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On the Issue of the Secular Deceleration of the Earth's Rotation

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Abstract: *The paper examines the peculiarities of the problem of the secular deceleration of the Earth's rotation. The following main causes of this phenomenon are indicated: the solar and lunar tidal effects on the Earth; the resistive torque arising from friction between the rotating Earth and the surrounding cosmic medium; and the long-term increase in the Earth's mass and average diameter. Based on the equation of uniformly decelerated rotational motion and an average value derived from observational data, the corresponding angular acceleration has been determined. From this angular acceleration, an approximate numerical value of the total braking torque responsible for the secular deceleration of the Earth's rotation has been obtained.*

Keywords: *Planet Earth, secular deceleration of rotation, solar and lunar tides, angular acceleration, braking torque.*

1. INTRODUCTION

Issues related to the motion and interaction of celestial bodies are among the most important topics in celestial mechanics. These include the study of the rotational motion of planets—particularly our own planet, the Earth. In this regard, it is of significant interest to consider the peculiarities of the Earth's rotational motion. One of these features is the secular deceleration of this rotation. This question has been addressed in many astronomical studies, including textbooks, monographs, and individual papers [1-8].

Certain aspects of the mechanics of motion and interaction of cosmic bodies—and, more broadly, of matter in the Universe - have also been examined in our earlier works [9 - 11].

SOME KINEMATIC AND DYNAMIC ASPECTS OF THE PHENOMENON OF SECULAR SLOWDOWN OF THE EARTH'S ROTATION

The deceleration of the Earth's rotation leads to a long-term increase in its rotational period, i.e., the length of a day. Judging by available data, this increase appears insignificant. However, it is important because it is closely related to the history of the formation and evolution of the Solar System and has been ongoing since its origin. It is of interest to cite various numerical values of the secular increase in the length of the day given by different authors. For example, the increase in the day's length over one hundred years is reported as follows: Parisky N.N. - 0.0036 s [6]; Byalko A.V. - 0.0020 s [4]; Ryabov Yu.A. - 0.0016 s [5]; Yazev S.A. - 0.0014 s [2].

Although the increase in the Earth's rotation period is very small, and possibly varies in different epochs, its persistence over millions or billions of years has ultimately led to substantial changes in the length of the day, which is now 24 hours, whereas "once it was only 5–6 hours" [1].

Given this, it is important to identify the main causes of the secular deceleration of the Earth's rotation. According to existing studies and our own analysis of the mechanics of this phenomenon, the following major factors may contribute to this effect:

- Tidal braking forces caused by tidal phenomena on Earth induced by the gravitational attraction of the Sun and Moon.
- Resistive torque arising from friction between the rotating Earth and the surrounding cosmic medium.
- Secular increase in the Earth's mass and average diameter.

Let us now examine these causes separately.

1) Tidal braking forces

These are generated by tidal phenomena on Earth due to the gravitational forces of the Sun and Moon [4–8]. Some authors regard tidal braking forces as the sole cause of the Earth's secular rotational deceleration. In this view, the lunar tidal effects are considered dominant, while solar tides are either ignored or regarded as negligible due to the large distance between the Earth and the Sun.

To illustrate the influence of lunar tides on the Earth's rotational deceleration, we can cite the explanation from [1]:

"Since the Earth rotates about its axis much faster than the Moon revolves around the Earth, the Moon pulls the tidal bulge slightly ahead of the Earth-Moon line. Friction occurs between the water and the solid ocean floor, resulting in so-called tidal friction. This friction slows the Earth's rotation, and the days gradually become longer."

It should be noted, however, that some authors have argued that Earth's lunar tides can explain no more than one percent of the observed secular deceleration of rotation [6].

2) Resistive torque due to friction with the cosmic medium

Such resistance to rotation can be modeled as viscous friction. The presence of rotational resistance from the cosmic medium can be inferred from studies such as [12 - 14]. These works assert that a resisting force acts on a cosmic body moving through the interplanetary medium. "The problem of resistance of the medium first attracted astronomers' attention in connection with the motion of Encke's comet" [12]. The author of that study suggested that the observed effect could be fully explained by the influence of the surrounding solar material and that the resistive force could be considered proportional to the body's velocity relative to this medium - consistent with the model of viscous drag.

SECULAR INCREASE IN THE EARTH'S MASS AND AVERAGE DIAMETER

Research has established that there is a very slow – secular - increase in both the Earth's mass and its mean diameter [15–24]. These effects do not directly produce a braking torque that slows the Earth's rotation, but they gradually increase the Earth's moment of inertia about its axis of rotation. If we approximate the Earth as a uniform sphere of radius (R), its moment of inertia is [21]:

$$J = \frac{2}{5} M R^2 , \tag{1}$$

Where (M) is the Earth's mass.

From this expression, it follows that increases in (M) and (R) both increase (J), leading to a gradual reduction in angular velocity. This can be shown from the expression for the kinetic energy of a sphere rotating with angular velocity **w** [21]:

$$K_Э = J \frac{\omega^2}{2} \tag{2}$$

from which we obtain

$$\omega = \sqrt{\frac{2K_з}{J}} \tag{3}$$

It is also important to clarify the causes of the secular increase in the Earth's mass and average diameter. It is generally accepted that the increase in the Earth's mass occurs due to the accumulation of cosmic material falling onto its surface - meteorites, various particles, and dust from interplanetary space. The increase in the Earth's average diameter may occur for two reasons: first, due to the aforementioned deposition of cosmic material on the Earth's surface, and second, as a result of a presumed long-term decrease in the gravitational constant [15]. It is believed that the gradual reduction in the value of this constant, which appears in the law of universal gravitation, leads to a decrease in the density of the Earth's material and, consequently, to its inevitable expansion.

Thus, as (J) increases, ($\boldsymbol{w}$) decreases. The reasons for the secular increase in the Earth's mass and diameter are generally attributed to two processes: accumulation of cosmic material (meteorites, interplanetary dust, etc.) on the Earth's surface; and a possible long-term decrease in the gravitational constant (G). It is assumed that as (G) decreases, the Earth's material becomes less compact, causing gradual expansion.

However, the extent to which this increase in mass and size contributes to the deceleration of the Earth's rotation remains uncertain and requires further study. According to [16], the influence may be quite significant.

From the above, it follows that the Earth and all other celestial bodies are, in essence, bodies of variable mass. Therefore, the following statement from [16] about the mechanics of such bodies is noteworthy: "The mechanics of bodies with variable mass plays a major role in accurately describing the motion of planets, especially that of the Moon."

Let us now consider some kinematic and dynamic aspects of the secular deceleration of the Earth's rotation. For simplicity, we will ignore precession and nutation of the Earth's rotational axis and will not distinguish between the Earth's rotation about the Earth - Moon barycenter and its rotation about its own axis. We will treat them as a single uniformly decelerated rotational motion.

The well-known kinematic equation for uniformly decelerated rotational motion of a rigid body is:

$$\omega = \omega_0 + \varepsilon t \tag{4}$$

where ω_0 is the initial angular velocity at (t = 0), and $\boldsymbol{\varepsilon}$ is the angular acceleration.

At two moments t_1 and t_2 :

$$\omega_1 = \omega_0 + \varepsilon t_1 \,, \qquad \omega_2 = \omega_0 + \varepsilon t_2 \tag{5}$$

Letting $t_2 - t_1 = \Delta t$, from (5) we obtain:

$$\varepsilon = \frac{\omega_2 - \omega_1}{\Delta t} \tag{6}$$

Let T_1 and T_2 be the periods of the Earth's signals at approximately times t_1 and t_2, respectively. Then, in accordance with the principles of theoretical mechanics, we can write:

$$\omega_1 = \frac{2\pi}{T_1} \,, \qquad \omega_2 = \frac{2\pi}{T_2} \tag{7}$$

Taking into account (7) and (6), we have

$$\varepsilon = -\frac{2\pi}{\Delta t} \cdot \frac{T_2 - T_1}{T_1 T_2} \tag{8}$$

Numerical example.

Let's assume that Δt=100 years=100·365.25·86400 sec≈315576·10^4 sec; T_1 =24 hours=86400 sec. We take the increment in *T* over the time interval Δt according to [4] as a relatively average, i.e. T_2 =86400.0020 sec. Then $T_2 - T_1$ =0.0020 sec, T_1 T_2≈864002 sec2. Substituting these data into (8), we find the corresponding value of the Earth's angular acceleration:

$$\varepsilon = -\frac{6{,}2832}{315576 \cdot 10^4} \cdot \frac{0{,}0020}{86400^2} = -5{,}334 \cdot 10_{-22} \text{sec}^{-2}$$

The negative sign indicates deceleration of the Earth’s rotation.
It is of interest to estimate how long it would take for the day’s length to increase to, say, 30 hours. If the rate of day-length increase is 0.0020 s per 100 years (i.e., $2 \cdot 10^{-5} \frac{sec}{year}$). Then the lengthening of the day to thirty hours will occur in $\frac{3600\ (30-24)}{2 \cdot 10^{-5}} \approx 1{,}03 \cdot 10^9$ years. Thus, if the current angular deceleration remains constant, the day will be about 30 hours long roughly one billion years from now.

DYNAMIC ESTIMATION OF BRAKING TORQUE

To obtain an approximate value for the total braking torque of the Earth’s rotation, we use the basic dynamic equation for rotational motion of a rigid body with constant mass:

$$J\varepsilon = M_T \tag{9}$$

where M_T is the total braking torque, including the combined tidal (lunar and solar) and cosmic-medium friction components.

Neglecting the effect of long-term mass and diameter changes, and using J = 8,12· 10^{44} г· $см^2$ = 8,12· 10^{37} кг· $м^2$ [6], we find:

$$M_T = J\varepsilon = 8{,}12 \cdot 10^{37} кг \cdot м^2 \cdot (-5{,}334 \cdot 10^{-22} сек^{-2}) \approx -4{,}33 \cdot 10^{16}\, Н.м$$

The negative sign indicates that the torque M_T acts opposite to the direction of the Earth’s rotation. It should be emphasized that this value represents an approximate and total braking torque - that is, the sum of several contributing components.

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