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First Operations with the New Collective Thomson Scattering Diagnostics on the Frascati Tokamak Upgrade Device

W. Bin[a*], A. Bruschi[a], O. D'Arcangelo[b], C. Castaldo[b], M. De Angeli[a], L. Figini[a], C. Galperti[c], S. Garavaglia[a], G. Granucci[a], G. Grosso[a], S. B. Korsholm[d], M. Lontano[a], V. Mellera[a], D. Minelli[a], A. Moro[a], A. Nardone[a], S. K. Nielsen[d], J. Rasmussen[d], A. Simonetto[a], M. Stejner[d] and U. Tartari[a]

[a]*Istituto di Fisica del Plasma - Consiglio Nazionale delle Ricerche,*
Milano (Italy)
[b]*ENEA for EUROfusion,*
Frascati (Italy)
[c]*Ecole Polytéchnique Fédérale de Lausanne, Centre de Recherches en Physique des Plasmas,*
Lausanne (Switzerland)
[d]*Technical University of Denmark, Department of Physics,*
Kgs. Lyngby (Denmark)
E-mail: `wbin@ifp.cnr.it`

ABSTRACT: During the last years, in addition to signals recognized as Collective Thomson Scattering (CTS), other anomalous emissions have been found in the spectra analyzed with the CTS diagnostics in tokamak devices like TEXTOR, ASDEX and FTU. The signal frequency, down-shifted with respect to the probing one, suggested a possible explanation of their origin in terms of Parametric Decay Instability (PDI) processes correlated with the presence of magnetic islands and taking place even for values of the pumping wave power well below the threshold predicted by conventional models. A threshold lower or comparable with the power levels routinely used could pose limitations, under certain conditions, to the use of the ECRH in fusion devices. An accurate characterization of the conditions for the occurrence of this phenomenon and of its consequences is thus of primary importance. Exploiting the front-steering configuration available with the real-time launcher, a new CTS setup allows studying in FTU these anomalous emissions in conditions of density and wave injection that are a step towards the ITER CTS system. The upgrades of the diagnostics are presented as well as some preliminary spectra detected with the new system during the very first operations carried out in 2014. The present work has been carried out under an EUROfusion Enabling Research project.

KEYWORDS: Nuclear instruments and methods for hot plasma diagnostics; Microwave Antennas.

*Corresponding author.

Contents

1. Introduction

Since the first installation [1, 2] on the Frascati Tokamak Upgrade (FTU) device, the main feature of the Collective Thomson Scattering (CTS) experiment consisted in studying the thermal scattering of electron cyclotron waves in the propagation window below the 1^{st} harmonic, in a condition similar to the one foreseen for the CTS diagnostic of fast ion distribution function in ITER. An additional and recent aim of this experiment is to resolve anomalous signals sometimes measured with the CTS diagnostics of different tokamaks, that may be correlated to the presence of rotating MHD magnetic islands. The first observation of such signals has been carried out in TEXTOR [3, 4], where a strong dependence of the measured power from the magnetic field and the plasma density has been found, as described in [4]. Subsequently, evidences of similar radiation have been found also in ASDEX and FTU. These anomalous emissions have been attributed [5, 6] to a parametric decay instability (PDI) process occurring at a probing power threshold well below the one predicted by other conventional models [7], leading to power thresholds for PDI appearance several orders of magnitude higher than the typical power levels emitted by gyrotrons. If confirmed, this phenomenon might, under certain conditions, affect the detection of the thermal CTS spectra in tokamaks, preventing an accurate measurements of ion and fast ion temperature, and such (unexpected) low power threshold for PDI could even prevent, under some other conditions, an efficient use of ECRH in fusion devices. FTU offers the possibility to carry out these studies in a plasma with electron density similar to the ITER one, where a sub-harmonic millimeter wave probe can be injected, in both ordinary and extraordinary propagation modes. The main aim of the CTS experiments in progress in FTU is to study the scattered signal from the MHD tearing modes position and to characterize this phenomenon as deeply as possible, exploiting a new CTS diagnostics system.

2. The new CTS diagnostics in FTU

2.1 The new layout

In the new CTS diagnostic layout, one of the two lines of the real-time front-steering launcher of FTU [8, 9, 10] is used to launch the probe beam. The launcher is shown in Figure 1-left during laboratory tests at low power [11]. The second line of the launcher is designed either to inject ECH power or to receive 140 GHz radiation, for both CTS experiments and studies of the reverse OXB mode coupling scheme [12, 13]. In the new diagnostics this line is used to transmit the scattered signal to the radiometric system.

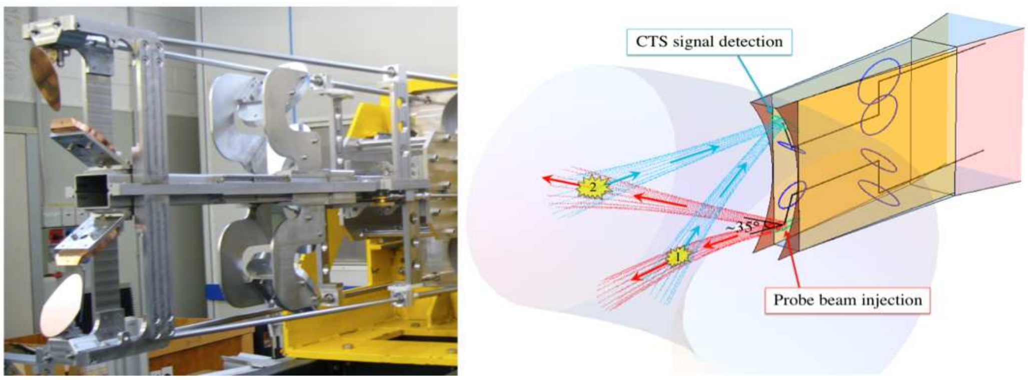

Figure 1. Left: picture of the two front steering electron cyclotron antennas used in the new CTS diagnostics of FTU to inject the probe beam (the lower one) and to detect the scattering signal (the upper one). Right: 3D view of the new CTS configuration of FTU from the vacuum vessel side. The CTS beams, simulated with beam tracing calculations, are shown while crossing at low toroidal angle ($\approx 0^\circ$) off-axis (intersection 1) and at high toroidal angle ($\approx 35^\circ$) on-axis (intersection 2).

In Figure 1-right two simulations of launched and received CTS beams are presented, showing, from the plasma side, the poloidal symmetric configuration of the two antennas of the FTU front steering launcher with respect to the equatorial plane of the torus. The simulation is made using GRAY [14], a quasi-optical beam tracing code that can compute electron cyclotron wave propagation, absorption and current drive in a general tokamak equilibrium.

The receiving line of the launcher is provided with a box for switching the received radiation from the ECH transmission waveguide to the receiver front-end [15, 16], connected to the 140 GHz radiometer. The transmission line exploited to propagate the CTS signals from the torus hall to the radiometer has been recently installed on FTU and consists of a mix of quasi-optical mirrors and a section of low loss HE_{11} overmoded corrugated waveguide with 88.9 mm diameter.

To allow the selection of the ordinary or the extraordinary propagation mode in the received radiation and to match correctly the polarization ellipticity to the receiving horn, a couple of universal polarizers with $\lambda/4$ and $\lambda/8$ corrugation depths has been installed in front of the feed horn of the CTS front-end. The control of polarization of both the injected and the received beams opens the possibility to perform CTS experiments in FTU exploring all the possible combinations of propagation modes. A numerical code, capable to calculate the beam changes after all the reflections (20) present along the CTS line has been developed in order to define the correct configuration of the polarization section, checked also with low power measurements before starting the experiments. The calculations in the code are carried out by mapping the polarization parameters from the plasma back to the polarizers.

2.2 Recent improvements on the signal analysis

For the investigation mentioned above and to allow the study of rapidly modulated emissions correlated with rotating islands, the CTS diagnostics of FTU has been recently improved with a new fast data acquisition, which was implemented for the first time in ASDEX [17], allowing spectra reconstruction by direct FFT of the intermediate frequency signal and added in parallel to the preexisting multichannel spectrum analyzer, which was originally installed in FTU for thermal ion distribution measurements. The spectrum analyzer consists of a 32 channels filter bank, optimized for a single-sideband detection of ± 1.2 GHz from the local oscillator frequency (tuned at the same frequency of the probe beam, provided by a 140 GHz 500 kW GYCOM gyrotron). The new digitizer (8 bit, NI PXIe-5186 express) is capable to resolve signals in an analog bandwidth of 5 GHz and a maximum of two channels in parallel can be used to acquire signals: a single channel can be exploited at a maximum sampling rate of 12.5 GS/s while two channels in parallel can be digitized @6.25 GS/s each. The down-converted signal is directly acquired and sampled after the front-end radiometer stage, which includes the local oscillator, the mixer and two cascaded amplifiers. Once sampled, the digital signal is stored and can be numerically processed by FFT analysis. A dedicated software has been developed to Fourier transform the raw digital signals and to visualize the final spectra. Calibration of spectra is made with a shot with electron cyclotron resonance in the plasma, by normalizing the data on the ECE reference emission, in such a way to obtain constant signal when receiving ECE. When needed, also offset (taken at times after the shot) is subtracted to the ECE to obtain the calibration spectrum. The data acquisition in parallel with both the digitizer (fast but with short time duration due to memory constraints) and the spectrum analyzer (whose signals are acquired for the whole shot duration) can be helpful for the study of the different signals detected. At the present status, the bandwidth of the digitizer is limited ($\sim$1.2 GHz) by the bandwidth of the IF amplifiers installed after the mixer in the receiving chain and in common to both the systems. For this reason the level of signals gradually decreases at frequencies beyond $\sim$1.2 GHz from the local oscillator frequency, going to zero at a frequency distance up to near 2.0 GHz. Since the mixer output band in principle can cover several GHz, an upgrade with amplifiers with a wider frequency range is scheduled. This will open the possibility to operate with the full capability of 5 GHz bandwidth allowed with the digitizer.

3. Starting the operations with the new diagnostics

In 2014 the first experiments started with the upgraded CTS diagnostics, using both the fast digitizer and the spectrum analyzer in parallel during the plasma shots. A careful analysis of the antennas configuration was required to locate the scattering volume on the rational surfaces of magnetic islands and has been carried out by simulating the propagation of the probe and the received beams with the FTU plasma parameters. Typical islands in FTU are located at the rational surfaces where the safety factor q equals the ratios m:n=2:1 and m:n=3:2, and they may be spontaneous (under certain plasma conditions) or they can be induced by Neon or Argon injection.

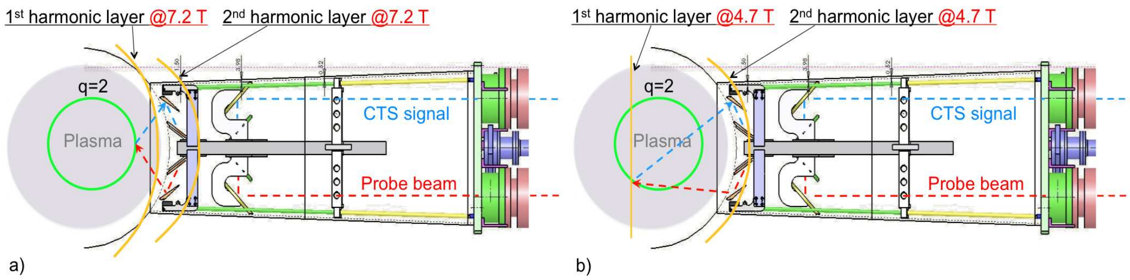

Figure 2. Left: poloidal view of the FTU launcher where the two paths of the probe beam (red) and the received beam (blue) are shown, intersecting on the equatorial plane at the plasma flux surface where the m:n=2:1 island forms. The 1^{st} and 2^{nd} harmonic resonance layers are sketched for B_T=7.2 T. This CTS configuration with intersection on the equatorial plane has been exploited with both magnetic fields of 7.2 T and 4.7 T. Right: configuration studied only at B_T=4.7 T, where both the m:n=2:1 island and the 1^{st} harmonic resonance layer are intersected by the scattering volume. In this case the locations of the two harmonic layers are sketched for B_T=4.7 T. Note that, in this case, the 2^{nd} harmonic layer is closer to the backside of the launching and receiving mirrors with respect to the 7.2 T case.

Two plasma scenarios have been tested with the front steering launcher (see Figure 2). The first one was with a toroidal field of B_T=7.2 T, such that the 1^{st} electron cyclotron harmonic resonance (which for 140 GHz is @5 T) was out of the plasma on the low field side of the torus. In principle a toroidal field up to 8 T may be exploited in FTU, but 7.2 T has been chosen as the proper one to operate sub-harmonic since lower fields would imply the resonance layer to shift too close to the plasma edge while at higher fields it would be too close to (or even in correspondence of) the antenna mirror. The configuration with B_T=7.2 T allows sub-harmonic CTS operations using a non-resonant probe whose frequency is below the fundamental harmonic in all the plasma volume and is the most similar to the one foreseen in the ITER CTS system. As in ITER, in the FTU sub-harmonic scenario the fundamental harmonic layer turns out to be located in a region of the transmission line which is under vacuum. Nevertheless, it is worth noting that in FTU the 1^{st} harmonic layer is always close to the vacuum vessel wall, in front of the plasma-facing mirror surfaces, even using a high toroidal field such as 7.2 T. On the other side, according to the present design of the CTS system [18, 19], the sub-harmonic operations in ITER are foreseen with the resonance layer far from the plasma edge. From the point of view of possible effects due to the beam passage at the resonance layer this may be different with respect to the FTU layout, since the risk of arcing depends on the local electric field and on the neutral gas density at the resonance location that are more controllable in the ITER case than in FTU.

The second scenario with a lower field of 4.7 T led to a positioning of the fundamental harmonic resonance in the plasma, on the high field side. This last scenario is more suitable for lowering the stray radiation, which turns out to be strongly dumped at the cyclotron harmonic layer. It is worth noting that the expected anomalous emissions due to PDIs should be considerably stronger than ECE. Therefore, in spite of the strong ECE which reduces the possibility to study the faint thermal CTS emissions, such a resonant scenario can be exploited to study possible PDIs phenomena at the magnetic islands surface. The scenario with B_T=4.7 T has been used for scattering measurements either crossing the probe and the receiving beams in the low field side on the equatorial plane of the torus (thus forming the scattering volume in a region far from the resonant layer @5 T) or intersecting them at the 1^{st} harmonic resonance, in this case with an asymmetric CTS configuration and the scattering volume out of the equatorial plane, to reach at the same time also the m:n=2:1 island position. This last kind of intersection is carried out to study the effects of possible PDIs on ECH, at the position where the beam is absorbed in the plasma.

In both cases the scattering volume has been placed in correspondence of the expected m:n=2:1 tearing mode location, in order to stimulate the occurrence of anomalous signals from plasma regions associated with non-monotonic electron density profile, according to what is expected by some theoretical models [5, 6]. The comparison of resonant and non-resonant scenarios should be helpful to better comprehend possible interactions of PDIs on the ECH efficiency. From the point of view of the launcher safety the main difference between these two scenarios consists in the position of the electron cyclotron harmonic layers (mainly the 1^{st} harmonic layer in the 7.2 T scenario and 2^{nd} harmonic layer in the 4.7 T case) with respect to the launching mirror used for the probe injection. In Figures 2-a and 2-b a poloidal view of the FTU launcher is shown, where the two paths of the probe beam (red) and the received beam (blue) are indicated, intersecting at the plasma flux surface where the m:n=2:1 island forms, on the equatorial plane in Figure 2-a and out of it in Figure 2-b. The 1^{st} and 2^{nd} harmonic resonance layers are sketched in Figure 2-a for the case B_T=7.2 T, the first one in front of the antenna mirrors (but outside the plasma), the second deeper in the port. This CTS configuration, with beams intersection on the equatorial plane, has been exploited also in experiments where the magnetic field was 4.7 T. The CTS configuration in Figure 2-b, used instead only with B_T=4.7 T, shows the two CTS beam intersecting at the plasma flux surface where the m:n=2:1 island forms but this time crossing also the 1^{st} harmonic resonance layer. This configuration, which for geometrical reasons requires that the beams cross out of the equatorial plane, is used to investigate if the phenomena observed with the CTS diagnostics affect the wave absorption. In Figure 2-b the 1^{st} and 2^{nd} harmonic resonance layers are sketched for the case B_T=4.7 T. It can be seen how only the 2^{nd} harmonic layer turns out to be in the proximity of the launcher mirrors in this case. The interception of the probe beam with the receiving line of sight has been studied for the two toroidal angles 5° and 35°. Angles lower than 5° are discarded to prevent possible direct back-reflections of power into the transmission line while angles higher than 35° would be too close to the angular limits of the automatic protection system of the antenna steerable mirrors [20, 21]. The interest in studying CTS at different toroidal angles lies in the fact that when the angle between the magnetic field and the scattering vector (which is the difference between the two wave vectors of the incident and scattered radiation) approaches 90° modulations appear in the thermal CTS spectra at the ion cyclotron frequency ω_{ci} [22], while other emissions could be unaffected for any launching (and receiving) angle.

4. First experimental observations on the plasma

With the FTU launcher a great dynamical flexibility and a capability to intersect the beams in most of the plasma volume in real-time with continuous movements are available. In the CTS experiments carried out up to now the scattering volume has been located on the equatorial plane of the torus, whenever possible. The reason is to preserve the symmetry of the scattering configuration allowed by the two antennas, which for probe injection and CTS detection are provided with two plasma-facing mirrors that are located at positions with an up-down symmetry in the poloidal plane with respect to the equatorial plane. As already said an asymmetric CTS configuration, with the

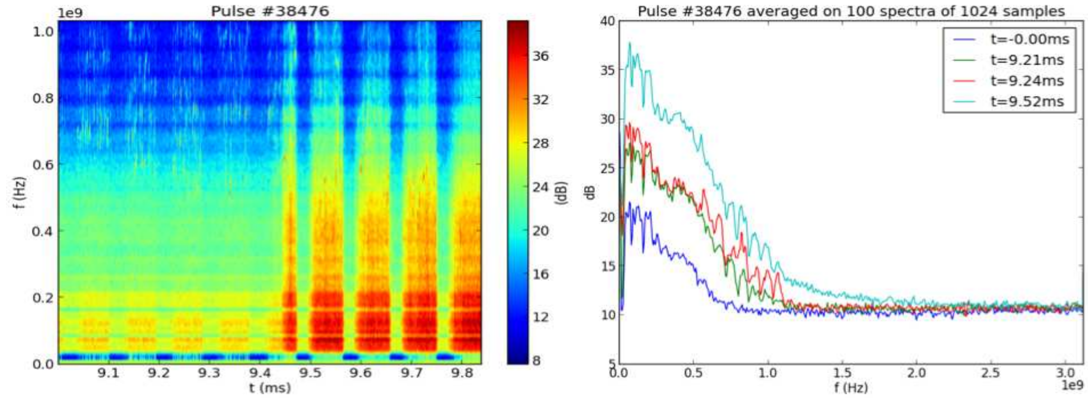

Figure 3. Left: uncalibrated spectra measured with the fast digitizer in shot #38476 (B_T=7.2 T, without magnetic islands), displayed in dB. A transition from quiet to intense activity occurs at t≈9.45. Time on abscissa starts from the end of an interval at the beginning of the pulse when the gyrotron frequency is unstable (leading the radiation frequency falling partially out of the notch filter cutting frequency range) during which a pin diode blinds the receiver, in order to protect the mixer from the high level of stray radiation. A 10 kHz chopping (period of 0.1 ms) is also visible, made to exploit modulation-demodulation stages on the spectrum analyzer for increasing the signal-to-noise ratio. Frequencies in the spectra are measured in GHz. Right: a few spectra are shown at different times of the shot.

scattering volume out of the equatorial plane, was used only in plasma scenarios with B_T=4.7 T, to intersect the scattering volume with the 1^{st} harmonic layer and the m:n=2:1 island.

The first operations at high toroidal field of 7.2 T were carried out without any major technical problems. Such high field was expected to be the most critical for the safety of the launcher, due to the position of the injecting mirror close to the fundamental resonance layer, with a risk of mirror damage in case the injected power intersects with the resonance forming a plasma close to the mirror surface. The safe operations of the probe beam injection at high field have been confirmed both during the experiments, by monitoring the plasma with UV spectroscopy for checking possible release of copper from the mirror surface, and at the end of the experiments, performing a visual inspection of the launcher front which confirmed the good condition of the mirror after the operations with B_T=7.2 T. The visual inspection has been carried out from the vacuum side of the vessel with the launcher installed in the FTU port, using the inspection system described in [20].

All measurements from the plasma have been carried out so far injecting and receiving ordinary polarized radiation. In the scattering spectra detected during the first experiments different types of signals have been measured in the frequency range of 1.2 GHz from the probe frequency. The real origin of several signals (that sometimes have been found with intensity level comparable to the ECE emission) is still under investigation and, at the present status, seems to be mostly ascribed to the gyrotron frequency instability found during the first phase of experiments, leading to exclude a real CTS nature.

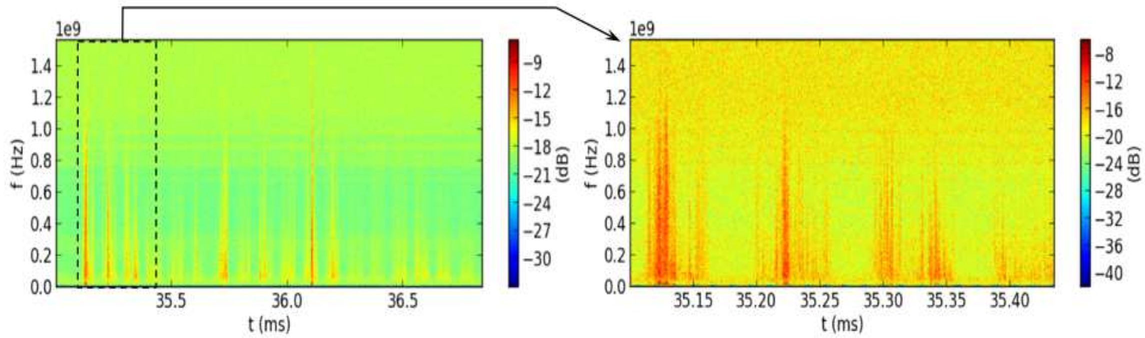

Figure 4. Left: another example of spectrogram measured (@4.7 T) with the fast digitizer acquisition. Rapid emissions are detected in this case as bursts and spikes. Right: expanded view of dashed region on the left picture, showing the great time resolution available with the new fast digitizer. Also in these cases the overlapping modulation-demodulation stages made with 10 kHz chopping (period of 0.1 ms) is superimposed.

In the spectrum shown in Figure 3, acquired in shot #38476 (B_T=7.2 T), the power detected by CTS varies slowly from quiet to more intense in a few tens of μs, where corresponding changes in the plasma conditions are not evident. Another spectrogram is shown in Figure 4, measured this time at B_T=4.7 T in shot #39005. In this case the detected signal show emissions at high frequency, rapidly changing in time, in the form of rapid bursts. Thermal CTS signal may be excluded in both the spectra shown in Figure 3 and 4, since attenuations in this phase of experiments were too high to allow detection of such faint emissions. Anyway, in both these examples, the high resolution in time allowed by the new fast digitizer and the potentiality of the new diagnostics can be appreciated.

4.1 Investigation of breakdown plasma in the launching port

The formation during the probe beam injection of an undesired breakdown plasma in the port, at the harmonic resonance layer in the proximity of the injecting mirror, is under investigation. It is the most likely origin of emissions showing slow variation in time and being uncorrelated with the MHD activity, that have been measured with both the magnetic configurations at 4.7 T and 7.2 T. An indication of breakdown in the antenna port is given by the appearance of gyrotron mode jumps during the plasma discharges. Sometimes more than a single jump have been observed in the same shot, as in the case shown in Figure 5-left, where broadband emissions are detected (shot #38995, B_T=4.7 T) for most of the pulse length and two subsequent mode jumps occur before the gyrotron pulse is interrupted, probably due to back-reflections into the transmission line. When breakdown occurs in the antenna port and ionized gas is encountered along the beam path, in fact, the correct polarization control of the wave can be lost, while the beam propagates through the breakdown plasma, and the extraordinary polarized component of radiation can be back-reflected to the gyrotron, leading to disturbances and mode jumps in the cavity. In the spectrogram shown in Figure 5-left, during the different time lapses delimited by mode jumps, signals are emitted with different power levels and at different frequencies, at well defined frequency distance from the probe. The spectrogram has been acquired with the multichannel spectrum analyzer.

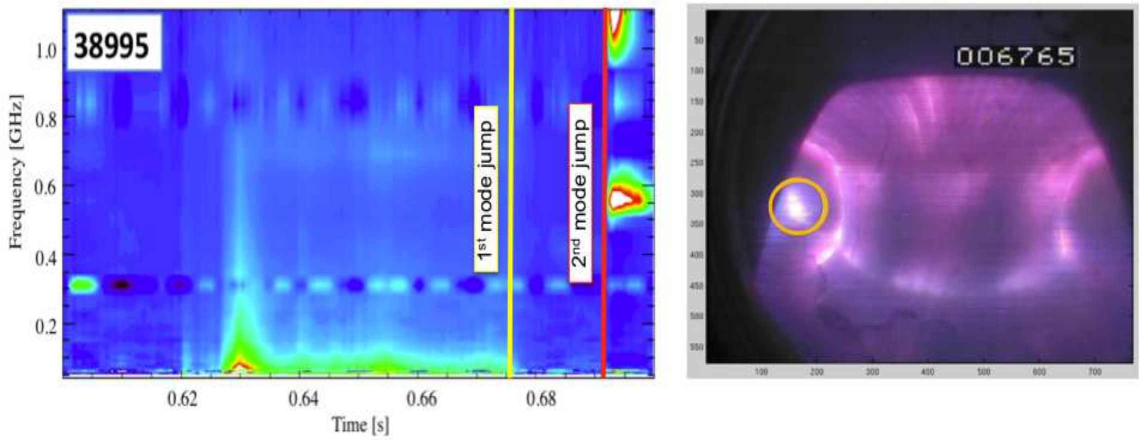

Figure 5. Left: broadband signals appearing in a spectrogram measured with the spectrum analyzer (shot #38995, units are V). The origin of this kind of emissions is ascribed to the formation of breakdown in the port. A first gyrotron mode jump occurs at t≈0.675 s (yellow marker), followed by a second mode jump (red marker), in correspondence of which strong signals are detected with CTS. Right: light detected during the pulse from the inner low field side of the vacuum vessel (orange circle) with a visible light camera looking the ECRH port from 90° line of sight.

In support of this hypothesis also a strong light could be detected from the inner low field side of the FTU vacuum vessel during several shots using a visible light fast camera looking towards the launcher port during the ECRH pulses. In Figure 5-right a frame is shown, taken from a movie recorded with the camera during the ECRH injection in shot #38995, 70 ms after the beginning of the gyrotron pulse. The study and the characterization of this phenomenon may become important also in view of ITER, in particular in the proximity of the fundamental resonance in the sub-harmonic CTS scenario. The aim is to investigate the conditions under which this phenomenon can be prevented.

In order to monitor the phenomenon as accurately as possible during the probe injection three new diagnostics have been installed in 2015 in the FTU port housing the front-steering electron cyclotron launcher. They are implemented for detection of light and radiation due to breakdown in the port where the probe beam is launched. The goal is to discriminate the signals due to plasma creation in the port from signals coming from the FTU plasma. The three systems have been installed on the vacuum flange of the two antennas used for CTS and they monitor the inner (vacuum) side of the launcher from outside, through two different optical windows. The three diagnostics, which can be remotely controlled during the experiments, are shown in Figure 6-left, as installed on the back flange of the launcher.

The first diagnostics is a visible-light CCD sensor camera (Toshiba®, model csu9001p, 12 mm diameter/12 mm focal length) which has been installed on one of the two optical vacuum windows. The camera allows recording images from a line of sight looking to the inner side of the ECRH line used to inject the CTS probe. The evidences of breakdown in the antenna have been confirmed with the use of this camera. A light emission during several ECRH pulses has been detected, when a similar light could be detected also with the visible camera looking at the launcher front from the vessel side (as in Figure 5-right). A couple of images taken with this system are shown in Figure 6-right. A frame taken in a time interval of the discharge when no power is injected is shown on top of the figure (where only the light emitted by the plasma is detected from the vessel, on the far side), while a strong light emission due to breakdown in the port during the ECRH pulse is visible in the picture on the bottom.

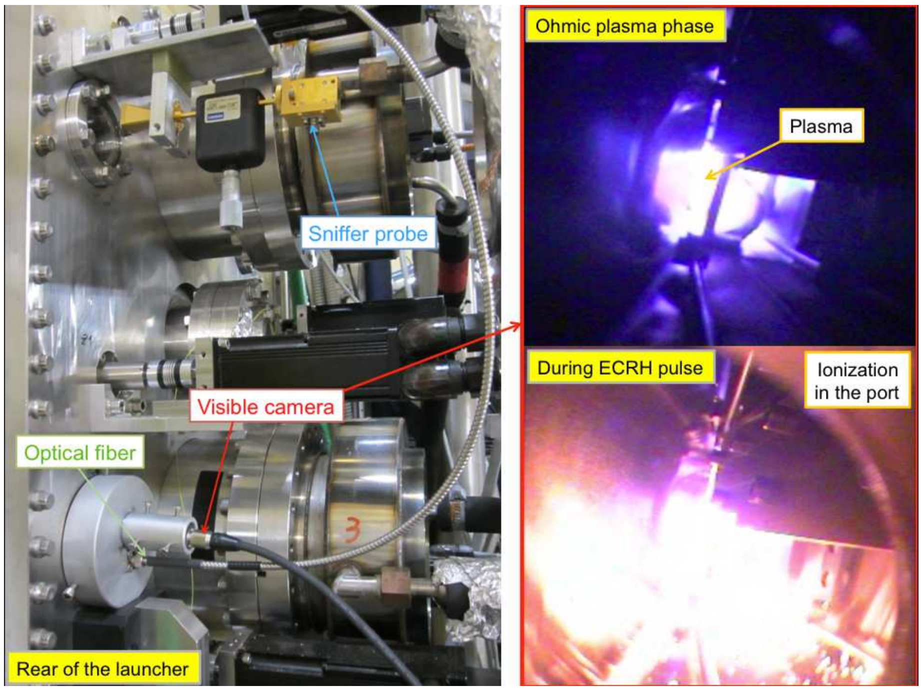

Figure 6. Left: picture of the vacuum flange on the backside of the FTU launcher. The visible camera, the optical fiber and the sniffer probe that have been recently installed to monitor breakdown in the port during the ECRH pulses are shown. The visible camera and the optical fiber shares the same sustain on the lower optical vacuum window while the sniffer probe is mounted alone in front of the second (upper) window. Right: two frames taken from a movie recorded with the visible camera in shot #39690 (@4.7 T). The first one is out of the ECRH shot, showing light coming only from the plasma seen through the launcher while the second one is taken during EC injection, when breakdown occurs in the launcher line.

The second diagnostics consists of an optical fiber (indicated with the green arrow in Figure 6-left) formerly used in FTU for an electro-optical probe [23] and connected to a photon counter, acquiring signals from the same line of sight of the visible camera described above. The fiber shares the same support on the backside of the flange with the camera. This system has a time response much higher than the camera and acquires light data with a time resolution of 10 μs. The signals acquired with the fiber during the power injection confirmed the presence of strong emissions, in accordance with what has been observed with the other diagnostics. Both the visible camera and the optical fiber systems turn out to be reliable diagnostics to monitor emissions from the port.

The third system, installed in front of the second optical vacuum window, is a sniffer probe exploited to measure the level of stray radiation in the port. The sniffer is a Millitech DXP 08 detector whose signal can be directly acquired and stored in the FTU database and which now is automatically acquired during the plasma shots. Presently, this diagnostics (which has been already installed on the vessel port) is still under commissioning, requiring a proper signal conditioning and attenuations to operate during CTS experiments.

5. Future prospects

Apart from mode jumps, ascribed to wave reflections from the port, during the first experiments of 2014 sometimes the gyrotron turned out to be not stable enough in frequency to carry out accurate CTS measurements. Several frequency shifts arose during the pulses, in a range up to some tens of MHz, with fast changes of about 0.5 GHz in around 50 μs, making the stray gyrotron radiation fall outside the notch filter central frequency. To protect the mixer from the stray power, the experiments were carried out setting attenuations higher than the proper one for CTS measurements. In the beginning of 2015, an intervention on the gyrotron system was made, with success, to better stabilize the frequency of the gyrotron, from the end of the first phase (of some tens of ms) when the frequency is normally unstable, to the end of the CTS pulse length. The final performances of the gyrotron after the improvement has been confirmed by measuring its frequency with both the fast digitizer and the multi-channel radiometer. A frequency measure performed using the fast digitizer is shown in Figure 7, where the local oscillator frequency (corresponding to 0 on the ordinates) has been set about 500 MHz away from the gyrotron frequency, to allow a central visualization of the gyrotron line in the spectrogram.

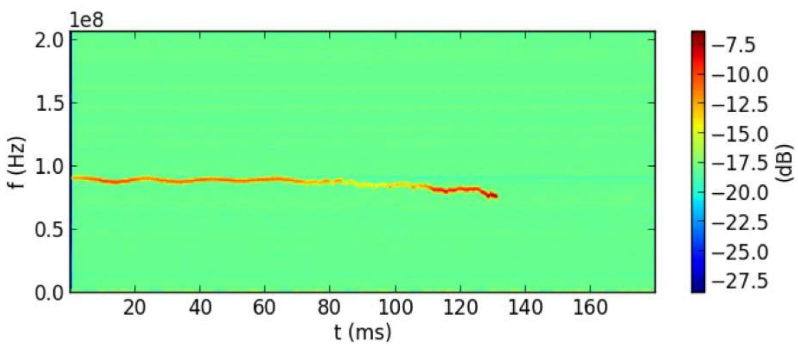

Figure 7. Measure of the gyrotron frequency acquired with the fast digitizer after the improvement of the gyrotron stability in frequency. The measure of the signal has been carried out acquiring the signal from the plasma, with a regulation of the gyrotron parameters such that the frequency of the probe was slightly shifted from the central frequency of the notch filter and setting proper attenuations on the front-end to protect the mixer. Frequencies on ordinates are in 10^8 Hz.

A second radiometric system is also being prepared, to be installed in the CTS diagnostics of FTU. The system is now in the laboratories at IFP-CNR (Milano), for off-line tests and for refurbishment of front-end and back-end, and its installation in the CTS diagnostics of FTU is scheduled between the end of 2015 and the beginning of 2016, to be used in parallel to the present one. The front-end and the back-end of this system, already operating in the past in the W7-AS device [24], are very similar to the system operating on FTU and now they have been reassembled.

As the present multi-channel spectrum analyzer, this system is provided with 32 channels and a set of bandpass filters. These new front-end and radiometer will be connected to a second branch of the polarization section of the CTS line and to the second channel of the fast digitizer. These upgrades will allow to perform measurements in FTU simultaneously with both the two channels available on the fast digitizers (@6.25 GS/s of resolution each) and both the two filter banks (with 32 channels each, acquired @2 kHz). The two synchronized radiometric systems will be used to detect radiation in both O- and X-mode at the same time, to identify emissions of different origin, or alternatively to measure scattered signals from two different lines of sight. As already implemented in the ASDEX CTS system [25], for this aim a further receiving antenna and the relative optics matching this new antenna to the present receiving line are being designed also in FTU. This new receiving antenna will operate simultaneously to the current receiver and it will be integrated in the same port and launcher exploited for CTS, between the two injecting and receiving lines. The new system will allow to have a second line of sight for CTS experiments, with an angular capability of about $\pm 15^\circ$ in toroidal or poloidal direction, which will be used also for cross-calibrations and reference of the background signal out of the magnetic island position.

6. Conclusions

The recent advances of the new CTS diagnostics installed on the FTU device consist in the addition of a new fast digitizer put in parallel to the pre-existing multichannel spectrum analyzer and in the use of the new diagnostic layout, which exploits the front steering electron cyclotron launcher recently installed on FTU.

After a first characterization of the scattering configuration carried out with beam tracing calculations the first operations on the plasma started in 2014. This first phase of experiments has been carried out using two different toroidal magnetic fields of 7.2 T and 4.7 T. The scenario at 7.2 T has been explored for the first time with the front steering launcher of FTU. The two toroidal fields allowed to test two different regimes for CTS, the first one (B_T= 7.2 T) with a sub-harmonic probe beam, similar to the CTS configuration in ITER, and the second one (B_T=4.7 T) with the fundamental electron cyclotron harmonic in the plasma. The first measurements carried out on the plasma in 2014 have been affected by a frequency instability of the gyrotron found during the operations, which forced to use high attenuations to protect the mixer on the front-end from stray radiation falling outside the notch filter. In any case the spectra show several features that are presently under investigation.

The formation of a breakdown plasma in the antenna port during the probe beam injection is the most likely origin of emissions with slow variation in time and several line emissions due to gyrotron mode jumps found during the operations. Three new diagnostics have been installed on the CTS launching system, consisting of a couple of visible systems (a camera and an optical fiber), to detect visible light emissions in the antenna port, and a sniffer probe detector, to measure the level of 140 GHz stray radiation at the probe injection point. The three diagnostics will help in the discrimination of signals originating in the port from those coming from the plasma.

In 2015 the gyrotron used to inject the probe beam has been stabilized in frequency, after the first experiments carried out with high attenuations. Now the CTS gyrotron, more stable in frequency, is ready to be used for the upcoming experiments.

A second radiometric system is also being prepared to carry out measurements using simultaneously the two channels available on the fast digitizers and two filter banks radiometers. This will open the possibility to measure scattered radiation in O-mode and X-mode simultaneously and to receive signals from two different lines of sight in the plasma with a new receiving antenna.

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