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Measurements of Fast particles in magnetic fusion devices

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In magnetically confined plasmas suprathermal ions can drive instability associated to the shear Alfvén wave. These instabilities have been observed in several machines worldwide and are the subject of dedicated theoretical and experimental investigations because of the threat they constitute for the confinement of α particles in a burning deuterium-tritium plasma. Alfvén waves have a peculiar dispersion relation. Due to toroidal simmetry, the refraction index is periodic and the continuum wave spectrum has gaps where the radial group velocity of the wave vanishes. Here reside discrete and weakly damped Alfvén eigenmodes of various origins, which can be excited by ions with orbital frequencies matching that of the wave. Once a mode is driven unstable, its evolution is intrinsically non linear and depends on the fast ion energy distribution, that is in turn affected by the eigenmode itself. In addition to these instabilities, if the energetic ion pressure is sufficiently large, additional modes not pertaining to the background plasma, called energetic particle modes, are manifested.

From the experimental point of view dedicated diagnostics have been developed on present day machines to measure the energy distribution of suprathermal ions in the hundreds keV range, to identify unstable modes and to study their interaction with the energetic ion population. Neutral particle analyzers are commonly adopted to determine the distribution function of fast ions. Mirnov coils displaced along the toroidal and poloidal direction allow to measure the mode frequencies and to identify the associated toroidal and poloidal mode numbers. Time traces from neutron counters are used to monitor drops in the neutron emission produced by energetic ion redistribution or losses. More recently, an application of charge exchange recombination spectroscopy based of the Balmer Dα emission, named FIDA, has allowed precise measurements of fast ion redistribution and comparison with simulations. Fast ion loss detectors with unprecedented time resolution have been used to characterize losses due to energetic ion driven instabilities. For the first time, the spatial structure of the eigenmodes has been measured through an imaging technique based on electron cyclotron emission and provided good agreement with the simulations.

As the energy of the fast ions is increased towards the MeV range, such as that expected in next step fusion devices, many of the mentioned techniques present limitations and nuclear physics based diagnostics must be employed. Interesting candidates are represented by neutron and gamma ray emission spectroscopy, as demonstrated in recent experiments at the Joint European Torus.

In this work the various techniques used to diagnose fast ions in today's magnetic fusion devices will be reviewed, with emphasis on the detection principles and on the plasma parameters which can be measured. The talk will also outline the challenges that must be faced to perform fast ion measurements on future burning plasma experiments such as ITER. Of special interest is the diagnose of the fusion alpha particle population of a DT fusion plasma (D +T -> n +α). The 3.5 MeV α particle population, by depositing its energy via slowing down in the bulk plasma, is the key actor to reach the goal of a self sustaining thermonuclear plasma. The techniques proposed for diagnosing the α particle population will be reviewed with the experimental results achieved.

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