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ROCKET-BORNE LANGMUIR PROBE RESPONSE TO AN APPLIED PERIODIC POTENTIAL

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ABSTRACT

A Langmuir Probe (LP) payload designed and developed at Instituto de Pesquisas Espaciais (INPE/MCT) was flown on-board a SONDA III rocket at 2259 hrs. (LST) on October 31, 1986 from the Centro de Lançamento da Barreira do Inferno in Natal, RN, Brasil, under a collaborative programme between INPE and Instituto de Atividades Espaciais (IAE/CTA). The rocket reached an apogee of about 444 km and the LP payload functioned satisfactorily during the ascent as well as descent of the rocket. A sweep voltage varying between -1V and +4V in a period of about 2.6 seconds was applied to the LP sensor. As the applied voltage increased from -1V to +4V, the LP sensor current first showed an increase, reached a saturation level, and then, though the sensor potential increased towards a steady value, the current showed a systematic decrease. This sensor current characteristic also showed a clear dependence on altitude and hence on the ambient plasma parameters. Possible physical mechanisms responsible for these LP response characteristics are analysed and discussed here.

INTRODUCTION

In-situ measurements of plasma density and temperature using Langmuir Probes (LP) are often associated with certain problems that originate from the LP sensor surface contamination and the formation of plasma sheath surrounding the sensor (see Oyama and Hirao, 1975 and references therein). Any suggestion towards improvement in the LP technique is based on approximate modelling of the contaminated probe surface and the surrounding plasma sheath by appropriate capacitances and resistances (Hirao and Oyama, 1972). Experimental observations have clearly shown that contaminated Langmuir Probes indicate "hotter" electron distributions than actually present in the ambient medium (see Homes and Szuszcewicz, 1975 and references therein).

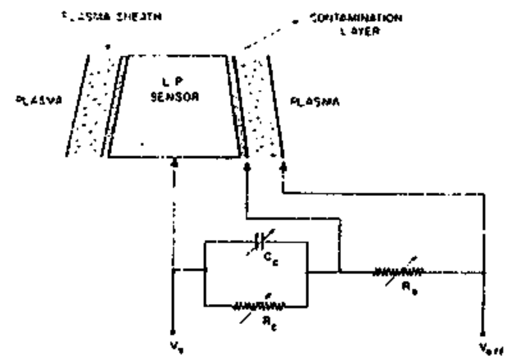

Fig. 1 - Equivalent circuit for a contaminated Langmuir Probe.

Considering an equivalent circuit shown in figure 1, for a slowly varying potential one can express the sensor current voltage relationship as

$$V_S = (R_C + R_S + R_P)\ I \quad (1)$$

where V_S is the applied sensor potential, I is the collected sensor current and R_C, R_S and R_P are the equivalent resistances of the contamination layer, the plasma sheath and the ambient plasma respectively.

Measurements made by a Langmuir Probe payload developed at INPE and flown onboard a SONDA III rocket at 2259 hrs (LST) on October 31, 1986 from the rocket launching station CLBI in Natal-RN, showed clearly the effects of surface contamination layer and the plasma sheath surrounding the sensor on the current collected by the sensor. Implications of the present observations are presented and discussed here.

RESULTS AND DISCUSSIONS

The LP sensor used had the shape of a conical cylinder, mounted just below the nose-tip of the rocket. A sweep potential varying between -1V and +4V in period of about 2.6 seconds was applied to the sensor The current

collected by the sensor for positive sensor potentials (with respect to the rocket body) during selected sweeps representing various height regions during rocket ascent, is shown in figure (2). The mean height corresponding to each curve is also indicated. The y-axis in the figure represents the sensor current and has a logarithmic scale. The positive-portion of the sweep applied to the sensor is also shown in the figure.

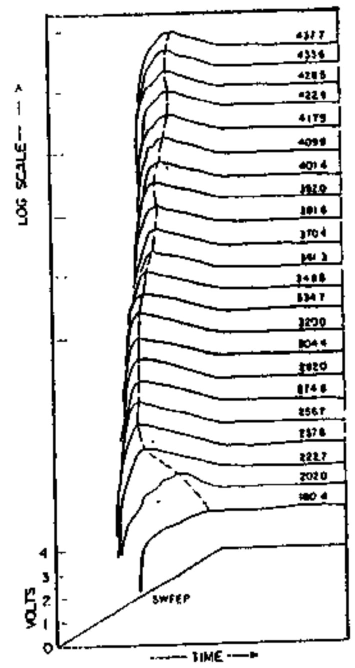

Fig. 2. Variation of LP sensor current with applied sensor potential for different altitudes during the upleg of the rocket. Positive portion of the applied sweep also is shown in the figure.

It can be seen from figure (2) that as the sensor potential increases from 0 to + 4V the sensor currrent first increases rapidly, reaches a maximum value and then starts decreasing even for increasing sensor potential. The current falls to an almost steady level, as the sensor potential reaches a steady value of +4V. The general pattern of current variation is practically same at all the height regions during ascent as well as descent of the rocket. But, a closer examination of figure (2) shows that, in fact, there exist systematic differences between the curves, namely

(1) the applied sensor potential at which the sensor current reaches its maximum changes continuously with altitude; and

(2) the "current decay" time from its maximum to a steady value changes with altitude.

These two aspects can be clearly seen in figure (3) where the applied sensor potential at which the sensor currrent reaches its maximum value is plotted as a function of height. The time taken by the sensor current to fall from its maximum value to its steady level is also indicated (the scale on top) in figure (3).

The effects of sensor surface contamination on the I-V characteristics have been studied in detail (see Oyama, 1976) and references therein. Equation (1) representing the relationship between the sensor current and voltage for a slowly varying sensor potential can also be written in the form.

$$V_s = V_{eff} + \delta V \text{ ——————— } (2)$$

where V_{eff}. (= IR_p) is the sensor potential as seen by the ambient plasma and δV [=(R_c + R_s) I] is the potential drop across (R_c + R_s), the total resistance due to the contamination layer on the sensor surface and the plasma sheath surrounding the sensor. Though the potential applied to the sensor is V_s, the ambient plasma sees a potential V_{eff} which is less than V_s by an amount δV.

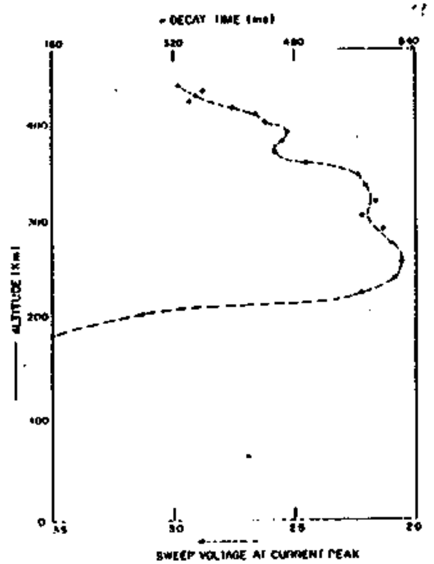

Fig. 3. Height variations in the applied sensor potential (lower scale in Volts) at which the sensor current is maximum, and of the current "decay time" (upper scale in ms.)—the time taken by the sensor current to decay form its maximum value to a steady value.

While R_c depends on the characteristics of the contamination layer formed on the sensor surface, R_s depends on the sheath thickness and density. As a first approximation let us assume that the resistance R_c due to the contamination layer on the sensor surface remains constant and the resistance R_s of the plasma sheath surrounding the sensor varies with altitude. The sheath thickness d on a plane sensor is given by the approximate relation,

$$d = 1.3 \; n^{3/4} \; h \text{ ——————— } (3)$$

where η is a measure of the potential difference between the sensor and the surrounding space in terms of the thermal energy of electrons and is given by $\eta = eV/(kT_e) = 11600V/T_e$, and h is the Debye shielding length given by $h = [\varepsilon kT_e/(n_e e^2)]^{1/2}$. In other words the sheath thickness d can be written as

$$d = C \left[\frac{V^3}{n_e^2 T_e}\right]^{1/4} \qquad (4)$$

where C is a constant ($= 1.0027 \times 10^5$) and V is the potential difference between the sensor and the surrounding plasma. If one assumes the sheath resistance R_s to be proportional to the sheath thickness, and the sensor current to be proportional to the electron density n_e the potential drop δV_s across the sheath can be written as

$$\delta V_s \propto \left[\frac{n_e^2 V^3}{T_e}\right]^{1/4} \qquad (5)$$

The potential drop across Rc is given by $\delta V_c = IR_c$, and the total potential drop δV is given by

$$\delta V = C_1 \left[\frac{n_e^2 V^3}{T_e}\right]^{1/4} + IR_c \qquad (6)$$

where C_1 is a constant. The first term in this equation represents the potential drop across R_s and the second term, the drop across R_c. We will confine our discussion here only to the possible effect of the first term in the current collected by the LP sensor, or in other words we will assume that the second term is a constant. Even if, the second term, in reality can vary with height, that will not alter the conclusions of the present discussion.

As the sensor potential V_s with respect to the rocket body is increased, the sensor potential V with respect to the ambient plasma also increases from a negative value, becomes equal to the space potential and then becomes positive with respect to the ambient plasma. When V becomes positive the sheath effect starts increasing which in turn drops V by an amount δV given by equation (6). The first term in equation (6) contributes to a potential drop that is proportional to the square root of n_e and inversely proportional to the fourth root of T_e.

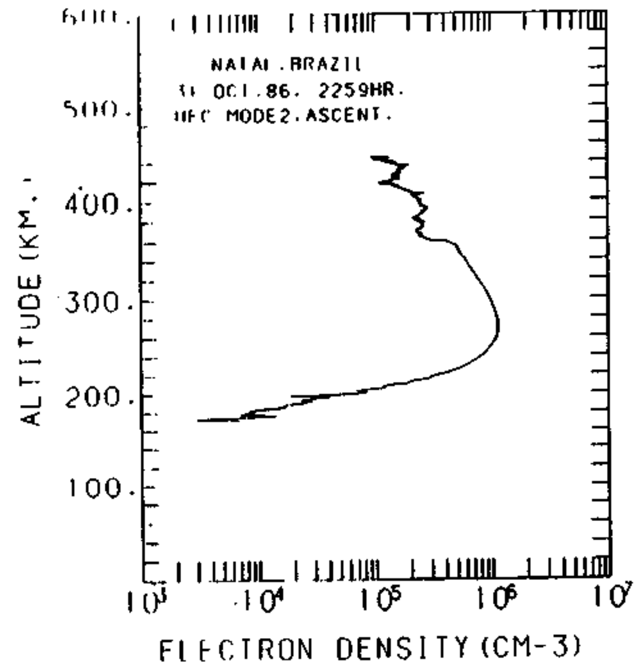

Fig. 4. Height profile of the electron density observed by a High Frequency Capacitance probe flown along with the LP.

It can be easily seen that, though, what is shown in figure (3) is the sensor potential at which the sensor currrent reaches its maximum value, it also represents the potential drop between the sensor surface and the ambient plasma caused by Rc and Rs. Figure (3) has close resemblence to the normal electron density profile. For a comparative study, the electron density profile observed by a High Frequency Capacitance probe flown onboard the same rocket, is shown in figure (4). The two profiles shown in figures (3) and (4) have striking similarities. Even some of the minor details are common to both the profiles. In other words one can say that the sensor potential at which the sensor current reaches a maximum and hence the potencial drop across the contamination layer and plasma sheath resistances is a function of electron density as can be expected from equation (6).

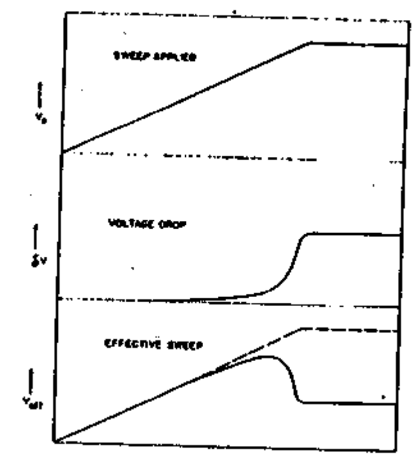

Fig. 5. Typcal variation of the effective sensor potential for an applied sweep potential V_s.

Typical variations in the sensor potential V , the potential drop δV across $(R_c + R_s)$ and the effective potential V_{eff} as seen by the ambient plasma are shown in figure (5). When the applied sensor potential increases from 0 to +4V, the potential drop across$(R_c + R_s)$ first increases slowly, and then increases exponentially, finally reaching a steady value. when the applied potential also reaches a steady value. The effective potential V_{eff} in such a case will have same type of variation as the observed sensor current variation shown in figure (2).

CONCLUSIONS

From qualitative studies of the sensor current variation with height, and its comparison with height profile of the electron density one can reach at the following conclusions.

(i) The formation of plasma sheath surrounding the sensor electrode, tends to increase the potential drop across the sheath and this distorts the probe characteristics.

ii) The potential drop across the plasma sheath reaches a maximum at a sensor potential that depends on the ambient plasma density as shown clearly by the similarity between the height profiles of electron density (fig.4) and the potential drop across the plasma sheath (fig.3).

(iii) The sensor current "decay time" or the plasma sheath build-up time also depends on the ambient electron density as can be seen from figures (3) and (4).

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