Overview of the ITER In-Vessel coil (IVC)

1. Purpose of the market survey

With the present survey we would like to get from the Domestic Agencies a list of potential suppliers around the world for the procurement of the ITER In-Vessel coils (27 ELM coils, 2 VS coils and some spares). The present plan for procurement will be split into two parts:

1) Procurement for conductor manufacturing, for both ELM and VS coils, approximately 3 km. of conductor.

2) Procurement for coils manufacturing and onsite assembly inside the ITER vacuum vessel.

We are also open to alternative contract strategies, e.g. to combine the two procurements together, or to exclude onsite installation from the procurement 2, or others.

The tentative schedule for the procurement is as follows:

1. Call for nominations to be launched in 2014
2. Contracts to be signed in 2015
3. Onsite delivery of the manufactured coils in 2018
4. Onsite Assembly and Installation starts in 2019.

The information presented below is to give a general overview of the system.

2. Introduction

ITER is incorporating two types of In-Vessel Coils (IVCs): ELM Coils to mitigate Edge Localized Modes and VS Coils to provide Vertical Stabilization of the plasma. Strong coupling with the plasma is required so that the ELM and VS Coils can meet their performance requirements. Accordingly, the IVCs are in close proximity to the plasma, mounted just behind the Blanket Shield Modules. This location results in a radiation and temperature environment that is severe necessitating new solutions for material selection as well as challenging analysis and design solutions. Fitting the coil systems in between the blanket shield modules and the vacuum vessel leads to difficult integration with diagnostics and cooling water manifolds.

3. Layout of the IVC.

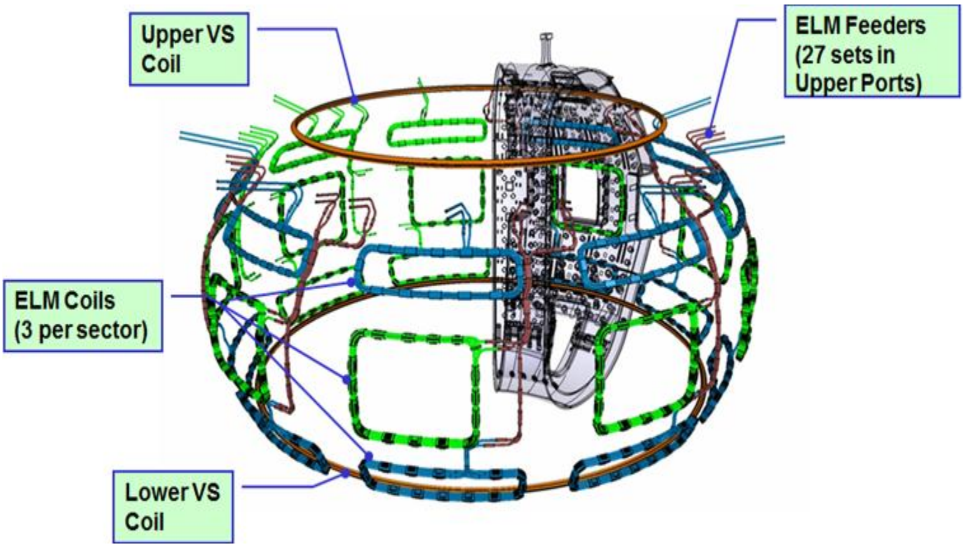


Figure 1: Overview of the IVCs inside the machine

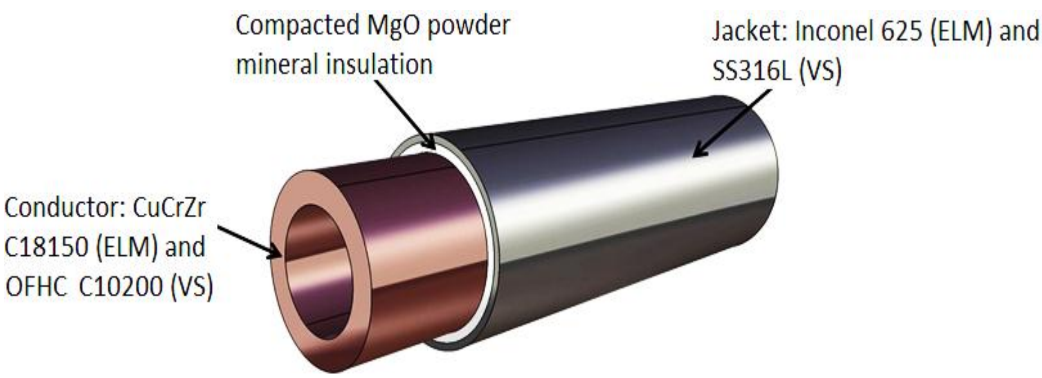
The ELM coils consist of three (upper, midplane, and lower) 6-turn rectangular “picture frame coils”, for a total of 27 coils mounted to the vacuum vessel and positioned behind the blanket shield modules (BSM).

The VS coils consist of one upper and one lower 4-turn solenoidal “ring” coil connected in an anti-series “saddle” arrangement. The coils are mounted to the vacuum vessel and positioned behind the blanket shield modules.

All IVCs are supported via bolts to the rails which are welded to the VV wall.

4. Details of the IVC design

All ELM and VS coil conductor’s design and materials are given below:



	ELM	VS
Jacket material	Inconel 625	SS 316L
Jacket- Outer diameter	59 mm	59 mm
Jacket- Inner diameter	51mm	55 mm
Conductor material	CuCrZr (C18150)	OFHC (C10200)
Conductor outer diameter	46 mm	45 mm
Conductor inner diameter	33.3 mm	30 mm
Mineral insulation thickness	2.5 mm	5.0 mm

Table 1: Dimensions of the IVC conductors

Conductor unit lengths in the order of 11 m have been produced so far in the frame of a R&D task with ASIPP Hefei (China). Candidate suppliers are also invited to indicate if longer unit lengths could be produced at their facilities.

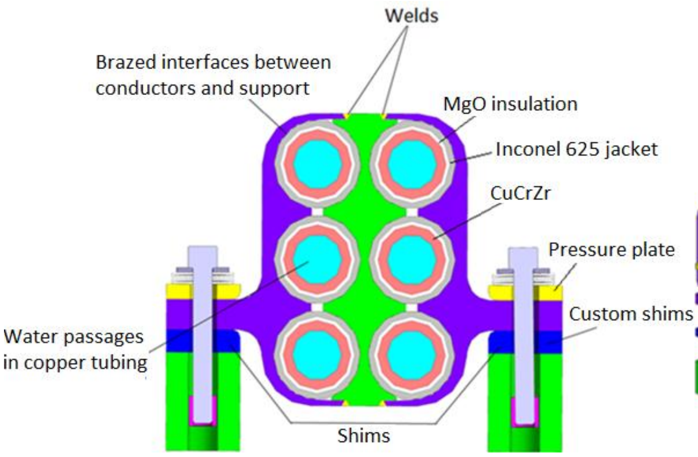


Figure 2: Cross-section of ELM coil with bracket

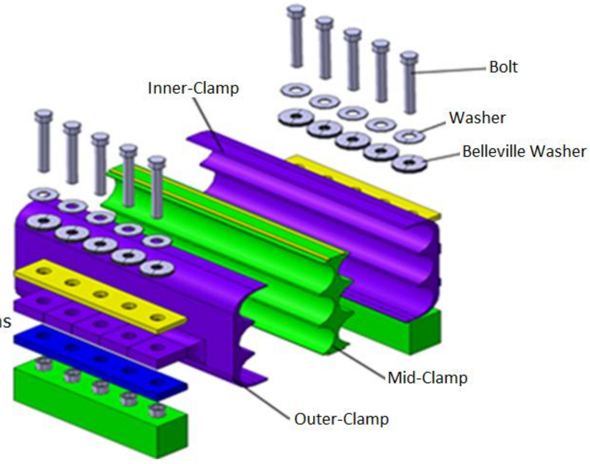


Figure 3: the explosion view of the bracket

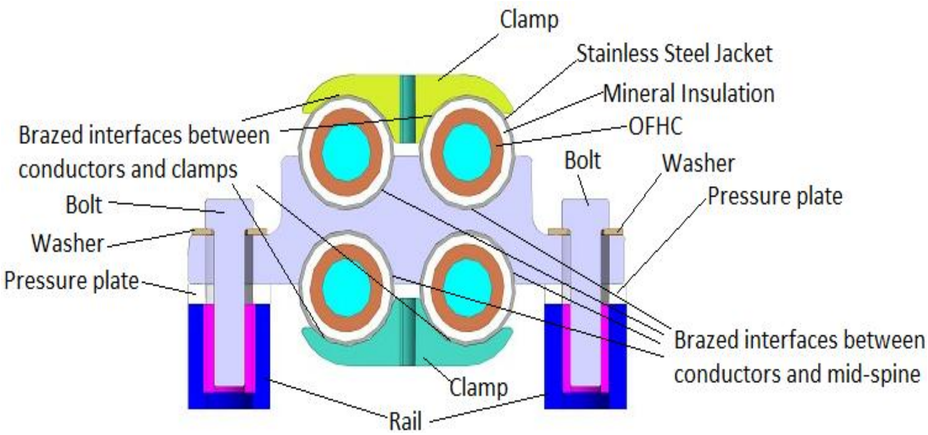


Figure 4: Cross section of VS coil with clamps and mid-spine

4.1. Integration layout of the ELM coils

The ELM coils are located on the outboard side of the VV inner shell. They consist of 27 coils in total, 3 per sector, designated as Lower, Middle, and Upper ELM coils. Each of them consists of 6 turns and a single flow path. The choice of the conductor is CuCrZr, MgO acting as insulator and Inconel 625 jacket. There are 324 internal joints (12 per coil) in all 9 sectors and 144 joints to feeders. The conductors are joined together via induction brazing method, but alternative techniques could be considered. At the location of those joints a sleeve of Inconel 625 is welded to the jacket via lap or butt weld. At various locations, the coils are being brazed to brackets and via the brackets bolted to the VV rail for good mechanical anchoring. The VV rails will be welded to the VV inner shell at the VV sector manufacturing facilities. Some brackets have different designs and their location varies from sector to sector.

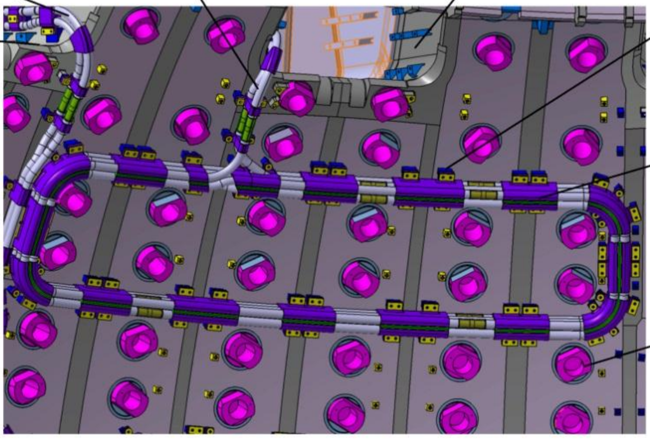


Figure 5: Example: Upper ELM coil installed on the VV wall

4.2. Integration of the Upper and Lower VS coils

There are 2 VS ring coils. One is located at the upper part of the triangular support and the second one is right above the upper ports. Each VS coil has four turns which are independently connected. They are segmented in 3 segments, of 120 degree each which are joined together. The conductor is made of OFHC. The insulation is MgO and the jacket is made of 316 Stainless Steel. Similar to the ELM coils, the conductor is being brazed. Spines with different designs and complexity will help to keep the VS turns in place and support the electromagnetic loading. The spines are continuously brazed to the coils. They are attached to the VV with preloaded Inconel 718 bolts. VS coils contain complicated bumps and crossovers.

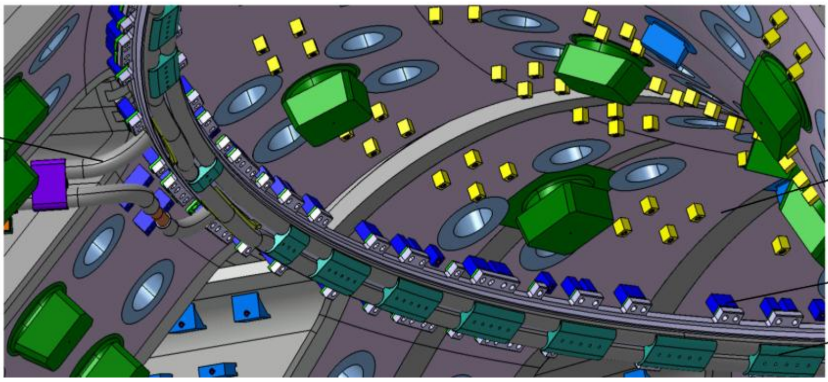
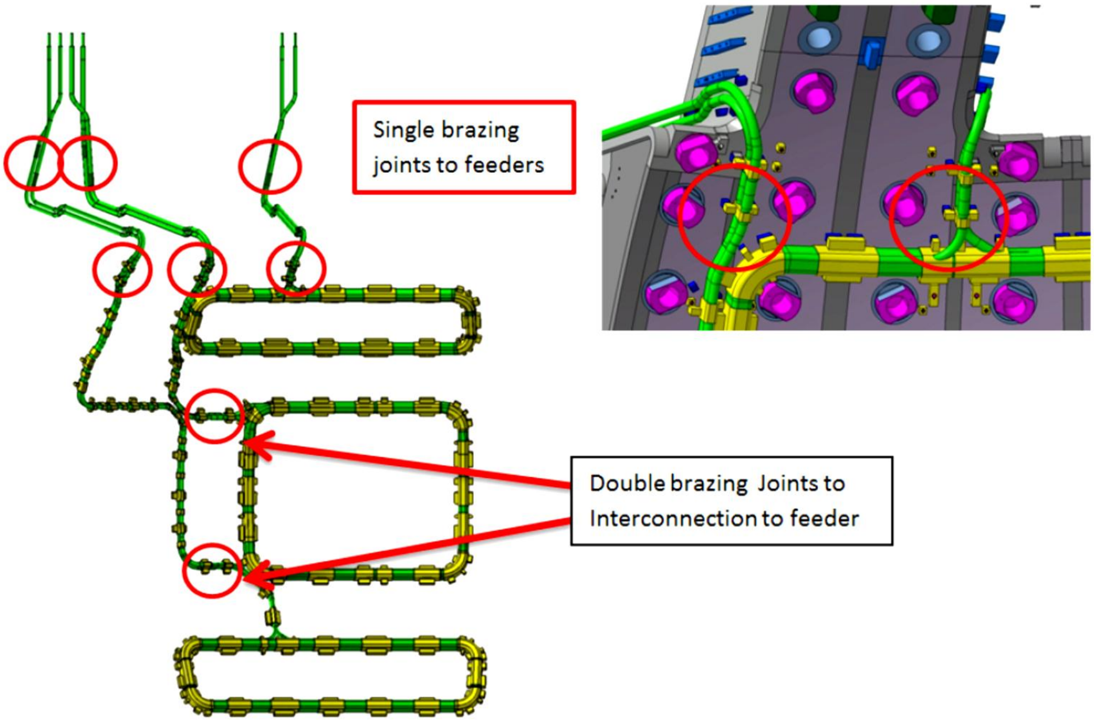


Figure 6: Integration of the Upper VS coil

5. In-situ assembly of IVC

The assembly and joining between the feeders and the coils will be done on site and inside the machine. There are 144 joints to feeders for the ELM coils in all 9 sectors and 24 internal joints (4 joints between each segment) and 48 joints to feeders for the VS coils.



6. The Challenges from the Loads and Fatigue point of View

The maximum EM force on the VS coils achieve 1.15MN, and the maximum EM force on ELM achieve 0.8 MN, in order to reduce the vibration of the coils and manifolds, the clamp for VS coil and brackets for ELM coils with bolts should provide enough preload to prevent slippage of the coils in operation.

One challenge appears on the thermal loads from the ohmic heating of the coils itself and neutronic irradiation; in order to reduce the cycle nuclear heating load, all brackets and clamps should be brazed to coil turns to transfer the thermal heat into coil cooled by water, however, the brazing technology between brackets and conductor turns need to be developed, and maximum thermal loads obtained are 12.72MW totally for all IVC during normal operation. Alternative joining processes could also be considered.

Another challenge is the fatigue point of the bracket materials which was proposed to use, the fatigue stress obtained from analysis calculation is about 85.7MPa and the fatigue limit stress of 316 SS is about 64MPa, according the 20×30000 cycle pulses; so Inconel 625 brackets are proposed and acceptable for calculation results, however, the cost of the Inconel 625 is larger than other materials, and brazing & welding is also more difficult.