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April 2017

Supercomputers Provide Fusion Researchers with Fast-Turnaround 3D Magnetic Field Spectral Data

A new milestone in the use of remote high-performance computing enables researchers to calculate complex 3D magnetic field manipulations between tokamak discharges in order to optimize performance levels.

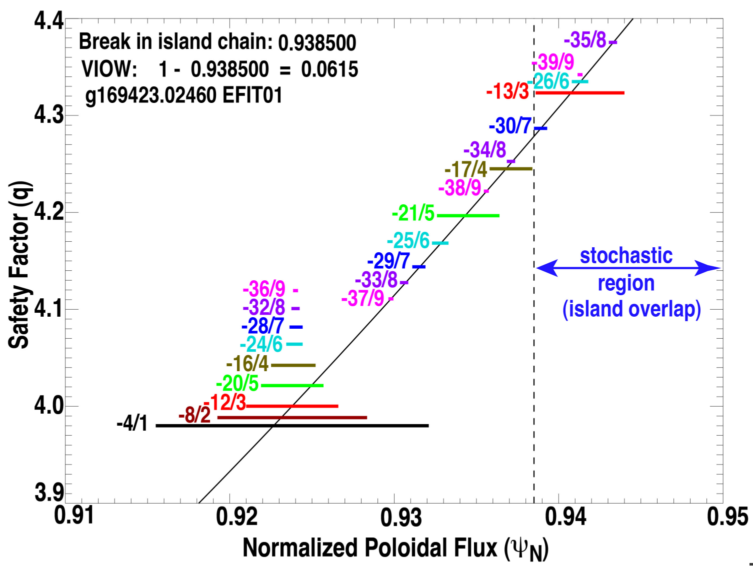

Image courtesy of General Atomics
Horizontal bars show the widths of magnetic islands in terms of a radial parameter (normalized poloidal flux) produced by the 3D fields in DIII-D discharge 169423 using the SURFMN code. Here, the numbers next to each bar designate the poloidal/toroidal periodicity of each magnetic island. The vertical axis measures the inverse field line pitch as one approaches the edge of the plasma (field pitch decreasing).

The Science

Small externally applied 3D magnetic fields can either be beneficial or detrimental to the plasma performance in tokamaks. In order to optimize the applied 3D fields in the DIII-D tokamak, a computer code known as SURFMN is used to calculate the properties of the fields inside the confined plasma. A supercomputer, located 2060 miles away at the Argonne Leadership Computing Facility (ALCF), has recently been used to demonstrate that high-resolution SURFMN spectral calculations can be carried out fast enough to allow researchers the time they need to adjust and re-optimize the 3D fields for the next plasma discharge.

The Impact

This fast-turnaround demonstration of tokamak discharge optimization by a remotely located supercomputing opens up new opportunities for advancing fusion research. It establishes, for the first time, the feasibility of optimizing fusion plasmas in reactor scale tokamaks such as ITER in real time, using large-scale numerical codes that require access to petaFLOP (10^{15}, floating point operations per second) or exaFLOP (10^{18}) computing capabilities.

Summary

Tokamak plasmas are nominally confined with a strong toroidal magnetic field (B_T) and a somewhat weaker poloidal magnetic field (B_p) that provide the basic 2D axisymmetric equilibrium. If properly applied, very small radial magnetic fields (B_r), of order a few times 10^{-4} B_T can prevent dangerous Magnetohydrodynamic (MHD) instabilities and control edge plasma pressure profiles. This technique can be used to control plasma MHD instabilities such as Edge-Localized Modes (ELMs). ELMs release large bursts of energy from the plasma edge, which can damage the walls of fusion reactors such as ITER. These small B_r perturbations are created using 3D magnetic coils. They break the 2D axisymmetry of the magnetic field resulting in complex 3D magnetic field structures, known as magnetic islands, which can overlap to create regions of stochastic or chaotic field lines. In order to optimize the effects of B_r on plasma performance, the spectrum of the applied B_r field, shown in the figure, needs to be adjusted to match the tokamak parameters during various modes of operation. This requires a sophisticated computer code, known as SURFMN, that uses a reconstructed 2D axisymmetric B_T, B_p equilibrium, along with advanced numerical models of field-error sources and 3D coil geometries, to calculate the applied B_r spectrum at regular time intervals during each discharge. Increasing the spatial Fourier resolution of the SURFMN analysis grid from 32x32 to 128x128 results in a substantial improvement in the accuracy of the calculations and the number of magnetic islands that can be resolved. This also increases the computational requirements needed to return the resulting SURFMN data within the time frame required for making decisions on the parameters needed for the next discharge. In order to meet the fast-turnaround times required when high-resolution SURFMN grids are used, supercomputers capable of petaFLOP speeds are needed. Future developments in the accuracy of the SURFMN code, as well as those used for other large-scale plasma optimizations codes, will benefit from the ability to run on exaFLOP computational facilities and will greatly enhance our ability to optimize burning fusion plasmas such as those in ITER.

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Publications

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Related Links

DIII-D user facility: https://diii-d.gat.com/diii-d/Home

FES-DIIID

ALCF user facility: https://science.energy.gov/ascr/facilities/user-facilities/alcf/

ASCR-ALCF

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