EM + thermal analysis of PF1a coil

1. Scope

a. The aim of the analysis:

The aim is to simulate the combined effect of worst-case electromagnetic and thermal loading of PF1a coil. Full 3D geometry of the coil will be modelled. Electromagnetic forces for 3 worst case plasma scenarios will be used, together with thermal load of the coils. The analysis should provide deformation and stresses in the coil conductor and insulation. The calculation is requested for 3 different electromagnetic loading scenarios.

b. Details of PF2 coil:

PF1a coil (see Fig.1) is a high power tokamak coil wound in toroidal direction, creating a poloidal magnetic field inside the vacuum vessel to shape the plasma. It carries large electric current in the range of -25 to +25kA and is placed in the region of very strong magnetic fields, resulting in significant material stresses. It is made of OFHC copper conductor insulated by fiberglass-reinforced epoxy resin composite CTD101K (simplified cross-section of the coil, describing the layout of insulation is shown in Fig.2.). The coils will be actively cooled through internal conductor cooling channels by gaseous helium to liquid nitrogen temperature (80K) in order to reduce their el. resistivity. Machine protection system will be designed to allow maximum temperature increase of the coils by 80K (i.e. up to 160K) during a discharge. Both the electromagnetic forces (created by the coil itself as well as other coils and plasma) and coil heat-up during a discharge will induce significant stresses in the conductor and insulation. PF1a coil comprises 32 turns in 4 radial layers (4 x 8 turns) and has a central diameter of 1157 mm. The coil is supported from top and bottom by two large stainless steel disks. The coil is sitting on special metallic pads with a low friction surface, allowing the coil to expand in radial direction.

c. Description of the model

As a preparation of the model, the coil will be placed between two ideal infinitely stiff surfaces representing the coil supports. The loading steps will be applied as follows:

1. The upper surface will push on the coil by 2.5 MN force to pre-compress it (see Fig.4)
2. Cool down the whole structure (coil conductor + insulation) from the room temperature of 300 K (no stress reference) down to 77 K.
3. Apply EM forces acting on the coil conductor (body force density will be provided by IPP for the 3 requested scenarios after meshing of the model)
4. Heat-up the coil conductor only (not insulation) to 160 K

2. Input documentation to start and realize activity

a. Type of analysis:

i. Coupled electromagnetic-thermal-structural static analysis

b. Geometry

i. Geometry file of the coil and insulation (.step) will be provided.

ii. 3D model of PF1a coil composed of copper turns with internal cooling channels, fiberglass reinforced epoxy insulation in between the turns and filler G10 parts (to fill voids and create rectangular coil shape).

c. Material properties

i. OFHC copper 10700 as the conductor of CS coil, fiberglass reinforced epoxy insulation (CTD101-K) and G10 glass-fiber laminate as void filler.

ii. OFHC copper: values of density, Young modulus, Poisson ratio, Yield strength and coeff. of thermal expansion (CTE) provided.

iii. CTD101-K (fiberglass reinforced epoxy insulation): values of density, Young modulus, Poisson ratio, Flexural modulus and coeff. of thermal expansion (CTE) are provided. CTD101-K is orthotropic material, with significantly different thermal expansion in the fiberglass plane and in the normal direction - therefore CTE values will be provided as orthotropic. Description of the insulation layers direction can be found on Fig.2. below.

iv. G-10 void fillers: values of density, Young modulus, Poisson ratio, Flexural modulus and coeff. of thermal expansion (CTE) are provided. For the purpose of this model, G-10 is assumed to be isotropic material.

Table 1: Material properties

Material	Material property	Value
OFHC copper half-hard	ρ [kg/m^3]	9009
	CTE [K^{-1}]	data file[1]
	E [GPa]	122
	E_T [GPa]	0
	YS [MPa]	304[2]
	v [-]	0.306
G-10	ρ [kg/m^3]	1850
	CTE [K^{-1}]	data file[3]
	E [GPa]	20.6
	v [-]	0.35
	G [GPa]	8.6
CTD101-K	ρ [kg/m^3]	1850
	CTE [K^{-1}]	data file[4]
	E [GPa]	16.7
	v [-]	0.3
	G [GPa]	27.9

d. Boundary conditions: Contacts

i. All contacts within the coil (Cu - insulation - G10) are bonded

ii. Coil is sitting between two ideal infinitely stiff surfaces, which exert a vertical compressing force of 2.5 MN on the coil. (one of the surfaces is fixed, the second one is pushing on the coil).

iii. Frictional contact between the coil and the idealized surfaces with frictional coefficient 0.05

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[1] See attached data file *Cu_CTE.csv*
[2] Bi-linear model is required
[3] See attached data file *G10_CTE.csv*
[4] See attached data file *CTD101K_CTE.csv*

Deliverables

Intermediate report

provide intermediate report (in form of presentation) after calculation of the first electromagnetic loading scenario is performed:

- Presentation in English
- Analysis results (first scenario)
- von Mises stress and deformation in the coil conductor
- First principal stress, shear stress and deformation of the insulation and G10 parts
- Provide all files (.doc, .xls, .ppt, ...) constituting the report

Final report

- Presentation in English
- Analysis results (all 3 scenarios)
- von Mises stress and deformation in the coil conductor
- First principal stress, shear stress and deformation of the insulation and G10 parts
- Provide all files (.doc, .xls, .ppt, ...) constituting the report
- Provide all files (ANSYS, ...) constituting the modelling and results

Attachment: figures

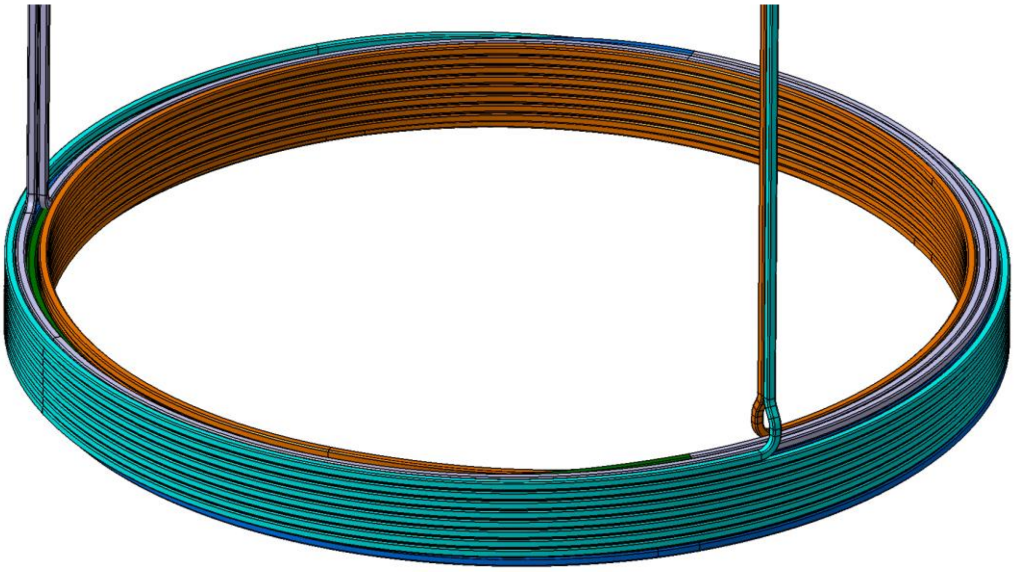

Fig.1: Realistic model of poloidal field coil PF1a with parallel leads

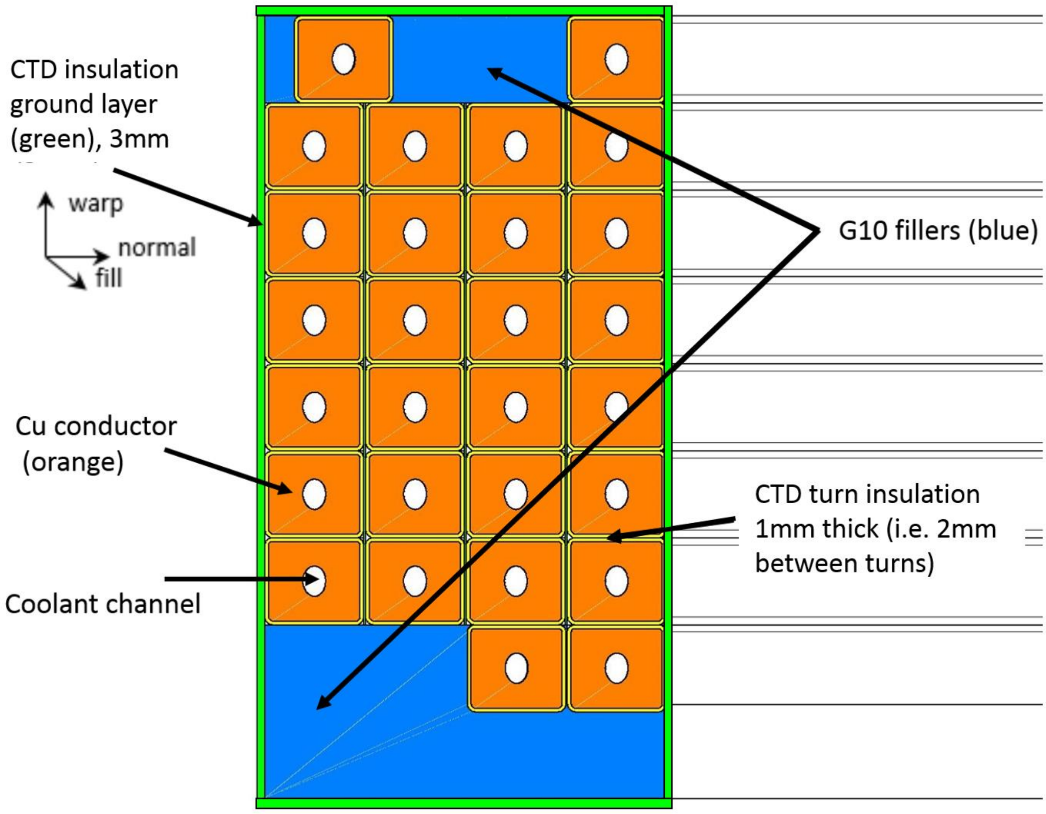

Fig. 2: (left) Schematic cross section of the PF1a coil. Scheme of the insulation layers: (1) inter-turn, (2) ground.

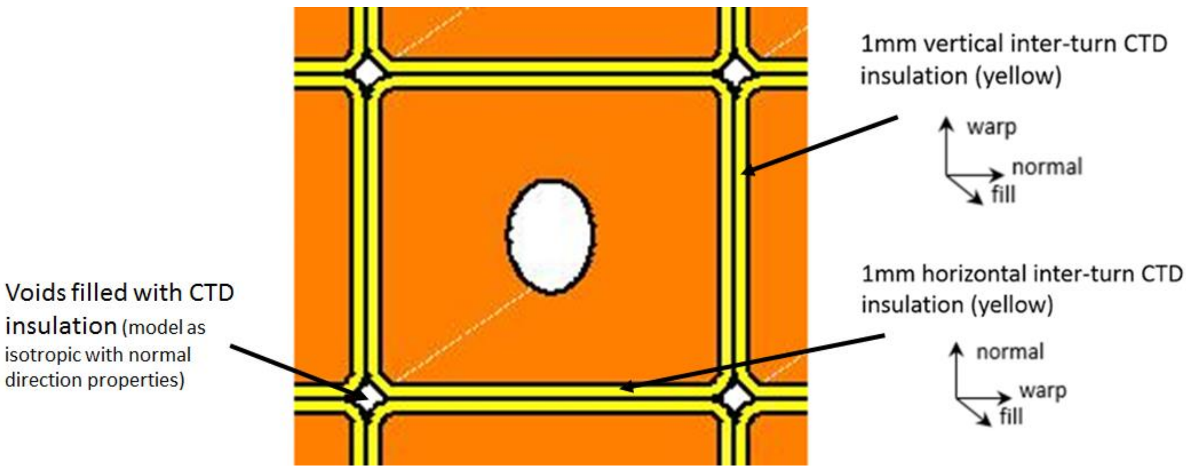

Fig. 3: Detail of inter-turn insulation with insulation wrap directions

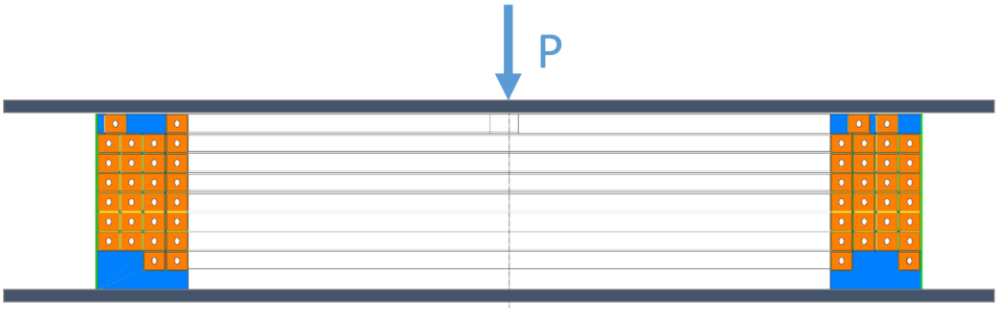

Fig. 4: Idea of the coil compression - coil placed between 2 infinitely stiff surfaces. Lower surface is fixed, upper surface is pushing on the coil with force P = 2.5 MN.