Radially resolved bifurcation theory for the dynamics of L-H-mode transitions

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The H-mode in tokamaks arises when, for sufficient heating power, a transport barrier emerges near the last closed magnetic surface. This is a bifurcation, exhibiting hysteresis in the heat transport: The back-transition to the L-mode happens at a significantly lower heating power. The limited range of available quantitative experimental tests cannot fully discriminate between the many proposed models. Instead we use bifurcation theory to examine the transition characteristics of the L-H transition, such as hysteresis and dithering L-H transitions (oscillatory L-H transitions during a slow increase of heating power).

The L-H and H-L transitions are quite naturally characterized as (codimension-1) fold bifurcations, with heating power as control parameter. Including another parameter which controls the existence and magnitude of the hysteresis, one finds a (codimension-2) cusp bifurcation, where the two fold bifurcations meet.

In this paper we demonstrate that this bifurcation behaviour is sensitive to a third type of parameter, related to the relative importance of the density and temperature gradients in the evolution equation for the radial electric field. If temperature gradients dominate, L-H transitions show hysteresis, while if density gradients are more important, hysteresis is absent and stable limit cycle oscillations appear instead, giving rise to dithering L-H transitions.

Using transport equations for the density, temperature and radial electric field, see e.g. [1], but without actually solving this coupled system of PDE’s, we show that a codimension-3 bifurcation is the organizing point of such transition dynamics. The limit of negligible temperature gradient effects of this model indeed exhibits only dithering transitions, as found in [2]. Finally, the effects of interactions between turbulence level and zonal flows [3] will be discussed.

References

