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Characteristic timescales in plasma control
制御に影響する特徴的時間

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In order to maintain steady operation with a constant fusion power in DEMO, it is necessary to identify not only the operation point but also the operation range surrounded by operation limit. The operation range should be determined by considering plasma characteristic timescales, delay times of diagnostics and response times of plasma to actuators. In this presentation, the characteristic plasma timescales in magnetic control, kinetic control and instability control are summarized together with objective of control, purpose, control variable and actuator.

1. Introduction

In order to maintain steady operation with a constant fusion power in DEMO, it is necessary to identify not only the operation point but also the operation range surrounded by operation limit. Since the burning plasma is controlled by actuators based on diagnostics signals, the operation range is determined by considering plasma characteristic timescales, delay times of diagnostics and response times of plasma to actuators. In this presentation, the characteristic timescales of both tokamak and helical plasmas are summarized.

2. Characteristic timescales in tokamak plasma control

The tokamak plasma control can be divided into three categories that are magnetic control, kinetic control and instability control. The role of magnetic control is to maintain the plasma position and shape in order to avoid contact between plasma and first wall. The role of kinetic control is to keep the plasma within the operation range, which consists of controls of pressure, current profiles and divertor detachment. The characteristic time scales in tokamak plasma control are summarized in Table I together with objective of control, purpose, control variable and actuator. Although magnetic measurements are required for magnetic control, magnetic sensors should be located behind the breeding blank due to severe radiation environment in DEMO. Therefore, magnetic sensors are surrounded by conductive structures and then affected by eddy currents, which leads to delayed response and degradation of accuracy. In the case of the delayed response close to or longer than the characteristic time scale of magnetic control, special countermeasures are required for magnetic control. Special consideration is also required for the short timescale of disruption

3. Characteristic timescales in helical plasma control

The characteristic timescales in helical plasma control are summarized in Table II. In the case of helical plasma, magnetic configuration is basically determined by helical coil system. Therefore, requirement of magnetic control is mitigated compared to tokamak. Controls of magnetic axis and correction of magnetic shear profile might be required in high beta operation regime, where characteristic timescale of ~1 sec is controllable. Since helical plasma can be operated by self-ignition condition, kinetic control is basically performed by pellet injection. Its characteristic timescale of energy confinement time level is controllable from the viewpoints of the delay times of diagnostics and response times of plasma to pellets.

References

[1] Program Committee of Technical Study on the Diagnostics for Control of the Fusion DEMO Reactors: NIFS-Memo-68 (2014).

Table I. Characteristic timescales in tokamak plasma control

Category	Object of control	Purpose	Characteristic time scale	Control variable	Actuator
Plasma position and shape control (magnetic control)	Clearance between plasma surface and first wall	To avoid contact between plasma and first wall	~ 0.1 sec	Magnetic field	PF coil currents
	Vertical position	To hold vertical position within control range	~ 0.1 sec	Magnetic field	PF coil currents
	Plasma current	To keep total plasma current constant	~ 100 sec	Magnetic flux	CS coil currents, NBCD, ECCD
Plasma pressure and burning control (kinetic control)	Fuel	To keep density below its limit (n_{GW}), To avoid NB shine through	A few 10 sec (τ_p level)	Density	Pellet, Gas puff
	Heating (pressure) profile	To keep fusion power constant	A few sec (τ_E level)	Neutron, density, temperature	NB, ECRF, ICRF
	Plasma current profile	To sustain high confinement and to ensure MHD stability	~ 100 sec (a few 10 sec in local)	Safety factor (magnetic pitch angle)	NBCD, ECCD
	Heat and particle fluxes	To maintain divertor detachment for protection of first wall and diverter target	A few sec (τ_E level)	Neutral pressure, Radiations	Gas puff
Instability control	NTM	To suppress NTM	~ 10 sec	Magnetic island	ECCD
	RWM	To suppress RWM	~ τ_W level	Rotation	NBI
	Disruption	To mitigate disruption	~ ms – 50ms		Massive gas inj.

Table II. Characteristic timescales in helical plasma control

Category	Object of control	Purpose	Characteristic time scale	Control variable	Actuator
Plasma position and shape control (magnetic control)	Magnetic axis	To avoid MHD instability, fast ion loss, increase in helical ripple	~ 1 sec	Magnetic field	PF coil currents
	Plasma current	To suppress degradation of magnetic shear near edge region due to toroidal current	~ 1 sec	Magnetic flux	PF coil currents
Plasma pressure and burning control (kinetic control)	Fuel	To keep fusion power constant	~ 0.1 sec (pellet interval)	Density	Pellet
	Heat and particle fluxes	To maintain divertor detachment for protection of first wall and diverter target	~ τ_E level	Neutral pressure, Radiations	Gas puff
Instability control	Ideal mode	To avoid confinement degradation by core MHD activity	~ 1 sec	Magnetic field	PF coil currents
	Resistive mode	To avoid confinement degradation by edge MHD activity			
	Radiation collapse	To avoid plasma disappearance	~ 0.1 sec	Density, Radiations	Pellet