Contribution ID: **173**

Type: **Invited Oral**

Virtual Engineering of a fusion reactor: application to divertor design, manufacture and testing

Monday 5 June 2017 11:40 (20 minutes)

Owing to ever-growing computational power, Virtual Engineering is transitioning from a possibility to an absolute necessity, and has exciting potential to accelerate the realisation of a fusion power reactor. Virtual Engineering is the use of sophisticated computational modelling to enhance the traditional route of component qualification by providing deeper insight, shortening the design cycle, reducing the burden of costly experimental testing or by answering questions that are simply not possible to answer by testing or real-world measurement. Finite element analysis (FEA), has been used for decades to perform engineering calculations and support design substantiation. In Virtual Engineering, the execution of FEA is highly parallelised, and mathematical optimisation is used to efficiently explore the design space, dramatically reducing design time. Further, typical FEA uses a much simplified and idealised representation of a real component, often taking input from computer aided design models. The advent of high performance computing and 3-D volumetric scanning offers the capability to create a highly accurate virtual "twin"of an as-manufactured component, including any unintended features or imperfections. These virtual components can be virtually tested under realistic conditions to simulate manufacturing, assembly, commissioning or operating phases.

In this work, the potential of Virtual Engineering in the design and validation cycle is demonstrated for the first time in an application to DEMO water cooled divertor target design, manufacture and testing. First, FEA-based design search and optimisation is used to improve the established tungsten monoblock divertor concept [1]. Fabricated mock-ups are imaged using X-ray tomography and analysed using image-based finite element modelling (IBFEM) to simulate the in-service high heat flux conditions. The IBFEM captures imperfections in the manufacturing process; in the example here an incomplete braze between components of the monoblock mock-up. The response of the FEA model to in-service simulations of heat flux indicated that the stress within the monoblock exceeded design limits leading to mechanical failure. A revised manufacturing procedure was introduced to improve the joining procedure and eliminate voids. The in-service simulations can be used to investigate the impact of an imperfection not only to identify early failure but also to identify acceptable imperfections that do not compromise lifetime performance, avoiding unnecessary component rejection and thus reducing cost and time to realisation. Mock-ups fabricated to the improved joining procedure have been successfully tested by infrared thermography, and under high heat flux at up to 25 MW/m² with no sign of damage.

[1] T. Hirai et al., Fusion Engineering and Design, 88 (2013), p1798-1801.

Eligible for student paper award?

No

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Session Classification: M.OA2: Divertors and High Heat Flux Components

Track Classification: Divertors and high heat flux components