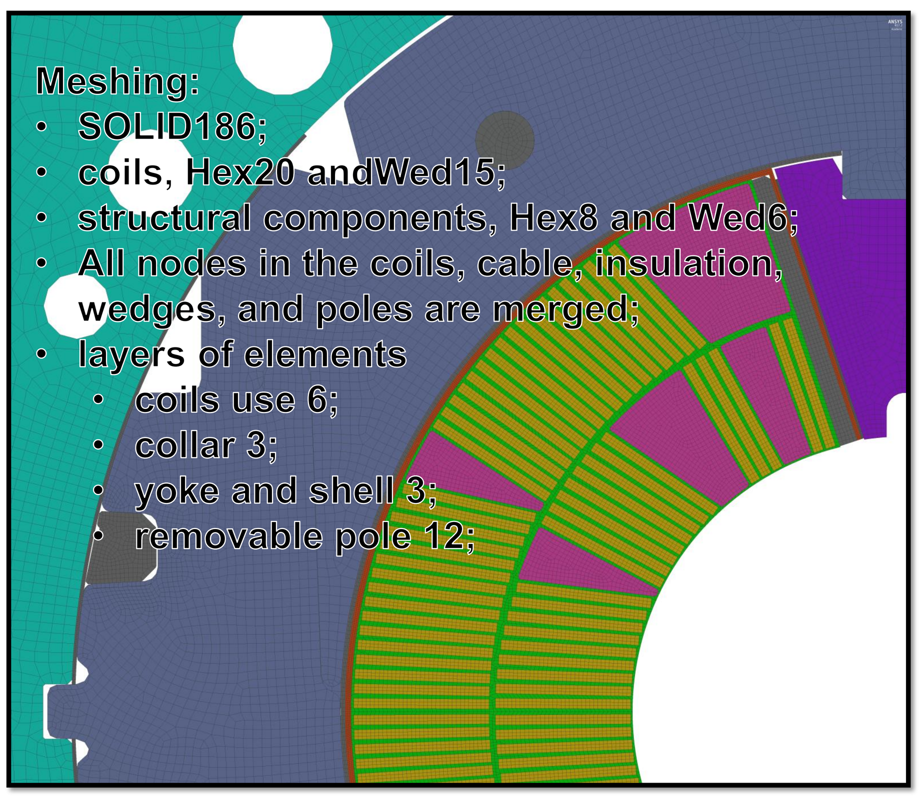
The mechanical design of the DS11T dipole magnet features two-layer Nb3Sn half-shell-type coils, cosine theta design, stainless-steel collars, and a vertically split iron yoke covered by a stainless-steel skin. The collars are laminated pieces of 3mm thickness, while the yoke laminations have a thickness of 6 mm. The key-feature of the DS11T is the removable pole piece, which is able to move relative to the coil. The mechanical link between the collars and the pole face of the coils is the removable pole. This design concept is inspired by the MFISC model.

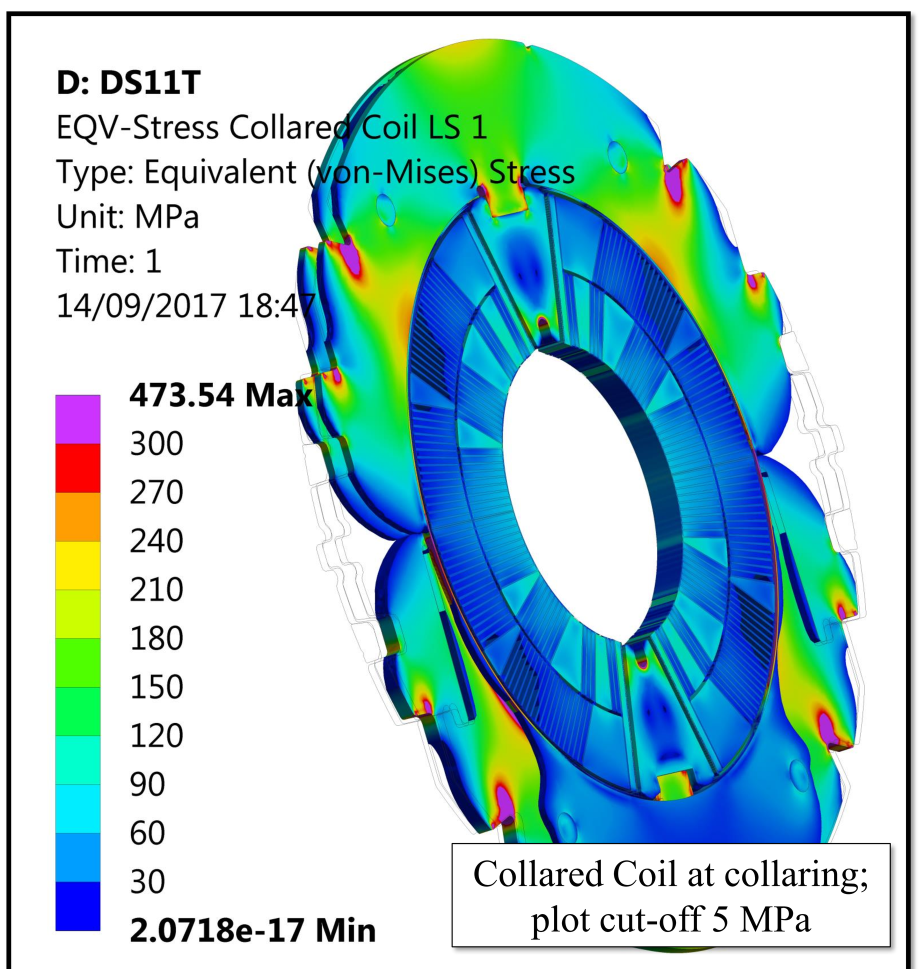




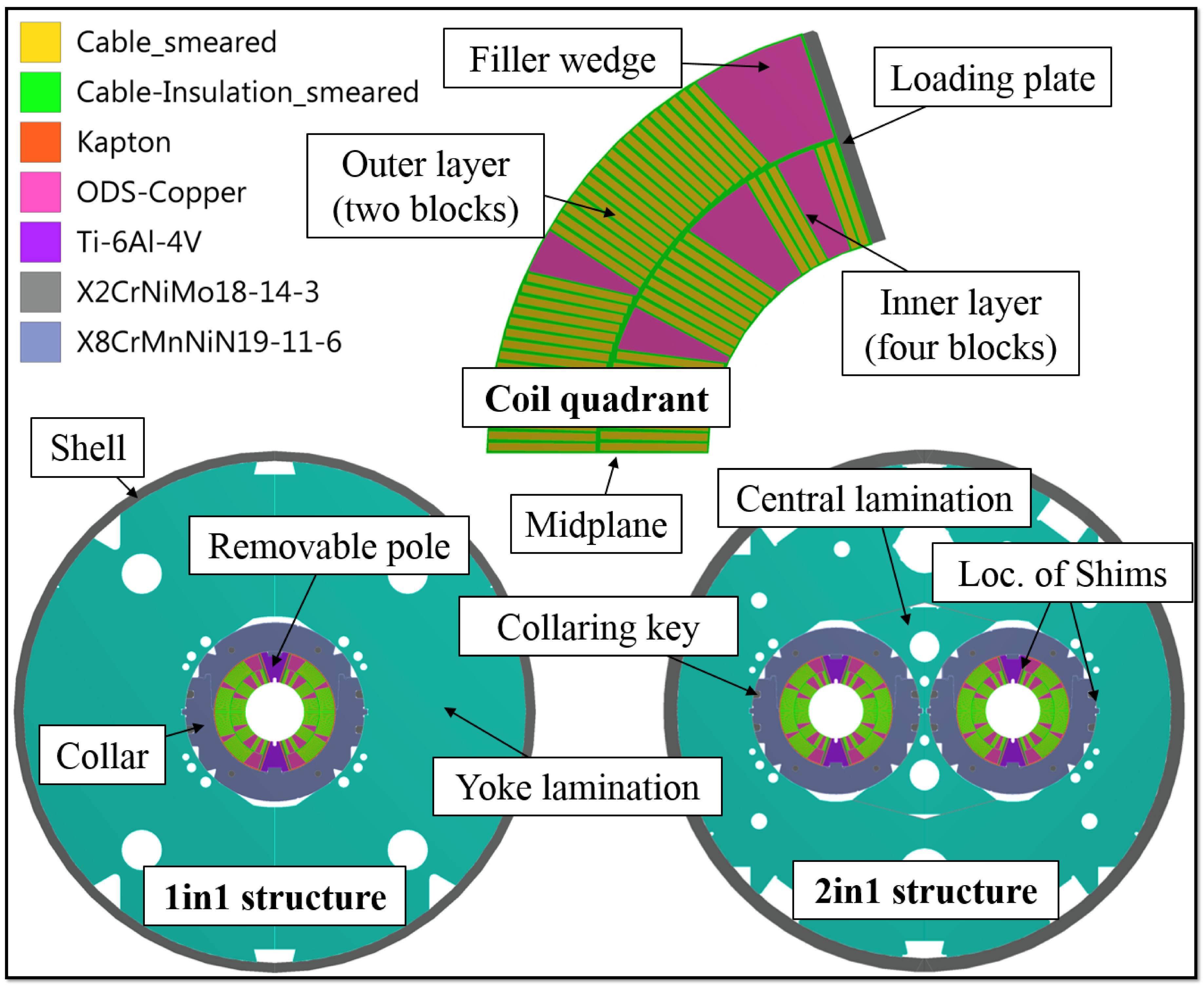
The Finite Element Model

Two finite element models—one for each structure—are used. The models have exactly the same geometry and boundaries for the collared coil; only the yoke structure and the shell are changed. A 3D model is used to represent a 6mm thick cross-section of the magnet, to realistically depict the influence of the interleaving collars. The longitudinal boundary shows plane strain and no thermal shrinkage.





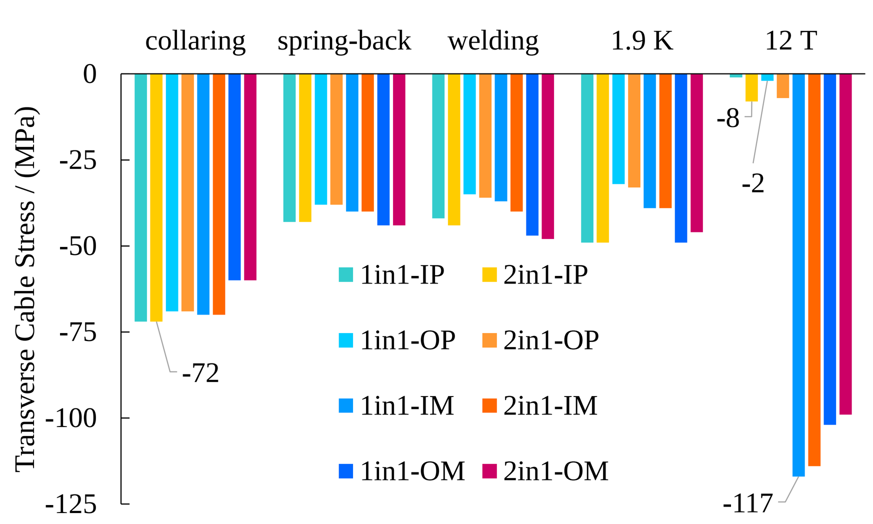
Collared Coil at collaring; plot cut-off 5 MPa



Load Steps used for the FEA

LS	Name	Description
1	Collaring	Collars move vertically by 0.2 mm
2	Spring-back	Displacement boundary on the collars is removed, contact of the collaring key is activated
3	Welding	Contact between yoke and collars is activated, half-shell is "shrunk" by 1.2 mm
4	Cool-down	Cool down of all components to 1.9 K
5	Excitation	Powering to 12 T; 12.8 kA

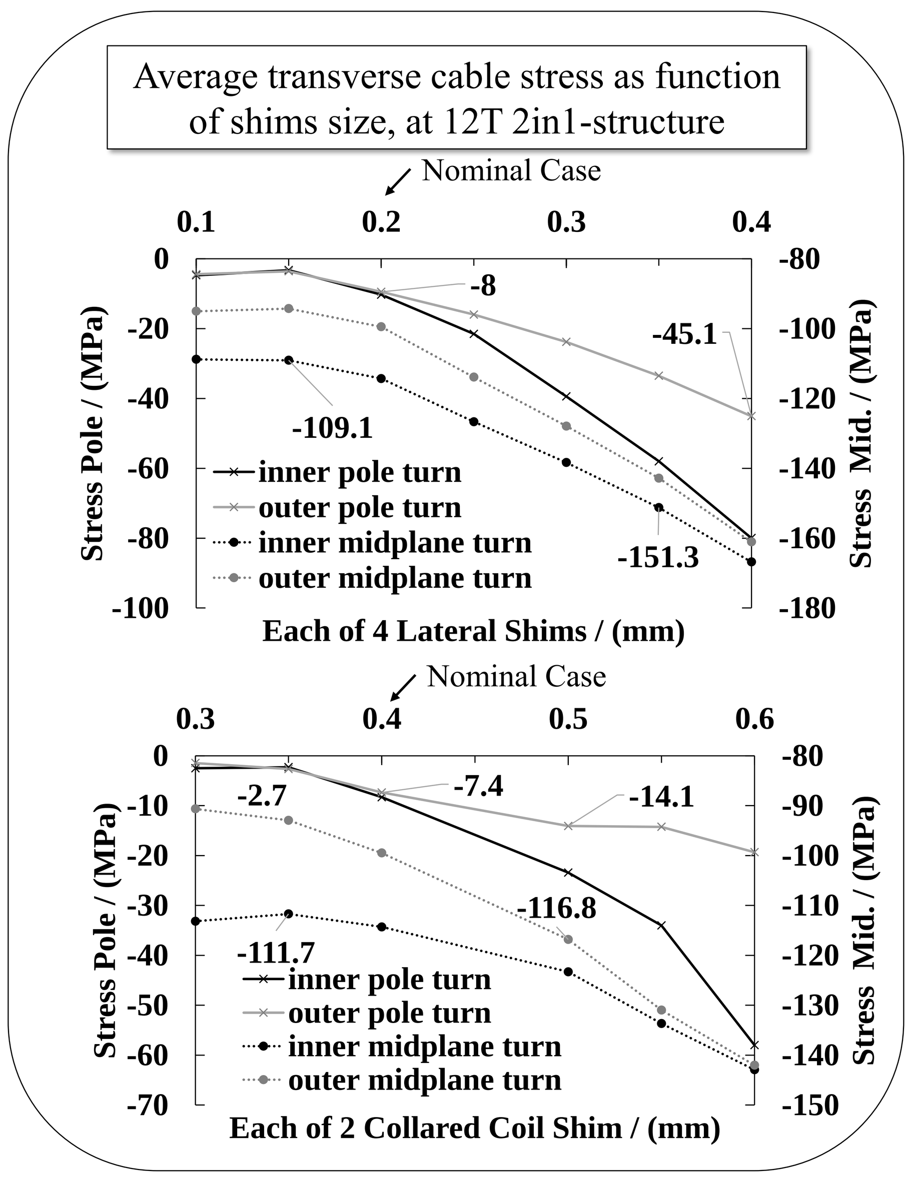
Transverse Cable Stress during assembly and excitation; 1in1 vs. 2in1 structure



IP-inner layer pole; OP-outer layer pole
IM-inner layer midplane; OM-outer layer midplane

Nominal Case

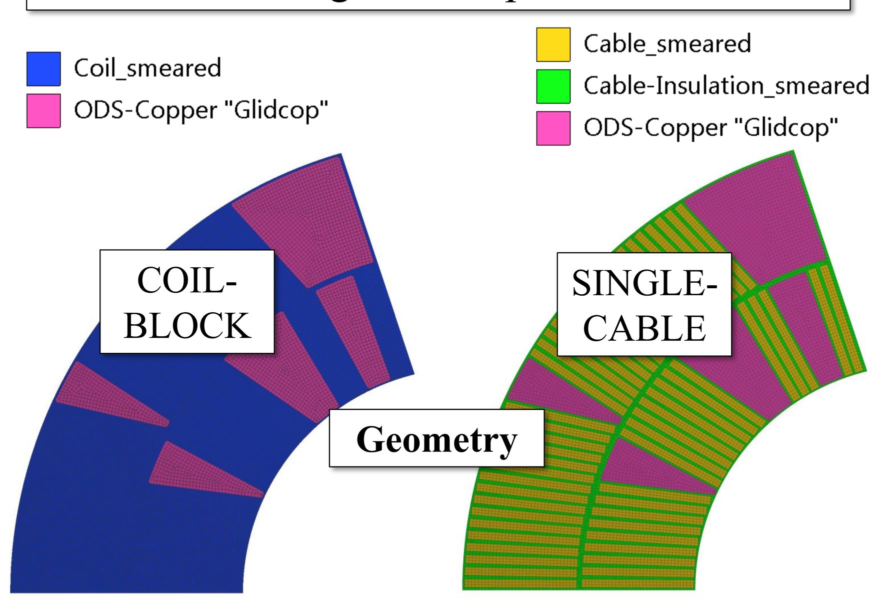
The DS11T has two ways to adjust the pre-stress in the coils—the lateral shims, on the pole acting directly on the coils and the yoke-collared coil shims compressing the collared coil on a 90° arc from both sides. A nominal case of shimming needs to be established. The goal is that the pole turns should be about 10 MPa under compression at ultimate current 12.8 kA, which results in a bore field of 12 T. While reducing the midplane stress.

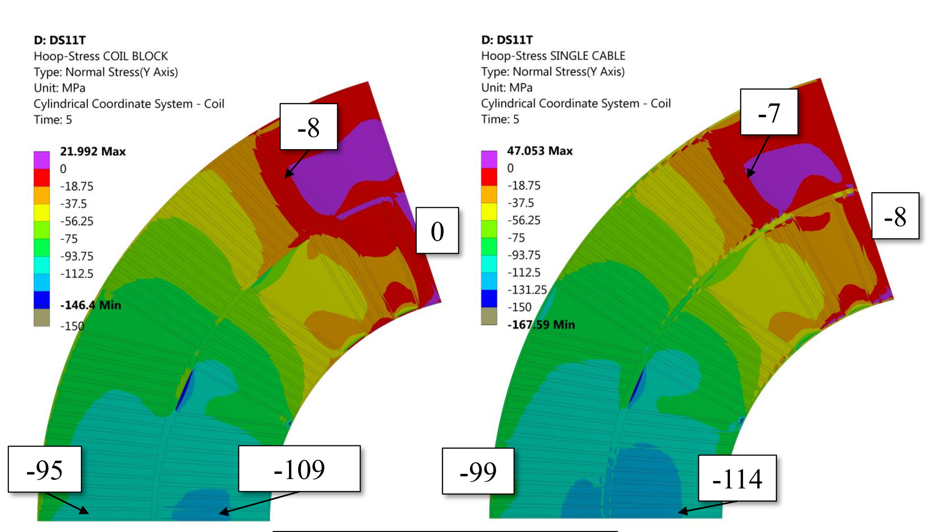


Coil-Block vs. Single-Cable

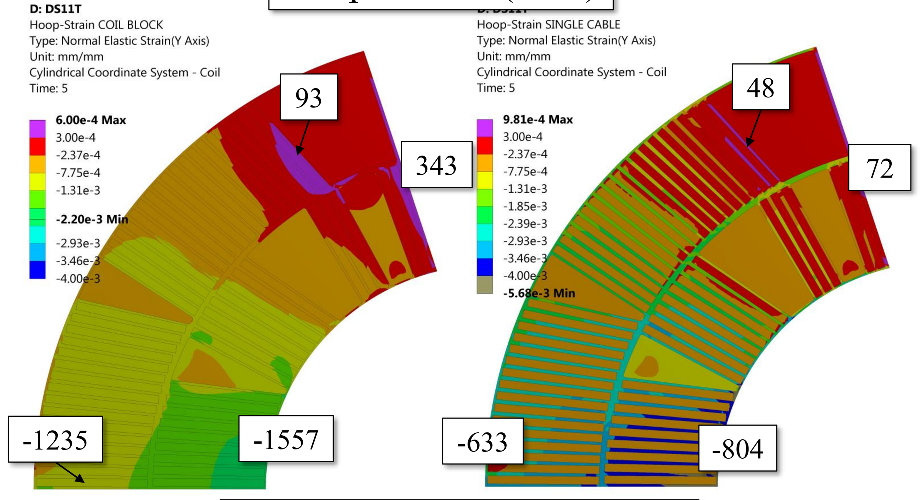
In former finite element models used for the 11T, the conductor-insulation composite was represented by one block with a smeared material property. Here, a comparison is made between a finite model with single cables and insulation and the coil-block model. selected for the nominal case are used for this comparison. The strain in the single cable model is lower than in the coil block model roughly by a factor of two.

Block vs. Cable model Comparison at 12T / average values per cable

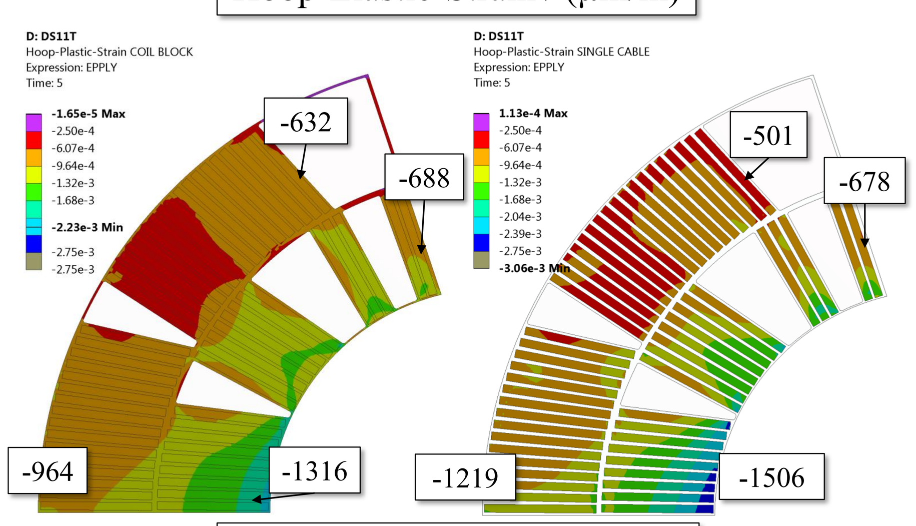




Hoop-Stress / (MPa)



Hoop-Elastic-Strain / (µm/m)

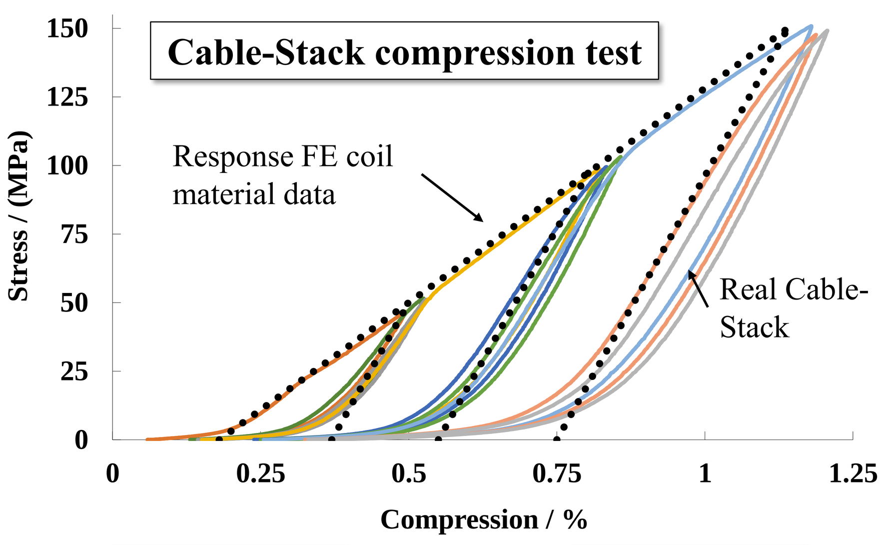


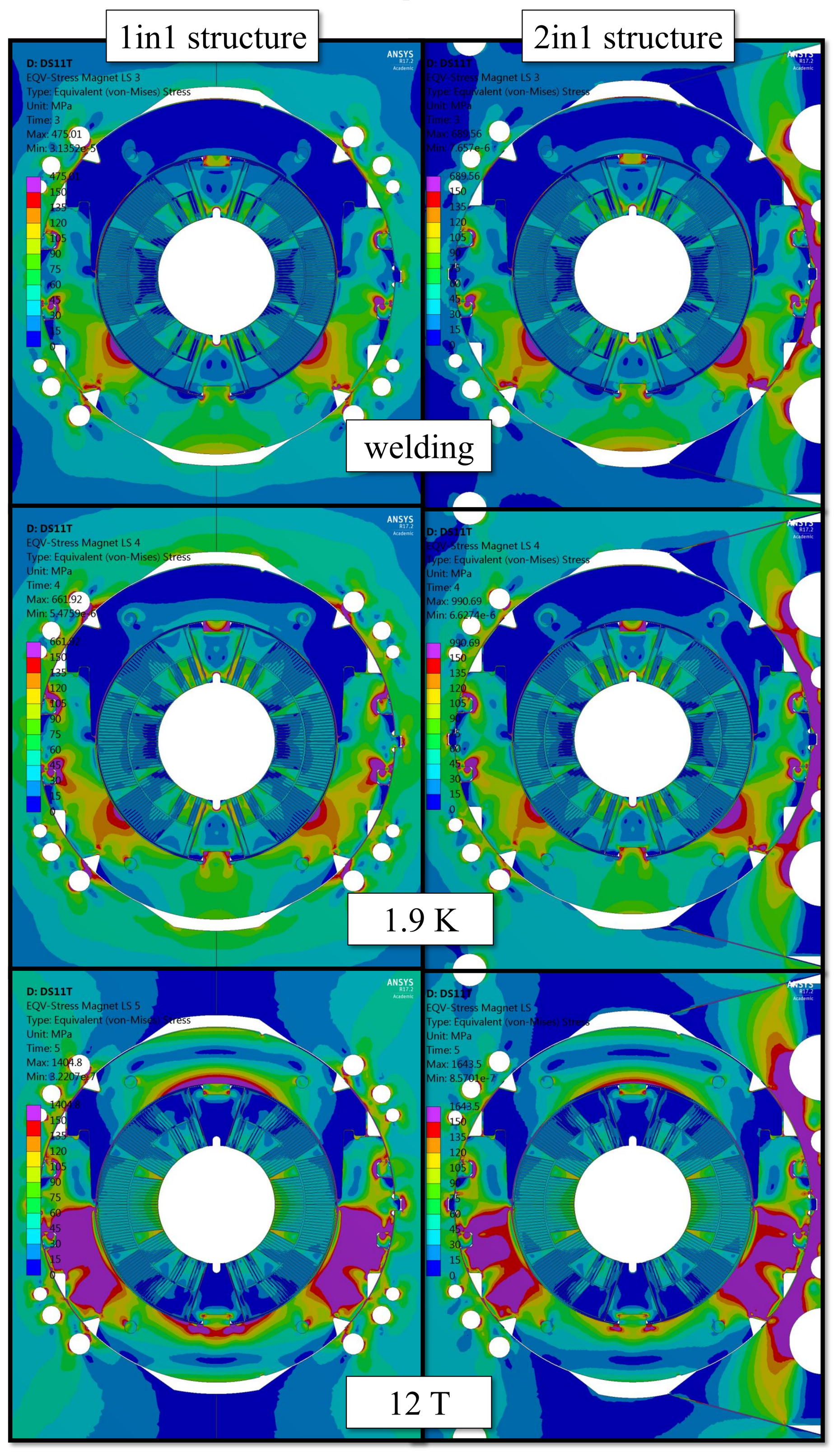
Hoop-Plastic-Strain / (µm/m)

Material Properties

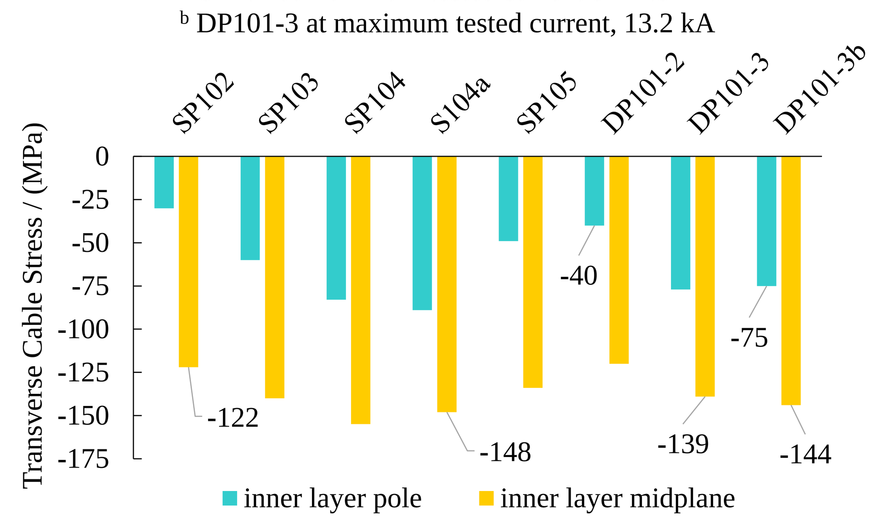
Material Name	E / GPa (295/4 K)	Poisson's Ratio	Sec. Coe. Ther. Exp.	Yield / MPa / (295/4 K)
Coil smeared	39/39	0.35	9.89E-6	10/-[a]
Cable-axial smeared	124/112	0.35	1.06E-5	10/-[b]
Cable[d] smeared	114/92	0.35	1.06E-5	10/-[b]
Cable-insu. smeared	12.9/19.7	0.35	6.50E-6	790/1260[c]
Kapton	2.5/8.96	0.34	1.51E-5	207/346
Magnetil	205/210	0.30	7.22E-6	115/820
ODS-Copper	88/95	0.33	1.11E-5	332/-
Ti-6Al-4V	115/125	0.33	2.85E-6	868/-
X2CrNiMO18-14-3	196/210	0.30	9.97E-6	324/1360
X8CrMnNiN19-11-6	19./202	0.30	8.93E-6	415/1360

Secant coefficient of thermal expansion is for 295 to 4 K.
[a] tangent modulus = 18 GPa
[b] tangent modulus = 20 GPa
[c] in compression
[d] transverse and radial direction





Build Models - Transverse Cable Stress at 12T
[a] SP104 at maximum tested current of 12.3 kA
[b] DP101-3 at maximum tested current, 13.2 kA



Expected Stresses in the Magnet Models

Several magnet models have been built. The collared coil was tested first in a one-in-one structure and afterwards in the two-in-one structure. The collared coils of SP102 & 3 are also used in DP101. The average azimuthal geometric excess for two quadrants—caused by the lateral coil shims and the size of the quadrants—is for the collared coil 102–105: 0.6, 0.75, 0.88, 0.7 mm. The "nominal case" is 0.4 mm; the difference in excess to the built models is due to a change in material data after the models were built. For the models, half the stiffness of the coil was assumed. SP104 and DP101-3 were limited by quenches on the midplane.