Measurement of the Internal Structure of MHD Fluctuations in Spherical Tokamaks

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Low frequency, 2-20 kHz, magnetohydrodynamic (MHD) fluctuations are ubiquitous features in magnetically confined fusion devices. These fluctuations are typically pressure driven, and they affect a number of different plasma parameters including particle and energy confinement, rotation damping, and fast ion loss. It has been shown in both conventional and spherical tokamaks (ST) that long-lived kink like modes (LLM) result in increased fast ion loss and a decrease in the energy confinement time[1-3]. While several diagnostics, such as edge magnetic coils, soft x-ray (SXR) emission, and beam emission spectroscopy (BES), have identified signatures of these modes, measuring the spatial structure of the modes has proven difficult. Furthermore, fewer diagnostic tools are available in STs because the lower magnetic field magnitude makes measurement prohibitively difficult (e.g. electron cyclotron emission). We propose the use of the MSE diagnostic to measure the internal structure of these MHD instabilities in direct support of MAST-U research goals[4].

The Motional Stark Effect (MSE) diagnostic can be used to measure the spatial distribution of MHD mode power via fluctuations in neutral beam emission. The principle of MSE polarimetry relies on modulation of the retardation of a fused silica plate, known as a photoelastic modulator (PEM). If two PEMs, driven at different frequencies, are used, the pitch angle can be determined from the ratio of the Fourier amplitudes at each frequency. When fluctuations are present in the plasma, the mode frequency beats with the modulator frequencies, resulting in the appearance of sidebands at the sum and difference frequencies between the modulator and mode frequencies in spectrograms of the MSE data. By analyzing the amplitude of these sidebands and the low-frequency fundamental, we can gain information on both the spatial location of the fluctuation and the amplitude of the fluctuations. MSE emission is localized to the intersection of the neutral beam and the viewing sightline, thus enabling spatially resolved measurements of the MHD mode internal structure. The measurement technique has been demonstrated previously in both bench-top [5] and tokamak scenarios [6]. Nova Photonics is also actively applying this technique to NSTX discharges, which display similar modes to those observed in MAST/MAST-U. This work will expand the capability of the MAST-U MSE diagnostic without the need for any hardware upgrades.

The increased magnetic field and plasma current in MAST-U extends the work already accomplished on NSTX and probes a complementary parameter space to the upcoming work at even higher fields in NSTX-U when it resumes operation. The new off-axis beam line enables the study of modes with off-axis current drive, which will modify both the current and pressure profiles. Additionally, fast ions play a role in destabilizing these modes. Studying these modes with the addition of a new source of fast ions could provide insight into their drive and stability.

In the first year of the grant period we will demonstrate the applicability of studying MHD instabilities with the MAST-U MSE system. This will include dedicated experimental runs that involve cross calibration and correlation with other diagnostics that observe fluctuations, including BES, Doppler backscatter, and SXR. Part of this period will be focused on developing a machine-learning algorithm to search and identify shots containing LLMs in the MSE signal, enabling us to quickly bootstrap a database of observations for analysis. Such analysis includes examination of both time evolution and spatial structure of the amplitude of short time windowed fast Fourier transforms in MAST-U discharges.

Once we have established the applicability of the technique to studying modes in MAST-U, in the second and third years comparison will be made with MHD modeling codes, enabling better understanding of these modes on plasma performance and the root cause of the modes. This work will be done in support of other physics studies, as well as proposing new experiments in collaboration with the MAST-U team, including studying fluctuations during off-axis neutral beam current drive.

**References:**

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