The Obtaining of Required Coefficient of Friction Using Nanocoatings and its Impact on Autobalancing Regime

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***Abstract* - The paper deals with torus-shaped autoequalizer with vertical axis, the body of which is placed relatively eccentric to the rotation axis and the internal working walls of which are covered with nanocoatings, which allow providing different values of friction coefficient on the respective inner zones of the body, thus making it possible to adjust the ball's working modes. Autoequalizer with torus-shaped body contains one ball-shaped adjustment mass moving freely within the autoequalizer's body both circularly and crosswise. This reduces to the minimum the resistance force during the ball motion mode, and at the same time decreases the possibility to start the autoequalizer. The design of an autoequalizer ensuring working state when at rotation the ball stops relative to the autoequalizer's body opposite to the imbalance has been experimentally worked out. The autoequalizer design has been protected by patent.**

***Keywords* - nano-coatings, friction coefficient, autoequalizer, working mode, ball, rotor, torus-shaped body.**

I. INTRODUCTION

The reduction of rotor system vibrations is the necessary condition for the development of higher quality structures. It is very important to reduce vibrations in stable as well as other rotor movement conditions. Devices being able to reduce rotor vibrations include automatic equalizers with balls, liquid, etc.

To ensure the optimum place for the balls within the equalizer's body it is necessary to reduce the fiction force to the minimum. This is possible in case the ball has only one contact point with the body surface, i.e., the body mast has a torus-shape with round cross-section. In experimental researches with real autobalancing devices it was stated that the balls have different motion modes, when the rotor is rotating at the working speed. In the balancing condition the balls stop relative to the equalizer device body motionless opposite the imbalance [1]. In the other mode the balls move stably and continuously relative to the equalizer device body and the rotor vibrations grow. This continuous ball motion case is realized experimentally in the centrifuge researches [2]. To ensure the working mode for the equalizer experimentally a structure was developed [3] functioning only in the working mode, i.e., during the rotor rotation the balls stop relative to the body opposite the imbalance.

II. EXPERIMENTAL RESEARCHES

Experimental centrifuge diagram and body vibration amplitudes during two ball movement modes are given in Fig.1. The mass fixed to the centrifuge container imitates the rotor imbalance. The mass of 50 g is fixed at 270 mm from the base. The body vibrations are measured at point A 200 mm from the base (see Fig.1. a). The centrifuge rotor was rotating at an angular velocity ω=140 s^{-1}.

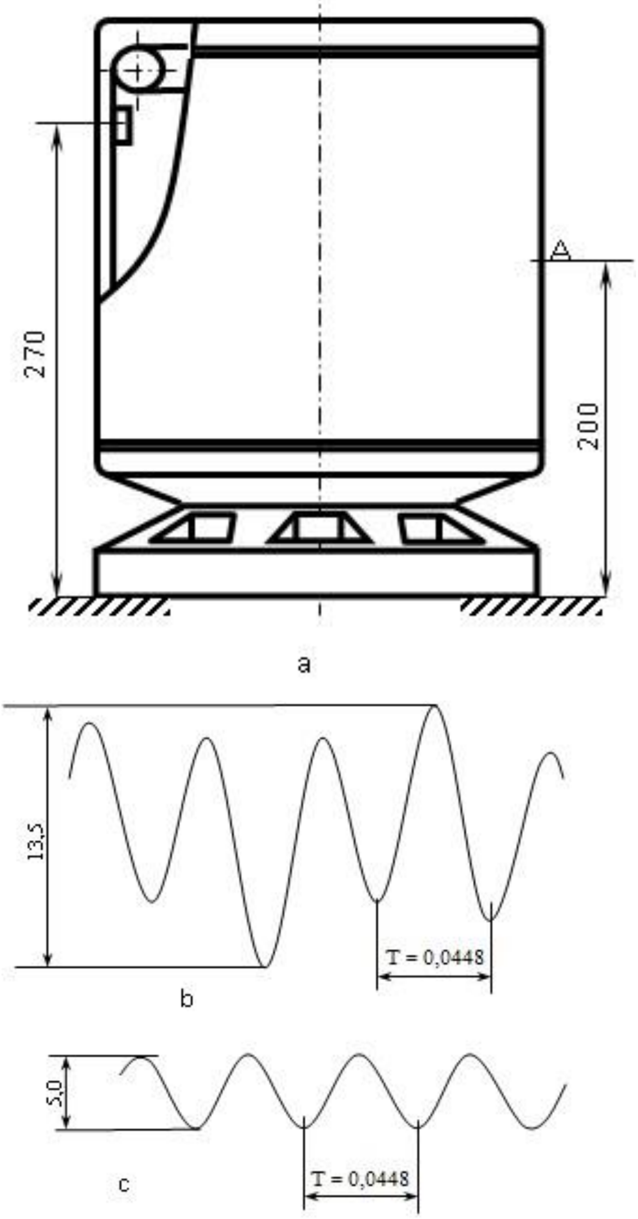

Fig.1. Experimental centrifuge diagram (a); body vibration amplitudes at point A in two modes: b – in case of the relative movements of the ball; c – in case of autobalancing (T = 0,0448 s^{-1} – rotation period)

Experimental research of ball-shaped autoequalizer with vertical rotation axis shows that the equalizer has different working modes. During one mode the balls move stably and continuously relative to the equalizer device body and as a result the vibration of centrifuge's body grows (see Fig.1. b).

During the other mode the balls stop relative to the equalizer device body opposite the imbalance and this constitutes the balancing mode. In this mode the centrifuge body vibrations reduce (see Fig.1. c).

III. NUMERICAL DIAGRAM AND MATHEMATICAL MODEL OF BALL EQUALIZER

This paper deals with a rigid rotor that is fixed in bearings, having no possibility to move in space, symmetric, vertical. The body of equalizer device has a torus-shape, holding within a ball with mass m. The geometrical axis of torus body is moved aside relative to the rotation axis by value e.

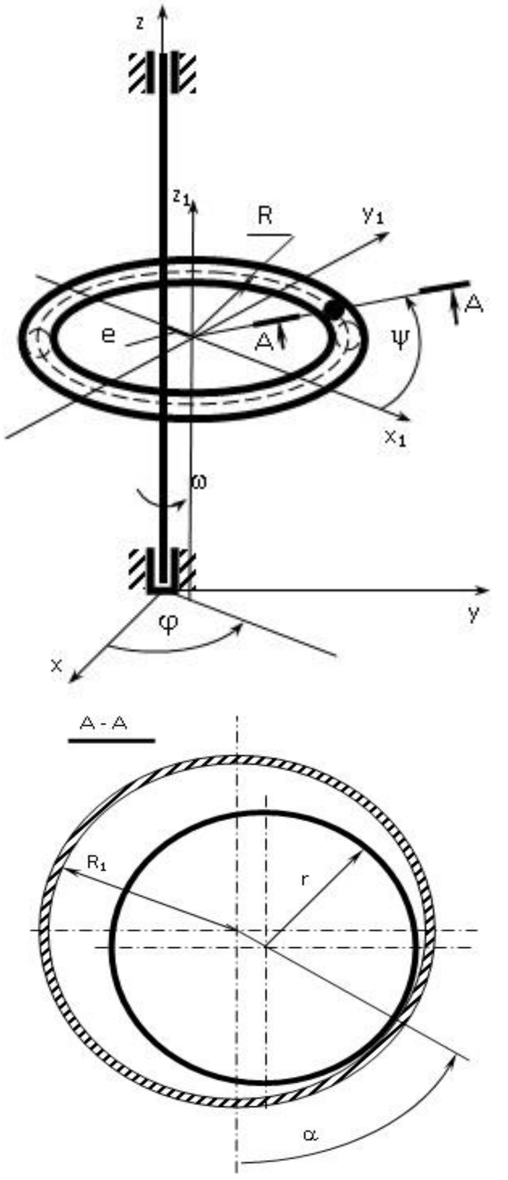

Fig.2. Numerical diagram of rotor

The standing place of adjusting mass (ball) is determined by two coordinates α and ψ in the mobile coordinate system, which is connected to rotor and rotates with the angular velocity ω. The numerical diagram of rotor with two degrees of freedom is shown in Fig.2. The rotor rotates with constant angular velocity $\omega=140\ s^{-1}$.

The coordinates of the ball's centre of gravity in the immovable system of coordinates are:

$$x = e\cos(\omega t) + \left[R + (R_1 - r)\sin\alpha\right]\cos(\omega t + \psi) \tag{1}$$

$$y = e\sin(\omega t) + \left[R + (R_1 - r)\sin\alpha\right]\sin(\omega t + \psi) \tag{2}$$

$$z = -(R_1 - r)\cos\alpha \tag{3}$$

The differential motion equations in rotor systems with automatic equalizer according to the numerical diagram are as follows:

$$\begin{aligned}\ddot{\psi} = &-\frac{10(R_1 - r)}{7R}(\omega + \dot{\psi})\dot{\alpha}\cos\alpha + \\ &+\frac{5e\omega^2}{7R}\sin\psi - \frac{5N\cdot k}{7\cdot R\cdot r}\operatorname{sign}(\dot{\psi})\end{aligned} \tag{4}$$

$$\begin{aligned}\ddot{\alpha} = &-\frac{5e\omega^2\cos\alpha}{7(R_1 - r)}\cos\psi + \frac{5R\cos\alpha}{7(R_1 - r)}(\omega + \dot{\psi})^2 - \\ &-\frac{5g\sin\alpha}{7\cdot(R_1 - r)} - \frac{5N\cdot kR_1}{7\cdot(R_1 - r)^2\cdot r}\operatorname{sign}(\dot{\alpha})\end{aligned} \tag{5}$$

where:

ψ – angle determining the position of the centre of gravity of adjusting mass relative to the straight line connecting rotor axis with the axis of equalizer's body towards rotation direction;

α – angle determining the position of the centre of gravity of adjusting mass at the body's cross-section relative to the vertical straight line passing through the centre of the body's cross-section.

k – rotation friction coefficient between the ball and equalizer's body in rotation and transversal directions, m.

φ = ω·t – rotor movement angle around its axis, rad;

R – radius of torus centre line, m;

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R_1 – radius of torus cross-section, m;

r – ball radius, m;

$g = 9.81\ m/s^2$ – free fall acceleration;

e – rotor eccentricity;

N – specific normal force of the ball on the equalizer surface, m/s^2.

$$N = g\cos\alpha + R(\omega + \dot{\psi})^2\sin\alpha + (R_1 - r)\dot{\alpha}^2 \tag{6}$$

IV. RESEARCH OF MATHEMATICAL MODEL

Differential motion equations (1), (2) in rotor systems with automatic equalizer are investigated with the help of SPRING software ‘[4], which allows to calculate the ball motions both in working and spare modes.

The ball situated within the autoequalizer’s torus body has different motion modes during the rotor rotation time. One of which is that when the ball stops relative to the autoequalizer’s body from the opposite side of imbalance on torus side edge, i.e. ψ = 3.14156 rad and α = 1.56825 rad. We will call this type of ball motion together with the autoequalizer’s body the working mode. In this mode two forces affect the ball, being divided into two components. One force component acts towards radial direction and the other towards tangential. The tangential component in the working mode tries to move the ball contrary to the rotor imbalance. In its turn the closer the ball is to the place of working mode (ψ = 3.14156 rad) the less the tangential force Pτ affects the ball (see Fig. 3). It is the working mode place where ψ = 3.14156 rad, where the tangential force Pτ = 0. If the ball leaves this place, the tangential force emerges, which will bring the ball back to the previous place.

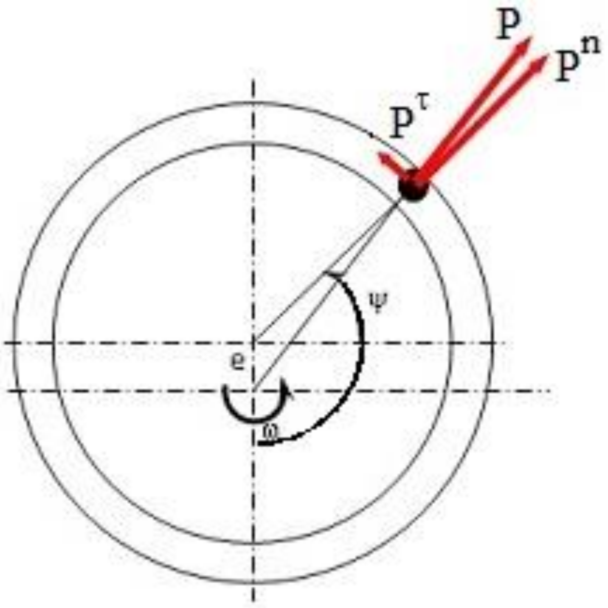


Fig.3. System of forces affecting the ball during the working mode

The first motion mode is investigated at the following rotor system parameters:

R = 0,2 m – radius of equalizer’s centre line;

R_1 = 0,015 m – radius of equalizer’s cross section;

r = 0,0125 m – ball radius;

ω = 140 s^{-1} – angular velocity of rotor;

e = 0,02 m – eccentricity of equalizer’s body relative to rotation axis;

k = 10^{-5} m – friction coefficient.

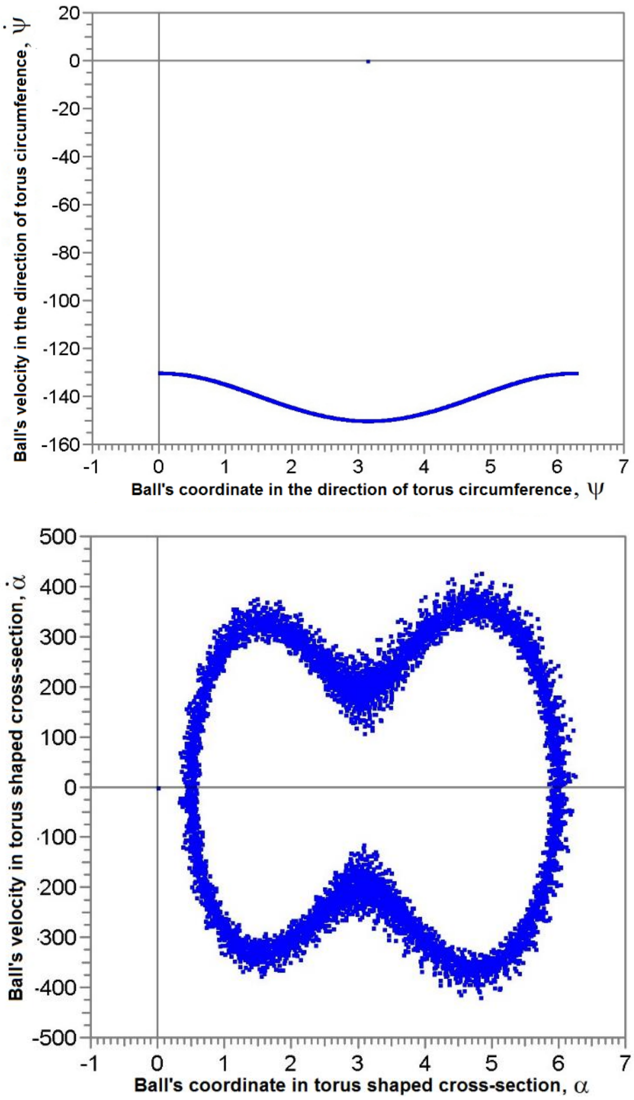


Fig.4. Picture of spare motion mode phases

In the second ball motion regime the ball moving constantly relative to the autoequalizer’s body both towards torus circular direction and transversal direction. We will call this type of ball motions a stable spare motion mode (see Fig. 4).

V. RESEARCH RESULTS

Fig. 5 shows that the ball during the working mode stops in the torus body towards rotation direction ψ = 3,14156 rad,, and in transversal direction on the body surface with coordinate α = 1,56825 rad.

To find the initial conditions at which the ball will launch the working mode, the graphs in the ball phase coordinate system are drawn up. The dark area means that at these initial conditions of ψ and $\dot\psi$ (coordinates of initial phases in cross section $\alpha=0$ and $\dot\alpha=0$) working mode is ensured for the equalizers. Where the initial conditions ψ and $\dot\psi$ are taken outside the dark area (at $\alpha=0$ and $\dot\alpha=0$) the equalizer will encounter a spare ball motion mode. The model is investigated at different friction coefficients k: k = 10^{-4} m; k = 10^{-5} m (see Fig. 6).

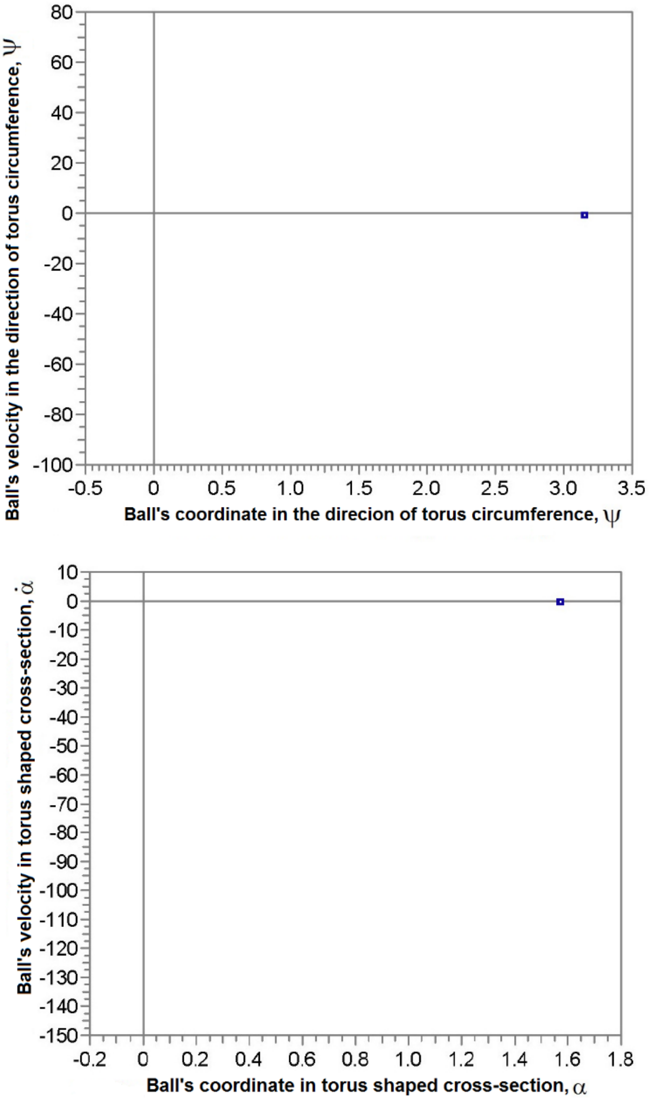
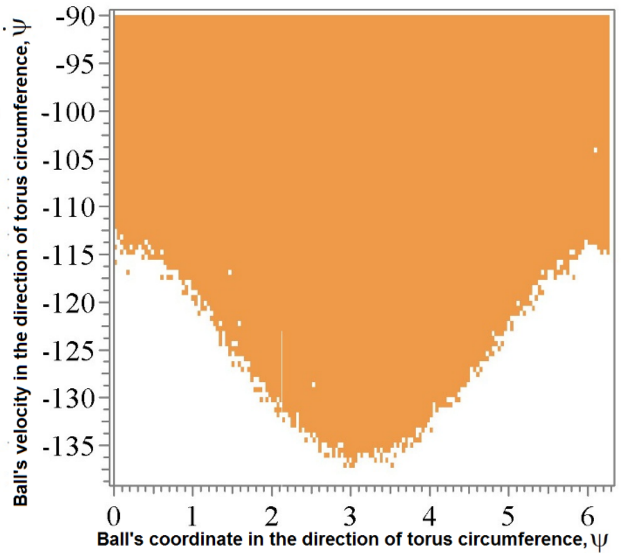
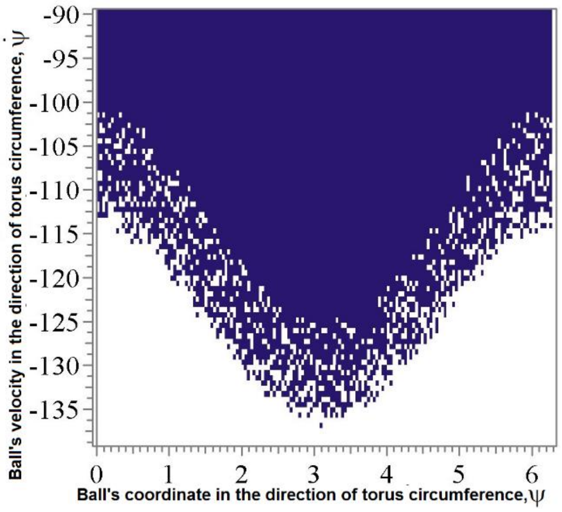


Fig.5. Picture of working mode phases



a)



b)

Fig.6. Initial conditions according to phase coordinates ψ and $\dot{\psi}$ at α=0 and $\dot{\alpha}$=0 with friction coefficient: a) k = 10^{-4} m; b) k = 10^{-5} m

Increase of the friction coefficient using corresponding nano-coatings allows the ball to accelerate itself till working mode at any initial conditions, but this affects negatively the autoequalizer's sensitivity. At the friction coefficient k=$3\cdot10^{-4}$ m the ball is ensured with the working mode at all initial conditions, which can be seen in Fig. 7.

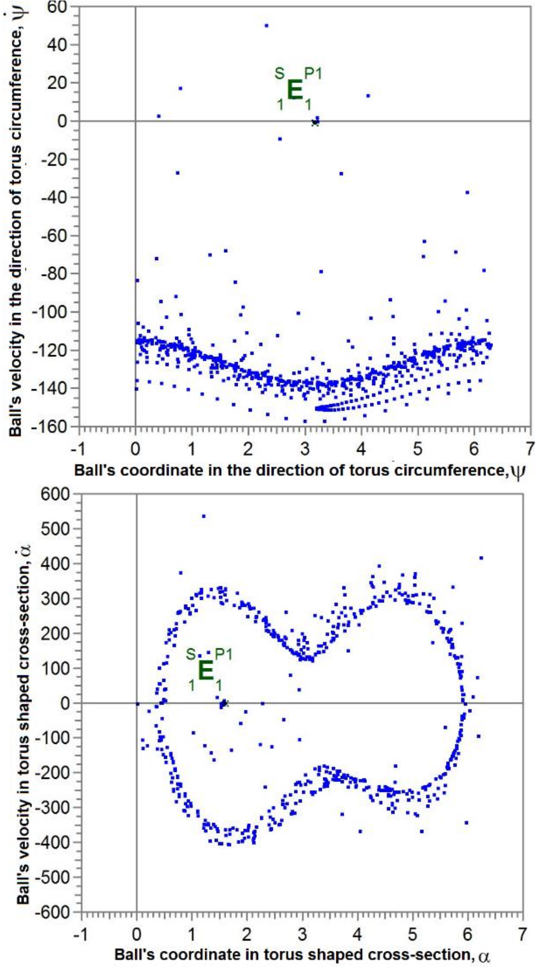


Fig.7. Picture of transition mode phases at k = $3\cdot10^{-4}$ m

VI. CONCLUSIONS

The calculation results have shown that in equalizers with torus-shaped body the ball has at least two motion modes, of which one is the working mode and the other – the spare mode. With the growth of friction coefficient value, which can be reached by applying the necessary nano-coatings with respective surface harness, there are more possibilities to ensure the required working mode.

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Guntis Strautmanis, Ivans Griņevičs, Natālija Mozga. Nepieciešamā berzes koeficienta iegūšana, pielietojot nanopārklājumus un tā ietekme uz autobalansēšanas režīmu

Darbā tiek izskatīts lodes autobalansieris ar vertikālu asi, kam korpuss izvietots ekscentriski relatīvi rotācijas asij. Autobalansieris ar tora korpusa formu satur vienu lodveida koriģējošo masu, kas brīvi pārvietojas autobalansiera korpusā gan pa riņķi, gan šķērsvirzienā. Tora korpusa iekšējā sienas virsma ir pārklāta ar nanopārklājumiem, kas dod iespēju nodrošināt berzes koeficienta dažādas vērtības uz korpusa iekšējās sienas attiecīgajām zonām, tādējādi dodot iespēju koriģēt lodītes darba režīmus.

Eksperimentālie pētījumi ar lodes balansieri parādīja, ka vienlaicīgi ar darba režīmu, kad lodīte apstājās relatīvi rotējošajam korpusam pretī disbalansam, ir režīms, kad lodīte nepārtraukti kustas relatīvi balansiera korpusam. Eksperimentāli iegūta autobalansiera konstrukcija, kas nodrošina darba režīmu, kad lodītes apstājas relatīvi korpusam pretī disbalansam rotora rotācijas laikā. Autobalansierim ir sastādīts matemātiskais modelis ar diviem diferenciālajiem vienādojumiem. Aprēķinu rezultātā tiek parādīts, ka balansiera ar tora korpusa formu lodītei ir vismaz divi kustības režīmi, no kuriem viens ir darba režīms, otrs - lieks režīms.

Гунтис Страутманис, Иван Гриневичс, Наталья Мозга. Получение необходимого коэффициента трения с использованием нанопокрытия, и его влияние на режим автобалансировки.

В работе рассмотрен шариковый автобалансир с вертикальной осью, у которого корпус закреплен с эксцентриситетом относительно оси вращения. Автобалансир с корпусом тороидальной формы содержит одну массу в виде шарика, которая свободно перекатывается в окружном и поперечном направлениях. На поверхности внутренней стенки корпуса нанесено нанопокрытие, что позволяет обеспечить различные значения коэффициента трения на определенных зонах внутренней стенке тора, таким образом появляется возможность регулировать режимы работы шарика.

Экспериментальные исследования шарикового балансира показали, что вместе с рабочим режимом, в котором шарик останавливается относительно вращающегося корпуса с противоположной стороны от дисбаланса, существует режим, в котором шарик непрерывно движется относительно корпуса автобалансира. Экспериментально получена конструкция автобалансира, в которой обеспечен рабочий режим , когда при вращении ротора шарик останавливается относительно корпуса балансира противоположно дисбаланса. Составлена математическая модель автобалансира из двух дифференциальных уравнений. В результате расчета показано, что у автобалансира с корпусом тороидальной формы у шарика имеется, по крайней мере, два режима движения, один из которых - рабочий режим, второй – побочный режим.