Improved energy confinement in tokamaks

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Introduction

Energy confinement is a key issue in fusion research, since it describes how well the energy remains in the extremely high temperature plasmas that are required to reach fusion. The parameter used to characterise the confinement is the energy confinement time, defined as the ratio between the plasma energy and the heating power required to maintain it stationary. This parameter directly enters in the Lawson criteria, which tells to what extend the fusion reactor is profitable. Therefore, significant efforts have been devoted worldwide to understand the mechanisms that affect the confinement and to explore operational regimes with improved confinement.

Improved confinement regimes

Inter-machine analyses show that the energy confinement strongly increases with the plasma size and with the plasma current and to a less extent with the plasma density and the toroidal magnetic field. Conversely, it strongly decreases with the injected power.

Besides these variations, experiments performed in 1982 already, in ASDEX [1], showed that the plasma might, in some circumstances, undergo a rapid transition towards a regime with significantly improved confinement, which was named H-mode, for High confinement mode, in opposition to the normal mode, then called L-mode (L for low).

Although H-modes are obtained routinely in most tokamaks, the physics governing the L-mode to H-mode transition is not fully understood. Generally, L-H transitions are observed in diverted plasmas when the heating power exceeds a threshold that depends on plasma density, toroidal magnetic field and plasma size. These observations led to the characterisation of the access to the H-mode by power-law scalings [2]. However, a series of other parameters, such as the distance between the plasma and the vessel, are known to also play a role [3].

The signature of the L-H transition is a sudden decrease in the light emitted by the plasma (Dα line), followed by an increase of the plasma density, as shown in Figure 1. A transport barrier forms at the plasma edge, materialized by the build-up of a so-called edge pedestal in the plasma pressure. It then induces higher density and temperature profiles in the whole plasma and thereby increases the energy confinement.

In some cases, the transport barrier is so strong that the plasma density increases up to a limit at which the plasma disrupts.

Stationary H-modes are generally obtained when the transport barrier regularly releases a burst of particles called ELM for Edge Localised Mode.

The energy confinement, in these ELMy H-mode plasmas can exceed twice the L-mode values. The drawback of these ELMs lies in the detrimental effect their corresponding heat bursts have on the vessel walls. Different techniques have been developed to control their amplitude or even to get rid of them while keeping the tiny leakage necessary for maintaining the plasma in stationary conditions.

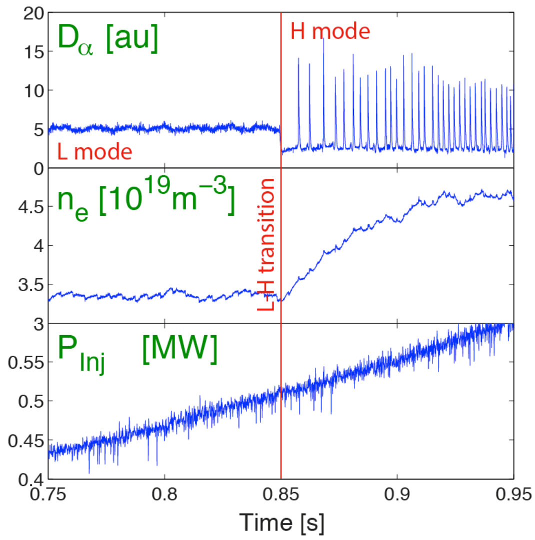

Figure 1: Evolution of a plasma discharge showing a L-mode to H-mode transition: Dα emission at the top, plasma density at the middle. It is induced by the injected power ramp, trace at the bottom.

Confinement regimes in future devices

ITER, the fusion reactor that should reach a power amplification of 10 (P_{fusion} / $P_{injected}$=10), is conceived for operation in the ELMy H-mode regime. ELM mitigation systems are currently being designed.

References:

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