THREE INDEPENDENT TECHNIQUES TO STUDY SPATIAL CURRENT DENSITY

Valery Korepanov, Fedir Dudkin
Lviv Centre of Institute of Space Researches, 5-A Naukova str., 290601, Lviv, Ukraine

ABSTRACT

For experimental investigations of wave processes in space plasma one of the main tasks is the determination of dispersion relations between the wave vector and the frequency. For this it is enough to measure simultaneously variations of magnetic field and current density. The measurements of the magnetic field fluctuations usually are made by a variety of magnetometers using well developed methods. Unfortunately, up to the moment there are no reliable measurements of space current density although some attempts to do it with an instrument called «Split Langmuir Probe» were made. The spatial current density can be measured not only by split Langmuir probe, but also by a contactless probe of the type of Rogovski coil and by Faraday cup. The comparative analysis of such probes operation in near Earth plasma is made.

1. INTRODUCTION

For experimental investigations of wave processes in space plasma one of the main tasks is the determination of dispersion relations between the wave vector and the frequency. It can be shown that simultaneous measurements of magnetic field and current density fluctuations allow to determine experimentally wave vector components. The measurements of the magnetic field fluctuations usually are made by a variety of magnetometers using well developed methods. Unfortunately, up to the moment there are no reliable measurements of space current density, although some more or less successful attempts were made [1, 2].

The three sensors which could be used for the measurement of this value are proposed. First of all it is well known «Faraday Cup» instrument, installed at some spacecrafts for plasma population investigation [3]. Then so called «Rogovsky Coil» sensor is proposed as a second meter. It was never used before for spatial current investigations, although its parameters can suit for this [4]. At last the sensor «Split Langmuir Probe» is investigated as the instrument for current density study [2]. The theory of its operation is developed and discussed below.

2. FARADAY CUP

A Faraday cup (FC) is the device for the direct electron or ion current measurements in space plasma. Such measurements were realized, in particular, on board of «Prognoz» satellites and in experiment «Interball» [3].

The FC allows to measure the space current density J following expression:

$$J = IS^{-1}, \tag{1}$$

where I is the current that goes through FC entrance window, S is the area of this window.

The charged particles go through the entrance window to collector. The current formed by these particles is transformed into voltage by current amplifier with high input resistance R.

Thus the input voltage is connected with current density by relation:

$$u = JSR. \tag{2}$$

The sign of collected particles depends on the sign of voltage on FC grids G2,G3 (Fig. 1).

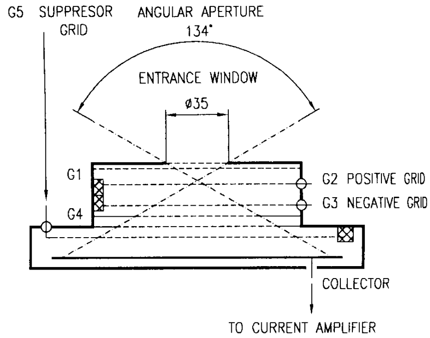

Fig.1.Faraday Cup Sensor diagram

The entrance grid G1 protects the space near FC from influence of another grids potentials. The grid G4 protects in the same way the space near collector from influence of potentials of the grids G2,G3. The potentials of grids G1 and G4 have to be maintained to be equal to the potential of satellite. The suppressor grid G5 (the nearest to the collector) reduces the photoelectron and secondary electron currents from the collector. Additionally for reduction of the photoelectrons current the collector surface is corrugated and covered with a special black nickel coat. All these measures provide a photocurrent reduction in 200-300 times.

The space diagram pattern of FC is a circular cone with basement that oriented to FC. The angle at the top of the cone diametrical cross section or angular aperture is 134° as shown on Fig.1.

In order to provide the possibility of the measurement of charged particles fluxes along one axis it is necessary to have two of such FC's, pointing opposite sides. Then such arrangement will react to the charged particles fluxes or what is the same, spatial current flowing along given direction. The experimental model was constructed and the tests revealed enough good sensitivity of the device: about 10^{-11} A/cm^2 to current density fluctuations. As it is seen from this very short instrument description, from the first sight the main principal limitations of the method could be the influence of direct sunlight and high-energy charged particles and spacecraft floating potential changes.

3. ROGOWSKY COIL

The principle of Rogowsky Coil (RC) operation is based on the following concept. The instrument itself consists of the ring core from high permeability material with the toroidal winding on it (Fig. 2) [4].

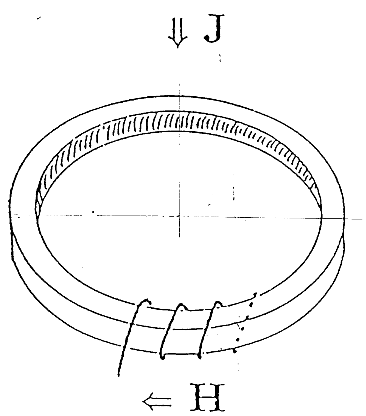

Fig.2. Rogowsky Coil sensor diagram

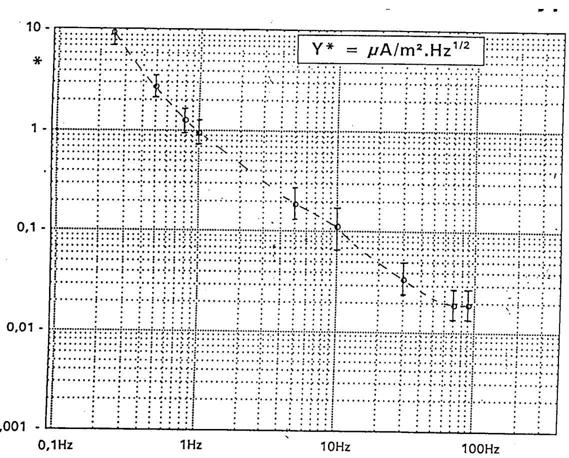

Fig.3. Rogowsky Coil noise level

The current J flowing through the core inner hole in the direction parallel to the axis of this toroid causes magnetic field intercepting the turns of the RC winding. When the current J is oscillating it provokes time varying magnetic field H and an e.m.f. e_i is induced in each turn of the winding:

$$e_i = \mu S \frac{dH}{dt}, \tag{3}$$

where S is core cross-section and μ - permeability of the material.

The total e.m.f. e consists of the summation of e_i (i=1, N), where N is the number of turns that can be transformed into integral along the mean major radius ρ of the toroid:

It can be shown [4] that the output e.m.f. of the sensor depends upon the time derivative of the normal component of the current density by the relation

$$e = \frac{\mu S N \rho}{2} \frac{dJ}{dt} = K \frac{dJ}{dt}, \tag{4}$$

where K is the instrument's constant.

Such an instrument was constructed and showed rather good sensitivity having diameter ρ equal to 30 cm: minimum noise level was about 10^{-12} A/cm^2 ·Hz$^{1/2}$. Namely the frequency dependence of the RC is its most serious principal limitation. The transfer function shape for the given device is presented on fig. 3, which reveals rather narrow frequency band of its application. But other specific noise sources, important for FC, especially influence of sunlight and high-energy charged particles, seem to be not distorting the RC operation.

4. SPLIT LANGMUIR PROBE

The Split Langmuir Probe (SLP) operation principle is rather simple: two conducting plates are placed in space plasma at as small distance or split d as possible and they are connected with a resistor R_s (Fig. 4). The SLP output signal U is formed as follows:

$$U = IR_s = JSR_s \tag{5}$$

where S is the surface of one SLP plate and I - current via equivalent resistance of probe R_s.

Further SLP is connected to the preamplifier and in order to investigate how it operates let us analyze its equivalent circuit including R_s, C_s are equivalent parameters of the sensor and R_i, C_i - those of amplifier.

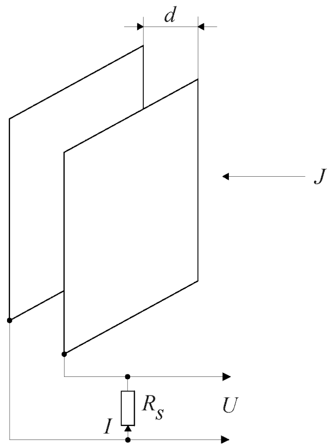

Fig.4. Split Langmuir Probe Diagram

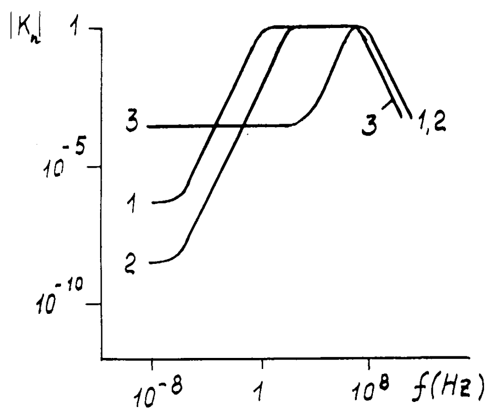

Fig.5. Split Langmuir Probe transfer function

The relation U with J can be written as follows:

$$U = JSR\left(1 + (\omega\tau)^2\right)^{-0,5} \exp(i\varphi), \tag{6}$$

where $R = R_i\left(1 + R_i R_s^{-1}\right)^{-1}$; $\tau = CR$; $C = C_s + C_i$; $\varphi = -\mathrm{arctg}(\omega\tau)$.

From (6) transformation coefficient K_T is equal to:

$$K_T = UJ^{-1} = K_s\left(1 + R_i R_s^{-1}\right)^{-1}\left(1 + (\omega\tau)^2\right)^{-0,5}\exp(i\varphi) \quad (7)$$

The parameters f_c - critical SLP frequency - and f_0 - quasiresonance SLP frequency - are introduced:

$$f_c = I_s\left(2\pi\varepsilon_0 K_s\right)^{-1}; \quad f_0 = \left(1 + C_i C_0^{-1}\right)^{0,5} f_{pe}, \quad (8)$$

where C_0 is the sensor capacitance in vacuum, f_{pe} - Langmuir frequency of electrons in plasma, ε_0 - dielectric constant.

The limits of operation frequency band are determined by the relation of f_c and f_{pe} [5]. The dependence of K_T on frequency for three different values $f_{pe1} << f_{pe2} << f_{pe3}$ is shown at fig.5. At quasi-resonance frequency $|K_n| = |K_T K_s^{-1}|$ has maximum value, equal to

$$|K_n|_{\max} = \left(1 + \nu_n f_c^{-1}\left(1 + C_i C_0^{-1}\right)\right)^{-1}, \quad (9)$$

where $\nu_n = (2\pi)^{-1}\nu$, ν- electron-ion collision frequency. When $f \to \infty$ $|K_n| \to 0$; when $f \to 0$ $|K_n| = \left(1 + (f_c \nu_n)^{-1} f_{pe}^2\right)^{-1}$. Our assumptions are valid for solar wind plasma (curves 1,2) when $f \geq (1 \div 3) \times 10^{-2}$ Hz and for F-layer (curve 3) when $f \geq 5 \cdot 10^3$ Hz.

It seems to be enough to prove that SLP really operates as electric current density to voltage transformer. The estimation of SLP noise level gives the order of 10^{-13} A/cm^2. The most important noise source for SLP as for FC is sunlight which also can produce very dense flux of photoelectrons, masking measured current.

5. CONCLUSION

From the description of three possible arrangements for spatial current density measurement it follows that all three of them can be used for this purpose. The SLP simplicity has doubtless advantages. As to the external factors influence, RC seems to be the less sensitive, whereas both SLP and FC are sensitive to the sunlight. All sensors are influenced by spacecraft potential. The last creates the potential barrier which will moderate the charged particles flux with lower energies.

It is expected that the planned in frames of VARIANT experimental onboard Ukrainian SICH-1M satellite (launch year 2000) comparative study will help to find the most reliable instrument for wave activity investigation in space plasma. These works were partially supported by INTAS grant 97-1769 and NSAU contract № 1189.

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