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EU-DEMO vacuum vessel port closure plate fastening developments

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ABSTRACT

The EU-DEMO project, which has been in the Concept Design phase since 2021, is already focusing on the integration of the main system components but is also analysing variants to simplify this process. One of these is the fastening and sealing of vacuum vessel closures, known as port closure plates, in order to simplify the execution of the work with the aid of remote maintenance. Recognising the key role of industry, the fusion programme roadmap foresees intensive industry involvement in specific tasks. To provide a starting point for such collaboration, the Fusion Technology Department (FTD) has developed an initial design for a mechanical fastening solution based on the design of ship bulkhead doors. This could be combined with a welded seal, also developed to an early stage in FTD, which could cope with all load cases without additional measures. This system of easy to use fastening and reliable welded seal could be a significant simplification compared to other established technical solutions to this function. This paper presents the above issues and describes the current state of development. It also outlines initial plans to involve experienced industrial partners in these tasks.

1. Introduction

The EU-DEMO development entered the Concept Design (CD) phase from 2021. This phase will continue to focus on the synthesis of variants for different components or technical solutions. These will be analysed in a subsequent step to find the most suitable concept. The given boundary and environmental conditions and other requirements must always be sufficiently investigated and taken into account. The integration of the various technical components is crucial. The CD phase aims to simplify this, also through organisational adjustments.

Technical research and development (R&D) will continue to be carried out in specific work packages (WPs), while integration work will increasingly be done by the system design managers in the Fusion Technology Department (FTD). This approach is intended to further facilitate close collaboration in the integration of the various systems [1].

The fusion programme roadmap [2] foresees that EU-DEMO will not only be designed by research organisations. Industry should gradually become a driving force in the development of fusion and should therefore be intensively involved through specific tasks at an early stage. Amongst other things, the investigation of possible solutions for the fastening and sealing of the vacuum vessel (VV) closures, the so-called port closure plates (PCP), was considered suitable for early industrial involvement. The planned approach to address these issues with industry has already been described [3].

Of course, PCPs are required for all openings of the VV. This document focuses on the current work and results and refers to the upper port (UP), which is mainly used for remote maintenance of the Breeding Blankets (BB).

2. EU-DEMO upper port configuration

In order to be fuel self-sufficient, EU-DEMO aims to produce the tritium required for its operation. For this purpose, the BBs are installed inside the VV and cover most of the surface of the inner walls of the VV. Due to neutron irradiation, the BB materials are subject to degradation and must be replaced within the lifetime of EU-DEMO.

In preparation for the removal of a BB segment, several tasks have to be performed. One of the essential early steps is the removal of the UP PCP [4]. The sectional drawing (Fig. 1) gives an overview of the whole structure and the relevant parts. A comprehensive concept study has addressed the issues related to the transport of BBs between the VV and...
the Active Maintenance Facility (AMF) [5]. Important findings are: i) Due to the activation of the in-vessel components (IVCs), only remote maintenance (RM) methods can be applied. Therefore, a BB transporter is required to carry the heavy load and to fulfil the complex kinematics to remove the BBs. ii) The transport of the removed IVCs to the AMF must take place in so-called casks (i.e. sealed containers) to avoid contamination of the environment. Although not explicitly considered in this study, it can be assumed that the same requirements apply to the PCPs for cleaning and preparation for reinstallation in the AMF.

2.1. Upper port closure plate design considerations

In principle, high vacuum sealing of the VV is not an uncommon problem and is addressed by many mounting and sealing concepts. A certain challenge arises from the following characteristics of the UP PCP:

Fig. 1. Sectional drawing of the EU-DEMO with the relevant parts BB transporter, port closure plate, VV, Breeding Blankets.
Size and geometry. In order to maximise the available space between
the magnetic coils, the geometry is an elongated trapezoid with the
smallest possible radii at the corners. The approximate size is
currently thought to be 6.3 metres by 3.9 metres.

Remote maintenance. To achieve high reliability, common sources of
error must be eliminated as far as possible. This is a very broad
subject and includes phenomena such as cold welding between
identical material pairings, thread seizure [6], overstressing of
dependents due to poor manufacturing or improper assembly.
The latter is particularly critical when using RM tools without sufficient
haptic feedback. Some of these issues are currently being addressed
at ITER. It is already possible to carry out extensive investigations at
an equatorial port on a test stand there. It is therefore expected that
more experience and knowledge will soon be available [7].

Use of suitable materials. According to the current state of materials
development, it is unlikely that elastomers or other plastics will be
used for the gaskets of the VV. For this reason, it can be assumed that
only metallic sealing solutions can be considered.

Cask and contamination control door (CCD). In order to transport
IVCs in a sealed manner, the cask must be airtight. At the same time,
the VV must also be sealed to prevent the exchange of contaminants
with the environment. To achieve this, the cask is equipped with a
double door, the two individual components of which seal the VV
and the cask, respectively, after they are separated from each other.
The external surfaces of the VV or cask remain free of contamination
until and after separation. The design of the PCP must always be
considered to be compatible with the requirements of this cask sys-
tem [8].

2.2. Upper port closure plate fastening

To ensure a vacuum-tight seal of the VV, it is essential that the PCP is
firmly connected to the VV port. It is essential that the chosen method
of connection securely connects the two components, PCP and VV, at
the maximum pressures occurring in the VV, even in the event of malfunc-
tion, and prevents transverse movement. In the case of the vertically
oriented UP, the dead weight of the horizontally mounted PCP sup-
ports these requirements. The UP is therefore particularly suitable for
the resumption of studies on fastening and sealing solutions. Initial in-
vestigations are currently being carried out to determine the re-
quirements for a locking system for the UP’s PCP. Essentially, the
following criteria have been identified as important:

- Minimising the number of bolted joints used.
- Avoidance of threads exposed to vacuum.
- Sufficient rigidity of the PCP construction in relation to the relevant
  pressure conditions.
- Operability of the locks with the use of RM tools.
- Transport of the PCP with the BB transporter. Therefore, the PCP
  shall be equipped with a compatible docking mechanism for the BB
gripper [9].
- Provide sufficient preload to minimise any movement between
  components.

The use of RM tools can be greatly simplified by using an easy to use
locking system. Solutions such as those used for bulkhead doors on
submarines or for locking large vault doors could serve as a model. Here,
a central operating element usually mechanically transmits a movement
to a number of locking bolts. These then engage with correspondingly
designed counterparts in the frame and can also generate a certain
amount of contact pressure.

There are limitations to this design, such as the uneven generation of
contact pressure and the use of the PCP surface by the drive unit.
In general, a PCP without additional use for feedthroughs of any kind is
preferable. However, this cannot be ruled out in the early stages of the
CD, as many IVCs need to be supplied with diagnostic signals or coolant

[10].

A solution based on the functional principle described above, but
without central actuation, was developed as a first design point. In
this solution, locking and contact pressure generation is performed by mul-
tiple wedge clamps distributed around the circumference of the PCP, as
shown in Fig. 2.

The translational drive of the wedge-shaped locking bolt is generated
by a scissors gear operated by a counter-rotating lead screw mechanism.
By defining the lengths and angles of the levers, the thread diameter and
pitch, and the angle of the wedge, it is possible to generate a suitable
contact pressure for each lock. In principle, a pneumatic or hydraulic
drive could also be used to replace the screw or even the entire gearbox.
The drive unit itself is hermetically isolated from the locking pin by a
bellows. Fig. 3 gives an impression of this concept.

2.3. Welded seal

The hermetically welded lip seal is one of the sealing methods
envisioned for ITER [11]. Numerous studies have been carried out to
qualify it and it is already at a high Technology Readiness Level (TRL).
However, to prevent damage from excessive deformation in the event of
an in-vessel loss of coolant accident (IV-LOCA), the current design ap-
plies additional support clamps. These are likely to require additional
RM activities during assembly and disassembly.

To gain a better understanding of the various requirements for a lip
seal, the results of the extensive structural analysis of the ITER vacuum
vessel [12] and the initial definition of the structural loading conditions
in EU-DEMO [13] were used. Taking these results into account, an initial
design was created to simplify remote handling by eliminating the
support clamps (see Fig. 4). This design was then created in Ansys as a
finite element (FE) model to analyse and better quantify the stresses and
deforations caused by different loads on the lip seal. Further analysis is
required, so only a small aspect is described here: Despite the intended
use of dowel pins to align the PCP, it is expected that minor alignment
errors may occur during assembly and adjustment due to the large di-
ensions of the UP PCP. A deviation from the target value of 1 mm has
been assumed as an achievable value for positioning. Ideally, the lip seal
should be as narrow as possible in order to minimise the amount of space
taken up in the opening and to achieve greater stability.

The simulation process in Ansys was continuously optimised and
then carried out as follows: The first step was to “simulate” the instal-
lation of the PCP itself. To reduce the size of the model, work was
concentrated on a single corner. Contact areas between the surfaces of
the joint and the lip seal were defined to model the deformation due to
misalignment (see Fig. 5). The welding process was then approximated
by progressively creating bonded joints between the seal edge and the
mating surface. This simulates mechanical clamping of the lip seal to the
VV port weld lip prior to actual welding. The material model of the
gasket was kept linearly elastic in the model to avoid further compli-
cations with the already complex non-linear model.

Although it was possible to obtain some converged solutions, further
work or a different approach is needed to explore the lip seal paramete-s: geometry, sheet thickness, etc. The stresses obtained are still high
and may be due to the ‘welding’ process implemented in the model it-
self, also the use of an elastic-plastic material model may be necessary.

3. Industry involvement

The involvement of industry partners for the further development of
the PCP fastening and sealing started successfully in 2021. One of the
first topics has been the investigation of the proven HELICOFLEX®
metallic seal with regard to a reduced contact pressure required to
guarantee the sealing effect.

Now this industry participation is to be extended with the current
primary areas of emphasis being: i) Qualification of interlocks as used
for doors and gates in shipbuilding, large vault doors, or nuclear
**Fig. 2.** View of the UP PCP with the locking mechanism around the circumference, the coupling, and the BB Gripper.

**Fig. 3.** Possible design of a PCP locking mechanism. The scissors gear with counter rotating lead screw converts a rotation into a translatory motion.

**Fig. 4.** Sketch of the welded seal in position between PCP and VV port.
applications. ii) Investigation of relevant issues that arise during the application of a welded seal. This includes, for example: Optimisation of the lip seal design for sufficient elasticity and overpressure resistance. Selection of an appropriate welding process [14], including consideration of the required welding positions. Investigating the opening and re-welding of the seal. Consider the effect of material degradation due to continuous neutron irradiation. iii) The use of leak testing and non-destructive testing (NDT), such as ultrasonic testing or radiography to qualify welds, is considered essential during assembly and operation to obtain approval for such a nuclear facility.

This list is not exhaustive but gives a rough idea of the issues to be expected.

4. Summary

In order to provide a starting point for further industry involvement, developments have already been initiated in two directions within the Fusion Technology Department. i) A mechanical locking mechanism for the port closure plate, based on the operation of a ship’s bulkhead door, was developed in a first draft. The application of this solution could significantly simplify the requirements for remote maintenance. By eliminating the bolts used in many other solutions as connecting elements, the risks associated with threads such as cold welding and galling can be significantly reduced. ii) An initial iteration of a welded lip seal design has been created with the aim of simplifying the assembly and resealing process. This design was modelled in Ansys to better understand all the issues involved. Numerous variations in sheet thickness, misalignment and assembly procedure were carried out. It was found that this is a very broad subject. Further investigation and optimisation of design and modelling is therefore required. Separately, it is planned to identify and involve industrial partners with expertise in these specific areas.

CRediT authorship contribution statement

T. Haertl: Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. C. Bachmann: Writing – review & editing. G. Janeschitz: Writing – review & editing. T. Steinbacher: Writing – review & editing. Z. Vizvary: Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Fig. 5. Total displacement due to 1 mm radial misalignment between lip seal and upper port after lifted in position in Ansys.