Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Preliminary Study of Fast ion diagnostics by Collective Thomson Scattering (CTS) in KSTAR

Min Park*, C. Y. An, dongjin Ku, S. H. Kim, S. J. Wang, S. K. Kim
Nuclear fusion Engineering & Development center, Korea Atomic Energy Research Institute (KAERI), Daejeon, 305-353, Korea
**Corresponding author: mpark@kaeri.re.kr*

1. Introduction

Nuclear fusion is one of the most promising candidates for ultimate energy source in the future. To initiate the fusion of two nuclei, each nucleus must have enough kinetic energy to overcome their Coulomb repulsion when they approach to each other as close as the short-range nuclei attraction forces dominate.

Magnetically confined plasma is one method in which sufficiently heated nuclei can be fused together. There are various types of magnetically confined plasma reactors. A tokamak type reactor, a toroidal plasma confinement system, is now regarded as having the optimum potential.

KSTAR(Korea Superconducting Tokamak Advanced Research) is the tokamak type plasma reactor, where various heating techniques such as Neutral Beam Injection (NBI) and Ion Cyclotron Resonance Heating (ICRH) are used to heat the plasma, both being extensively developed in KAERI.

Up to now the most preferable fusion reaction is the use of deuterium ($_1D^2$) and tritium ($_1T^3$) in virtue of its highest reaction cross-section. The reaction is as follows.

$$D^2 + T^3 \rightarrow He^4(3.5\text{ MeV}) + n^1(14.1\ MeV)$$

The first reaction product He^4 (α-particle) with 3.5 MeV as a kinetic energy is expected to be the main energy source for the future self-sustained plasmas. α-particles' energy must be transferred to the bulk plasma before escape from plasma. The second product is neutron which is collected by a blanket around the plasma and heat up the blanket. The heat from the blanket can be converted into electricity.

As mentioned above, fast alpha particles produced during the D-T fusion reaction play a significant role in the magnetically confined plasmas for the future fusion power plant. It is necessary to experimentally measure the fast ion distribution with required time, space and velocity resolutions for further understanding the dynamics of fast ions and their interactions with the plasma, and eventually the realization of the fusion plant.

Collective Thomson Scattering (CTS) is the method to measure the fast ion velocity distribution based on the scattering of electromagnetic waves off microscopic fluctuations, principally in the electron distribution, driven by the ion motion.

Now we plan to develop CTS system in KSTAR in near future and here we investigate theoretical and experimental aspect of CTS.

2. Theoretical approach

In this section some of the fundamental equations are presented to understand the physics of CTS.

2.1 Thomson Scattering

Scattering of radiation by a free electron is called Thomson scattering. When a stationary charge is oscillated by the incident electromagnetic wave, the oscillating charge itself radiates with the same frequency of incident wave. This is simply regarded as a radiation by an oscillating dipole. If the charge has velocity, scattered radiation is Doppler-shifted depending on the scattering geometry.

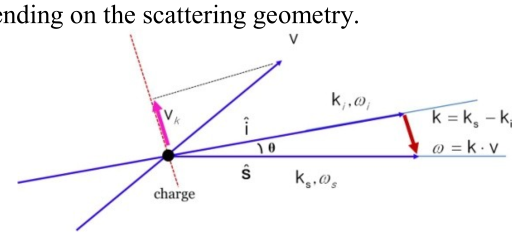

Fig. 1 Wave vector diagram for the scattering of radiation.

The shift in frequency ω and the shift in wave number **k** are expressed as

$$\omega = \omega_s - \omega_i = (\mathbf{k}_s - \mathbf{k}_i) \cdot \mathbf{v} = \mathbf{k} \cdot \mathbf{v} \quad (1)$$

$$\mathbf{k} = \mathbf{k}_s - \mathbf{k}_i \quad (2)$$

where, subscript s and i indicate scattered and incident respectively, and $k_i = \frac{\omega_i}{c}\hat{\imath}$, $k_s = \frac{\omega_s}{c}\hat{s}$.

In Fig.1, $|\mathbf{k}| = \sqrt{k_s^2 + k_i^2 - 2k_s k_i \cos\theta}$ and in nonrelativistic (v/c « 1) case, this reduces to

$|\mathbf{k}| \cong 2|k_i|\sin(\frac{\theta}{2})$. Thus, we can in principle obtain the velocity component in *k*-direction from the shift in frequency ω as follows.

$$\omega = \mathbf{k} \cdot \mathbf{v} \cong 2|k_i| \sin\left(\frac{\theta}{2}\right) v_k \quad (3)$$

2.2 Collective and Non-Collective

The scattering of radiation by plasma can be simply considered as the vector sum of the scattered fields of the individual electrons within the scattering volume under certain conditions. The time-averaged scattered power per unit solid angle is

$$\frac{dP_s}{d\Omega} = \frac{cR^2}{8\pi} N E_2^2 + \frac{cR^2}{4\pi} N(N-1)\overline{\left(\mathbf{E}_{js} \cdot \mathbf{E}_{ls}\right)}_{j \neq l} \quad (4)$$

At this point, it is convenient to introduce the Salpeter parameter α defined as $\alpha \equiv 1/k\lambda_{De}$. In non-relativistic case,

$$\alpha \approx \frac{1}{4\pi \sin(\frac{\theta}{2})} \frac{\lambda_i}{\lambda_{De}}$$

, where λ_i is a wavelength of the incident wave and θ is the scattering angle between incident and scattered radiation.

If the incident wavelength is shorter than Debye length and $\alpha \ll 1$, the wave sees each free charge and the first term of Eq. (4) dominates because the second term would be zero due to random distribution in space. This case is non-collective scattering. When $\lambda_i \geq \lambda_{De}$ such that $\alpha \geq 1$, motions of each charge are correlated i.e. they behaves collectively with respect to the incident beam. Then the second term of Eq. (4) contributes considerably and we have collective scattering. (For further details on [1])

In tokamak plasmas, microscopic fluctuations in the electron distribution are mainly driven by the ions surrounded by Debye shielding clouds. Thus, CTS scattering can reflects ion dynamics.

3. Experimental aspect

First, let us see the experimental raw data of CTS in TEXTOR tokamak [2]. The data was measured by the 42-channel heterodyne receiver with bandwidths from 80 to 750 MHz, giving complete coverage from 107 to 113 GHz. The probing radiation is 110 GHz gyrotron operated at 150 kW. Gyrotron is pulse-modulated with a period of 4 ms and a 50% duty cycle (250 Hz).

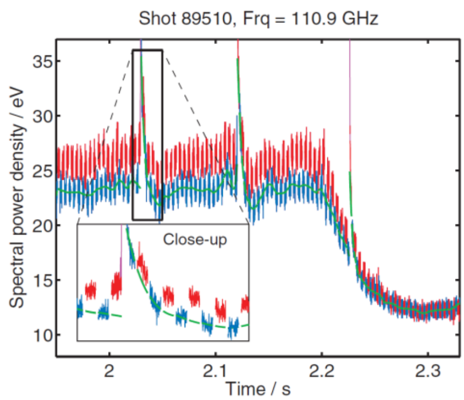

Fig.2 (color) Raw data time trace for a CTS channel. ECE background in blue and CTS + background (gyrotron on time) in red. The green line represents the reconstructed background during the gyrotron probing period.[2]

Our main goal at this moment is to obtain the date as above. From the data, we can notice that the ECE background noise is the main obstacle and thus pulse-modulation of probing beam is necessary. In addition, mm-wave requires quasi-optical design and analysis with high precision. Lastly, broadband high resolution heterodyne receiver development is needed.

The development of CTS in KSTAR requires the following.
- mm-wave optics analysis.
- High resolution multi-channel heterodyne receiver development.

REFERENCES

[1] Dustin H. Froula et al. "Plasma Scattering of Electromagnetic Radiation: Theory and Measurement Techniques", ELSEVIER, Amsterdam, 2011

[2] H. Bindslev, S. K. Nielsen, L. Porte *et al.*, Fast-Ion Dynamics in the TEXTOR Tokamak Measured by Collected Thomson Scattering, Phys. Rev. Lett. 97, 205005(2006)