IPP COMPASS INSTITUTE OF PLASMA PHYSICS ASCR

IPP INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

COMPASS-U
Poloidal field coils
v 1.5

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Presentation for Preliminary Market Consultations

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

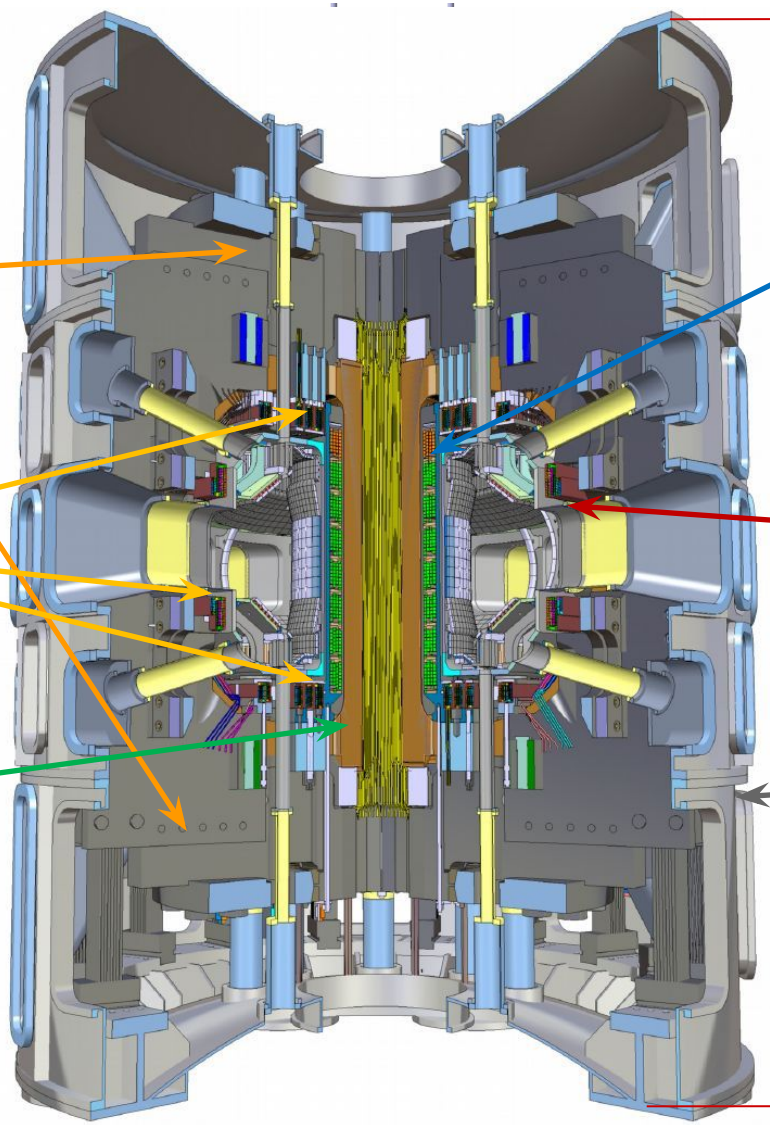
MINISTRY OF EDUCATION, YOUTH AND SPORTS

Key properties of COMPASS-U:

- 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
- mid-size tokamak device

=> unique capabilities to address future tokamak fusion reactor challenges

COMPASS-U cross-section



Support structure

Poloidal Field coils

Toroidal Field coils

Central solenoid

Vacuum vessel

cryostat

6,5 m

Total weight approx. 250 tons!

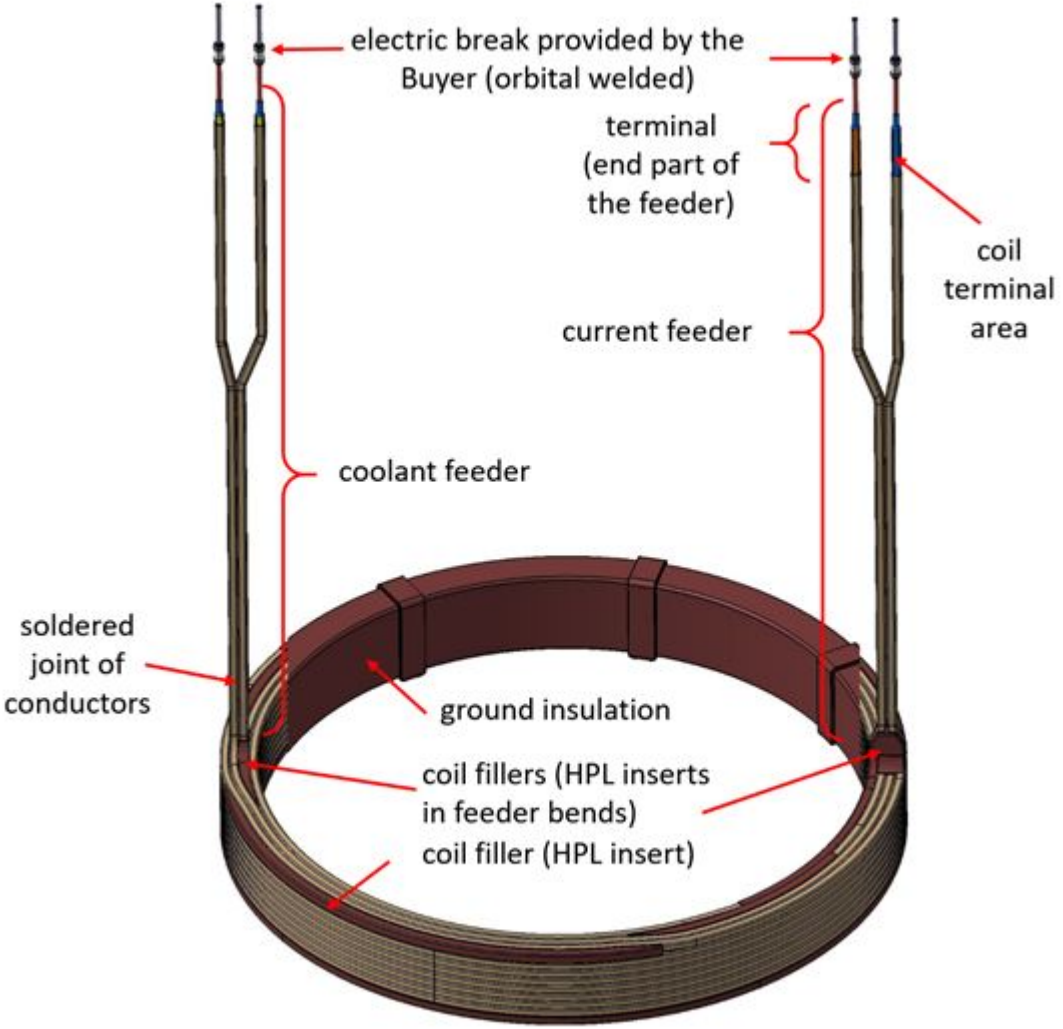
Presumed scope of work

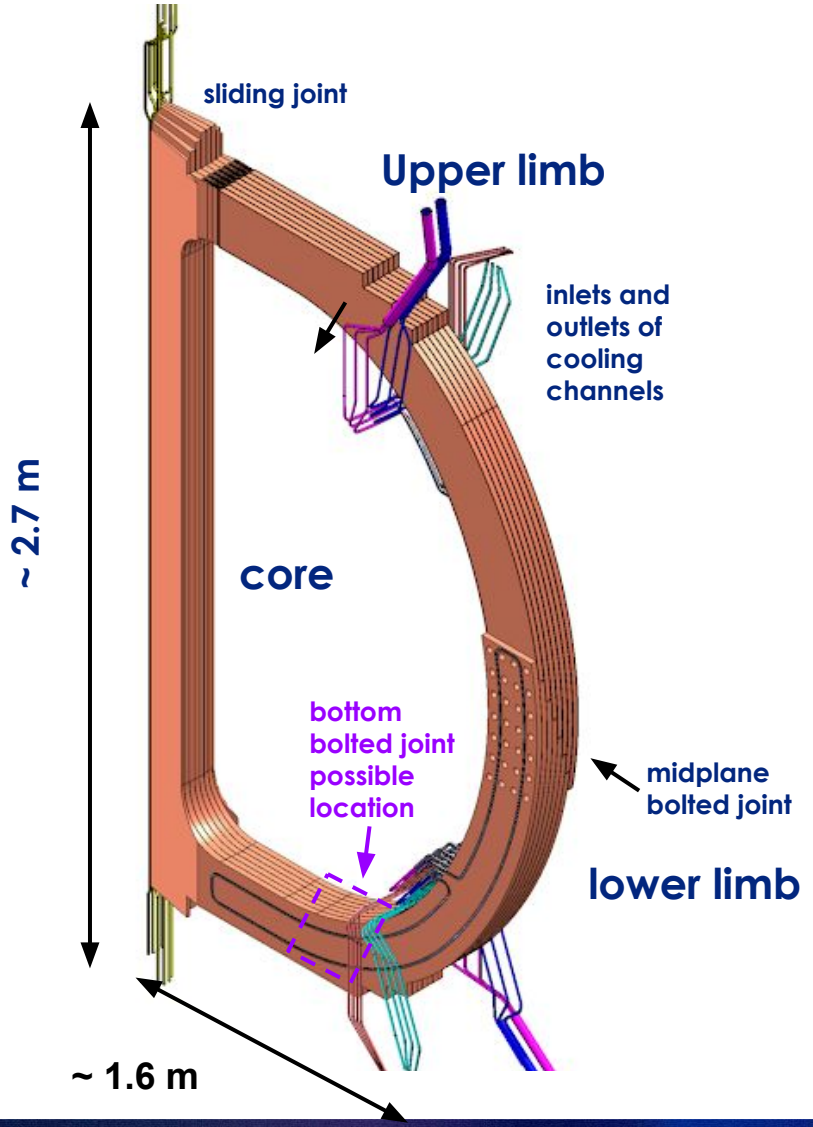
- **Prototype coil** to confirm design and manufacture procedure
- Manufacture of **10 individual poloidal field coils** from **hollow conductor** from **High conductivity oxygen free silver bearing copper alloy** with different radius of coils (0.5 – 1.5 m) and mostly **hard temper of material**

Presumed scope of work on the coil

- Winding, Insulation, Vacuum pressure impregnation, soldering, brazing
- **Welding of el. breaks** to current and coolant feeders
- **Ground shield by conductive varnish** - **addition to the design**
- Additional **ground wrap**
- Electrical and leak testing
- **Paschen tests** - **local paschen tests are mandatory for each coil**
- Transport to IPP

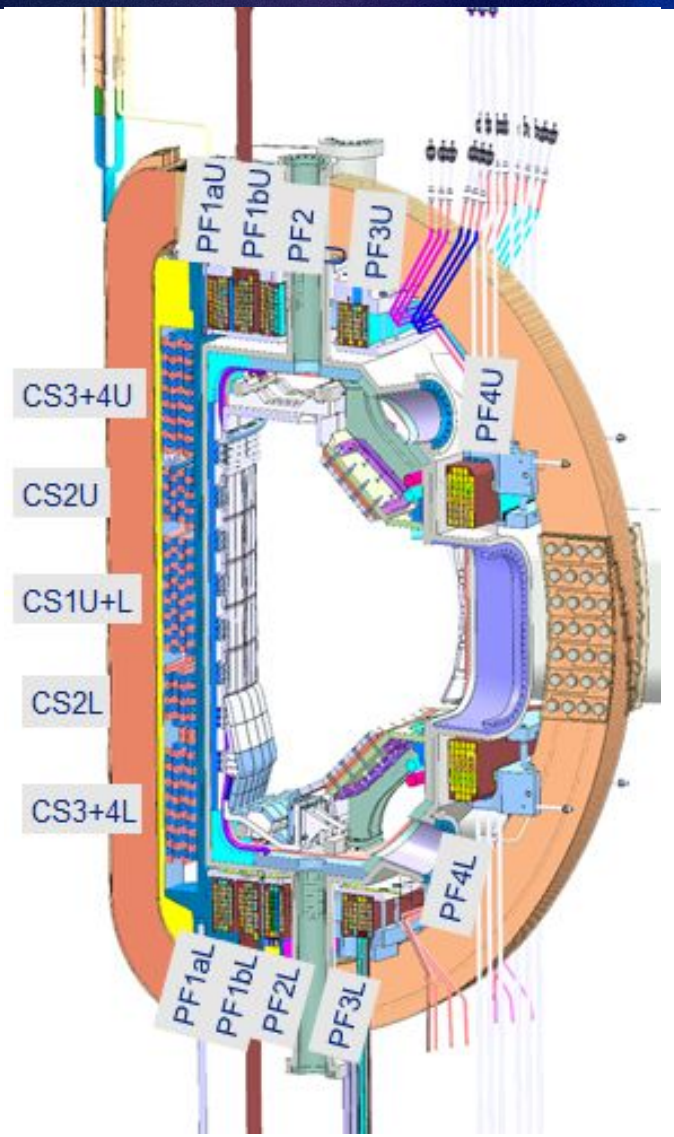
Terminology PF and TF coil





Parameters of the coils

coil	Copper turn crossection [mm^2]	Coil copper mass [kg]	dR [m]	dZ [m]
PF1Ua	185.66	199	0.074	0.159
PF1Ub	185.66	229	0.074	0.159
PF2U	185.66	257	0.074	0.159
PF3U	185.66	401	0.108	0.125
PF4U	275.52	845	0.102	0.182



Conductor design overview:

coil and quantity	material of the conductor	Height [mm]	width [mm]	dia of hole [mm]	radius of corner [mm]	numb. of turns	medium radius of the coil [m]	total length of the conductor [m]	length of the uninterrupted conductor [m]
2 x PF1a	C10700	15	14.7	7	2	33	0.576	120	65
2 x PF1b	C10700	15	14.7	7	2	33	0.662	139	74
2 x PF2	C10700	15	14.7	7	2	33	0.749	158	84
2x PF3	C10700	15	14.7	7	2	37	1.06	246	87
2x PF4	C10700	20	17	9	2	38	1.43	343	90

1 x Prototype coil: PF1a

Primer and epoxy:

- CTD-450, GY282 (Manufacturer may suggest alternative products, but have to prove the quality of the proposed solution)
- Tensile and shear/compression insulation tests are mandatory even if recommended design options are chosen (insulation qualification program)

Conductor

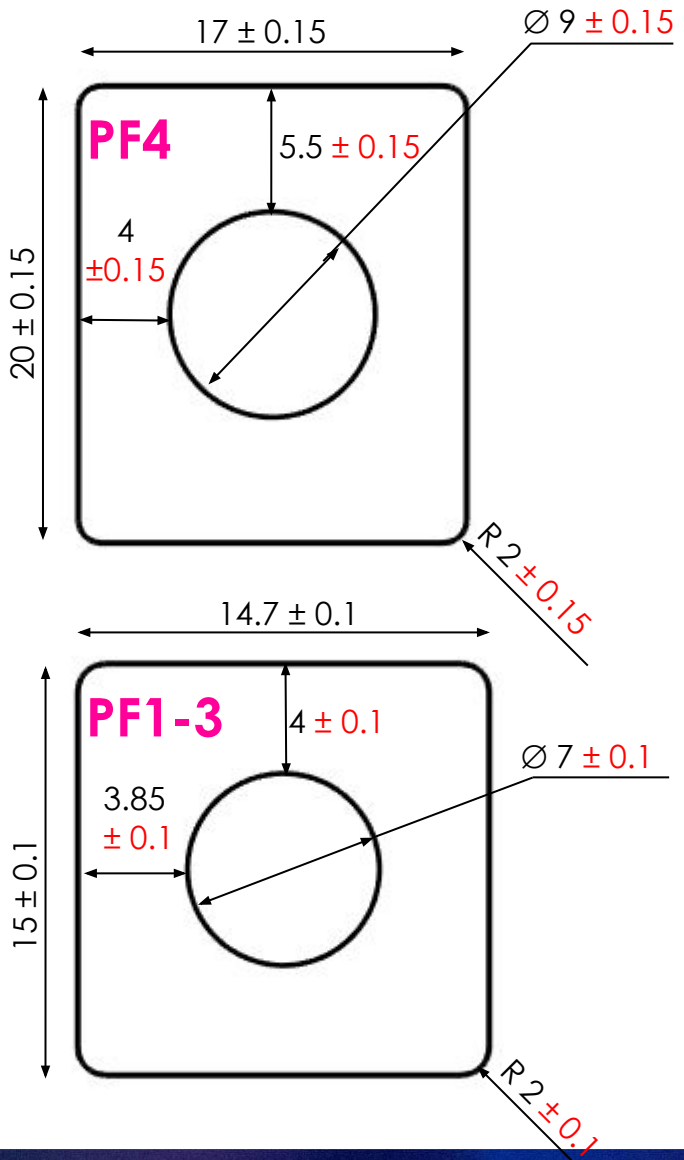
Hollow conductor Cu-Ag0.1 according to EN CW019A or UNS C10700

Chemical composition

A chemical analysis shall be carried out on a sample from one extruded/drawn conductor from each cast to confirm that the chemical composition meets the requirements.

Coil conductor cross-section tolerances per EN 13600 as a baseline but with some parameters more strict

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**



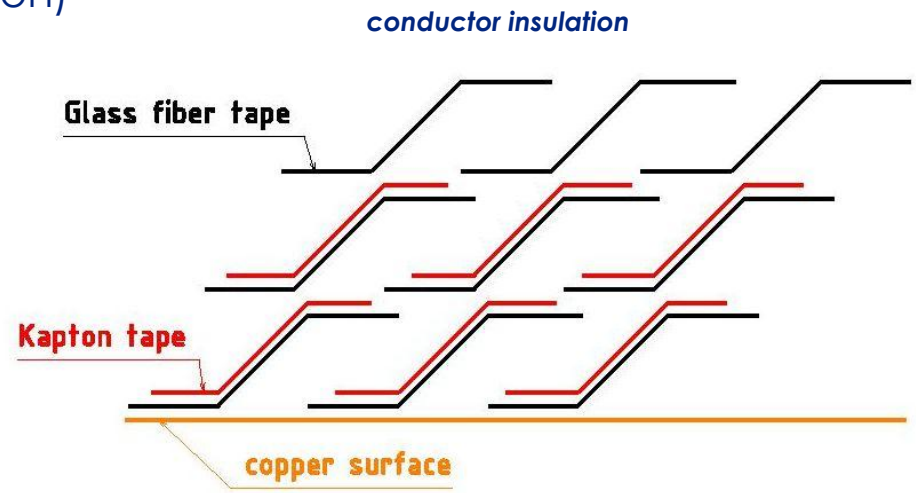
Insulation overview

Insulation system

- The **glass fibre content** of the insulation is preliminary set to **40% ± 5% volume -** but final decision will be given after confirmation from the manufacturer tests. The manufacturer will test **3 sets of samples** with different **vol. glass fibre ratio (30, 40, 50 ± 5%).**
- **Nominal voltage** of power supplies for PF system is **1 kV**

Conductor insulation

- **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% E glass tape
- **total thickness 1 mm** (turn-to-turn insl. = 2x 1 mm)



Ground insulation

- **at least 5 layers** of half-lapped E glass fibre tape (no Kapton) - **total thickness 2,5 mm**:

Insulation qualification program

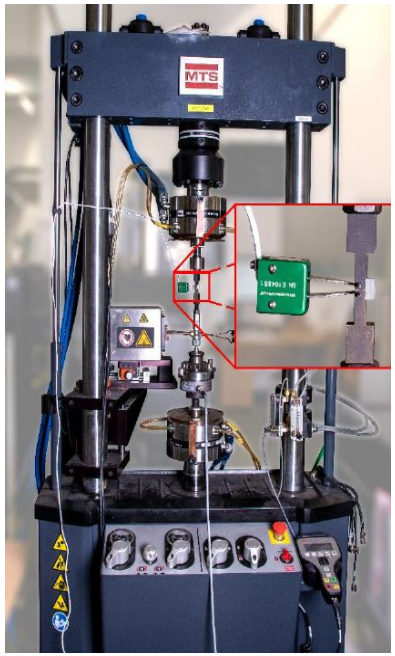
PF Supplier is required to qualify insulation by testing samples, performing **static tensile** and **shear-compression tests** at room temp. for **3 different sets of samples** (with varying fiberglass ratio)
For reference, IPP conducted its own insulation sample qualification tests, see summary below.

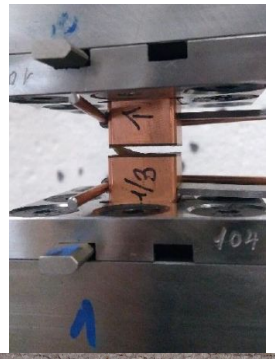
IPP tensile tests:

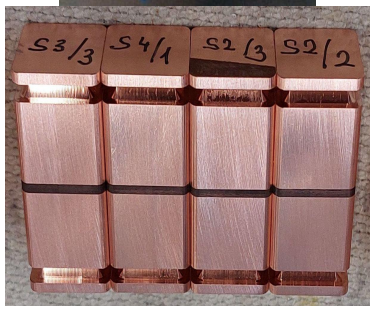
- **static @293 K**: Tensile strength min. 39.5 MPa, avg. 45.8 MPa
- **static @80 K**: Tensile strength min. 33.9 MPa, avg. 41.1 MPa
- **cyclic @80 K**: Tensile strength ≥ 29.6 MPa @ 10k cycles, ≥ 26.0 MPa @50k cycles (95% conf.)

IPP shear-compression tests:

- 30° and 45° angle between shear and compression load
- static @293 K: Shear strength 53.8 MPa, lower bound ≥ 50.3 MPa (95% conf.)
- static @80 K: Shear strength 48.0 MPa, lower bound ≥ 40.1 MPa (95% conf.)





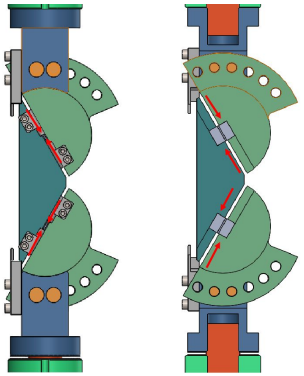


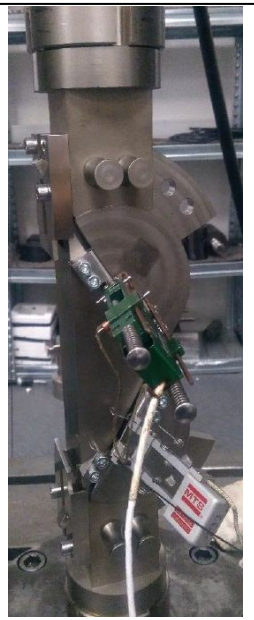
IPP insulation samples:

- CuAg0.1 base plate
- 2 mm insulation thickness (PF turn-to-turn layout)
- primer CTD 450
- E-glass fiber tape, satin weave interleaved with Kapton tape
- vol. fiberglass ratio ~50%

2 resins tested:

- Araldite GY 282
  - better performance, recommended by IPP
- CTD-101K



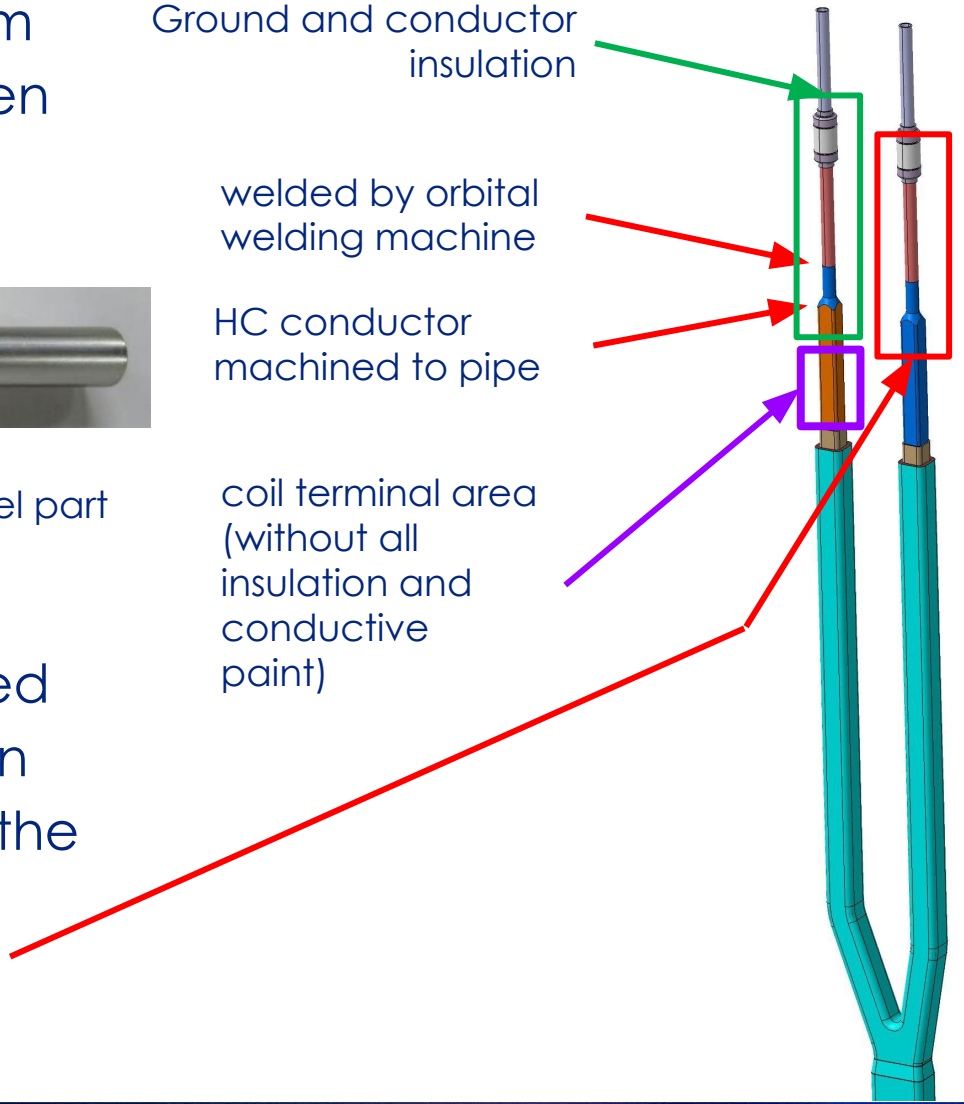


Current and coolant inlets

- Coolant inlets **are machined** from HC shape to pipe shape and then the el. break is **welded**
- **El. breaks** are provided by IPP

copper side el. ceramic breaks Stainless steel part

- The part is insulated with **same insulation layout** as coil and VPIed
- Ground and conductor insulation terminated ends 10 mm behind the electric break
- Conductive layer at this area



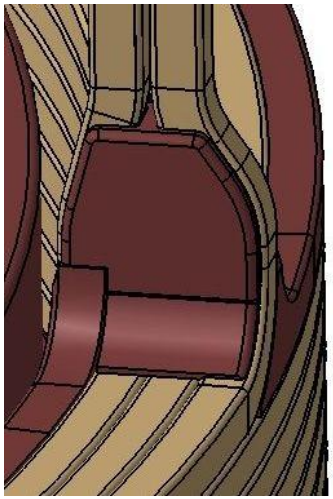
Small radius conductor bends

Small radius conductor bends

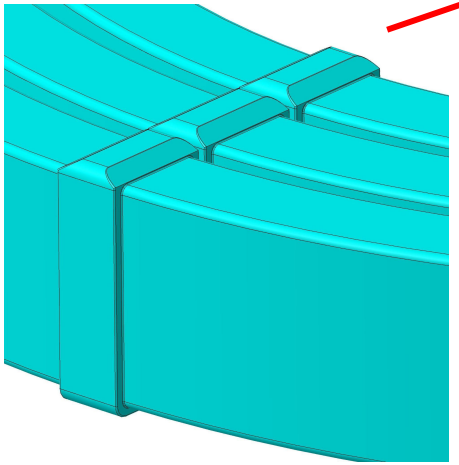
- PF supplier shall **demonstrate their ability to wind the coils** including **90° small radius conductor bends** at places where the conductor is leaving the bulk of the coil and forms coil feeders. These bends will be subject to strong EM forces and it is essential that the integrity of conductor is not compromised.
- To illustrate, the smallest bend of PF1a coil conductor has inner radius 37.5 mm. This gives copper elongation 16.7% for bending around the conductor centre. This may be problematic due to the **required material condition of the conductor (min. YS 250 MPa, min. UTS 290 MPa)**, as **elongation at break of such a hard copper will be low**.
- **IPP acknowledges that there is not an established bending process and as such this activity carries a risk for the supplier**.
- To **develop the bending process**, the supplier has **12 months** to try to qualify **3 bending processes** by **bending tests of samples** and their inspection (metallographic cuts, tensile tests):
  - bending of conductor at room temperature ("as is")
  - bending of sub-cooled conductor (LN2)
  - bending of locally annealed conductor (however, YS of conductor shall be restored during the bending process)
- **If this development does not yield a successfully qualified technological process, the responsibility to develop the process is transferred to IPP and the supplier contract deadlines will be postponed by this delay.**

PF1a, PF1b and PF2

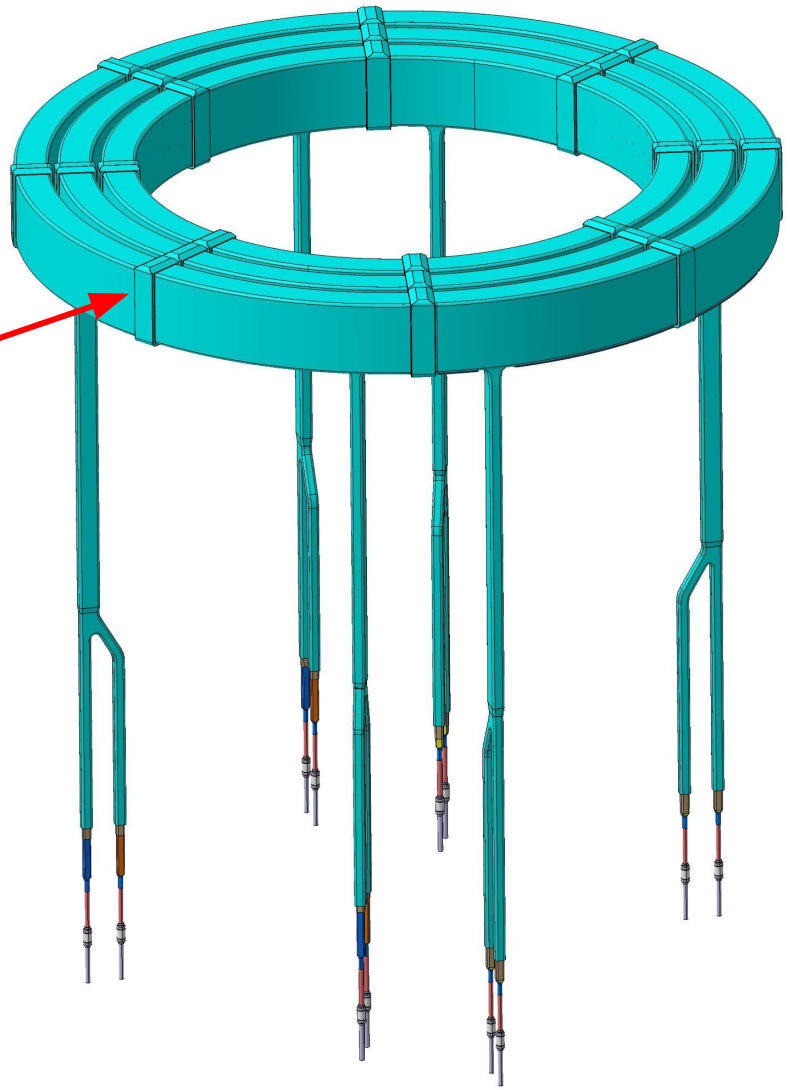
- Coils are shown with ground insulation, sliding pads and ground shield
- HPL inserts in the body of coils, supports of current and coolant feeders



supporting pads



additional wraps and centering elements



PF3

- The cooling pipes have to be insulated as well till the electrical break
- **PF1a, PF1b, PF2 and PF3** are **wounded as planear** with short joggles to next turn and layer
- Diameter ~ 2 m
- Feeder length ~ 1,4 m
- **Ground shield** "cyan" layer with dedicated grounding points

PF4

- **Pancake winding** - conductor is wounded radially by individual turns
- Different design of the coolant and current outlets for PF4U and **PF4L (on the picture)**
- **Electric breaks** are placed almost at **3.6 m diameter**

- Current feeders and coolant feeders have ground insulation and ground shield
- **Conductive layer** is toroidaly divided to **4 segments** with conductive overlap.
- Each ground shield sector have **dedicated grounding point**

Testing of the coils

Electrical tests for all poloidal coils

- coil **DC resistance** at room and LN2 temperature
- **Impedance and phase angle measurement (Coil impedance test,** 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 -** for current and coolant feeders, **mandatory for all coils**
  - **Full surface coverage Paschen**, mandatory for prototype coil, subject of additional order by IPP. Can be conducted as a **series of local Paschen tests** covering the whole coil surface or **Paschen test of the whole coil + feeders in one go**

Mechanical tests

- **Tensile test of the conductor** at RT according to EN ISO 6892 – 1 at RT
- **Integrity tests of small radius conductor bends**
- **Sectioning & tests of prototype coil**

Leak inspection

- The coolant medium of coils is **gaseous helium**
- The coil has to be tested to ensure 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	10e^{-10}

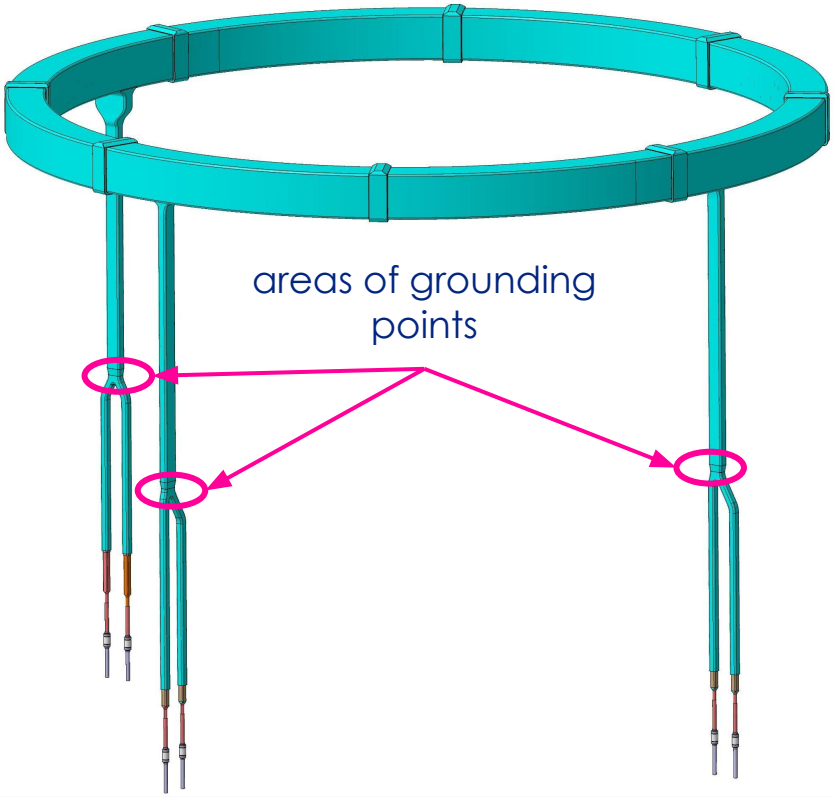
Thermal cycling of each coil

- **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**

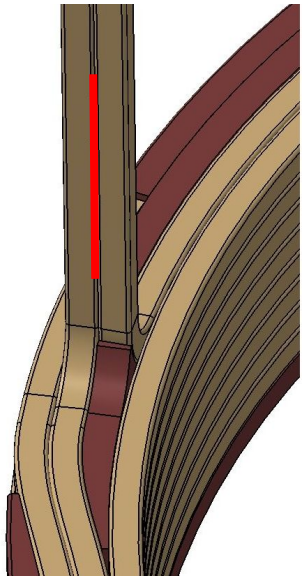
Ground shield

- Applied on all PF coils
- semi - conductive varnish on coils surfaces (on top of ground insulation)
- Resistance of layer **0,5 kΩ/square**
- **Dedicated grounding points** for each coils. Number of points for coils PF1,2 and 3 depends on number of feeders
- **Copper grounding wire/strip** attached to the coil feeder by prepreg or alternative solution
- PF4 have **10 connection points** (each with grounding wire/strip)

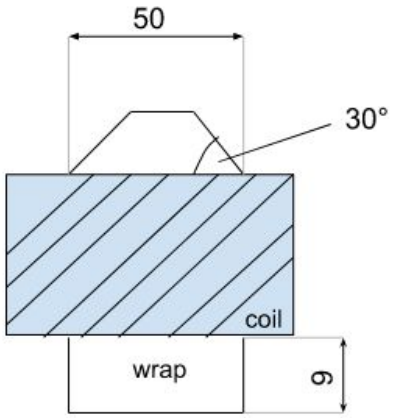


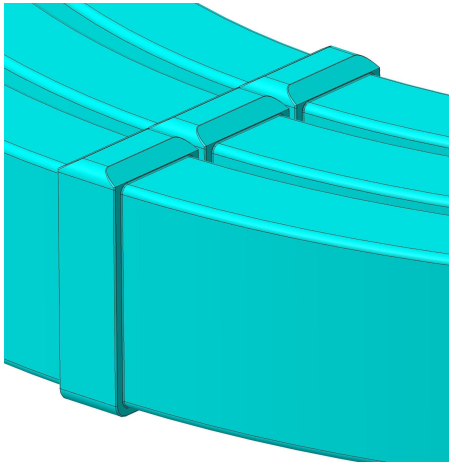
Points of interest

Solder joint of coolant inlets



- Ater joint is soldered, hollow conductors shall be insulated by conductor and ground insulation and VPI-ed
- Soldering area is 100 -150 mm above the coil





Additional wraps

- Additional layers of insulation to secure coil on it´s place **total high of pad is 9 mm**
- one side has trapezoid shape of the wrap
- If the ground shield is connected beneath wraps => no need of conductive layer on additional wraps

Tender specification

- Tender will be launched as **“Framework purchase agreement”** - The Buyer have to 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.** On our web site is released document “**information for suppliers.pdf**” which give overview of what foreign supplier has submit.
- IPP strongly recommended to Sellers to hire czech layer company to help with all necessary documentation which accompanying the bid. **If any of statutory requirements are not met**, **the bid is removed from tender competition**.
- **Deadline for delivery** of the coils is **2 years** + **2 months if Paschen testing** is ordered.

More informations about preliminary market consultation can be found at:

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

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