Control of advanced scenarios for steady-state tokamak operation

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Improvement of the tokamak concept in terms of confinement and stability is a crucial challenge which could lead to operating the device in a continuous mode. The development of fully non-inductive operational regime with the potential of a simultaneous increase in the plasma confinement properties and plasma pressure to compensate for the plasma current reduction is known as 'advanced tokamak' research. Continuous operation by maintaining the plasma current indefinitely is made possible by a combination of a large amount of self-generated bootstrap current complemented with various mechanisms for non-inductive external current drive. Steady-state operation in ITER is foreseen to be with 100% non-inductive current drive at moderate plasma current (I_p~$9MA$) with Q_{DT}~5 for a burning time of 3000s.

Reliable steady-state operation will require a simultaneous control of the kinetic and magnetic energy (pressure and current density profiles) under the conditions of a highly autonomous state. This is a challenging task because of the strong non-linear coupling of the q-profile, thermal confinement, bootstrap current, fusion power and MHD stability. Various approaches to control the core confinement properties and reach MHD stable state will be presented. Recently, progress has been made to simultaneously control in real time the pressure and current density profiles. The ultimate challenge will be to develop (real time) control techniques in high bootstrap regimes but also in conditions where the alpha-particle heating source is dominant. Indeed, in future burning plasmas reactors the dominant heating source is the internal alpha-heating which strongly depends on the plasma parameters. This is an open field of research and further progress (experimental and modelling) is indeed required to design the most reactor relevant control techniques for burning plasmas conditions that minimise the requirements in term of external heating powers. Modelling of the control of a steady-state burning plasma where the alpha-heating is simulated using for instance on-axis electron heating will be discussed. Finally, effort has been progressively devoted to develop steady-state regimes with edge conditions compatible with good core confinement together with constrains imposed by the plasma wall interaction, i.e. power handling capabilities and plasma exhaust of the divertor in advanced regimes. Recent progress to control the core profiles while taking into account the limits imposed by the plasma wall interaction will be presented.