IAC

Observation of MHD stabilized operation during NBI-sustained discharge in 17 T axisymmetric mirror

T. M. Qian[1,4], J.K. Anderson[1], O.L. Anderson[1], T. Biewer[3], M. Clark[1], E. Claveau[2], D. Endrizzi[2], K. Fujii[3], J. Pizzo[1], S.P. Oliva[1], K. Sanwalka[1], K. Shih[2], D.A. Sutherland[2], A. Tran[1], J. Viola[2], J..P. Wallace[1], D. Yakovlev[1], M. Yu[1] and C.B. Forest[1]

[1] University of Wisconsin – Madison, Madison, WI, USA
[2] Realta Fusion Inc – Madison, WI, USA
[3] Oak Ridge National Laboratory – Oak Ridge, TN, USA
[4] Princeton University – Princeton, NJ, USA

Email: tqian23@wisc.edu

MHD (m=1) oscillations are observed to be stabilized, and plasma particle confinement enhanced, through a combination of electrode ring driven rotation and neutral beam injection in the Wisconsin HTS Axisymmetric Mirror (WHAM) [1]. End ring electrode bias improves confinement by (1) allowing the plasma to capture Neutral Beam Injection (NBI) after the Electron Cyclotron Heating (ECH) pulse, (2) increasing the particle confinement time as observed by a mm-wave interferometer, (3) broadening the radial profile of signals observed by XUV diodes, and (4) decreasing the ***spatial*** fluctuation of XUV signals by an order of magnitude.

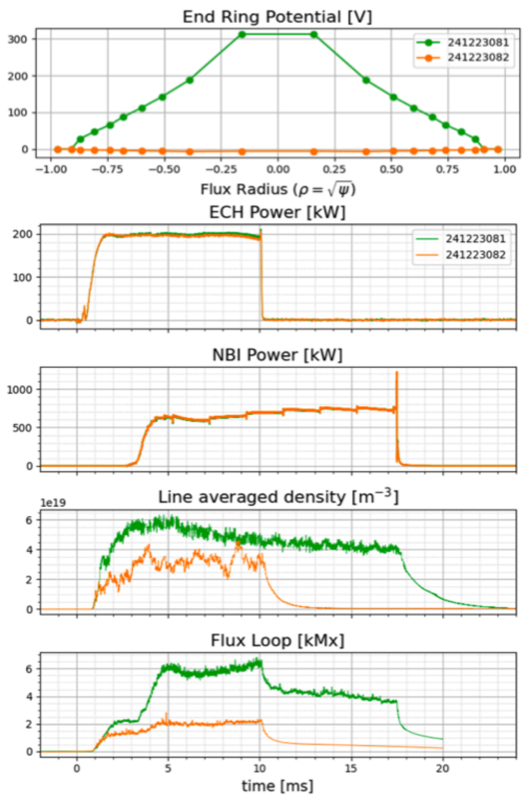

Figure 1: End Ring Bias radial profile; Time evolution for ECH, NBI, average density, and diamagnetic pressure.

A comparison of shots with (081) and without (082) electrode bias, at constant heating power, indicates significant enhancements in both density and stored energy. In the no bias case the plasma signals terminate abruptly after ECH turn off, while with bias electron density and diamagnetic pressure measured near the z=0 midplane are maintained for the full duration of the NBI pulse. The density signal continues without discontinuity, while the pressure signal adjusts to a new steady state. The **particle confinement time is improved** significantly from 0.64 ms to 4.0 ms, as measured by exponential fits to the interferometer density decay.

Achieving NBI sustainment required **significant upgrades to vessel conditioning** in addition to bias. We added four Ti gettering pumps to the neutral beam dump, carried out a glow discharge cleaning campaign with the 17 T HTS coils turned off (they are on for months at a time), and baked the vessel at 100 C. We also introduced a new baffled gas injector to minimize neutral leakage into the central cell.

Analysis of the XUV diode array shows an order of magnitude reduction in spatial fluctuation metrics: (1) the emissivity profile as a function of radius broadens in the biased case; (2) the shift in center-of-mass $\Delta_{COM} = \sum r\,A = C$ is much more stationary for the biased case, where A is the emissivity and r is the impact parameter in the sum over 20 view chords; (3) a statistical width proportional to the plasma radius $a_{RMS} = \sqrt{\sum A(r - \mu_{COM})^2 / \sum A} = R$ is both larger in magnitude and lower in fluctuation amplitude for the biased case. This measurement is significant because the low amplitude fluctuation constrains the size of higher wavenumber $m > 1$ oscillations; (4) an overall stability metric can be constructed from the two preceding terms as $\chi^2 = \sqrt{\sigma_{CC}\sigma_{RR} - \sigma_{CR}^2}$, where σ_{XY} is a bi-variate root mean square.

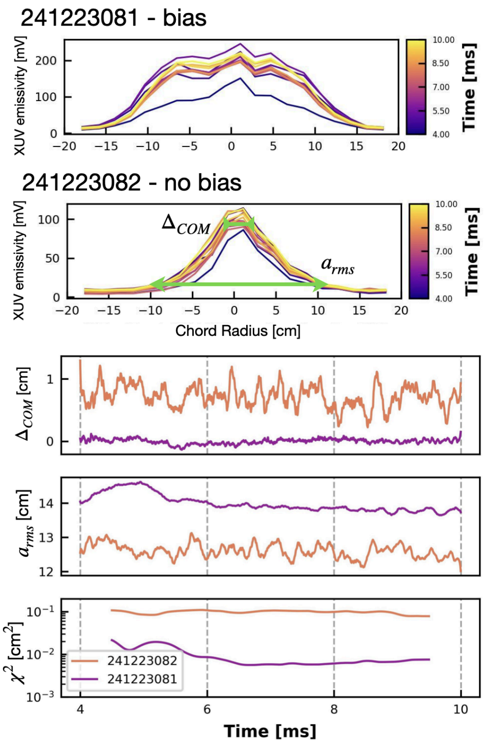

Figure 2: Radial emissivity profiles, with time in color axis; Δ_{CM}, a_{RMS}, χ^2 stability metrics.

This metric is an order of magnitude lower for the biased case, **indicating stabilization of MHD interchange** in this regime. While we cannot yet diagnose the exact spatial mode structure, single-fan XUV analysis indicates side-to-side motion is reduced, and the oscillation of the radial extent has become stationary. Fast camera video taken at 80k frames per second provides supporting evidence. The unbiased case deforms into filaments and its visual center moves about the magnetic axis, and the biased case forms a quasi-stationary plasma column. In the frequency domain most of the fluctuations appear during the ECH pulse. The magnitude of these hot electron interchange modes is lower for the NBI-sustained bias discharges.

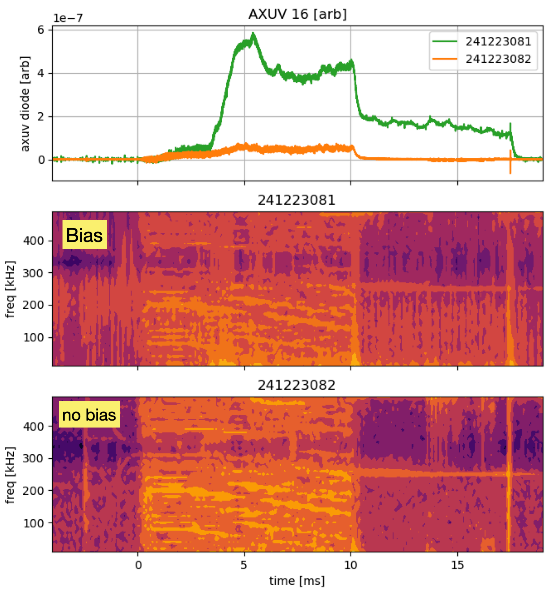

Figure 3: XUV signals; short time Fourier transform for biased and unbiased plasma, log plot of magnitude.

The observation that bias electrode actuators stabilize MHD fluctuations in WHAM is an important step toward Q~1 HTS axisymmetric mirrors, such as the ANVIL device actively designed by Realta Fusion [2]. The development of a breakeven class magnetic mirror has significance for all paths to fusion, in addition to burning plasmas in a tandem mirror [3], because the mirror provides relatively low cost access to volumetric fusion neutrons for reactor material tests.

ACKNOWLEDGMENTS This work was supported by ARPA-E award DE-AR0001258, NSF-GRF grant number DGE-2039656, Commonwealth Fusion Systems, UW-Madison WARF, and Realta Fusion.

REFERENCES

[1] D. Endrizzi, *et al,* Physics basis for the Wisconsin HTS Axisymmetric Mirror (WHAM). *Journal of Plasma Physics*, **89** (2023) 975890501.

[2] C. B. Forest, *et al,* Prospects for a high-field, compact break-even axisymmetric mirror (BEAM) and applications. *Journal of Plasma Physics*, **90** (2024) 975900101.

[3] S. J. Frank, *et al,* Integrated modelling of equilibrium and transport in axisymmetric magnetic mirror fusion devices. *arXiv*, (2025, in review JPP).