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NEW EQUATIONS FOR THE SPINNING TOP

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ABSTRACT

It is pointed out that at present there is no complete theory of the top that answers all questions. This theoretical work provides a complete mathematical description of the top, including equations of top dynamics at any speeds. New well-known experiments that currently do not have any explanation are considered in details. The resulting equations use the fact disputed by today's science that the Coriolis force and the centrifugal force are real forces that do work. The coincidence of the calculation results and experiments is a proof of this fact.

Keywords: Coriolis force and centrifugal force, spinning top, top dynamics.

INTRODUCTION

The question of why the top does not fall is constantly raised despite the fact that there is a well-founded theory of how the top works. This question is not new. It was asked in 1890 by Prof. John Perry (Perry, J. 1890. Spinning Tops. The "Operatives' Lecture" of the British Association Meeting at Leeds, UK, 6th September, 1890, https://www.gutenberg.org/ebooks/34268, page 93). He wrote *"... in a spinning top, obviously, only with rotation does life and stability appear, or, in other words, only then do forces act that oppose the earth's gravity, which tends to overturn the spinning top. Where do these forces come from and how are they explained?"* The questioner intuitively feels that the initial push cannot give the energy that is needed for a long and vigorous rotation. Also, the questioner intuitively feels that there must be a real force that keeps the top from falling. However, the theory explains why it spins, and the unspoken sounds like answer is "doesn't fall because it spins." But maybe our intuition is deceiving us and the spinning top actually has enough energy? This issue first of all will be discussed below.

THE STATE EQUATIONS

Figure 1 shows a spinning top in its simplest form. The spinning top has

- rotation of the top around its own vertical axis at the angular speed ω_1,
- rotation of a top inclined at an angle α to the plane around its own axis at the angular speed ω_2,
- precession on the circumference of a top inclined at an angle α to the plane, at the angular speed ω_3.

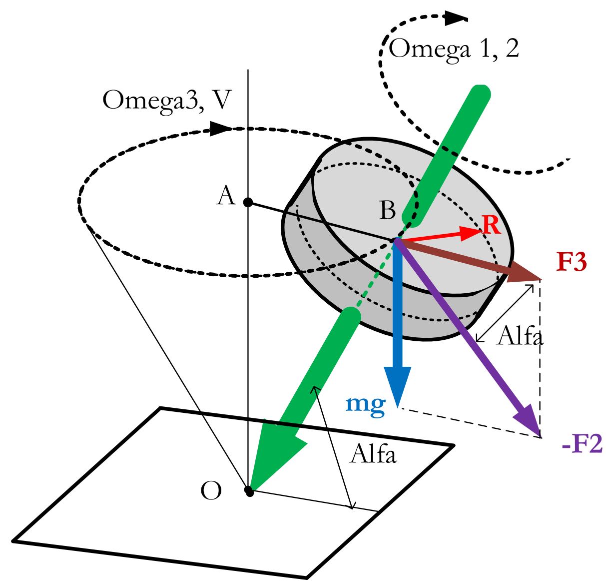

Fig. 1. The simplest form of the spinning top.

Table 1 lists the parameters of the state of the top at the initial moment 1 and at the moment 2, when the top is in a position at which the angle $\alpha < \pi/2$. At moment 1, there is only rotation around the vertical axis. At moment 2, a precession additionally appears.

Let us write down for moment 2 the equations of the laws of conservation of momentum L and energy W, which do not depend on how and by what forces the top passed into this state:

$$L_2 + L_3 = L_1 \quad (1)$$
$$W_2 + W_3 = W_1 \quad (2)$$

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Table 1. The formulas.

Angular speed	Moment of inertia	Angular momentum	Kinetic energy
ω_1	$J_1 = \frac{mR^2}{2}$	$L_1 = J_1\omega_1$	$W_1 = \frac{1}{2}L_1\omega_1 = \frac{1}{4}J_1\omega_1^2 = \frac{1}{8}mR^2\omega_1^2$
ω_2	$J_2 = J_1$	$L_2 = J_2\omega_2$	$W_2 = \frac{1}{2}L_2\omega_2 = \frac{1}{4}J_2\omega_2^2 = \frac{1}{8}mR^2\omega_2^2$
ω_3	$J_3 = mq$, where $q = h^2 - \left(\frac{2}{\pi}h^2 - R^2\right)\alpha$, see formula (7)		
		$L_3 = J_3\omega_3$	
			$W_3 = \frac{1}{2}L_3\omega_3 = \frac{1}{4}J_3\omega_3^2 = \frac{1}{4a}mR^2\omega_3^2$

Here we determine the parameters of the state of the spinning top at moments 1 and 2. Table 1 lists the basic formulas, where the following notation is accepted:
α is the angle of inclination of the spinning top to the rolling plane,
m is the spinning top mass,
g is the acceleration of gravity,
mg is gravity,
R is the spinning top radius,
h is the spinning top height (segment OB in Fig. 1),
ω_1 is the angular speed of spinning top rotation around the vertical diameter at moment 1,
ω_2 is the angular speed of spinning top rotation around the vertical diameter at moment 2,
ω_3 is the angular speed of precession at moment 2,
v is the linear speed of precession,
L is the angular momentum,
J is the moment of inertia,
W is energy.

Substituting the equations listed in Table 1 into equations (1) and (2), we get:

$$J_2\omega_2 + J_3\omega_3 = J_1\omega_1 \quad (3)$$

$$\frac{1}{2}J_2\omega_2^2 + \frac{1}{2}J_3\omega_3^2 = \frac{1}{2}J_1\omega_1^2 \quad (4)$$

where

ω_1 and ω_2 are the angular speeds of rotation of the top at moments 1 and 2 around the axis, which is the rod,
ω_3 is the angular speed of precession around the vertical axis,
J_1, J_2, and J_3 are the moments of inertia during rotation at the corresponding speeds ω_1, ω_2, and ω_3.
L_1, L_2, and L_3 are the angular momenta during rotation at the corresponding speeds ω_1, ω_2, and ω_3.

The moments of inertia are

$$J_1 = J_2 = m\frac{\pi R^2}{2} \quad (5)$$

The moment of inertia J_3 changes depending on the angle α (Figure 2). For $\alpha = 0$, this moment can be taken equal to $J_3 = mh^2$. For $\alpha = \pi/2$ this moment is $J_3 = J_2$ by the Steiner theorem. So,

$$J_3(\alpha) = \begin{cases} mh^2 & \text{if } \alpha = 0 \\ m\frac{\pi R^2}{2} & \text{if } \alpha = \frac{\pi}{2} \end{cases} \quad (6)$$

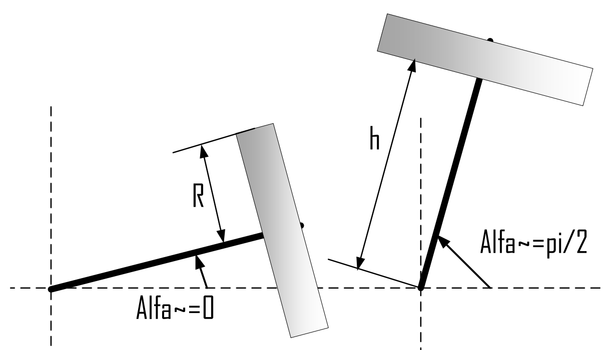

Fig. 2. The changes in the inertia moment J_3 in dependence on the angle α.

We will assume that this function is linear. Then we get:

$$q = J_3/m = h^2 - \left(\frac{2}{\pi}h^2 - R^2\right)\alpha \quad (7)$$

From formulae (3), (5), and (7) we find:

$$q\omega_3 = \frac{1}{2}\pi R^2(\omega_1 - \omega_2) \quad (8)$$

Substituting equalities (1), (5), (7), and (8) into formula (4), we find that

$$\frac{1}{4}\pi R^2(\omega_2^2-\omega_1^2)+\frac{1}{4}q\omega_3^2=0 \tag{9}$$

or

$$\pi R^2(\omega_2^2-\omega_1^2)+q\omega_3^2=0 \tag{10}$$

Combining formulas (8) and (10), we can obtain that

$$\pi R^2(\omega_2^2-\omega_1^2)+\left(\frac{1}{2}\pi R^2(\omega_1-\omega_2)\right)^2\Big/q=0 \tag{11}$$

or

$$4\pi R^2(\omega_2^2-\omega_1^2)+\pi^2R^4\,(\omega_1-\omega_2)^2/q=0 \tag{12}$$

or

$$a(\omega_2^2-\omega_1^2)+b(\omega_1-\omega_2)^2=0 \tag{13}$$

where it is obvious that

$$a=4\pi R^2, b=\pi^2R^4/q \tag{14}$$

Regrouping formula (13), we get the following equation to find the ω_2 in dependence on the ω_1:

$$\omega_2^2(a+b)-2b\omega_1\omega_2+\omega_1^2(-a+b)=0 \tag{15}$$

Resolving equation (15), we find:

$$\begin{aligned}\omega_2&=\frac{1}{2(a+b)}\left(2b\omega_1\pm\sqrt{4b^2\omega_1^2-4(a+b)\big(\omega_1^2(-a+b)\big)}\right)\\&=\frac{1}{2(a+b)}\left(2b\omega_1\pm\sqrt{4b^2\omega_1^2-4(b^2-a^2)\omega_1^2}\right)\\&=\frac{1}{2(a+b)}\left(2b\omega_1\pm\sqrt{4a^2\omega_1^2}\right)\end{aligned}$$

As a result, we have

$$\omega_2=\frac{(b\pm a)}{(a+b)}\omega_1 \tag{16}$$

Physically, there is a solution of the following form:

$$\omega_2=\frac{(b-a)}{(a+b)}\omega_1 \tag{17}$$

Using formulas (17) and (8), we can finally get that

$$\begin{aligned}q\omega_3&=\frac{\pi R^2}{2}(\omega_1-\omega_2)=\frac{\pi R^2}{2}\left(\omega_1-\frac{(b-a)}{(a+b)}\omega_1\right)\\&=\frac{\pi R^2}{2}\frac{2a}{(a+b)}\omega_1=\pi R^2\frac{4\pi R^2}{(a+b)}\omega_1=\frac{4\pi^2R^4}{(a+b)}\omega_1\end{aligned} \tag{18}$$

or

$$\begin{aligned}\omega_3&=\frac{4\pi^2R^4}{(aq+b)}\omega_1=\frac{4\pi^2R^4}{(aq+\pi^2R^4)}\omega_1\\&=\frac{4\pi^2R^4}{(4\pi R^2q+\pi^2R^4)}\omega_1\end{aligned} \tag{19}$$

or

$$\omega_3=\pi R^2\frac{1}{(q+\pi R^2/4)}\omega_1 \tag{20}$$

Consider the particular cases shown in Figure 2. At the same time, from definitions (7), (14), (17), (20) we find:

$$q(\alpha)\approx\begin{cases}h^2 & \text{if } \alpha\approx 0\\ \frac{1}{2}\pi R^2 & \text{if } \alpha\approx\frac{\pi}{2}\end{cases} \tag{21}$$

$$b(\alpha)\approx\begin{cases}\pi^2R^4/h^2 & \text{if } \alpha\approx 0\\ 2\pi R^2 & \text{if } \alpha\approx\frac{\pi}{2}\end{cases} \tag{22}$$

$$\omega_2(\alpha)\approx\begin{cases}\frac{(h^2-4\pi R^2)}{(h^2+4\pi R^2)}\omega_1 & \text{if } \alpha\approx 0\\ -\frac{1}{3}\omega_1 & \text{if } \alpha\approx\frac{\pi}{2}\end{cases} \tag{23}$$

$$\omega_3(\alpha)=\begin{cases}\frac{\pi R^2}{(h^2+\pi R^2/4)}\omega_1 & \text{if } \alpha\approx 0\\ \frac{4}{3}\omega_1 & \text{if } \alpha\approx\frac{\pi}{2}\end{cases} \tag{24}$$

THE FORCES ACTING ON THE SPINNING TOP

The resulting formulas show the change in the speed of its own rotation and the precession speed of the top in the process of falling, i.e. the change in the angle α from $\pi/2$ to 0. The top goes into an inclined position under the action of gravity force mg. But at the same time, the Coriolis force and the centrifugal force act on the top, depending on the rotation speeds and therefore changing their value depending on the α. These forces counteract the force of gravity and therefore, the spinning top falls very slowly. Obviously, with such deceleration, the source of the Coriolis force and centrifugal force consumes energy. Therefore, there is an energy source for this force. But this assumption is hampered by the persistent modern notion that the Coriolis force is a fictitious force. A fictitious force cannot deliver energy...

Let us consider these forces. The Coriolis force is

$$\mathbf{F_2} = -2m\boldsymbol{\omega_2} \times \mathbf{v} \tag{25}$$

where v is the linear speed of precession. This is the speed of movement of p. Point B on the radius AB rotates at the angular speed ω_3 (Figure 1):

$$v = \omega_3 h\cos(\alpha) \tag{26}$$

In addition, the following centrifugal force acts on the top directed horizontally along AB from the center:

$$F_3 = m\omega_3^2 h\cos(\alpha) \tag{27}$$

At each moment of time, the forces acting on the top are F_2, F_3, and the following force of gravity:

$$F_4 = -mg \tag{28}$$

which directed vertically down. Thus, at each moment of time, the following total force acts on the top:

$$F_s = F_2 + F_3 + F_4 \tag{29}$$

The horizontal and vertical projections of this force will be denoted as F_{sx} and F_{sy}, respectively. The force F_{sy} creates an overturning moment of rotation of the top around the pivot point. This moment is equal to

$$M = hF_{sx}\sin(\alpha) - hF_{sy}\cos(\alpha) \tag{30}$$

In addition, the force F_s creates a pressure force on the pivot point, which is directed along the bar and equal to

$$T = -hF_{sx}\cos(\alpha) - hF_{sy}\sin(\alpha) \tag{31}$$

Using these formulas, one can find both the aforementioned forces and the moment of rotation as functions of the angle α found at the known speeds in the previous section.

There is a certain angle α_0 at which the top takes a stable position, maintaining this angle of inclination α_0 for a long time. For $\alpha = \alpha_0$, we have the function $M(\alpha) = 0$ and the following derivative:

$$dM(\alpha) \,/\, d\alpha < 0$$

These conditions allow us to find the angle α_0 from the graph of the function $M(\alpha)$.

SEVERAL EXAMPLES

Figures 3, 4, 6, and 8 in **Examples 1**, **2**, **3**, and **4** show the following functions of the argument α:
F2x is the horizontal projection of the Coriolis force,
F2y is the vertical projection of the Coriolis force,
F3 is the horizontal centrifugal force,
FSx is the total horizontal force,
FSy is the total vertical force,
M is the torque,
T is the pressure force on the hinge in the bar direction,
om1, om2, om3 are the angular velocities ω_1, ω_2, ω_3, respectively.
The color of the graph line is indicated in the parentheses: (b) is for the blue color, (r) is for the red, (g) is for the green.

Example 1.

In this example, the functions listed above are found at $h = 0.6$; $R = 0.15$; $\omega_1 = 6.5$, $m = 1$ (Fig. 3). The dotted vertical (light blue line) in the lower left figure highlights the point where $\alpha_0 = 0.33$. At this point, we have the function $M(\alpha) = 0$ and its derivative $dM(\alpha)/d\alpha < 0$. Therefore, at this point the top is in a stable position.

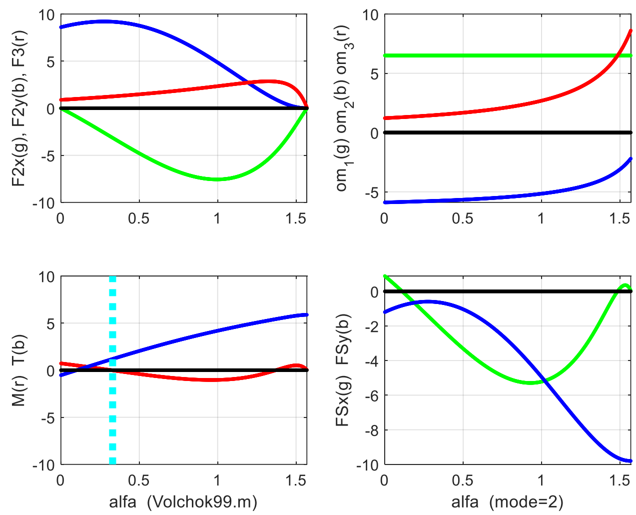

Fig. 3. The functions for the following parameters' values: $h = 0.6$, $R = 0.15$, $\omega_1 = 6.5$, $m = 1$.

Example 2.

In this example, these functions listed above are found at $h = 0.8$; $R = 0.15$; $\omega_1 = 5.5$, $m = 1$ (Fig. 4). The dotted vertical (light blue line) in the lower left figure highlights the point where $\alpha_0 = 1.04$. At this point, there are the function $M(\alpha) = 0$ and its derivative $dM(\alpha)/d\alpha < 0$. Therefore, at this point the top is also in a stable position.

The practical implementation of such cases, which are considered in **Examples 1** and **2**, are ordinary top toys. Another option is shown in Figure 5 below that was borrowed from the following video experiment (Flying

spinner:
https://www.youtube.com/watch?v=rDDfKVjjG2g).

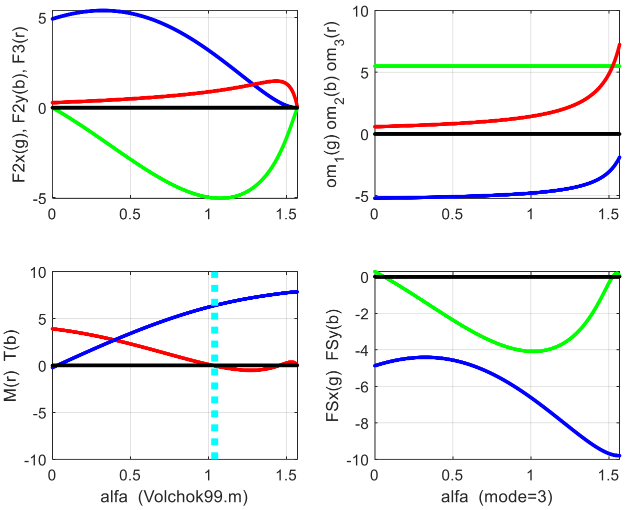

Fig. 4. The functions for the following parameters' values: h = 0.8, R = 0.15, ω_1 = 5.5, m = 1.

Fig. 5. The flying spinner experiment.

Example 3.
In this example, the functions listed above are found at h = 0.8; R = 0.2; ω_1 = 60, m = 1 (Figure 6). The dotted vertical (light blue line) in the lower left figure highlights the point where $\alpha_0 = \pi/2$. At this point, the function $M(\alpha)$ = 0 and its derivative $dM(\alpha)/d\alpha$ < 0. Therefore, at this point the top is also in a stable position.

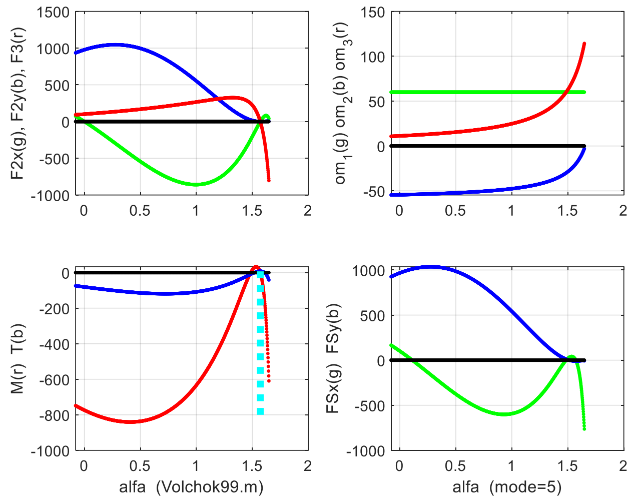

Fig. 6. The functions for the following parameters' values: h = 0.8, R = 0.2, ω_1 = 60, m = 1.

The practical implementation of this case, i.e. when the barbell of top is in a vertical position, and the disk is horizontal, can be found on the Internet (Figure 7). It can be seen that the top in this case hangs motionless in the air, i.e. the vertical force acting on the top is equal to zero. In our example, the reader can also see that the vertical force acting on the top is equal to zero (the F2x force graph in the upper left figure in Figure 6).

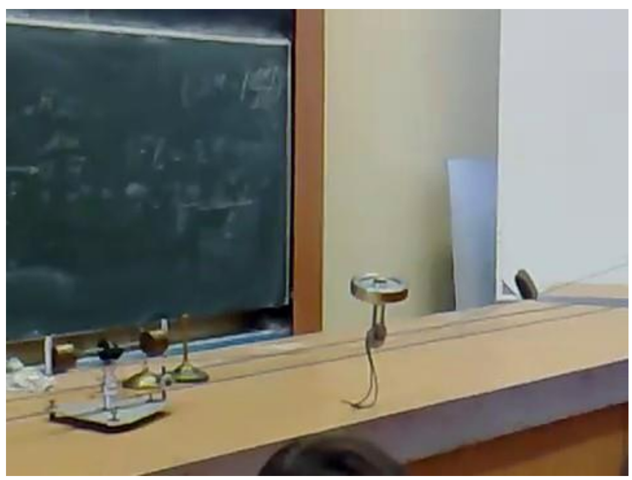

Fig. 7. The wheel experiment.

Example 4.
In this example, the functions listed above are found at h = 0.6; R = 0.15; ω_1 = 6.9 (Fig. 8). The dotted vertical (light blue line) in the lower left figure highlights the point where α_0 = 0. At this point, the function $M(\alpha)$ = 0 and its derivative $dM(\alpha)/d\alpha$ < 0. Therefore, at this point the top is also in a stable position.

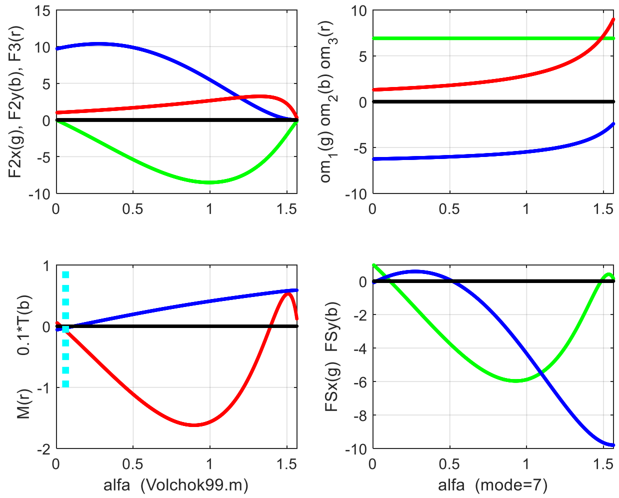

Fig. 8. The functions for the following parameters' values: h = 0.6, R = 0.15, ω_1 = 6.9.

The practical implementation of this case, i.e. when the barbell of top is in a horizontal position and the disk is vertical, is considered in many video experiments, for instance, Figure 9 from (The experiment concerning wheel versus gravity at the University of Sydney: https://www.youtube.com/watch?v=GeyDf4ooPdo) and Figure 10 from (Beletsky, I. Gyroscope loses its weight? https://www.youtube.com/watch?v=FwrlRpC8BDA) and (Professor Eric Laithwaite gives a demonstration of a large gyro wheel: https://www.youtube.com/watch?v=JRPC7a_AcQo). It can be seen that the top in this case rotates on a horizontal rod. The measurements in (Beletsky, I. Gyroscope loses its weight? https://www.youtube.com/watch?v=FwrlRpC8BDA) show that its top weight is equal to zero. There are no explanations. In our example, the reader can also see that the vertical force acting on the top is equal to zero (the F2x force graph in the upper left figure in Figure 8). Thus, both practically and theoretically it is shown that in this position the top is weightless.

Such an experiment is also considered in (Provatidis, 2021) with reference to (Professor Eric Laithwaite gives a demonstration of a large gyro wheel: https://www.youtube.com/watch?v=JRPC7a_AcQo). The article begins by stating that for such a device "*the detailed mechanics of which are still an enigma*". The author of this article has developed three new Euler equations that are much longer than those found in textbooks. The resulting nonlinear equation is modeled in the MATLAB system to obtain and visualize a numerical solution. Under certain conditions, providing small oscillations of the gyroscope axis (maximum oscillation of eight degrees in the angle of inclination) near the horizontal plane through the fulcrum, linearization is performed, which is successfully compared with the above-mentioned nonlinear numerical solution. Provatidis argues that the numerical solution under certain conditions «*is crucial to the debate about whether such an engine may produce a net thrust, or not. A relevant paradox is resolved*». The question of where the source of forces is up in the air, as is the device in question.

Fig. 9. The very heavy wheel versus gravity at the University of Sydney.

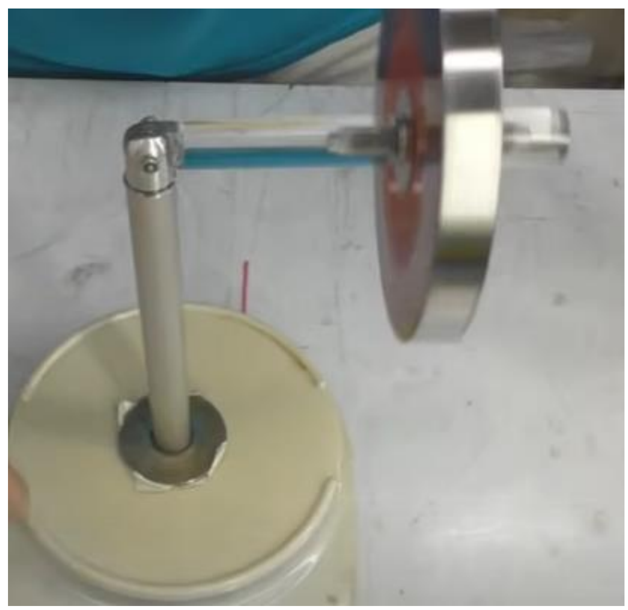

Fig. 10. The other wheel.

DYNAMICS

Above we considered a sequence of static states that differ in the value of the angle α. In the simplest case, we can assume that the top stays in a position with given α for a time inversely proportional to the overturning moment M. Under this assumption, we can calculate the duration of the top in position α by the following formula:

$$t(\alpha) = 1/\mathrm{Abs}(M(\alpha)) \tag{32}$$

The duration of the fall of the top from the position $\alpha = \pi/2$ to the given position α is determined by the following formula:

$$\mathrm{T}(\alpha) = \int_{\pi/2}^{\alpha} t(\alpha) d\alpha \tag{33}$$

The stable position α_0, as mentioned, is determined by the following conditions: $M(\alpha_0) = 0$ and $dM(\alpha_0)/d\alpha < 0$. The top remains in this position until the friction against the air reduces its kinetic energy.

Example 5.
Consider **Example 2** and Figure 4. Under the conditions of this example, we construct the functions $t(\alpha)$, $T(\alpha)$, $M(\alpha)$ shown in Figure 11. The left border of the graphs corresponds to the steady position of the top.

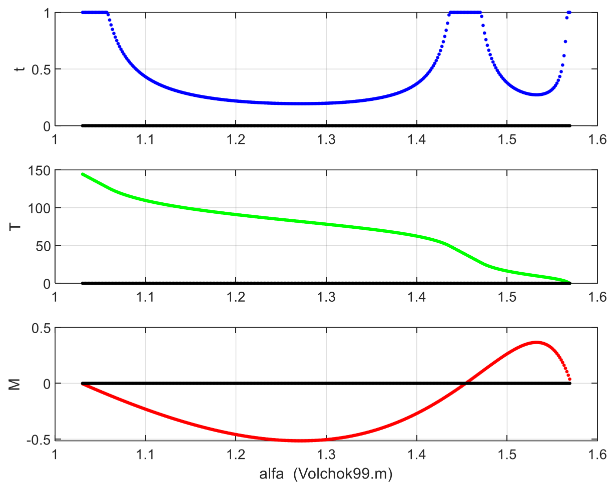

Fig. 11. The functions $t(\alpha)$, $T(\alpha)$, $M(\alpha)$.

Let us now consider the equations written above, taking into account the equation of the dynamics of the rotational motion of a rigid body around a fixed axis, which has the following form:

$$M_0 = J_0 \frac{d\omega_0}{dt} \tag{34}$$

where

M_0 is the moment of forces acting on the body,
J_0 is the moment of inertia of a rotating body,
ω_0 is the angular velocity of body rotation.

The top performs two rotations simultaneously and its equivalent moment of inertia J_1 and the equivalent rotation speed ω_1 are connected with the moments of inertia and the speeds of the terms of the rotations by equation (3) of the momentum conservation law. Therefore, in our case formula (34) takes the following form:

$$M = J_1 \frac{d\omega_1}{dt} \tag{35}$$

where M is the overturning moment of the top, considered above. Then

$$\frac{d\omega_1}{dt} = \frac{M}{J_1} \tag{36}$$

Using the formulae listed in Table 1, it is possible to demonstrate that

$$J_1 = \frac{1}{2} mR^2 \tag{37}$$

Hence,

$$\frac{d\omega_1}{dt} = \frac{2M}{mR^2} \tag{38}$$

This means that the speed ω_1 given at the initial moment changes according to the dependence demonstrated by formula (38) from the overturning moment of the forces. With a large mass of the top, acceleration (38) can be considered equal to zero and the abovementioned method for calculating the top can be used. Taking into account acceleration (38), the calculation of the dynamics of the top should be performed according to the following algorithm:

1. At the initial moment, we have $\alpha = \pi/2$, $\omega_1 = \omega_{10}$, and $M = 0$.
2. The set of equations (3) and (4) is resolved, as shown above, and thus the speeds ω_2, ω_3 are determined.
3. The moment M is calculated as shown above.
4. Both the conditions such as $M = 0$ and $dM/d\alpha < 0$ are checked. The fulfillment of these conditions means that the top has passed into a steady state and the calculation is terminated.
5. The new value of $\alpha = \alpha_{old} + Md\alpha$ is calculated.
6. $d\omega_1/dt$ is calculated using formula (38) with the obtained value of M.
7. The new value of $\omega_1 = \omega_{1old} + (d\omega_1/dt)dt$ is calculated.
8. Go to step 2.

In equation (4), consider the left term such as $J_1\omega_1^2/2$. It corresponds to the total kinetic energy of the top. Since (as follows from the algorithm) the speed ω_1 changes, the kinetic energy of the top also changes: It can decrease and increase. The power delivered by the overturning moment in a given position of the top depends on α and is defined as

$$P(\alpha) = M(\alpha)\omega_1(\alpha) \quad (39)$$

DISCUSSION

The algorithm for calculating the dynamics of a top is based on the use of the equation of dynamics of rotational motion of a rigid body and the laws of conservation of momentum and energy. In addition, it uses the notion that Coriolis forces and centrifugal forces are real forces. Such an action of the Coriolis forces and centrifugal forces is possible only if they can do work, i.e. they are real powers. This proves the reality of these forces. On the other hand, a mathematical proof of this fact is given in (Khmelnik, 2022). It shows that these forces can be justified as a consequence of Maxwell's equations for gravitomagnetism, and the energy source for these forces is the Earth's gravitational field. But even in the absence of such evidence, there are many doubts about the assertion that these forces are fictitious (Astakhov, 2006). Another proof of the reality of these forces is the explanation of many astronomical facts found in (Ermolin, 2017) using the Coriolis forces.

The author is repeatedly pointed out the MEPhI experiment (a ball rolling on a rotating platform: https://www.youtube.com/watch?reload=9&v=LkrmALM8TsA) demonstrated at the National Research Nuclear University MEPhI (Moscow Engineering Physics Institute, Russia) in which the fictitiousness of the Coriolis force is convincingly proved (Fig. 12). Consider this proof. But first of all, the author wants to note that the author is not criticizing the lecturer, nothing personal. The experimenter is one of the best teachers in Russia at one of the best physics institutes in Russia.

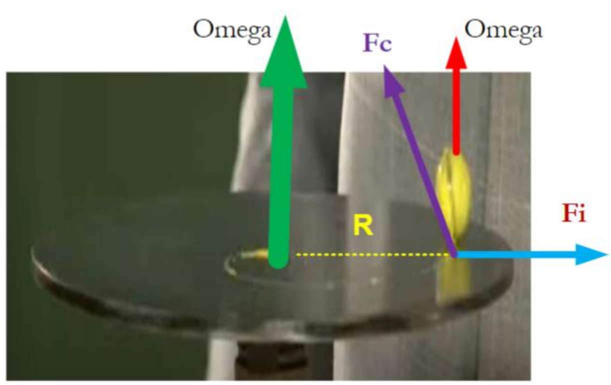

Fig. 12. The proof of the Coriolis force.

The disk rotates with an angular speed ω. The ball is pushed out by the experimenter from the central hole along the radius R of the disk and moves along the radius under the action of the inertial force F_i at a linear speed v. In this case, the Coriolis force F_c perpendicular to the radius R acts on it. As a result, the ball describes a spiral, moving in the direction opposite to the rotation of the disk (therefore, we cannot suspect that the disk is pulling it with the force of friction). The force that pulls the ball tangentially is the Coriolis force:

$$\mathbf{F}_c = -2m\boldsymbol{\omega} \times \mathbf{v} \quad (40)$$

The question is, where did this power come from?

Further, the experimenter argues that this force appeared because the ball moves in a coordinate system associated with a rotating disk, and the angular speed ω of the disk is present in formula (40). The experimenter is one of the best teachers in Russia at one of the best physics institutes in Russia. Modern Physics speaks through him.

We can suggest a modification of the experiment. Let there be a thin plane above the disk and let the ball lie on this plane. At the same time, we completely exclude the mechanical influence of the disk. Only the coordinate system of the disk remains. So, we push the ball and bring the rotating disk to the plane. In this case, the Coriolis force appears, moving the ball. No fraud! No wonder because there really is no power. The question of where this power came from is superfluous. Such is nature, says physics. Physics is fine with that. But how can a physicist accept such an explanation?! It would be more honest to admit that physics has no explanation and it must be sought. Or, following the example of Mach, it is possible to assume the influence of celestial bodies.

But in this experiment, the explanation is much simpler. The ball, lying in the central hole, rotates together with the disk with an angular speed ω and continues to rotate after the central impact of the experimenter. The speed ω in formula (40) is the speed of the ball but not the disk.

It is the lack of a clear answer to the question "where does the power come from?" and led to the emergence of such a theory: It was necessary to find the answer so that the students respected the teachers! It would be possible not to build hypotheses about the nature of this force (as Newton did with the force of inertia). But the times at that time were, apparently, not the same. And off we go. The force was not recognized as real, but fictitious and incapable of doing work. The following physicists had to show miracles of ingenuity in order to find both the coordinate system due to which the Coriolis force appeared and the source of energy that works for it. This issue is considered in detail by Astakhov (2006).

CONCLUSION

An algorithm for calculating the dynamics of a top is proposed. It can be used at any top rotation speed. It allows us to explain known but still unexplained experiments. It explains, in particular, the increase in weight and energy of the spinning top. This article also gives a mathematical description of the top, which is still missing, which uses the known facts of mechanics and the notion of the Coriolis force, which is NOT accepted in mechanics, as a real force.

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