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Lithium beam diagnostic system on the COMPASS tokamak

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HIGHLIGHTS

- Li-beam diagnostic system on the COMPASS tokamak is an improved and compact system to allow testing of Atomic Beam Probe.
- The possibility to measure background corrected density profiles on the few microseconds time scale.
- First Li-beam diagnostic system with recirculating neutralizer.
- The system includes the redesigned ion source with longer lifetime.

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ABSTRACT

An improved lithium beam based beam emission spectroscopy system – installed on COMPASS tokamak – is described. The beam energy enhanced up to 120 keV for Atomic Beam Probe measurement. The size of the ion source is doubled, using a newly developed thermionic heater instead of the conventionally used heating (tungsten or molybdenum) filament. The neutralizer is also improved. It produces the same sodium vapor in a cell but minimize the loss condensing the vapor on a cold surface which is led back (in fluid state) into the sodium oven. This way we call it recirculating neutralizer. The observation system consists of a CCD camera and an avalanche photodiode array.

1. Introduction

Spatially and temporally well resolved density measurements are of great importance in the operation and scientific study of magnetic fusion devices. It is well known that the standard non-perturbative density measurement techniques such as Thomson scattering and microwave interferometry have serious limitations in their time resolution and spatial resolution respectively. A very good additional tool for time resolved edge density profile measurements is the lithium-beam emission spectroscopy (Li-BES).

Accelerated lithium beam based BES diagnostics are used at almost every present tokamak (JET, ASDEX, DIII-D, JT-60, KSTAR, EAST) and is planned to be used also at W7-X [1–4].

The working principle of the Li-BES can be summarized as follows: lithium ions are extracted from a thermionic ion source and accelerated in an ion optic. The ions are neutralized in sodium vapor and the neutral beam reaches the plasma without any significant energy loss. During the plasma–beam interaction Li-atoms are excited to the 2p state by plasma electrons. The excited state decays with the emission of a photon of characteristic wavelength ($\lambda = 670.8$ nm). These photons can be observed using an appropriate interference filter and various detector systems (CCD camera, Photomultiplier, Photodiode or Avalanche Photo Diode) [5,6]. As the detected light intensity is connected with the local electron density, observing the intensity as a function of time of this Li resonance line along the beam, it is possible to reconstruct the density profile and the two-dimensional correlation map of the electron density fluctuation. Using a pair of deflection plates the beam can be either chopped out from the plasma or poloidally deflected (swept). Chopping the beam with a given frequency allows to correct for the background light during the density profile reconstruction.

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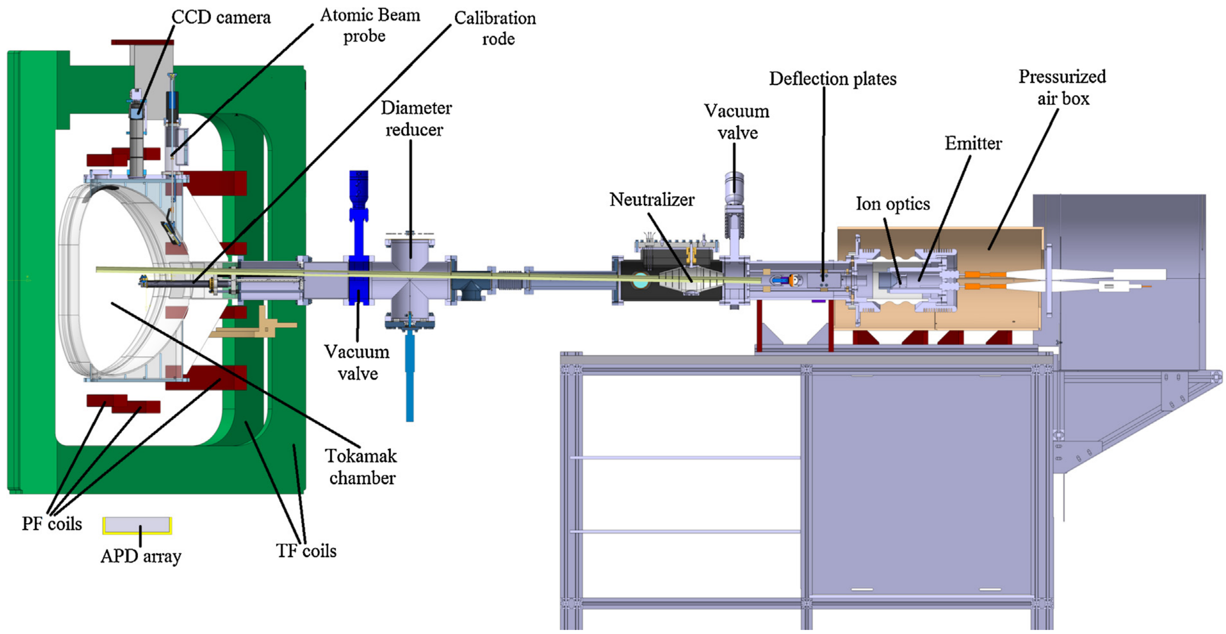

Fig. 1. Set-up of the diagnostic beam.

Switching frequency of the sweeping/deflection system can be increased up to a 400 kHz [2] allowing profile measurements even if the background light varies relatively fast during the shot. Using the fast deflection mode, quasi two-dimensional fluctuation measurements can be performed.

The Atomic Beam Probe (ABP) is an extension of the Li-BES system based on the idea of collecting the Li^+ ions after the ionization. Ion trajectories are strongly dependent on the magnetic field structure. The toroidal component of the field determines the exit position of ions in the radial–poloidal plane while the poloidal component slightly deflects the trajectory toroidally. Measuring the variations of the toroidal displacement plasma current fluctuations can be detected [7].

Present Li-BES systems have energies ranging from 30 keV to 60 keV, providing 10–20 cm penetration into the plasma depending on the edge plasma parameters (L-mode, H-mode). In order to make possible the ion detection outside the plasma volume for the ABP, the beam energy has to be increased significantly, see [7]. The neutralization efficiency (which drops to about 70% at 60 keV) and the finite lifetime of the observed atomic state, impose a limitation on the beam energy, therefore there is an optimal energy depending on the main goal of the experiment. In the design process of the compass Li-beam, it has been decided that an increase in beam energy up to 120 keV, has to be implemented.

In the remaining part of the paper, first the hardware modifications are discussed in consecutive subsections: the high voltage system, the magnetic shielding, the ion source, the neutralizer and the observation systems. These subsections are followed by a description of first data produced using the Li-beam in different COMPASS discharges [8,9]. The discussion is closed by a short summary.

2. Hardware modifications

Fig. 1 introduces the main components of the system. It consists of the accelerator (with the ion optic), the beam manipulation chamber (with two deflection plate pairs and a Faraday-cup), the neutralizer chamber, a flight tube, a diameter reducer for ABP measurement (with a second Faraday-cup) and a calibration rod.

2.1. High voltage system

To enhance the main voltage up to 120 kV several modifications, with respect to other Li-beam systems such as at ASDEX and JET, were necessary. The final design, which has been implemented on COMPASS is shown in Fig. 2.

Basically the system consists of two high voltage power supply, one 120 kV/10 mA and the other is 120 kV/0.25 mA. The first one is connected to an isolation transformer (Powersources, HVTT-1K-120K) which is followed by a second transformer to produce the necessary heating current (about 70 A). The heating current is controlled by a thyristor unit (Eurotherm, 7100A Single-phase power thyristor). This line is connected to the ion source, which is located in the Pierce electrode (see Fig. 3). The second power supply is connected directly to the extractor electrode on the acceleration voltage. The difference between voltages of these two power supplies is the extraction voltage. The third part of the ion optic, called *the puller* is connected to the ground.

The main ceramic insulator is 140 mm long made of China. There are aluminum heat sinks on both sides. The pressurized air chamber placed around the ceramic break is filled up to 1.5 bar with air to isolate the 120 kV voltage. The current (and HV) feedthroughs on the pressurized air chamber do not break the isolation of the HV cables (they only fix the cables and close the pressurized chamber).

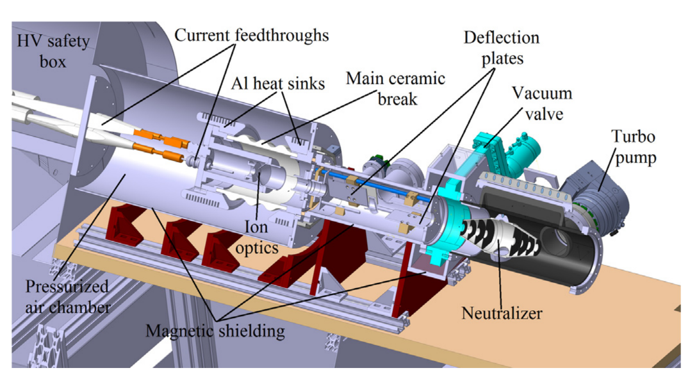

Fig. 2. High voltage system.