External resonance magnetic field control system based on the Siemens S7-400 controllers at the T-10 tokamak

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Abstract. A multilevel control system of a tokamak-reactor should provide measurements of the physical and technological plasma parameters in real time under conditions of high radiation fluxs. For the control systems of the ITER tokamak-reactor, it is planned to use automatic control systems based on the Siemens S7 programmable logic controllers (PLCs) which can operate under these conditions. Along with the possibility of multilevel remote control of the equipment, the PLC provides timely responses in emergency situations without human involvement and adaptive control in real time. This article presents results of using the Siemens S7 417-4 controllers for external resonant magnetic field control in the T-10 tokamak in the regimes with increased electromagnetic fields and radiation fluxs in shots with ohmic and additional microwave plasma heating.

1. Introduction

Automatic control systems based on programmable logic controllers (PLCs) are used to measure the physical plasma parameters and control the tokamak-reactor technological systems in real time under conditions of high radiation fluxes. Among plenty industrial control system, the Siemens S7 PLCs controllers were chosen. These PLCs are widely used at different devices under adverse environmental conditions. Tokamaks are high-power sources of neutron fluxes and electromagnetic radiation emitted in a wide spectral range (from radio waves to gamma photons), so the additional experimental data on the reliability of the tokamak control systems based on PLCs of this type is needed.

To test the algorithms for tokamak diagnostic systems control, elements of the multilevel control system based on the SIMATIC S7 CPU-417-4 PLC were tested at the T-10 tokamak. Generally, the neutron yield in the shots was approximately $(1-8) \times 10^9$, and sometimes it amounted to $10 \times 10^{12}$ [1]. The generation of external magnetic fields in the T-10 tokamak is provided by VDU-1250 thyristor converters with an automatic control system based on the S7 controllers, which consist of PLCs, galvanic insulator units and sensors that measure power supply system parameters. The general arrangement of the power supply and control systems is shown in Figure 1.

2. System of external resonance magnetic fields generation in the T-10 tokamak

The system of external magnetic fields generation consists of eight saddle-shaped windings installed symmetrically relative to the torus equatorial plane on the outer side of the vacuum vessel (Figure 2). The winding looks like a rectangle with a length of 2 m and a height of 1.5 m. Each winding has eleven turns made from a PV-3 cable that has single copper core with a cross-sectional area of 120 mm² and PVC electrical insulation. The calculated inductance and ohmic resistance of each winding were $R_{SC} = 11 \, \text{m} \Omega$ and $L_{SC} = 490 \, \text{mH}$, respectively.
The power supply system of the saddle-shaped windings is based on four controlled thyristor VDU-1250 converters with a total power of 300 kW. The power supply provides a nominal output current of 1250 A which can be increased for a limited time up to 1900 A. The maximum output voltage of the loaded supply system is 45 V. The power supply can be remotely controlled, which makes it possible to turn the power supply on and off at specified times, adjust the output voltage in the range of 24 to 45 V and perform measurements of the main circuit parameters (output voltage, current, and logic current sensor). The delay time of the thyristor converter switching on is determined by the turn-on time of the control relays and it is less than 5 ms.

3. External resonance magnetic fields control
The control system includes a processor module, a power module, and analog and digital input-output modules. The interface modules with optocoupler protection and relay modules were designed to match the controller to the power supplies. They are installed near the power supplies (Figure 3).

The PLCs are remotely controlled from the MP 370 operator panel in the T-10 control room using the PROFINET communication protocol. Start of the controller operating programs, data acquisition and storage are performed using the computer and then transmitted through the Ethernet network. Each of four power supplies is independently controlled by the designed controller and their joint operation can be organized according to the algorithm set by the operator. The control system based on the S7 417-4 controllers provides creation of the pulsating external resonant magnetic fields with a frequency of up to 10 Hz.
Figure 2. Wiring scheme of the T-10 tokamak saddle windings.

Figure 3. Block diagram of the power supply control system for the T-10 tokamak resonant windings.
Figure 4. (a) View of calibrated winding on the tokamak, b) calibration curves for the resonant magnetic field windings and (c) their effect on the plasma.

4. Calibration and experimental results
Calibration of the magnetic fields generated by the windings was performed using a Hall sensor installed on a tie stick. The tie stick with the sensor was inserted into the tokamak vacuum vessel through an open horizontal branch pipe. The measured magnetic field as a function of the distance to the end of the branch pipe is shown in Figures 4a and 4b.

The effect of the external resonant magnetic coils is shown in Figure 4c. When the current is applied to the external windings, the rotation frequency of the mode (m = 2, n = 1) decreases (750–900 ms), and then becomes zero. As a result of the mode (m = 2, n = 1) locking, its amplitude begins to nonlinearly grow in the external magnetic fields, which results in the current disruption (910 ms). Preliminary experiments have demonstrated that the threshold of MHD perturbations development in plasma depends on the conditions of plasma discharge [2]

5. Conclusions
The T-10 tokamak is equipped with a control system based on S7 417-4 controllers, in which all control system nodes are mounted: the power supply unit, programmable logic controllers, galvanic isolator units and diagnostic sensors. Experiments have been conducted to study the plasma stability under the influence of external magnetic fields generated by a system of four pairs of saddle-shaped windings based on thyristor converters in the quasistationary (up to 2 s) and pulsed (up to 10 Hz) operation modes. A software package has been created that provides multi-level equipment management in real time. Designed, manufactured and tested samples of the system components and special equipment can be used to create the technological systems of the fusion devices – the T-15 and ITER tokamaks.

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