Physics of plasma control towards steady-state operation of ITER

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ITER is a fusion experimental reactor to show scientific and technological feasibility of fusion energy. It is designed to produce fusion power of 500MW for 300-500 seconds with fusion energy gain Q at least 10 ($Q \geq 10$) [1], [2]. ITER should show scientific and technological feasibility of fusion energy as one step to DEMO, which produces electricity by fusion energy. Although design of DEMO will depend on the outcome of ITER, steady-state tokamak reactor [3] utilizing the bootstrap current [4] is an attractive candidate of DEMO. ITER research has to be undertaken by considering the application to DEMO in mind. Plasma control in ITER is one of essential elements to fulfill ITER mission, which is the main theme of this 4th ITER summer school. In this introductory talk, I will introduce fundamentals of plasma control in tokamak and key physics to establish steady-state operation of ITER.

Plasma control in tokamak has been developed extensively in many tokamaks such as JT-60U, JET and DIII-D. Plasma control system consists of actuator and measurement. Plasma configuration control (horizontal and vertical position, elongation, triangularity, divertor strike points, etc.) is most fundamental using poloidal field coil system and magnetic measurement. Plasma density and fuel mix is controlled primary by (D&T) ice pellet injection. Plasma temperature is controlled by the auxiliary heating systems such as NBI, ECRF and ICRF. From the operational point of view, it is quite important to know operational space in key parameters since tokamak has certain operational boundaries above which plasma becomes unstable. Examples for global parameters are (l_i, κ) for vertical stability, (q_{95}, l_i) for disruption, (n/n_{GW}, HH_{y2}) for high-density operation, (β_t, $l_i I_p/aB_t$) for high beta operation. Operational regime is usually expanded as wall conditioning progressed and sophisticated profile controls are implemented.

There are some key plasma instabilities in tokamaks to limit plasma performance and divertor lifetime, sawtooth, classical and neoclassical tearing modes, double tearing modes, peeling/ballooning modes, resistive-wall modes and Alfven eigen modes. Profile control is key for is plasma control and requires knowledge's of plasma physics, especially on Magneto Hydro Dynamics (MHD). Examples of local parameters are (s,α), (J_{edge}, α) diagrams for ballooning and peeling modes.

After introduction of steady-state tokamak and ITER, lecture on physics of plasma control towards steady-state operation of ITER will be given including formulation of generalized Ohm's law (neoclassical electrical conductivity, bootstrap current, beam driven current etc.), high-bootstrap current operation scenario (weak shear regime, reversed shear regime, and current hole), associated specific instabilities such as infernal modes, NTM, DTM, RWM, RSAE with emphasis on physics aspect [5].

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