

Global monitoring of Earth gravitational field utilizing space navigation systems

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For conduct of measurements of the Earth gravitational field (EGF), a radiophysics technique is recommended, which is based upon an effect of electromagnetic radiation frequency changes in the gravitational field.

Taking measurements of the radiation frequency changes under exposure to gravity (Pound-Rebka effect), we can compute the value of acceleration of gravity.

Measuring accuracy of gravity by the radiophysics technique may be evaluated reasoning from the equivalence principle of the general relativity theory:

$$\hbar f = \hbar f_0 - \frac{\hbar g l f_0}{c^2} = \hbar f_0 \left(1 - \frac{g l}{c^2} \right), \quad (1)$$

where \hbar – Planck's constant;
 l – transmitter position altitude relative to receiver;
 g – acceleration of gravity;
 f_0 – radiation source frequency;
 f – receiving frequency;
 c – velocity of light.

$$f = f_0 \left(1 - \frac{g l}{c^2} \right), \quad (2)$$

$$g = \frac{c^2}{l} \times \frac{\Delta f}{f_0}. \quad (3)$$

For circular orbit

$$k = \frac{c^2}{l} = \text{const}. \quad (4)$$

Consequently, the value of gravity force directly proportionally depends upon the relative frequency change

$$g = k \frac{\Delta f}{f_0}. \quad (5)$$

Global monitoring of the Earth gravitational field is feasible on conditions that navigation systems of the onboard frequency standards featuring radiation stability not worse than 10^{-15} are utilized onboard navigation spacecraft.

Yuzhnoye SDO together with cooperation may work out the following tasks:

- delivery of the onboard hydrogen frequency standard with characteristics specified in Table 1;
- development and manufacture of ground receiving devices for measuring the Earth gravitational field;
- secure control over gravitational field parameters at the Operators Center of Yuzhnoye SDO.

Table 1

| | |
|--|-------------------------|
| Output signals: | |
| sinusoidal, (1 ± 0.2) V on 50 Ohm load | 5 MHz, 100 MHz |
| impulse, $(1,5 \pm 2,8)$ V on 75 Ohm load | 2,048 MHz |
| impulse, TTL level on 50 Ohm load, positive polarity | 1 Hz |
| Error per frequency (frequency reproduction) | $\pm 1 \times 10^{-13}$ |
| Frequency correction | |

| | |
|--|--------------------------|
| Minimum pitch | 1×10^{-15} |
| Range | 1×10^{-10} |
| Frequency instability | |
| 1 s | $\leq 7 \times 10^{-13}$ |
| 10 s | $\leq 2 \times 10^{-13}$ |
| 100 s | $\leq 7 \times 10^{-14}$ |
| 1 hour | $\leq 2 \times 10^{-14}$ |
| 1 day | $\leq 5 \times 10^{-15}$ |
| Power supply (continuous current) | $48V \pm 10V$ |
| Consumed power | 60 W |
| Temperature coefficient of frequency, (1/°C) | $< 5 \times 10^{-15}$ |
| Working temperature range, (°C) | $+5 \div +40$ |
| Dimensions (mm) | 470x200x55 |
| Mass (kg) | 30 |
| Expected service life (years) | 20 |

Yuzhnoye SDO as a directing Ukrainian agency on development of space systems may ensure collaboration with the ESA covering three trends:

- development of the EGNOS system's eastern branch as a space navigation assurance system (SNAS);
- expansion of navigation system functions by dint of securing global monitoring over the Earth gravitational field;
- solution of tasks of the C-band messages anchor stations, MUS (Mission Uplink Station), and of the S-band receiving and transmittal stations, GUS (Galileo Uplink Station).
- During the process of development of the SNAS, there shall be created:
- navigation field control center (NFCC) on the basis of Yuzhnoye SDO Operators Center (OC);
- network from 10 – 12 regional navigation control terminals;
- complex of data transmittal aids and appliances (CDTAA).

At present, Ukraine is prepared to accomplish the following activities:

- ensure reception and transmittal of navigation information via relay installations of Yuzhnoye SDO OC;
- deploy three control-correcting stations of domestic development (AO NIIRI, Kharkov).
- Creation of the EGNOS eastern branch as the SNAS on influence the basis of the OC in Yuzhnoye SDO is required for:
- continuous monitoring of navigation and gravitational fields, formation of differential corrective information (DCI), provision of services to DCI users;
- creation of data base pertaining to the status of frontiers and adjacent territory borders, changes of geophysical environment, forecasts of seismic activity and other dangerous geophysical phenomena;
- research and studies into the influence of geophysical changes on a psychophysical status of man with an objective to predict social order and behavior of population of regions and whole countries;
- development of an automated system of rapid information submittal, response and decision making in relation to emergency situations;
- utilization of navigation field studies for detection and avoidance of emergency situations in outer space.

The core objectives and tasks of the suggested research are as follows:

- continuous monitoring over the status of territories, boundaries, regions, and identification of emergency situations;
- analysis, processing, inventory and filing of incoming information via the SNAS, creation of data base per diverse categorization of emergency situations (seismology, floods, fires, explosions, conflict situations, terrorism, etc);
- provision of information to end users and execution of services pursuant to their applications through the SNAS system;
- creation of an intergovernmental automated control system to handle rapid information submittal, response and decision making on emergency situations in the EU framework;
- studies into the influence of geophysical fields on a psychophysical status of population;
- development of concept on avoidance of emergency situations in outer space, interorbital tugging of space objects.

Potential results:

- creation of the SNAS (EGNOS system eastern branch);
- continuous monitoring of navigation and gravitational fields of the Earth for detection of crisis and emergency situations on the territory of EU countries;
- automated informational system for provision to end users of differential corrective navigation information;

- data base (archives) pertinent to the status of frontiers and adjacent territory borders, changes of geophysical environment, forecasts of seismic activity and other dangerous geophysical phenomena;
- recommendations on records with respect to the impact of geophysical changes on psychophysical status and health of man;
- automated system of rapid information submittal, response and decision making on emergency situations in the framework of EU countries;
- recommendations per problems of detection and avoidance of emergency situations in outer space;
- preparation of high-precision maps for implementation of privatization and civil engineering;
- determination of coordinates of agricultural areas with an accuracy up to centimeters;
- assessment of crop capacity from each square meter;
- studies into the impact of the Earth geophysical parameters on crop yields;
- identification of mineral deposits per anomalies of geophysical fields;
- conducting studies in the area of the relativity theory;
- explanation of Hubble effect by changes of electromagnetic radiation in the gravitational field.