LITHIUM DIAGNOSTIC BEAM DEVELOPMENT FOR FUSION PLASMA MEASUREMENTS

PhD thesis

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Background of the research

Nucelar fusion as clean (free from long half-life radioactive waste) and inexhaustible energy source is an intensively studied research field from the 1950's. The most promising fusion process is the Deuterium-Tritium reaction, which can be used for practical energy generation if the thermal energy of the particles is in the 10-15 keV range, meaning very high, about 100 million K temperature. At this temperature materials are ineviatbly in the plasma state.

Among fusion devices the most promising one is the tokamak, which confines a torus shaped plasma in a helically twisted toroidal magnetic field. In contrast to the theoretical calculations experiments showed that the particle and heat transport through the magnetic confining magnetic field is well above the so-called "neoclassical" particle and heat transport, calculated from the Coulomb collisions of plasma particles in toroidal geometry. This process is called anomalous transport which is, according to the mostly accepted theories, driven by plasma microturbulence arising from mm and smaller scale instabilities. The past decade a wealth of experimental evidence has been collected on plasma turbulence mostly through the measurable density, temperature and potential fluctuations caused by it.

Turbulence arises from instabilities driven by inhomogeneities in plasma parameters. So-called drift waves are considered to be the most ubiquitous instabilities in the core plasma, while other processes are responsible for turbulence at the plasma edge. These primary unstable waves can induce different mesoscopic (i.e. between the microturbulence and the device scale) flow structures: poloidal zonal flows and radial "streamers". The sheared flow stuctures act on the drift waves as they tear eddies apart built by the drift waves. The unstable drift waves and flow structures establish a self regulating system which is responsible for the control of the above mentioned anomalous heat and particle transport.

In special cases the flows in the boundary layer can amplify and stabilise to the extent to suppress the turbulence in a macroscopic layer, i.e. a transpoert barrier develops at the plasma edge and the plasme global confinement inproves. This is called High Confinement Mode (H-mode).

At present, besides the qualitative understanding of turbulence and H-mode, there is no theory capable of reliably and quantitatively predicting anomalous heat and particle transport.. The most critical problem is that the H-mode and the parameters of the related transport barrier (width, temperature maximum at the top of the pedestal) are not given by any model. Because of this the experimental study of the turbulence and flows is of special importance from the aspect of the progress of fusion research.

The plasma diagnostic methods developed in the past decades can measure most of the plasma parameters (temperature, density, potential, current distribution, flow velocity, etc.) but most of these diagnostics are not able to measure with such a high spatial and/or temporal resolution which is necessary for the study of turbulence. The difficulty is that the correlation length of the turbulence is about mm-cm, the relative fluctuation amplitude is 0.1-10% and the frequency is about 10-100 kHz. Moreover the statistical character of the turbulence makes it necessary to study long time series. There are only a limited number of such special plasma turbulence diagnostics.

Objectives

The self regulating system of drift waves and mesoscopic flows can be well studied by the different types of *beam emission spectroscopy* (BES) diagnostic. The basis of this method is that some kind of atomic beam is injected into the plasma and the atoms excited by the plasma emit characteristic photons in the visible electromagnetic range. The intensity of this photon flux is measured.

Earlier measurements made by accelerated Lithium BES diagnostics showed that the appropriate spatial and temporal resolution needed for turbulence and flow velocity measurement can be achieved, but the statistical error of the diagnostics makes the measurement possible only in the outer regime of the plasma, where the relative amplitude of the turbulence is high. The measurement is limited by the low photon flux, which is determined by (additionally to the parameters of the detection system) the typically 2 mA beam current. The measurement accuracy could be increased, the range could be extended and even new measurement possibilites would open up if a stronger beam and better detectors were available.

The objectives of this thesis is the detailed experimental characterisaction and numerical simulation of the recently used accelerated Lithium beam diagnostic in order to determine the limiting phenomena of the beam current and diameter. After this study proposals for upgrading the diagnostics can be elaborated. New types of ion sources and ion accelerating systems can designed, which provide higher beam current and possibly smaller beam diameter. This knowledge was used at the optimization, upgrade and construction of the JET, TEXTOR and COMPASS tokamak Lithium beam diagnostics.

Methods

Study of the accelerated Lithium beams were done in the laboratory of the KFKI Research Institute for Particle and Nuclear Physics, in the Li-beam laboratory of the Institut für Plasmaphysik, Garching and at Forschungszentrum Jülich. I developed a novel method to measure the beam diameter and current distribution. Intersecting the beam path with a metal plate, the beam ions get neutralized on the surface and some of them become excited to the 2p state. Measurement of the distribution of this light emission reveals information on the beam current distribution. The proportionality between the beam current and the total detected light was poven by experiments. The ion and atom beam current distribution was investigated in detail by this method in the whole operational parameter range of the Li-beam.

I studied the beam formation and the process of acceleration by two different numerical simulations. These are the CPO and the AXCEL numerical codes. The numerical results were systematically compared to the results of the laboratory experiments. The validated numerical techniques were used to investigate the beam current and diameter for different accelerating systems. Proposals were made for the modification of the ion optic and for the direction of ion source development.

I participated in the modification and reinstallation of the TEXTOR Lithium beam diagnostic, in the development of the new beam control and observation system. Using this diagnostic I measured the plasma electron density distribution at the edge plasma edge at the H-mode transition.

Based on the results of the laboratory experiments, the numerical simulations and the measurements at TEXTOR I designed and built up the COMPASS Lithium beam diagnostic.

New scientific results (thesis)

The new scientific results achieved during my PhD work are summarised in the following theses:

1. I developed a novel method to measure the ion and atom beam current distribution. The accelerated Lithium beam diagnostics of the JET and TEXTOR tokamaks were investigated in detail in the full operational parameter range of the the ion source and accelaration system using this method. [1]
2. I pointed out that the effect of the space charge will act on the beam current distribution above 1 mA beam current. This effect appears only inside the ion optic, because outside that secondary electrons originating from the vessel wall neutralize the space charge. Measurements showed that in the case of both diagnostic beams current is limited by the ion source [1, 2]
3. I designed and built up a special ion optic where, without beam forming, the beam current and the temperature of the emission surface can be measured at the same time [1].
4. To interpret the results of the experiments I used two different simulation codes. I got good correspondence between the codes and the experiment if I took into account the space charge effect inside the ion optic. Using the validated methods I gave proposals for the modification of the ion optic and the ion source which can enhance the current of the diagnostic beams and can decrease the divergence of them [3].
5. By the help of Lithium beam diagnostic I measured the electron density distribution in the edge plasma of the TEXTOR tokamak [5, 6, 7, 8, 9, 10].
6. I designed and built up the accelerated alkali beam diagnostics of the COMPASS tokamak [10].
7. I designed and built up a novel neutralizator for alkali atom beam diagnostics.

Related publications

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