Thermal-Fluid-Structural Stress Analysis Of The High Flux Isotope Reactor's Outer Reflector

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Abstract

The Oak Ridge National Laboratory's High Flux Isotope Reactor (HFIR) is an 85 MW research reactor which provides unique material irradiation, isotope production, and neutron scattering facilities. It relies on a series of concentric beryllium reflectors surrounding the reactor core for neutron reflection/moderation. The lifetime of these components is limited by cracks that eventually form due to a combination of thermal stresses and radiation damage. While the HFIR is designed to allow for the inner concentric reflectors to be relatively easily replaced due to their higher rates of radiation damage and correspondingly shorter lifetimes, the outermost reflector has a much lower rate of radiation damage but requires an outage of many months for replacement and is much more costly to make. The current outer reflector has a lifetime of ~20 years and is nearing replacement age.
As part of the upcoming replacement, we are updating the previous thermal-fluid-structural stress analysis of the outer reflector using modern tools in the form of COMSOL Multiphysics running on a new high performance computer cluster for a massive increase in fidelity. The outer reflector is ~2 feet tall with an outer diameter of ~ 3.5 feet and an inner diameter of ~2 feet. It has non-symmetrical arrays of 1/8 inch diameter vertical coolant holes, ~1.5-3 inch diameter vertical experiment facility holes, and ~6-10 inch diameter horizontal beam tube holes. Thus, it must be modeled in 3D and has very high aspect ratio features that are difficult to accurately resolve. The finite element model used previously had ~250 thousand degrees of freedom whereas now we can run a model with ~125 million degrees of freedom in only few hours. This allows us to calculate the stresses in the current design with much higher accuracy and quickly iterate on potential design changes. In particular, coupling COMSOL's Nonisothermal Pipe Flow interface with the Heat Transfer in Solids and Solid Mechanics interfaces allows us to capture the effects of the large array of small diameter cooling holes with high fidelity and low computational cost. Preliminary calculation results for the current outer reflector design have indicated the potential for a positive radial temperature gradient during reactor operation. This would lead to tensile hoop stresses on the inner part of the outer reflector where radiation damage accumulates more quickly, thus increasing the likelihood of cracking. Also, due to the negative radial radiation damage gradient, the inner part of the outer reflector will likely see compressive hoop stresses when the reactor is not operating, introducing the possibility of low cycle fatigue due to the HFIR's short (~1 month) operating cycles. The current analysis also allows us to directly calculate stresses at the coolant holes where these had to be inferred in the previous analysis. Applying current analysis tools in the form of COMSOL Multiphysics is giving us much greater insight into a complicated thermal-fluid-structural engineering problem and will allow us to improve the performance of the next HFIR outer reflector, and hence the HFIR itself.