

COMPASS-U

Poloidal field coils

v 1.3

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Presentation for Preliminary Market Consultations



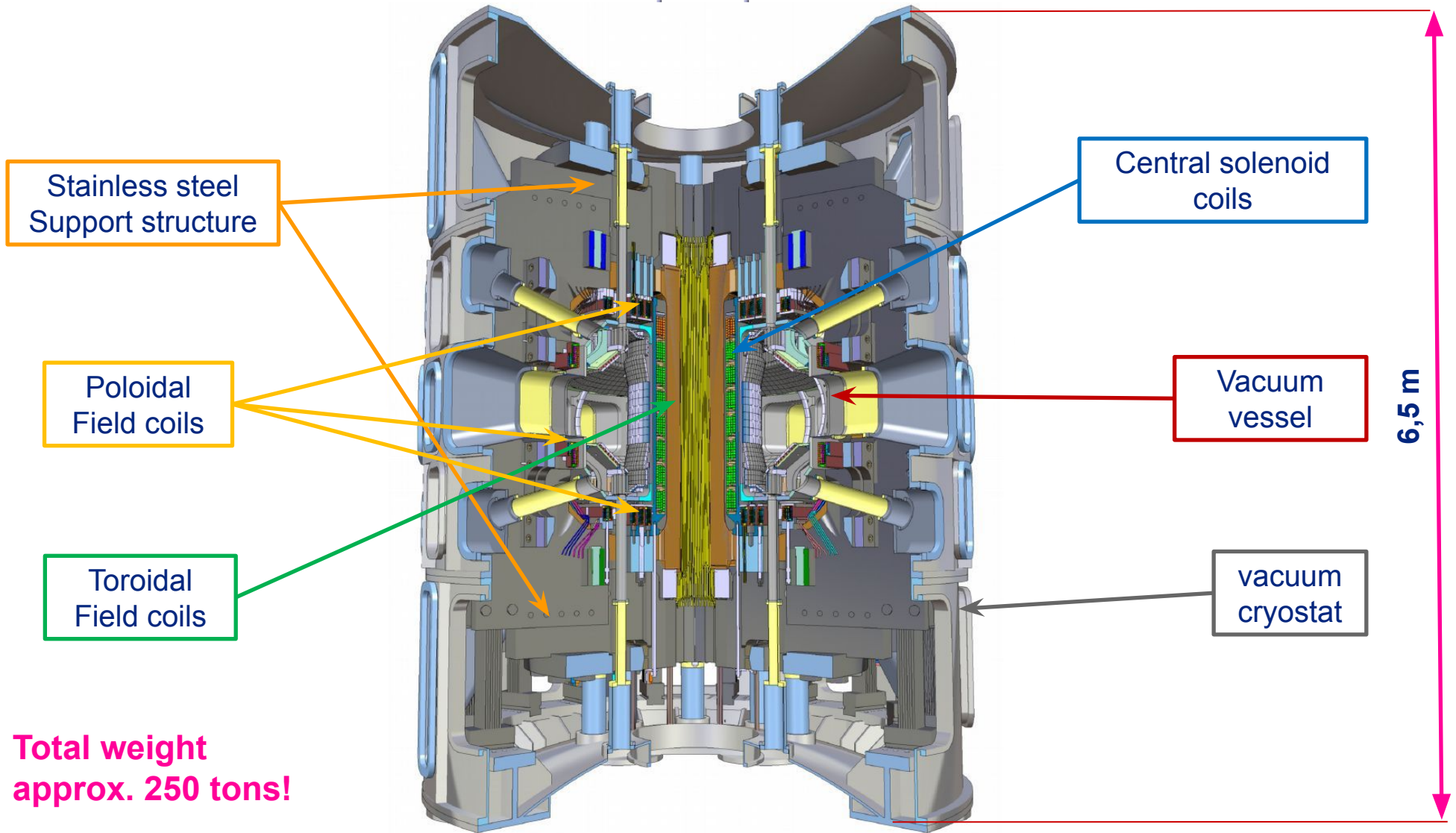
EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education



MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Key properties of COMPASS-U:

- Mid-sized tokamak device (**major radius 89 cm, minor radius 27 cm**)
- High **toroidal magnetic field (5 T)** to confine plasma
- High **plasma current (2 MA)**
- High **TF coil currents** up to **200 kA**
- High **PF coil currents** up to **50 kA**
- Both coil systems from **Oxygen Free Silver-Bearing Copper CuAg0.1(OF)**
- Discharge **duration** up to **severals seconds**
- Support structure and coils operate at **cryogenic temperature (-200° C)**
- Operation with **high temperature first wall** – up to **500 °C**
- Encased in **vacuum cryostat** for thermal insulation - high vacuum environment

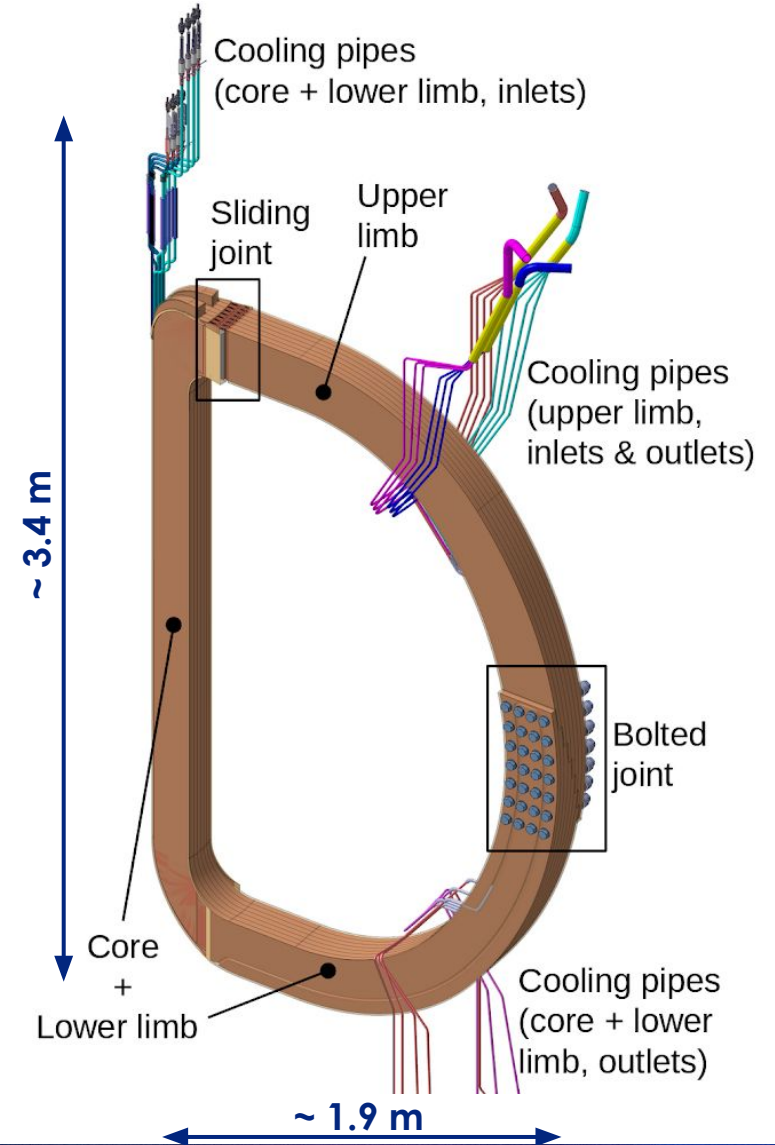
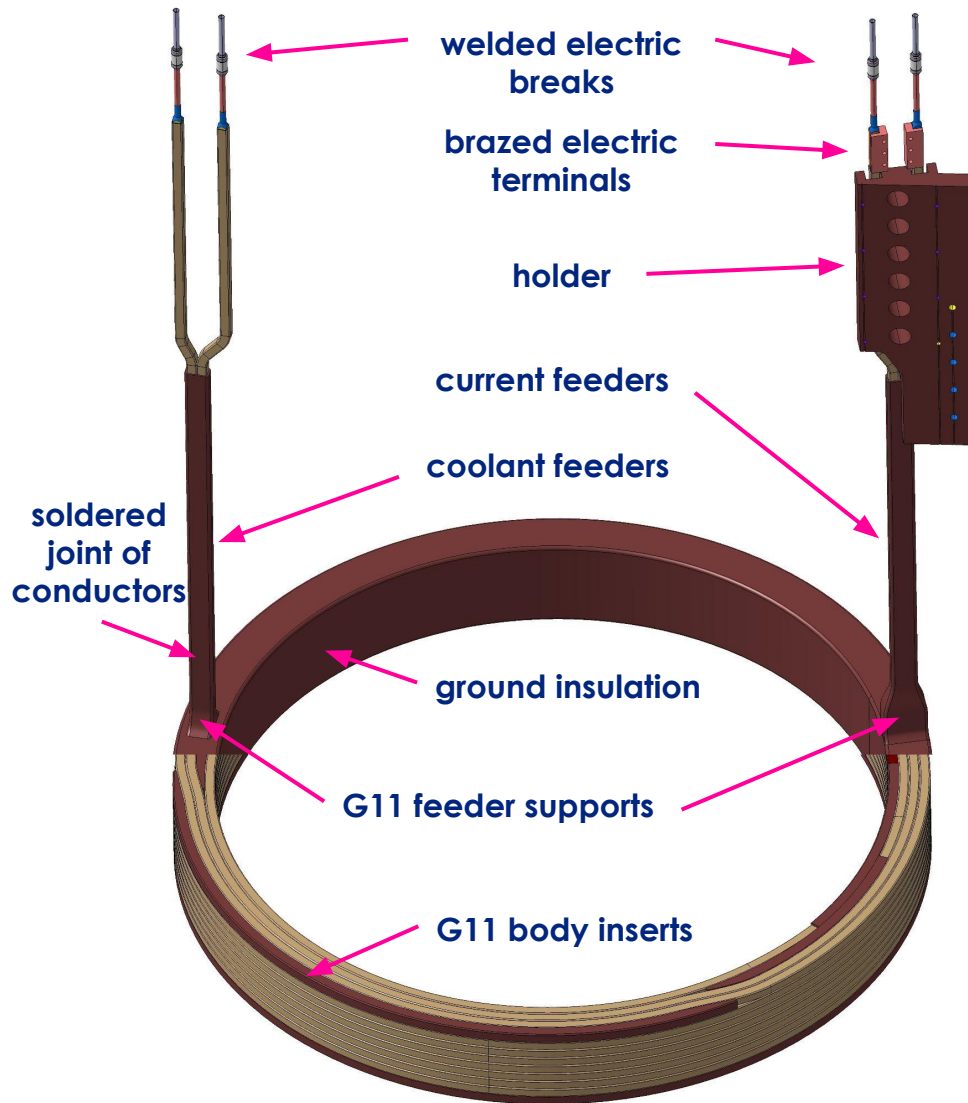


Presumed scope of work, overview:

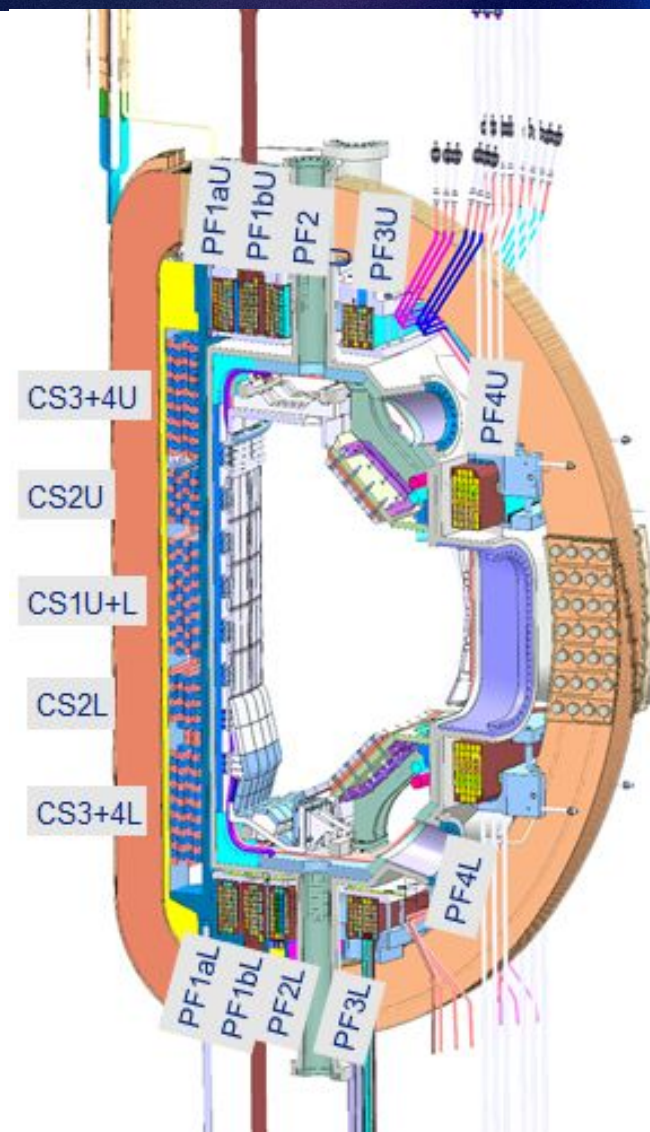
- Testing of conductor and insulation samples
- 1 extra prototype coil (PF1a) to confirm manufacturing procedure
- 10 individual PF coils
 - coil radii **0.5-1.5 m**
 - hollow conductor **15 x 15 mm** (PF1-3), **20 x 17 mm** (PF4)
 - min. yield strength **250 MPa** (PF1-3), **150 MPa** (PF4)

Presumed scope of work, single coil:

- Taping and Winding, Vacuum pressure impregnation, Soldering, Brazing
- **Welding of el. breaks** to the current and coolant feeders
- **Ground shield by conductive varnish - recently added to the design**
- Electrical and leak testing, **Paschen tests - local paschen tests are mandatory for each coil**
- **Sliding pads - recently added to the tender**
- Transport to IPP



coil	Copper turn cross-sec. [mm ²]	Copper mass [kg]	R_c [m]	Z_c [m]	dR [m]	dZ [m]
PF1Ua	185.66	199	0.58	0.895	0.074	0.159
PF1Ub	185.66	231	0.67	0.895	0.074	0.159
PF2U	185.66	262	0.76	0.895	0.074	0.159
PF3U	185.66	408	1.06	0.87	0.108	0.125
PF4U	275.52	845	1.43	0.412	0.102	0.182



Conductor design overview:

coil and quantity	material of the conductor	Height [mm]	width [mm]	dia of hole [mm]	corner radius [mm]	number of turns	total conductor length [m]	uninterrupted conductor lengths [m]
2 x PF1a	CuAg0.1(O _F)	15	15	7	1	33	125	61, 64
2 x PF1b	CuAg0.1(O _F)	15	15	7	1	33	144	70, 74
2 x PF2	CuAg0.1(O _F)	15	15	7	1	33	163	80, 83
2x PF3	CuAg0.1(O _F)	15	15	7	1	37	253	83, 84, 86
2x PF4	CuAg0.1(O _F)	20	17	9	1	38	345	75, 90, 90, 90

- extra prototype coil: PF1a

Hollow conductor

CuAg0.1(OF) material designation:

EN CW019A or UNS C10700

Chemical composition

Analysis of conductor samples will be done for each batch to confirm chemical composition.

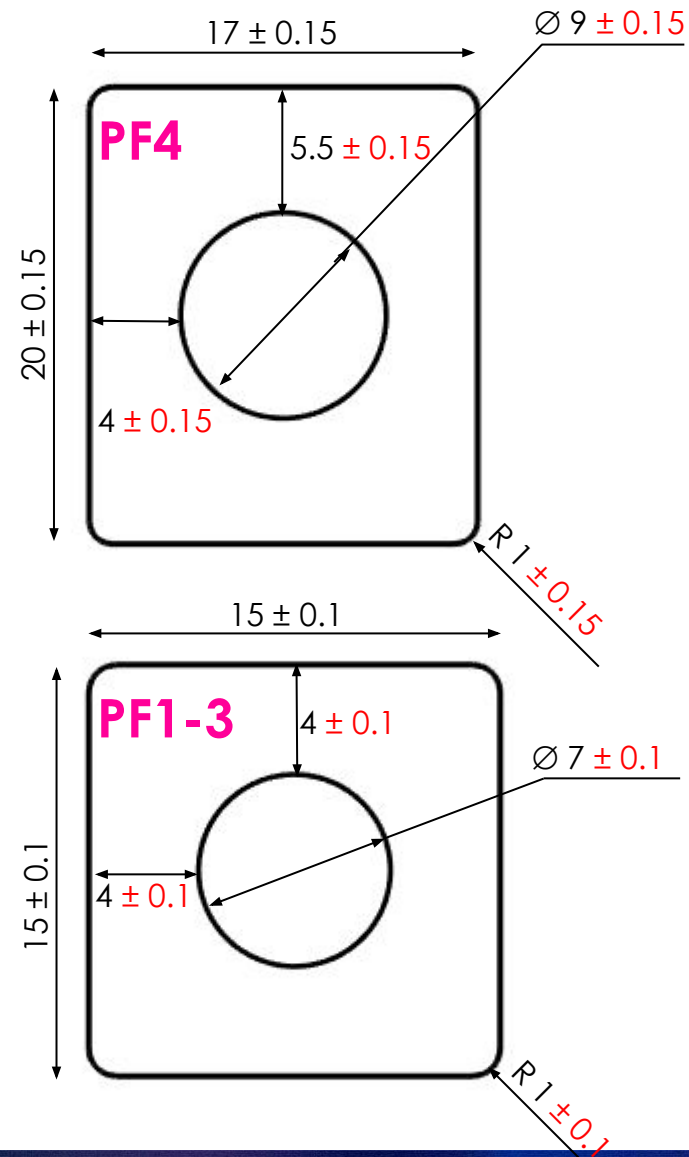
Tensile yield strength

Tensile test of conductor samples will be done for each batch to confirm required yield strength.

Conductor properties defined by EN 13600 as a baseline norm.

Stricter dimensional tolerances

Coil	yield strength [MPa] (0.2% proof stress)
	at room temperature (293 K)
PF1aU, PF1aL	> 250
PF1bU, PF1bL	> 250
PF2U, PF2L	> 250
PF3U, PF3L	> 250
PF4U, PF4L	> 150



Insulation system

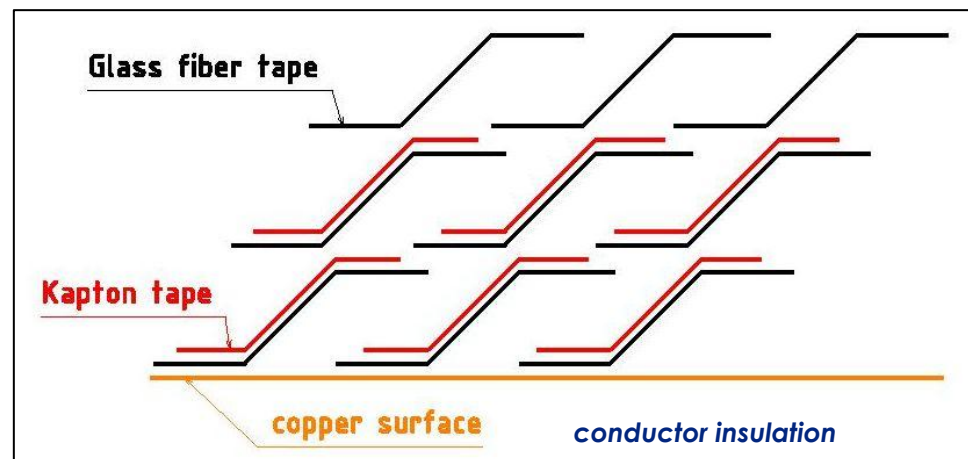
- **Nominal voltage** of power supplies for PF system is **1 kV**.
- Conductor surfaces will be **primed** prior to insulation. **Recommended primer** is **CTD-450**
- **Recommended epoxy resin GY 282**
(Manufacturer may suggest an alternative, but they have to prove equal/superior mechanical properties and vacuum requirements)
- **Tensile and shear/compression tests** of insulation samples are mandatory and shall to prove equal/superior mechanical properties

Conductor insulation

- **total thickness 1 mm**
- **2 layers** of half-lapped **E- glass** fibre tape interleaved with 25 μm Kapton
- **1 layer** of half-lapped **E-glass** fibre tape (no Kapton)
- Kapton tape width is 80% of E-glass tape

Ground insulation

- **total thickness 3 mm**
- **10 layers** of half-lapped E-glass fibre tape



Requirement	Value / description
Volumetric fiberglass ratio	55 ± 5 %
Turn-to-turn insulation nominal thickness	2.0 ± 0.2 mm
Ground insulation nominal thickness	3.0 ± 0.3 mm
tensile strength @80 K	Min. 33 MPa
shear/compression 45° strength @80 K	Min. 64 MPa
Insulation void gap (any direction)	Max. 0.025 mm
insulation resin rich area	Max. 0.5 mm

General insulation requirements

- Minimize void content.
- Minimize resin rich areas.
- Resistance to the long-term effects of partial discharges.
- Stable in the range of used temperatures (80 K to 300 K) with low degradation caused by cool-down cycling.
- High mechanical strength over the range of operational temperatures.

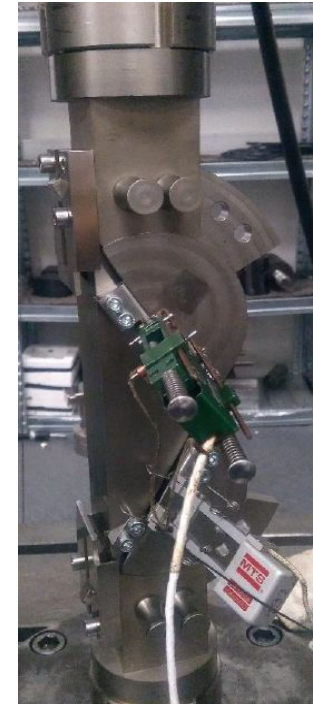
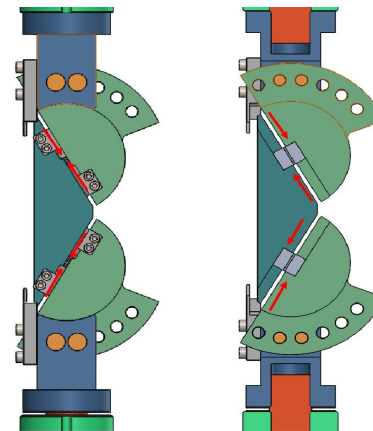
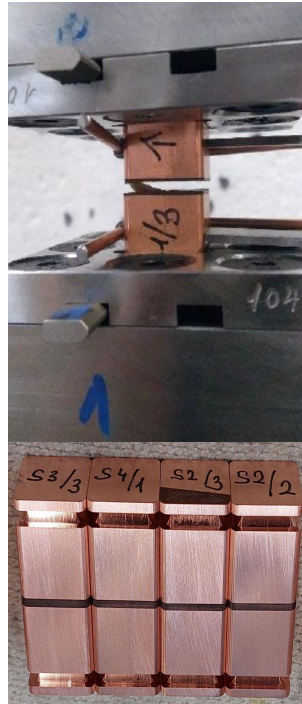
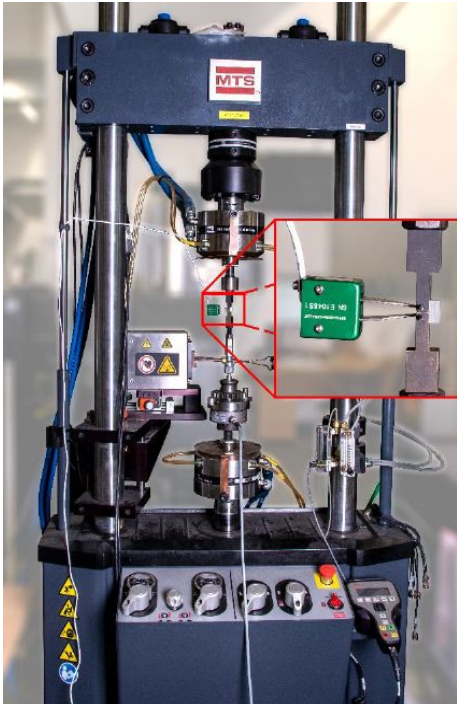
samples: primer **CTD-450**, 2 layers half-lapped 0.15 mm **E- glass fibre** tape (4H Satin weave 220g/m²) interleaved with 25 μm **Kapton**, 1 layer half-lapped E-glass fibre tape w/o Kapton, **epoxy GY 282**

Tensile tests at 80 K:

- 6 samples, **through-thickness tensile strength**
- Min. **33.9 MPa**, avg. **41 MPa**, max. **49.2 MPa**
- Fatigue testing: **36.3 MPa** @ 50 000 cycles

Shear/compression tests at 80 K:

- 6 samples, **45° degrees** sample tilt
- min **64.5 MPa**, avg. **80.5 MPa**, max. **88.6 MPa**



Coil dimensional tolerances:

- General dimension tolerances must comply with ISO 2768-m.
- More stringent tolerances defined for some dimensions in technical drawings

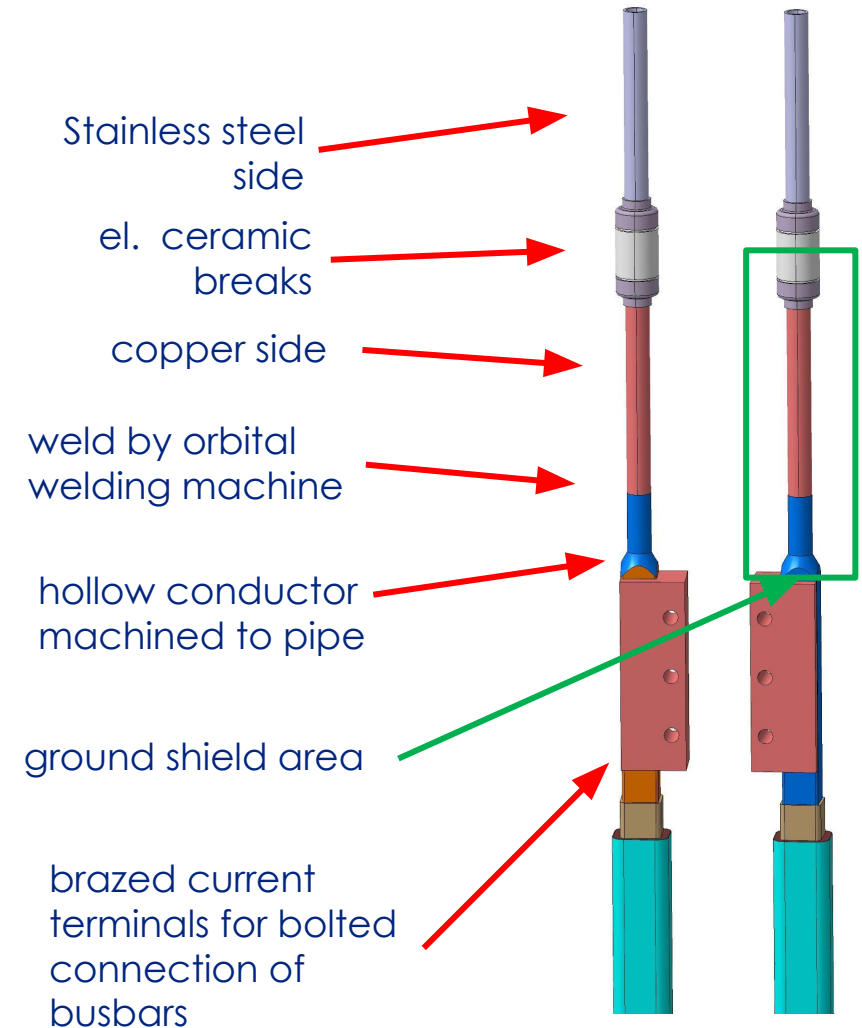
coils dimensional tolerances [mm]

coil	PF1a, PF1b	PF2	PF3	PF4	PF1a vs PF1b vs PF2 sliding pads included
Inner diameter	-0 +0.1	-0 +0.1	-0 +0.1	-0 +0.2	
Outer diameter	-0 +1	-0 +1	-0 +1	-0 +2	
total height	-0 +1	-0 +1	-0 +1	-0 +2	± 0.1

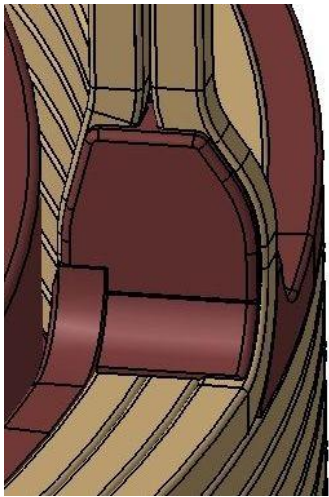
- Coolant inlets **machined** from conductor shape to pipe shape
- **Welding** of **electrical break** part
- **El. breaks** will be provided by IPP



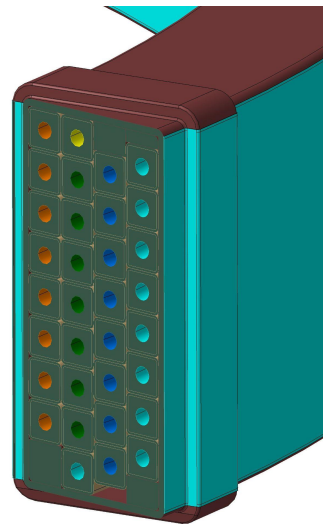
- El. break will be insulated with the **same insulation layout** as coil and also VPI-ed
- Insulation will be terminated in the middle of the ceramic part
- Conductive top layer shall be also applied in this area



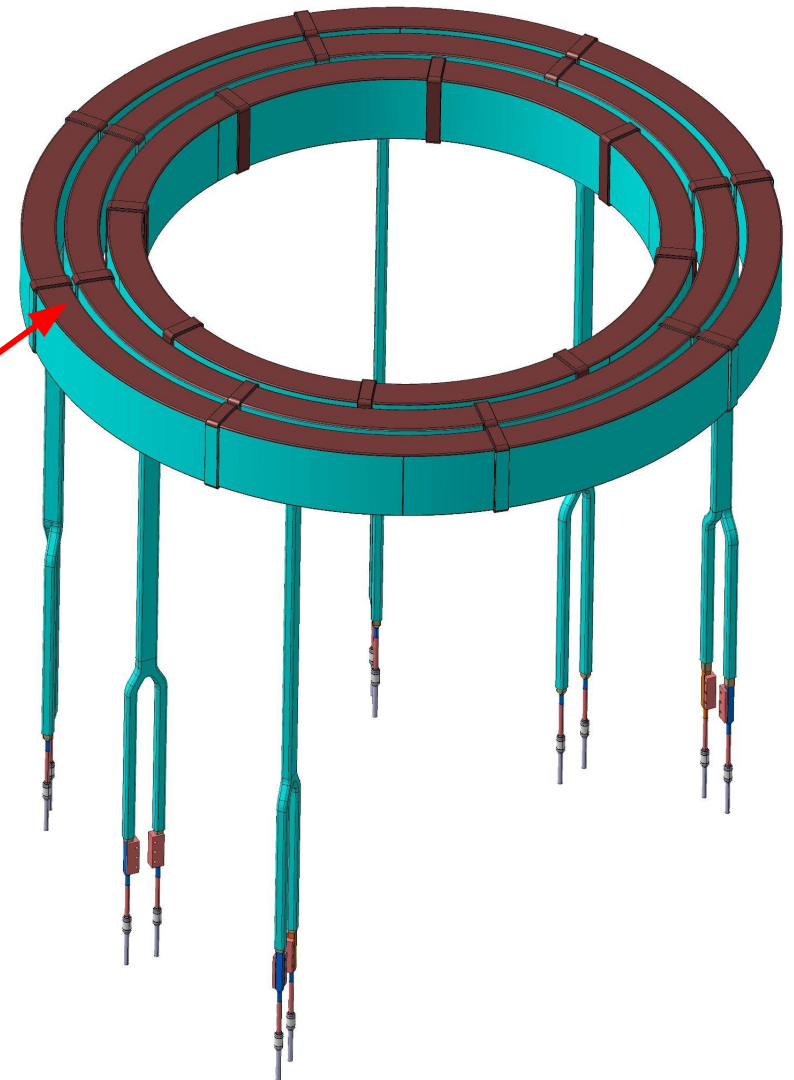
- Coils are shown with **ground insulation** and **ground shield** (conductive top layer)
- **G11 inserts** in the body of coils - to fill void spaces, to support feeders
- Use of **G-11CR** material - according **NEMA G-11 norms**



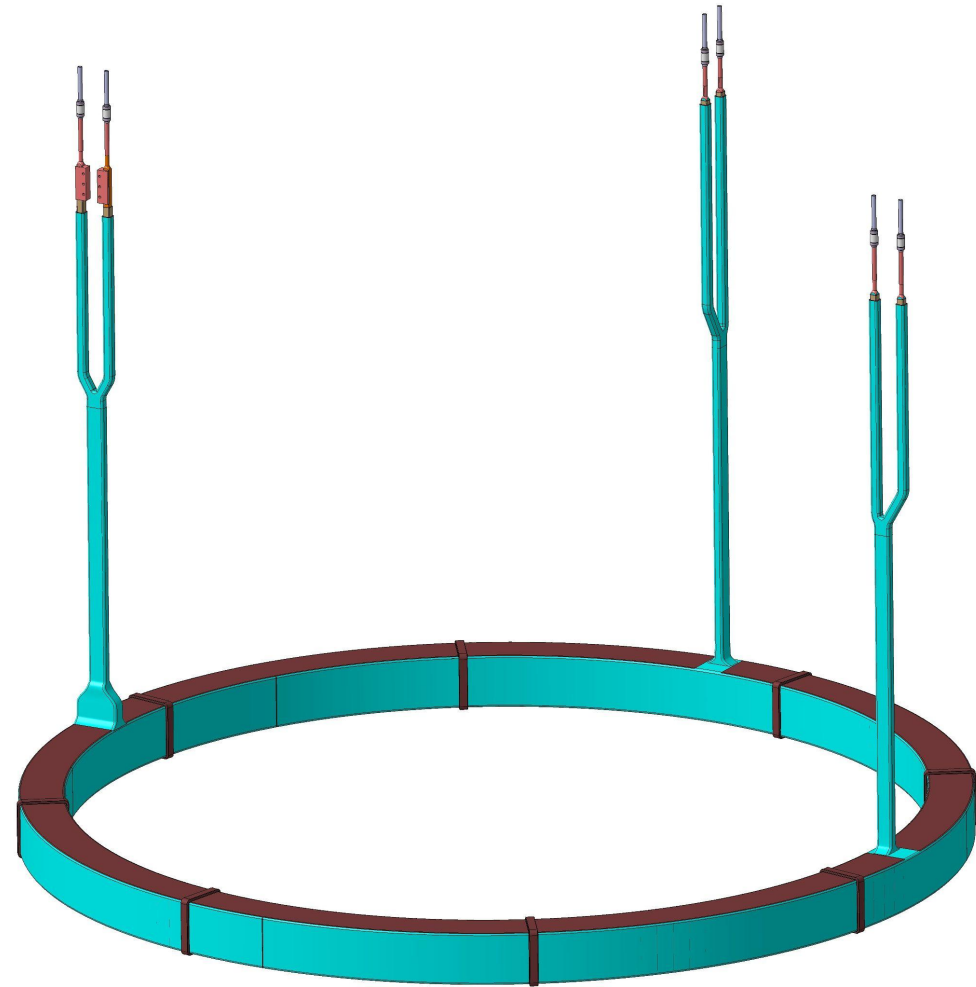
supporting pads

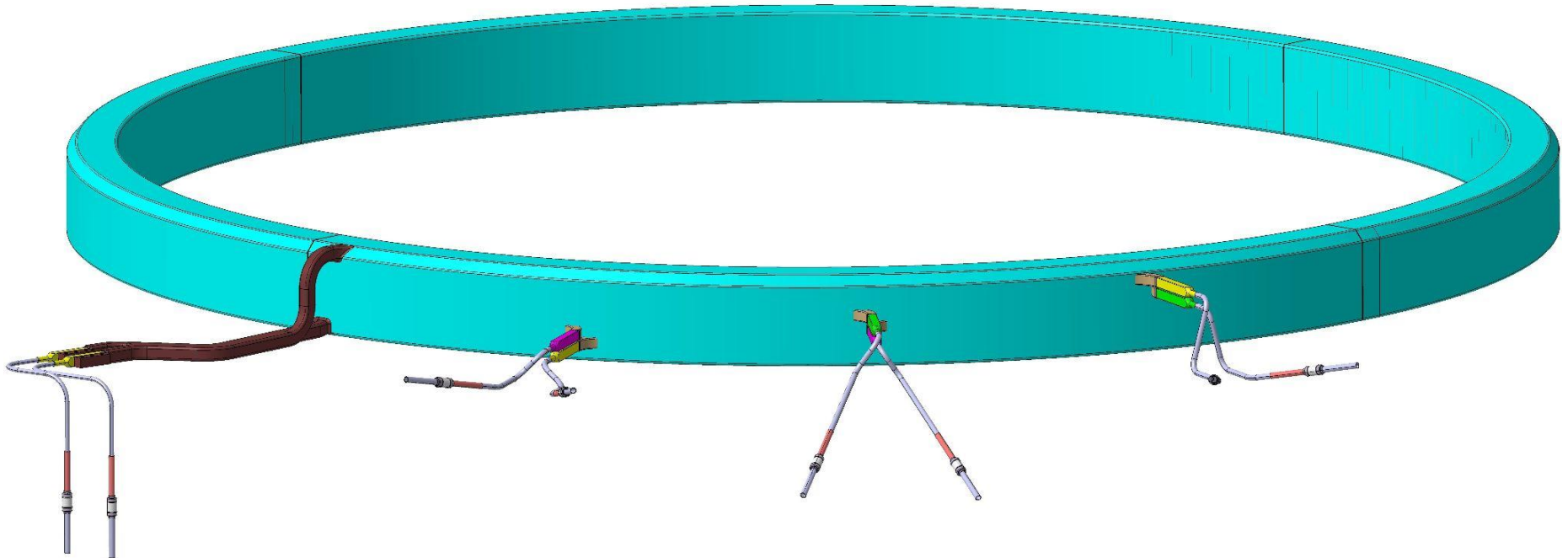


additional wrap



- **Cooling pipes** have to be insulated up to the middle of electrical break
- Detailed design of **insulation of current feeders** will be proposed by the manufacturer
- **PF1a, PF1b, PF2 and PF3** are **wound as planar** with short joggles to the next turn and layer
- Feeders length ~ 1,5 m
- **Ground shield** “green” layer divided to three segments, each with its dedicated grounding point.





- PF4 has **pancake winding**, radial coolant and current outlets
- Coil **dimensions** up to the **electric breaks** is **~4.2 m in diameter** (largest PF coil)
- Current feeders and coolant feeders have ground insulation and ground shield (valid for all PF coils)
- **Ground shield** top conductive layer is toroidally divided to **4 segments** with 2 mm gap in between.
- Each ground shield sector has its own **dedicated grounding point**

Electrical tests of all PF coils, prototype coil:

- coil **DC resistance** at room and LN2 temperature
- **Impedance and phase angle measurement** (frequency range 20 Hz to 500 kHz)
- **Insulation resistance test** according to **IEEE Std. 43-2000**
- **Dissipation factor** according to **IEEE Std. 286-2000**
- **Partial discharge test** according to **IEC 60270**
- **DC Hipot test** according to **IEEE Std. 95**
- **Paschen test**
 - **Local Paschen** - current and coolant feeders, **mandatory for all coils**
 - **Full Paschen** - **test of the whole coil**, can be ordered for individual coils

Mechanical tests of samples, prototype coil

- **Tensile and shear/compression** tests of insulation samples, **3x3 mock-up**
- **Tensile test of conductor** at RT according to EN ISO 6892-1
- **integrity test** of **90° conductor bend samples**
- **Sectioning** of **prototype coil** & inspection of **insulation quality**

Leak inspection

- The coolant medium of coils will be **gaseous helium**
- Manufactured coil has to be tested to confirm that the **cooling path is free from obstructions**
- **Hydrostatic pressure test** will be performed with 1,5 of nominal working pressure for at least 15 minutes

circuit	nominal working pressure [Bar]	testing pressure [Bar]	max. leak rate [Pa.m ³ /s]
PF	20	30	1e ⁻¹⁰

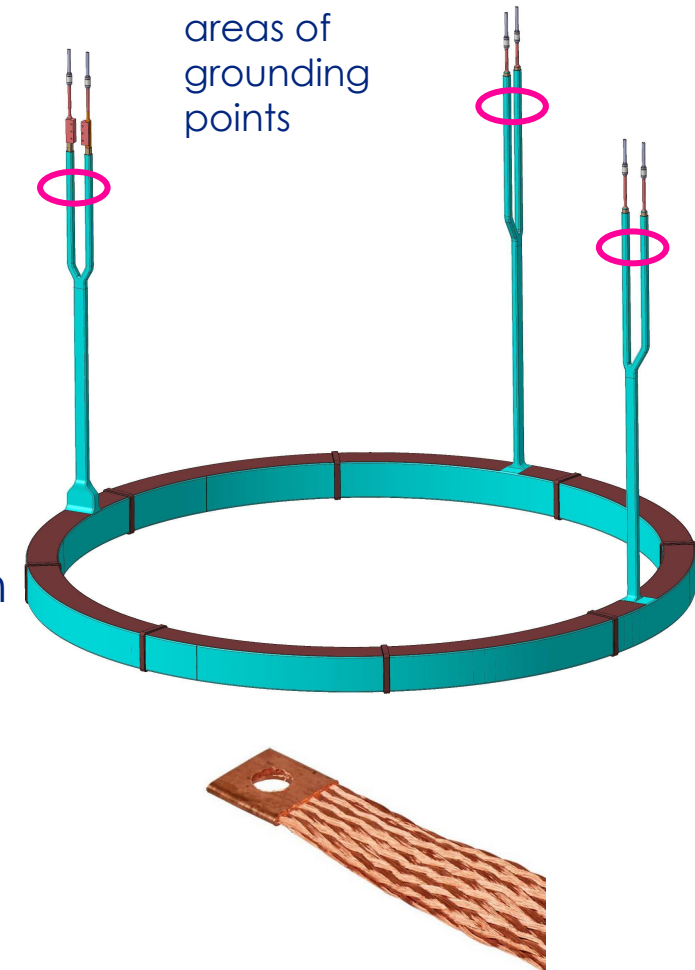
Thermal cycling of each coil

- **Each coil shall be thermally cycled** from RT to 85 K

Number of thermal cycles	3x
Temperature range	From Room temperature down to 85 K
Temperature gradient (for cool down and warm up)	0.5 – 5 K/min
Max. temperature gradient between the hottest and the coldest spots of the coil	40 K
Environment	Atmospheric pressure air

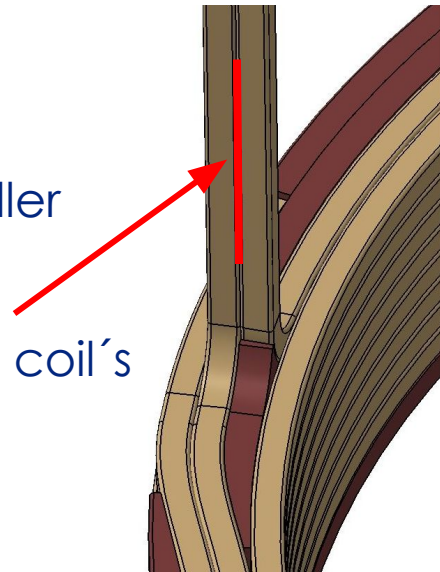
Ground shield

- All poloidal field coils
- Conductive varnish **Glyptal 9921** (or alternative) on part of coils surfaces
- Interrupted conductive layer in poloidal and toroidal direction
- Resistance of layer between 3 - 30 k Ω /square
- Dedicated grounding points for each coils. Number of points for coils PF1,2 and 3 depends on the number of feeders (2-3)
- Copper grounding wire/strip attached to the coil feeder by prepreg or alternative solution
- PF4 have 4 connection points



Soldered joint of coolant inlets

- Electrical connection of 2 conductors forming separate cooling circuits
- After soldering, conductor and ground insulation tape will be applied (4 mm in total)
- Detailed design of insulation will be proposed by the Seller
- Soldering area is 100 -150 mm above coil's body



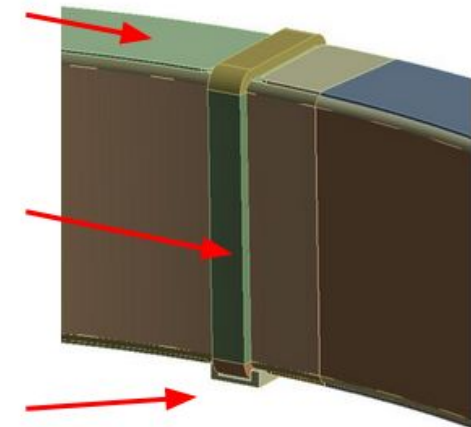
Additional wrap

- width 30 mm, thickness 6 mm
- E-glass fibre tape, same properties as general insulation
- Detailed design and manufacturing process will be proposed by the Supplier (VPI x prepreg ...)

Sliding pad

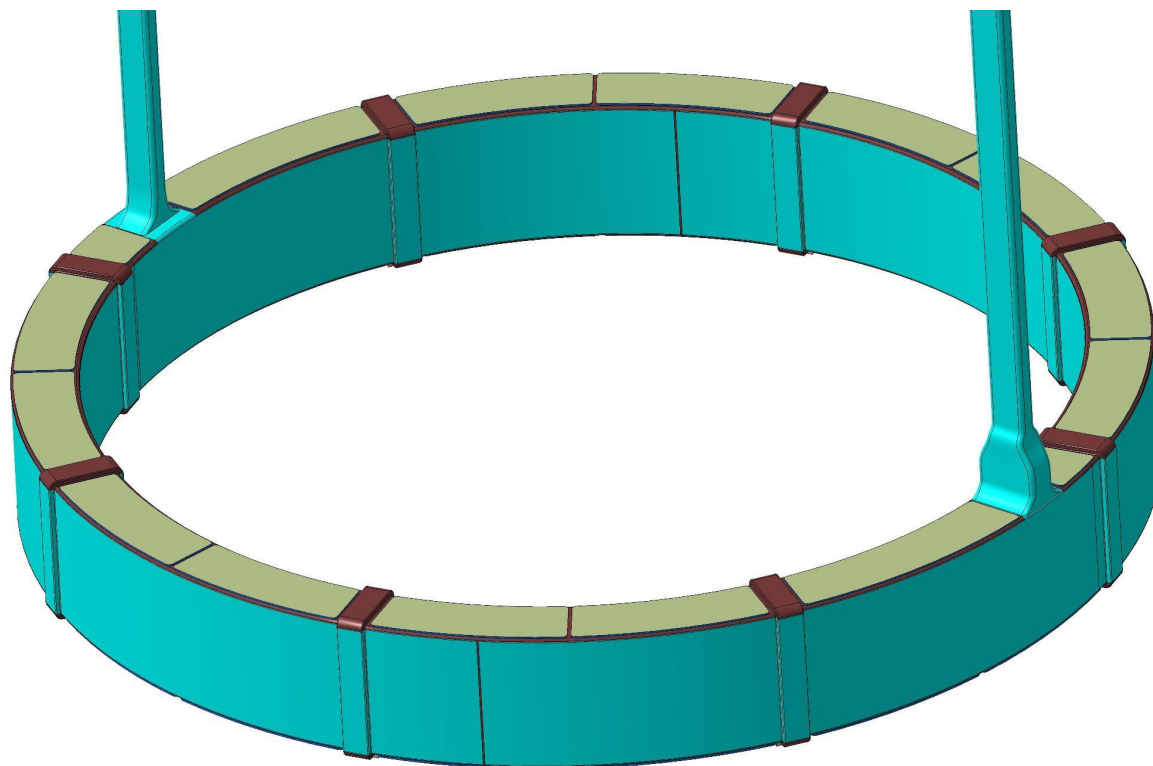
Additional wrap

stabilizing element



Sliding pads

- **Allow expansion of the coil** during discharge
- Top and bottom of the coil
- Material: polished **Stainless steel**
- Dimensions (approx): **200 x 132 x 2 mm**
- Bottom 16 pieces, top 16 pieces for PF1a
- **Glued to the the coil** just for assembly (not yet decided if in the tender)



- Tender will be launched as “**Framework purchase agreement**”
 - The Buyer (IPP) has the right to purchase any item(s) from tendered contract
- Czech law regulating public procurement procedure **is one of the most strict and formalistic laws in the EU**. The document “**information for suppliers.pdf**” released on our website gives an overview of what documentation has to be submitted by a foreign supplier.
- IPP strongly recommends to the potential Supplier to hire Czech layer company to help with all necessary documentation accompanying the bid. **If any of statutory requirements are not met, the bid has to be removed from the tender competition.**
- **Time for procurement** of the coils is **2 years + 3 months for full Paschen testing** (optional) after the contract is signed.

Some details are still being investigated and fine tuning with other parts of the tokamak is still ongoing, therefore the final tender technical specifications can be slightly modified.

More information about planned tenders can be found at:

http://www.ipp.cas.cz/o-ufp/Verejne_zakazky/doc.html

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