10.1;10.4

High latitude geocompass

© *V.A. Shulgin*

Voronezh State University, Voronezh, Russia
E-mail: shulgin@cs.vsu.ru

Received April 1, 2022
Revised April 12, 2022
Accepted April 12, 2022

An autonomous navigation system for orientation on the surface, under water, and under the surface of the Earth is considered. The passive location of the Earthś rotation axis is carried out by the vector of the geocompassś radiation pattern during angular scanning of space. A solid-state design of a geocompass is proposed and implemented, in which the deformations of the medium under the action of an alternating acoustic field and field of the Earthś Coriolis acceleration form the diagram vector. Experimental space scanning confirms the formation of a direction vector coinciding with the orthogonal to the Earthś rotation axis, which makes it possible to qualify the device as a geocompass oriented at high latitudes to the geographic pole.

Keywords: Coriolis acceleration, Earthś rotation, acoustics, navigation.

DOI: 10.21883/TPL.2022.06.53575.19209

The paper presents the results of research in the field of developing hardware for a fully autonomous system for navigation on the Earthś surface, under water, and in underground horizons; the system would be resistant to external electromagnetic field and unable to emit electromagnetic and acoustic signals. The investigation was based on using such known quantities as: gravity force vector, vector field of the rotating Earth Coriolis accelerations, and interaction between this field and wave–propagation media.

Satellite navigation systems are quite efficient; however, they are expensive, vulnerable and not everywhere applicable, for instance, they cannot be exploited under water or under the Earthś surface, i. e., in zones inaccessible for electromagnetic radiation. Inertial navigation systems are conditionally autonomous. Multiple versions of this–type devices intensely evolve from the middle of the 20th century. Accuracy of the inertial sensors increases with time, which makes them more and more practically applicable in view of their size, weight, cost efficiency, accuracy of navigation, and possibility of using them in targeting systems [1]. Errors of the inertial sensors still remain an acute scientific problem concerning such operating conditions when they have to work for a long time without updating the data on coordinates by auxiliary stationary sensors, e. g., ground–based ones. This is because those devices create an isolated analog of the absolute frame of reference, which results in error accumulation. Therefore, expansion of investigation devoted to creating an autonomous navigation system remains a topical task.

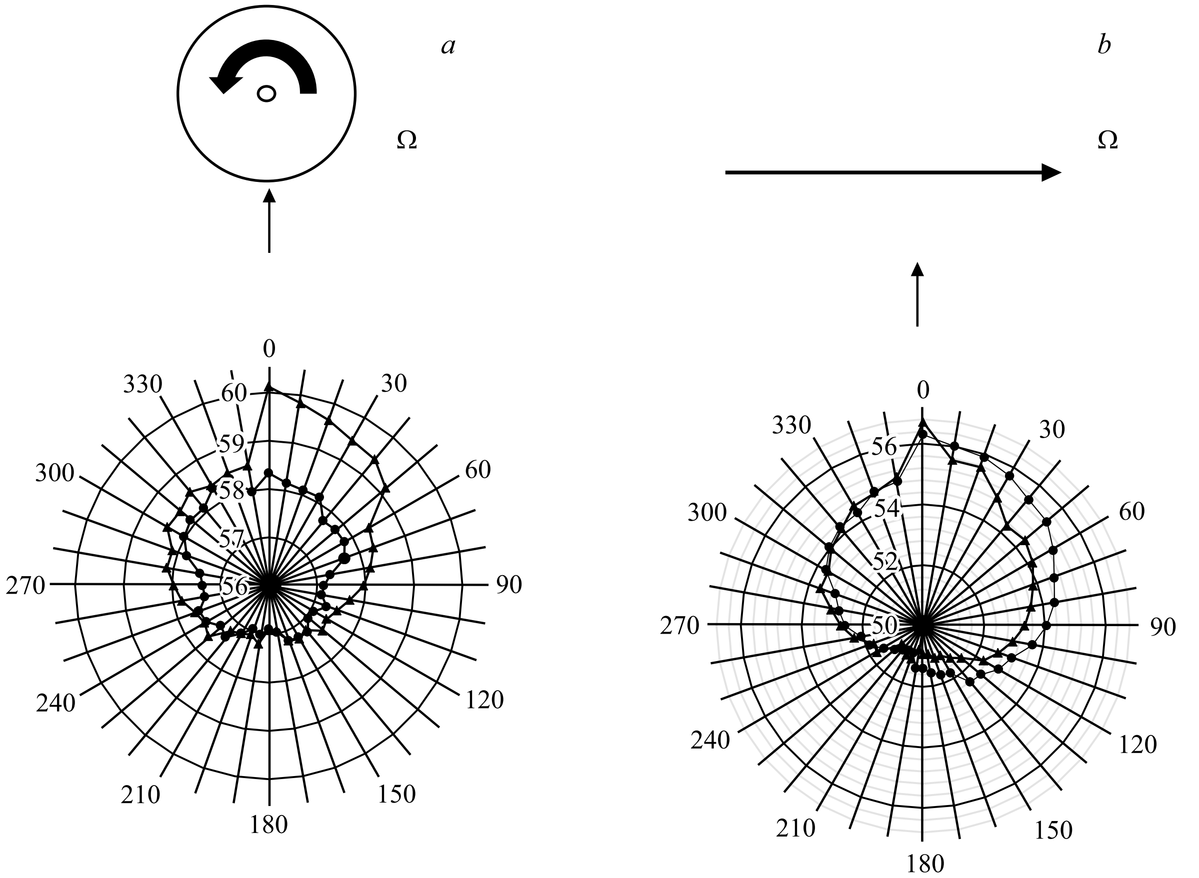
Paper [2] has proposed the solution of this task. Fixation of the direction orthogonal to the rotation axis of the Earth as a motionless object in the absolute space (within the Earthś limits) will enable determination of navigation parameters. The latitude is the angle between the direction towards the Earthś center and line orthogonal to the rotation axis. To determine the latitude, it is sufficient to fix relative positions of the Earthś rotation axis and rotation axis of the Earth–Moon system center of mass with the reference to the Universal Time. The size of the Earth orbit around the Earth–Moon barycenter is $\sim 0.74R$, where R is the Earth radius. Terms „New Moon", „Full Moon" may be also applied to the Earth position relative to the Sun–barycenter line, i. e. fixation of the relative positions of both the Earthś rotation axis with respect to the barycenter and the Earthś axis is equivalent to referencing the navigation measurements to the celestial sphere at a relevant time moment. This may be the base for constructing an algorithm for the latitude determination.

Paper [2] describes a version of the detector of the Earthś Coriolis acceleration vector in the form of a gas–filled acoustic resonator. There a concept of a coherent self–oscillator with a feedback resonator was chosen, as well as a spectral range for data detection and processing. The investigation showed that low sensitivity of this detector makes its practical application hardly possible.

Paper [3] gives a definition according to which the absolute point acceleration is generally equal to the sum of the translational, relative and Coriolis accelerations. Let us consider only a particular case when the detector is motionless relative to the Earth surface. In this case, only the Coriolis acceleration defines the force impact on the moving masses of the solid–state sensor medium. In the proposed device, motion is a regular medium deformation caused by the field of an acoustic signal of the external frequency oscillator. Coriolis acceleration $\mathbf{a}_c$ is defined as a vector product [3]:

$$\mathbf{a}_c = 2\mathbf{\Omega} \times \mathbf{V}, \quad (1)$$

where $\mathbf{\Omega}$ is the axial vector of the Earthś angular rotation speed, $\mathbf{V}$ is the vector of the medium particle velocity. In the case of longitudinal waves, vector $\mathbf{V}$ is collinear with the



Results of circular scanning of space with a geocompass in opposite directions and orthogonal cross sections: in the plane orthogonal to axis $\mathbf{\Omega}$ for the 52° northern latitude (a) and in the plane containing the Earthś rotation axis and the 39° eastern longitude meridian (b). In the scanner scales, 0° is the direction orthogonal to vector $\mathbf{\Omega}$ of the Earthś rotation axis.

direction of the acoustic wave propagation in the resonator. The absolute acceleration vector value is

$$|\mathbf{a}_c| = 2|\mathbf{\Omega}||\mathbf{V}|\sin\alpha, \tag{2}$$

where α is the angle between $\mathbf{\Omega}$ and $\mathbf{V}$. The acceleration is maximal in the direction $\mathbf{V}$ orthogonal to the rotation axis and obeys the $\sin\alpha$ law. The Coriolis acceleration field gives rise to an acoustic wave that propagates orthogonally to the exciting wave and can be detected. Scanning by angle α (2) is a method for creating a radiation pattern allowing determination of the direction orthogonal to the Earthś rotation axis. The detector may be functionally regarded as a high−latitude geocompass since the radiation pattern on the equator is oriented towards the Earthś center, while that at high latitudes is oriented towards the geographic pole.

The result of this work is a workable model of the sensor whose acoustic wave propagation medium is a polished plate of fused quartz $113 \times 55 \times 3.5$ mm in size. On the plate butt ends (55 mm), piezoelectric transducers are glued: one for exciting an acoustic longitudinal wave from the external oscillator, the other for the oscillographic analysis of the plate acoustic field distribution, which is necessary for, e.g., selecting a method for attaching the resonator. On the side faces, piezoelectric sensors are glued, which detect both the initial wave generated by the oscillator and the orthogonally directed same−frequency wave arising in accordance to the vector product (1). By mechanically rotating the resonator, direction $\mathbf{V}$ is varied, and passive location is achieved. Due to the axial symmetry of the device design, the wave excited by the oscillator comes to the lateral piezoelectric sensors with the same time delay thus creating in−phase signals, while the orthogonal signal —$\mathbf{a}_c$— is phase−shifted at these sensors because the Coriolis acoustic wave front passes through the sensors sequentially. The sum of two signals (the in−phase one and differential one) is detected. Just this is the basis for the principle of information retrieval by suppressing the high in−phase signal and amplifying the low differential one. In this study, oscilloscope HDO4054 and lock−in amplifier hboxSR-7265 with an integrated frequency synthesizer were used. The sensor operating frequency was 22 660 Hz. The excitation signal amplitude was 5 V, the Coriolis signal voltage amplitude was detected in percent of the 50 mV scale of the SR-7265 amplifier. The figure presents the results of circular scanning in opposite directions and in two orthogonal cross sections: in the plane orthogonal to the Earthś rotation axis for the 52° northern latitude (a) and in the plane containing the Earthś rotation axis and 39°

eastern longitude (b) (Voronezh city). The initial point of the scanner scales 0° is the direction orthogonal to vector $\mathbf{\Omega}$ of the Earthś rotation axis. Vector product (1) for vector $\mathbf{V}$ having a zero projection on the direction orthogonal to axis Ω (90 and 270° on the scanner scale) should be $|\mathbf{a}_c| = 0$. The figure (panels a and b) does not exhibit this minimum. This is because the piezoelectric transducer generate, along with longitudinal waves, transverse waves that create the maximal level of the Coriolis transverse wave at the 90 and 270° points. Later it will be necessary to complete the geocompass with a rejection filter suppressing the transverse waves.

During measurements, the expected „Foucault pendulum"effect was revealed: the resonator wave field exists in the absolute space [1], and attempts to „turn" it within a short time fail. Change in the scanning direction $\mathbf{V}$ is accompanied by long$-$term field reconstruction. Disconnection of the oscillator for the time of changing the direction resulted in reducing the duration of this process to 20 s per single measurement. However, in this case the reconstruction time also increases, if the resonator at the initial point is affected by the acoustic field for a long time. This is confirmed by the plot in the vicinity of the starting point. As the figure shows (a), the start in the $0-350^\circ$ direction is accompanied by asymptotic approximation to the stationary dynamic mode of measurement. In the opposite ($350-0^\circ$) direction, the cycle terminates as an extension of the stationary dynamic mode. It is assumed that the effect of additional accumulation of the time delay is caused by local heating of the medium under the action of the exciting acoustic signal.

Each of the plots corresponding to two orthogonal cross sections of the spatial radiation pattern has an extremum in the direction orthogonal to the Earthś rotation axis. The ratio of deviations of points of each opposite$-$direction angle of the stationary dynamic measurement mode relative to the dynamic signal range caused by the Earthś Coriolis acceleration is ~ 0.1.

The known engineering solutions are characterized by the fact that inertial systems should be regarded as conditionally autonomous if they retain for a limited time the absolute frame of reference within which the Earthś rotation axis exists. The fully autonomous navigation system has been shown to be realizable provided the detection of the Earthś Coriolis acceleration field vector and, hence, of the direction orthogonal to its rotation axis, is achievable. The topicality of solving this problem is undoubtful, first of all, for submarine navigation. Such a device was proposed and tested under real operating conditions. This is a fused$-$quartz acoustic resonator within which the wave$-$type medium deformation interacts with the vector field of Coriolis acceleration and induces a force impact generating an acoustic wave of the same frequency and direction defined by the vector product of the Earthś rotation vector by the vector of the medium displacement during deformation. The geocompass radiation pattern was measured by angularly scanning the space near the direction orthogonal to the Earthś rotation axis. The 3D experimental pattern has an extremum in this direction. At this research stage, the quartz resonator was not subjected to thermostating.

Acknowledgements

The author is grateful to G.V. Pakhomov (Voronezh State University, Physical Department) for useful discussion of the experimental results.

Conflict of interests

The author declares that he has no conflict of interests.

References

[1] N. El-Sheimy, A. Youssef, Satell Navig., **1**, 2 (2020). DOI: 10.1186/s43020-019-0001-5
[2] V.A. Shulgin, v sb. *XXVII Mezhdunar. nauch.-tekhn. konf.* „*Radiolokatsiya, navigatsiya, svyaz*"(Izd. dom VGU, Voronezh, 2021), t. 3, s. 81. https://rlnc.ru/ (in Russian)
[3] A.P. Markeev, *Teoreticheskaya mekhanika* (CheRo, M., 1999), s. 71–76. (in Russian)