Design validation of the gyrotron diamond output window for the upgrade of the ECRH system at W7-X

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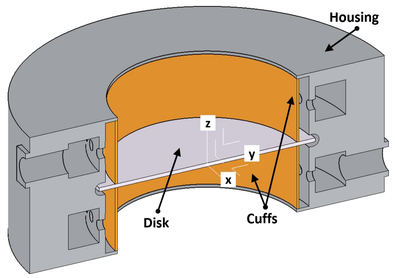
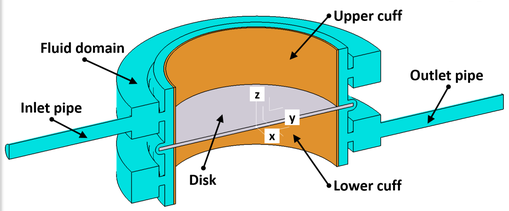
Motivation



The W7-X gyrotron design, operating successfully at 1 MW and 140 GHz CW, is being upgraded for operating at 1.5 MW to achieve regimes with high plasma beta and low collisionality

The gyrotron features a CVD diamond output window with a 1.8 mm thick and 106 mm diameter diamond disk brazed to two copper cuffs, which are enclosed in a stainless steel housing

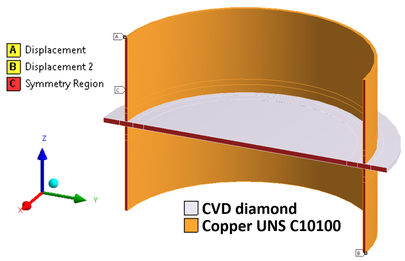
Approach



CFD conjugated heat transfer analysis

- Symmetry: half of the window modelled
- Coolant: silicon oil Dow Corning 200(R) with the kinematic viscosity 5 cSt
- Mass flow rate of 0.2 kg s^{-1} at inlet (25°C) and 0 Pa reference pressure at outlet
- 1.5 MW Gaussian mm-wave beam with 20 mm radius
- Heat load applied to disk with Gaussian distribution normalized to obtain in the disk the total absorbed power of 1.5 kW (comparison reasons to 1 MW case analyzed in 2010 with 1 kW power absorption)
- Runs with different tanδ values and mm-wave beam radius (15 mm and 24 mm)

	tanδ	Absorbed power in the diamond disk
	[-]	[W]
CFD analysis with 1.5 kW absorption	5.68×10^{-5}	1500
D90, average on 25 bare disks	3.49×10^{-5}	921.4
D50, average on 25 bare disks	2.10×10^{-5}	554.5



Structural analysis

- Plastic steady-state structural analysis: multilinear isotropic hardening
- Load in terms of temperature distribution
- Stress assessment for the two extreme cases: cuffs free to expand (isostatic boundary condition) and expansion blocked by housing (fixed support condition)

Objectives

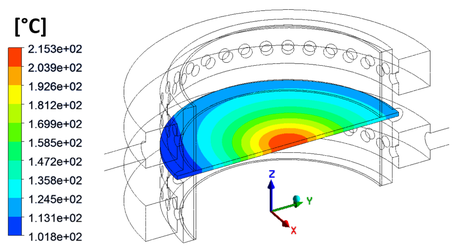
- Investigate the window performance at 1.5 MW operation from the thermal perspective, in comparison to the 1 MW case, by CFD conjugated heat transfer analyses (ANSYS CFX V19.2)
- Perform sensitivity studies with respect to the mm-wave beam radius at the window location and to the absorbed power in the disk by using loss tangent (tanδ) values obtained as average over measurements done in the past for 25 bare disks for W7-X at the KIT laboratories
- Validate the window design against the applicable stress limits by structural analyses (ANSYS V19.2)

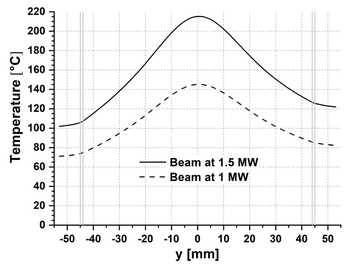
Results

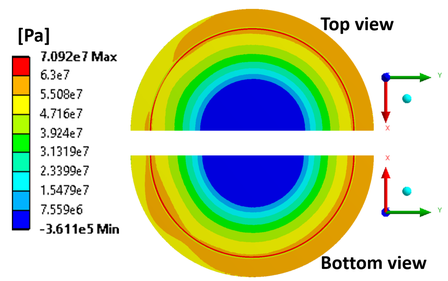
- Max T of 215°C at disk center, well below the diamond conservative limit of 250°C
- Non axially-symmetric temperature distribution
- T increase of 4.4°C for the oil at the outlet

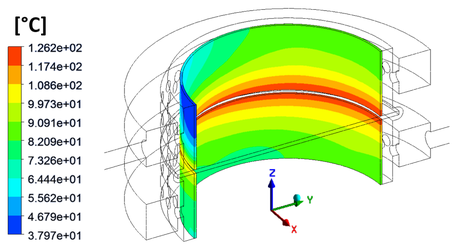
- Going to 1.5 MW operation, max T increases by ~70% and, as expected, thermal gradients become steeper
- With a ~3 times lower tanδ, max T reduces from 215°C to 95°C in the disk
- The 1.5 kW assumption is thus conservative, but it assures a good margin against the potential tanδ degradation caused by the brazing and the window manufacturing

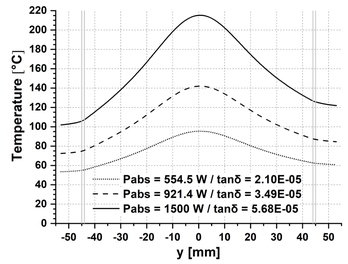
- Max stress in the disk well below the conservative limit of 150 MPa
- Max stress in the cuffs well below the minimum ultimate tensile strength (175 MPa)
- Real stress state in the disk and cuffs is in between the two analyzed extreme cases

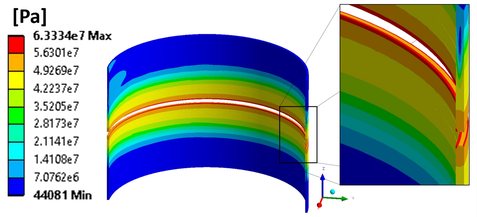












Even in the worst case of 1.5 kW absorbed power, the window performance was validated

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Coordinates for online discussion: 21st of September 2020, 17:00 – 18:30 by Skype (contact: gaetanoaiello1984)

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