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Design progress of structural components of the EU DEMO EC equatorial launcher

P. Spaeh[1a], A. Bruschi[2], R. Chavan[3], A. Clément[3], F. Crisinel[3], A. Cufar[4], F. Fanale[5], S. Garavaglia[2], J.P. Hogge[3], A. Mas Sanchez[3], M. Noël[3], N. Rispoli[2], D. Strauss[1a], C. Wu[1b]

***Abstract*—The EU DEMO Tokamak is foreseen to be equipped with an EC system for plasma heating, MHD control and thermal instability suppression. Up to six launchers will be installed into equatorial ports with the aim to inject a maximum of 130 MW millimeter wave power at frequencies of 136/170/204 GHz towards dedicated positions into the plasma. This paper presents the current layout of the typical EC system launcher components within the available space reservation areas in the equatorial level of the DEMO baseline model. Beside the general arrangement of the EC launcher components, preliminary design features of the launcher port plug modules, an active cooling system approach, integration concepts for mirrors and waveguides of the optical system, the shielding component formation, and safety important elements of the first containment barrier of the launcher are presented. Furthermore relevant aspects of assembly and potential Remote Maintenance procedures are discussed.**

***Index terms*— DEMO, ECRH, EC Launcher, Port Plug.**

I. INTRODUCTION

FOR the EU DEMO Tokamak, six Electron Cyclotron (EC) launching systems with a maximum total power of 130 MW for plasma heating and stabilization are under development. Based on the EU DEMO engineering baseline [1] and the pre-conceptual design study performed in 2019 [2] the structural design of an EU DEMO equatorial EC launcher and its integration into one of the DEMO equatorial ports was further advanced (see figure 1).

The design of the launcher features the concept of Magnetohydrodynamic (MHD) control (mainly Neo-classical Tearing Modes – NTM) by two mid steering antennas (MSAs) with a partially quasi-optical beam layout and steerable mirrors (SM) at a recessed position behind the breeding blanket (BB) segments. For plasma heating purposes and suppression of thermal instabilities, an open-ended waveguide (OEWG) concept with 2 x 8 beamlines and a set of two times two fixed mirrors (FM) is developed. The assigned maximum power for the six launchers in dedicated operation modes are given in Table 1 [3], however for spare and reliability aspects, a total number of 108 gyrotrons with 2 MW each will be installed [4].

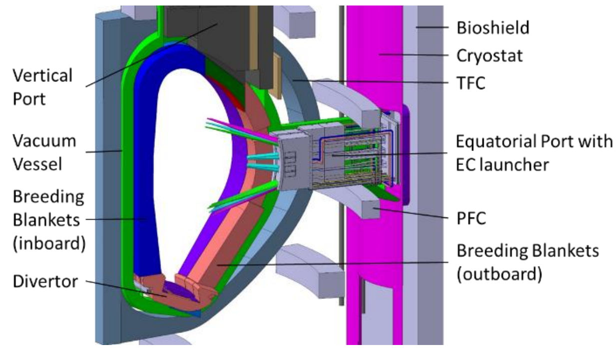

Fig. 1. EU DEMO baseline model with EC launcher integrated.

The antennas for plasma heating are vertically layered in symmetric positions with respect to the toroidal DEMO reference plane (tokamak mid-plane). For the NTM control system this is slightly different, since the top module is dedicated to the q = 3/2 plasma surface while the bottom module is dedicated to the q = 2 plasma surface, which means that the different targets require different toroidal and poloidal angles.

TABLE 1.
ASSIGNED EC POWER IN DEMO

Operation type	Assigned power [MW]
Ramp up	130
Flat top	
- Burn control	30
- NTM control	30
- Thermal stabilisation	70

To guarantee reliable operation of the launcher, a structural system must be designed which provides secure fastening and alignment of the optical components, sufficient heat dissipation, and protection of sensitive areas against nuclear loads from neutrons by adequate shielding capability. The structural

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[1]P. Spaeh, D. Strauss and C. Wu are with Karlsruhe Institute of Technology, Association KIT-EURATOM, Institute for Applied Materials (a), Institute for Pulsed Power and Microwave Technology (b), P.O. Box 3640, D-76021 Karlsruhe, Germany, [2]A. Bruschi, S. Garavaglia and N. Rispoli are with Institute for Plasma Science and Technology (ISTP-CNR), I-20125 Milan, Italy, [3]R. Chavan, A. Clément, F. Crisinel, J.P. Hogge, A. Mas Sanchez and M. Noël are with Swiss Plasma Centre EPFL, CH-1015 Lausanne, Switzerland, [4]A. Cufar is with Reactor physics department, Jožef Stefan Institute, SI-1000 Ljubljana, Slovenia, [5]F. Fanale is with ENEA, Fusion and Nuclear Safety Department, I-00044 Frascati, Italy

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system has to cope with substantial mechanical loads and shall be maintainable by reliable remote maintenance (RM) procedures.

For the conceptual design a CAD model of the main components and related auxiliaries is composed and integrated. It takes into account the available major design requirements on position and dimensions, mechanical and thermal loads, nuclear constraints, physics performance, maintenance and geometrical and functional interfaces.

2. Input data and models

The EU DEMO EC launcher conceptual design is carried out on the basis of three major design input models:

- The EU DEMO engineering baseline model.
- A preliminary version of the EU DEMO building, customized for EC system.
- The optical system design 2020 V3, provided by the Italian Institute for Plasma Science and Technology (ISTP).

The optical system is composed of an MSA with two systems of three beamlines each for NTM control at 170 GHz and two further OEWG antenna systems with eight waveguides (WG) each for plasma heating (at 170/204 GHz) and to counteract thermal instabilities at 136 GHz [3]. The optical system for plasma heating is arranged in a symmetric layout with respect to the equatorial plane of the EC launcher, such that the heating section is located in the inner area of the port. The NTM control systems are located at the poloidal top and bottom of the port. Their position is slightly asymmetric with respect to the equatorial plane, since the upper stabilization system aims to act with an 15.2° launching angle in neutral position (± 1.83° steering) on the q = 3/2 plasma surface at a toroidal angle of -25°. The lower system aims to act with a - 3.5° (± 2.03° steering) launching angle on the q = 2 plasma surface at a toroidal angle of -16° [4]. An outline of the optical system is given in figure 2 below .

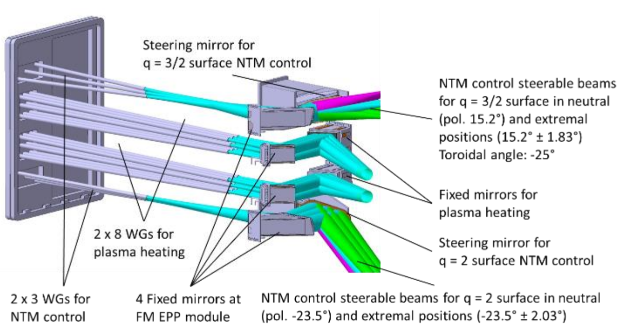

Fig. 2. EU DEMO EC launcher optical system.

The engineering baseline model was provided with an equatorial port customized for a limiter system. For properly shielded accommodation of the EC launcher optical system, the equatorial EC port requires a larger cross-section and must be shifted towards the left, looking from the rear into the plasma. This affects the dimensions of the required cut-outs in the BB segments, in the VV and also further back in the cryostat and in the bioshield. For the same reason also the DEMO building model has been adapted to the needs of an EC equatorial port.

3. Design layout of the EC equatorial launcher

The EC launcher is the in-vessel part of the EC system and is sub-divided into the optical (in-vessel) system, the structural system (port plug modules and shielding) and auxiliaries (e.g. the piping forest). The EC equatorial port plug (EPP) modules are the two structural front elements of the EC launcher. They are mounted into the equatorial extrusions of the VV and mainly serve as housing and cooling supply for the optical system´s mirrors, but also contribute to the formation of the neutronic shielding barrier of the EC launcher.

For the conceptual design phase of the EC launcher the requirements management is still under development. Thus not a full set of clearly defined requirements was available, but on the basis of major design characteristics agreed between the stakeholders of the EC system the layout of the structural system was sketched as follows:

The equatorial port is rigidly attached as a cantilever to the VV. It contains the EPP modules, the in-vessel components of the optical system, cooling lines and gas supply (for actuators), additional shielding blocks and features for installation and fastening of the EPP modules and all other auxiliaries. The FCS barrier at the rear side shall be realised by a closure plate.

The SM EPP module is placed into the left side of the equatorial port extrusion, looking towards the plasma. It accommodates the steering mirrors of the NTM control system as well as the second set of fixed mirrors of the plasma heating system. The SM EPP module with a direct line of sight towards the plasma will be made of Eurofer steel to cope with the high neutron damage rate and must be actively cooled. Moreover, it shall provide cooling supply also for the optical system components through dedicated water channels, pipes and manifolds. The SM EPP module shall be designed according to a simplified maintenance strategy which allows regularly scheduled replacement in case a limitation of its lifetime becomes mandatory.

The FM EPP module is placed on the right hand side of the port (looking towards the plasma). It houses the first set of fixed mirrors of the NTM control system and the ones of the plasma heating system as well. It is expected that due to its well-protected position behind the BB and the VV it will not require dedicated neutron damage resistance and can be made of standard in-vessel material like stainless steel 316 LN (SS 316 LN). The component must be actively cooled and in addition must provide individual cooling also for the integrated optical components by dedicated internal cooling lines. Scheduled replacement of this port plug module due to material degradation is not planned. Nevertheless remote maintenance shall be possible in case of failure of one or more of the optical components.

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The closure plate shall be designed not as a single component, but as a staggered assembly of closure sub-plates to allow partial opening of the port according to required access:

- Partial access for maintenance of the SM EPP and/or the SM racks.
- Partial access for maintenance of the in-vessel WGs.
- Full access for maintenance of all other components (e.g. the FM EPP).

No active cooling of the closure plates is required. Sealing of the closure plate and all sub-plates is considered to be made either by double metallic seals (DMS) with monitored interspace or by lip-welds [5].

Cooling and supply lines shall be guided along the sidewalls of the port in order to enable clash-free removal of the port plug modules for maintenance and repair through the opened closure plate or sub-plates, respectively. They exit the equatorial port via feedthroughs on the port flange.

The EC launcher shall contribute by design to comply with the EU DEMO design limits for nuclear loads in general. Thus it is equipped with auxiliary shielding elements whose efficiency has been validated by neutronic analyses [6]. The general layout of the EC launcher is displayed in figure 3.

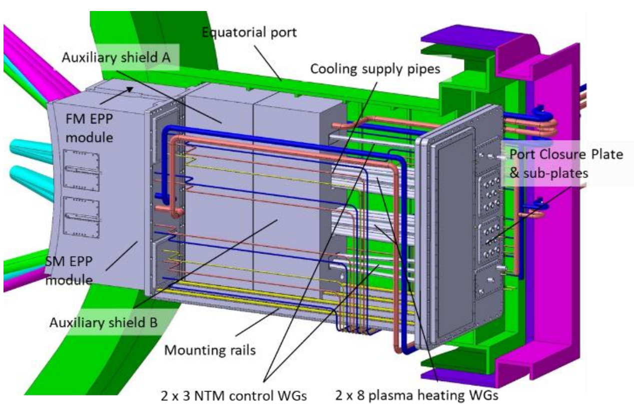

Fig. 3. Layout of the EU DEMO equatorial EC launcher.

4. CONCEPTUAL DESIGN OF EC LAUNCHER COMPONENTS

4.1 EC equatorial port

The equatorial ports in the current EU DEMO concept offer the possibility of customized dimensions for particular installations. The dimensional limits are set on principle by the poloidal clearance between the poloidal field coils (PFCs) and the toroidal clearance between the toroidal field coils (TFCs) while the maximum radial extension is defined by the position of the bioshield.

The EC port consists of three major segments – the vessel extrusion, the central port section and the rear end. A poloidal cutaway is shown in figure 4.

Proper integration of the current microwave system leads to a height of 3,260 mm and a width of 2,510 mm for the vessel extrusion. This section has a wall thickness of 200 mm on top, bottom and on the left side and 300 mm at the right side (thicker due to higher demands for TFC coil protection) and forms the shell into which the EC launcher port plug modules will be mounted. This section is expected to be actively cooled.

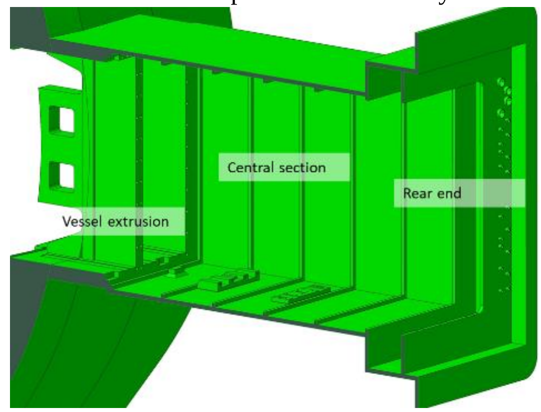

Fig. 4. EU DEMO Equatorial EC Port

From this front element, the port then is stretched by the central port section, which has a width of 2,800 mm. This part is formed by a rectangular cask where the in-vessel WGs, the cooling supply lines and the auxiliary neutron shielding elements are located. The largest profile of the port is at its rear end section, where the maximum height is 4,210 mm while the width ranges up to 3,490 mm. It provides additional space for the sidestepped layout of the cooling pipes and gas supply lines and is radially enclosed by the closure plate and sub-plates.

4.2 EC equatorial port plug modules

The EPP modules are arranged side by side with a zig-zag profile where they face the walls of the VV and the port extrusion in order to create a labyrinth gap which minimizes neutron streaming towards the rear. Also between the port plug modules and the inner port extrusion wall such elements are created. These labyrinth steps (doglegs) feature a nominal gap of 10 mm and have a dimension of 40 mm which results in an structural overlap of 30 mm. The doglegs are arranged such that the RM concept can be executed without collisions between any parts.

The EPP modules are fastened in a cantilevered scheme into two matching openings inside the vessel extrusion of the ports. Each EPP module is equipped with a circumferential flange at its rear side and is attached to the vessel extrusion by 26 bolts of size M45. Additional shear keys are foreseen to cope with radial moments, caused by electromagnetic (EM) loads.

The microwave beams, coming from the set of WGs on the right hand side of the port, enter the FM EPP module after they were guided through a set of shielding blocks, positioned at the rear side of this module. The FM EPP is equipped with mirrors and customized beam passages for propagation of the beams with minimum interference.

From the FM EPP module the beams are reflected towards the SM EPP module. Also this module is equipped with mirrors and customized pathways for the microwave beams. Contrary to the FM EPP module, the SM EPP module has not only static mirrors but also two steerable mirrors which allow to inject the beams for NTM control into dedicated positions in the plasma, aiming to suppress plasma instabilities effectively. Figure 5

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outlines section views through the two relevant poloidal levels of the port plug modules.

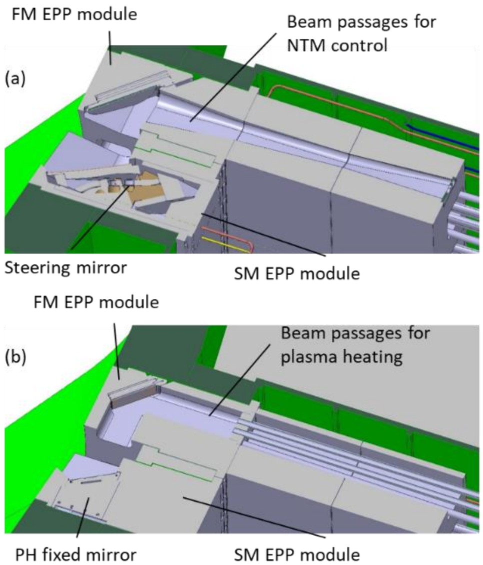

Fig. 5. Microwave beam passage (a) for NTM control; (b) for plasma heating and thermal stabilization

4.2.1 SM EPP module

A SM EPP module has been designed on a conceptual level, featuring remarkable cut-outs for mirror installation and beam propagation and also a basic rear flange for solid fastening into the equatorial port. The SMs and their actuator systems will be integrated into dedicated drawers, which will be installed from the rear side of the port plug module. The FMs for the heating beams will be mounted onto matching block elements, which can be inserted through openings at the outer side wall of the port plug module. Basic manufacturing considerations indicate the fabrication of such a port plug preferably from a massive forged block, which is subsequently machined to its final shape. Isometric views of the SM EPP module from the front and rear side are given in figure 6.

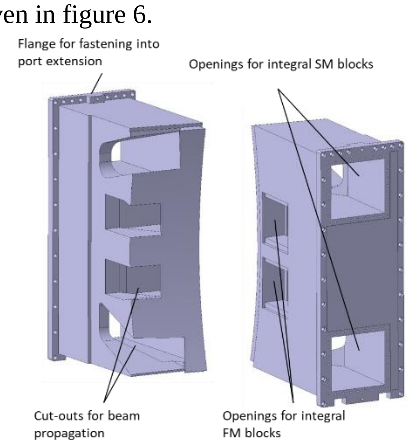

Fig. 6. EC Launcher SM EPP module (front and back).

The SM EPP module has an outer dimension of approximately 2,840 x 910 x 1,900 mm³ (h x w x l) and a total mass of up to 23 tons, including the mirrors. Its shape is a cuboid with a front side that mimics the rear side shape of the BB's profiles, but with an offset of 20 mm. On the rear side of the port plug a fastening flange of 100 mm thickness has been designed in order to connect with according fasteners at the port extrusion through bolted joints. Additional shear keys are integrated into the flange at the top and the bottom. Two additional bores in the center of the bolted joints allow the application of alignment pins for precise installation of the SM EPP module.

The SM EPP will be equipped with a complex cooling system, which guarantees heat dissipation from all structural parts as well as dedicated coolant supply for the integrated mirrors.

The neutronic analysis of 2020 resulted in a total volumetric heat from neutrons and photons of 1.3 MW for the SM EPP module, which is the value used for preliminary examination of the heat loads to be dissipated from the cooling system. Taking into account also plasma radiation of 90 kW/m² [7] for the SM EPP module front surface of 1.56 m² with an amplification factor of 1.3 for further plasma radiation on surfaces set back from the front panel and adding another 200 kW for stray radiation in the SM EPP module, the total heat to be dissipated sums up to ca. 1,300 kW + 180 kW + 200 kW = ca. 1.7 MW. As basic heat balance we can use equation (1):

$$\dot{Q} = \dot{m} \cdot c_p \cdot \Delta T \quad (1)$$

With $\dot{Q}$ = 1.7 MW, c_p = 4.2 kJ·kg^{-1}K^{-1} and assuming ΔT = 40 K, we get a required mass flow of ca. 10 kg/s of cooling water for the structural components of the SM EPP module.

4.2.2 FM EPP module and auxiliary shields

The FM EPP module features a similar design approach as the SM EPP module – a massive block with dedicated cut-outs for mirrors and beam propagation and a rear flange for aligned and reliable fastening towards the port extrusion. In addition, the FM EPP has also loose bearings for support of the in-vessel plasma heating WGs. It also requires an active cooling system, removing nuclear heat from the module and supplying cooling water to the mirrors installed.

Despite the FM EPP module is expected to be designed for lifetime (due to its much better protection from the plasma by being located behind the BB), it will be capable for RM replacement in case of failure of the mirrors or damage of the plug itself.

The FM EPP module has an outer dimension of approximately 2,840 x 910 x 1,800 mm³ (h x w x l). As well as the SM EPP module its outer shape creates labyrinth steps to block neutron streaming. Its total mass sums up to 22 tons, including the mirrors. The volumetric heat from neutrons and photons is 0.6 MW for the FM EPP module. Since its front side is mainly hidden behind the BB, radiation from plasma is expected to be moderate. Thus conservatively 100 kW for plasma radiation and another 200 kW for stray radiation in the FM EPP module were added, which results in total heat of 0.9 MW to be dissipated by the water cooling system. As basic heat balance again we use equation (1) and we get ca. 5.4 kg/s

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as required cooling water mass flow for the FM EPP structural components. The FM EPP module is shown in figure 7.

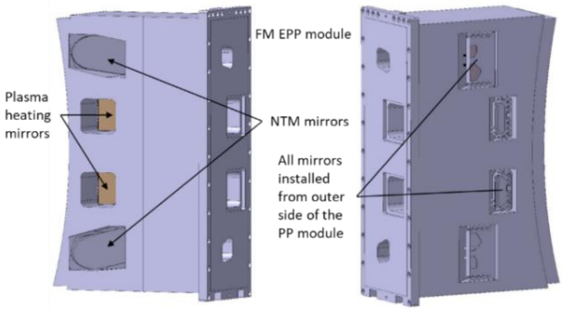

Fig. 7. EC Launcher FM EPP module (front and back).

Contrary to the SM EPP module, the FM EPP module has openings for beam propagation and WG support also on its rear side. This reduces the shielding capability substantially, which is why additional shielding elements are foreseen to be installed rear of the FM EPP module, enclosing the WGs and the quasi-optical beams, respectively. These auxiliary shields (cf. figure 3) are sketched as simple blocks with penetrations for WGs and quasi-optical beams. They were taken into account for the 2020 MCNP neutronic analysis [6] and the results were prove of their shielding efficiency (see peak values in Table 2). Also a fastening concept for the auxiliary shields is suggested and a preliminary prove of this concept is described in chapter 6.

TABLE 2.
RESULTS FROM MCNP NEUTRONIC ANALYSIS 2020

Comp.	Power density $[W/m^3]^1$ $[MW/m^3]^2$	N induced damage [dpa/fpy]	He prod. [appm]
TFC	60^1	-	-
FM EPP module	3.3^2	2.8	46
SM EPP module	4.6^2	3.2	61

5. INTEGRATION OF IN-VESSEL OPTICAL COMPONENTS

The in-vessel part of the optical system features four sets of WGs and eight mirrors, of which two are equipped with a steering drive for rotational movement in order to suppress plasma instabilities at variable poloidal positions in the plasma. Their integration into the DEMO EC system is an iterative task which is carried out in parallel with the progressing design of these components. The integration of the in-vessel mirrors is described hereafter.

5.1 Fixed mirror integration

Both, in the FM EPP module and in the SM EPP module, fixed mirrors for microwave beam reflection are installed. In the FM EPP module two mirrors at the top and at the bottom respectively, are corresponding with the NTM control system. Two more mirrors close to the toroidal mid-plane, are being part of the plasma heating system. The size of the reflecting surface of the NTM control fixed mirrors in the FM EPP module is in the order of 1,000 x 350 mm² and the size of the much smaller plasma heating fixed mirrors surface is ca. 510 x 340 mm². The fixed mirrors in the SM EPP module belong to the plasma heating system as well and they are approximately of the same size as the ones in the FM EPP module.

The mirrors will be inserted through openings with an 45° inclination from the outside of the FM EPP module and are fastened towards corresponding flanges. Access to the cooling line connections is also possible from outside. Figure 8 indicates the concept.

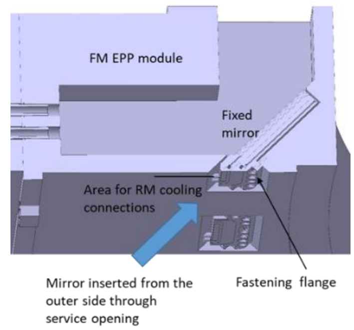

Fig. 8. Fixed mirror integration into the FM EPP module.

For the fixed mirrors of the plasma heating antenna in the SM EPP module a mirror block concept has been realised. The reflectors and their associated support structure are mounted towards a massive block which is inserted into lateral openings in the SM EPP module. Beside reliable fastening by flanges they also provide optimum shielding performance inside the otherwise empty volumes in the SM EPP module. Figure 5 illustrates the fastening of the mirror blocks and their position inside the SM EPP module.

5.2 Steering mirror integration

Colleagues from Swiss Plasma Center (SPC) in Lausanne (CH) have designed a first concept of a steering drive [8], based on a pantograph gear which provides a virtual rotation axis for the mirror. For integration of this component a mounting drawer was sketched. It accommodates the entire mirror assembly and it is capable to be installed from the rear side of the SM EPP module. This concept has the advantage that in-situ maintenance of the SMs is conceivable. For integration the SM EPP module features appropriate cut-outs for the upper and the lower SM assemblies. The mounting drawers do not yet feature any details like cooling channels, joints, RM mechanisms or any other provisions but their shape is customized and a flange at the rear for installation into the SM EPP module is indicated. The integration concept is visible in figure 5.

6. MECHANICAL DESIGN PROVE OF COMPONENT FASTENING

For a rough estimation of the feasibility of the component fastening concept, a FEM simulation of the EM loads on both the EPP modules (including the mirrors) and the auxiliary shields has been performed in 2022 [9]. From this analysis the total peak values of a relevant load case (centered disruption of

74 ms; Current Quench at End Of Flat top) were taken to check the mechanical stresses in the joint bolts and also the surface pressure at the form keys. The acting peak loads are outlined for the auxiliary shield A and the FM EPP in Table 3 below[1].

TABLE 3.
EM PEAK LOADS FROM FEM SIMULATION 2022

Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
Auxiliary shield block A					
-30.5	9.4	-20.6	247	-27.4	-22.3
FM EPP module					
-378	124	-114	2,510	925	-302

6.1 Mechanical feasibility check of auxiliary shield A fastening

The auxiliary shield A is attached to the bottom of the port central section by four bolts M22. In addition there are vertical support pads at the front and rear side of the bottom area of the shield and also toroidal shear keys at the top and bottom. Beside the EM loads from table 2, a dead weight of the auxiliary shield A of 17,000 kg is taken into account for the stress calculations.

To simplify the analytical approach, it is assumed that the dead weight, the toroidal moment M_y, the poloidal force F_z and the moment caused by the radial force F_x are taken by the vertical support pads; the radial moment M_x and the toroidal force F_y are taken by the shear keys at the top and bottom and the poloidal moment M_z and the radial force F_x are taken by the bolts at the bottom shoulder.

For the surface pressure on the higher loaded support pad at the front of the shield block, which has to bear a vertical force of 158 kN through a surface of 0.019 m², we get a pressure of 8.3 MPa. The shear keys at top and bottom with an acting surface of 5,900 mm² each will experience a maximum surface pressure of 14.7 MPa.

Having four bolts M22, connecting the shoulder at the bottom of the auxiliary shield with the port, the highest loaded bolt is the outer one on the right hand side, where the tension force can be up to 28 kN, which causes tensile stress of ca. 80 MPa in the core of the bolt.

6.2 Mechanical feasibility check of FM EPP module fastening

The FM EPP module is attached as a cantilever to the rear side of the port extrusion by a circumferential flange with 26 bolts M45, distributed upon top and both sides of the flange. In addition there are shear keys at top and bottom. Beside the EM loads from table 2, the dead weight of the FM EPP of 22,500 kg is taken into account for the stress calculations.

For the FM EPP module it is presumed that the moment created by the dead weight and the toroidal moment M_y causes tension stresses in the upper bolts. The radial moment M_x and the toroidal force F_y are taken by the shear keys and the poloidal moment M_z is taken by the bolts at one side of the flange. Additional stresses will be induced into all 26 bolts from the poloidal force F_z and the dead weight of the component. These loads would create shear stresses in the bolts, which is why they will be taken by friction between the flanges due to pretension of the bolts. The radial force F_x has not been taken into account, since it reduces the maximum stresses on the bolts.

By doing so, we get a maximum tensile stresses on the bolts at the top side of the flange of 20 MPa; maximum tensile stresses of the bolts at the side of the flange of 31 MPa and a surface pressure at the shear keys of 79 MPa. Additional stresses of up to 60 MPa will be applied to all the bolts from the required pre-tensioning of the flange to cope with the vertical forces. Depending on the material choice, the operating temperature and qualification requirements, the stresses on the shear keys and the additional stresses on the bolts must be reduced by design optimization.

6.3 Evaluation of the feasibility check of fastening concepts

The results presented above – despite the very preliminary load specifications, the high level of design uncertainties and further coarse assumptions – indicate the feasibility of the mechanical concept for fastening of the auxiliary shield block and the FM EPP module into the equatorial port. However, especially the FM EPP fastening will require further improvement, which might lead to an increase of the shear key´s surface area and also to additional fasteners to take the vertical loads from the poloidal forces and the dead weight. These steps towards higher design maturity will be executed through iterative design steps in the future.

7. CONCLUSION

The design study of structural components for an EU DEMO EC launcher has undergone another iteration. The conceptual design of the port plug modules with additional shielding blocks has been further developed with updates of the mirror integration concept, optimization of the microwave beam channels and fastening provisions. On the basis of a FEM electromagnetic load analysis, feasibility proves of the fastening concepts were performed.

REFERENCES

[1] C. Bachmann et al.: Containment structures and port configurations, Fusion Engineering and Design, 2021, 112966, DOI: 10.1016/j.fusengdes.2021.112966
[2] P. Spaeh et al.: Structural pre-conceptual design studies for an EU DEMO equatorial EC port plug and its port integration, Proceedings of the 14th ISFNT conference, 2019, Budapest (HU) DOI: 10.1016/j.fusengdes.2020.111885
[3] M.Q. Tran et al.: Status and future development of Heating and Current Drive for the EU DEMO, Fusion Engineering and Design, Fusion Engineering and Design 180 (2022) 113159, DOI: 10.1016/j.fusengdes.2022.113159
[4] A. Bruschi et al.: Conceptual design of a modular EC system for EU DEMO, Synopsis of the 29th IAEA Fusion conference, 2023, London (UK), under review.

[1] It shall be mentioned that EM loads from mirrors were only taken into account if they cause an increase of the total peak values for the integral components.

[5] T. Haertl et al.: Vacuum Vessel Port Closure plate sealing and fixation activities, Proceedings of the 32nd SOFT conference, 2022, Dubrovnik (HR).
[6] A. Cufar et al.: Neutronics Analyses of EU DEMO 2020 EC Port Configuration, Proceedings of the 30th NENE conference 2021, Bled (SLO).
[7] T. Franke et al.: Integration concept of an Electron Cyclotron System in DEMO, Fusion Engineering and Design 168 (2021) 112653, DOI: 10.1016/j.fusengdes.2021.112653
[8] A. Mas Sanchez et al.: Pre-conceptual design of the steering mirror for the DEMO Electron Cyclotron Heating system, proceedings of the 15th ISFNT conference 2023, Gran Canaria (E), under review.
[9] I. Pagani et al.: Electromagnetic analysis on conceptual design of the EU DEMO EC equatorial launcher, Proceedings of the 15th ISFNT conference 2023, Gran Canaria (E), under review.