# Effect of Control Coil Configuration and Feedback Gain on Resistive Wall Modes in HBT-EP*

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Control of long-wavelength MHD instabilities using conducting walls and external magnetic perturbations has been shown to be a promising route to improved performance of magnetic fusion devices [1,2,3]. The control physics issues of optimized feedback and sensor coil layout and geometry are crucial to maximizing the efficacy of MHD instability control for fusion systems. Using a flexible multi-element set of 30 independent sensor/driver feedback coils, the resistive wall mode (RWM) has been suppressed [4], and feedback effectiveness has been investigated as a function of coil coverage and feedback loop gain. These studies are important to on-going efforts to optimize active mode control systems. In addition, we have investigated the response of external RWMs to pre-programmed resonant magnetic perturbations generated using a 30-channel, high-speed programmable digital waveform generator to drive the present “smart-shell” control coil set. Saturated RWMs are observed to phase lock to an applied static resonant field with a paramagnetic or amplifying plasma response as recently observed on DIII-D [5] and predicted by theory [6]. Using this information gained on RWM behavior in HBT-EP along with VALEN 3-D electromagnetic modeling studies [7] we have designed and are implementing a new 20 sensor/driver feedback coil system optimized to theoretically stabilize HBT-EP RWMs up to the ideal wall limit.

These experiments were carried out on the HBT-EP tokamak which has previously demonstrated passive wall stabilization of the ideal kink [8] and feedback suppression of the RWM [4]. The HBT-EP conducting wall is made of 20 segments that can be independently positioned ($1.08 < b/a < 1.70$), allowing the position of the wall to be adjusted relative to the plasma. Half of the wall segments are made of aluminum (Al) and half of stainless steel (SS) so that the effective wall eddy current time constant can vary from 0.4 ms to more than 40 ms.

In the feedback experiments reported in this paper, newly optimized control loop circuitry capable of excluding 95% of the penetration of radial magnetic fields through the SS wall segments has allowed the suppression of RWM amplitude and inhibited RWM induced plasma disruption. Resistive wall mode induced disruptions are generated using a plasma current ramp of ~ 1.8 to 2.2 MA/s to drive the $q^*= 3$ and 4 surfaces through the plasma boundary [4,8]. When these low order rational surfaces enter the vacuum large amplitude $n=1$ resistive wall modes are excited that lead to plasma disruption and current termination. Figure 1 presents the results of feedback inhibition of these wall mode induced disruptions for an ensemble of similarly prepared plasmas. By

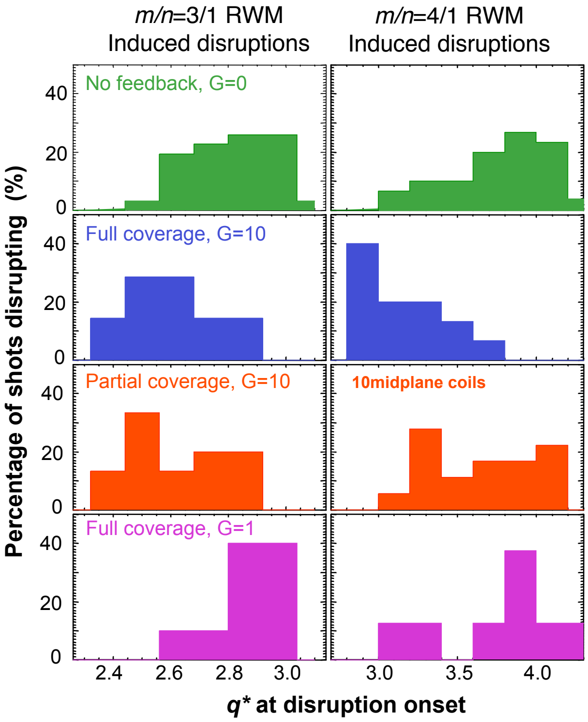

*Figure 1*

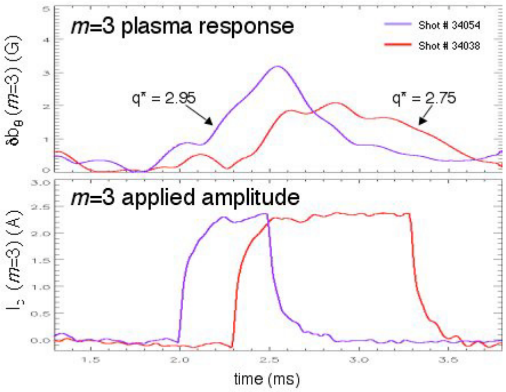

*Figure 2*

varying the plasma current ramp rate and plasma position either $m/n=4/1$ resistive wall modes or $m/n=3/1$ resistive wall modes can be generated. At full-gain/full-coverage $q^*=3$ and $q^*=4$ disruptivity is strongly affected and plasma operation at lower $q^*$ is possible. Energizing only the 10 coils above and below the mid-plane is still effective at inhibiting $m/n=3/1$ and $m/n=4/1$ induced disruptions as seen in Fig. 1. Resistive wall modes are not significantly affected, however, when feedback gain is reduced an order of magnitude. These changes in feedback effectiveness are currently being modeled by VALEN and will serve as an important benchmark for code validation.

Figure 2 shows the effect of an applied static, predominantly $m/n=3/1$, external resonant magnetic perturbation to a rotating saturated RWM. The observed plasma response has a phase locked growing $m=3$ poloidal mode structure. This response is observed to be paramagnetic or amplifying relative to the magnitude of the applied vacuum field [5,6]. The observed plasma response is shown to depend upon the stability limit of the resistive wall mode as indicated by differing plasma response to the external resonant magnetic perturbation at a given $q^*$. Experiments are currently underway to characterize RWM amplification and induced plasma torque as the frequency of the external perturbation is systematically varied to further characterize these important wall mode physics issues.

Finally, an optimized RWM feedback 20 sensor/control coil system has been designed and is currently being installed on HBT-EP. As seen in Fig. 3, the new control coils are cantilevered off of the present "smart shell" SS segments. These are connected to toroidally separated poloidal field sensors to minimize sensor-control coil mutual inductance. The 20 new control coil pairs are mounted on 0.010 inch thin SS shim stock to minimize control coil wall mutual inductance and enable strong control coil plasma coupling. VALEN modeling of this control geometry as seen in Fig. 3 predicts RWM stabilization equivalent to ideal conductors replacing all the passive Al and SS shell segments currently installed on HBT-EP.

*Work supported by DOE Grant DE-FG02-86ER53222

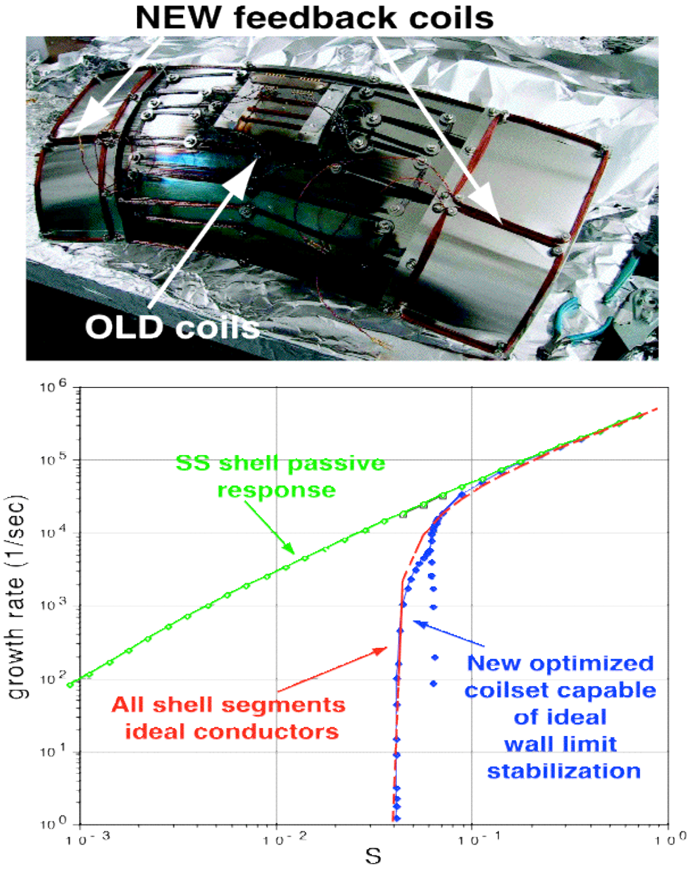

*Figure 3*

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