High temperature multi-layer insulation

Preliminary requirements

This document describes requirements on high temperature multi-layer insulations for COMPASS-U tokamak and is intended for companies who have shown interest in the Preliminary Market Consultation for COMPASS-U to initiate discussion and to have feedback on fabrication viability of the system. It will provide very basic information about the system which is in the design phase.

Version	Published	Changes
1.0	16. 1. 2020	Initial revision
1.1	3. 2. 2020	Small changes in the sake of clarity

Introduction

Institute of plasma physics of Czech Academy of sciences is building new high performance tokamak - research device on field of nuclear fusion - named COMPASS-U. Its main design parameters are toroidal field intensity 5 T, plasma current 2 MA, pulse length 5 s and first wall temperature 500 °C.

Magnetic field will be generated by copper coils (both TF and PF coils) which will be cooled down to 80 K (-193 C) by cryogenic system. This will significantly lower their electric resistance and joule losses and enable us to reach requested parameters.

On the other side, to achieve operating regimes relevant to DEMO (planned fusion power-plant), temperature of 500 °C is needed on first wall (this means inner vacuum vessel surface which is facing plasma during operation). And this can be in reality achieved only by heating whole vacuum vessel to this temperature.

Device is now at the design phase, current schedule includes finalizing design in the first half of 2020, tendering process in half of 2020 and assembly in 2021. Commissioning is planned on beginning of 2022.

Insulation

As mentioned in the introduction, two “basic” parts ok tokamak will be on significantly different temperatures. Vacuum vessel heated to 770 K and coils cooled down to 80 K are in some places separated only by few centimeters.

To make such construction possible, heat transfers between hot and cold parts must be carefully lowered. For initial phases available cryogenic cooling power will be about ~ 10 kW, so it is important to keep heat load as low as possible.

Whole tokamak assembly will be situated in vacuum cryostat that will eliminate heat transfer by convection. To limit heat conduction, vacuum vessel and coil support structure will be mostly separated and connected only at specific, thermal anchored places.

Multi-layer insulation

To limit heat transfer by radiation, multi-layer insulation (MLI) is to be used. Maximum pressure in cryostat should be below 10^{-3} Pa (design target 10^{-5} Pa), so complete evacuation of MLI is guaranteed. However it's design has two caveats.

Temperature tolerance

At first, the biggest (and most important) portion of MLI will be situated and mounted directly on vacuum vessel. This means its one side will be heated up directly by **800 K** surface. MLI must withstand this temperature for a long time without any damage.

T_{max_MLI} = 800 K

Changing magnetic field resistance

Second design caveat is hidden in tokamak operation itself. Some situations during tokamak discharge can lead to rapid termination of plasma, called "plasma disruption". During these events the plasma current abruptly disappears and significant currents are induced into the vacuum vessel and nearby metallic structures on small timescales. In our case, the fastest magnetic field change outside the vacuum vessel is estimated is **1 T in 10 msec**.

This induces eddy currents in all metallic structures (including MLI), depending on their size (conductive loop area). 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. Resulting in significant Lorentz forces 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 and lowering inductive loop areas or assuring that the non-conductive support material can cope with such force.

$dB_{disruption}/dt$ = 1 T / 10 msec

B_{static} = 3 - 5 T

The MLI and its anchoring **must** survive the forces and heating caused by these disruptive events!

Heat transfer

Maximal required heat transfer from 800 K to 80 K is ~ 2.5 kW. Regarding surface constraints, this gives maximal permissible heat transfer rate across MLI **~ 100 W.m^{-2}**.

$P_{max}/S = 100$ W

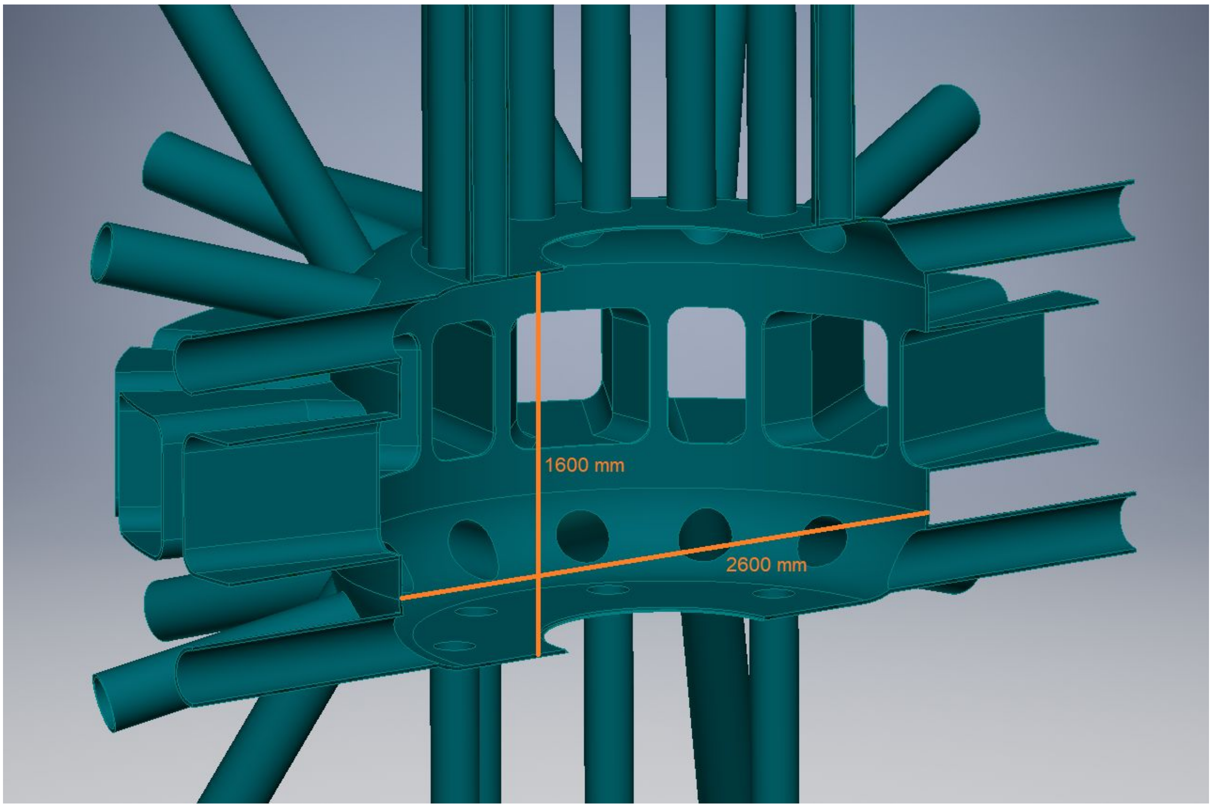
Shape

Requested multi-layer insulation will be covering whole toroidally-shaped vacuum vessel and its port leading towards cryostat. It should be segmented to allow comfortable installation and access to critical components in later disassembly.

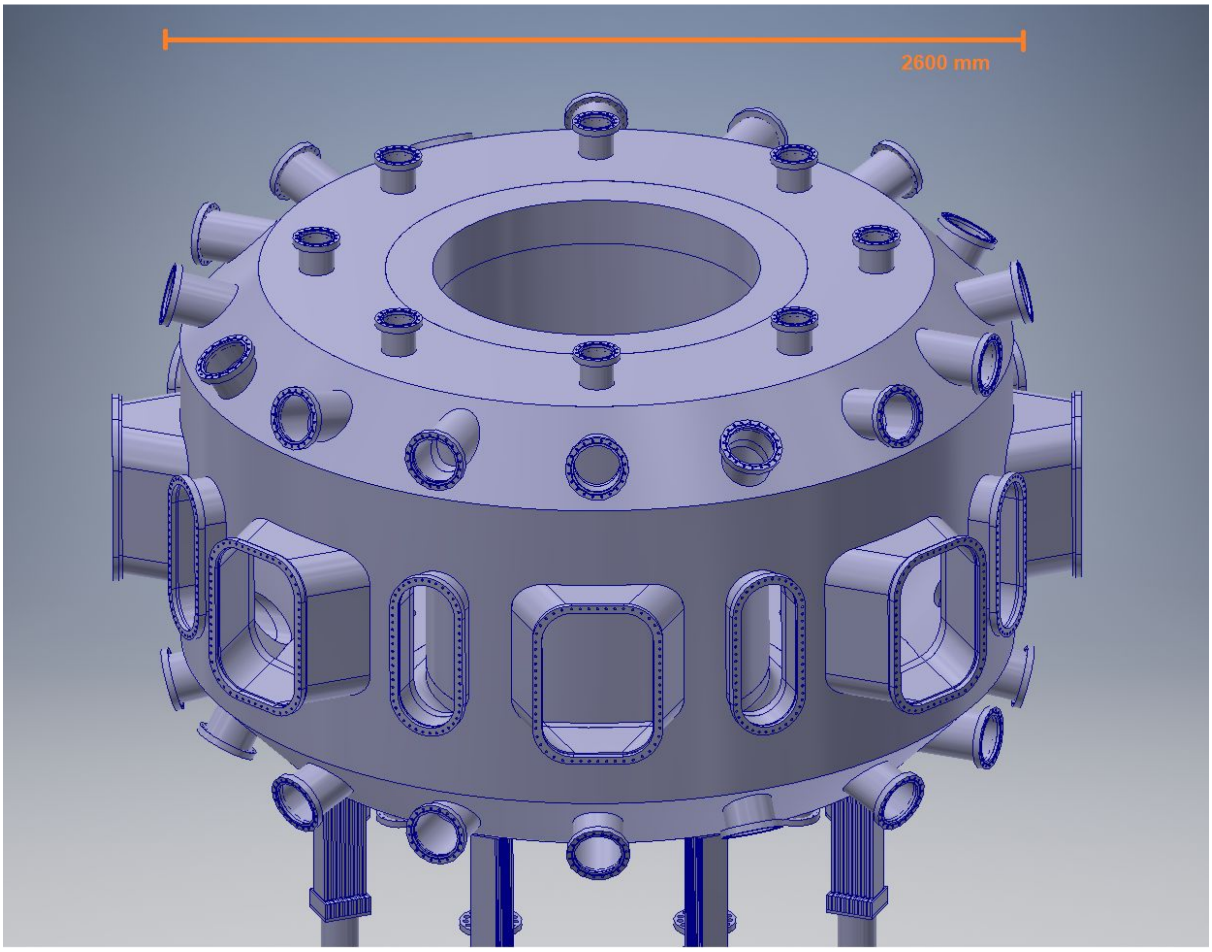
Surface of vacuum vessel (primary surface covered with MLI) is ~ **25 m^2**. Surface of port extension is ~ 0.5-1 m^2 per port, in total **~50 m^2**. As ports will not be actively heated (only heating by conduction from vacuum vessel is considered), insulation of first ~ 50 cm of ports is sufficient.

$S_{vessel} = 25$ m^2

$S_{ports} = 50$ m^2



On picture (half section view), in green is shown space allocated for insulation.



Overview of vacuum vessel. Space allocated for MLI is situated almost directly on the surface of the VV.

Mounting

MLI should be attached to vacuum vessel, not to allow movement and possible thermal short circuits during regular operation and plasma disruptions. Mounting scheme should be proposed by manufacturer, please keep in mind that vacuum vessel is made of ~ 40 mm thick sheets of Inconel 625 and thus welding of small pieces can be difficult. Also space for insulation is limited (~ < 2 cm) and mounting scheme should be compact enough to fit inside this allocated space.