§63. Real-Time Equilibrium Calculation and Control on QUEST

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In the spherical tokamak QUEST (Bt=0.25T, R=0.68m, a=0.40m), the achievement of steady state operation is one of important objectives. For this, the real-time identifications of plasma position and shapes including its controls are required. Here, we intend to develop the real-time equilibrium calculation and embed the control loop into the control system of QUEST.

In the control system of QUEST, the PXI systems based on National Instrument Corp. are adopted, and the Core 2 Quad 2.2GHz controller is used for the main control loop which acquire fundamental data such as coil and plasma currents and magnetic signals and send control signals to power supplies, RF systems, and gas puff systems with 4kHz frequency. In the other hand, the calculation of identification of plasma position and shape cannot be always done within 4 kHz frequency. Thus, the identification parts called sub calculation loop are separated from the main control loop and are calculated in parallel with freely settable frequency using the advantage of Core 2 Quad multi core technology. These two loops communicate each other with referring a common information file.

In order to calculate equilibrium, there are three procedures. In the first procedure, magnetic flux profile is calculated from the coil currents and plasma current. In the second, the last closed flux surface (LCFS) is searched with this flux profile. In the last, the Grad-Shafranov equation is solved on inside of LCFS. Here, we installed the first and second procedures into the sub calculation loop of the plasma control system, and evaluated execution speed.

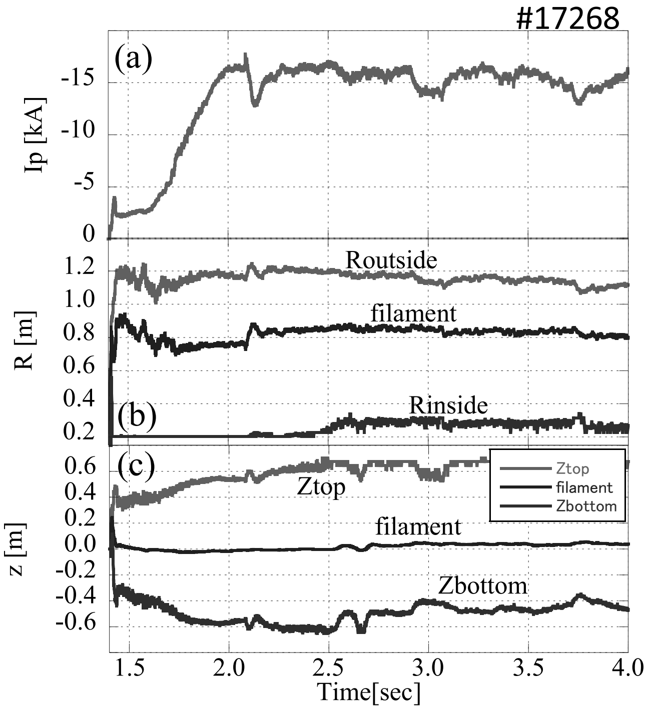

Fig 1. The waveforms of (a) plasma current, (b) and (c) filament position and plasma edges in R and z direction, respectively.

In particular, the acquired data of the coil currents and plasma current, and the calculated data of plasma position are transferred to the sub calculation loop, and the sub calculation loop calculates the magnetic flux profile and searches the LCFS. Here, the flux values induced by plasma are evaluated as one filament current located on the calculated plasma position for simplicity. In order to calculate magnetic flux profile in a short time, the mesh data are calculated on ahead for each coil and plasma current. The mesh area is set to $0.0 < R$ (m) <1.5 and $-1.2 < z$ (m) < 1.2, and the mesh sizes of both sides are 30mm. Thus, the mesh grids sizes of horizontal and vertical direction are 50 and 80, respectively. Whereas the mesh data is discrete, the plasma position calculated in the main control loop is continuous. Thus, the magnetic flux induced by plasma is calculated from the three nearest mesh points to the calculated plasma position with considering its weights. After this, LCFS is searched. The local minimum or the local maximum mesh point of the magnetic flux profile almost corresponds to the calculated plasma position. The LCFS is searched by widening the closed flux surface area centering around this local minimum point gradually. This resembles dropping water into the hollow area gradually. When the water touches vacuum vessel, it means the limiter configuration, and the LCFS is the shape of water. When the water spills out from a saddle point of the hollow area without touching vacuum vessel, it means divertor configuration, and the saddle point is a null point. Whereas this manner might take much time to search a LCFS if the mesh grids size was large, this contributes the source code simplification because that a unified approach can be used without considering its magnetic configuration. The plasma edge positions are calculated from the flux value of LCFS using linear interpolation without defining directly from mesh points in order not to be discrete.

This simple method to identify plasma shape assuming plasma as one filament has been installed into the control system, and this calculation can be done within 0.5msec. In Fig. 1, the waveforms of plasma edges calculated by this method in real-time are shown. In this discharge, the combination of coil currents was changed from limiter configuration to divertor configuration between 2.0sec and 2.5sec. During this period, the inside edge is calculated in such a way as to move outward and be detached from center stack R=200mm. This indicates that the plasma configuration is changed to a divertor configuration.

In the future, the magnetic flux profile is calculated treating plasma as not one filament but a distributed one, and the Grad-Shafranov equation is solved in order to identify the plasma shape with high accuracy.