POSITIVE PLASMA BIASING IN FRONT OF THE LOWER HYBRID GRILL OF CASTOR TOKAMAK

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Abstract:

Parasitic generation of suprathermal particles in front of lower hybrid (LH) antennas in tokamaks represents a potential danger for the parts of tokamak first wall connected with this region directly by magnetic field lines. Presence of electrons in radially very narrow wave-plasma interaction region, accelerated up to the energy 200eV, has been proved recently on CASTOR tokamak by Langmuir probes (a substantial drop of floating potential is observed). Using emissive Langmuir probes, first experimental evidence of increase of plasma potential in the interaction region is given in this paper. This result confirms predictions of theory about the charge separation due to the escape of accelerated electrons with successive acceleration of plasma ions.

1. Introduction

Lower hybrid waves (LHW) are commonly used in tokamaks for non-inductive generation of electrical current. This current substitutes the current induced in the plasma by transformer and in this way it could enable stationary operation of fusion tokamak-reactor. However, if LH power of order of MW is used in big machines, a detrimental effect of parasitic acceleration of edge particles in front of the RF antennas has been discovered. Namely, such particles (with energy up to several keV) can hit surface of the first wall connected by magnetic field lines with region of their acceleration. Strongly localized erosion of some elements of the first wall has been already found and creation of “hot spots” directly during LHW application has been already observed [1,2,3].

Small tokamak CASTOR enables direct measurements of the plasma as well as electric field behaviours just in front of the LH antenna (i.e. directly in the wave-plasma interaction region) using Langmuir probes technique. Recently a well expressed decrease of insulated probe potential (floating potential) up to minus 200V has been observed in several mm radially narrow layer in the interaction region on this machine [4]. Because the floating potential is sensitive first of all to the presence of energetic electrons, a generation of such non-thermal accelerated electrons at LH wave application could be deduced from this fact.

However, by theory predicted increase of plasma potential in the interaction region [5] (caused by free escape of accelerated electrons along confining magnetic field) could not be proved up to now. In this paper results of the first direct measurement of plasma potential in front of CASTOR LH antenna, using an emissive Langmuir probe [6], are given. In this case, if emissivity (i.e. temperature) of the probe surface is high enough, the probe potential approaches the plasma potential, independently on the fast electrons presence. It has been found that floating potential of the heated probe located near to the antenna exhibits, in contrast to the floating potential of the cold probe, an expressive positive increase during LHW phase. Because of no macroscopic changes of the plasma parameters are observed during the LHW phase, this fact can be considered as the first direct proof of the theory mentioned above: primary mechanisms of the effect observed is acceleration of electrons in front of the antenna, while erosion of the first wall is probably caused predominantly by ions accelerated due to the charge separation.

The structure of the paper is following. The experimental arrangement is shown in the following Sec.2. In Sec.3 radial profiles of floating potential (i.e. potential of insulated probe submerged into the plasma) of cold and heated (to temperature above 2500°C) probe will be given together with dependence of the effect on LHW power. Discussion and summary of the results will be presented in the last Sec.4.

2. Experimental set-up

Tokamak CASTOR (R/a=0.4/0.085m, where *a* denotes the radius of the poloidal aperture limiter) is a small device with magnetic field $B(0) \leq 1.5T$, plasma current $I_p \leq 20kA$, central density $n(0) \leq 3.10^{19}m^{-3}$ and pulse length up to 40ms. For experiments with LH current drive a three-waveguide grill working at the frequency 1.25GHz (power up to 50kW) is used. The grill mouth with dimensions 160mm in poloidal and 50mm in toroidal direction is partially shaped in the poloidal plane (with radius r=86mm). For the measurements presented in this paper 3ms pulses of the LH power have been applied in quasistationary discharge phase starting from the 6th millisecond.

The emissive probe consists of a small loop of thin tungsten wire with diameter of the wire 0.2mm. The plane of the loop is oriented in toroidal direction, perpendicularly to the small radius (i.e., the loop is placed on one magnetic surface, to assure a high radial resolution). The dimension of the loop exposed to the plasma doesn't exceed 1mm in poloidal direction, while its length in toroidal direction 1.65mm is given by distance between centres of two together fixed tiny corundum bushings, protecting the tungsten wire not exposed to the plasma and the current feeding Cu conductors. A heating current 7A is sufficient to reach a stationary temperature of the wire more as 2500°C in less than 1 second (probe is heated several seconds only, just before and during the CASTOR pulse).

The probe is fixed in a spherical joint located in upper port of the CASTOR, in the cross-section where the grill antenna is placed. Vertical position of the probe can be changed by vertical shift of the probe holder, radial position of the probe (for the profile measurements on shot-to-shot basis) simply by tilting of the probe holder in the poloidal plane. Due to the low plasma energy in CASTOR, short pulses (20ms or even less for our measurements) and a good pulse repetition, the probes could be moved through the whole interaction region in front of the grill. Broad radial profiles of the probe floating potential have been obtained in this way (alternately without and with the probe heating for every radial position). All measurements presented below have been done 20 or 30mm above the tokamak equatorial plane, toroidally in the grill centre, with maximum LH power 20kW. The signals have been sampled with the frequency 1MHz.

3. Results of the measurements

A typical time course of the probe floating potential in the interaction region (here r=84.5mm) before and during the LHW application between 6th and 9th ms is shown in Fig.1. For better orientation, the floating potential of the cold probe is denoted as V_{fl} (floating), while floating potential of the heated probe as V_{pl} (plasma; however, how much this potential can approach the real plasma potential see e.g. [6]). Importance of sufficient emissivity of the probe surface is demonstrated by comparison of the LHW effect at heating current 6A (left side of the figure) and 7A (right side of the figure). It may be seen from this comparison that the lower emissivity at 6A is already sufficient to compensate fully the biasing effect of small number of fast electrons, however, for approaching to the plasma potential, a still higher emissivity is needed. In the lower part of the figure difference of the V_{pl} and V_{fl} signals is given, to characterize the effect of LHW better quantitatively (please, take into account that V_{pl} and V_{fl} are measured in two different shots). It may be seen that this difference, corresponding value of several electron temperatures in the case of Maxwellian plasma during

OH phase, is much enhanced during LH phase. And what is further important, this enhancement during LH phase is not only due to the compensation of the biasing effect of the collected fast electrons by electron emission, but partially also by an increase of the value V_{pl} itself (at least for the heating current 7A, see V_{pl} on the right side of the figure), in full concordance with the theory predictions. For the reason of reasonable life time of the tungsten wire the current 7A has not been exceeded and this value has been used for all other measurements.

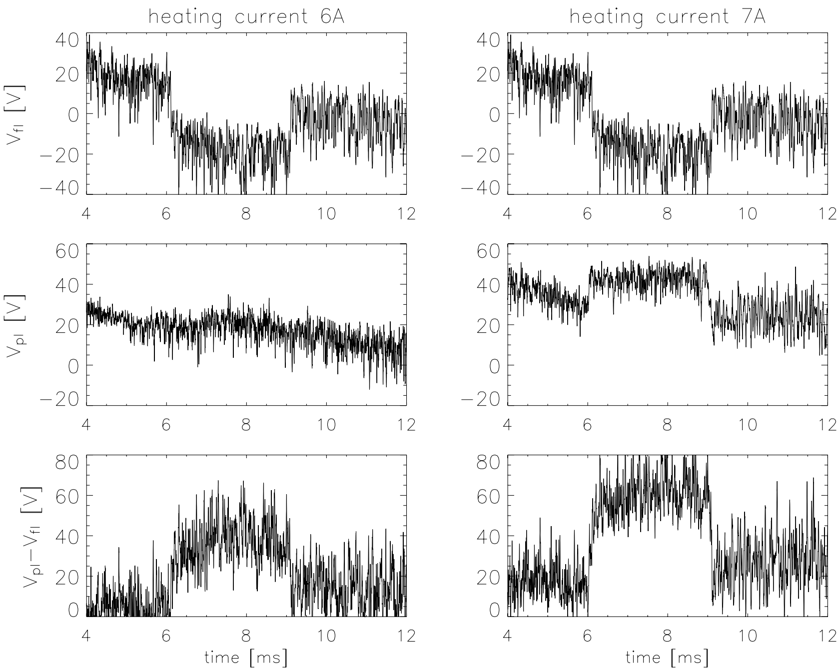

Fig.1. Time dependence of the floating potential of cold (V_{fl}) and emissive (V_{pl}) probe with two different heating current 6 and 7 A. LH wave is applied between 6 and 9ms.

The radial profile of the potentials V_{fl} and V_{pl} in front of the CASTOR grill is given in Fig.2. It has been obtained 20mm above the equatorial plane on shot-to-shot basis by averaging of 10^3 samples of fluctuating signal during OH (diamonds) just before application of LHW and by averaging of the same number of samples during LHW application (asterisks). Formation of a narrow potential dip ("well") in the V_{fl} profile is clearly visible between radii 82 and 85mm during LH phase, while, in contradiction to this effect, V_{pl} exhibits a certain increase, especially quite near to the grill mouth (r=86mm). To judge better the change when LHW is applied, difference V_{pl}-V_{fl} is shown in the figure as well (again, note that corresponding values of V_{fl} and V_{pl} are obtained in two different discharge pulses). It may be seen that while this difference remembers the case of Maxwellian plasma deeper in the plasma, it is much enhanced just in the "well" of V_{fl}. Because no macroscopic changes in the plasma quality are observed and local increase of electron temperature has been excluded by probe characteristics analysis, the enhancement observed must be caused by generation of fast electrons with corresponding energy. The net effect ΔV_{LHW} of LHW, i.e. change of difference V_{pl}-V_{fl} during LHW comparing to this difference in OH phase, is shown in the figure as the last trace. It may be seen again that this net effect is concentrated in only several mm radially narrow layer just in front of the grill.

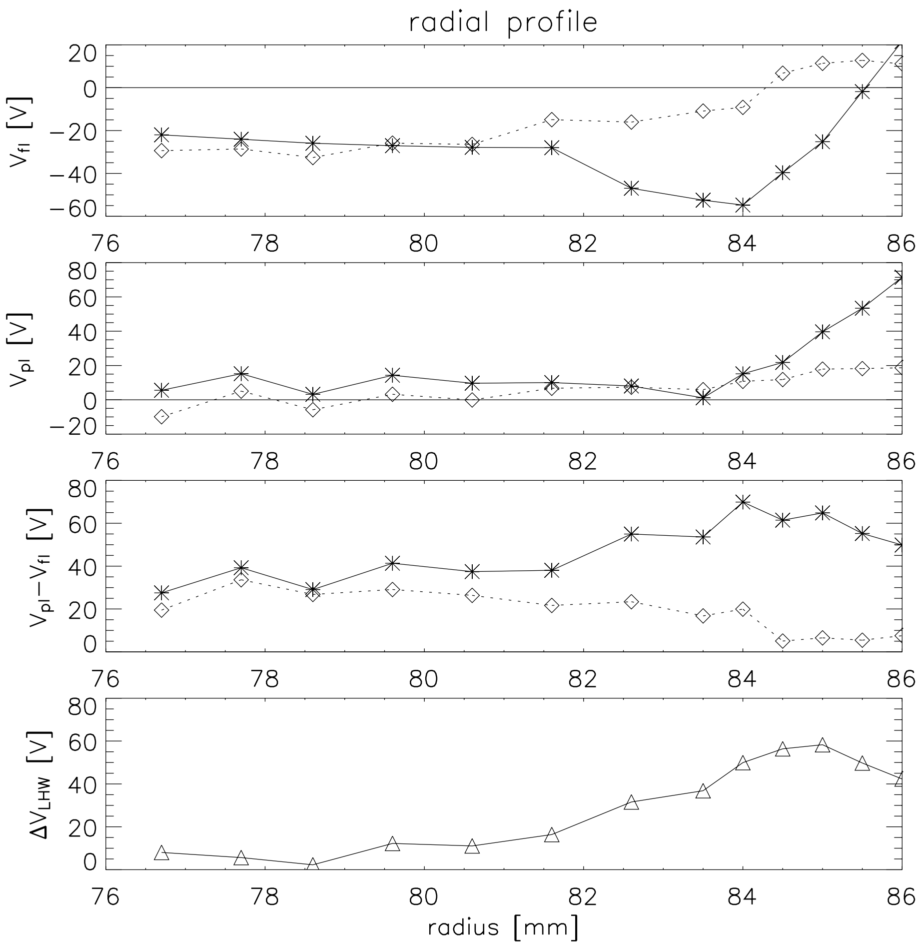

Fig.2. Comparison of radial profiles of the cold (V_{fl}) and emissive (V_{pl}) probe floating potentials in OH (diamonds) and LHW (asterisks) discharge phase. Difference of both potentials V_{pl}-V_{fl} is shown also. The last trace denoted as V_{LH} (triangles) is a net change of V_{pl}-V_{fl} due to the LHW with respect to its ohmic value.

The following Fig.3 shows dependence of investigated effect on incident LHW power. The all quantities in the figure have the same meaning as in the foregoing Fig.2. The dependence has been measured in the minimum of the V_{fl} potential "well" (r=85mm), 30mm above the tokamak equatorial plane. It seems that effect has no power threshold and that dependence on the power has a linear character. This is in agreement with theoretical predictions of increase of accelerated electrons energy with the power launched into the tokamaks.

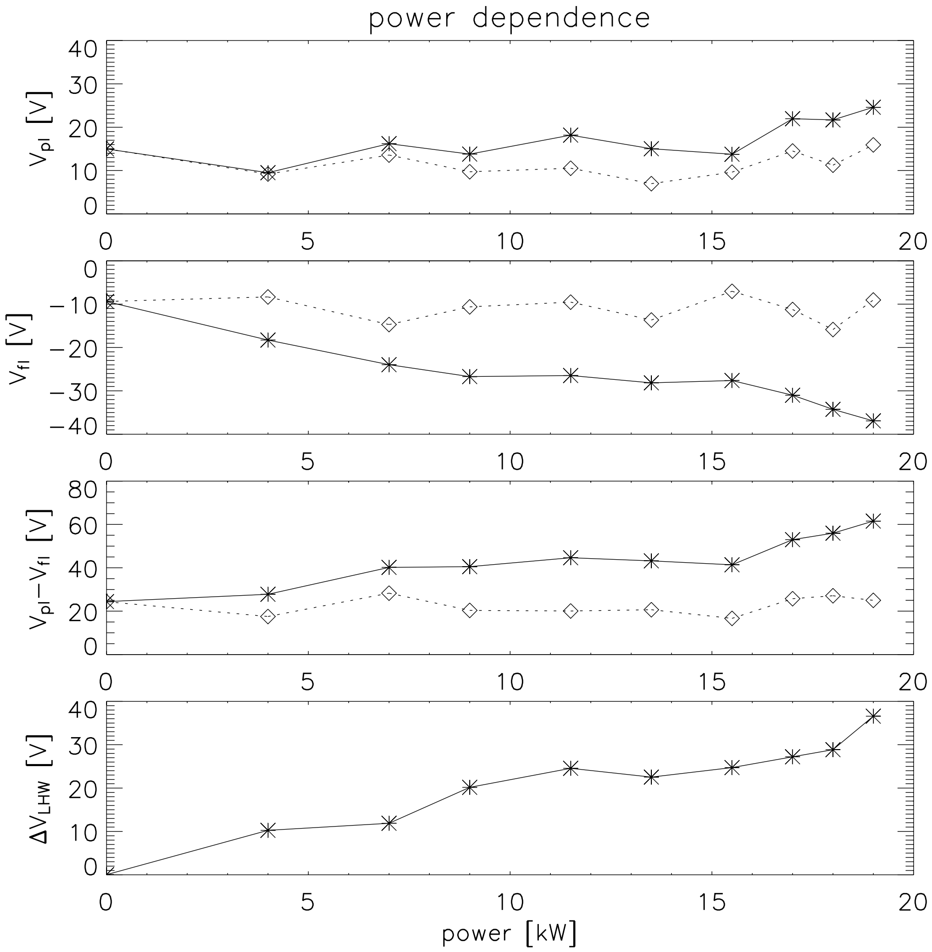

Fig.3. Power dependence of the LHW effect measured by the probe in the potential "well" of the probe floating potential (r=85mm).

4. Summary and discussion of the results

Using emissive probe new experimental facts have been obtained concerning the character of interaction between LHW and periphery plasma in front of the LH antennas. Results can be summarized as follows:

(i) The measurements with non-emissive probe (i.e. without probe heating) confirmed formation of a "well" on the profile of floating potential during LH discharge phase, observed already on CASTOR tokamak before and interpreted as existence of a group of electrons accelerated to the corresponding over-thermal energies.

(ii) Radial width of this "well" is less than 4mm and its minimum is localized about 2mm in front of the grill mouth.

(iii) On the other hand, floating potential of the probe heated to the temperature over 2500^{o}C (i.e. the probe becomes to be emissive) exhibits near to the grill an expressive increase if LHW is applied.

(iv) This increase of the emissive probe floating potential is localized still closer to the grill mouth as the "well" of the cold probe floating potential. It starts to be observable at a distance 2-3mm from the grill and increases till the grill mouth itself, maybe due to a continuous decrease of the plasma density to the grill.

(v) If we consider this measured potential to be the plasma potential, formation of a strong radial electric field nearly 30kV/m can be derived in this radially very narrow layer just in front of the CASTOR grill at LHW power 20kW. Shear velocity layer, formed under such electric field, can result in substantially changes in the transport coefficients in this region (see e.g. routinely observed improvement of global particle confinement in CASTOR [?]).

(vi) Dependence of the effect on the LHW power, characterized as difference of the floating potentials heated and cold probe in LH and OH plasmas, seems to have a linear character, i.e. still much higher radial electric fields can be expected in front of antennas launching power up to several MW.

The results obtained can be considered as a direct experimental proof of mechanism of parasitic acceleration of electrons in front of LH antennas, already predicted by the theory. Escape of these electrons along the magnetic field lines results in positive plasma biasing with successive acceleration of plasma ions. These ions are then responsible for erosion of the parts of the first tokamak wall, connected directly by magnetic field lines with interaction region (observed already in tokamaks with LH power of MW order, where energy of accelerated particles can reach values up to several keV). Effect observed exhibits a linear dependence on the power, without any power threshold, at least in the limits of reproducibility of CASTOR discharge pulses.

Acknowledgement

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