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Diagnostic Systems for the TJ-II Flexible Heliac

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Abstract

An overview of the TJ-II diagnostic systems is given, with attention to the particular problems of the standard systems (derived from the specific TJ-II highly shaped 3-dim geometry, the large ratio vacuum vessel to plasma volume and the small distance between the plasma and the central conductor) as well as to specific systems which reinforce the diagnostic capability in areas derived from the peculiarities of TJ-II and its physics programme: plasma wall interaction, stability-fluctuation studies, electric fields. To handle the data (100–150 Mb/discharge) expected from TJ-II, a powerful data acquisition system is devised.

Keywords:

helical axis stellarator, plasma diagnostics

1. Introduction

In order to reach an optimum profit of the TJ-II scientific potential, a state of the art set of diagnostics is being installed, including most of standard systems used in magnetic fusion experiments. TJ-II has excellent diagnostic access (96 ports) but has also several limiting factors: great distance from the plasma to the diagnostic ports, no access from the high field side due to the closeness of the central conductor, full 3-dimensional plasma structure, strong plasma wall interaction at the central conductor protection (hard-core), which can make even standard diagnostics extremely difficult. The paper is organized as an overview of the different diagnostic techniques.

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2. Magnetic Diagnostics

In TJ-II the plasma column is limited (for practically all configurations) by the so-called hard-core (protrusion of the vacuum vessel that allows the central conductor to come very close to the plasma), it has been necessary to design very thin coils and install them in the small room available between two adjacent thermal shielding tiles. In addition it was necessary to machine grooves for some toroidal positions on the vacuum side of the hard-core. The resulting cross-section of the available space is 6 mm×3 mm. The Rogowski coils are wound with 0.1 mm copper wire and inserted into stainless steel tubes 2 and 3 mm, inner and outer diameter, respectively. Laboratory calibration tests with similar wave forms as the ones expected in TJ-II yield a sensitivity factor of about 20 mV/kA, after integration.

The diamagnetic loops are subjected to the same restrictions, four diamagnetic coils have been installed using the special grooves in the hard-core. Flux loops to measure the average β will be also installed. The optimum positions are being studied by means of the NEMEC equilibrium code. Mirnov coils are also in the last steep of the design phase. It is planned to install four arrays of B_θ coils surrounding the plasma cross section in fixed toroidal planes and 14 sets of B_r and B_φ coils.

3. Thomson Scattering

The Thomson Scattering system is being built in collaboration with FOM (The Netherlands) and is based on the concept presently used at RTP. The TJ-II system uses a single pulse 10 J ruby laser. In the detection branch of the system, a third generation image intensifier is used to increase the number of photons to be detected by the (two) intensified CCD cameras. The image intensifiers of the ICCDs are used as shutters, and one of the cameras will subtract the contribution of plasma and/or stray light from the useful signal.

The scattering yield is expected to be $\mathrm{Nphotons_{out}/Nphotons_{in}} = 4\times10^{-16}$. The number of photoelectrons detected will be of the order of several thousand. Random variations of this number related to the performance of image intensifier, ICCDs, etc. set a fundamental limit for temperature resolution of about 5%. Spatial resolution expected is about 3 mm.

In order to cover the full configuration space of TJ-II the whole system is installed in a stiff C-frame which can be horizontally displaced. This solution avoids problems with system alignment and focusing.

4. Optical and Spectroscopy Diagnostics

Line spectroscopy in the VUV region will be carried out with a grazing incidence spectrometer (GISMO). The system has a 0.5 m radius Rowland circle and two detectors. Selected lines in the visible and near UV radiation will be monitored with two small monochromators.

Two high resolution spectrometers with multichannel detectors will be used for ion temperature and rotation measurements using passive emission spectroscopy.

A simple compact phosphor detector has been developed for TJ-II [2]. The system operates like a high sensitivity broadband detector by converting UV into visible radiation. It can withstand the 150°C backing temperature and the detector has been designed to operate either as a multichord device with a few channels or as a scanning system. This detector will be used for impurity monitoring which will be injected in the TJ-II device by the laser blow off technique.

5. X-Ray and Bolometry

Three pyroelectric bolometers have been installed to estimate global radiation losses. As intense plasma wall interaction at the TJ-II hard core is expected, it is important to monitor separately this radiation source. Single detectors are equipped with remote handled movable collimators and in-vacuum chopper systems. The tomographic system will consist of 3 arrays of 20 pyroelectric detectors each (supplied by IOFAN, Moscow).

Also NaI (Tl) and Si (Li) detectors working on Pulse Height Analysis mode are installed. They are equipped with filters to select different energy windows. Hard X detectors are placed at the torus hall walls as total flux monitors.

For Soft X tomography, a system with four arrays including 16 detectors (p-n silicon photodiodes) each is under construction. The system will be capable of 2 cm spatial resolution at the plasma center.

6. IR and Microwave Diagnostics

A 2 mm heterodyne interferometer will operate during the first phase of TJ-II (ECRH Heating). For the NBI heated plasmas with higher density, an IR interferometer operating with a CO_2 laser for plasma probing (10.6 μm) and an He-Ne laser for vibration compensation is being built. The lower sensitivity of the 10.6 μm radiation is compensated by the availability of high power commercial sources. The system uses acousto-optical modulators for heterodyne detection. A

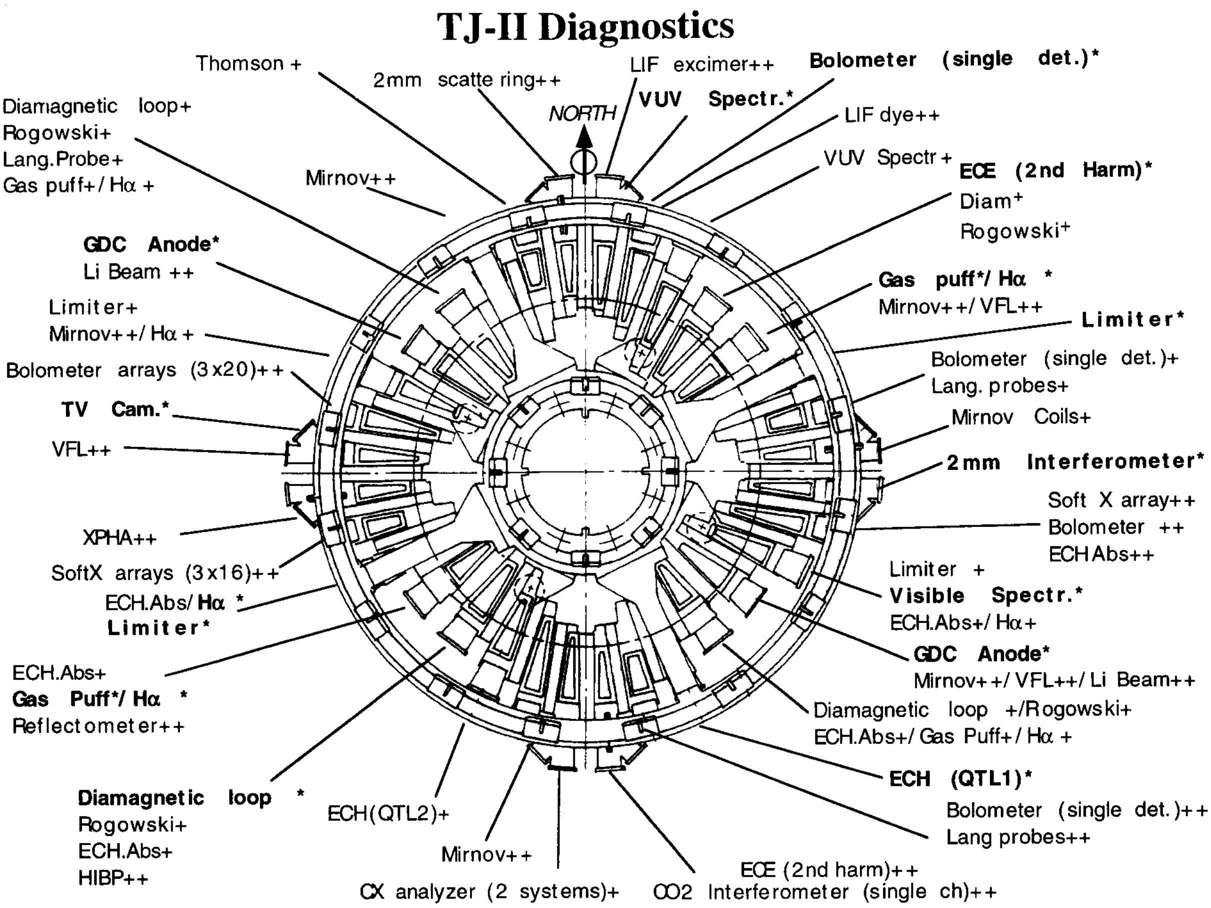

Fig. 1 Schematic view of the TJ-II diagnostic distribution, *Systems already installed, +Systems to be installed by 01.98, ++Systems to be installed by 01.99.

high performance phase meter is being designed for the measurement of the very small phase displacements (in the order of 10^{-2} radians).

Electron Cyclotron Emission radiometry for the determination of the electron temperature will be provided during the ECH phase by a 2nd harmonic x-mode heterodyne radiometer. The radiometer temperature including the losses in the transmission line is about 20,000°K. Absolute calibration of the radiometer is provided by observation of a hot-cold source (room temperature *vs.* liquid nitrogen).

The plasma observation optics uses a corrugated gaussian horn irradiating an elliptical mirror, leading to a 4 mm spot. A code for corrections due optically thin plasmas (useful for the edge) is available. Extension of the system to measure fluctuations of the electron temperature as well as a 3rd harmonic radiometer for the NBI phase are under study A 2 mm scattering system is being built in collaboration with IOFAN (Moscow). The system is designed to measure electron density fluctuations in the range of wavenumbers $k = 5-20\ cm^{-1}$. The different sample volumes will be selected by the combined movement of the emitting antenna and the three receiving ones.

Microwave reflectometers for TJ-II are under development in collaboration with IST (Lisbon). For the first phase a system operating in the x-mode 25—50 GHz is being installed. The reflectometer is designed to operate both in the Amplitude Modulation and in the Frequency Modulation modes. The emission system is built with a fast swept (10 μs) Hyperabrupt Varactor Tuned Oscillator (HTO) in the 12—18 GHz range followed by a series of frequency multipliers. For the later phases fast swept heterodyne detection as well as additional bands and fluctuation measurement channels are foreseen.

7. Plasma Wall Interaction

The plasma-wall interaction is a major concern in TJ-II due to the vicinity between the hard-core groove and the plasma center with highly compressed flux surfaces. Two Laser Induced Fluorescence (LIF) systems are prepared, the first one uses a flash lamp pumped dye laser for H_α excitation, it will be used, together with the H_α array detectors, for neutral distribution studies. The second LIF uses an excimer laser to pump a dye system which will be tuned to selected transitions of metallic impurities (Cr, Fe...).

In addition, a series of atomic beams have been developed: a thermal Li beam and a supersonic He beam will be used for plasma edge characterization. The great distance between the vacuum vessel ports and the plasma will advise to introduce part of the device inside the vessel. The supersonic He beam was developed for TJ-IU and is able to provide a beam speed of 1.7 km/s with a beam size (FWHM) of 7 mm at 30 cm from the source. H_α diagnostics will include a series of distributed single detector systems near the limiters and gas puff valves.

8. Particle and Probe Diagnostics

A Fast Reciprocating Langmuir Probe has been developed and constructed for TJ-II. The fast stroke, pneumatically driven, has a length of 0.1 m at a speed of 1.5 m/s. The system's head can be extracted by a vacuum valve and exchanged for the different experiments (replace damaged pins, heads with Langmuir and magnetic probes, etc.).

The charge exchange neutral particle distribution for the determination of the ion temperature will be measured by means of two standard spectrometers. One of them is equipped with 6 energy channels for Hydrogen plus 6 more for Deuterium, whereas the second one has 5 channels which can be selected for either species. A moving frame allows to change toroidally and poloidally the systems orientation.

Electric fields will be matter of great interest in the TJ-II physics programme. The key tool for those studies will be the Heavy Ion Beam Probe, which has been designed and constructed in collaboration with KFTI (Kharkov) and IST (Lisbon). Extensive trajectory analyses have been performed to cope with the complicated 3 dimensional structure of the TJ-II magnetic field. The HIBP operates up to 200 keV with Cs ions and will use two types of analyzers (which are designed for simultaneous operation). The first analyzer (already constructed) will be a standard system for the measurement of plasma density and potential at selected positions, whereas the second one will be a 100 channel system for the measurement of density turbulence. A dedicated Data Acquisition system based on VME is being built for this diagnostic.

9. Data Acquisition

The data acquisition of TJ-II is designed to acquire and manage a large amount of information per discharge ($>$ 100 MBytes) and a special compression technique was developed for this purpose [2]. The system is based on a central Unix server (DEC Alphaserver 8400) and fast links (FDDI rings and Ethernet segments) to the different acquisition subsystems, the main of those being a VXI-based 300 digitizer channel system, developed at CIEMAT. The VXI digitizers operate with 12 bits resolution and the faster ones reach 20 Msample/s and incorporate a Digital Signal Processor to allow users to programme their own filters [3]. In addition to the VXI system, CAMAC, VME and PC-based systems can be integrated. The user interface for data acquisition and visualization is based on X-Windows/Motif.

Most diagnostic variables (temperature, position, valve or voltage settings...) will be monitored and remote controlled from terminals in the TJ-II control room. Simatic PLC controllers within a Local Area Network are used for that purpose.

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