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The Anomalous Currents In The Front Foils Of The JET Lost Alpha Diagnostic KA-2

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The anomalous currents in the front foils of the JET lost alpha diagnostic KA-2[a)]

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We have examined the observed currents in the front foils of the JET Faraday cup lost alpha particle diagnostic KA-2. In particular, we have sought to understand the currents during Ohmic plasmas for which the ion flux at the detectors was initially assumed to be negligible. We have considered two sources of this current: plasma ions (both deuterium and impurity) in the vicinity of the detector (including charge exchange neutrals) and photoemission from scattered UV radiation. Based upon modeling and empirical observation, the latter source appears most likely and, moreover, seems to be applicable to the currents in the front foil during ELMy H-mode plasmas. A very thin gold or nickel foil attached to the present detector aperture is proposed as a solution to this problem, and realistic calculations of expected fluxes of lost energetic neutral beam ions during TF ripple experiments are presented as justification of this proposed solution. [doi:10.1063/1.3502040]

I. INTRODUCTION

The JET lost alpha diagnostic KA-2 consists of sets of thin (2.5 μm) Ni foils mounted in a poloidal array near the plasma boundary in octant 7 of the JET tokamak, as seen in Fig. 1. The design and operating principles of KA-2 are given elsewhere.[1] Pending future d-t plasmas, we have sought to utilize KA-2 as a diagnostic of lost energetic particles from deuterium plasmas during, for example, neutral beam (NBI) and ion cyclotron radio frequency heated (ICRH) plasmas. Deuterons with energies up to 500 keV will stop in the front foils of the detectors, and hence, the study of lost NBI ions is limited to these front foils. We have consistently observed front foil currents exceeding 1 μA during the Ohmic phases of the tokamak plasmas where ion temperatures are limited to a few keV, as seen in Fig. 2. In this report, we discuss possible sources of this anomalous current and propose a solution. In addition, we report realistic calculations of NBI losses, which suggest that the proposed solution would allow the observation of these losses. Since devices comparable to KA-2 have been installed on DIII-D (Ref. 2) and NSTX (Ref. 3) and are being considered as a lost alpha particle diagnostic for ITER,[4] it may be useful to consider the present proposed solution for these machines as well.

[a)]Contributed paper, published as part of the Proceedings of the 18th Topical Conference on High Temperature Plasma Diagnostics, Wildwood, New Jersey, May 2010.

[b)]See the Appendix of F. Romanelli *et al.*, Proceedings of the 22nd IAEA Fusion Energy Conference 2008, Geneva, Switzerland, 2008, and the Appendix of Nucl. Fusion **49**, 104006 (2009).

II. POSSIBLE SOURCES OF ANOMALOUS CURRENT

The following three sources of this anomalous are considered:

(a) thermal plasma in the immediate vicinity of the detector,
(b) neutral ions becoming reionized near the detector, and
(c) photoemission from the front foils due to scattered UV.

A. Thermal plasma in the immediate vicinity of the detector

This plasma may be assumed to consist of deuterium ions as well as impurity ions (e.g., carbon, oxygen, and beryllium). The detector is located about 3 cm from the plasma edge. At this location during the Ohmic phase of the shot indicated in Fig. 2, the temperature is about 25 eV and the total density is about 10^{12} cm^{-3}, 10% of which is assumed to be carbon. We have modeled the deuterium and carbon plasma currents reaching the front foils of the detector assuming purely helical orbits.[5] For the conditions noted above, we find about 2 nA of carbon ions and less than 1 pA of deuterium ions reaching the front foils of the detector. While repeating these calculations with a fully collisional code would probably increase the predicted currents, we would be most surprised if they would reach the microampere levels indicated in Fig. 2. In addition, we find no correlation between the front foil currents and the CIII light signals from the horizontal and vertical edge cameras on JET. Such a correlation would be expected if the foil currents were due to carbon plasma ions.

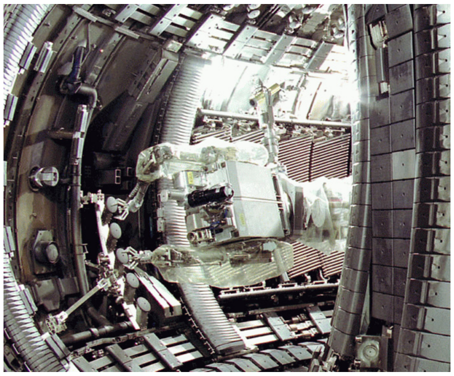

FIG. 1. (Color online) JET interior showing the installation of KA-2 in May 2005.

B. Neutral ions becoming reionized near the detector

Alternatively, we might consider charge exchange neutral ions in the detector vicinity. This was proposed by Jarvis *et al.*[6] to explain the observed currents in the front foil of KA-1 during ICRH and neutral beam heated plasmas on JET from 1995 until 2000. The neutral ion flux during the Ohmic phase of 69707 is about 10^{10} cm^{-2} s^{-1} (Ref. 6) and as such would not be capable of generating microamperes of current in the KA-2 front foils, even if all the neutrals were reionized. This possible source of the KA-2 front foil currents during Ohmic plasmas is likewise discounted.

C. Front foil photoemission from scattered UV radiation

Finally, we consider the possibility of the photoemission from the front foil by reflected UV radiation. (The apertures were designed to face away from any direct line of sight to exclude hard x rays from entering the detectors; however, there is a direct line of sight from the foils in the second through the fifth poloidal locations to the bottom of the next higher pylon.) The plausibility of this mechanism is suggested by comparing the measured front foil current to the plasma bolometric radiation, which is a good measure of the total UV radiation from the plasma, as seen in Fig. 3, where the relative concordance of the two signals is to be noted.

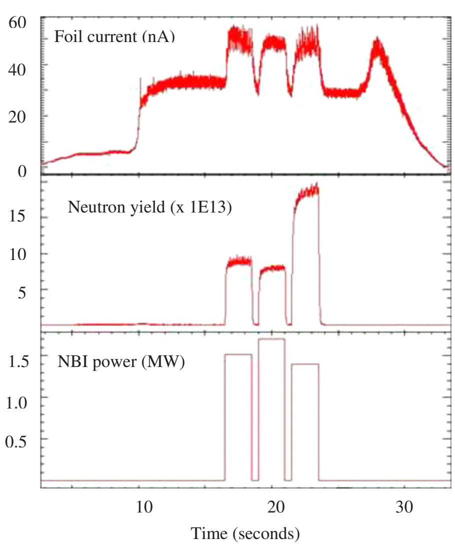

FIG. 2. (Color online) Comparison of current in front foil with neutron yield and NBI power during JET pulse 69608. The large foil current during the Ohmic phase of the plasma (time < 16 s) is to be noted.

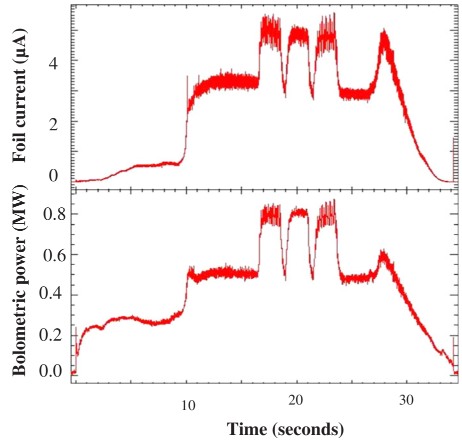

FIG. 3. (Color online) Comparison of the front foil current in KA2–411 (top) and the total bolometric radiated power for JET pulse 69608.

As seen in Fig. 4, there is an approximately linear relation between the current in KA2-411 and the total radiated power as measured by BOLO/TOPI for a number of JET pulses over nearly three orders of magnitude with a proportionally constant between I_{411} and bolometric radiation of about 8 μA/MW.

The source of the current in this model is the photoelectrons ejected from the surface by the UV photons, and this loss of negative charge from the foil is measured as a positive current. This hypothesis may be tested by inserting a small battery in the circuit between the foil and the current amplifier, which feeds the diagnostic digitizer. This would provide a positive bias to the foil, which would prevent the photoelectrons from leaving the foil. In addition, as the positive voltage is increased, other electrons from the environment would be attracted to the foil causing a negative current to be measured. This is indeed what was observed, as seen in Fig. 5. In addition, this model is especially supported by the fact that the KA-2 front foil current-to-bolometric power ratio with a negative voltage of 1.5 V is about the same as with no voltage.

We may estimate the expected current from the UV photoemission by considering the UV scattered into the front foil of KA2-411 from the back of the pylon for KA2-311, which is located approximately 10 cm from the KA2-411 front foil

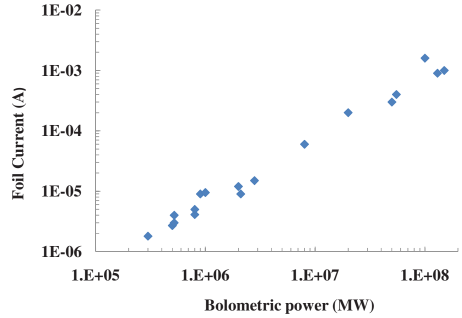

FIG. 4. (Color online) A comparison of the current in KA2-411 and the total bolometric power BOLO/TOPI for plasmas from Ohmic to ELMy H-mode.

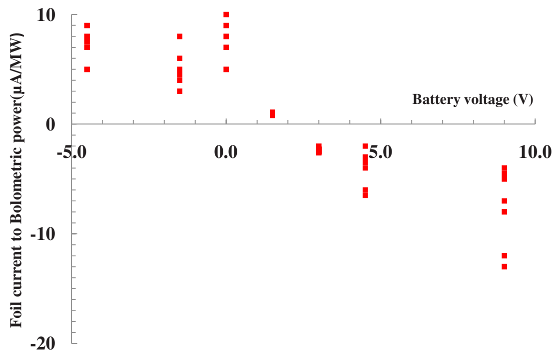

FIG. 5. (Color online) The ratio of KA2-411 current to the total bolometric power as a function of the voltage of a battery placed in the line from the foil to the amplifier to suppress the electrons from being ejected from the foil surface by scattered UV radiation.

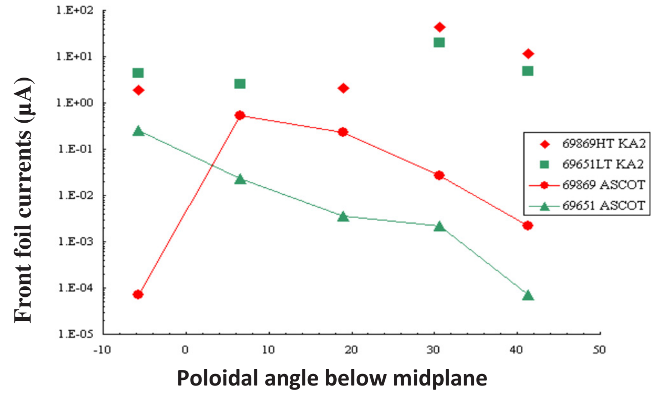

FIG. 6. (Color online) Comparison of calculated and measured quiescent currents in the five front foils of KA-2 during the H-mode phase of the JET plasmas 69869 and 69651. These plasmas were, respectively, high and low triangularity pluses with a 1% ripple.

and is tilted at an angle of 45° to the minor radius of the tokamak. Assuming an average energy of the UV radiation of 10 eV, a reflectance of the inconel pylon of 20%,[7] we estimate a reflected UV power onto the front aperture of KA2-411 of 0.025 $\mathrm{W/cm^2}$. From this power, assuming a quantum efficiency of 10^{-4} (Ref. 8) would estimate a current in KA2-411 of about 2 μA/MW of bolometric power; this is within an order of magnitude of the observed relation of 8 μA/MW.

III. PROPOSED SOLUTION

One solution to the problem of the anomalous currents is to install a very thin foil in front of the aperture, which would eliminate the scattered UV while allowing relatively energetic ions, such as beam ions with energies ~100 keV, to reach the front foils. For a foil of thickness 0.1 μm, deuterons with energy less than 14 keV will stop in the Ni (27 keV for a Au foil of the same thickness). The shielding against impurity atoms is even more effective with C ions of energy up to 90 keV stopping in 0.1 μm of either Ni or Au foil. On the other hand, 100 keV deuterons from NBI will lose less than 20 keV in either 0.1 μm foil. Similarly, the energy loss of the 3.5 MeV alpha particles from the d-t plasmas will be only about 50 keV in either 0.1 μm foil.[9] In terms of the protection of the front foils of KA-2 from the scattered UV radiation discussed above, the transmission of 10 eV UV radiation will be roughly 10^{-9} (Ref. 10). Thus, a gold or nickel foil of thickness 0.1 μm can be placed in front of KA-2 and will eliminate low energy deuterons, impurity ions, and UV radiation without compromising the study of fast ions such as NBI deuterons and d-t lost alphas.

Similarly, there should be no danger of foil melting. The temperature of either a gold or nickel foil exposed to a sustained UV flux 0.025 $\mathrm{W/mm^2}$ (the expected flux if the total bolometric radiative power is 100 MW on JET) reaches an equilibrium value of about 900 K within a time of about 20 ms after the onset of the flux assuming an ambient temperature of 600 K. This equilibrium temperature is well below the foil melting temperatures of nickel (1727 K) or gold (1336 K). In addition, since the foils are facing *away* from the plasma (to avoid any x-ray flux as discussed above in Sec. II C), they will not be susceptible to damage by the outward flux of neutral beam ions. As noted in the calculation below, reaching the front foil will not exceed 1 $\mathrm{mA/m^2}$.

While the proposed solution appears to provide a heat resistant mechanism for the elimination of the anomalous currents in the KA-2 front foils, it is important to address the issue of whether we would expect to make useful measurements prior to any d-t operation in the absence of these currents. Using the fully collisional orbit code ASCOT, we have calculated the currents into the front foils of KA-2 during high and low triangularity H-mode plasmas with 1% toroidal field ripple. We compare these calculations with measured currents (the quiescent currents between the ELMS) in KA-2. This comparison is shown in Fig. 6, where it is noted that the peak predicted losses are well in excess of a nanoampere and should be readily measured if the anomalous currents are eliminated with the proposed thin foil.

IV. CONCLUSION

We propose the installation of very thin (0.1 μm) Ni foils in front of the existing apertures to the JET lost alpha particle diagnostic KA-2 or comparable Faraday cup based lost ion diagnostics at other machines. These foils would eliminate scattered UV radiation as well as deuteron and impurity plasma currents from the KA-2 front foils and allow the study, for example, of lost neutral beam ions during TF ripple experiments on JET. The foil temperatures would not approach melting even at extreme UV fluxes.

Finally, we would like to emphasize that the present background signal in the front foils does not compromise the reliability of KA-2 as a diagnostic of lost alpha particles from d-t plasmas since these alpha particles will generally stop in the second and third foils. One of the second foils, KA2-132, for example, maintains a quiescent background of with $I_{rms} < 1$ nA, while the front foil KA2-131 is recording several microamperes.

ACKNOWLEDGMENTS

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