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Design and development of a synchronized operation control system for Thomson scattering diagnostic on J-TEXT

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Abstract

A Thomson scattering diagnostic system is under construction at the Joint Texas Experimental Tokamak (J-TEXT). A 1064 nm Nd:YAG laser with 50 Hz repetition rate is used as the laser source. We have used a software for careful and precise control of the laser through serial communication. A time sequence operating system has been developed to synchronize the laser control and data acquisition system with the central control system (CSS). The system operates commands from the CSS of J-TEXT and generates triggers for the laser and data acquisition system in the proper sequence. It also measures an asynchronous time value that is needed for accurate time stamping. All functions are served by a field-programmable gate array development platform that is suitable for high-speed data and signal processing applications. Several embedded peripherals, including Ethernet and USB 2.0, provide communication with the CSS and the server.

Keywords: Thomson scattering diagnostic, laser control, synchronized operation

(Some figures may appear in colour only in the online journal)

1. Introduction

Thomson scattering (TS) is a widely used diagnostic system to measure the electron temperature \( T_e \) and electron density \( n_e \) and to obtain their profiles \([1, 2]\). A laser TS system has been designed or constructed for many tokamaks such as DIII-D, JT60-U, KSTAR, EAST, HL-2A, and ITER, of which the last one is considered the largest tokamak in the world \([3–8]\).

Currently, at Joint Texas Experimental Tokamak (J-TEXT), \( T_e \) and \( n_e \) are obtained using an electron cyclotron emission (ECE) diagnostic and polarimeter–interferometer diagnostic, respectively \([9, 10]\). However, ECE can be used to measure electron temperature over a small range of plasma parameters \([11]\). Therefore, it is important to develop a TS system that can be used to measure electron temperature accurately.

When a laser is injected into a plasma, it is scattered under the action of electrons. The frequency shift of the scattered light is related to the electron temperature, and the total energy of the scattered light is proportional to the plasma density. The J-TEXT TS system has been designed to measure \( T_e \) in a temperature range from 200 eV to 2 keV \([12]\). It comprises a laser source, collection optics, polychromators, data acquisition system, and a synchronized operation control system (SOC). A commercial Nd:YAG laser provides 3 J/pulse 1064 nm laser beams with 50 Hz repetition frequency. The collection optics is used for collecting scattered light at 14 points from the plasma center to the edge. The scattered light is transformed into electrical signals and amplified by the polychromators. The electrical signal is integrated and digitized using a data acquisition system to calculate the total
energy of the scattered light when a gate trigger signal is active.

A SOCS is essential for a TS system whose data acquisition is based on a VME bus. The laser beams are so intense that the laser should be set up and controlled safely by software. A SOCS is also designed to generate the time sequence of all subsystems. Different laser systems have different SOCSs. The higher the repetition frequency of the laser system, the more complex is the SOCS. For example, KSTAR has laser repetition rate of 10 Hz, and therefore, its TS signal controller is relatively simple [13]. By contrast, EAST has a multilaser TS system [14], and therefore, its laser control system is more complicated. The J-TEXT TS system has repetition frequency of 50 Hz, and therefore, the SOCS is challenging to realize.

This article describes the laser control software and field-programmable gate array (FPGA)-based time sequence operation system (TSOS) of the SOCS in detail. The TSOS is used to generate and synchronize laser control signals and gate triggers. The duration of integration is determined by the gate trigger width. This width should be large enough to integrate the signal completely. However, a long gate duration leads to large plasma background noise. We use a gate width of 120 ns and signal width of 40 ns with the objective of generating the gate trigger at an appropriate time during an operating period of 20 ms.

2. SOCS

2.1. Laser control software

The laser startup process is as follows. After the power supply is turned on, operating parameters such as the working frequency are set up to complete the configuration of the internal subsystems of the laser. Next, a trigger signal called CLK_IN is sent to the laser to warm up the flash lamps. After warming for 60 s, Q_switch is opened, and laser beams are output when another trigger signal called Q_IN is received.

The trigger pulses CLK_IN and Q_IN are designed to have variable pulse width, and the time delay between these two pulses determines the output energy of a laser beam. We obtained maximum energy of 2.93 J for pulse width of 50 μs and time delay between CLK_IN and Q_IN of 330 μs. Figure 1 shows the desired trigger signal and the actual signal. Optically coupled isolation amplifiers are used to transform the voltage levels and to suppress interference signals. Figure 1(b) shows that the optoisolator causes a large delay at the falling edge of the pulse. However, the laser is triggered by the rising edge, and therefore, this delay at the falling edge does not reduce the control precision.

A laser with an RS485 interface can be controlled over long distances. We have developed a C# based graphical user interface to interact with the laser remotely. Figure 2 shows the flowchart of the laser control software. This software uses two types of commands. The first type sets parameters, including the discharge voltage, adjustments to output energy, and operating frequency. The second type sets the state of the mechanical switches.

2.2. TSOS

Figure 3 shows the layout of the J-TEXT TS system. The TS server is used to control the laser and data processing. It sends an instruction to the TSOS to indicate that the laser is ready for operation. Then, the central control system (CSS) sends an operation sequence command called START. The TSOS receives commands over Ethernet. After the START command, the TSOS can output logics with the FPGA modules.

Figure 3 shows the operation sequence of the control system. When it receives the START command, the TSOS generates two transistor–transistor logic pulses whose repetition rate is also 50 Hz. The command CLK_IN is delivered to the laser 65 s before the plasma discharges and the flash lamps warm up. The TSOS does not send the Q_IN signal until it has received the SHUTTER command from the CSS. The laser needs to warm up for ~60 s, so the SHUTTER command is only available 5 s before the plasma shot, which is marked as 0 s. Laser beams are output when the Q_IN signal is received by the laser. After passing through the optical system, the laser beams are injected into the plasma.

The scattered light is detected by avalanche photo diode (APD)-based polychromators that convert the scattered light to a negative electrical signal of ~40 ns width. The signal
Figure 2. Flowchart of laser control software.

Figure 3. Operation sequence of control system.
is sent to a charge-to-digital convertor module (V792N, CAEN) that houses 16 input channels. When the GATE input of V792N is active, the integrated current is converted to a voltage level by the charge-to-amplitude conversion (QAC) section. Then, the voltage levels are multiplexed and subsequently converted by two fast 12 bit ADCs and stored in a 32-event buffer memory. The data is transferred to the server for processing. Figure 4 shows a sequence diagram of the TSOS.

To eliminate the influence of stray light, both the TS light and the background scattered light are acquired for data processing. Figure 5 shows the signal conversion timing of the QAC section. To acquire complete data, the gate trigger is designed to be 120 ns, which is wider than the APD output on both sides. In addition, there is a time delay between the SHUTTER command and the gate trigger. The SHUTTER command is preset at −5 s and is emitted randomly between two trigger pulses. We need to measure the exact time delay so that we can record when we start the acquisition and calibrate the time axis of the data. A 32 bit register in the FPGA chip can satisfy the timing needs. The module sends the value to the server via Ethernet after the discharge. Then, the data acquisition system provides accurate timing using this value.

2.3. Application

Control software has been developed to control and monitor the laser. Figures 6(a) and (b) show the running interface of the power supply and the laser control software. The state of the button indicates whether the operation has been successful. If the system sends an instruction but does not receive the correct reply, it indicates that the operation has failed. In addition, we monitor the laser based on conditions such as the water flow, water temperature, and internal safety interlock. If an error such as excess temperature or cooling system malfunction occurs, the laser is powered off.

Because the TS system is still under construction, we can only test the operation sequence control system in the laboratory. We use an oscilloscope to provide two pulse signals that represent CSS commands. When the laser is ready, a START signal is sent from the oscilloscope to the system, and the SOCS sends a trigger signal to fire the flash lamps. After ~60 s, when the SHUTTER command is received from the oscilloscope, another trigger is delivered to output the laser beams. The SOCS begins timing as soon as the laser beams have been output and generates the gate trigger for the acquisition system according to the preset delay. The delay value is transmitted to the PC via Ethernet.

3. Summary

We have developed software to control a TS laser remotely. We used a SOCS to synchronize operations between the laser control and the data acquisition systems with the CSS. A signal test was performed using this system. After the TS system of J-TEXT is completed, the time delay value, which is crucial to completing the acquisition, needs to be adjusted according to the actual experimental conditions. Then, the operation sequence control system is completed by joint
testing with other systems. The TS system of J-TEXT will provide reliable $T_e$ and $n_e$ profiles.

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