Geophysical parameters-based space system of Earth remote diagnosis

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Abstract: *The paper dwells on the development of the Earth remote diagnosis system basing on geophysical parameters. The issues of spacecraft-assisted Earth gravity field studies are under consideration.*

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The aim of the suggested project of the Earth remote diagnosis system (ERDS) is to enhance the precision of the Earth gravity field (EGF) studies, monitoring of time variation of parameters and comparing of measured data with the geological, seismological and weather situation on Earth. Integrated measurements will allow to create high resolution and accuracy EGF global and local models. Studies of the fine structure of the gravity field will extend the exploration activities and facilitate the simulation and researches of the forces responsible for displacement of tectonic plates, possible transformations of the structure of mantle and lithospheric processes [1].

Comparison of the Earth surface displacement measurements with the measurements of global and local gravitational field characteristics will extend the abilities for forecasting of earthquakes and tidal deformations, allow to make relations between various frames of reference more exact and improve geocentricity control of the global geodesic frame of reference.

Creation of local and global high-resolution EGF models will permit to significantly increase the calculation accuracy of geopotential derivatives: gravity force acceleration components on the surface of general global ellipsoid (GGE) and in outer space, values of plumming line declination relative to GGE surface normal and geoid excess, that constitute source data of geophysical ground for high-precision inertial navigation systems of rocket and space complexes [2].

There are three approaches to EGF map-making problem:

- ground-based;
- aerospace;
- combined.

Solution of global EGF investigation problem using ground-based means doesn't appear to be possible both from economical position (too large number of gravitometers must be available), and from technological point of view (70% of the Earth surface is difficult to access).

EGF model improvement with autonomous aerospace methods can be achieved by development of the satellite gravitational gradiometer (SGG), capable of measuring second derivatives of gravitational potential with accuracy 10-2-10-3 Etv. Investigations, carried out in Russian Federation State Scientific Center, Central Research Institute «Electropribor» [3], have shown principal possibility to develop SGG on basis of cryogenic sensitive elements technology. Similar investigations are being carried out abroad in frame of "Aristotiles", "Step", "Geoid" programs, that reached the stage of experiments onboard the spacecraft (SC) [4-10].

At present time, the devices based on pairs of accelerometers, are preferred to traditional devices, that employ torsion balance [4; 6; 8] in development of advanced gradiometers for scientific research (especially space research).

Basic principles of SGG design for devices with extremal sensitivity about 10-4 Etv, working in conditions without SC drift, are the following:

- to achieve extremal possible limit accuracy in measuring of gravitational potential second derivatives onboard SC free motion of sample bodies (SB) in process of measurement must be provided;
- introduction of feedback's, that compensate displacement of SB center of gravity relative to the hull, and SB relative displacements, caused by gradient of imaginary acceleration, will not affect sensitivity;
- measuring devices (MD) must provide high measuring accuracy of SB displacements relative to the hull, and relative displacements of SB pairs;
- SGG sensitive elements unit must be isolated from translations and angular motion enough to provide capability of MD functioning with the given accuracy;
- feedback systems noise must not exceed thermal noise of the structure.

Transition to noncontact SB suspension and cryogenic temperatures allows to significantly increase measurement accuracy and provide SGG design principles, listed above [3].

Preliminary estimations give 80÷90 kg for SGG weight, and 50W for its power consumption. One must note, that development of SGG with limit sensitivity about 10-2-10-3 Etv appears to be complicated technical problem on the global scale. Up to now, there hasn't been yet developed any SGG industrial prototype in Russia [10].

Estimations of the project implementation, carried out in Central Machinery Construction Research Institute [10], have shown, that from the technical point of view in conditions of sufficient financing the proposed geophysical SC development is possible in the nearest 5-6 years.

EGF measurement problem in GRACE project (Germany) is solved using SC precise positioning with help of GPS and satellite laser location. Specially developed receiver BlackJack is used for this purpose. It provides 2-3 cm accuracy of position data measurement. Earth gravitational field parameters are determined from the SC orbit evolution.

Determination of gravitational field parameters in GRACE project uses change of the distance between two SC and has the following disadvantage: employing only two SC gives no opportunity to precisely determine spatial direction of change in mutual position. Hence additional inaccuracies arise.

Principal possibility to implement combined «ground-space» EGF investigation method was first shown by academician Selin A.A. in his work [11]. This method is based on the Paund-Rebka experiment [12].

American physicists Paund and Rebka used Mössbauer's effect to detect gravitational redshift of photon, foreseen by general relativity (for the photon weight detection). It is followed from the general relativity theory, that photon frequency must vary with the change of gravitational potential. According to so-called equivalence principle

$$\hbar\omega' = \hbar\omega - \frac{\hbar\omega gl}{c^2} = \hbar\omega\left(1 - \frac{gl}{c^2}\right) \quad , \qquad (1)$$

whence for photon frequency we have

$$\omega' = \omega\left(1 - \frac{gl}{c^2}\right) \quad . \qquad (2)$$

According to formula (2), relative variation of photon frequency

$$\frac{\Delta\omega}{\omega} = \frac{\omega - \omega'}{\omega} = \frac{gl}{c^2} = \frac{\Delta\varphi}{c^2} \qquad (3)$$

is proportional to the variation of gravitational potential

$$\Delta\varphi = gl \, . \qquad (4)$$

The light, arriving to the Earth from the Sun or the stars, overcomes strong gravitational field of this luminaries. Near the Earth it experiences only the effect of weak accelerating field. That's why all spectral lines of stars must be slightly shifted in the red spectrum direction. Such a shift, called gravitational shift, was qualitatively supported by observations. [12].

Paund and Rebka have made an effort to detect this phenomenon in ground conditions. They positioned γ-source (Fe57) and absorbing material one under another at 21-m distance in a vertical tower. Relative variation of γ-quantum energy when passing this distance is only

$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{\Delta\omega}{\omega} = \frac{gl}{c^2} = \frac{9{,}81\cdot 21}{9\cdot 10^{16}} \approx 2\cdot 10^{-15}. \qquad (5)$$

This alteration causes relative shift of absorption and emission lines and must reveal itself in slight weakening of resonant absorption. In spite of extremal insignificance of the effect (shift constituted only 10-2 of the line width), Paund and Rebke succeeded to detect and measure it with sufficient degree of accuracy. The result, obtained by them, gave 0,99±0,05 from the one foreseen by theory [12]. Method sensitivity can be appreciated at least because relative change of the photon energy per meter is approximately 10-16 .

Thus, placing the radiation source on the Earth surface, and receiver on SC, and measuring the radiation frequency shift on the receiver, one can measure absolute values of gravitational potential in every point on the terrestrial globe with great accuracy. Such a method is even more interesting because 20 years ago in SDO Yuzhnoye the SC, capable of detecting frequency and position data of a radiation source, was developed and successfully operated.

It appears to be possible and efficient to implement the radiophysical Paund-Rebka method of measuring gravitational potential with an application of the existing spacecraft system and ground-based radiation equipment (GRE).

The usage of existing spacecraft system has series of advantages, the main is the long term of operation (~20 years), in cooperation with Russia, and usage of Ukrainian space systems by Russia: SC and launch vehicle «Zenit-2».

SC has a series of essential advantages compared to another Earth Remote Sensing Spacecraft System (ERS SS), among them all-weather operability, and independence from daytime and seasons. Survey band ~5000 km and ability to determine position data of several radiation sources allow to claim it universal and having no analogies in the world in geophysical parameters.

Taking into account the experience of development of ERS SS "NHM", "Ocean" and "Sich" in SDO Yuzhnoye, it appears to be possible and efficient to equip SC with the Earth magnetic field investigation devices of type "Variant", radioaltimeter, the Earth limb ultraspectrometer with spectrum resolution 0,001-0,1 nm and ultraviolet Sun telescope. In this case the proposed SC will cover all the tasks of the perspective geophysical SCs.

One of the promising variants of radiophysical method implementation is the insertion to geostationary orbit of the radiation source with carrying frequency 35GHz and 45GHz on basis of hydrogen standard, having relative stability not worse than 10-15. In this case, placing the receiver in required point of the Earth surface, one can define the value of gravitational potential in it.

The elements to be developed on the basis of existing spacecraft system for ERS SS are the Ground-based special complex (GSC) and Ground radiation equipment (GRE).

It is obvious, that ERS SS is efficient to develop on the basis of GSC operator center (OC) in SDO Yuzhnoye, especially taking into account the multipurpose application of the existing spacecraft system data.

It is possible to use the complex of geophysical equipment machinery 73P (GEM complex) as GRE, as soon as this complex is equipped with Satellite Navigation Consumer Equipment (SNCE) 3Zh6 and the gravimetric equipment assembly ZI1 [8].

Equipping of GEM unit with additional sensors of contact measurements in Acquisition Data Sea Platform (ADSP) "DIPOS-1" composition will allow to use it as a mobile metheoecologic station.

It appears to be efficient to use in ESR SC context various elements of the Mobile Reception Center (MRC) of "MOST" system, developed in Regional center of special data acquisition and processing, located in Vinnitsa city, in particular:

- 21В 311 complex (uniform antennae installation SM-318 with reflector of 5-m diameter), that can be used as a mobile segment of data acquisition;
- diesel powerplant 15I1061M (4 diesel generators of 30kW power), can be used as autonomous power source;
- space communication station R 440-0, can be used primarily as the radiowave source, and for transmission of contact ground-based sensors data to the SC.

Thus, ground segment of ESR SS can be practically implemented on basis of the existing equipment, that needs some revision.

The following conclusion can be made as a result of the performed analysis on necessity and possibility on ESR SS development for geophysical parameters on basis of the existing spacecraft system.

1. There is a principal possibility of EGF investigation using combined "ground-space" method, based on gravitational red shift effect on photon frequency.

2. There is a possibility to implement "ground-space" method quickly, cheaply and efficiently on basis of existing means: space segment – on basis of the existing spacecraft system, ground segment – on basis of GEM complex, MRC of "MOST" system and GBC OC in SDO Yuzhnoye.

3. There appears a principal possibility to create special SC, covering all perspective geophysical tasks, on basis of the existing SC and GBC OC in SDO Yuzhnoye.

4. The development of ESR SS is of significant practical value (creation of gravitational map of the Earth, earthquake warnings, mineral products exploration and other). It also represents scientific interest (development of gravitational research, the Earth sciences, research on influence of gravitation on psychophysical condition of humanity etc.).

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