Automatic scanning system to detect plasma radiation

M V Lukashevsky1,2, S D Fedorovich1 and I V Lanie1

1 National Research University "MPEI", Moscow, Russia
2 E-mail: lukashevsky-m@yandex.ru

Abstract. In this study, the spatial distribution of plasma parameters in an experimental RF plasma device was performed. An automatic scanning system for the spectrometer and linear drive to detect plasma radiation was developed and implemented. The system is used to measure the spatial distribution of the electron temperature in a plasma discharge.

1. Introduction
To obtain experimental data on the spatial distribution of plasma parameters by detecting radiation, it is necessary to scan the plasma volume along different spatial axes and to perform data analysis via computer tomography techniques. In the case when a laboratory has a spectrometer equipped with only a single-axis radiation CCD detector, an additional system is needed for spatial scanning to detect plasma radiation. In this system, it is necessary to control the spatial location of the spectrometer detector using a stepper electric motor as a driver for linear displacement of the spectrometer’s optical fiber. The main task here is to develop and implement a control system for the spectrometer detector.

This system will be used for experimental measurements on plasma devices at National Research University "Moscow Power Engineering Institute" (NRU "MPEI"). The RF discharge facility at NRU “MPEI” includes a cylindrical induction coil. The last coil contains 2.5 turns and has an internal diameter of 35 mm and a height of 36 mm. There is a cylindrical quartz tube with an internal diameter of 26 mm inside the coil. A plasma discharge is created inside the quartz tube. The main parameters of the RF discharge are as follows: an operating frequency of 27.12 MHz, discharge power of up to 2 kW, discharge from atmospheric pressure gas, the operating gas is argon, an electron temperature of up to 1.5 eV, an electron density of up to $10^{21}$ m$^{-3}$, and a degree of ionization of approximately $2 \cdot 10^{-3}$.

The linear plasma device with the multicusp magnetic field at NRU "MPEI" [1] has a stationary plasma discharge with the following parameters: a plasma density of up to $3 \cdot 10^{18}$ m$^{-3}$, a discharge current of up to 30 A, an electron temperature of up to 4 eV with a fraction of hot electrons up to 30 eV, an ion flow to the test sample of up to $3 \cdot 10^{21}$ m$^{-2}$s$^{-1}$, a heat plasma load on the test materials of up to 1 MW/m$^2$ or more; the working gases are helium, argon, and deuterium. The facility has been developed to test materials with high-energy steady-state hot plasma loads. Such studies will make it possible to advance the understanding of the physics of the interaction of a hot plasma with materials, such as tungsten, molybdenum, steel, first-wall material and the ITER divertor.

2. Experimental methods
The plasma emission detection system consists of (1) an Avantes Avaspec 2048 optical spectrometer, (2) a stepping motor coupled to a linear device for the transfer of a fiber optic cable of the spectrometer, (3) a NI PXIe-6363 digital converter with a set of transistor keys to control the motor power supply, and (4) a computer with the developed software codes (Figure 1).
Computer code in LabVIEW [2] has been developed to control the stepper motor operation. The code consists of two nested loops. The first loop controls the condition for completing the algorithm and a reverse transition. The second loop controls sequential switching of the electrodes by logical conditions specified before the start of the loop.

The developed code was tested for the experimental setup using the Avaspec 2048 spectrometer. Experimental spectra have been measured and saved in a database.

**Figure 1.** Schematic view of the control system to detect plasma radiation.

The logic of the code is as follows: checking the exit from the loop or going back to the reverse, checking the experimental data and displaying them graphically on the screen, moving the running gear of the electric motor by one step, and then returning to the initial point.

The developed diagnostic system is used to measure the spatial distribution of the electron temperature in the RF plasma device. An approximation of the partial local thermodynamic equilibrium of the plasma was used, and the temperature of the electrons was estimated from the measured intensities of approximately 15 spectral lines of ArI [3]. The advantage of this method is to reduce the influence of the uncertainties in the energy calibration of the spectrometer. The cylindrical symmetry of the RF plasma discharge under investigation was assumed, and transverse sections of the discharge were measured. By using the developed system, optical spectra of plasma radiation along a line in the transverse section of the RF discharge (Figure 2) were measured. To estimate the radiation intensity distribution of each spectral line along the radial direction in the transverse section (Figure 3), the inverse Abel transformation was used. The size of the scanning area was 48 mm (in the transverse section of the discharge). Figure 4 shows the estimated plasma temperature distributions along the radial direction in three different transverse sections of the RF discharge. The electron temperature was ~1 eV. Section 1 was located at a distance of 3 mm, and section 2 was located at a distance of 6 mm. Section 3 was located at a distance of 9 mm from the last turn of the induction coil in the direction of the flow of the operating gas.

**Figure 2.** The intensity (I, in arbitrary units) of the spectral line (794.86 nm) vs. the distance along the scanning axis; × - experimental data; line is a fitting. RF plasma discharge.
Figure 3. The intensity (in arbitrary units) of the spectral line (794.86 nm) vs. the distance along the radial direction in the transverse section of the RF plasma discharge.

Figure 4. Experimental data for the plasma electron temperature in the RF discharge: radial profiles in different transverse sections of the plasma discharge.

3. Conclusion
A spectral diagnostic equipped with computer control of the spatial location to detect plasma emission has been developed. Scanning of the CCD detector along a certain line has been implemented. The system enables the measurement of the spatial distribution of the electron temperature, which has been tested on the RF plasma discharge. The diagnostic system will be used in experiments on the RF plasmatron and on the linear plasma device at “MPEI”.

Acknowledgments
This study was supported by the Megagrant RF № 14.Z50.31.0042.

References
[1] Budaev V P 2017 Problems of Atomic Science and Technology, Series Thermonuclear Fusion 40 23–36
[2] Travis J. Kring J 2010 LabVIEW for Everyone: Graphical Programming Made Easy and Fun Pearson Education Inc.
[3] Zhukov M F, Ovsyannikov A A 2000 Plasma Diagnostics Cambridge Int. Science Publishing