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# On the Utilization of the Spheric Ion Traps in Floating Potential Regime of Their Analyzing Grids

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The floating potential regime of the outer analyzing grid of the three-electrode spheric ion trap is of a great interest and reveals possibilities for a broad application of this type of sensor during direct space-probe measurements. A possible application of this operation regime is the employment of the spheric ion trap as a measuring device of ion (electron) density in the composition of a specialized satellite complex for low frequency and very low frequency measurements. In that case, the supply of any kind of oscillations to the outer parts of the satellite sensor is not recommended because even the disturbances through the general source of feeding in this frequency range will discredit the measurements. On the other hand, when applying a linearly changing voltage to the analyzing outer grid of the trap — to the point of the voltampere characteristics at which the potential of the plasma (the outer grid has a floating potential) corresponds to a current determined by the ions contained around the trap, and when we know this current the ion concentration can be determined directly. That is why this regime is to be preferred in combined magnetic and electrostatic measurements (see [1]), where the experimental purity depends on the absence of impeding factors — plasma-induced potentials in the case.

The aim of the article is to examine the conditions under which the three-electrode spherical ion trap may be applied as a measurer of the ion concentration, under conditions of floating potential of the analyzing electrode of the transducer.

The necessity of regime control of the floating potential is apparent, i. e., it is necessary to measure the isolated outer grid potential of the trap with respect to the satellite body. But in order to have such a control it is necessary to know the limits of that potential change.

In the ideal case (a definite floating potential of the absolutely isolated outer grid from the satellite body) the following circumstance will be operative: $i_e = i_i$, i. e.:

$$a_i e n_t S_i V_0\left(1-\frac{2e\varphi_f}{M_i V_0^2}\right)=a_e e n_e S_e\cdot\frac{\overline{V_e}}{4}\exp\left(\frac{e\varphi_f}{kT_e}\right). \tag{1}$$

In (1) the quantities relating to the ion composition of plasma are denoted by indices $i$, the index $e$ is used for those related to the electron component, $a$ is the portion of the corresponding current due to the punching of the grids, $S$ is the accumulation surface for the corresponding charged particles, $M_i$ is the ion mass, $V_0$ is the velocity of satellite movement, and $\varphi_f$ is the floating potential.

The above equation takes into consideration the fact that $V_i < V_0 \ll V_e$, i. e. the average satellite velocity exceeds the thermal ion velocity and is insignificant compared to the corresponding average electron velocity. Because of that the ion current has a purely conventional specifics (does not depend on the ion temperature), while the electron current is thermal, i. e. it does not depend on the satellite velocity — therefore $S_i=\pi r^2$, $S_e=4\pi r^2$ which is a direct sequence of the above circumstance ($r$ is the radius of the trap outer grid).

If $\alpha_1$ and $\alpha_2$ are the trasparency indices of the inner and outer grid of the trap, then:

$a_i=1-a_2$ the part of the ions that will fall on the envelope;

$a_e=1-a_2+a_2(1-a_2)=1-a_2^2$ the part of the electrons that will fall on the envelope.

Moreover, quantity $\frac{V_0 M_i}{2}=e\varphi_{ret}$ where $\varphi_{ret}$ is the retarding potential of the corresponding $M_i$ type ions. The main thermal velocity of electrons is $\overline{V_e}=\left(\frac{2kT_e}{m_e}\right)^{1/2}$, then equation (1) takes the form:

$$V_0\left(1-\frac{\varphi_f}{\varphi_{ret}}\right)=\frac{1}{2}(1+a_2)\cdot\left(\frac{2kT_e}{m_e}\right)^{1/2}\exp\left(\frac{e\varphi_f}{kT_e}\right). \tag{2}$$

In the general case we obtain

$$\ln\left(1-\frac{\varphi_f}{\varphi_{ret}}\right)=A_1+A_2\cdot\varphi_f \tag{3}$$

where $A_1$ and $A_2$ are constants, depending on $V_0$ and $T_e$. The examination of this dependence is of interest since it is closely connected with the orbital data of the satellite. This will probably be done in a future study.

As our main purpose is to study the real conditions under which our trap will operate, we have to find out the influence of the real resistance in the potential measurer connected to the outer grid. Obviously, this resistance $R_{in}$ connected between the trap lattice and the satellite body will influence the outer grid potential approach to the subject potential. This is due to the current being generated in the measurer by the difference $\varphi_f-\varphi_S$ ($\varphi_S$ — satellite potential). The current ring is closed through the plasma surrounding the satellite and the trap, so that its value is determined also by the current carriers concentration in the vicinity of the subject (specifically, by the dynamic resistance of the sphere and the contact resistances trap-plasma and satellite-plasma). The influence of the real input measuring resistance, when neglecting the contact resistances, is calculated by the expression:

$$\ln\left\{1-\frac{\varphi_f}{\varphi_{\text{ret}}}-\frac{\varphi_f-\varphi_S}{R_{\text{in}}+\dfrac{\varphi_{\text{ret}}}{(1-\alpha_2)en_iS_iV_0}}\cdot\frac{1}{(1-\alpha_2)en_iS_iV_0}\right\}=A_1+A_2\varphi_f. \tag{4}$$

The member $\frac{\varphi_{\text{ret}}}{(1-\alpha_2)en_iS_iV_0}$ has ohm dimensionality and is plasma resistance in a concrete case (familiar composition and concentration). Equation (4) takes the form (3) when the trap envelope is isolated ($R_{\text{in}}\to\infty$). Upon short circuit ($R_{\text{in}}=0$) $\varphi_f$ equalizes with $\varphi_S$, and equation (4) becomes an equation of satellite potential (without taking the photoeffect into consideration). But as the dependence which is used to represent the ion current is valid only for relatively low body potential (under 1 volt), the above equation cannot be used to determine the satellite potential.

We are analyzing below the $R_{\text{in}}$ influence for a concrete case: $V_0=7.25$ km/s; $T_e=2500$°K (ionospheric satellite with circular orbit, flying at an altitude of about 400 km over the Earths' surface) (Table 1).

When $R_{\text{in}}=10^8$ ohms we use dependence $\varphi_S\approx\frac{k.T_e}{e}\ln\left(\frac{T_eM_i}{T_im_e}\right)^{1/2}$ to determine the potential $\varphi_s$. We adjust the concentration values and the respective temperatures of the charged particles to correspond to altitudes at which the given type of ions is predominant.

The last column of Table 2 shows the percentage error, compared to the case when $R_{\text{in}}\to\infty$. We see that for concretely selected conditions the error does not exceed 5 per cent. Within the concentration decrease the status is preserved, as $T_i$, or $T_e$ respectively, increases. Obviously, in controlling the floating potential in the upper atmosphere, an input resistance of the measurer of an order of $10^8$ ohms is completely sufficient to obtain unspoiled results. As indisturbed conditions for concentration measurements exist only when the trap does not measure within the satellite trace, it is clear that in the general case it is necessary to use two identical ion traps which have to work either simultaneously or in temporal sequence.

Table 1: $R_{\text{in}}\to\infty$

| Transforming ion | $\varphi_{\text{ret}}$ [V] | $\varphi_f$ [V] | $\varphi_f/\varphi_{\text{ret}}$ |
|---|---|---|---|
| $O^+$ | 4.4 | −0.705 | −0.160 |
| $He^+$ | 1.1 | −0.625 | −0.57 |
| $H^+$ | 0.275 | −0.512 | −1.87 |

Table 2: $R_{\text{in}}=10^8$ ohms

| Transforming ion | $\varphi_S$ [V] | $n_i$ [cm$^{-3}$] | $\varphi_f$ [V] | % error |
|---|---|---|---|---|
| $O^+$ | −1.18 | $10^6$ | −0.708 | 0.43 |
| $He^+$ | −1.1 | $10^4$ | −0.650 | 4.15 |
| $H^+$ | −1.1 | $10^4$ | −0.525 | 2.35 |

The preliminary results of the ion concentration measurements from the "Intercosmos-14" satellite confirm the logic presented above for the influence of $R_{in}$.

Upon recording the ion collector current $I_k$ of the trap with a floating potential of the outer grid, the ion concentration can be determined by using the dependence:

$$n_i = \frac{I_k}{\alpha_1 \alpha_2 \pi r^2 e V_0 (1 - \varphi_f/\varphi_{ret})}. \tag{5}$$

Table 1 shows that neglecting the term $(1-\varphi_f/\varphi_{ret})$ leads to an error increasing with the mass decrease of the recorded ions. Notwithstanding the fact that equations (1)÷(4) have been deduced without taking the ion thermal velocities into account (whose influence increases within the mass weight decrease), it is clear that (5) is closer to the actual situation than the accepted $\varphi_f/\varphi_{ret}$.

## References


1. F a h l e s o n, V. et al. Radio Science, 6, 1971, 2, 233–245.


## Использование сферических ионных ловушек в режиме плавающего потенциала анализирующей решетки


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(Р е з ю м е)

В настоящей работе предложен метод для определения ионной концентрации по данным, полученным от сферических ионных ловушек, у которых внешняя решетка находится под плавающим потенциалом. Рассмотрены условия работы ловушки при плавающем потенциале и определенном воздействии реального сопротивления между внешним электродом ловушки и поверхностью спутника. Предложено аналитическое выражение для определения ионной концентрации, в котором неизвестными являются коллекторный ток, плавающий и задерживающий потенциалы ловушки.