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Integration of service pipes into the lower port for the DEMO Double Null Concept Design Study

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ABSTRACT

A study into the viability of a double null concept for DEMO has been undertaken as part of the work to address Key Design Integration Issues within the DEMO powerplant. The objective of this study was to evaluate the feasibility of a double null architecture featuring split blanket segments to enable a wider range of maintenance options.

One of the main challenges found was the integration of the service pipes to provide connections to the cooling and tritium breeding systems for the divertor and breeding blanket. By understanding how these pipes might be integrated, the constraints on key details such as the length of the lower port could be understood. This allowed for progression of other areas of the design and investigations into the remote handling of these pipes during maintenance periods.

The key requirements identified for the service pipe routing included determining the removal sequence for the blanket and divertor segments during maintenance; access for the cutting and welding tool at the pipe/blanket interface; pipes grouped as modules per component; and optimisation of port space for the vacuum pumps.

Two proposals were considered to investigate their impact on the insertion location for the cutting and welding tool: pipes with large radii, and pipes with smaller radii. The former was found to be preferable due to the remote maintenance advantages, versus the limited space gains offered by the latter. This paper will describe the development of these requirements, both proposals, and discuss the challenges uncovered during the study in more detail.

1. Introduction

As part of the ongoing work to address Key Design Integration Issues (KDIIs) within the EUROfusion demonstration powerplant (DEMO), a double null (DN) architecture has been considered (Fig. 1.1) [1,2]. In order to facilitate a range of maintenance possibilities, the pre-concept design generated featured split blanket segments and a vertical lower port to allow for further exploration into the value of this port orientation [2].

By splitting the blankets, the number of service pipes required doubles, and so one of the challenges faced during the development of this DN pre-concept design was the integration of the service pipes. These pipes provide connections to the tritium breeding and cooling systems in sizes ranging from DN80 to DN125. The focus of the work was on the routes of these pipes within the lower port area in order to facilitate the remote maintenance activities for the lower blanket segments and divertor segments (Fig. 1.2), as well as to ensure the space availability for components relevant to the vacuum pumping system. By understanding how the pipes are integrated, constraints on key details such as the length of the lower port and maintenance viability could be understood.

2. Key Design Requirements

Several key requirements were identified which directly impacted the lower pipework design and routing.

2.1. Remote Handling/Maintenance

Remote handling is one of the most significant requirements, as the lower inboard blankets and the lower outboard blanket and divertor segments need to be periodically removed and replaced/maintained as

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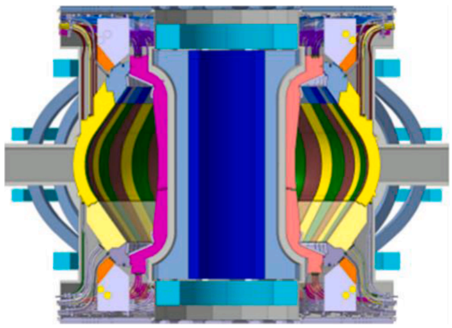

Fig. 1.1. Cross section of proposed Double Null infrastructure with split blankets.

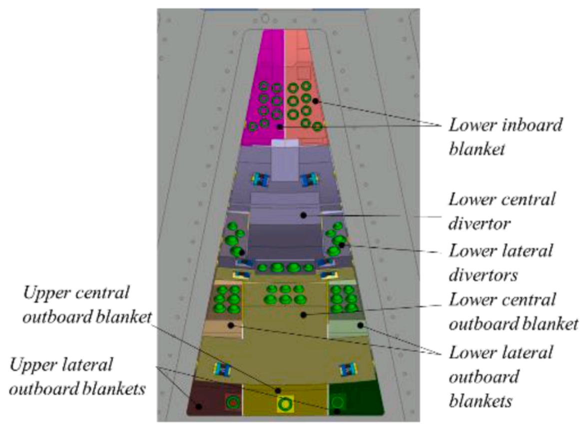

Fig. 1.2. Lower port divertor and blanket segments.

part of the DEMO maintenance strategy [3,4]. Fig. 2.1 demonstrates the remote maintenance (RM) vertical transport system (VTS) concept for the lower port maintenance. This must be carried out remotely and, in some cases, the lower port pipes will still be in place, for instance the divertor segments must be removed whilst there are blanket service pipes in place due to the higher maintenance frequency of the divertor [5]. Preferably, the pipe design should not increase the complexity of the manipulations required to remove in-vessel components.

2.2. Access for the Cutting/Welding Tool

The pipes are welded at the pipe cuff in the divertor or blanket segment. The existing design of the pipe cutting and welding tool Fig. 2.2 imposes additional constraints on the pipe routing design. This

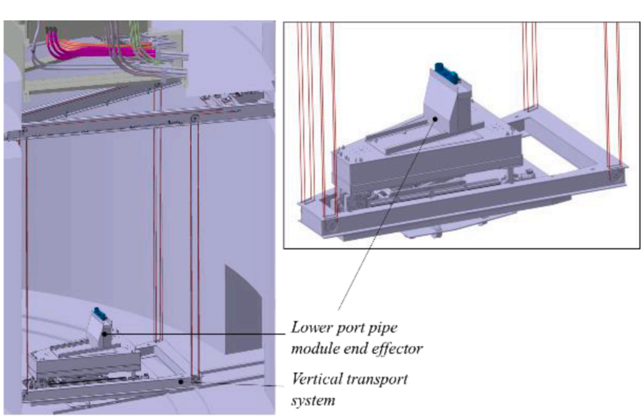

Fig. 2.1. Pipe module RM tooling on VTS.

Fig. 2.2. Cutting/Welding Tool on deployment system.

tool requires any bends to have a minimum 1.5 metre bend radius [6] to allow it to travel internally along the formed pipe and space is also needed to deploy the tool into the pipe. A design proposed for the upper port pipes utilised tighter bends [4] and had the addition of chutes after the bend to allow for the insertion of the tool. The insertion location for this tool has served as a driving force in the two proposals generated and examined in this study.

2.3. Lower Port Space

Access to the lower blanket and divertor segments is an important requirement to facilitate their remote removal from the port. Other components, namely the metal foil pump and linear diffusion pump, should be incorporated within or near to the lower port [7] to enhance vacuum pumping performance. These occupy a considerable volume and must be removed to enable divertor and blanket maintenance. The pipework must fit alongside these pumps during operation.

2.4. Pipe Modules

Pipes are to be grouped into modules and removed as one module, as opposed to each pipe being individually removed. The pipes are grouped per blanket or divertor segment as this is the most logical grouping arrangement due to the difference in maintenance periods for the divertor versus the blankets and consequential requirement to be able to remove individual divertor and blanket segments. This concept will therefore aid remote maintenance efficiency during the removal of these pipes. The pipe module will also be replaced when the blanket or divertor segments are periodically replaced as neutron damage is expected to impact the weldability of the pipe material. There is a requirement for a pipe module support frame, but these were not included as part of this study.

2.5. Mechanical Pipe Connections (MPC)

Some form of MPC [4] is required to make the mechanical connection between the portion of pipe connected to the blanket and divertor segments, and the portion of pipe connected to the rest of plant and routed around the building within pipe chases. One MPC is required per module of pipes. The MPCs negate the need for in-vessel welding here and allow the pipe modules to be released remotely and removed during maintenance operations. Whilst providing some support to the pipes, the primary function of the MPC is to make the pipe connection.

2.6. Drain Angle

A drain angle of at least a five-degree declination must be incorporated on the lithium lead drain pipes to allow for adequate draining of the blankets prior to removal of the segments during maintenance. This requirement is specific to the water-cooled lithium lead (WCLL) breeding blanket design, adding an additional challenge to the pipe routing which is not experienced with the helium-cooled pebble bed (HCPB) design.

3. Challenges

To ensure a viable solution was generated for the pipe routing, a WCLL breeding blanket design was assumed as this poses the most challenging scenario in terms of the number of pipes exiting the lower port. This is because the lithium lead drain pipes for the upper blankets must also exit via the lower port to allow them to drain under gravity alone. Conversely, there are fewer pipes exiting the upper port with the WCLL design.

The main challenge with generating a pipe routing concept for the lower port was the quantity of large diameter pipes exiting the lower port. Routing the upper blanket drain pipes past the rest of the blanket segments without interfering with the removal of any components from the lower port whilst enabling the remote maintenance strategy added to the challenge.

When designing the pipe routes, the order of removal of all parts had to be considered as some pipes will still be in place when removing in-vessel components.

Finally, the drain pipes for the upper inboard blanket segments are long, roughly eighteen metres to the outboard port wall. These must remain in place during the removal of all other pipes. Space is also required for these to be cut and dropped down to facilitate the removal of the upper inboard blankets from the upper port. The cutting/welding tool must have access along this pipe but may have limitations in its length of travel.

4. Lower Port Pipe Routing Design Concepts

Two concepts for the lower port pipe routing were considered that evaluated different tool entry points and hence minimum pipe radii.

Concept 1 focused on incorporating large bend radii of one and a half metres in the pipe route design to allow the pipe cutting and welding tool to be inserted inside the pipe outside the outboard port wall (Fig. 4.1). The tool will travel the length of the pipe up to the pipe cuff to make the connection.

This concept incorporates MPCs within the port near the outboard port wall. When released these allow the latter portion of the pipes to be retracted so the main pipe run can be removed. Routes were generated for all pipes and met the key design requirements. Some key space and maintenance advantages were realised with this concept;

- It is possible to route the lower inboard blanket pipes and lower outboard divertor pipes around the outer edges of the port, enhancing the space available in the centre of the port for vacuum pumping equipment and remote maintenance.
- The upper inboard blanket pipes can be routed to one side of the port, alongside the lower inboard pipes, allowing for these pipes to be removed last. Enough space is also available to cut them and drop them down to allow the removal of the upper blankets. However, the challenges associated with the length of these pipes were recognised and investigated further. The solution is discussed further in Section 5.1.
- The upper outboard pipes are routed vertically down before exiting the port with enough clearance (~425mm) above the lower outboard blanket and divertor pipes to allow the pipes to be cut and dropped down to allow the removal of the upper blanket segments if required.
- All remaining pipes run down the centre of the port but are angled towards the outboard port wall before dropping vertically down to create a much larger volume within the centre of the port. Again, this helps increase the space for the integration of vacuum pumps and for remote maintenance activities.
- Due to the compatibility of the route with the design of the tool, the cutting/welding tool can be inserted outside of the port. Therefore, the pipe disconnection is to be completed prior to clearing the rest of the port and, as this activity would not be on the maintenance critical path, the availability of the rest of the power plant is increased.

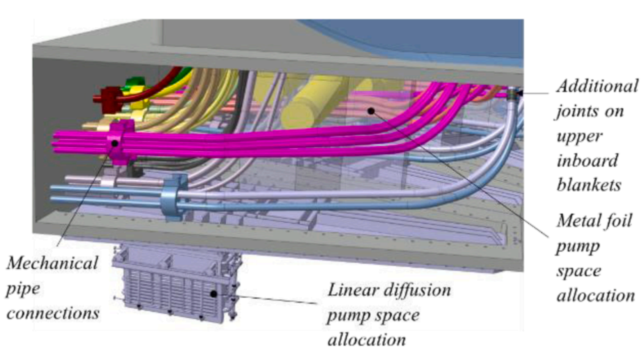

Fig. 4.1. Concept 1 – pipes with large bend radii.

Concept 2 focused on keeping the pipes as compact as possible using tighter bend radii and including vertical extension pieces to the pipe cuffs for insertion of the cutting/welding tool (Fig. 4.2).

The pipes are also clamped within the port towards the outboard wall using MPCs. The purpose of investigating this option in the lower port was to see if there were any significant space gains to be made by using small bend radii. Whilst it was found that there were some advantages to this concept, there were some significant challenges identified too;

- There is a vertical space gain of one metre in comparison to Concept 1 due to the tighter bend radii used.
- The path which the cutting/welding tool must travel is much shorter, increasing efficiency and reducing the risk of error. Conversely, the tool cannot be inserted outside the port and so the port must be adequately clear to allow for the tool to be offered up to the pipe extension. This will likely counteract any gains in maintenance efficiency provided by the reduced length of travel.
- There may be a significant issue of lithium lead congregating in the pipe extensions, impacting deployment of the cutting/welding tool; a solution for this was not generated.
- Without significantly changing the layout of pipe cuffs on the lower inboard blanket segments, it was not possible to incorporate an extension piece for each pipe which allowed clear access for the cutting/welding tool (Fig. 4.3). Accessible pipes for that segment could be removed first to allow access to those extensions which are blocked. However, this would require pipes to be grouped into more modules than identified by the design requirements, which specified one module per segment as the optimum for maintenance. The increased steps required to remove the pipes and segments from the port and the ability to incorporate a framework around a larger number of modules are points which would need further investigation if this concept was progressed.
- Due to the decreased space around the edges of the lower port as a result of having to fan out pipes for access to the vertical pipe extensions there was little space to incorporate the upper inboard blanket pipes. These are removed last and so cannot sit beneath the rest of the pipes. A solution was not found for this problem.

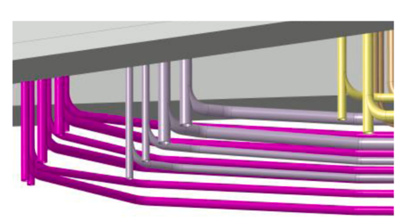

Fig. 4.2. Concept 2 – pipes with small radii and tooling extensions.

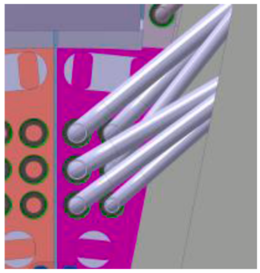

Fig. 4.3. Clash of pipe extensions on lower inboard blanket.

- It was found for the lower outboard blanket pipes that a large bend radius of 1.5 metres was still required as the pipe extension could not be incorporated adjacent to the pipe cuff whilst allowing sufficient space for the insertion of the tool due to clashes with the port wall. The challenges resulting from the proximity of the pipes to the port wall were similar for the upper outboard blanket pipes and a solution was not found for either.
- A solution was generated for the outboard divertor pipes, but the two DN125 pipes made this tight.

Following a constructive design review of the two concepts there were some clear advantages to progressing Concept 1. There are valuable remote maintenance benefits including the larger available volume for manipulating components in and out of the port, and space to insert the cutting/welding tool outside the port which removes the pipe cutting/welding task from the maintenance critical path. There is also adequate volume for vacuum pumps to be incorporated.

Whilst it was hoped that there would be some spatial advantages with Concept 2, the large number of pipes exiting the lower port with the WCLL design made it difficult to achieve any significant gains. The vacuum closure plate can be moved up by approximately one metre due to the more vertically compact pipework. However, as the pipes must be fanned out to allow for the cutting/welding tool pipe extensions, a similar albeit less compact layout to Concept 1 is required, as demonstrated in the comparison shown in Fig. 4.4. Consequently, whilst the vertical spatial gain is realised, this is overshadowed by the limitations to the overall compactness of the pipes imposed by the tooling requirements and volume of pipes.

The remote maintenance advantages of Concept 1 greatly outweigh the limited benefits of Concept 2's vertically more compact pipework. Coupled with the remaining challenges associated with Concept 2, Concept 1 is superior.

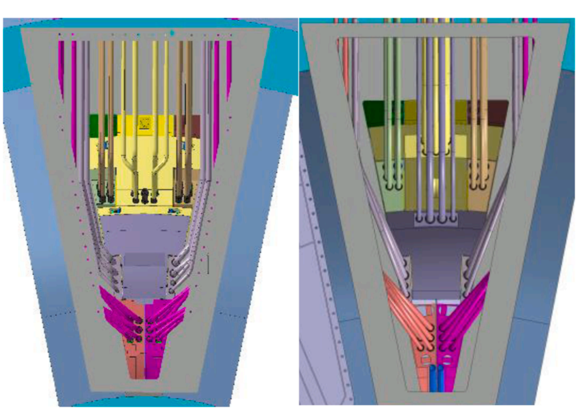

Fig. 4.4. Concept 2 (Left, design issues remain for some pipes) and Concept 1, shown looking up at lower port.

5. Viability of Larger Bend Radius Concept

To progress Concept 1, further assessment was required in order to confirm both the remote maintenance viability and the structural integrity of such long pipe runs subject to thermal expansion. The eighteen metre upper inboard blanket drain pipes were of particular interest in both cases.

5.1. Remote Maintenance

A significant point of consideration was the removal of the pipes; the concept is only viable if the pipes can be removed remotely. The kinematic path of the pipes was investigated to confirm the viability of handling the pipe geometries proposed remotely. It was found to be possible to handle and remove all pipes, lower blanket and lower divertor segments as per the remote maintenance strategy, apart from the upper inboard blanket pipes. The challenge was that their vertical height was roughly the same as their radial length. The solution was to add a joint approximately half-way along the pipe; the cutting/ welding tool can access this joint due to the large bend radii incorporated in the design.

The space availability for the MPC tooling was also investigated to ensure the latter ends of the pipes could be withdrawn from the port, enabling the pipe modules to be removed. A pipe connection is used per module, with one module consisting of all the lower port pipes for one blanket/divertor segment. It was found that some of the pipe groups needed to be spaced out to ensure adequate space for tooling. The orientations of the MPCs on the inboard blanket and outer divertor pipe modules were optimised to enhance accessibility and facilitate the blanket/divertor removal order.

5.2. Expansion Analysis

The spacing of the pipes is dictated by the spacing of the pipe cuffs at the blanket/divertor segment end. They are fixed by the MPCs near the outboard side of the port. A simple finite element analysis was undertaken to give an indication at this conceptual stage that the pipes were flexible enough to be able to deal with the thermal expansion of in-vessel components; the pipes were fixed at the MPC end and given an axial end deflection five millimetres at the blanket/divertor segment end. It was found that there are some areas of high stress, for instance the upper inboard and lower outboard blanket drain pipes see greater deformation and so see higher bending moments in the pipe bends and at the pipe ends where the pipe is not sufficiently flexible, as indicated in Fig. 5.1. Generally, the pipe routes appear largely appropriate from the static analysis undertaken, but some refinement to mitigate areas with higher stresses will be needed for future progression of the concept. Future work should consider the dynamic performance of the pipes so the suitability of the pipes when subject to seismic events can be assessed to ensure stresses are acceptable. Also, the pipe module support structure must be designed to account for the differing thermal expansions of coolant inlet and outlet pipes within the module.

6. Conclusions

The study found that the larger radius pipe route concept (Fig. 6.1) had many advantages over the smaller radius pipe route concept which made it more suited to exploiting the limited space of a lower port and in facilitating improved remote maintenance.

The key point learnt from this design study is that pipe integration in the lower port is not simply a matter of fitting the pipe diameters within the available space. Rather, many additional considerations were found to be significant in obtaining satisfactory pipe routing and sensibly utilising the lower port space;

- Space for remote maintenance activities and tooling.

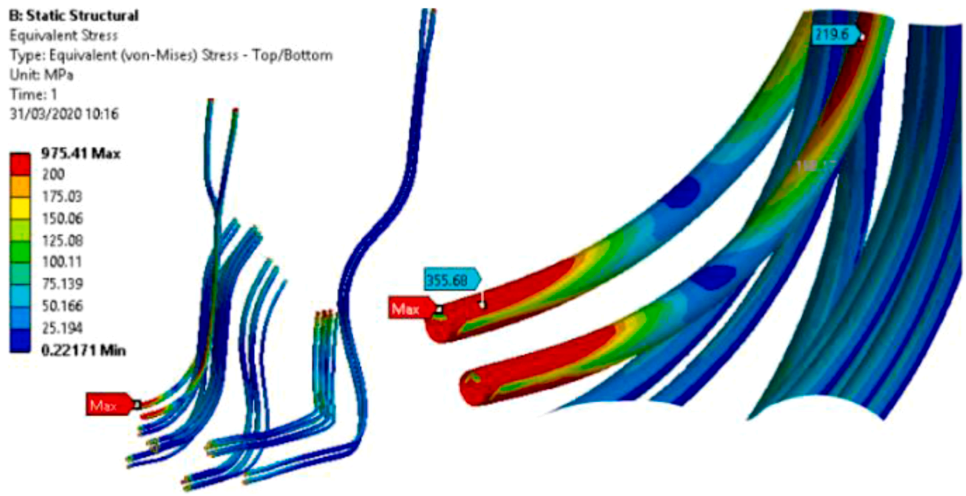

Fig. 5.1. Static structural stress results for lower port pipes.

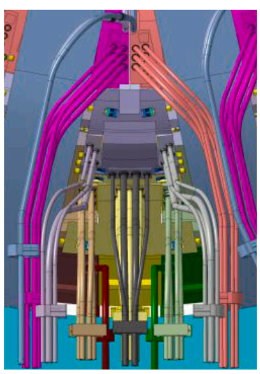

Fig. 6.1. Final pipe layout proposal for lower port (view looking up the port, port not shown for clarity).

- Ability to remove the pipes remotely.
- Manipulation space for large, heavy components.
- Access for the cutting/welding tool.
- Space for vacuum pumping.
- Space for MPCs and their tooling.

Concept 1 provides a possible solution to one of the main challenges identified in the wider study into a DEMO double null architecture. This aids the double null study in addressing the KDIIs within DEMO.

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.

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References

[1] G. Keech, et al., Issues of the vertical blanket segment architecture in DEMO: Current progress and resolution strategies, Fusion Engineering and Design 146 (SI:SOFT-30) (2019) 1408–1412.
[2] C. Bachmann, et al., Critical design issues in DEMO and solution strategies, Fusion Engineering and Design 146 (SI-SOFT-30) (2019) 178–181.
[3] A. Loving, et al., Pre-conceptual design assessment of DEMO remote maintenance, Fusion Engineering and Design 89 (9-10) (2014) 2246–2250.
[4] O. Crofts, et al., Overview of progress on the European DEMO remote maintenance strategy, Fusion Engineering and Design 109-111 Part B (ISFNT-12) (2016) 1392–1398. Vols.
[5] O. Crofts, J. Harman, Maintenance duration estimate for a DEMO fusion power plant, based on the EFDA WP12 pre-conceptual studies, Fusion Engineering and Design 89 (9-10) (2014) 2383–2387.
[6] S. Kirk, et al., "Remote in-bore laser cutting and welding tools for use in future nuclear fusion reactors," Abingdon, 2018.
[7] T. Giegerich, et al., Preliminary configuration of the torus vacuum pumping system installed in the DEMO lower port, Fusion Engineering and Design 146 (SI:SOFT-30) (2019) 2180–2183.