Karlsruhe Institute of Technology

Institute for Applied Materials IAM-AWP

FEM analyses of a CVD diamond Brewster window

G. Aiello, G. Grossetti, A. Meier, T. Scherer, S. Schreck, P. Spaeh, D. Strauss, A. Vaccaro

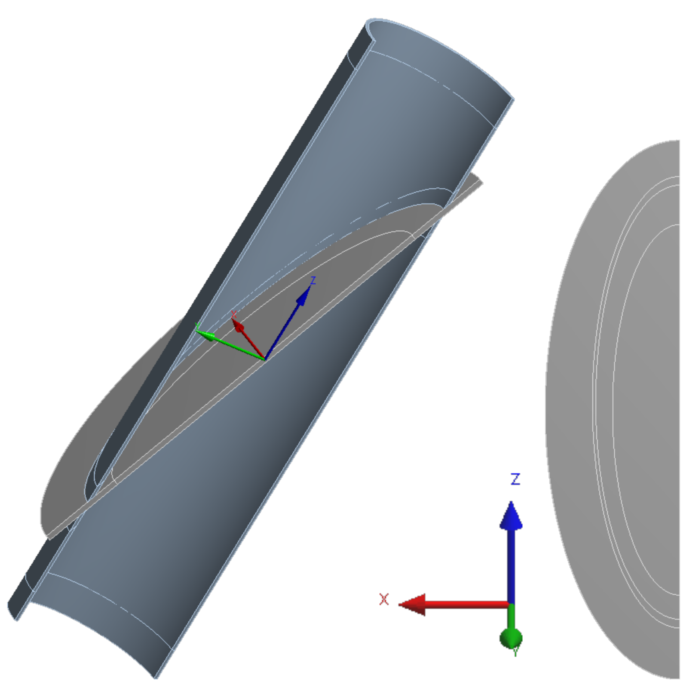
Institute for Applied Materials, Karlsruhe Institute of Technology (KIT), P.O. Box 3640, D-76021 Karlsruhe, Germany

Introduction and background

Chemical vapor deposition (CVD) diamond windows are a crucial component in heating and current drive (H&CD) applications. In order to minimize the amount of reflected power from the diamond disc, its thickness must match the desired beam wavelength, thus proper targeting of the plasma requires movable beam reflectors. This is the case, for instance, of the ITER electron cyclotron H&CD system. However, looking at DEMO, the higher heat loads and neutron fluxes could make the use of movable parts close to the plasma difficult. The issue might be solved by using gyrotrons able to tune the beam frequency to the desired resonance, but this concept requires transmission windows that work in a given frequency range (e.g. 105-140 GHz), such as the Brewster window. It consists of a CVD diamond disc brazed to two copper cuffs at the Brewster angle. The brazing process is carried out at about 800°C and then the temperature is decreased down to room temperature. Diamond and copper have very different thermal expansion coefficients, therefore high stresses build up during the cool down phase that might lead to failure of the disc. Considering also the complex geometry of the window with the skewed position of the disc, analyses are required in the first place to check its feasibility. The cool down phase was simulated by FEM structural analyses for several geometric and constraint configurations of the window. A study of an indirectly water-cooled configuration was also performed, considering the power absorption in the diamond disc due to a HE_{11} mode beam.

Methods

Reference configuration

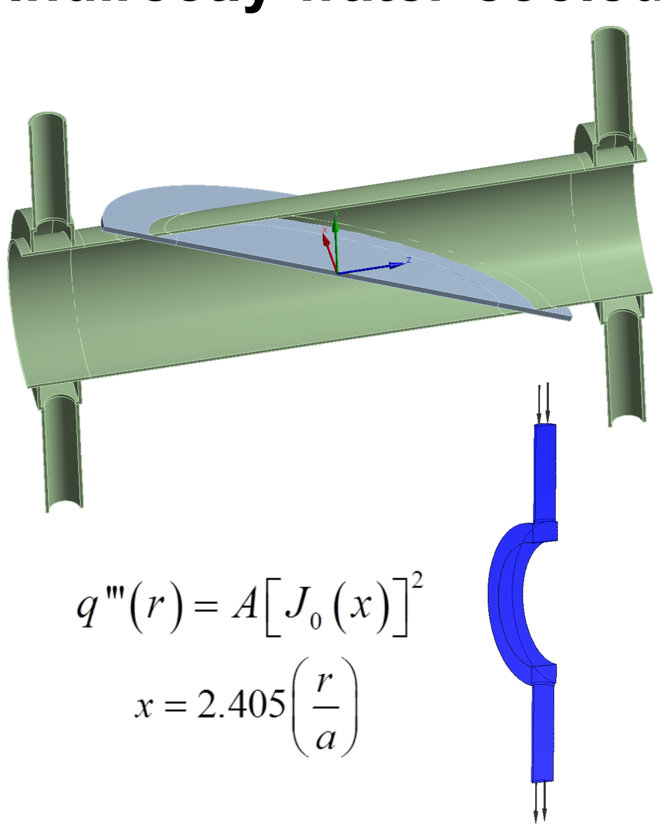


- Elliptical CVD diamond disc 160*80 mm, thickness 1.9 mm, Brewster angle 67.22°;
- Cylindrical OFHC copper cuffs of inner diameter 50 mm, thickness 1 mm, total length 200 mm;
- Symmetry along the disc major axis;
- Constant, temperature dependent, non linear material properties;
- Fixed support at the two ends of the cuffs;
- Structural analysis with equilibrium temperature of 800°C and applied thermal condition of 20°C.

Geometric and constraint configurations

- Thickness: from 0.8 to 2 mm for the cuffs and from 1 to 2.5 mm for the disc;
- Aspect ratio of the disc: 1.4 and 2.33 with major axis of 140 mm and minor axis respectively of 100 mm and 60 mm;
- Boundary condition: upper end of the cuffs free to move along the *z*-axis only (configuration 1) and upper end of the cuffs without constraints (configuration 2).

Indirectly water-cooled configuration

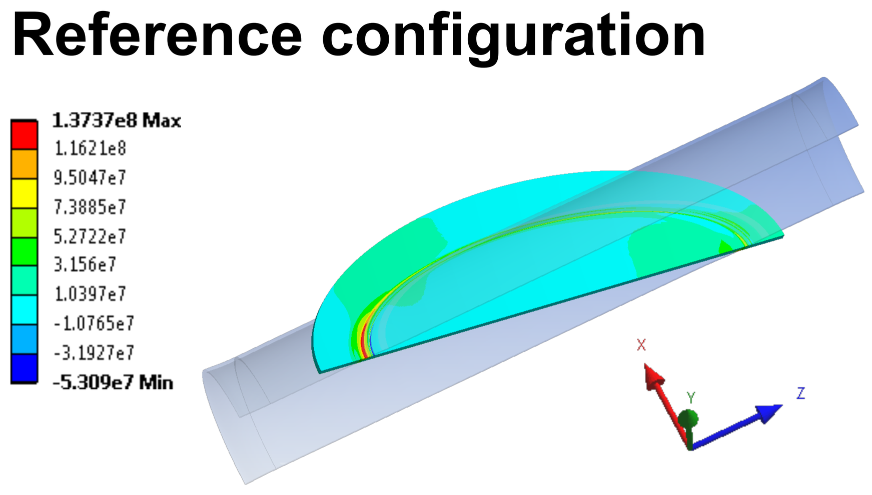


$$q'''(r) = A\left[J_0(x)\right]^2$$
$$x = 2.405\left(\frac{r}{a}\right)$$

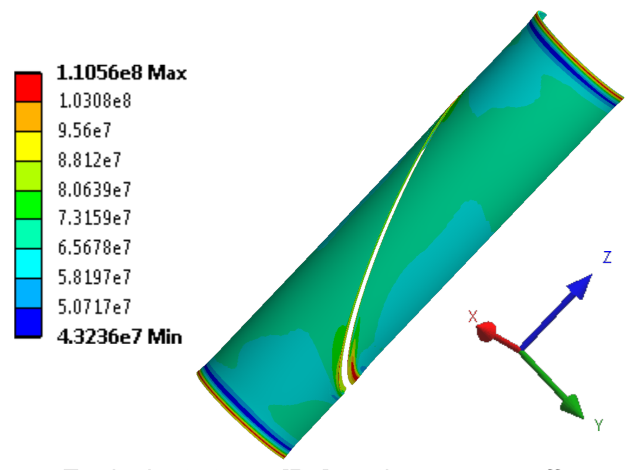
- OFHC copper cooling circuit added to the reference configuration;
- CFD analysis with the fluid domain only to calculate the heat exchange coefficient;
- Thermal analysis by applying the heat generation load to the disc according to the HE_{11} pattern. Temperature distributions were calculated for absorbed power values between 0.2 and 1 kW;
- Structural analysis of the reference configuration with second load step given by the temperature gradient corresponding to the absorbed power of 0.4 kW.

Results

Reference configuration

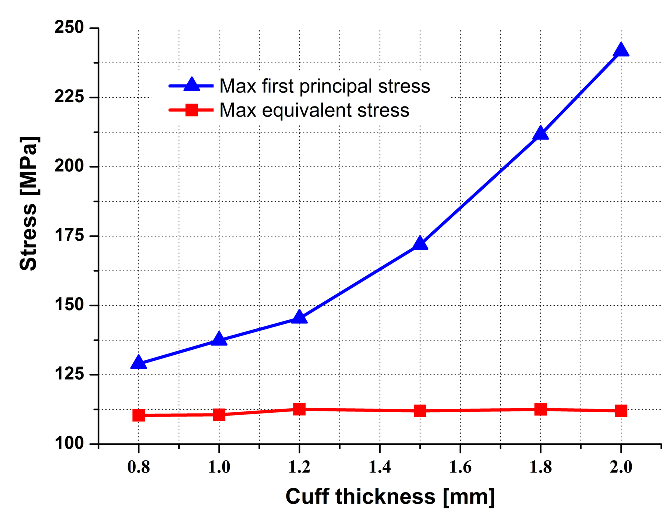


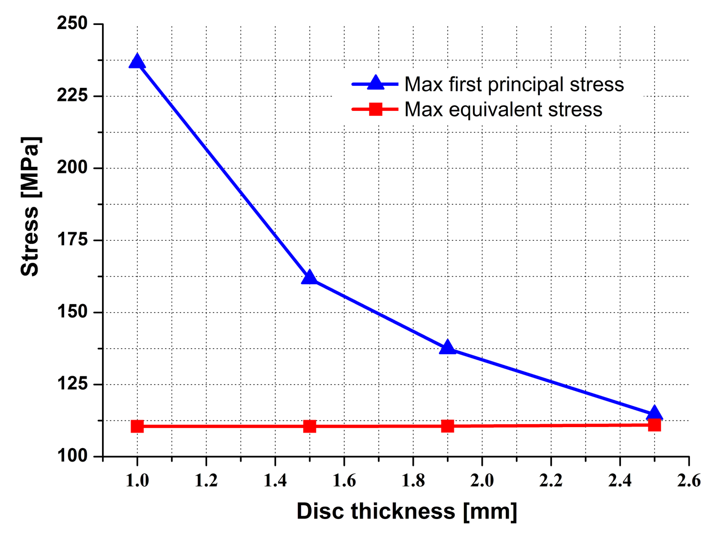
First principal stress [Pa] on the top side of the disc.

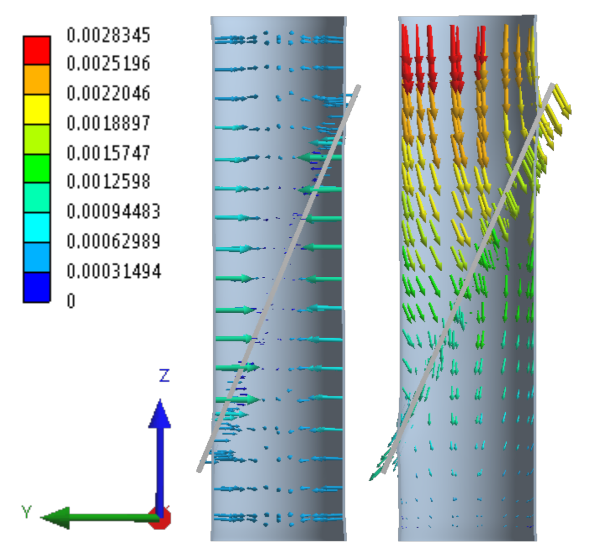


Equivalent stress [Pa] on the copper cuffs.

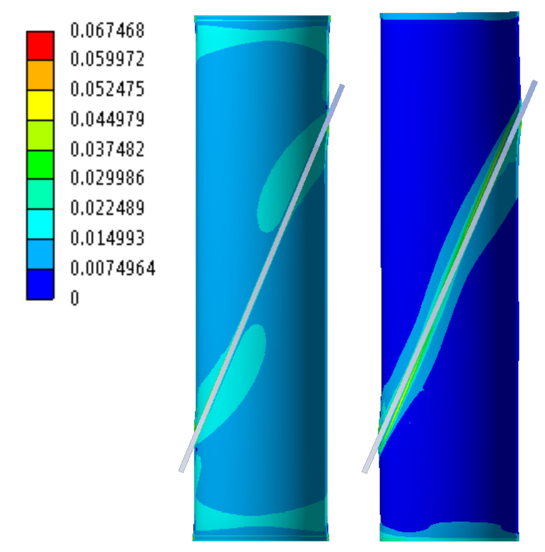
Geometric and constraint configurations



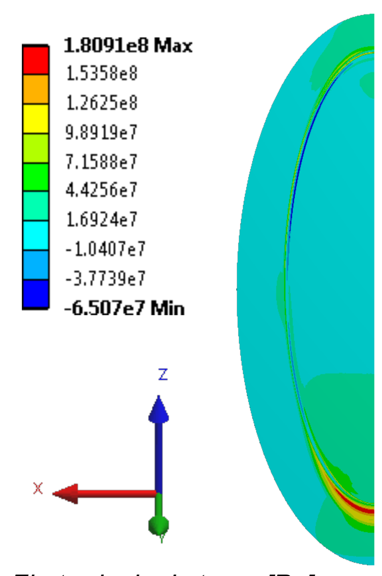




Comparison of the deformation mechanism [m] between reference configuration (left) and configuration 1 (right).

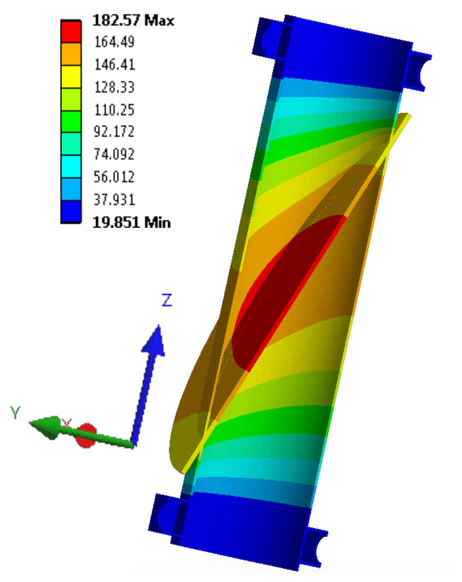


Comparison of the equivalent plastic strain distribution between reference configuration (left) and configuration 1 (right).

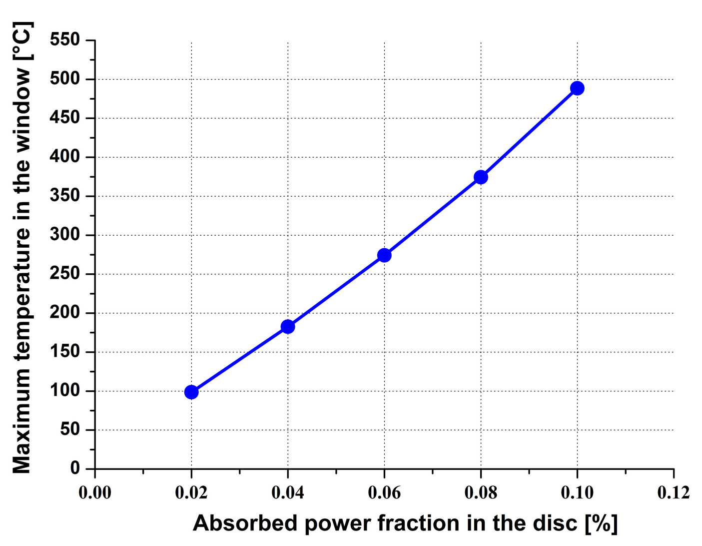


First principal stress [Pa] on the top side of the disc for the configuration 1.

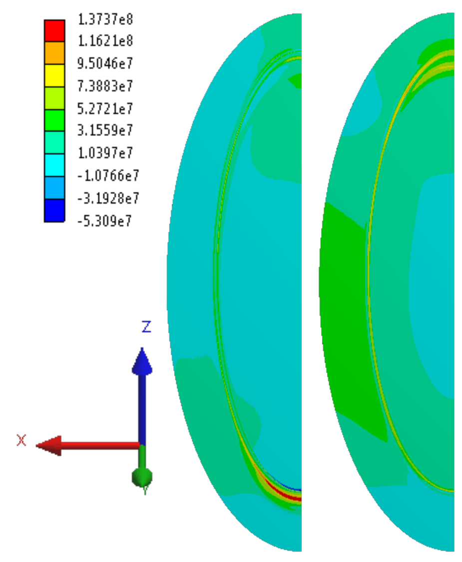
Indirectly water-cooled configuration



Temperature [°C] distribution for 0.4 kW absorbed power in the disc.



Maximum temperature as a function of the absorbed power fraction with respect to a 1 MW power beam.



First principal stress [Pa] on the top side of the disc between reference configuration (left) and reference configuration with second load step (right).

Conclusions

- FEM structural analyses have shown that the CVD diamond Brewster window is a feasible broadband window solution for H&CD applications. In the reference configuration, the maximum first principal stress is below the permissible stress of diamond which is 150 MPa (ultimate stress is 450-500 MPa).
- Values of cuff thickness greater than 1.2 mm and of disc thickness less than 1.7 mm are not recommended.
- The aspect ratio of the disc affects the first principal stress by less than 3%.
- The configurations 1 and 2 lead to stress values in the disc higher than those obtained in the reference configuration and above the permissible stress.
- The stress field generated in the disc by the cool down phase of the brazing process and the applied temperature gradient is well below the permissible stress.