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Constrained Feed-forward Waveforms for Tokamak Plasma Pulse Design

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Design is an iterative, creative process. In the context of plasma scenarios in magnetic confinement devices, a pulse design represents the specification or plan for a future pulse. Generation of these plans requires an understanding of the scenario's goals, any constraints that restrict the design space, and a list of assumptions that must be made in order to pose a well-formed problem.

Tools may be used to facilitate the design process by handling rudimentary tasks suited to computation, such as the inference of coil currents given target separatrix shapes or the calculation of machine limits. To be truly useful, these 'human-in-the-loop'tools must: run on human time scales such that the designer may 'effortlessly adjust, improve, and experiment'[1]; provide intuitive output such that design decisions may be quickly made; and be adequately flexible in their definition such that a design's goals, constraints, and assumptions, are not overly restricted by the tool in question.

We present the development of a feed-forward pulse design tool to facilitate the initial design of candidate voltage and current waveforms for a given set of target separatrix shapes. The tool is being designed as an actor within the workflow for the ITER Pulse Design Simulator, currently in the early stages of development, but could be used for this waveform design on any tokamak. At inception designs represent a lump of clay in that they lack form and precision but are very flexible in their scope. It is here that important design decisions are made. As a design matures, higher fidelity tools with longer run-times may be used to refine and verify that goals are achieved, constraints are met, and initial assumptions remain valid. Whilst critical to the overall workflow, it is important to realise that at this point that focus transitions from pulse design to pulse analysis and the ability to effortlessly adjust, improve and experiment is lost.

This feed-forward pulse design tool presented here is part of the NOVA free-boundary equilibrium code. This code includes the effects of passive conducting structures as well as an automatic treatment of non-linear constraints such as coil force and field limits, and plasma-wall gaps. These features free the designer to concentrate on core design aspects, separating themselves from algorithmic details encoded within NOVA's computationally light feed-forward pulse design tool.

A verification of this tool is made via comparisons to mature scenario simulations analysed by the DINA code. Here key design parameters such as a low order description of the plasma separatrix, plasma current, and Ejima coefficient are extracted from DINA outputs and de-featured [2, 3]. These parameters are then given to the NOVA waveform design tool from which voltage and current waveforms are extracted and compared to the source DINA simulations. The computation of a de-featured plasma scenario with a length of ~650 seconds from breakdown to termination requires a wall clock simulation time of ~5 seconds run on a laptop computer.

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