FIRST MEASUREMENTS OF ELECTRON ENERGY DISTRIBUTION IN RFX EDGE PLASMA

Y. Yagi*, V. Antoni, M. Bagatin, **D. Desideri**, E. Martines, G. Serianni, F. Vallone

Gruppo di Padova per Ricerche sulla Fusione
Associazioni EURATOM-ENEA-CNR-Università di Padova
Corso Stati Uniti, 4 - 35127 Padova (Italy)
*Electrotechnical Laboratory, Tsukuba (Japan)

1. Introduction

In the outer region of plasmas confined in reversed field pinch (RFP) experiments a high energy tail is commonly observed in the electron distribution function [1]. These superthermal electrons flow along the magnetic field lines, which in the outer region are nearly poloidal, carrying a substantial fraction of the edge current density. Their existence in the reversed field pinch experiment RFX has already been inferred from soft X-rays detected by a Target Emission Probe (TEP) [2] and from the up/downstream asymmetry in shot-integrated energy flux measurements with calorimetric probes [3]. The TEP measurements have also shown the presence of a small backflow.

In order to measure the time resolved flux and energy spectrum of superthermal electrons, an electrostatic Electron Energy Analyzer (EEA), developed at the Electrotechnical Laboratory of Tsukuba, has been employed in RFX.

2. EEA equipment and experimental setting up

The structure of the EEA is identical to that used on TPE-1RM20 [4] except for the outermost molybdenum jacket, which has been replaced with a graphite one to be compatible with the full graphite first wall of RFX. Because of the thicker jacket, the distance of the entrance hole for the electrons from the tip of the EEA is one millimeter greater on RFX (8.5 mm) than on TPE-1RM20 (7.5 mm). On RFX, the jacket has been kept electrically floating, whereas in TPE-1RM20 it was electrically connected to the vacuum vessel.

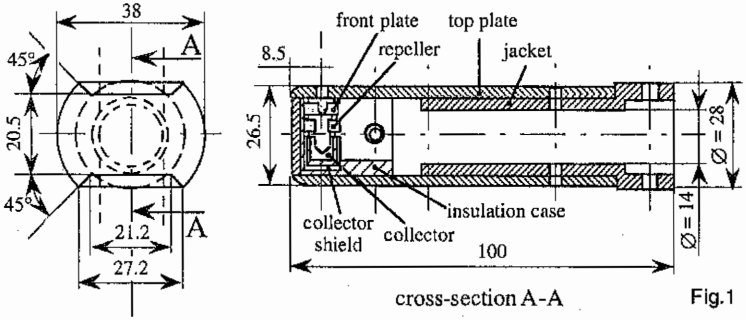

Fig.1

A schematic cross section of the EEA is shown in fig.1. The core of the device consists of a front plate, a repeller and a collector. The electron energy distribution is derived measuring the collector current as a function of the repeller voltage, which is varied in order to discriminate the energy of the electrons passing through a narrow pinhole in the front plate. The front plate is made of molybdenum, while the repeller and the collector are made of a W 65% and Cu 35% alloy. The front plate has a 2.5 mm ∅ channel with a 0.1 mm ∅ pinhole (0.05 mm thick) to reduce the current of superthermal electrons without distorting their energy distribution. Note that typical Larmor radii of bulk edge electrons and hydrogen ions in the edge of RFX for 600 kA discharges are 0.07 mm and 3 mm respectively. The Laplace equation has been numerically solved to simulate the potential profile in the repeller surroundings. The on-axis potential in the repeller hole (3 mm ∅) is found to be ~ 95% of the applied voltage. The collector is kept to a voltage of +70 V (referred to the vacuum vessel, as all the voltages reported in the following) in order to avoid the loss of secondary electrons. No breakdown is observed up to a repeller potential, V_{rep}, of -600 V, even though the inner volume of the EEA is not differentially pumped. The tip of the graphite jacket has been radially inserted up to 19 mm beyond the graphite tiles. The system can be rotated of ±180 degrees around its axis to ensure alignment with the local magnetic field.

A specific linear power supply has been developed in order to apply a variable voltage waveform to the repeller up to 1 kV, with a rise and fall time of a few milliseconds. The measured signals are: the voltage applied to the repeller, the collector current, the floating potential of the graphite outermost jacket and the front plate voltage. Ground loops have been avoided using isolation amplifiers.

The measuring circuits give a resulting bandwidth of 5 kHz for the floating potential signals, of 10 kHz for the collected current and of 35 kHz for the repeller voltage. The floating potential signals have been digitized by a 16 channels INCAA Model CADF transient recorder at a sampling rate of 10 kHz; the current and the repeller voltage by a 4 channels INCAA Model CADH transient recorder at a sampling rate of 80 kHz.

3. EEA operation

The repeller voltage V_{rep} has been linearly swept in 10-20 ms up to -600 V, several times per discharge. Figure 2 shows an example of V_{rep} and I_{col} (collector current) waveforms, along with the plasma current and the toroidal magnetic field at the wall. It is worth noting that the I_{col} signal starts when the toroidal field at the wall changes sign, as a consequence of the EEA becoming aligned with the local magnetic field. I_{col} vs. V_{rep} characteristics measured during each ramp have been used to obtain information about the electron distribution function.

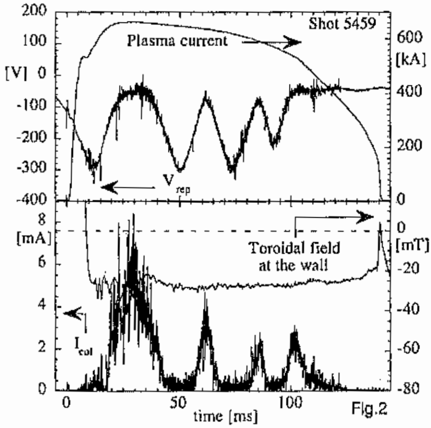

Fig.2

Two experimental campaigns were performed, both of them on 600 kA discharges. In the first one the front plate was electrically floating. The analysis of the data from this campaign showed that, due to the superthermal electron flux, the front plate reached a floating potential of ~ -200 V depending on the insertion depth. Only repulsive voltages lower than the front plate voltage are useful for the I_{col}-V_{rep} characteristic, since for higher ones the I_{col} signal becomes almost constant. In fact the Debye sheath thickness is comparable to the pinhole diameter, causing the front plate to act as an effective repeller. Therefore, during the second campaign the front plate was connected to the vacuum vessel through a 2.3 Ω, 50 W resistor. Such a connection led to typical front plate voltages of -20 V, allowing also the low energy part of the distribution function to be explored.

The front plate heating due to the superthermal electron energy flux has been estimated. The rise in temperature of the region around the pinhole during a typical RFX discharge turns out to be much less than the evaporation temperature of the molybdenum. The inspection of the pinhole after the experimental campaigns has confirmed that its diameter was unchanged even after many discharges.

4. Measurements

Applying a time changing voltage to the repeller, I_{col}-V_{rep} characteristics have been deduced with the EEA exposed to the electron drift side. On the ion drift side the current signal turned out to be too small to provide reliable characteristics. An example of characteristic obtained on the electron drift side is shown in fig.3. The characteristic changes slope at $V_{rep} \sim -150V$ so that two portions can be identified. In this context the lower energy portion, which could be distorted by space charge effects, is not discussed. It is worth noting that if this portion is fitted by a half-Maxwellian distribution function, the resulting temperature is $T_e \sim 50$ eV which is at least twice the bulk electron temperature expected in this region of plasma [3]. On the other hand, the higher energy portion of the characteristic confirms the presence of a superthermal tail. This high energy tail has been assumed to be a distinguishing feature of the electron drift side, in the hypothesis of negligible backflow. Following reference [5], the high energy tail has been fitted with a half-Maxwellian distribution. The result of the fit, also shown in fig.3, gives a temperature $T_h = 327$ eV, much larger than the edge electron temperature.

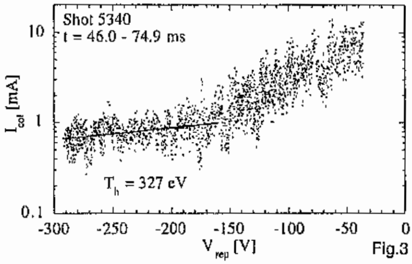

Fig.3

Generally speaking, the temperature T_h of the high energy tail turns out to be of the order of the on-axis bulk electron temperature T_0, which in these discharges was 250-350 eV. It is worth noting that the values found for T_h are comparable to those found in TPE-1RM20 with the same EEA. The intercept I_0 of the fitting curve with the I_{col} axis yields the population density n_h, according to the equations

$$I_0 = \frac{e n_h v_h}{\sqrt{\pi}} A, \qquad v_h = \sqrt{\frac{2T_h}{m}}$$

where A is the pinhole area and all perpendicular velocities are assumed to be collected. Such a procedure assumes the plasma to be at the same potential of the vacuum vessel, which is taken as the reference potential. Data collected in the past have shown that plasma potential in this region is in the range 0-30 V [3], so that, in consideration of the relatively high values of T_h, the error introduced by this assumption is negligible. The deduced values of n_h are between 10^{17} and $5 \cdot 10^{18}$ m^{-3}. The ratio between n_h and the line averaged electron density <n> is for most discharges of a few percent.

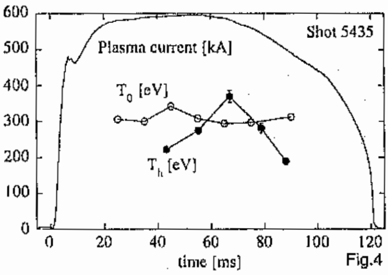

Fig.4

Under the assumption made above that the high energy electrons are present only on the electron drift side, the edge current density carried by them has been evaluated as $j_h = I_0/A$. Typical values are in the range 100-500 kA/m^2, consistent with the estimated current density in the

RFX edge region, although in some cases values exceeding 1 MA/m^2 are obtained.

The unique possibility of applying many voltage ramps to the repeller in a single discharge has led to the measurement of the time dependence of the superthermal electron temperature. An example of T_h as a function of time is shown in fig.4, superimposed to the plasma current waveform and to the on-axis bulk electron temperature T_0 as measured with a SiLi detector. T_h is observed to be comparable to T_0 and the time behaviour can be interpreted as a rise during the slow ramping phase of the plasma current followed by a decrease during the current decay. Different behaviours have also been observed.

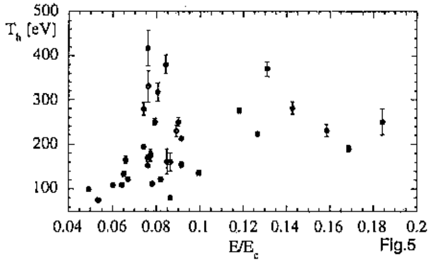

Fig.5

The data collected about T_h have been related to the non-dimensional parameter E/E_c, where $E = V_{loop}/(2\pi R)$ is the on-axis inductively applied electric field, while E_c is the on-axis critical field for runaway generation as defined in [6], assuming the on-axis density comparable to the line averaged one. This comparison has been made using data collected over a radial range of 7 mm, implicitly assuming the changes in T_h to be negligible over this range. Figure 5 shows T_h as a function of E/E_c. If the hypothesis of independence on radial position is confirmed, it may be concluded that there is a tendency of T_h to grow as E/E_c becomes greater. A similar tendency is observed also for the ratio T_h/T_0. The dependence of T_h on E/E_c shown in fig.5 and the fact that T_h is comparable to T_0 indicate that superthermal electrons are probably generated in the centre of the plasma, and then transported to the outer region, possibly flowing along stochastic magnetic field lines.

5. Conclusions

For the first time the electron distribution function in the outer region has been measured on RFX by means of an electrostatic EEA. The high energy portion of the data collected on the electron drift side shows the presence of a superthermal tail in the electron distribution function. Such tail has been interpreted assuming a half-Maxwellian shape. The EEA power supplies have made it possible to measure the time evolution of the superthermal electron temperature T_h. It has been found that T_h is comparable to the on-axis electron temperature and the superthermal current density j_h is in most cases of the order of the estimated RFP equilibrium current density in the edge region. The superthermal electron density n_h is a few percent of the line average electron density. A correlation between T_h and the E/E_c ratio has been found, in the hypothesis of independence of T_h from the radial coordinate on a 7 mm distance. This correlation, together with the fact that $T_h \approx T_0$, supports the idea that superthermal electrons found at the edge are produced in the central plasma.

References

[1] S. Ortolani, Plasma Phys. Controlled Fusion **34**, 1903 (1992).

[2] P. Martin, V. Antoni, A. Murari, S. Peruzzo, G. Serianni, Rev. Sci. Instrum. **66**, 431 (1995).

[3] V. Antoni, E. Martines, M. Bagatin, D. Desideri, G. Serianni, Nucl. Fusion **36**, 435 (1996).

[4] Y. Yagi, Y. Hirano, Y. Maejima, T. Shimada, to appear in Japanese J. of Applied Phys. **35** (1996).

[5] J. C. Ingraham et al., Phys. Fluids B **2**, 143 (1990).

[6] H. Knoepfel, D. A. Spong, Nucl. Fusion **19**, 785 (1979).