IN FLIGHT MEASUREMENT OF THE OUTSIDE SURFACE POTENTIAL OF THE "MIR" ORBITAL STATION

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Abstract

In connection with the beginning of realization of an International Space Station (ISS) again become actual questions of interaction of superlarge spacecrafts (SC) with ionospheric plasma. The current on a surface of SC is interest physical parameter in these researches. For such researches in 1987 on the orbital station (OS) "MIR" the ZOND-ZARYAD instrument was installed. The interpretation of some measurements executed by the instrument, was published earlier [1, 2]. In the given report the results of measurements of fluctuations of the current that has been carried out in 1999 are discussed.

1.CONFIGURATION of MEASUREMENTS

Physical configuration of measurements. Probes methods are widespread at researches of parameters of plasma, including currents in plasma. In space researches frequently is used two-probe system, in which one probe is the usual probe from a conductive material, another is spacecraft itself. In such system the sizes of one probe (SC) essentially exceed the sizes another. In this case current on the small probe, owing to the small area of its surface, is very small as contrasted to currents on the large probe, that is the small probe, introduces only small contribution to a current balance of the large probe. The characteristics of such system practically coincide characteristics of the single probe Langmuire [3]. Basic current sources, flowing in a measuring circuit of the ZOND-ZARYAD instrument, are ambient SC plasma and photocurrents. The configuration of measurement of a variable component (fluctuations) of a current on the probe is presented in a Figure 1.

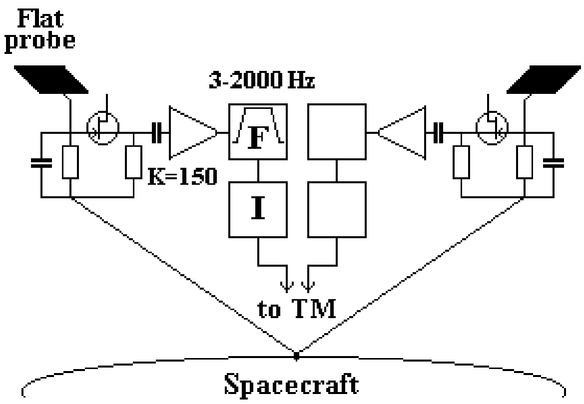

Figure 1. The configuration of measurement of fluctuations of a current on the probe.

Parameters of the instrument. The available measuring configuration is represented as follows. The detector of a measuring signal is the flat probe (square plate by the area 2.5õ2.5 cm^2, material – a copper, covered by a nickel). The measuring circuit consists of the resistor 150 ÌÎì, shunted by capacity 270 pF. The amplitude of current in circuits is determined by the measuring system, consisting from source follower cascade (FET transistor), ensuring a high input resistance (not less of 10^{11} Ohm), separating capacity, connecting a long-persistence repeater to the amplifier (an amplification factor K = 150) and filters (**F**) (a passband f = 3 – 2000Hz). The interfacing (**I**) sets to voltage output an initial level 3.15V ("support"), approximately appropriate to a zero value of a measuring variable signal, then the signal goes to telemetry. The range of amplitudes of currents is $1.3 \cdot 10^{-11} - 2.8 \cdot 10^{-10}$ A (tip-to-tip). The measurement range from below (threshold) is determined by an own noise of the amplifier, from above is restricted maximum level of a signal accessible by telemetry.

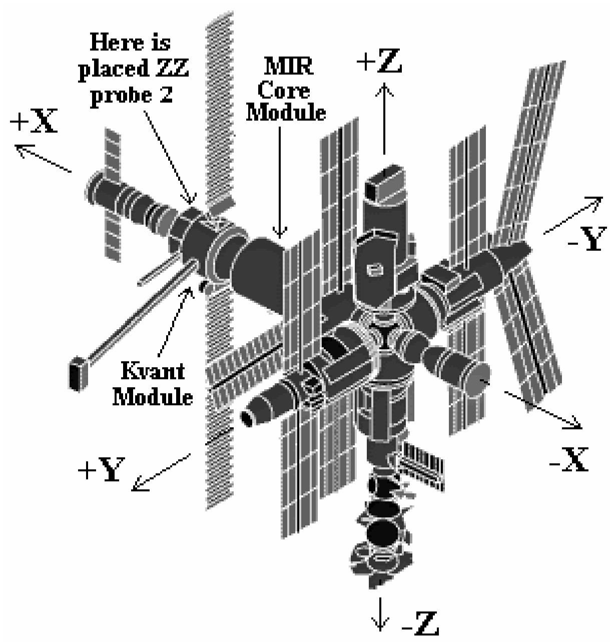

Figure 2.Common configuration of the "MIR" orbital station.

Disposition the instrument on board. Two probes of the ZOND-ZARYAD instrument are disposed on the "KVANT " module (see Figure 2, Figure 3) of the "MIR" OS. As see by image, the planes of a surface of each probe are directed diametrically opposite. And in co-ordinates of building axes of the core module of the "MIR" OS (CMOS) the aperture of one probe is oriented in a direction of an axis – Z (parameter NEP1), while the aperture of another probe is oriented in a direction of an axis + Z (parameter NEP2). The probes are mounted at a level of a surface OS.

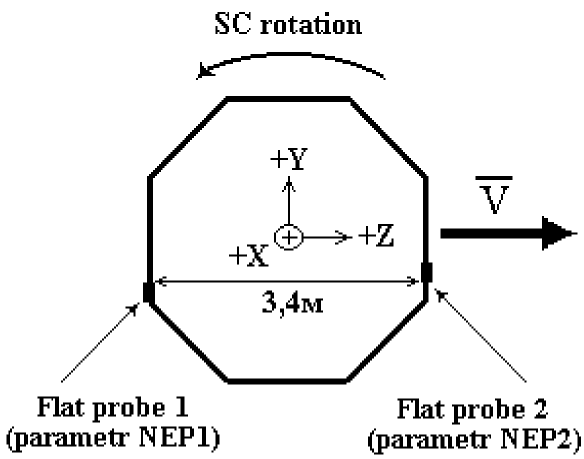

Figure 3. Directions aperture probes.

2.RESULTS of MEASUREMENTS

The given investigation is based on the analysis of measurements, carried out in 1999 on several orbits in a condition of three-axis orientation OS in an orbital co-ordinates and on one orbit in a condition of rotation OS.

The sampling of parameters is 128 ms. A memory-seance by duration 120 minutes contains about 56250 measurements. The initial telemetry information, evaluated on quality as satisfactory, was cleared of failures and incorrect measurements by criterion 5σ. The most obvious features detected in a mode of three-axis orientation, are illustrated below on an example of measurements carried out 1999 June 29, Figure 4. On first (upper) and third panels are shown more rarefid (it is shown everyone 5-th a point, that is the sampling corresponds 640ìñ, more than 11000 points) data of measurements of parameter NEP1 and NEP2, accordingly. On the second and fourth panels are shown data after further treatment (see below) of parameters NEP1 and NEP2, accordingly. The measured values in range of changes 0 - 6.3V are given in a linear scale 0 - 100% (panel 1, 3). In presented data it is possible to see separate points of measurements, range of change of parameters (shading in limits of changes), indicating scatter of values, and the rounding. On panels the magnitudes minimum (MIN) and maximum (MAX) of values of parameters on all an presented fragment are given. Mean value (M) is identified with "support". Standard deviation (SD) and correlation coefficient (RO) are presented also. On an ordinate axis on each panel the values of measured parameters in a scale of minimum and maximum values in an introduced fragment are shown. On axes of abscissas are presented of number more rarefid measurements data. The night fragment of orbit OS is shown in Figure as a shadow segment on panels. The times of sunlight and darkness on orbit, as well as values of geophysical parameters, were evaluated under the program CADR-4 [6]. On the bottom (fifth) panel some data of orientation are shown. On an ordinate axis is given the values of an angle in a scale a maximum and minimum minus 10 values of presented curves. The tokens "+" mark values of a angle between a direction of a building axis –Z of CMOS and velocity vector V direction of OS, the tokens "x" mark values of a angle between a direction of a building axis –Z and direction of a magnetic field of the Earth. Everyone 10-th a point of a curve is marked. Numbers of points of orientation are shown on an axis of abscissas. Under the bottom of panel the UT of an presented fragment and date of seance of measurements are given.

The orbit parameters of the "MIR" OS on a period of measurements were: the altitude 350 - 370 km (is higher than a maximum of a F-layer), inclination - 51°.7, orbital period – 91.5 minutes.

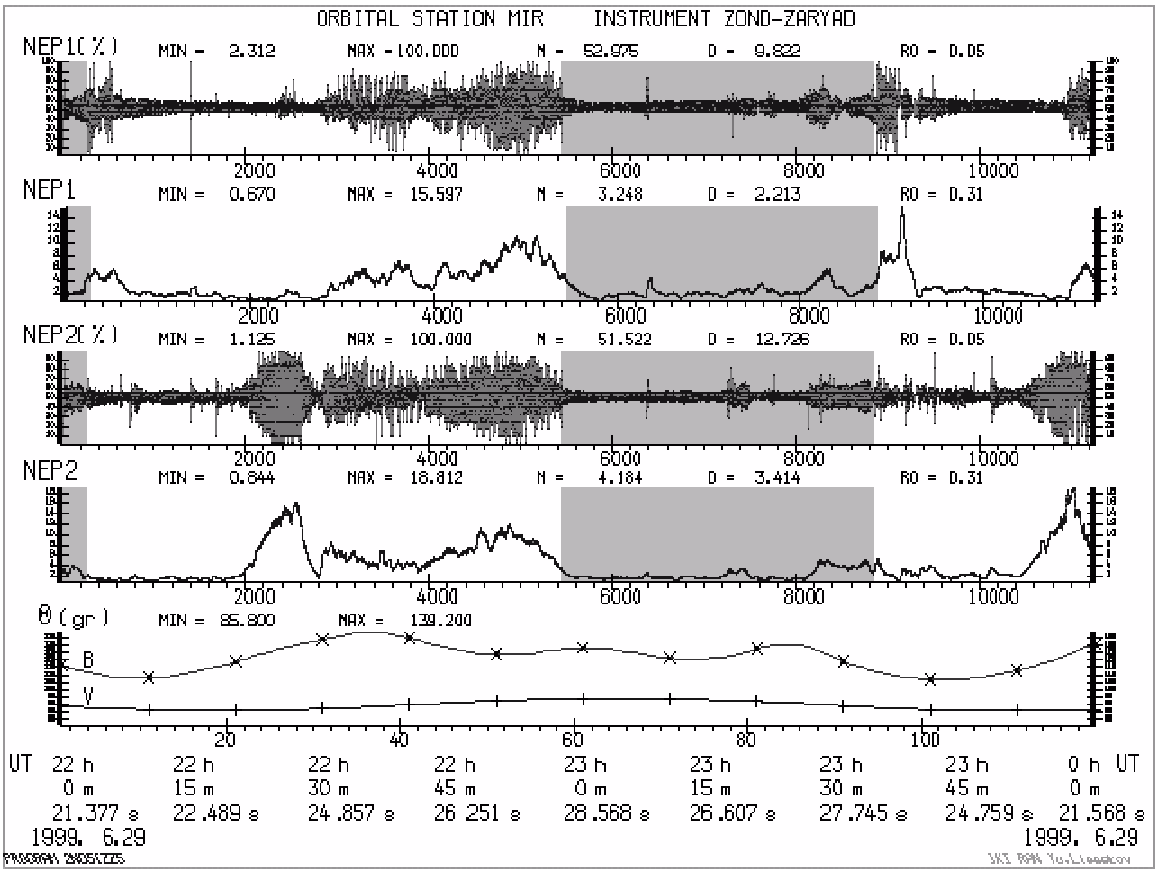

Fig. 4. Measurements 29.06.1999

Measurement in a mode of three-axis orientation OS 29.06.1999 (Figure 4) fall into a period of quiet geophysical conditions: $K_p=1_0$, $\Sigma K_p=14_+$. On parameters of orientation it can see both probes during all session are directed almost perpendicularly to OS velocity vector, the angle between velocity vector and building axes –Z was supported in limits

85 - 94°. In an angular variation of an axes –Z with vector of a magnetic field the period equal orbital is observed. On an analyzable fragment there are two intervals of a darkness: the 3-minutes interval in the beginning of a session and 36-minutes - in second half of session. On the sunlight segment of orbit the angles between building axes of CMOS and direction on the Sun were not changed and were equal to θ_x=138°, θ_y =48°, θ_z =83°. Is obvious, standard deviation (SD) of both parameters in some times is lower on night segments, than on sunlight segments. In a considered session on the sunlight segments of orbit the parameters NEP1 and NEP2 receive values from noise levels of the amplifier 300mV (± 150mV - ± 2.5% of a scale from a mean value on an interval), and up to a maximum of a scale 6.3V (± 3.15) - ± 50%.

On a darkness segment of orbit of both parameters a majority of time are near to a noise level of the amplifier, though the intervals, where the maximum values reach a level 35%, are observed too. The factor of cross correlation parameters on sunlight segment (-0.029) and on darkness segment (0.007) of orbit, as well as on all a session (RO = 0.05), is small, that is the parameters in a session do not detect interdependence, to what the insignificant magnitude of a correlation coefficient testifies statistically. At an input in a darkness segment of orbit the values of both parameters are sharply diminished. At an exit on the sunlight segment of orbit parameter NEP1 increases sharply. At the same time of sharp increase of parameter NEP2 is not observed.

In character of change of both parameters the features (similarity) reproduced through time of an orbital period are observed that corresponds to approximately 8580 points of measurements (91.5 min). For example, character of increase of parameter NEP2 from 22:21.30UT (point 2004) and further and from 23:53.00UT (point 10582) and further. The geophysical parameters appropriate to these times, are very close: at 22:21.30UT LAT=41°.8 N. lat., LONG=165°.8 E. long., L=1.55, Λ_0=36°.5; at 23:53.00UT LAT=41°.8 N. lat., LONG=142°.5 E. long., L=1.50, Λ_0=35°.2. By attentive consideration the similar phenomenon is observed in parameter NEP1 (compare exits from a darkness, to be on distance one from another on an orbital period). Comparison of the tendency of change of each of parameters (increase, decreasing, the general format) on intervals, to be distance on magnitude of an orbital period, displays noticeable coincidence (similarity) of behavior of parameters.

The following stage of treatment of parameters was included a centering on a mean value on all interval, the excluding values of parameters of a below zero level and filtration (smoothing). For smoothing of parameters the linear filter sliding mean with different number of points (and, accordingly, time frame) average was used. Let's remark, that the used linear filter diminishes amplitude of harmonics in a top of a spectrum, and the greater number of points participates in average, the below frequency of harmonicses, which amplitude is diminished, that is parameter becomes more "smooth". The rounding of the smoothed values allows to track change of measured amplitude by a variable component of a probe current during a session without masking influences of a noise component. On the second and fourth panels of a Figure 4 the values of parameters smoothed on the interval 30 s are shown. The smoothing diminishes a noise component and makes by less sharp fronts (sharp changes) signal. As SD of parameters was determined mainly by high-frequency (noise) component of a signal, smoothing, naturally, has reduced a scatter of values in some times. The correlation coefficient of parameter (0.31) was considerably increased. All features of behavior of parameters remarked at the analysis of the not smoothed signal, are observed and on the smoothed signal. The similarity of fragments, to be on distance on time of an orbital period, on the smoothed data is confirmed by magnitudes of the appropriate correlation coefficients: 0.85 for parameter NEP1 and 0.95 for parameter NEP2.

Measurement in a condition of rotation OS 16.09.1999 (Figure 5) were carried during 90 minutes. OS rotated around of an X axis CMOS (X axes is perpendicular orbital plane and, accordingly, vector of orbital velocity). The rotation rate was about 0.25 grad/s, period of rotation was about 23.5 minutes. Besides the precession of an axes Õ was about 35°. At the analysis of measurements the parameters of orientation with a discretization 10 s were used. The measurements fall into a period moderately of disturbed geophysical conditions: $K_p=4_+$, $\Sigma K_p=31_+$. In a Figure 5 the measurements in a format similar Figure 4 are shown. The session of measurements has one interval of a shadow. Both parameters NEP1 and NEP2 display characteristic modulation, defined change of orientation. For parameter NEP1 the maximum of a signal is observed, when the angle of an axes –Z CMOS with a direction of velocity vector θ_V has a maximum value close to 180°. It corresponds to a direction of a probe NEP1 against velocity vector OS, thus the probe is in wake. The probe NEP2 is directed to the same time on velocity vector, thus the probe is in ram. As OS rotates around of a building X axis CMOS, the probes NEP1 and NEP2 serially pass wake and, so that characteristic modulation of a signal with a period of OS rotation is connected. On the sunlight segment of orbit parameters have more noise components, than on darkness, besides on the sunlight segment the signal has large amplitude and is scattering on the greater interval of angles in relation to a maximum value. It is necessary to mark, that at the end of a fragment in parameter NEP1 the modulation is less clear. The angle of an axis –Z CMOS with vector of a magnetic field θ_B equal 90° corresponds to a direction of probes across the Earth magnetic field. On the measurements, smoothed data, except for characteristic modulation connected to rotation OS, it is possible to mark presence of maxima and minima of a signal (especially on the sunlight segment of orbit).

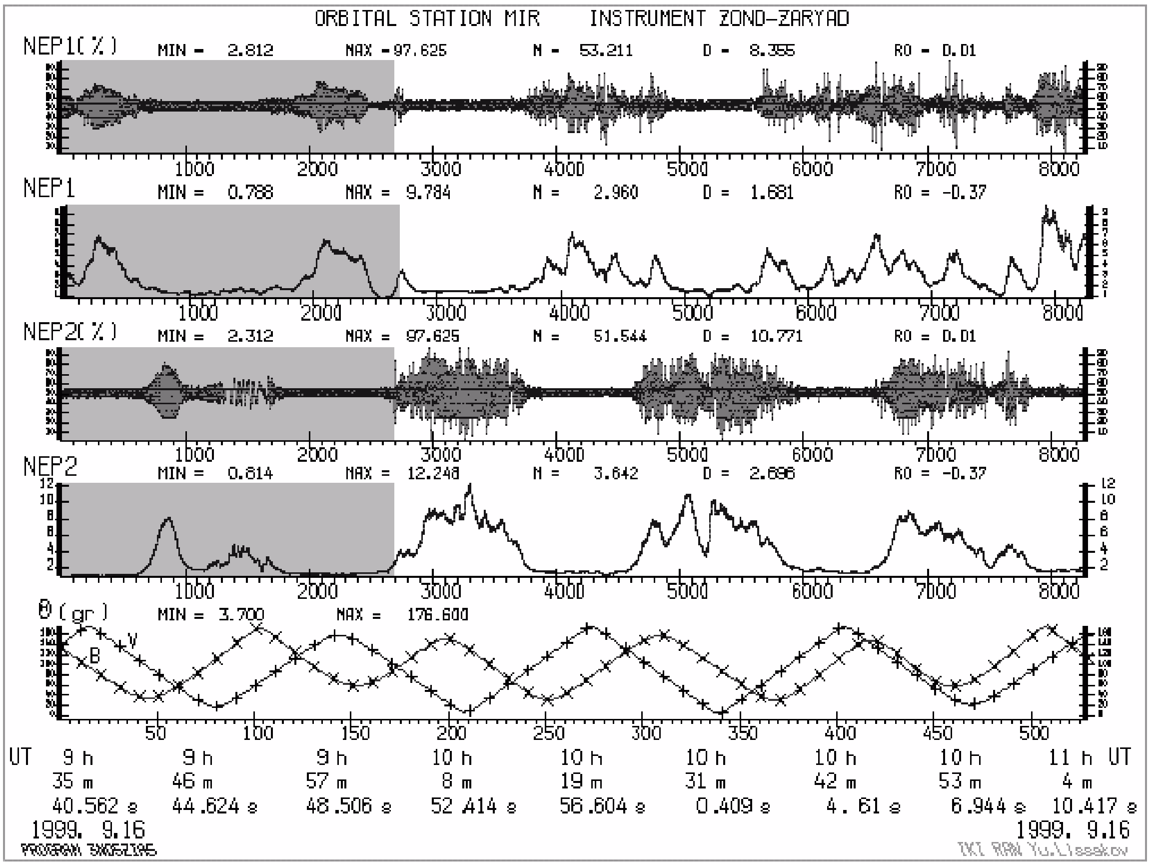

Fig. 5. Measurements 16.09.1999.

3.DISCUSSION of MEASUREMENTS

The interaction of SC with ionospheric plasma, except for parameters of the plasma, is determined by the geometrical sizes of SC itself, ratio of the areas of conductive and nonconducting surfaces of SC, shape and electrophysical properties of materials of its surface [4, 5]. Into such properties first of all fall: electroconductivity, photo-, second-, and termo- emission of property, used in a construction of SC of materials. The geometrical shape of a surface the "MIR" OS has a rather complicated configuration (Figure 2). The estimation of a total area of the "MIR" OS surface with an exactitude about 20 % is 1700 m^2 and about 70 % of a nonconducting surface (these are in a basic shield-vacuum thermal insulation, nonconducting surfaces of solar panels and other design elements) and about 30 % of a conductive surface (metal).

As the result of interaction, on a surface of SC is established floating (equilibrium) potential (FP), at which the ionic current on SC is compensated by an electronic current. FP in an ionosphere, as a rule, has a negative value and, according to theoretical estimations, usually reaches magnitude –(3-5)kT/e. Negative potential of a surface of SC will be neutralized by a positive layer of ions shielding it from ambient plasma. The width of an ionic layer is connected to basic parameter of plasma - Debye radius. A typical value of radius Debye in an ionosphere at the "MIR" OS altitudes is 0.2 - 0.7 cm. Thus, essential property of structure of plasma in environs of a body is the formation in some zone about its surface of the boundary charged layer owing to a strong influence of Debye shielding. The boundary charged layer is a double charged layer near to a surface, in which potential is sharply diminished from magnitude φ_s (equal FP) by its surface up to φ_p (equal to spatial potential) on the exterior boundary of the layer. The instrument probes mounted flush with a skin of SC are under effect of a bulk charge.

Spacecraft moving with supersonic velocity in ionospheric plasma calls perturbations of the plasma density, its neutral and charged components. Neutral particles and ions the having thermal velocity almost on the order smaller, than velocity of SC, interacting with a surface of SC, create specific structure accompanying its moving. Before SC the area of a condensation (ram), and behind – rarefid area (wake) is formed. The density neutral and ions in wake on small distances from a surface of SC exponential is small, as this area has no time to be filled by particles having thermal velocity. As to electrons, their thermal velocities much more exceed velocity of SC, hence, the distribution of electrons in a moving co-ordinates remains equilibrium, thus, density of electrons in a ram and in a wake should to differ a little (theoretically). However some researcher marked decreasing electronic density in a wake on some orders as contrasted with by density in a ram. The perturbation of the charged component at the "MIR" OS altitudes is appreciably determined electrical and magnetic fields. The effect from compression at the ram is caused that the ionic current reaches a maximum at equality to zero of a angle between the normal to an element of a surface of the probe and velocity vector (angle of attack), and to come nearer zero, when the probe is in a wake of SC, i.e. the current collected by the flat probe, depends on an angle of attack, and, thus, the characteristic modulation of an ionic current by moving across will take place maximum (effect of compression), when the aperture is coincided with direction of the velocity vector, and minimum (effect of a wake), when the aperture is directed in an opposite the direction. This phenomenon is observed in measurements on rotation SC mode, when the measurements in two diametrically opposite points are sequentially executed at a continuous angular variation of attack θ in an interval 0 – 180° with a period of rotation.

The analysis of measurements on profile planes at angles of attack close to 90° has shown difference of character of change of parameters on two is diametrically opposite directional probes. It can explain additional, uncontrollable because of the complicated shape OS by particle fluxes circulating SC, and on the sunlight segment of orbit - also by difference of photocurrents (condition of illuminant of probes, near design elements of OS, capability of dazzles on probes). The additional effects are most expressed in near surface area of SC. The large fluctuations of currents on the sunlight segments of orbits, in comparison with fluctuations on darkness segments, are explained more dynamics of interaction processes of SC with an environment stimulated by presence of solar radiation. At intersection terminator the level of fluctuations sharply varies: at an exit from a darkness it increases, at an input in a darkness it decreases. Significant correlation of fluctuations, measured on diametrically opposite planes, is not observed. Observable similarities of character of behavior of a level of fluctuations connected to an orbital period, is easily explained to that SC on consequent orbit, being on approximately same geomagnetic latitude, by saving orientation in direction to a local magnetic field, falls in area of plasma, which parameters differ from parameters of plasma crossed SC on a little to preceding orbit, that it is possible to explain by quiet geophysical conditions [7]. In addition to explained above, we shall mark, that at a research of interaction of SC with space environment it is necessary to mean, that SC lives rather complicated by electromagnetic "life", connected with operation of its equipment (i.e. SC is a source electrical, magnetic and electromagnetic fields in a broad band of frequencies from constant fields up to tens MHz overlapping characteristic frequency of ionospheric plasma). OS also lives by physical-chemical "life", connected with operation of life support systems of crew (for example, draw leaks of gases, drops of a water and waste products etc.), with operation of gas attitude engines, engines of transport SC, that modifies environment.

4.CONCLUSION

The comparison of ion densities (10^{-9} – 10^{-10} À/ñm^{2}) and electron currents (10^{-6} – 10^{-9} À/ñm^{2}), characteristic for ionospheric plasma at altitudes of 300-400 km, with measured by us by magnitudes of a variable component of current densities on probes ($4.5\cdot10^{-11}$ – $2.1\cdot10^{-12}$ À/ñm^{2}), displays, that the range of changes of a variable component (fluctuations) on the order is less than range of changes of an ionic current and on three order less - electronic current.

On our sight at measurements of parameters of an ionosphere and at a research of interaction of SC with ionospheric plasma by probe methods together with measurements with the purpose of construction current-voltage characteristic (curves) is expedient to analyze a variable component (fluctuations) of probes currents. However, obviously, that for researches of an ionosphere, the probes should be disposed far from a surface of SC, outside of a zone of perturbation of an environment and outside of a zone of possible falling on probes of additional particle fluxes from construction structure elements of SC, i.e. probes should be established on booms, in area before face and to not be shaded by construction structure elements. Researches of interaction of SC with an environment also need to have probes in near surface area of SC. The full analysis of ambient plasma and interactions of SC with it can be obtained at execution of measurements in a condition of rotation of SC, so that the probes sequentially scanned an environ at a continuous angular variation of attack from 0 up to 180°.

Presented here analysis of a fluctuation of a current on the flat probes of the ZOND-ZARYAD instrument displays, that the simple instrument, long and reliable working on the "MIR" OS, allows to carry out a long-time researches of interaction of superlarge bodies with ionospheric plasma. The modern modifications of similar elementary instruments are expedient for equip in a structure of research plasma complexes of scientific instrumentation with the purpose monitoring-researches of ionospheric plasma and interaction of superlarge bodies with ionospheric plasma, including interactions at active experiments. The researches of interaction of superlarge with ionospheric plasma have a perspective of prolongation by ISS. With this purpose IKI RAS is offered long-term, in some stage the complex experiment OBSTANOVKA (that means circumstances) with the research problem in near surface area of plasma-wave processes of interaction of superlarge SC with an ionosphere and monitoring of electromagnetic circumstances in environs of the ISS in direct connection with parameters of nonperturbed SC of ionospheric plasma and geophysical conditions.

ACKNOWLEDGMENTS

This work was partly supported by the contract ¹ 101-10(00)-P / Veter and INTAS grant 97-1769.

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