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Building a Virtual Tokamak - Integrated Multi-Physics Modelling for Fusion Engineering

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The design of any tokamak reactor presents one of the greatest engineering challenges in the world today, in particular for DEMO-class machines (which we define here as tritium self-sufficient, net electricity producing devices). By its very nature, such an endeavour requires the coordination of a vast effort spanning many fields, bridging physics and engineering disciplines. Typically, this activity is guided by the 0-1D systems code, PROCESS, which performs an extremely fast, preliminary, single-parameter optimisation of plant design parameters to meet a set of input constraints and requirements. This is done in a matter of seconds, and the design point generated forms the basis of all further design studies and analyses. These activities cover an extremely broad range of different areas (e.g. superconducting magnets, breeding blankets, remote maintenance, etc.) and typically last one to two years before meaningful results can be fed back to the systems codes and another design point can be generated.

This work presents UKAEA's approach to bridging the feedback gap between the ˜1s 0-1D systems codes and the ˜1-2 year discipline-specific design studies. We present case studies that illustrate the first steps towards the realisation of a UKAEA advanced parameterised engineering design tool enabling the rapid generation of optimised tokamak designs: a tool to build an in silico tokamak.

The design for a parametrically engineered tokamak concept is presented, with a focus on the automated design of the superconducting toroidal field (TF) and poloidal field (PF) coils. We demonstrate some of the early capabilities of the code, including the capability to parametrically design, analyse, and optimise the superconducting coil cage of a tokamak (to the first order). A comparison study of the numbers of TF and PF coils is presented, and the resulting stored energy, superconductor volume, and cold mass calculated for each configuration. The impacts of different design philosophies are also assessed, such as adopting a super-X divertor geometry, or different first wall and vacuum vessel shaping strategies. Engineering tools for assessing structural integrity are combined with tools which as traditionally physics-based, such as equilibrium generators and coil placement optimisation routines, to evolve a viable plant concept in the form of automatically generated 3D geometry. This geometry is then used as a basis to measure the designs'performance analytically using more detailed structural, thermal, and neutronics codes.

The advanced parameterised engineering design tool is aimed at supporting engineering decision making, rapidly delivering the necessary substantiated designs and performance data to the designer, so that they may better understand the far-reaching implications of their design choices on the performance of DEMO-class tokamaks and fusion power plants as a whole.

Keywords: DEMO, systems codes, TF/PF coils, plasma equilibria, super-X divertor

Eligible for student paper award?

No

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