Edge Thomson Scattering in RFX-mod: operation and first measures

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Abstract: During the 2009 experimental campaign the Edge Thomson Scattering System started the operations, after a commissioning period. The main modification has been the adoption of interferential filters spectrometers with APD detectors, similar to those used on the main TS. Other improvements were the optimization of the laser input path and of the collection optics, which increased the signal level of about 50%. With the present setup, temperature and density measures show good compatibility with those of the main TS diagnostic; density data have been calculated after Rotational Raman Scattering calibration, a method which is not affected by impurity deposition on the collection window. Present operational limits of the diagnostic are discussed as well as short terms planned operations, focusing in particular on laser multi-pulse issues and laser sharing with the impurity injection system by laser blow-off.

1. Components description

The edge Thomson Scattering (TS) diagnostic [1] has recently started to operate on the RFX-mod machine after a commissioning period. The diagnostic will be shortly described, focusing on the laser characteristics, the beam path, the collection optics, the spectrometer and the acquisition system. Mechanical and optical improvements will be highlighted, discussing the temperature and density data with some examples, as well as some coupling issues with the Laser Blow-off system.

The source is a Q-switch ruby laser ($\lambda=694.3$ nm) with 10 J beam energy, a pulse length of 30ns at FWHM, and it can produce two pulses in within a lamp discharge (in less than about 1 ms) 5 J each. The laser is located at the same level of the experiment, in a separate room, together with the main TS laser and the acquisition electronics. The beam reaches the input optics in the torus hall with the correct polarization (vertical) by means of a $\lambda/4$ waveplate; it is focused on a 4 mm pinhole placed in a metal pipe which can be remotely inserted in the vacuum vessel. Before entering the plasma, the beam is left-tilted of 30 degrees and the pinhole is imaged at 100 mm after the pipe exiting; the scattered radiation passes through a 83 mm, F#1.2 camera lens and it is collected by a linear bundle of 12 optical fibers (hard clad silica, 1mm core diameter). The collection optics and the pipe axis are on the equatorial level. The fibers bundle goes in the laser room and here is connected to two APD interference filters spectrometers, of the same type of those mounted on main TS [2]. An optical delay system accommodates three scattering volumes (6 fibers) in each spectrometer: 25m difference in fiber length separates the three TS signals of about 120ns; 4 channels waveform digitizers are used to acquire the signal (500 Mhz, 8 bits dynamic range).

2. Improvements

In the old configuration, a single spectrometer was used for all scattering volumes; it was based on four interferential filters in a cascade design but it was coupled to a CCD camera through a gated Image intensifier. All fibers were allocated into a single bundle whose image was repetitively focused
on four sectors of the camera field, corresponding to the four different spectral channels. A signal synchronized with the laser triggered the image intensifier with a gate whose width was typically 100 ns, optimizing the signal acquired with respect to the plasma light: the TS signal duration, defined as the time in which the signal is higher than the noise, is in fact about 60 ns.

The main problem was actually the impossibility to distinguish the contribution of the two sources of background light: plasma thermal and line emission, and diffused laser radiation (stray light). The first contribution could in principle be subtracted via a second CCD acquisition, but a minimum delay time of 15 ms was required by the image intensifier characteristics. This delay time was too long compared to the variations timescale of plasma light. In a similar way, stray light contribution could be subtracted from an acquisition performed during a vacuum shot, but the image intensifier gate times proved to be slightly variable, so that this procedure became inaccurate.

Plasma light detection was solved with APD and fast digitizers; thanks to the new acquisition system, it has been relatively simple to reduce the stray light firing repetitively in vacuum conditions and optimizing the laser path.

To keep the stray light level low, the laser head is inserted very near the plasma boundary; this could have generated thermal stresses on the AR coating of the sapphire wedge which tilts the beam (fig 1); this wedge showed surface damages only on the plasma-facing side – hence the hypothesis of a thermal detriment of the AR coating. To solve the problem, laser energy has been limited to 3 joule and a new set of wedges, without AR coating, has been purchased and mounted.

Being the laser energy limited to 3-3.5 J, the S/N ratio was too low even for average plasma densities, so two fibers per scattering volume have been grouped, in order to measure 6 radial points instead of 12.

Further modifications have been:
- The change in the pinhole size from 3 to 4 mm; a 3 mm pinhole caused the loss of a large fraction of laser power and made the alignment difficult and unstable.
- The rearrangement of the fibers on the objective side; previously fibers were mounted parallel each other; this mean that for the external ones the acceptance angle vignette by the objective. The fibers now are placed with their optical axis converging in the objective centre, gaining up to 25 % in the signal.
- The shifting of the objective of 50 mm toward the plasma, passing from an F\#5 to an F\#4.5; this reduced the magnification of the system, and thus the vignetting which affected the outer scattering volumes.

The objective mounting has been modified to hold a single lens: the substitution of the objective (which has an axial transmission of 70 %) by a lens should lead to a further 20 % increment in the signal, and is one of the planned modifications - together with a change in the shutter mechanism to avoid both vignetting and interference with the laser beam.
3. Temperature and density data

Electron temperature is obtained processing the relative heights of the signals to reconstruct the scattered spectrum shape: fig.1 shows the expected relative value of the signal in the four spectral channels, as a function of temperature. Density data, on the other hand, are related to the absolute value of the scattered power and thus require a calibration of the instrument, which has been done via Rotational Raman Scattering in nitrogen (see fig 3). On the core TS system, RRS calibration suffers from material deposition on the windows, and isn’t stable during plasma experiments. Edge TS isn’t affected significantly by this problem: the pipe where the collection window is mounted is far behind the plasma and, during wall treatments, the shutter is closed. RRS proved also to be useful in checking the laser alignment, maximizing the scattering signal.

With the present setup, the system is able to measure particles densities of $3-4 \times 10^{18} \text{m}^{-3}$ and works properly for core densities over $1.5 \times 10^{19} \text{m}^{-3}$ (fig 4). Over this value, edge temperature profiles can be compared with those from the Main TS showing the consistency of the two diagnostics in the radial overlap region (fig 5); density data of the internal points are also in good agreement with values given by the interferometer.

4. LBO coupling issues

The edge TS and the LBO system share the same laser beam: during the commissioning, the beam was directed toward the LBO assembly by a mobile mirror, if impurities injection was required during the experiments. The mounting of a mirror required the re-alignment of the LBO system on each use and didn’t permit the contemporary operation of the two systems.
Being the energy required by Laser Blow Off and by the Thomson scattering of the order of 3 J, it was decided to mount a 50 % beamsplitter on the laser path with AR coating for $\lambda = 694$ nm. Simultaneous operation of the two systems has been demonstrated: LBO injection timescale is of the order of few ms and so, even in case of multiple firing, it doesn’t perturb the measured temperature profiles.

5. Developments

In the short term, double pulse operation and real time laser triggering are the most interesting possibilities.

The ruby laser can fire up to four times within a lamp discharge, with successive partial openings of the electro-optical shutter (Pokels cell) in the oscillator cavity; despite this, performing more than two pulses represents a risk for optics of the input laser system, due to energy constraint and interpulse balance issues. The total energy of the device is limited to 15 J; multiple firing simply splits the available energy among the pulses. If the present setup is maintained, the presence of the beamsplitter will leave only 5-6J for the Edge TS, sufficient, in normal density conditions, only for two pulses. Besides, balancing the pulse to pulse energy is quite simple for the oscillator, but, as the pulse are amplified, the process can become unstable and deliver most of the amplifiers energy to a single pulse, resulting in a probable damage of optics. Obviously the issue is more severe as the number of pulses (and thus the energy) increases.

Real time triggering of the laser has been successfully tested for the Main TS: the trigger signal is generated as the dominant mode amplitude exceeds a given threshold. For Edge TS operation, an application can be selective shooting during QSH crashes, to characterize edge transport modifications.

6. References

[1] A. Alfier and R. Pasqualotto 2006 Rev. Sci. Instrum. 77 10E501
[2] A. Alfier and R. Pasqualotto 2007 Rev. Sci. Instrum. 78 01350

Figure 5: Example of electron temperature and density profiles obtained by the Edge TS, for the edge region (left) and for the whole radius (right); temperature data are consistent with the Main TS data (empty dots), while the density values for the inner points agree with the core value measured by interferometer.