Low-frequency MHD spectrum of Rotating Tokamak Plasmas

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Current tokamaks often show significant toroidal flow and flow shear, causing fundamental changes in the magnetohydrodynamic (MHD) stability and wave spectrum of the plasma. Toroidal rotation most significantly influences the low-frequency part of the spectrum, where at the same time MHD-stable waves are prone to destabilization by fast ions. Understanding the complete MHD spectrum of modes excited by fast ions or antennas is important for diagnostic purposes. Understanding the role of inertial and flow shear effects on the stability of MHD modes is another important aspect.

In the presence of purely toroidal flow, the ideal MHD equations leave the freedom to specify which thermodynamic quantity is constant on the magnetic surfaces. Depending on the amount of poloidal flow and the parallel heat conductivity one may have e.g. constant entropy or temperature on flux surfaces. Introducing a general parametrization of this quantity, analytical expressions are derived for the low-frequency continuous Alfvén spectrum using a large aspect ratio expansion.

The newly derived dispersion relation describes both Geodesic Acoustic Modes (GAMs), and zonal flow-like modes in rotating tokamak plasmas. Due to the centrifugal convective effect, these continuum modes acquire a finite 'Brunt-Väisälä frequency' or become unstable, depending on which quantity is constant on the magnetic surfaces.

A novel stability criterion is derived for localized interchange modes clustering below this Alfvén continuum. The various terms in this criterion can be interpreted in terms of well-known instabilities like the Rayleigh-Taylor, Kelvin-Helmholtz, convective, and magnetorotational instability. Numerical calculations of the linearized MHD equations show that besides these interchanges, also other types of modes cluster below the Alfvén continuum. An infinite sequence of nonsingular non-axisymmetric zonal-flow like modes is found. Because their motion is primarily within the magnetic surfaces, they do not contribute to radial transport and can play a role in storing some of the turbulent energy.

Above a critical Mach number, new global flow-induced Alfvén modes were found to arise below both the GAM and the zonal flow frequencies. Because of their low frequencies, these modes may be easily destabilized by energetic particles. Because of their sensitivity to the Mach number however, these modes can provide a valuable extension to MHD-spectroscopy by giving information on the rotational velocity.

In this talk, an overview will be given of various new results regarding low-frequency MHD modes in rotating tokamak plasmas. The influence of rotation on stability and on newly discovered MHD modes will be discussed, without making a priori assumptions on which thermodynamic quantity is constant on the magnetic surfaces. The analysis will be supported with and compared to numerical simulations.