High Resolution Study of MHD Dynamics and Control in the Small Tokamak: HBT-EP*

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The HBT-EP (High Beta Tokamak-Extended Pulse) MHD mode control research program at Columbia University aims to (i) quantify external kink dynamics and multimode response to applied 3D magnetic perturbations, (ii) understand the relationship between control coil configuration, conducting and ferritic wall effects, and active feedback control effectiveness, and (iii) explore advanced feedback algorithms. A new, segmented adjustable conducting wall has been installed on HBT-EP [1] made up of 20 elements with 40 sets of internal modular feedback control coils. Each internal coil set is capable of varying the toroidal angular control coil coverage width of 5˚, 10˚, and 15˚, to test the resistive wall mode (RWM) interaction and multimode response to such highly localized control fields. Measurements of non-axisymmetric radial and poloidal magnetic fields are made using 216 sensors positioned near the plasma surface. The control coils are energized with high-power solid-state amplifiers, and massively-parallel, high-throughput feedback control experiments are performed using a low-latency, multiple-input/output (MIMO) digital signal processing system controlled by a NVIDIA graphics processing unit (GPU).

In this paper we report results using biorthogonal decomposition (BD) to observe multiplesimultaneous resistive wall modes with poloidal mode numbers up to m=9 and toroidal modenumbers up to n=4. Transitions between dominant poloidal mode numbers were observed for m=4→3/n=1 accompanied by simultaneous m=7→6/n=2. Non-rigid mode behavior with strong multimode effects have been observed with independent m/n = 3/1 and 6/2 RWMs. ActiveMHD spectroscopy with application of an external 3/1 magnetic perturbation has been used to document the 3/1 resonant field response showing linear, saturated, and ultimately, disruptive behavior depending upon the perturbation amplitude and the edge safety factor.

A 512 core GPU based low latency (< 14 microsec) MIMO control has been implemented with 96 inputs and 64 parallel outputs. Initial feedback control experiments have used 40 magnetic sensors and 40 control coils, producing MHD mode amplification or suppression, acceleration or deceleration depending on the feedback phase angle, and the first observation of Adaptive Control of the RWM in a tokamak.

A high-speed (88,000 frames/sec) camera viewing the plasma toroidally in the visible spectrum has been used with a BD analysis of the 2D image stream to show excellent agreement with the magnetic sensor measurements of the MHD mode dynamics. This both validates the accuracy of this non-magnetic diagnostic of MHD activity and extrapolates to applications in the UV and soft x-ray spectral range in larger and fusion power producing toroidal plasmas for detailed spatially resolved study of internal edge MHD activity.

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[1] D. A. Maurer, J. Bialek, P.J. Byrne, B. De Bono, J.P. Levesque, B.Q. Li, M.E. Mauel, G.A. Navratil, T.S. Pedersen, N. Rath, and D. Shiraki, *Plasma Phys. Control. Fusion* **53**, 074016 (2011).