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Cooling concepts for the CVD diamond Brewster-angle window

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Introduction

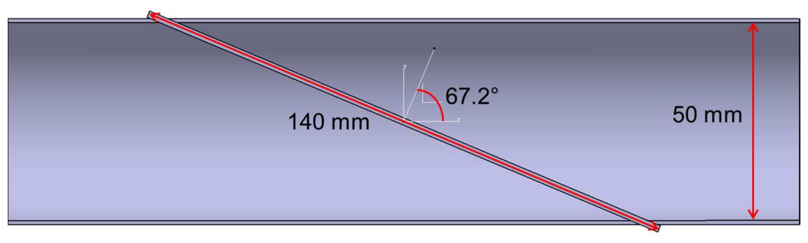
Frequency tunable gyrotrons able to switch their operating frequency in steps of around 2-3 GHz may be needed for control of plasma stability in DEMO. In this scenario, a diamond Brewster-angle window is a very promising key component as its configuration allows working in a broad frequency range with minimum reflection of the millimeter (mm) waves. In the frame of the Heating and Current Drive (HCD) Work Package (WP) of the Power Plant Physics and Technology (PPPT) programme launched by the EUROfusion Consortium, diamond Brewster-angle windows are being investigated for long pulse gyrotron operation.

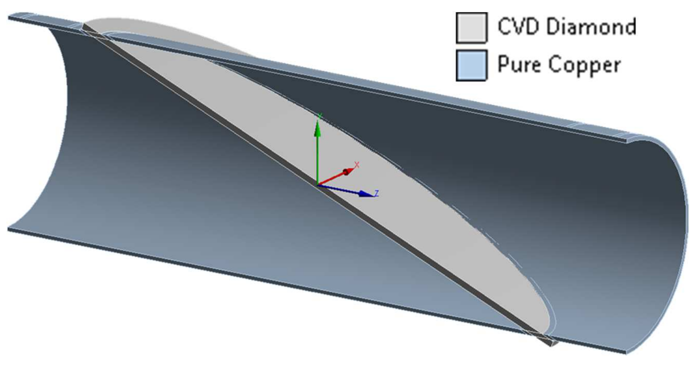
The typical configuration of the diamond Brewster-angle window consists of a CVD-diamond disc brazed to two copper waveguides (WGs) at the Brewster angle of 67.2°. The operation of this window concept was successfully shown for a high power gyrotron (~1 MW) working in the short pulse regime (< 10 ms) without any cooling of the window. In this case, a window with an elliptical shaped diamond disc of 140 mm major axis and 1.7 mm thickness was used resulting in a window aperture of 50 mm.

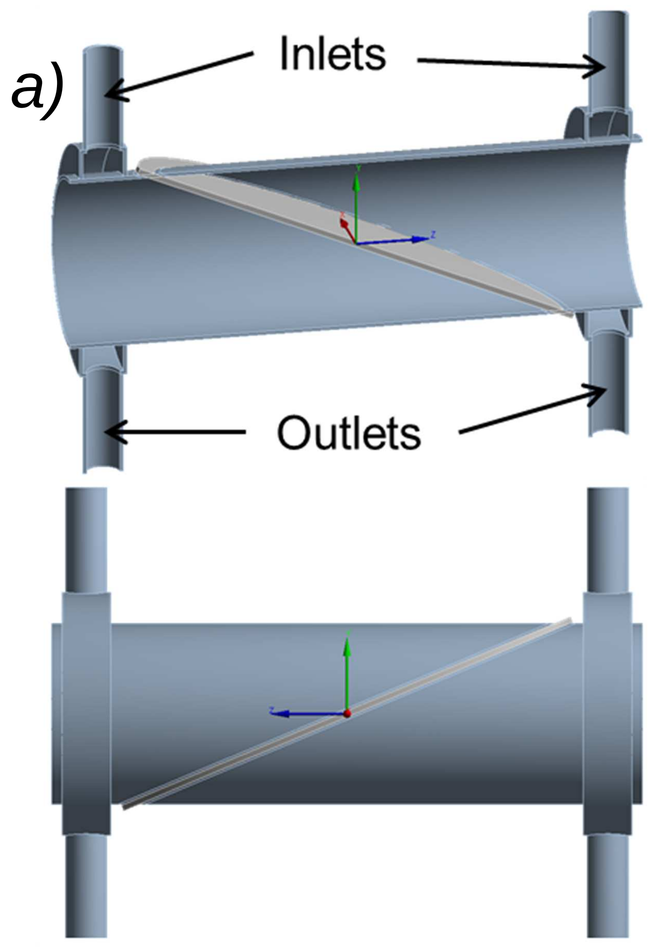
As a consequence the key challenges in the window development towards long pulse operation are the manufacturing of sufficiently large diamond discs, the proper joining of such discs to the WGs via brazing or other techniques able to reduce the manufacturing residual stresses in the window, and the design of a cooling layout able to guarantee a proper removal of the heat absorbed in the window during the beam transmission.

In this work, different cooling layouts were investigated by FEM thermal and structural analyses considering different power and frequency scenarios. For safety reasons, water is separated from the diamond disc since, in case of failure of the joining between the disc and the WGs, this design choice prevents the coolant from damaging the internal parts of the gyrotron (indirect cooling concept).

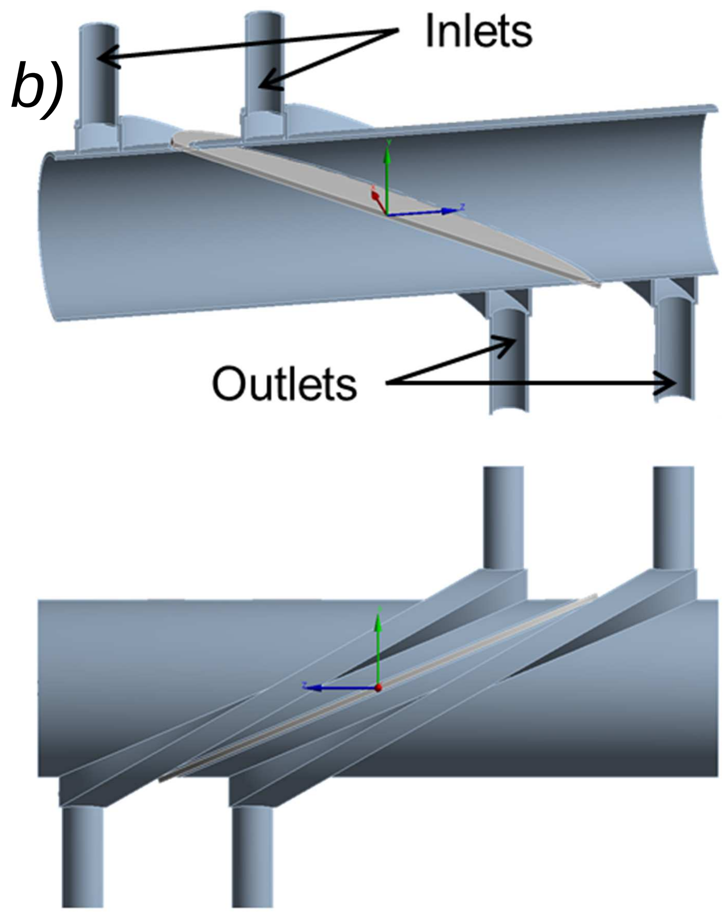
Geometry

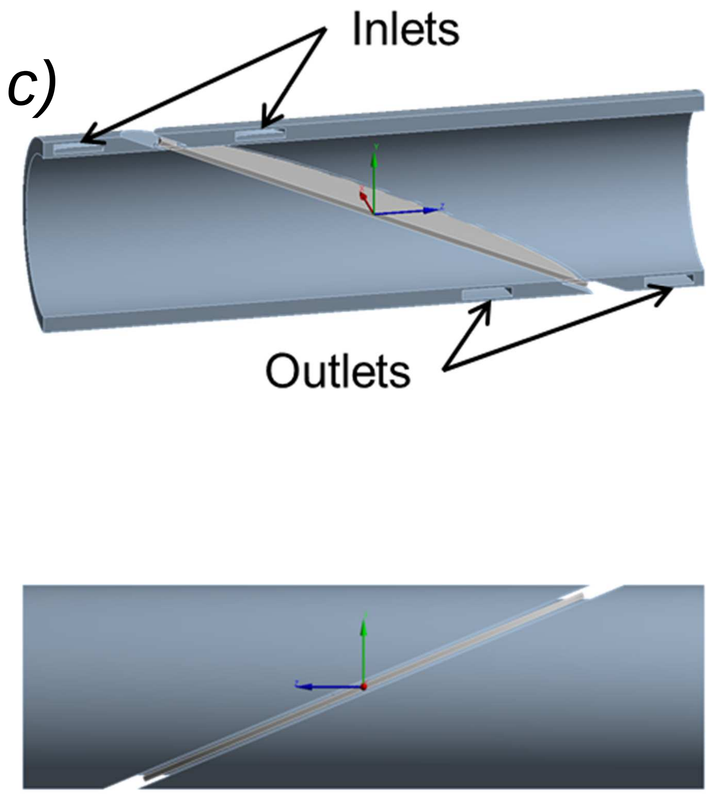






- The diamond disc has an elliptical shape with major axis of 140 mm, minor axis of 75 mm and a thickness of 1.7 mm.
- The copper WGs are cylindrical with inner diameter of 50 mm, thickness of 1 mm and total length of 170 mm.
- Symmetry along the major axis of the disc allowed analyzing only half of the window geometry.
- Three geometrical configurations of the cooling channels were considered: the simplest cooling configuration given by cylindrical channels (a), then channels able to follow the geometry of the disc as outer elliptical channels (b) and finally channels inside the WGs like inner elliptical channels.





Methodology

Scenarios	Absorbed power in the disc [W]
2 MW @ 170 GHz	1094
1.5 MW @ 240 GHz	1159
2 MW @ 240 GHz	1545

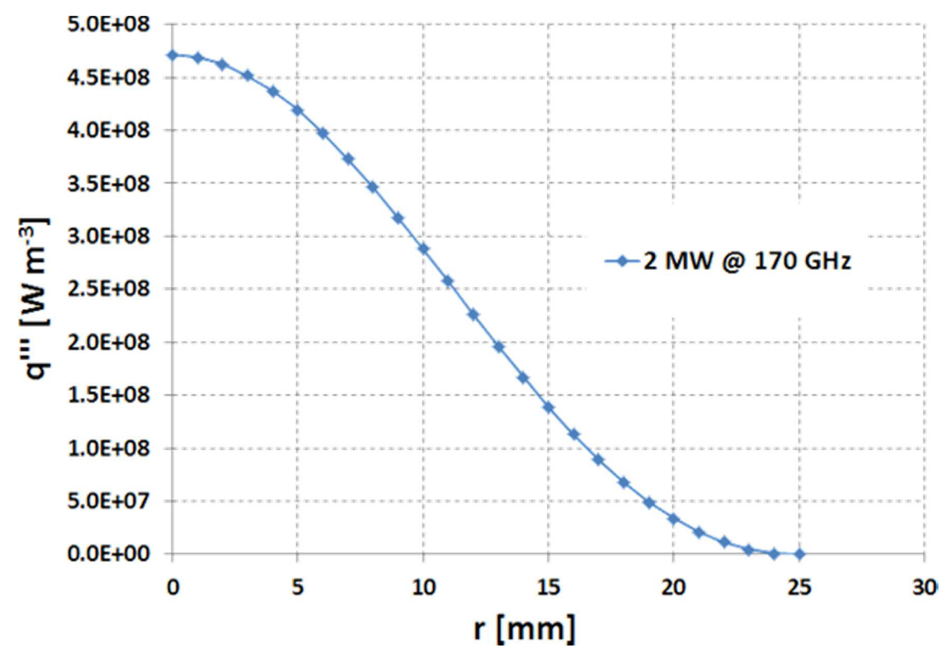
- Thermal analyses to calculate the temperature distributions in the window according to three HE_{11} beam scenarios.
- Heat generation load was applied to the disc by the Bessel function of order zero which describes the power pattern of the HE_{11} beam inside the WG having radius a = 25 mm.
- Heat exchange coefficient applied to the cooling interface was calculated by book equations.
- Structural analyses to calculate the correspondent thermal stress distributions in the diamond disc.

$\varepsilon_r = 5.67$
$tan\delta = 3.5 \times 10^{-5}$
$t = 1.7$ mm
$\Theta_B = 67.2°$

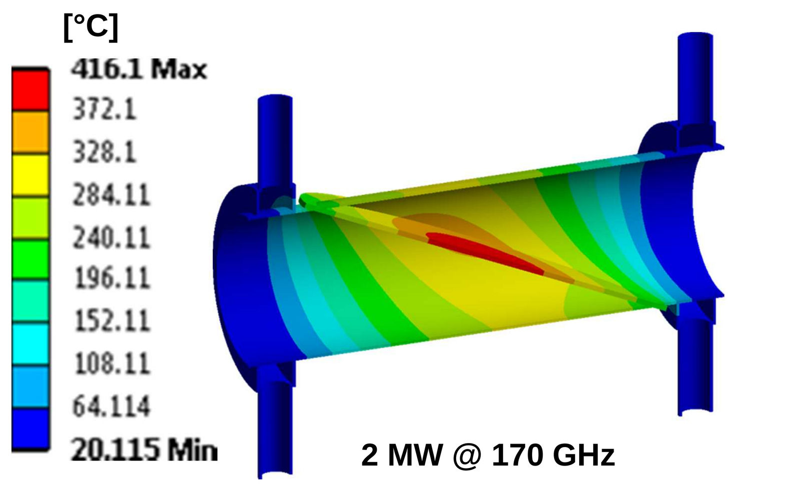
$$P_{abs} = P_{beam} \times \frac{2\pi\nu\sqrt{\varepsilon_r}tan\delta}{c} \times \frac{t}{\sin(\theta_B)}$$

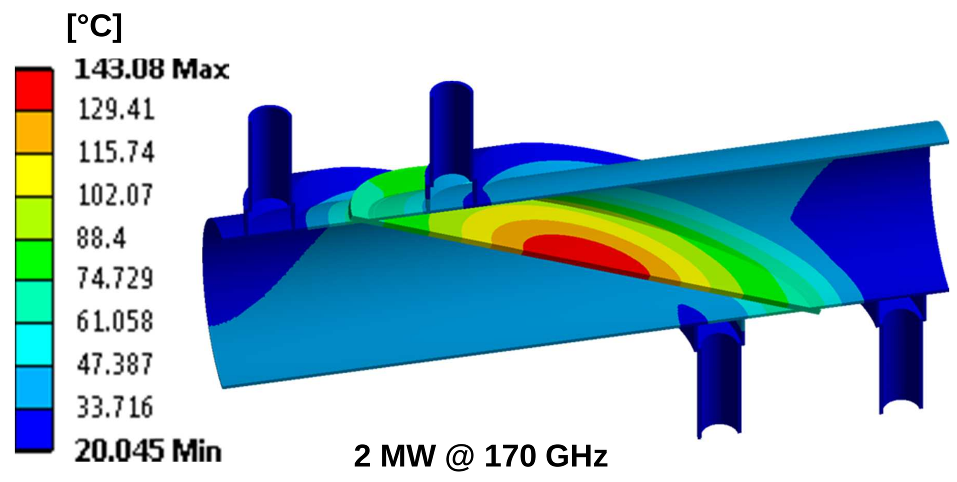
$$q'''(r) = A \times [J_0(x)]^2$$

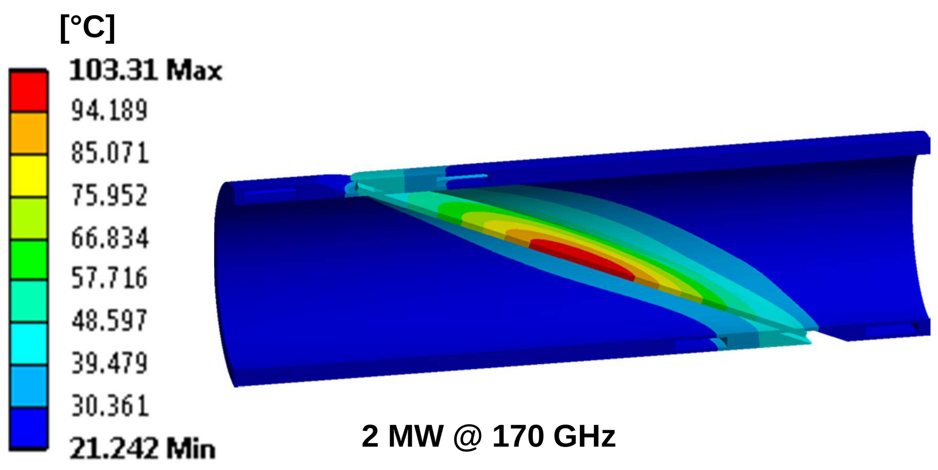
$$x = 2.405 \times \frac{r}{a}$$



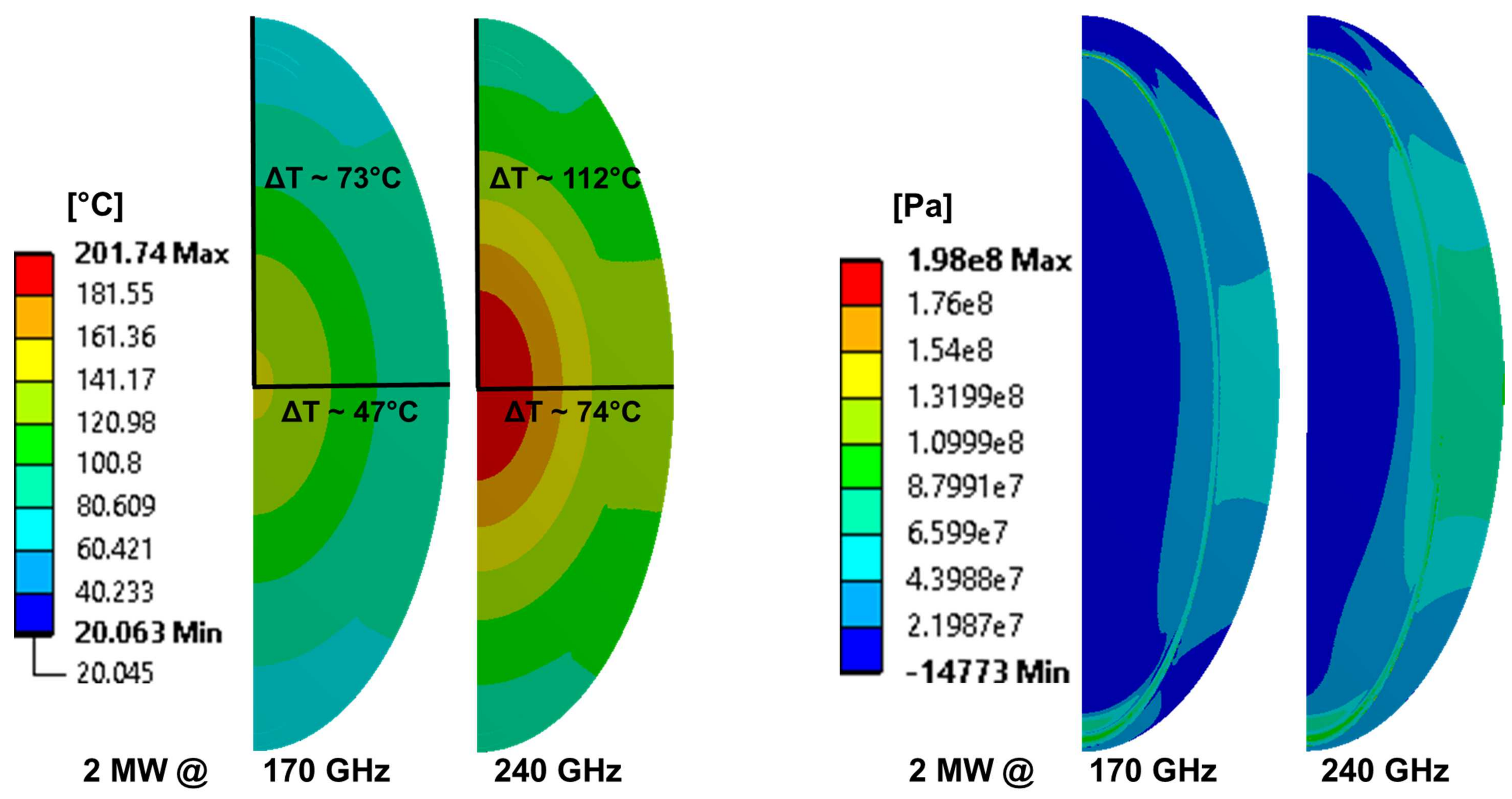
Results







- The analyses showed the necessity of having cooling channels that follow the skewed position of the disc (temperature limit for diamond is 250-300°C).
- Even for the worst beam scenario of 2 MW at 240 GHz, both outer and inner elliptical channels work well as the resulting temperatures and stresses in the disc are below the allowable limits.
- The choice between outer and inner elliptical channels shall be based on their manufacturing feasibility and it shall be part of a separate study.



Comparison of the temperature and the maximum principal stress distribution in the upper surface of the disc between the two extreme beam scenarios for the Brewster window with outer elliptical cooling channels.

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