Data Acquisition and Automation for Plasma Rotation Diagnostic in the TCABR Tokamak

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Abstract. In this work we describe the implementation of a full modular system of data acquisition and processing for the plasma rotation diagnostic in the TCABR tokamak. The experimental setup uses a single monochromator and six photomultipliers (PMT), in which pair of PMTs measures the light at slightly different wavelengths. Thus, it can measure the time evolution of the Doppler shift of the impurities emission lines coming from three spatial positions (one for toroidal rotation and two for poloidal rotation). The data acquisition and pre-analysis program were written with LabVIEW software and is capable of controlling the spectrometer wavelength, PMTs power supplies, data acquisition, and storage. All data are recorded in MDSplus trees that easily allow data visualization and post-processing analysis (both locally and remotely) via MATLAB, Python, Java and others programming languages. This system can run independently from other diagnostics and machine systems and can be integrated with the main tokamak control system by means of TCP/IP messages.

1. Introduction
It is well known that the plasma rotation in magnetic confinement experiments allow to stabilize large-scale MHD instabilities and to improve confinement reducing turbulent transport of particles and energy [1, 2, 3]. Due to its large size and to high density, effective momentum deposition by external neutral particles injection will be difficult to achieve in ITER. Therefore, if the spontaneous (intrinsic) rotation could be made large enough, it may play an important role in plasma stabilization. Furthermore, the role of plasma rotation in disruptions or in an H-mode transition, for instance, is not completely understood.

Thus we build a non-invasive diagnostic for measuring the time evolution of the intrinsic rotation in the TCABR tokamak ($R = 0.615$ m, $a = 0.18$ m, $I_p \leq 90$ kA, $B_t = 1.07$ T, $n_0 \leq 4 \times 10^{19}$ m$^{-3}$). The system employs a single monochromator with a beam splitter and two sets of PMTs for each radial position to record the light signal at slightly different wavelengths in order to estimate the Doppler shift due to the plasma velocity.

2. Plasma rotation diagnostic setup
The former experimental setup [2] could resolve temporarily the plasma rotation in just one optical port (toroidal or poloidal), the data acquisition was made using a Tektronix oscilloscope, and all high voltage power supplies for the photomultipliers (PMT) were manually adjusted, taking a lot of effort to proper store and record all relevant data for each tokamak discharge.

The upgraded system shown in the figures 1 and 2 is able to measure time-resolved and simultaneously two poloidal chords and one toroidal chord using the same technique. Currently the
data acquisition is controlled by a LabVIEW program, and the data acquired are stored in MDSplus trees, as detailed in next sections.

**Figure 1.** Experimental setup: the light from poloidal chords (A) and toroidal chord (D) arrive in the entrance slit (B) of the monochromator, and each signal is measured in the PMT at the axial and lateral output slit (C).

**Figure 2.** The light at the lateral and axial slits of the monochromator have slightly different wavelengths. So, from the ratio of the PMTs signals is possible to estimate the Doppler shift.

2.1. Doppler shift Calibration

The calibration is made with the optical ports looking at the central chord of the plasma poloidal cross section, where one expects to have no rotation along this line of sight (so, no effective Doppler shift). Then, the ratio of the signals of axial and lateral output slits are recorded from different wavelengths near the impurity emission, using tokamak discharges. The calibration is made separately for the Carbon III (464.7 nm) and Carbon VI (529.05 nm) lines because the Doppler broadening affects significantly the ratio of the outputs signals, as show in the figures 3 and 4. The optical chords are labelled as “central”, “poloidal” and “toroidal” since the first one usually is keep looking the central chord of the plasma.

**Figure 3.** Calibration curve for C III.

**Figure 4.** Calibration curve for C VI.
For the sake of simplicity we define zero “shift” in the calibration curves where the central chord ratio is 1. So, the velocity of rotation of the plasma can be estimated, taking as reference the ratio where there is no Doppler shift:

\[ v = \frac{c \Delta \lambda_{\text{Doppler}}}{\lambda_0} \]  

\[ \Delta \lambda_{\text{Doppler}} = \text{shift}_{i}(R_i) - \text{shift}_{i}(R_{\text{reference}}) \]

where \( v \) is the plasma velocity measured in the \( i \)-th chord, \( c \) is the speed of light, \( \Delta \lambda_{\text{Doppler}} \) is the Doppler shift of the impurity emission line of wavelength \( \lambda_0 \), which is the difference of wavelength associated with the signal ratio of axial and lateral PMTs (\( \text{shift}_{i}(R_i) \)) and wavelength associated signal ratio with no Doppler shift (\( \text{shift}_{i}(R_{\text{reference}}) \)) for that optical chord.

3. Experimental automation

During the experiments, it is necessary to control, monitor, and record the parameters of several instruments, like spectrometer position, PMT voltage, ADC gain, etc. The use of text-oriented programming language makes it hard the maintenance, and modifications would demand long time, specially if it uses any graphical user interface. Therefore we chose the LabVIEW graphical programming which has been used for wide applications in a multitude of instruments field like optics [4] and plasma physics [5] as well. The advantage of the LabVIEW platform over textual programming remains in its fast programming, readable source code, and instrumentation oriented interface due to its focus on instrument control.

The LabVIEW program controls the spectrometer wavelength by serial communication (RS-232), and the power supply for the PMTs by USBs ports. The data acquisition is made by NI PXI 5105 digitizers from National instrument, up to 60 MSamples/s and 12 bits resolution. The digitizers is connected to a PXI bus to the main controller, a NI PXIe-8108 with a Dual-Core processor running Windows 7.

The program running in the main controller takes also as input the radial position of the optical ports. The user interface of the program, for local setting, is shown in the figure 5 and 6.

Figure 5. LabVIEW interface for instrumentation setup for local control.
3.1. MDSplus

The MDSplus [6] is a set of programs and tools for experimental data acquisition, storage and control developed for managing the complicated environment of research as in plasma physics and nuclear fusion. Its focus in pulsed mode experiments (or intermittent events) makes it propitious for our experimental conditions. Besides, it is widely used in nuclear fusion experiments around the world [7]. Another important point is that the MDSplus provides application programming interfaces among different types of language (JAVA, Fortran, C, C++, Python) and programs such as MATLAB, IDL, OCTAVE [8].

Although MDSplus can also control the experimental setup and acquisition; in our case it acts just as a centralized data server in which the stored data is arranged hierarchically. After each plasma discharge, the LabVIEW Object Oriented programming interface (VLOOP) creates a new pulse file (an MDSplus Tree) and populates its nodes with all signals and parameters of the experiment. After this all data is already available for remote access. The full flowchart of the signals is shown in the figure 7.

**Figure 6.** LabVIEW interface for post-analysis.

**Figure 7.** Flowchart of signals and parameters for the rotation diagnostic.
The LabVIEW virtual instrumentation, with the MDSplus, was programmed in a modular way, so the experiment diagnostic can run standalone of the main tokamak control system [9] (unless for the start trigger signal), and integrated by means of TCP/IP messages to control the acquisition. Furthermore, the data can easily merge with the main tokamak signals, since it can be set as a branch (i.e., an MDSplus subtree) of the main system, preserving its hierarchy.

4. Results for the TCABR

As an example, in the figures 8 and 9 we present the average toroidal and poloidal plasma rotation profile in the TCABR tokamak. The data was taken for several discharges and post-processed, with the calibration data, in the software MATLAB environment.

A characteristic feature of the plasma rotation in the TCABR tokamak is the change of direction of the toroidal velocity close to the edge. Besides, it, the measured plasma rotation (except close to the edge) seems to agree with the neoclassical predictions in the collisional regime where the poloidal velocity is expected to be proportional to the gradient of the ion temperature [10, 11] as previously reported [2].

![Figure 8. Radial profile for toroidal plasma rotation; positive means in the toroidal field direction.](image)

![Figure 9. Radial profile for poloidal plasma rotation; positive means in the electron diamagnetic drift direction.](image)

5. Conclusion

The plasma rotation diagnostic system was developed and tested using a single spectrometer and several optical chords to measure it at different positions along the plasma discharge. The automated system allows easy control of the instrumental setup as well as to record all relevant data parameters and instrumentation settings. All this process can be controlled locally or remotely by mean of the TCP/IP protocol.

Furthermore, the MDSplus server data allows remote access for data post-analysis, and makes it easier to retrieve specific information of any plasma tokamak discharge. Moreover, this time-resolved diagnostic allows both reconstruct the profile of plasma rotation and its temporal evolution as well.

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