ESS-Bilbao Berilium rotating target design

S Terrón[1,2], F Sordo[1,2], M Magán[1,2], A Ghiglino[1,2], F Martínez [1,2], PJ de Vicente[1,2], R Vivanco[1,2], FJ Bermejo[1] and JM Perlado[2]

[1] ESS-Bilbao Consortium. Bizkaia Technology Park, Laida Bidea, Building 207 B Ground Floor, 48160 Derio (Spain).

[2] Instituto de Fusion Nuclear. ETS Ingenieros Industriales, Jose Gutierrez Abascal, 2 28006 Madrid (Spain).

E-mail: `santiago.terron@essbilbao.org`

Abstract. The ESS-Bilbao Accelerator Center site at the Leioa UPV/EHU campus will be provided, in a first construction phase with, a proton accelerator up to 50MeV. The proton beam will have an average intensity of 2.25 mA and 1.5 ms pulses at a frequency of 20 Hz. These beam characteristics allow to configure a low intensity neutron source based in the Be (p, n) reaction, capable of providing relevant neutron experimentation capacities.

The configuration of the neutron production target will be based on a rotating disk of beryllium slabs cooled by water. This work presents the solution chosen to implement that concept. The design of the coolant distribution system, the colling channels and the main mechanical components are described, including the thermo-mechanical and fluid dynamics calculations supporting them.

1. Conceptual design

1.1. Base data

Previous activities of the Target and Neutron Applications Group of ESS-Bilbao, mainly in the areas of source term and cooling, have been taken as a starting point for the design presented in this work.

In the area of source term, and starting from the proton beam parameters expected for the ESS-Bilbao accelerator (Table 1), the efficiency of the different neutron producing materials was evaluated [1]. A brief summary of the results obtained is shown in Table 2.

Particle	Protons
Beam type	Pulsed
Pulse length	$0.3 - 1.5ms$
Frequency	$20 - 50Hz$
Particle energy	$50 - 60MeV$
Peak intensity	$75mA$
Average intensity	$5mA$

Table 1. Proton beam parameters.

Material	Neutrons per proton	Average neutron energy (MeV)
Carbon	$7,54 \cdot 10^{-3}$	$8,04$
Lithium	$4,27 \cdot 10^{-2}$	$13,15$
Beryllium	$6,49 \cdot 10^{-2}$	$7,76$

Table 2. Source term estimation. [1]

Due to these results, beryllium was chosen as target material, since it is the most efficient candidate. The source term analysis also showed that the thermal power induced in the beryllium would be 112 kW. Regarding to the target dimensions, the neutronic analysis revealed that the optimum beryllium thickness in terms of neutron production is 15 mm.

Regarding to the structural material, 6061 T6 alluminum alloy is chose due to its low activation behavior, suitable mechanical properties and extended operational experience in experimental reactors.

On the other hand, cooling analysis [2] pointed out that, given that the power flux to be extracted for a single beryllium element would be around $15 MW/m^2$, a rotating target cooled by water is a suitable configuration. Taking advantage of the 20 Hz pulsed nature of the proton beam, a 20 beryllium plates configuration was chosen. In order to further spread the power input, a 45^o incidence angle between the proton beam and the plates was implemented. This angle makes necessary 11 mm thick beryllium plates, in order to reach the 15 mm long proton trajectory in the beryllium.

In order to reduce neutron capture, water and structural material thicknesses in the neutrons trajectory must be minimized. Source term analysis revealed that 5 mm and 7 mm where suitable values for water and aluminum alloy thicknesses.

Given this configuration, thermalhydraulics analysis showed that the implementation of a 2 m/s” coolant ”‘layer”’ is enough to ensure heat removal, and that a 5 bar pressurization provides enough margin from boiling.

1.2. Base solution

The conceived base solution consists of beryllium plates placed on structural supports endowed with inner cooling channels. The beryllium plates themselves close the cooling circuit, being in contact with the coolant. (Figure 1).

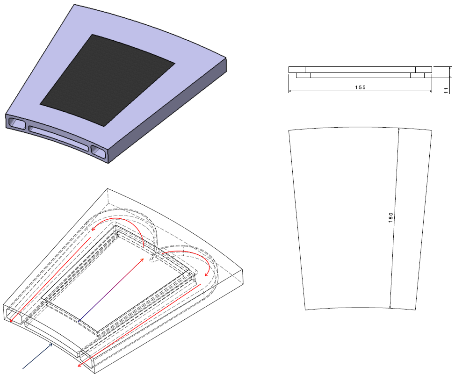

Figure 1. Base solution and plate dimensions (mm).

1.3. Manufacturing solution

Stating form the base solution, the manufacturing solution must configure a disk able to hold 20 beryllium plates and to provide and collect the coolant to all of them. Among the manufacturing solutions studied, we can set up two groups: modular and integral solutions. By modular, we mean the solution in which each beryllium plate is provided with an independent structure with an independent cooling channel; and by integral, the solution in which all the plates are held by a single structural element with connected cooling channels. Figures 2, 3 and 4, show an intuitive idea of theses possible solutions.

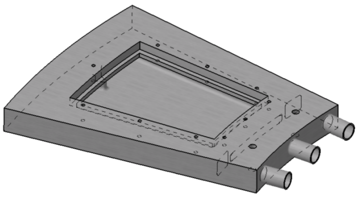

Figure 2. Modular bolted.

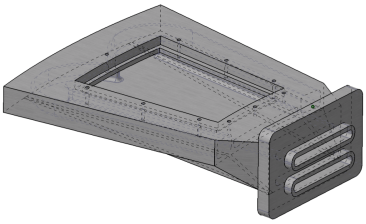

Figure 3. Modular flanged.

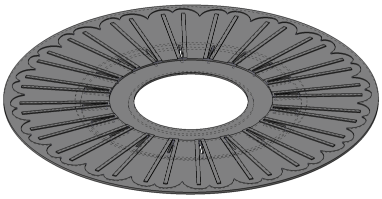

Figure 4. Integral solution.

First fluid dynamics analysis found some difficulties in ensuring an homogeneous coolant velocity under the plates for the modular solutions, and these solutions seemed to be less robust, so, after different considerations, the integral option was chosen.

This concept is based in a layered configuration, in which the space between the solid components configures the colling circuit volume. The structural components of this concept are shown in Figure 5 with set up the cooling circuit shown in Figure 6.

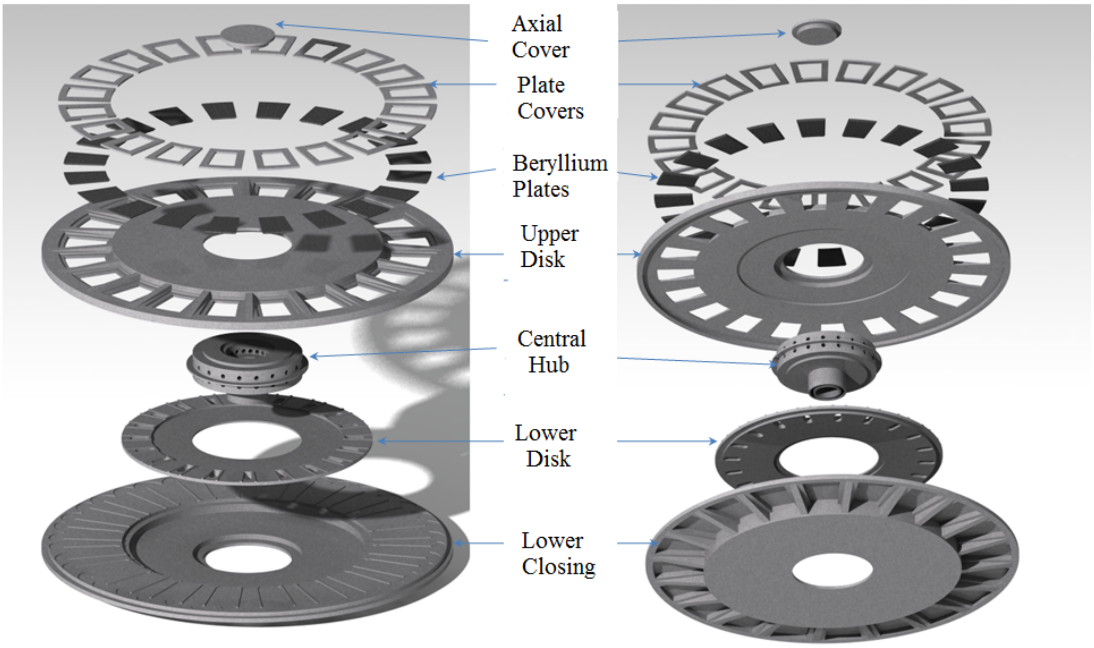

Figure 5. Integral solution components.

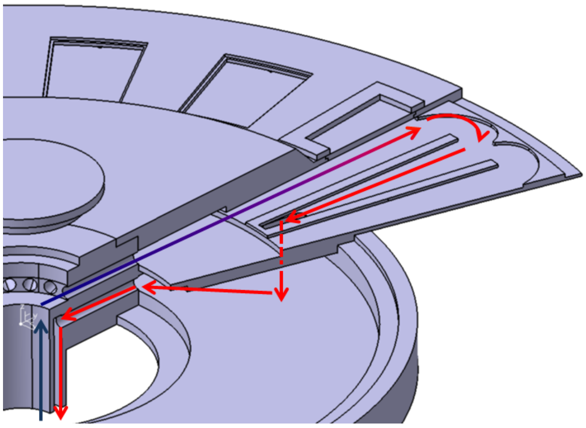

Figure 6. Coolant outline.

2. Hydraulic design

Once a reference configuration has been set up, its time to check if it provides the cooling velocities needed. Due to the axial symmetry present in the geometry, the whole domain can be calculated by means of a 18^o circular segment. A total water flow of 26 l/s is set in the axial inlet of the central hub. As it can be observed in Figure 7 the fluid velocity field obtained presents the necessary 2 m/s velocity under the plates.

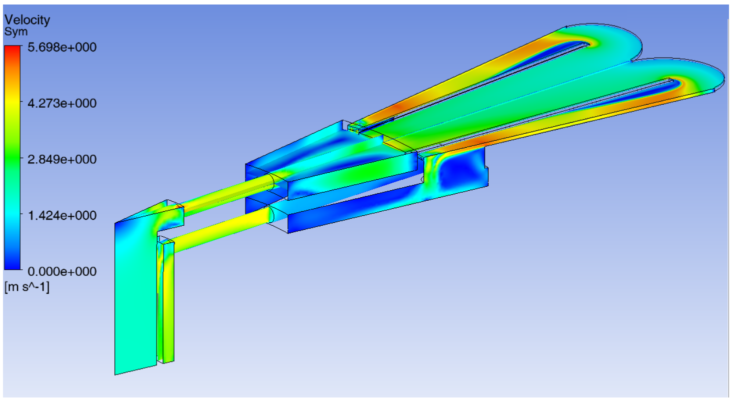

Figure 7. Coolant velocity distribution.

3. Thermo-mechanical design

3.1. Temperature distribution

In order to the calculate a simplified steady state thermal distribution, a uniform 5.6 kW power is implemented (112 kW / 20 plates), which implies a 18.86 MW/m^3 volume power source. Considering perfect thermal contact between components and an coolant inlet temperature of 300 K, the temperature distribution calculated present a maximum temperature around 330 K, in the beryllium plate (Figure 8).

Given the different thermal dilatation coefficients of the aluminum alloy (23,5 $10^{-6}K^{-1}$) and beryllium (11,5 $10^{-6}K^{-1}$), thermal stress rises up to 50 MPa. This value is not realistic, since both components, beryllium plates and aluminum alloy structure are modeled perfectly together, and in the real configuration there will be an elastic joint that will absorb part of the

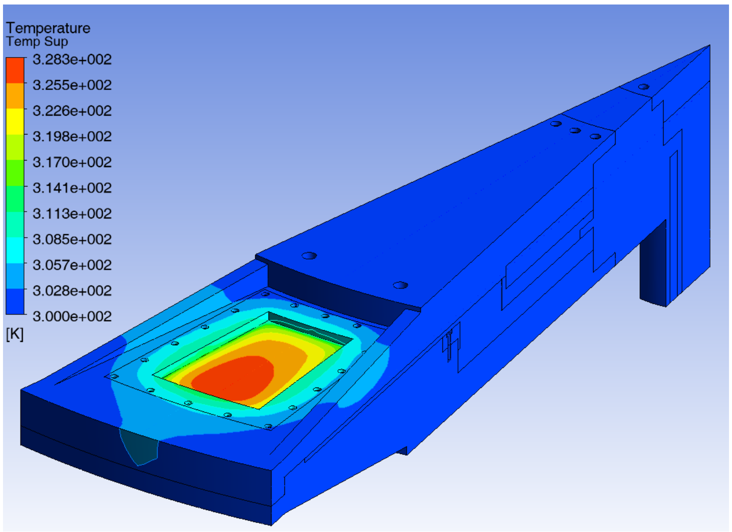

Figure 8. Temperature distribution.

differential dilatation stress. Nevertheless, this value of thermal stress is an upper limit for the actual value, and it is still far from the yield limit of both materials, which are 276 MPa for 6061 T6 aluminum alloy and 219 for Beryllium S-200E.

3.2. Coupled thermomechanical calculation

The previously calculated temperature distribution is applied to mechanical problem. All the components are joint together by the bolting system shown in Figure 9.

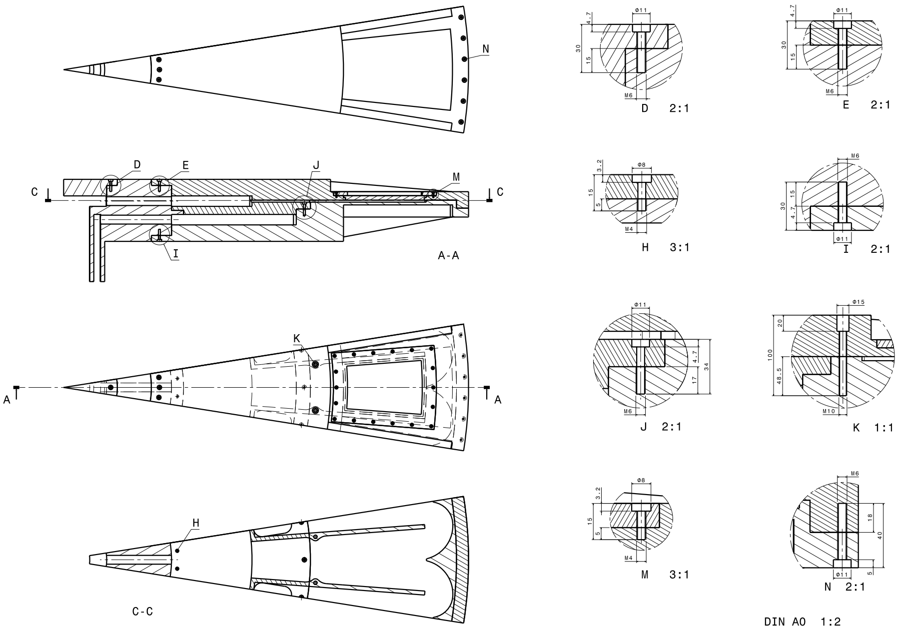

Figure 9. Bolted unions

In the mechanical model, the bolts have been modeled by means of beam elements, and constraint relationships between them and nodes of the structural components have been set, in order to transmit the bolting preload to the solid. A frictional contact model has been implemented between all the solid components and an inner pressure of 5 *bar* has been applied to all the surfaces in contact with the coolant. Next figures show the obtained results.

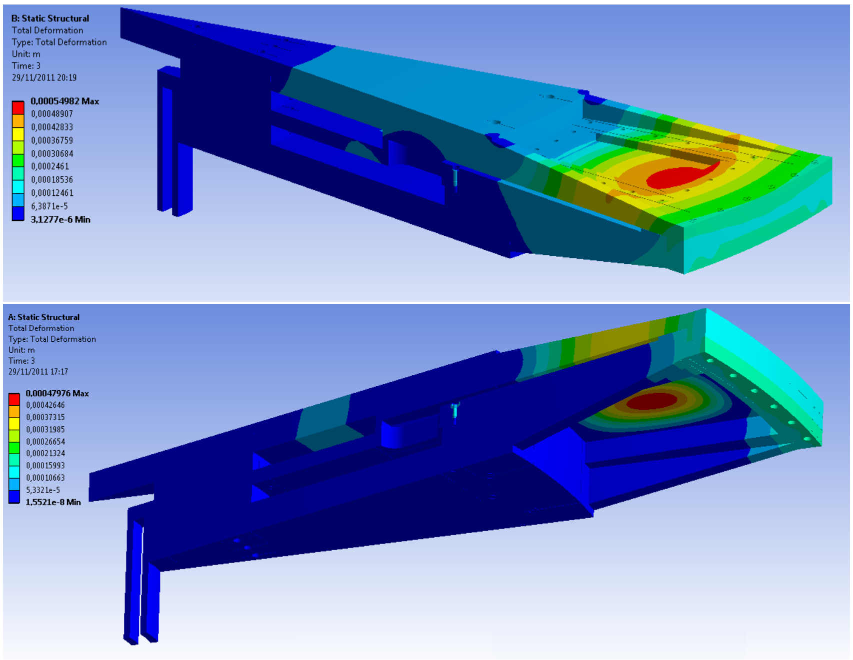

Figure 10. Deformation

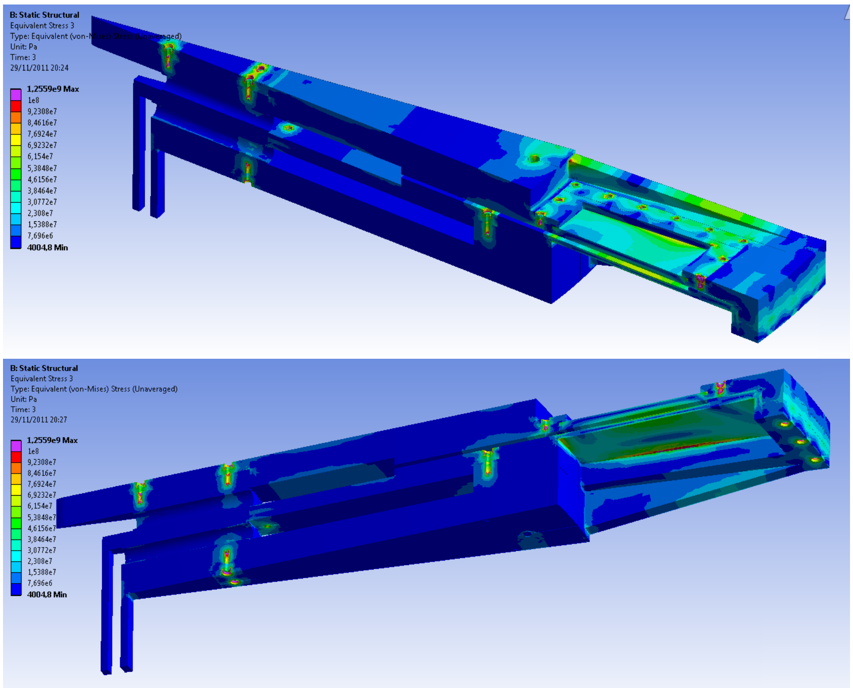

Figure 11. Von Mises stress

The global deformation present in the model is acceptable, being the displacements below 0.5 mm. Regarding to the stress, and considering only the locations far enough from the numerical divergent values, it maximum remains below 70 MPa, which is acceptable.

4. Future analysis

In order to advance to the detail engineering phase, some other calculations have been indetified as necessary, e.g.

- Highly non-linear local studies in the seals.
- Verification of the absence of effects due to rotation (60 r.p.m).
- Analysis of dynamic vibrational modes.
- Evaluation of transitory effects due to beam pulses.
- Fatigue and lifespan estimation.

5. Conclusions

As a general conclusion, we can state that, starting from the very preliminary neutronic and cooling calculations, a complete conceptual design capable to provide the needed cooling flow and to withstand the existing thermomechanical load has been developed.

Acknowledgments

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