Analysis of the Influence of Space Weather Factors on the Telemetry Parameters of Small Spacecraft in Low Earth Orbit

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***Abstract* — The paper shows that high solar activity and the associated increased geomagnetic disturbance have a significant impact on the functioning of small spacecraft (SSC) in low Earth orbit (LEO). An increase in the number of anomalies in the telemetry data of small satellites with an increase in the absolute value of the geomagnetic activity index Dst is studied. The influence exerted by space weather (SW) factors on the current state of the SSC systems is studied. An increasing dependence between the spacecraft parameters and changes in geomagnetic activity is shown, which intensifies in the subpolar regions of the orbit.**

Keywords — small spacecraft, space weather, telemetry, low earth orbit

I. INTRODUCTION

Telemetry data is one of the main elements in the small spacecraft control system, providing control of the state of its individual nodes and motion parameters [1]. A large amount of telemetry data continuously coming from the SSC to receiving stations around the world, as well as information about the spacecraft that affects the parameters of satellite systems, requires the development of new methods and algorithms for processing the received data in order to reduce the number of failures in the operation of the SSC caused by negative SW factors.

Timely prediction of malfunctions on small satellites is an integral part of their effective protection in the aggressive environment of near-Earth space. Some malfunctions, such as electrical breakdowns and failures in communication channels, can be predicted by measuring various parameters directly on board the spacecraft. Another approach to predicting malfunctions and failures on small satellites is a statistical one [2, 3]. A joint analysis of failures on satellites and variations in the parameters of the spacecraft makes it possible to establish the relationship between various states of the environment in which the device is located and the occurrence of emergency situations on it.

The combination of these methods will make it possible to comprehensively analyze the state of constellations of satellites that are similar in certain design characteristics, and, when jointly considering the geophysical situation [4, 5], parameters on the satellite, its position in space, will make it possible to predict anomalies on board a particular spacecraft [6].

II. METHODOLOGY

As part of the study:

- emerging anomalies in the data are analyzed, i.e. telemetry with non-nominal values of individual parameters, as well as the probable causes of such values;

- the degree of influence of space weather factors on the hardware systems of the small spacecraft was determined within the nominal values.

According to the Space Weather service of the SINP MSU, in the fourth quarter of 2020, ground stations recorded significant geomagnetic disturbances. Within the framework of this study, the emerging anomalous values in the telemetry data of the SiriusSat-1 small spacecraft in the specified period of time were analyzed. More than 323615 frames were received by downloading and decoding files from the database of the SatNOGS service.

Anomalies in the data were identified by setting boundary values for the telemetry parameters. The found data frames were fixed for further analysis.

The next step was to compare the identified anomalous values with the SW indicators recorded in the same time interval. In particular, the values of planetary indices of geomagnetic activity (Kp, Ap), integral solar activity index (F10.7), geomagnetic activity index at low latitudes (Dst) were analyzed. The largest number of anomalies was identified in the data of the temperature sensors of the four batteries installed on the SSC.In the table, the anomalous values of the selected telemetry parameter of the SSC are highlighted in color, as well as the SW indices characterizing the disturbed geomagnetic situation (Kp >=4, Dst< = -20) [7]. Also, as a result of the analysis, a predominant relationship was established between the data anomalies and geomagnetic activity index Dst. This is also confirmed by the article [2], where the influence of a change in the Dst index on full-sized spacecraft in the geostationary orbit was studied. Below, we will use this index as the main characteristic of geomagnetic disturbances.

However, the influence of the spacecraft factors is not always expressed in the form of a failure or anomaly on board the small spacecraft. Heliophysical factors affect the telemetry parameters of the small spacecraft within the nominal values.

To determine the dependencies in telemetry and space weather data, we calculate the correlation matrix, which includes all available data without ranking them. The performed calculations indicate the actual absence of interrelations between changes in telemetry data and geomagnetic activity indices. However, it is known that spacecraft factors affect the small spacecraft differently in all parts of its orbit.

First of all, the assumption that the influence of cosmic factors is not the same with the side of the Earth illuminated by the Sun and not illuminated by the Sun requires verification. Let us calculate the coordinates of the location of the SSC for each time moment of the available telemetry data frames. Similarly, using the calculation of the correlation matrix, we will analyze the dependences of the change in telemetry and geomagnetic activity indices in the parts of the orbit illuminated and not illuminated by the Sun. The obtained calculations show, as before, a low correlation of the studied parameters, however, on the illuminated side, the absolute value of the correlation coefficient is much higher. Therefore, we will further study the telemetry data obtained while the SSC was in the parts of the orbit illuminated by the Sun.

The data presented above also indicate the presence of the influence of the SW factors mainly on the temperature indicators of the small spacecraft, such as t1_pw, t2_pw, t3_pw, t4_pw. Let us further explore the relationships in the listed parameters.

As is known, near the magnetic poles of the planet, the lines of force of the Earth's magnetic field are closed and charged particles accumulate. This makes the polar regions a zone of particular risk for spacecraft. Let us calculate the correlation dependences of the data taking into account the geographic latitude of the small spacecraft in orbit.

The number of data frames is unevenly distributed over different latitudes and largely depends on the number of receiving stations at different points on the planet. Let's divide the available data set approximately into equal parts in accordance with the latitude (northern and southern) of the SSC in orbit and calculate the correlation coefficients for each resulting part and the Dst index (Tab.1).

TABLE I. SUMMARY CORRELATION MATRIX

Lat, °	t1_pw	t2_pw	t3_pw	t4_pw
00–30.99	0,138456	0,148133	0,134159	0,154412
31–40.99	-0,04223	-0,0458	-0,04843	-0,03829
41–45.99	-0,13606	-0,14338	-0,16366	-0,12336
46–49.99	-0,19003	-0,20994	-0,23866	-0,16497
50–50.99	-0,21494	-0,23792	-0,26261	-0,19546
51–51.49	-0,25405	-0,27238	-0,30083	-0,23232
51.5-51.8	-0,27466	-0,30003	-0,32145	-0,25934

The correlation index, close to and exceeding 0,3 in absolute value, which was calculated for orbital segments located at a latitude of 51,5°-51,8°, indicates the presence of a relationship. The number of elements in the sample confirms that the identified relationship is not random.

Unfortunately, the inclination of the SSC orbit of 51,8° does not allow a full assessment of the impact of the spacecraft on the SSC systems, but an exponentially changing trend towards strengthening the correlations between telemetry parameters and space weather factors at high latitudes is obvious (Fig.1).

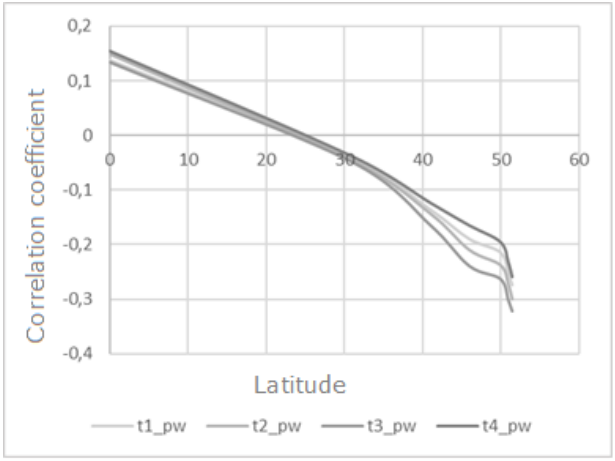

Fig. 1. Correlation trendline

III. CONCLUSION

The paper investigates the relationship between an increase in geomagnetic activity and the number of failures in the operation of small satellites. An increase in the number of anomalies in the SSC telemetry data is shown with an increase in the absolute value of the Dst index. The influence exerted by the SW factors on the current state of the SSC systems is studied. An increasing dependence between the spacecraft parameters and changes in geomagnetic activity is shown.

To prevent the negative impact of space weather on the fulfillment of the tasks of the SSC and to extend its lifetime in orbit, it is necessary to create a specialized technique that, together with methods for predicting space weather parameters, will help to respond in a timely manner to the occurrence of negative conditions in the space environment and significantly extend the lifetime of the SSC in orbit.

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