§72. Development of High Speed Equilibrium Calculation Code with the Assistance of FPGA

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The identification and its control of plasma current and position are crucial issues for the steady-state operation of tokamak plasmas. For the identification of plasma current and its position and shape in real time, the real-time equilibrium calculation code is under development on QUEST. In this calculation code, the grid resolution is 30 and 40 in radial and vertical direction, respectively, and the grid pitch is 50mm in both directions. This resolution is not so fine and makes calculation results coarse. And, with this resolution, it takes 2ms in one calculation loop which is executed continuously for the convergence of calculation. This order is comparable to the time constant of vacuum vessel's eddy current effects, and may be not fast for the real-time equilibrium calculation. This calculation code is described with C language, and is called as a dynamic link library (DLL) function from LabVIEW language of National Instruments Corp. This calculation is executed on 1.73 GHz Intel Core i7-820 quad core CPU on PXI system, and the faster calculation time cannot be expected on this system because the CPU utilization is almost 100 % already. On the other hand, the PXI system can implement the Field-Programmable Gate Array (FPGA) module. The FPGA can be configured on its function by a user, and its processing speed is sufficient high though the variable types are limited such as fixed-point number. The purpose of this research is to achieve the identification and its control of plasma current and position for the steady-state operation. Thus, the development of the real-time equilibrium calculation code executed on FPGA and the development of magnetic sensors which can be used for the long-pulse discharge are important. The usual magnetic sensors such as rogowski coil, flux loop, and pick-up coils are not suitable for the long-pulse operation due to the drift errors induced by long time integration. Here, we try to install the hall sensors.

Installed hall sensors on QUEST are linear position sensor ICs of A1389 and A1302 made by Allegro Micro Systems. Its sensitivities are ±220 Gauss and ±1600 Gauss, respectively. Figure 1 shows the installed position. These sensors output quiescent voltage of about 2.5V with no magnetic fields and the power supply of 5V. And, the signals change lineally according to the positive and negative magnetic fields. The plasma current and its position are identified with 10 hall sensors which measure poloidal magnetic fields. In this calculation, the plasma is treated as a filament current positioned in the vacuum vessel. Its filament position is evaluated by the each ratio of 10 signal intensities, and the filament current is evaluated by the absolute intensities itself. Figure 2 shows this calculation results. The plasma current and its position can be well-defined without any drift errors.

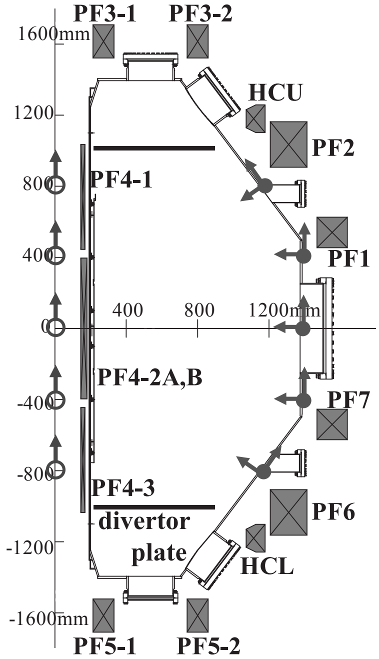

Fig. 1 Installed positions of hall sensors with the measuring direction of magnetic fields. Z-axis sensors with ±1600 G (open circle) and triaxial sensors with ±220 G and ±1600 G in TF direction (closed circle).

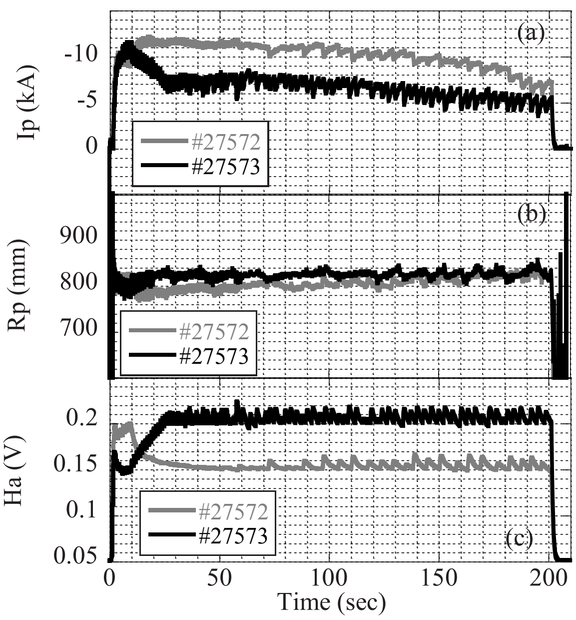

Fig. 2 (a) plasma current and (b) plasma radial position calculated with hall sensor signals, and (c) Ha signal.