COMPASS
INSTITUTE OF PLASMA PHYSICS ASCR

Multilayer insulation (MLI) at COMPASS-U

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Versions

Version	Published	Changes
1.0	23. 6. 2020	Initial revision

COMPASS-U - Overview

The **COMPASS-U** will be a high magnetic field (5 T) medium-sized tokamak with high wall temperature (< 770 K) operation.

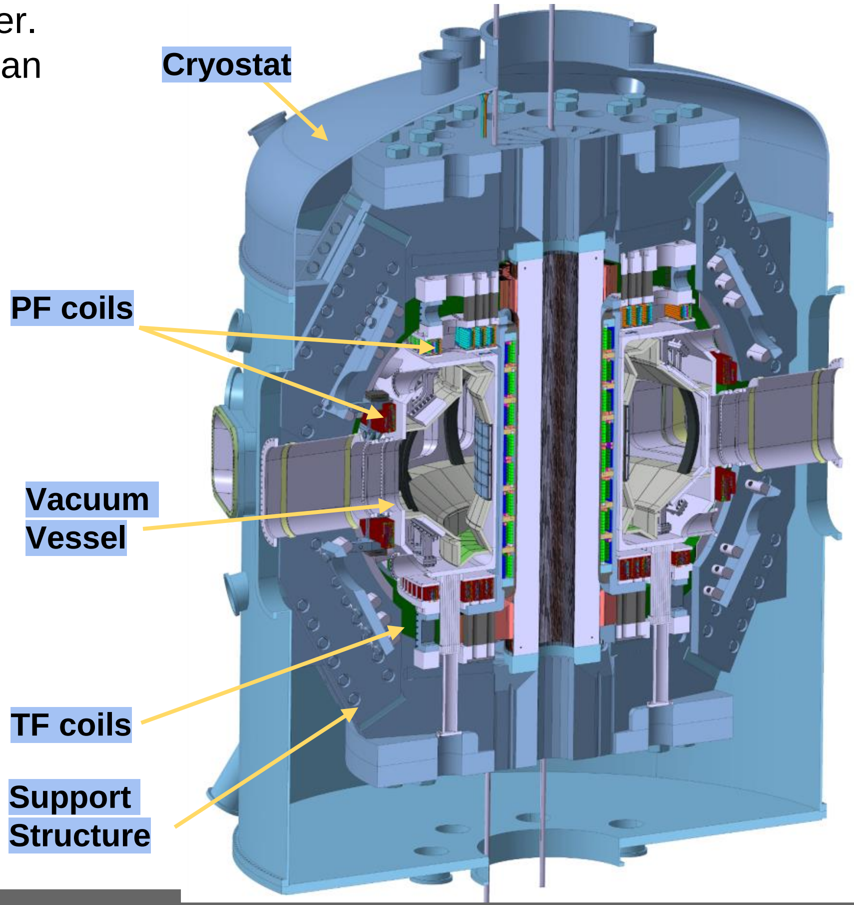
Tokamaks are devices in which various inter-plasma processes (incl. nuclear fusion) are investigated. Plasma is created and held by strong magnetic field in vacuum chamber. By the definition, tokamaks are pulsed devices - discharge can be run just for given amount of time, until maximal current through some of magnetic coils is reached.

Basic parameters:

R = 0.894 m
a = 0.27 m

B_t = 5 T
I_p = 2 MA
$t_{flat\text{-}top}$ ~ 2 s

V_{plasma} ~ 2 m^3
T_{wall} ≤ 500 °C

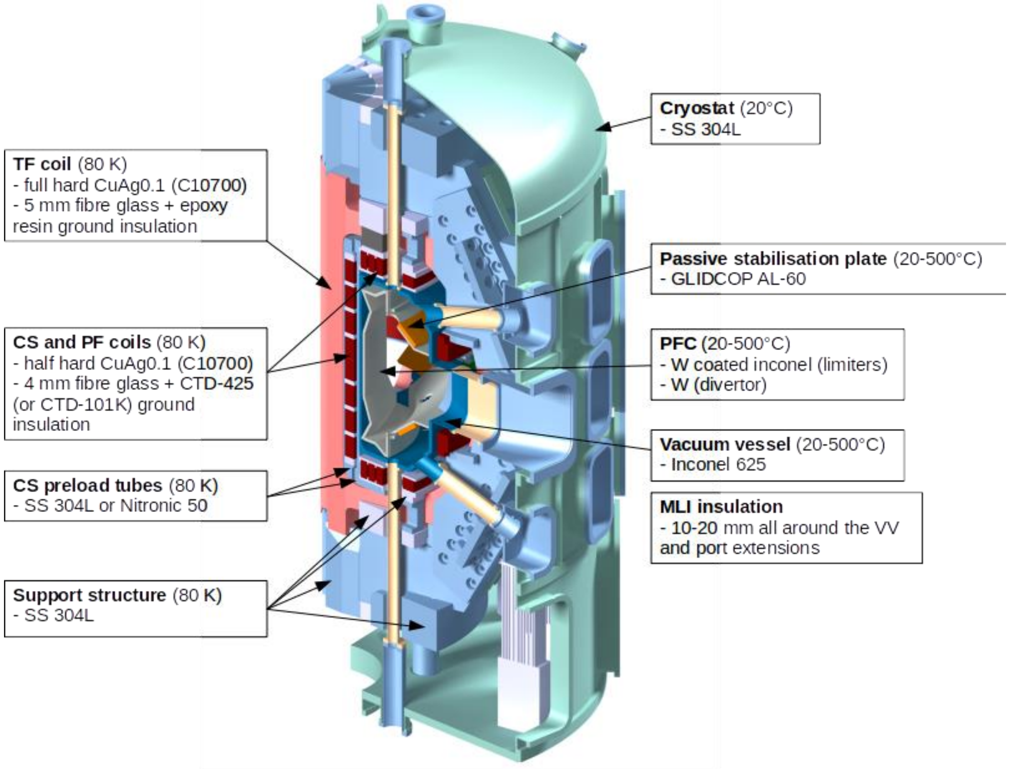


COMPASS-U - Introduction

Temperature distribution at COMPASS-U

Magnetic field will be generated by copper coils (both TF and PF coils) which will **be cooled down to 80 K** by cryogenic system for lowering their electric resistance and joule losses.

On the other side, to achieve operating regimes relevant to DEMO (planned fusion power-plant), temperature of **770 K is needed on first wall** (this means inner **vacuum vessel**). This can be achieved only by heating the whole vacuum vessel to this temperature.



COMPASS-U - Introduction

Heat transfer insulation

Based on information from previous slide it is clear that it is necessary to find a way how to limit heat transfer between warm and cold parts of tokamak.

Currently, it is planned to use **multilayer thermal insulation (MLI)** on cryostat inner wall (300 K) and vacuum vessel outer wall (770 K). However, any other ideas are very welcomed.

Target design limit for energy radiation of vacuum vessel is 100 -150 W/m^2. Vacuum vessel made of Inconel radiates almost 12 kW/m^2 at 770 K. If vacuum vessel was polished and silver-coated on both sides, radiation would be lowered to 300 W/m^2. Anyway, additional thermal insulation needs to be used.

Tendering process

COMPASS-U is currently at the design phase. Current schedule is finalizing design and tendering process in 2020, assembly in 2021 and commissioning at the beginning of 2022.

It is planned to launch cryogenics tender at the end of 2020. Officially, each manufacturer interested in collaboration with IPP CAS should attend PMC (Preliminary Market Consultation).

COMPASS-U – MLI

Multilayer insulation at COMPASS-U

Whole tokamak assembly will be situated in vacuum cryostat that will eliminate heat transfer by convection. Maximum pressure in cryostat should be below 10^{-3} Pa (design target 10^{-5} Pa), so complete evacuation of MLI is guaranteed.

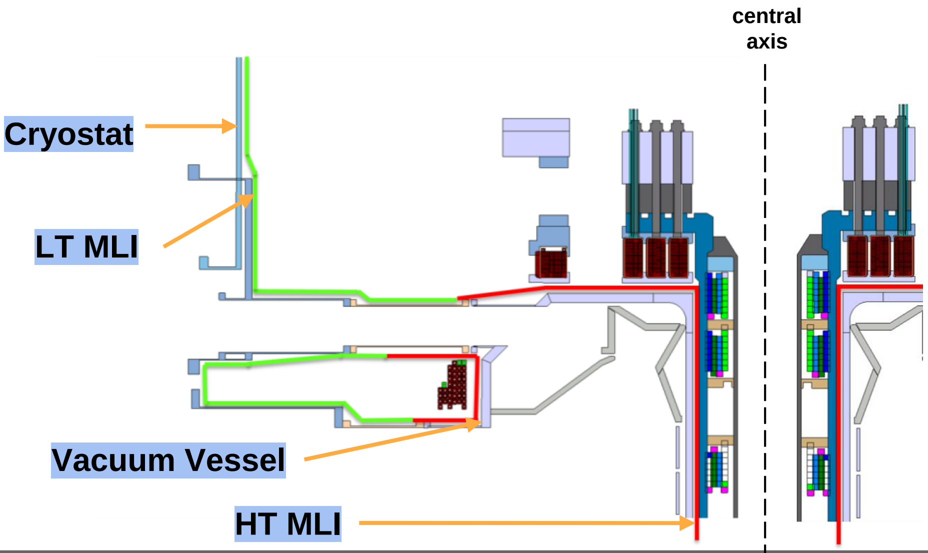
It is planned to install multilayer insulation:

- on inner wall of cryostat to reduce heat transfer between cryostat (300 K) and cooled parts (80 K).
- on outer wall of vacuum vessel to reduce heat transfer between vacuum vessel (770 K) and cooled parts (80 K).

Currently, we are planning to use two kind of MLI (at least) due to very various requirements on MLI properties and performance.

"Low temperature MLI" on cryostat and "high temperature MLI" on vacuum vessel (represented by green and red colour respectively in Sectional view of COMPASS-U).

Sectional view of COMPASS-U



COMPASS-U – High temperature MLI

Key requirements on high temperature MLI at COMPASS-U

Temperature tolerance

- MLI will be basically installed directly on outer wall of vacuum vessel (770 K). Then MLI must withstand T ~ 770 K for a long time without any damage.

Changing magnetic field endurance

- In tokamaks, rapid termination of plasma, called "plasma disruption" can occur. During these events the plasma current abruptly disappears and significant currents are induced into vacuum vessel and nearby metallic structures on small timescales. The maximal magnetic field change outside the vacuum vessel is estimated as **550 T/s for 12.5 ms.**
- Magnitude of eddy current depends on strength of mg field, eddy current loop's area, rate of change of mg flux and resistivity of conductive material.

- Furthermore, during and after the disruption event all other tokamak magnetic fields (toroidal magnetic field ~ **5 T**, poloidal magnetic field ~ **3 T**) are still present. This fact resulting in significant **Lorentz forces, F** = **J** x **B,** acting on conductive metallic parts into which currents have been induced.
- **These forces need to be addressed*** - either by lowering resistivity by means of cuts in metallic materials, lowering inductive loop areas, assuring that the non-conductive support material can cope with such force, anchoring design, etc.

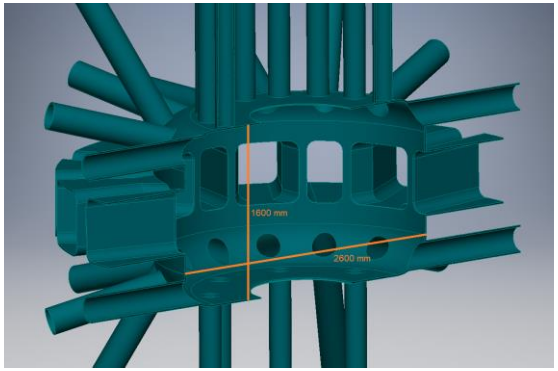
*Based on analysis made at IPP CAS, it was found that force depends strongly on MLI (more precisely conductive material) dimension, **F ~ l^3**. Several calculation was done for aluminium foil with thickness 10 um as it is usually used material for MLI suitable for high temperature. Taking into account the worst case scenario (max. dB/dt, T = 770 K), the max. allowed dimension of aluminium foil that would survive Lorentz forces was only couple cm. Then it is clear that completely new design of high temperature MLI specially suited for COMPASS-U is necessary.

COMPASS-U – High temperature MLI

Installation of high temperature MLI at COMPASS-U

Space allocation

- Allocated space between vacuum vessel and coil support is only 1 - 2 cm.
- To limit heat conduction, they will be mostly separated and connected only at specific, thermal anchored places.

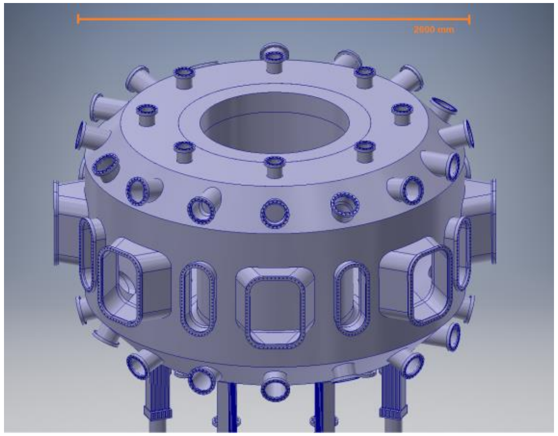


Mounting scheme

- MLI should be attached to vacuum vessel, not to allow movement or thermal short circuits during tokamak operations.
- Vacuum vessel is made of ~ 40 mm thick sheets of Inconel 625 and thus welding of small pieces can be difficult.

- MLI should be segmented to allow comfortable installation and access to critical components in later disassembly.

- Surface of vacuum vessel (primary surface covered with MLI) is ~ **25 m^2**.
- Surface of port extension is ~ 0.5-1 m^2 per port, in total ~ **50 m^2**



COMPASS-U – Low temperature MLI

Key requirements on low temperature MLI at COMPASS-U

No problem with changing magnetic field, high temperature or space allocation for MLI installation.

Probably standard material and installation process can be used:

- aluminized polymer foil (e.g. Mylar, Kapton) + polymer spacer (e.g. polyester), 20 layers each,
- sewn together with polymer thread,
- installation via Velcro fasteners.

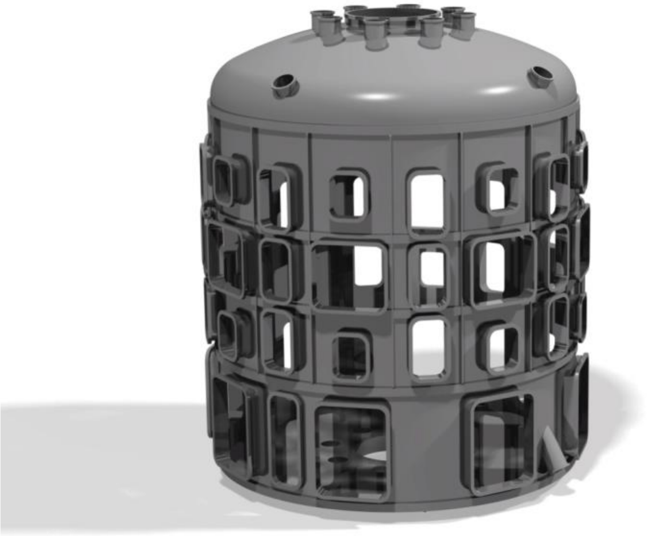
- Optional:
  - slits in metallic coating in poloidal direction for eddy current suppression,
  - outer covering layer (polyimide).

Installation of low temperature MLI at COMPASS-U

Low temperature MLI will be installed on inner wall of cryostat (300 K) made of stainless steel 304L.
Cryostat won't have any active temperature stabilization.

MLI should be segmented to allow comfortable installation and access to critical components in later disassembly.

Surface of cryostat is ~ **100 m^2.**



COMPASS-U – Summary

We are looking for efficient thermal insulation for reduction of heat transfer between warm (300-770 K) and cold (77 K) parts of new tokamak COMPASS-U.

Currently it is planned to use multilayer insulation but any other ideas are welcomed. If MLI was finally used, minimally two kind of MLI would be install at COMPASS-U due to various requirements:

Low temperature MLI

- Standard MLI suitable for low temperature can be used (consisting of aluminized polymer foil and polymer spacer).

High temperature MLI

- Currently in design phase.
- Due to eddy current induction in metallic parts of MLI at COMPASS-U and Lorentz force acting on it, new design is necessary.

We are **primarily interested** into ideas regarding high temperature MLI design and installation.