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Optimization of high heat flux components for DIII-D neutral beam upgrades

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Upgrade of the DIII-D neutral beams leads to enhanced heat loads on many components, such as pole shields, calorimeter and collimator. Higher power is now desired for the neutral beams, increasing from 2.6 MW to 3.2 MW per source leading to a normal heat flux loads of up to 55 MW/m2 for the calorimeter. Original designs experienced local melting and fatigue cracks during operation at 2.6 MW. The Princeton Plasma Physics Laboratory is responsible for the design and manufacturing of the upgrades of these components.
Heat flux distribution on neutral beam components is very uneven and leads to significant thermal stresses. High heat flux density impact requires surface optimization to reduce surface heat flux projection, and avoid localized melting. Several new design features were introduced to accommodate increased heat loads, such as molybdenum inserts for the pole shields, two-dimensional shaping for the calorimeter, and three-dimensional shape optimization and replaceable copper inserts for the collimator. Additionally, all three components include an optimized cooling system design featuring peripheral cooling of copper components. This takes advantage of the metal's high thermal conductivity to achieve cool down between the pulses, and, simultaneously, avoids high thermal stress situations where cooling channels are located close to the high heat affected zones.
The optimization process included applying analytical relations for the transient temperature distributions on the high heat flux components. These relations were confirmed by previous DIII-D experimental results. To validate the designs, numerical simulations were performed using ANSYS software and consisted of two stages: transient fluid flow simulation in conjunction with heat transfer analysis in the solid parts; and structural analysis using the temperature distribution obtained at the first stage. Special functions were introduced to include complex heat flux effects on the 3D surfaces. Results of the design optimization and numerical simulations will be presented.

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