Behavior of Langmuir probes in non-equilibrium plasmas

Kurt A. Polzin*
NASA-Marshall Space Flight Center, Huntsville, AL 35812

and

Alicia C. Ratcliffe† and Trevor M. Moeller‡
University of Tennessee Space Institute, Tullahoma, TN 37388

I. Abstract

LANGMUIR probes are diagnostic tools used to determine electron temperature, number density, and plasma potential. Irving Langmuir first used an electrostatic probe in the 1920s to find these characteristics in ionized gases. [1] Single, double, and triple Langmuir probes are commonly used in plasma diagnostics because of their relative simplicity. In the single probe, a swept voltage is applied between the probe tip and circuit common to acquire a waveform showing the collected current as a function of applied voltage. A double Langmuir probe consists of two tips, both inserted into the plasma, with a voltage applied between them. As this voltage is swept, a current-voltage characteristic is measured. In a triple probe three probe tips are electrically coupled to each other with constant non-swept voltages applied between each of the tips. The voltages are selected to represent three points on the single Langmuir probe I-V curve.

Elimination of the voltage sweep makes it possible to measure time-varying plasma properties in transient plasmas. Triple Langmuir probe measurements have been widely employed for various types of plasmas, including pulsed and time-varying plasmas such as those seen in pulsed plasma thrusters (PPTs),[2–4] dense plasma focus devices,[5] plasma flows,[6] and fusion experiments.[7]

The typical Langmuir probe analysis for determining electron temperature and number density of the plasma (for a single, double, or triple Langmuir probe) includes an assumption that the plasma is in thermal equilibrium. While the this assumption may be justified for some applications, it is unlikely that it is fully justifiable for pulsed and time-varying plasmas or for the entire time a plasma device is in use. In the present work, we model the responses of Langmuir probes as they are inserted into a range of simple equilibrium and non-equilibrium plasmas. We return to basic governing equations of probe current collection and compute the current to the probes for a distribution function consisting of two Maxwellian distributions with different temperatures (the two-temperature Maxwellian). A variation of this method is also employed, where one of the Maxwellians is offset from zero (in velocity space) to add a suprathermal beam of electrons to the tail of the main Maxwellian distribution (the bump-on-the-tail distribution function). For a range of parameters in these non-Maxwellian distributions, we compute the current collection to the probes. Comparing the distribution function that was assumed *a priori* with the plasma density and temperature one would infer when applying standard probe theory to analyze the collected currents serves to illustrate the effect a non-Maxwellian plasma would have on results interpreted using the equilibrium probe current collection theory, allowing us to state the magnitudes of these deviations as a function of the assumed distribution function properties.

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*Associate Fellow AIAA.
†Graduate Research Assistant, Student Member AIAA.
‡Associate Professor, Associate Fellow AIAA.

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