Engineering Scaling Requirements for Solid Breeder Blanket Testing

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An engineering scaling process is proposed for ITER TBM and applied to the various designs in accordance with the testing objectives of validating the design tools and the database, and evaluating blanket performance under Demo operational conditions. The goal is to improve design of solid breeder blanket test modules based on scaling law practices. The focus of this study is to address key issues concerning pebble bed thermomechanical and first wall structural response, as well as neutronic performance. The goal of scaling is to ensure that changes in structural response and performance caused by changes in size and operating conditions does not reduce the usefulness of the tests. In addition, in order to evaluate statistical significance, the question of to what extent the size of the test article can be reduced such that a multiple number of test articles can be tested simultaneously is addressed. Since there is no simple analytical scheme that can be applied, brute-force computational approaches, including FEM, are utilized to recapture key Demo parameters under a reduced neutron wall load in ITER.

Reproducing Demo operating temperature is key to ITER test module design since it has a crucial influence on solid breeder blanket performance. However, complexities arise, since the issue is driven not only by temperature magnitudes but also by temperature gradients, which affect pebble bed performance under thermomechanical loads. For example, temperature gradients determine the stress magnitude exerted on the coolant wall, yet temperature magnitudes influence the rate of bed creep strain, which results in reducing stress magnitude once bed compaction initiates. Initial analysis of a design in which the Demo-like temperature magnitude is preserved shows an increase in stress magnitude of 15%. The pulsed operation nature of ITER further complicates the engineering scaling design process, due to the alteration of the thermal time constant. Ultimately, the size of the test module is greatly impacted by the trade-off between these competing factors. Neutronics performance scaling issues aim to achieve high confidence on tritium production rate prediction (i.e. ±5% relative to the characteristics in the full coverage case found in Demo). Geometrical requirements dictate scaling down the test module to a small size to ensure high spatial resolution for a specific measurement, taking into account the presence of the test port frames and divider plates. Preliminary results show that a test module of ~45 cm in the poloidal direction and ~60 cm in the toroidal direction may achieve the neutronic accuracy goals. As for the first wall performance, the issue is whether Demo characteristic stress and deformation magnitudes can be preserved by modifying geometric parameters. To ensure Demo relevant testing conditions a FEM analysis is employed to determine necessary changes to the ITER TBM design.