In Flight Results of Spacecraft Charging Investigation for Russian High Altitude Satellites

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Abstract. Our research program on spacecraft charging based on using of serial satellites as platforms for the experiments. Additional equipment for spacecraft charging experiments was mounted on the serial communication and navigation satellites GORIZONT, GLONASS, GALS and EXPRESS designed by Scientific Production Association of Applied Mechanics (NPO PM). Electrostatic field strength outside the spacecraft body is the major parameter that we measured in those experiments. Value of electric field strength between 20-30 kV/m was indicated during magnetosphere substorm and Earth eclipse. Disturbances of spacecraft charging caused by plasma thruster has been detected for GALS-12, EXPRESS-11 and GORIZONT-30 spacecraft. The value of electric field strength in flight experiments is correlated with magnetosphere activity based on Ap, Cp- indexes. In this paper we present a short review of the results of Russian high altitude spacecraft charging investigation.

1. Introduction

Our spacecraft electric charging explorations are based on the direct electric fields strength measurements on serial communication and navigation spacecraft. This is our major difference from traditional instruments such as particle spectrum analysis [1] and electric potential probe [2] used by other researchers. Traditional methods have problems caused by self-consistent: charged particle fluxes determine shape of spacecraft electric potential, but on the other hand spacecraft electric potential disturbs original charged particle fluxes. Direct electric fields measurements significantly amplify traditional spacecraft electric charging investigations and instrument verification.

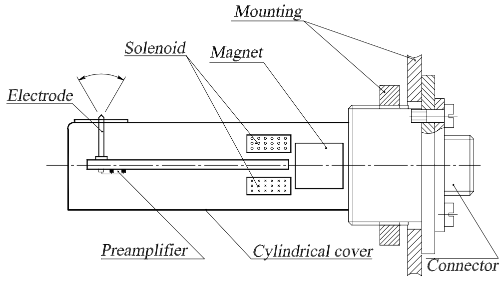

Fig. 1: Vibration type electric field strength probe.

Our general instrument is vibration-type DEP-probe (Fig. 1). The probe has a cylinder of 26 mm in diameter and 70 mm long, the weight of one probe is 60 to 70 g. Its measured field range is 0-200 kV/m.

In flight active experiment using I-60 Xenon Plasma Source (XPS) (Ip=1.5 A, Up=150 V, m=1.8 mg/s) was performed at geostationary spacecraft GORIZONT-30 positioned at 90° E. Nine electric field probes were mounted at various points of a spacecraft. The investigation of spacecraft charging reaction caused by plasma source was made on July 23-25, 1990.

Three DEP-probes and two DNT-probes as Faradey cylinder were used on GLONASS-56 (launch 1992) and GLONASS-60 (launch 1993) satellites with circular (20000 km) orbit. The variations of electric field strength during 12-hour and 6-hour periods and amplitude in range from about 1.5 to 4 kV/m were observed.

The next step of Russian spacecraft charging program was a project "Patrol system" based on instrument DIERA. The project was started on spacecraft EXPRESS-11 (launch 1994, 14° W) and GALS-12 (launch 1995, 36° E). EXPRESS-11 and GALS-12 spacecraft implied Xenon plasma thrusters. The DIERA instrument controlled three electric field probes and several electromagnetic noise detectors.

Diurnal variation of electric field strength on spacecraft surfaces has been observed. Total negative charging of the spacecraft during the Earth eclipse was indicated Disturbances caused by plasma thrusters similar to that of GORIZONT-30 have been detected.

2. Experiments

2.1. Active experiment

In flight experiment using ADIPE-662 research system was aimed at seeking for efficient means for neutralization of the electrostatic charge accumulated on S/C surface and body. BN-1 unit of ADIPE-662 by Novosibirsk State University gathers, stores, processes, and transmits data associated with the charging conditions on S/C surfaces. Nine compact electric field probes of a vibration type were installed on the S/C surfaces. BN-1 unit is controlled by module of a central processor which function is to sort out commands from the permanent memory, to carry out data exchange with outer devices and to read data from detectors. It stores 32 hours of field data into the memory of BN-1 unit. BN-2 unit of ADIPE-662 system by Moscow Aviation Institute is a Xenon Plasma Source (XPS) and its aim task is to generate plasma that in its turn decreases the differential S/C charge. XPS working fluid is Xenon of high purity. The operational principle of the PS is based on the radial acceleration of electrons analog a closed loop. The working fluid supply is 0,2 kg, operation consumption is 1,8 mg/sec, and value of acceleration potential 150 volt,

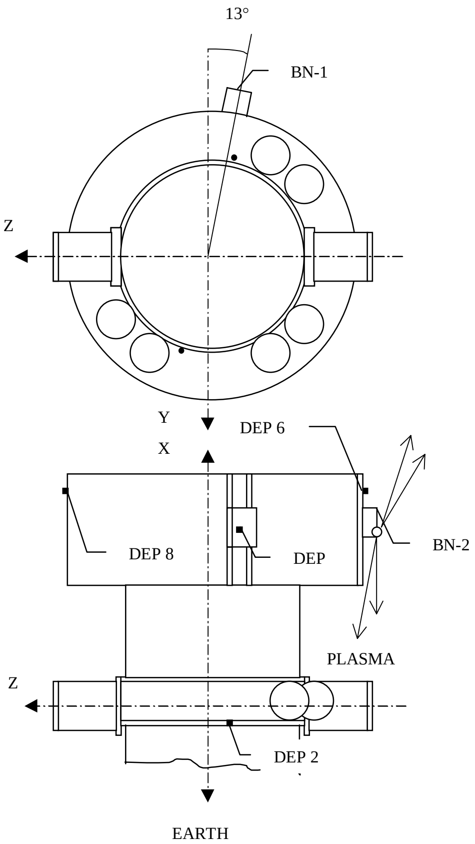

Fig. 2: A general plan of GORIZONT spacecraft, BN-1, BN-2 and several DEP-probe disposition.

with discharge current 1 A, mass of XPS is 9 kg, power consumption is greater than 290 watt. The active experiment was carried out on June 1990. On the 24 and 25 of a June 1990, the XPS was turn on and it was functioning continuously during about 20 minutes. Locations of BN-1, BN-2 and several DEP-probe on GORIZONT S/C are shown on Figure 2. The satellites are stabilised such way that X-axis is always directed outward the centre of Earth, Y-axis directed toward spacecraft velocity (W-E) and Z-axis directed toward North.

2.2 Technological experiment

Russian orbital group GLONASS is a 3-orbit navigation system with 8 S/C on every orbit. Its circular (20000 km) orbit had a 65° inclination and 12-hour period of rotation. DIERA-2 system was installed on two satellites GLONASS (launch 1992) and GLONASS-60 (launch 1993). Three vibration type DEP-probes, two Faradey cylinder type DNT-probes and sensor of differential potential between S/C body and solar array DRP-probe were used for the spacecraft charging investigation on both satellites.

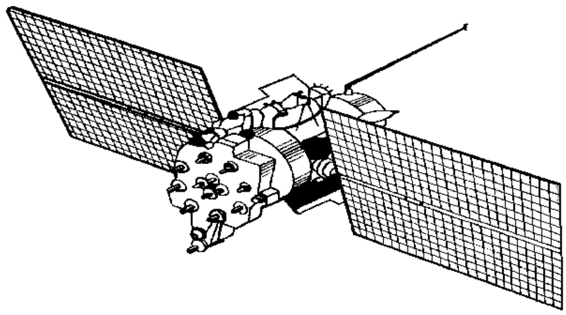

Fig. 3: GLONASS satellite

2.3. Patrol System

Communication satellites EXPRESS-11 and GALS-12 built by NPO PM corporation were launched in October 1994 (positioned at 14° W) and November 1995 (positioned at 36° E) accordingly. We currently use DIERA instrument that consists of two packages: KDM DIERA for investigation of radiation fluxes by Institute of Nuclear Physics of Moscow State University (INP MSU) and MIPE DIERA for investigation of spacecraft charging by Novosibirsk State University (NSU). Both of the satellites EXPRESS-1 and GALS-12 were produced using similar platform. Only payload and antenna systems differed. EXPRESS and GALS satellites are stabilised as GORIZONT. A plan of EXPRESS satellite and DEP-probes disposition is shown on Figure 5. DEP 1 probe disposed on satellite quartz radiator on +Y-axis side. DEP 2 probe disposed on satellite quartz radiator on -Y-axis side. DEP 3 probe disposed on satellite antennas unit on Z-axis side. MIPE DIERA unit for investigation of spacecraft charging by NSU is shown on Figure 4.

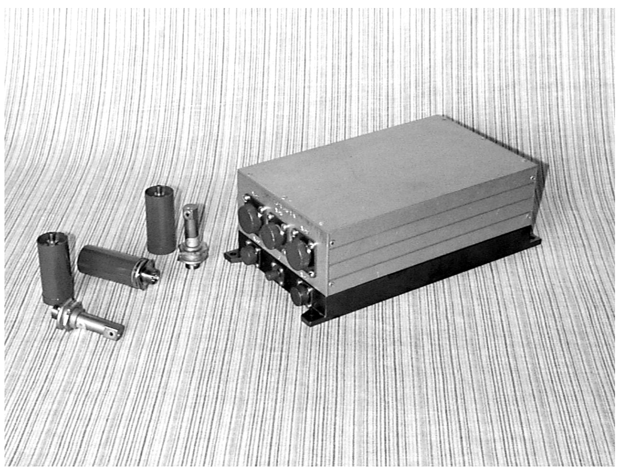

Fig. 4: MIPE DIERA Patrol System Prototype

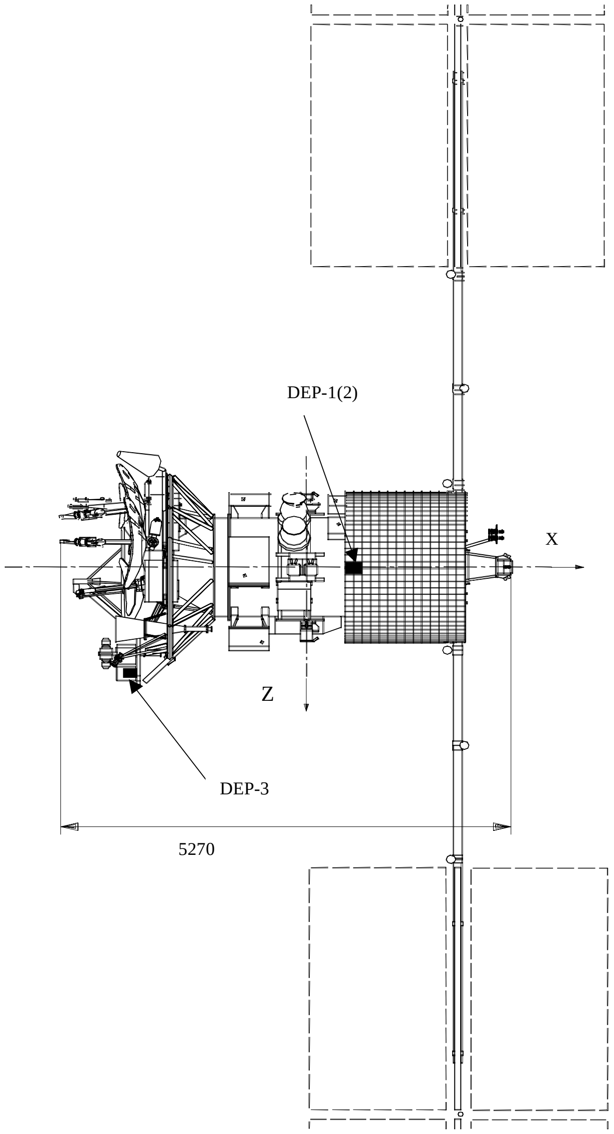

Fig. 5: A general plan of EXPRESS satellite and DEP-probes disposition

3. In Flight Results and Data Analysis

3.1. GORIZONT-30

For this experiment we selected days with quiet geomagnetic condition. Contents of action with ADIPE-662 system are shown in Table 1.

Table 1

Period	Action	Remarks
June 21, 1990	Gorizont-30 launch	Stay point is 90° East
June 23, 1990	Installation of the ADIPE-662	ADIPE-662 system "ON'
June 24, 1990 10.24-10:44 LT	Installation of the Plasma Source	Functions time is 20 minutes
June 25, 1990 10:15-10:35. LT	Installation of the Plasma Source	Functions time is 20 minutes

Figure 9 presents the electric field data from four DEP-probes mounted on GORIZONT-30 satellite. The data were obtained during the period of actions from Table 1. We selected probes in typical points of S/C body (see Fig.2). DEP-4 probe disposed on antenna system on –X-axis. DEP-7 probe disposed on BN-1 unit on –Y-axis. DEP-6 and DEP-8 probes disposed on satellite quartz radiator on -Z-axis and +Z-axis side accordingly. DEP-6 probe located side by side BN-2 unit. In Figure 9 Y-axis marked as value of measuring electric field strength and X-axis is a Local Time for 3 days.

The first result for this experiment is presence of diurnal variation of the electric field strength. Data analysis for DEP and DEP-4-probes shows that data charts obtained on June 23-24 and June 24-25 are practically identical at the same local time. Even thin structure of the data waveform is the same. At sunlight position between 12:00 and 00:00 LT for the DEP-probe the field strength is negative, at dark position between 00:00 and 12:00 LT the field is positive. We can see the same picture for DEP-4 probe but in this case sunlight position located between 18:00 and 06:00 LT and dark position located between 06:00 and 18:00 LT.

Most observed phenomena could be explained by using of very simple electrostatic model. Dark side surface, as usual covered by dielectric, accept negative charge. It causes charge separation on metal spacecraft body. Positive charge will be inducted on the dark side of the body, negative charge on the sunlight side. In this case electrically connected with body DEP-probes will show negative fields values on sunlight side, and positive on dark side. We will use the approach that potential φ_1 of sunlight side of dielectric surface is approximate zero value. This approach looks reasonable for us for at least observed electric fields with typical value of several kV/m. We will use φ_2 as a definition of dark side dielectric potential, and φ_0 for conductive metal body potential. Let us DEP-probes measure the electric field E_1 on the sunlight side dielectric surface and E_2 on the dark side of S/C. In this case the electric field probes measure difference of potential between dielectric surface and spacecraft body because probes are electrically connected with spacecraft body. Negative dielectric surface charge will generate positive electric field E_2. This value would be directly proportional to dielectric surface charge and inversely proportional to distance between probe and dielectric with it's own reduction coefficient k. According to this, $E_2 = k\cdot(\varphi_2-\varphi_0)/h$, where h is effective distance between probes and dielectric. Calculation result is:

$$|E_1| \cong |E_2|,\ \varphi_2 \cong -2E_2 h,\ \varphi_0 \cong -E_2 h.$$

In this case we can estimate φ_2, φ_0 values based on measured probe values: $E_1 \cong E_2 \cong 2{,}5$ kV/m, h =10 cm. From above we can get $\varphi_2 = -500$ B, $\varphi_0 = -250$ B.

Second general result is a typical disturbance on daily waveform of electric field strength during plasma source was "ON". On Figure 6 we can see two splashes located between 10-11 LT for June 24, 1990 and June 25, 1990.

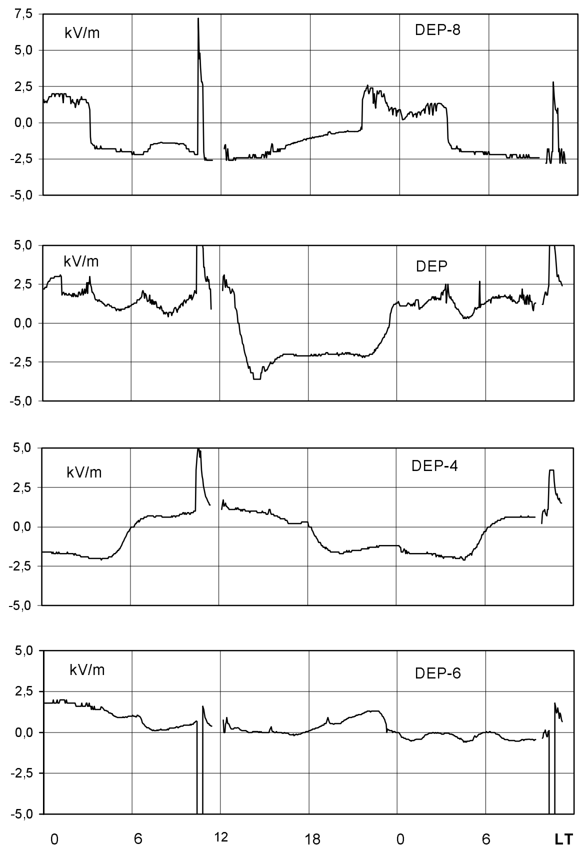

Fig. 6: The Electric field data from four DEP-probes mounted on GORIZONT-30 satellite obtained during the active experiment on 24-25 June 1990

DEP-4, DEP, DEP-8 probes show positive electric field splashes with values about 3-5 kV/m that corresponded for S/C potential changes of 300-500 V. It may be result of induced charge influence. Positive particles from Xenon plasma precipitated at dielectric surface beside BN-2 unit Negative charge was induced on S/C metal body for this side and positive charge was induced on other parts of S/C. Positive reaction of the all probes with the exception DEP-6 confirms this theory. Negative reaction DEP-6 probe is the result of positive charge on dielectric beside its position. We do not say that neutralization of S/C charge from Xenon plasma had been founded. The influence of plasma to S/C charge has been indicated only.

3.2. GLONASS-56 and GLONASS-60

Both plus and minus power line are isolated from S/C body on a part of Russian spacecrafts. In this experiment we connected one of the power lines with spacecraft body and observed differential potential change. Commutation experiments on GLONASS-56 and GLONASS-60 S/C were made on 30 March 1993 and 29 September 1994 accordingly. Figures 7 and 8 present the data for DRP and DEP-probes from GLONASS-56 and GLONASS-60 satellites. Y-axis is the satellite differential potential or the electric field strength. Measured parameters are volts for the DRP-probe and kV/m for DEP-probes. X-axis is a Moscow Time for 2 days. The last point of X-axis corresponds to time when data were downlinked from spacecraft (presented in right-down corner of Figures). The first point of X-axis corresponds to 2 days before. Spacecraft charging change were observed for both satellites during experiments.

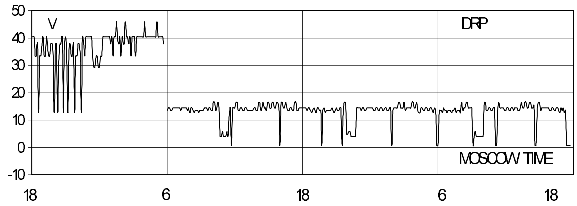

Fig.7: The differential potential data from DRP-probe on GLONASS-56 satellite during the commutation experiment on 29-31 March 1993

We can use the isolation parts of S/C as double Langmuir probe. In this case differential potential corresponds to the plasma parameters and physical properties of spacecraft dielectric surfaces.

A typical value of differential potential between solar array and S/C body before commutation is 40V for GLONASS-56 and 180V for GLONASS-60. Polarity of differential potential is positive in both cases. Different leakage resistors between solar array and S/C body for these satellites may explain this difference. Commutation was made with a resistor of 200 kΩ. Results of the measurements show that a value of the leakage resistor is more than this value. If we assume for leakage resistor a value of 1000 kΩ then 30-150 volt change during the commutation corresponds to a current I=0,03-0,15 mA through the leakage resistor. It corresponds to a current density j=1-5 nA/sm^2 for a total dielectric surface of 3 m^2.

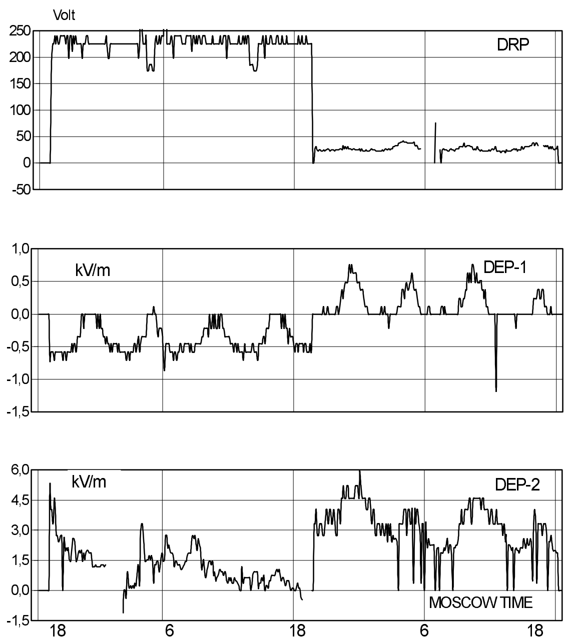

Fig.8: The differential potential and electric field data from DRP and DEP-probes on GLONASS-60 satellite during the commutation experiment on 28-30 September 1994

The variations of the electric field strength with 12-hour and 6-hour periods and amplitude in a range from about 0.5 to 5 kV/m were observed for both satellites. It may be corresponded to 50-500 V of differential potential change of dielectric surfaces along orbit. The fact is that after commutation the electric field strength by DEP-1, DEP-2 probes (Fig.8) changed to plus 0,5 kV/m for DEP-1 probe and 3 kV/m for DEP-2 probe. It is corresponded to situation that differential potential of solar array changed from +180V to +20V because we stay that electric field had value "+" if charge on S/C body positive. In this case positive trend of electric field strength during commutation corresponded to negative change of solar array potential.

3.3. EXPRESS-11 and GALS-12

We considerate here some results of spacecraft charging in flight experiments with DIERA Patrol System at EXPRESS-1 (1994-067A) and GALS-12 (1995-63A) satellites. Figures 9-11 present the typical data for DEP-probes. Y-axis marked as value of measuring parameters. X-axis is a local time. Figure 9 presents the electric field data from three DEP-probes on EXPRESS-11 satellite during the geomagnetic substorm on 26-29 January 1997, when Ap-index was 18-24. Results for a quite days 3-6 February 1997 with Ap=6-7 are shown on Figure 10. Disturbances caused by plasma trusters have been detected during 9-11h LT for both periods. Disturbances during 0-6h LT have been observed for geomagnetic active days.

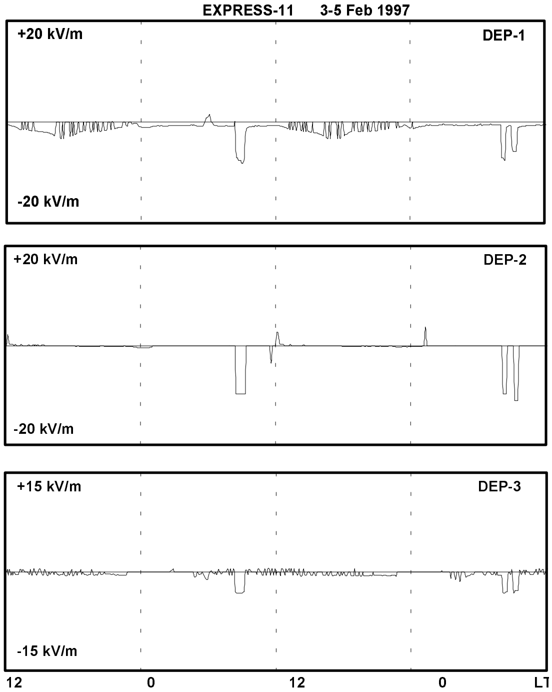

Fig. 10: The electric field data from three DEP-probes on EXPRESS-11 satellite during the quite period on 3-5 February 26-28

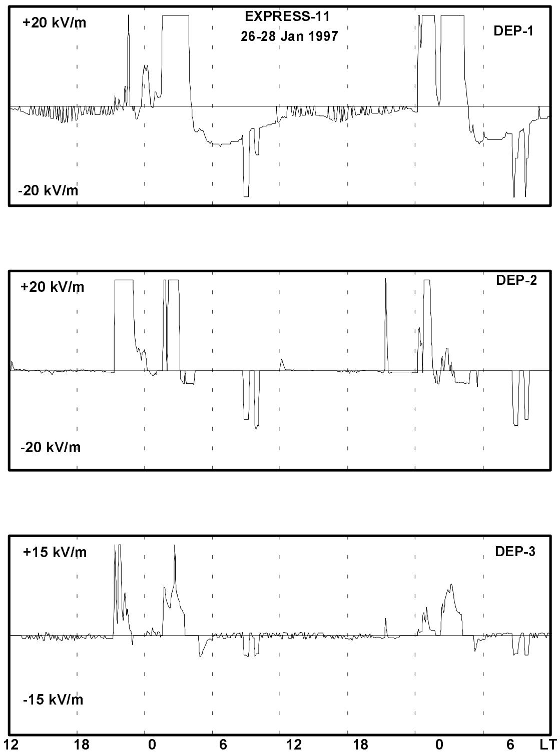

Fig. 9: The electric field data from three DEP-probes on EXPRESS-11 satellite during the geomagnetic substorm on 26-28 January 1997

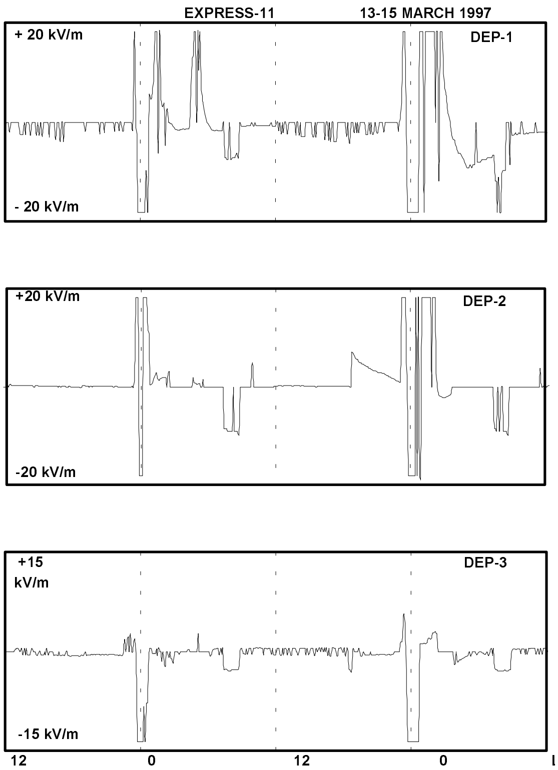

Fig. 11: The electric field data from three DEP-probes on EXPRESS-11 satellite during the Earth eclipse on 13-15 March 1997

Total negative charging of the spacecraft during the Earth eclipse has been detected nearly 0h LT due to environmental plasma electrons in the absence of photoemission from the surface on EXPRESS-11 satellite (Fig. 11). The value of electric field strength indicated 20-25 kV/m that may be treated as Spacecraft charging up to potential of 8-15 kV.

We introduce an effective index ED (Electrisation Disturbances) for describing spacecraft charging. The index ED was calculated for flight data from both satellites on the base of the electric field strength value, frequency of polarity change, high level period. We determined this parameter as a value in range from 1 to 10.

Mutual correlation for ED-index and Cp-index, ED-index and Ap-index were calculated. We have got Cp-index and Ap-index from Internet site: http://www.gfz-potsdam.de/pb2/pg3/niemegk/kp_index. Correlation interval was ranged from -5 to +5 days. Days when data are absent did not take into consideration. The correlation coefficient reaches maximum at the interval equal zero. The noticeable maximum reflects the presence of correlation between DE and Ap indexes. Correlation between DE and Cp indexes shows even bigger value (by 0.1-0.2 points). Correlation results presented on the two next diagrams (Fig. 12), where Y-axis is value corresponded to correlation coefficient for EXPRESS-11 on up panel and for GALS-12 on down panel. X-axis is a time period from -5 to +5 around base date of correlation.

Similar results were shown for Russian GORIZONT spacecrafts [3] where correlation between Kp-index and value of electric field change was indicated.

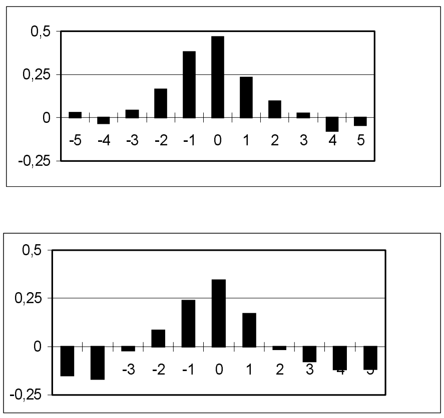

Fig.12: Correlation results of Ap and ED indexes for EXPRESS-11 on up panel and for GALS-12 on down panel

4. Summary

In this paper we presented a part of the results of Russian high altitude spacecraft charging investigations.

Direct electric fields measurements with a compact vibration-type DEP-probes significantly complete traditional spacecraft electric charging investigations.

High potential charging during geomagnetic substorms and Earth eclipse was observed.

Correlation between ED-index introduced for describing spacecraft charging and Ap-geomagnetic index has been founded.

Spacecraft charging disturbances caused by plasma thruster and plasma source have been detected.

The data from MIPE DIERA Patrol System for the Russian Space Environment Monitoring Program (SEMP) covered more than 60% of current time. Instruments worked well and showed that the MIPE DIERA is suitable system for space monitoring.

5. Intention

NPO PM corporation plans to launch EXPRESS-A N1 in 1999. New version of DIERA instrument would be installed on this satellite. The instrument includes unit MIPE DIERA and new device DIERA-M which control two inversion-magnetron probes for measuring of spacecraft's atmosphere pressure. Discharge Detector Experiment (DDE) by ESA will start at EXPRESS-A N2 satellite with launch 1999. MIPE DIERA and DIERA-M experiments will be also used on this satellite.

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