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Development of Divertor Configuration Control in QUEST with Experiments and AI-Based Identification

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In the Advanced Fusion Research Center at Kyushu University, a comprehensive program of experimental research and technological development is being conducted using QUEST (Q-shu University Experiment with Steady-State Spherical Tokamak), a unique spherical tokamak facility dedicated to exploring key challenges in steady-state plasma operation. One of the objectives in QUEST is to realize long-duration plasma discharges by implementing plasma-facing components that are actively temperature controlled, which enable precise management of particle recycling processes critical for stable plasma sustainment [1]. Alongside this, the development of techniques for non-inductive plasma current ramp-up without relying on a central solenoid coil is progressing [2], paving the way for advanced current drive scenarios applicable to future fusion reactors.

To advance the understanding of fundamental plasma confinement physics in spherical tokamak configurations, the deployment of diagnostics capable of measuring plasma fluctuations and transport phenomena is underway [3]. Notably, it has been indicated by scaling studies, such as those derived from Globus experiments, that the parameter dependencies of the energy confinement time in spherical tokamaks differ substantially from those observed in conventional tokamaks [4]. This discrepancy highlights the importance of investigating the aspect ratio dependence of energy confinement to identify the underlying mechanisms contributing to improved performance.

Due to the relatively large vacuum vessel volume compared to the plasma volume in QUEST, equilibrium calculations suggest that a broad variety of plasma shapes and configurations can be achieved with considerable flexibility (Fig. 1). This presentation will discuss detailed evaluations of the feasibility of generating plasma equilibria with varying aspect ratios and elongations, including analyses of their vertical position stability under experimental constraints. According to empirical scaling trends, the energy confinement time is predicted to increase as plasma elongation is raised. Therefore, we will also address the implications for vertical position control and examine whether the capabilities of existing vertical control power supplies are sufficient to maintain stable operation as elongation increases.

Furthermore, accurate, high-speed identification of plasma position and shape is indispensable for enabling robust real-time control of advanced configurations. As part of these efforts, we have applied deep neural network-based machine learning methods to achieve fast and precise equilibrium reconstruction. In this talk, we will present the development, implementation, and initial experimental validation of these AI-driven identification techniques and discuss their potential impact on the future of plasma control in spherical tokamak devices.

References

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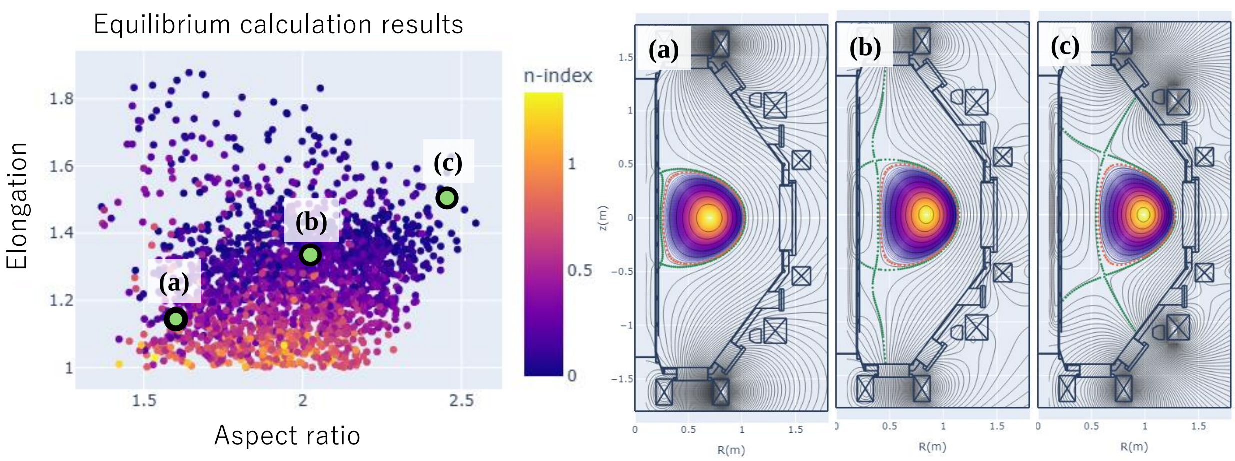

Figure 1 The range of aspect ratios and elongation expected to be achievable from equilibrium calculations (left) and some specific equilibrium configurations within that range (right).