Remote network control plasma diagnostic system for
Tokamak T-10

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Abstract. The parameters of molecular plasma in closed magnetic trap is studied in this paper. Using the system of molecular diagnostics, which was designed by the authors on the «Tokamak T-10» facility, the radiation of hydrogen isotopes at the plasma edge is investigated. The scheme of optical radiation registration within visible spectrum is described. For visualization, identification and processing of registered molecular spectra a new software is developed using MatLab environment. The software also includes electronic atlas of electronic-vibrational-rotational transitions for molecules of protium and deuterium. To register radiation from limiter cross-section a network control system is designed using the means of the Internet/Intranet. Remote control system diagram and methods are given. The examples of web-interfaces for working out equipment control scenarios and viewing of results are provided. After test run in Intranet, the remote diagnostic system will be accessible through Internet.

1. Introduction

Among the processes occurring in edge plasma, hydrogen isotope recycling is of special importance. In the course of this process atoms and molecules, formed as a result of ion-wall interaction, enter plasma. The ratio between the flow of particles (molecules and atoms) returning to plasma and the ion flow characterizes recycling efficiency. Since the particle flow from plasma can lead to the release of the particles previously captured by the wall, the value of this coefficient can be far greater than unity. Uncertainty of recycling characteristics, particularly of radioactive tritium, can further complicate the interpretation of tokamak’s modes. Analysis of radiation arising as a result of optical transitions of hydrogen isotopes molecules facilitates the studies of edge-plasma processes which is proved by the experiments on tokamaks TEXTOR, DIII-D, JET, etc [1-3]. For instance, results in [1] show that the rotational temperature $T_{rot}$, obtained experimentally using molecular spectra, is a function of electron concentration $n_e$ and limiter surface temperature, which characterize plasma-wall interactions. Thus, the analysis of molecular spectra provides us with an opportunity to estimate these parameters.

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2. Diagram and hardware resources of the molecular diagnostic system

To study molecular radiation of hydrogen-deuterium plasma within the visible range of wavelengths we developed and optimized several optical schemes for detecting radiation from two diagnostic cross-sections (A and D) of the tokamak T-10 [4]. One of molecular diagnostic subsystems is located within cross-section D (multi-channel subsystem) and allows us to register spectra at the tokamak edge plasma coming from 14 different observation lines (figure 1).

Another subsystem, with monochromator MDR-23 as its basis, was placed in limiter cross-section A within direct view of graphite circular limiter used for restricting the radius of discharge. The monochromator’s characteristics are the following: diffraction grid – 1200 gratings/mm, wavelength range – 400-900 nm, inverse linear dispersion – 1.3 nm/mm, spectral resolution – 0.08 nm. In the exit slit plane of this spectral device there is a digital camera Proscan HS101H (CCD-matrix, 512x512 pixels, pixel size – 24x24 μm, resolution - 16 bits), which allows registering of spectrum areas up to 16 nm wide for one discharge of tokamak. The monochromator has a drive with step motor, which provides an opportunity to choose desirable spectrum areas using a computer.

For this diagnostic channel we installed a remote control system for monochromator MDR-23 and digital camera Proscan HS101H. This system allows adjusting of remote equipment before each tokamak discharge and can be used independently by several groups of scientists. Note that the like technology is planned to be used in the ITER project for remote diagnostics.

The electronic atlases of radiative transitions of deuterium and protium has been created earlier for the quick identification and analysis of the registered molecular spectra [4]. The work with tables of the each atlas is performed using DBMS MySQL, and the access to the atlas can be performed using a Web-interface or a specialized software package of automated identification of atomic lines and molecular bands created in the MATLAB environment. The paper [5] served as basis for creation of electronic atlas of transitions in deuterium molecules. At present, this atlas includes information about more than 7000 deuterium rotational lines grouped according to the electronic transitions. Wavelengths, quantum characteristics of the corresponding transition, tabular intensity, and affiliation to any electronic system are given for each rotation line. The electronic atlas for protium molecules

![Figure 1. Scheme of registration of molecular spectra within diagnostic cross-sections of tokomak. Dotted lines show equipment used remotely.](image-url)
includes data on more than 13400 lines. Specialized software with MATLAB-based Graphical User Interface (GUI) was also used for further analysis and processing of molecular spectra.

3. System for remote control of diagnostic channel

To study the parameters of molecular plasma we developed the system for remote control of spectral equipment and analyzed different scenarios of its work. Remote network control plasma diagnostic includes automated dispatch and information system [6]. The software for the developed system on the one hand provides a dialogue between a remote experimenter and a web-server and, on the other it allows establishing regime for operation of equipment and translation of results to remote computer. Figure 2 shows a diagram illustrating the used method.

![Diagram of remote control system for spectral equipment](image)

**Figure 2.** Diagram of remote control system for spectral equipment.

The control computer (Lab-server) is connected by local network with the Web-server accessible through the Intranet/Internet. The control interface for remote experimenter is generated by the Web-server using PHP-scripts and dynamic HTML-pages. User indicates the desired wavelength range and necessary camera parameters in the corresponding fields of an HTML-page. Next, these scenario characteristics are sent to Web-server, where they are put into integrated MySQL database.

The Lab-server software for control of spectral equipment repeatedly reads information on spectrum registration queries produced by remote experimenters from corresponding database tables. After correctness check scenarios are placed in the queue and special table field show the operation status. Remote experimenter is also informed about the course of experiment by means of special messages («scenario is placed in the queue», «spectrum is being registered», and «results can now be viewed», etc).

The Lab-server software determines the work regime of the spectral equipment in accordance with the scenario parameters indicated by remote experimenter and saves the spectrum registration results in the database. Experiment results can be accessed using special PHP-scripts, which provide remote experimenter with data on registered spectra in the form of graphs and tables.

Remote user can execute the following operations:
- log in the system and, if necessary, restore the lost data on registration;
- order remote diagnostics sessions through their personal cabinet;
- create scenarios for remote control of diagnostic equipment;
- view the spectra obtained at the end of scenarios.

Some Web-interfaces of remote experimenter are given below. Figure 3 shows the main page of the remote control system web-site. There are the following sections: «Remote experiment», «Equipment» and «Contacts». User can use the first section to register and authorize in the system. The «Equipment» section provides information on characteristics and regimes of used diagnostic equipment.
After filling out the registration form and entering the system, user gains access to their personal cabinet. Using a special Web-form user makes up and sends a request for conducting a remote control session at the convenient time. The administrator scans the submitted requests; if necessary, changes the time periods for sessions and assigns a status to the experiment (allowed/banned).

![Remote molecular diagnostics of edge plasma T-10 tokamak](image)

**Figure 3.** Main page of remote control web-site.

If the requested session is allowed, remote user gains access to Web-interface for equipment control (figure 4).

![Web-interface for equipment control](image)

**Figure 4.** Web-interface for equipment control.
The developed system allows storing spectrum data, obtained by remote users. This data, as well as all the necessary information on spectrum registration parameters, is provided to users through their personal cabinet in the form of graphs (figure 5) or tables and can be viewed both in the course of session and on its completion.

![Figure 5. Web-interface for viewing and saving of results.](image)

After experimental operations of the system in Intranet we plan to make it accessible through global network.

4. Conclusion
The diagnostic facility for registration of molecular spectra in two diagnostic cross-sections of tokamak T-10 is designed. The electronic atlases of radiative transitions of hydrogen isotopes (protium, deuterium) with Web-oriented user interface are developed. The software package for processing of molecular spectra and for identification of rotational lines is created. Vibrational and rotational structure of hydrogen isotopes molecular spectra is identified.

Rotational and vibrational temperatures for ground ($X^1\Sigma^+_g$) and excited ($d^3\Pi_u$) states are estimated using the spectra registered in the course of experiments. The dependencies of temperatures on electron density of edge plasma are obtained. Some experimental results are published in paper [4].

Method and software for remote control of spectral equipment of molecular diagnostics using Internet are developed.

References
[1] Brezinsek S, Mertens Ph, Pospieszczyk A, Sergienko G and Greenland P T 2002 Contrib. Plasma Phys. 42 668-74
[2] Hollmann E M, Pigarov A Yu, Rudakov D L, Brezinsek S, Brooks N H, Groth M and McLean A G 2006 Plasma Phys. Control. Fusion 48 1165-80
[3] Meigs A, Stamp M, Pospieszczyk A, Brezinsek S, Sergienko G, Huber A, Mertens Ph, Samm U, Wiesen S and Greenland P T 2005 Journal of Nuclear Materials 337-339 500-4
[4] Zimin A M, Krupin V A, Troynov V I and Klyuchnikov L A 2015 Phys. Atom. Nucl. 78 1319-25
[5] Freund R S, Schiavone J A, Crosswhite H M 1985 J. Phys. Chem. Ref. Data. 14 235-383
[6] Zimin A, Shumov A and Troynov V 2015 Online experimentation: emerging technologies and IoT, ed M T Restivo, A Cardoso and A M Lopes (Barcelona: IFSA Publishing) pp 275-94