ANTENNA PLASMA INTERACTION AND HARMONIC GENERATION IN ALFVEN WAVE HEATING

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Introduction Additonal plasma heating by Alfven waves (AWH) has been studied on TCA for some years. Although considerable agreement between fundamental wave and coupling phenomena has been observed [1,2], the heating results have always been poor and difficult to interpret. Only recently has energy deposition within the plasma been shown to be determined mostly by the density rise [4] and ohmic effects and not by Alfven resonant absorption within the plasma [3].

In TCA, the standard AWH antennae are unshielded and are in direct contact with the plasma scrape off layer (SOL) in the shadow of the limiter. In this paper we test the hypothesis that a Langmuir current (resistive and capacitive [5]), henceforth referred to as the default current, flows from the antennae to the plasma on application of RF potential and we estimate the parasitic power deposited at the plasma SOL interface.

Experiment In TCA there are four pairs of antennae spaced at 90^0 intervals around the machine. In each pair there is one antenna on top and one on the bottom of the plasma. AWH is normally effected by applying approximately 30kW of RF power per antenna at 2.04 MHz. If desired, these antennae can be artificially polarised negatively with respect to machine earth by a biasing circuit coupled to the antenna RF lines. One of the TCA antennas is shown in Fig. 1. We monitor the current entering each terminal of one of its three bar pairs by Rogowski coils. In addition, we monitor the RF potential with respect to the machine earth by one voltage divider on each terminal. The signals obtained are therefore proportional to the time derivatives of the current and the voltage. Under normal conditions and according to the prescription for AWH, a large antenna current, the circulating current, flows in one terminal, through the antenna bars, and out the other terminal. If a default current flows from the antenna into the plasma then the current entering one terminal of the antenna is no longer

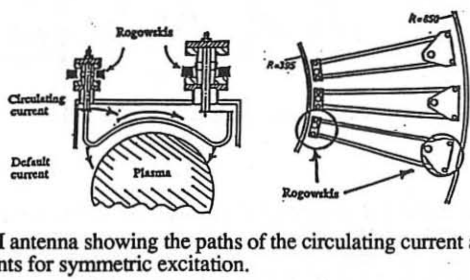

Fig. 1 AWH antenna showing the paths of the circulating current and the default currents for symmetric excitation.

equal to the current leaving the other terminal. Subtraction of the two Rogowski signals therefore permits a measurement of the default current, which must flow from the high power generator, through the terminals of the antenna, and into the SOL.

Under normal conditions the TCA antennae are excited symmetrically at RF with respect to machine earth (the terminals of the antenna are excited in push-pull) and are electrically floating at DC with respect to the plasma. The default currents entering each terminal of the antenna should then be more or less equal. Since these currents consist mainly of a rectified electron current flowing in each terminal on positive half-cycles of the terminal voltage, we predicted a default current signal at the second harmonic of the Alfvén generator frequency (2.04 MHz). The prediction was confirmed by an experiment in which a top and a bottom pair of antennae were excited (Fig 2a). The signal waveform obtained is independent of the chosen antenna poloidal phasing. The magnitude of the default current is typically 0.02 to 0.05 of the circulating antenna current for our conditions. This could explain a substantial part of the measured Alfvén power if the individual default currents flowing in both terminals are in phase with their terminal voltages, as will be shown later, and the other, unmonitored, bar pairs have similar default currents.

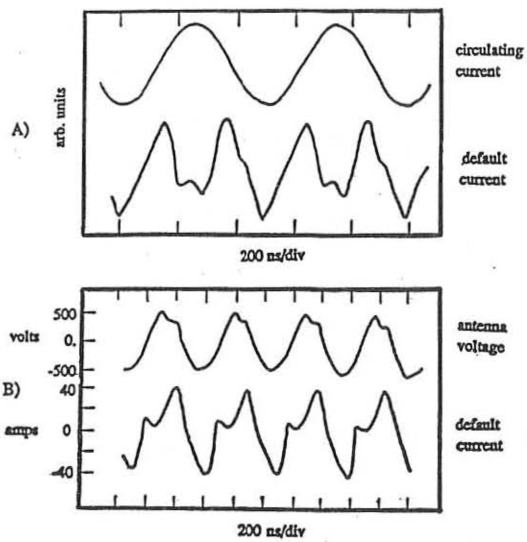

Fig. 2 Typical signal traces showing the time derivatives of the antenna potential, the circulating current and the default current.

a) Symmetric excitation. The default current trace shows the sum of the default currents entering at both antenna terminals.

b) Asymmetric excitation with one side of the antenna at machine earth. The signals are calibrated for the first harmonic at 2.04 MHz.

The default current has some interesting properties. Firstly, the current drawn from the plasma by a passive antenna circuit when RF is applied at another toroidally separated antenna is of the same order as the directly excited default current measured on the excited antenna. This means that different antennae interact. Indeed, observation of the default current of one antenna whilst all eight antennae were excited revealed a very complicated waveform consisting of mainly first and second harmonic signals. Second, in the case of relatively high power excitation, the default current does not depend on the artificial polarisation applied to the antenna when this polarisation is more negative than the natural polarisation. According to simple floating probe theory, an oscillating potential applied to a floating metallic object in a plasma will draw a DC current until the object has charged sufficiently negative to equalise the average ion and electron currents on each half-cycle [6]. This is similar to the technique of grid-leak bias used in circuits involving electron tubes. If a more negative potential is applied to the object, then any increase in RF current must be due to an ion current which causes a DC current to flow to the polarisation source. This increase in RF current is small due to the low ion thermal velocity.

It is not possible to measure the individual default currents in each antenna terminal using the above experimental technique. In order to measure the power deposited in the plasma edge it is therefore necessary to excite the antenna in such a way that the default current enters through a single known terminal. The time averaged product of this current with the measured terminal voltage with respect to machine earth then gives the parasitic power.

This was achieved by grounding one side of the antenna so that all points along the antenna bars oscillate in phase. In this case, for a plasma of static potential, we may hypothesise that only the active side of the antenna sources a default current. A typical unintegrated default current is shown in Fig. 2b with the corresponding unintegrated terminal potential trace. Note that the second harmonic of Fig. 2a for the case of symmetric excitation has largely disappeared; in agreement with the hypothesis.

The default current in this experiment has half the amplitude of the circulating current since the antenna potential was fixed at DC earth. In this case the antenna never attains the negative polarisation necessary to reduce the large electron current on positive half-cycles of the oscillating potential to the value of the ion current on negative half-cycles and hence extinguish the DC current. As a result the power estimated is not directly relatable to that measured in the symmetric, floating antenna case. The power, 10 kW, calculated from the trace for this bar pair corresponds to a total antenna power between 20 and 30 kW assuming that the other outside bar pair behaves identically and depending on how much default current can be drawn along field lines by the centre bar pair. Unfortunately, due to the asymmetrical load, the normal AWH power measurement diagnostic was made nonoperational by this experiment so that a direct comparison is not available. Nonetheless, this magnitude of parasitic power would represent approximately 240 kW of wasted power if all eight antennae were excited asymmetrically in the same way with one terminal at machine earth. The AWH RF power is calculated by a voltage measurement across the symmetric RF power line and by a measurement of the average current in the line. This measurement is therefore expected to include the default current power.

The presence of some second harmonic on the default current with asymmetric excitation (Fig. 2b) is poorly understood, however unlike the first harmonic (2.04 MHz) the second harmonic is strongly fluctuating and varies considerably with plasma conditions. It could have two origins. The first is that the plasma potential oscillation produces a current component into the antenna. The second is that the second harmonic is a natural trait of the high voltage, high frequency Langmuir current effect in the SOL. In this case the characteristic can be checked by disconnecting completely one side of the antenna so that no circulating current flows and the antenna potential is uniform along the length of the antenna bars. The fact that the default current flows from one terminal to the plasma can be checked by measuring the harmonics of the individual Rogowski currents.

The difference in the amplitude of the observed default current signals in the symmetric and asymmetric excitation experiments may be due to the natural polarisation of the antenna in the symmetric case and the non polarisation in the asymmetric case. It may also be due to the fact that a good portion of the first harmonic of the default currents flowing to the SOL in the symmetric case are cancelled during addition of the Rogowski signals.The natural polarisation of the antenna can be preserved during asymmetric experiments by connecting a low impedance capacitor from the antenna terminal to ground instead of making a direct connection. In this way one should obtain a default current of similar magnitude to that seen in the symmetric, floating antenna experiments.

During AWH with symmetrical excitation, harmonics have been observed on the magnetic wave field and ion saturation current signals in the SOL. The second harmonic (4.08 MHz) has been shown in some cases to be 50% of the fundamental signal. All harmoncs of the ion saturation current measured by a Langmuir probe, positioned far from the excited antenna, peak around the antenna radius. Such harmonics however have only been detected in the SOL. They have not been detected deeper in the plasma by the density fluctuation imaging diagnostic. Their level within the plasma does not exceed the sensitivity threshold of the Kinetic Alfven Wave amplitude at the applied frequency. It has been suggested [7] that these harmonics are due to the Langmuir effect at the antenna-SOL interface. An experiment with asymmetrical excitation has been performed in which the harmonics of the default current were measured as a function of the harmonics of the toroidal component of the magnetic wave field during an RF power scan. Since it is known that the amplitude of these harmonics all decrease with the negative level of artificial polarisation, the antenna was grounded as in the case of the default current power measurement to eliminate the effect of the antenna natural polarisation on the SOL. Asymmetrical excitation also permits excitation of a default current in a single antenna terminal to provide a single source of the plasma wavefields. It was predicted that the level of the harmonics (4.08, 5.12 and 8.16 MHz) of the plasma signal would increase linearly with those of the default current. Experiments however are still preliminary and have not yet provided clean enough signals for a valid comparison.

Conclusion Experimental results have been presented which form the first stage of a study of the plasma-antenna parasitic interaction during AWH in TCA. The results demonstrate that it is physically feasible to obtain a direct measurement of the power dissipated by the default current at the antenna-SOL interface and the measurement indicates that 20 - 30 kWs is delivered to the SOL in the particular case of the asymmetrically excited antenna when grounded directly at the machine earth.

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