§81. Development of Plasma Density Control System for the Steady-state Operation

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The achievement of a steady-state operation on tokamak plasma is an important issue for the future fusion power plants. On QUEST, the feed-back control of the fueling is currently done with referring to Hα signal for the sustainment of plasma. Namely, when the actual Hα signal is below the target Hα signal, the fueling is done, and the fueling is stopped in the contrary case. However, since the Hα signal does not correspond to the plasma density directly, this feed-back control cannot be used for the plasma density control. On QUEST, the plasma density is measured by an interferometer with over 10 kHz sampling frequency, and is calculated not in real-time but after the plasma discharge because of the lack of the calculation capability when the CPU-based system is used. In the other hand, the Field-programmable gate array (FPGA) which can be configured by a customer after manufacturing is recently developing by the minute. Thus, the purpose of this assignment is to develop the method to calculate the plasma density in real-time with FPGA for the feed-back control of the plasma density.

The plasma control system (PCS) on QUEST is based on the PXI system of National Instruments Corporation. In this system, the FPGA board of PXI-7842R is newly installed. This board has 8 analog input channels with 200 kHz sampling frequency and Virtex-5 LX 50 as a FPGA function. This FPGA is developed with the programing language of the LabVIEW, and cannot basically treat floating-point variables but fixed-point variables. Thus, when a variable of decimal fraction is used, the appropriate widths in bits have to be applied to the integer part and the decimal part respectively for the representation of its value.

For the calculation of plasma density from cosine and sine signals, an arctangent function is required for its phase. This function is developed with LabVIEW on FPGA. In this function, the cosine and sine signals are given by the 16 bit signed integer, and are normalized in order for the length from the origin to become unity at first. Then, the arctangent is defined with referring to the look-up table which has the number of 1025 data points. This procedure is shown in Fig. 1. The origin of a phase plane moves slightly from hour to hour because of the offset of isolation amplifier, the change of environmental temperature, and so on. The phase cannot be defined correctly without the recognition of this movement, and the density cannot be also calculated correctly. For the recognition of this movement for the origin, the maximum and minimum values of the cosine and sine signals are monitored during plasma discharge, and the average of them are defined as the origin of the next plasma discharge. With this method, the origin of phase plane is automatically regulated.

Since the maximum operating frequency is measured as 76 kHz, its frequency is set to 50 kHz in the actual installation to the PCS. This new function samples the cosine and sine signals and calculates the plasma density with 50 kHz, and transfers it to main control loop of which the operating frequency is 4 kHz. Figure 2 shows the wave of (a) plasma density calculated in real-time and (b) Hα signal for the comparison. The plasma density in real-time has been confirmed to be same to the plasma density calculated by post-processing. In future, the feed-back control of the fueling with referring to the plasma density will be implemented on the PCS of QUEST

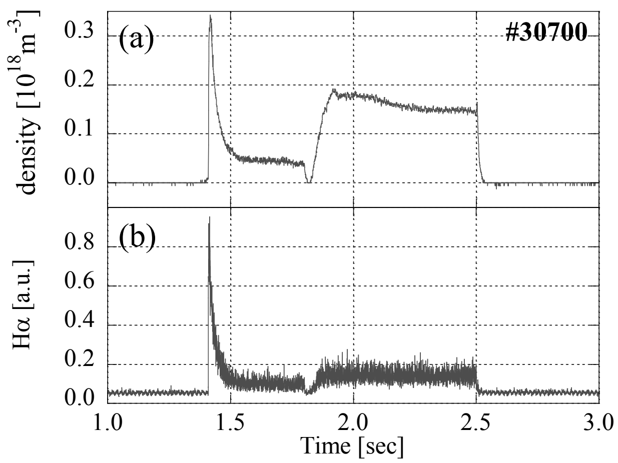

Fig. 2 (a) plasma density calculated in real-time (b) Hα

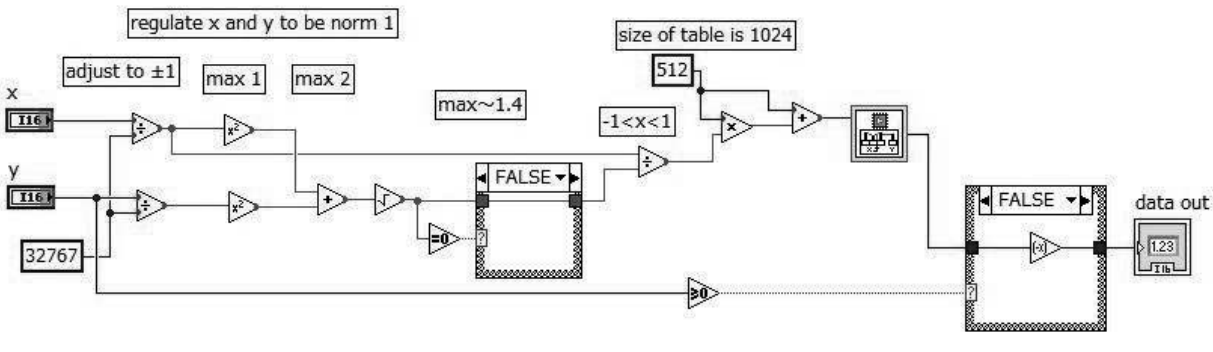

Fig. 1 Developed arctangent function by LabVIEW on FPGA