About some features of dynamic acceleration of vibration machines with self-synchronisation inertion vibroexciters

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Abstract

It is shown that in the case of two self-syncronized imbalance vibroexciters the running of vibration machines declines (if only their options are not absolutely equal) compared to machines with one exciter. The separate start of electric engine rotor exciters may be effective for improvement of running process. It is shown that in this case, the value of braking vibration moments, influencing on rotor exciters in resonance zone decreases approximately twice compared to simultaneous start of engines.

In analytical form the expressions for vibration moments (average values of extra dynamic load on the electric engine rotor, caused by baring body fluctuations) when passing resonance zone for vibration machines with two self-synchronized imbalance vibration exciters additional to the well-known results for machines with one imbalance exciter.

1 Urgency of the problem

Detection and theoretical explanation of the self-synchronisation of unbalanced rotors effect created new opportunities in vibration technique. Vibration machines with inertial self-synchronized vibration exciters – screens, conveyors, feeders, mills etc. are produced in great series and function successfully in wide variety of industrial branches [1-4]. Machines with inertial vibration exciters are mostly over-resonance. The main their problems come out at start and run. In particular, at the running point when imbalance exciter is passing the resonance zone the "jam" of rotor frequency (if its power is not overstated) around frequency of its own vibrations the demonstration of Sommerfeld effect exists. In this case, significant fluctuations may appear in the system and respectively dynamic load upon the elements of construction may significantly grow. In addition, imbalance vibration exciter requires the power of electric engine for running point several times greater than that for the work in set mode, besides, during the heavy vibration machines start with drive from asynchronous electric engines the inrush current impact negatively influences on feeding circuit.

The process of passing of resonance zone by the unbalanced rotor was observed by various methods in many for works their overview you can find in [1, 5, 6, 7]. [1, 6] shows, that theoretical explanation and quantitative description of the famous regularities taking place at Sommerfeld effect demonstration relatively easily is achieved by the usage of direct separation of movements method , for the case of one inertial vibration exciter set on the bearing body the same degree of freedom the expressions are presented for vibration moment influencing on unbalanced rotor on its passing the resonance zone, [7] - for exciter set at solid body with plane-parallel movement.

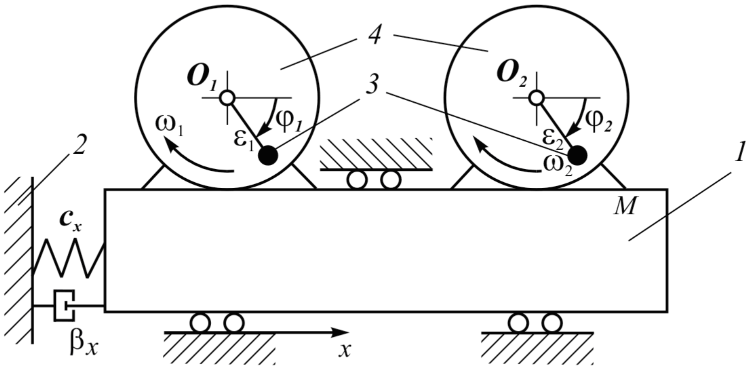

Figure 1: Scheme of vibratory system.

The same approach to study the running of the vibration system with two self-synchronized vibration exciters is used in this work.

The analysis of resonance passing process dynamics by vibration machines with inertial excitation of vibrations is important in start conduction systems design . Such systems allow to decline significantly the power of drive engine, necessary to overcome the resonance zone [8].

2 Formulation of the problem

Most of the features of formulation and solution of problems about self-synchronization of mechanical exciters as well as many regularities of its manifestation can be found out on simplest system – two imbalance exciters on bearing body with the same degree of freedom (Fig. 1). Bearing body 1 (vibrating operating body) is considered to be a solid body which can move along fixed direction x. The bearing body is connected with stable base by the system of elastic inflexibility c_x and snubber elements with viscous resistance b_x. Two imbalance vibration exciters are installed on it (unbalanced rotors) 3, which go into rotation by independent asynchronous electric engines 4. Rotor exciters axles are perpendicular to the plane parallel to which movement of bearing body is going on.

Differential equations of motion of system we shall put down in the next form (see, for example, [1])

$$I_i\ddot{\varphi}_i = L_i(\dot{\varphi}_i) - R_i(\dot{\varphi}_i) + m_i\varepsilon_i(\ddot{x}\sin\varphi_i + g\cos\varphi_i), (i = 1, 2) \quad (1)$$

$$M\ddot{x} + \beta_x\dot{x} + c_x x = \sum_{i=1}^{2} m_i\varepsilon_i(\ddot{\varphi}_i\sin\varphi_i + \dot{\varphi}_i^2\cos\varphi_i), \quad (2)$$

where x – the coordinate of the bearing body; M – the total mass of the bearing body; φ_i – rotation angle of the rotor i-vibration exciter; m_i, ε_i, I_i – respectively, the mass of the i exciter, its eccentricity and moment of inertia relatively to axle of rotation; $L(\varphi_i)$, $R(\varphi_i)$ – rotation moment of the i-engine and moment of resistance rotation forces, g – acceleration of free fall.

3 Methods of study

To study rotor exciters when passing the resonance zone we shall use the method of direct separation of movements [1]. In accordance with the basic presequisite of method we shall assume that observing motions of system can be represented in the next form, $\varphi_i = \omega_i t + \alpha_i$, $x = x(t, \omega t)$ where – $\omega_i = \omega_i(t)$ – slowly changing function of time; α_i -– constant starting phases of rotation; x – quick functions of time, and they are the ones 2π – periodical to $\tau = \omega t$ and their mean value for this period is equal to zero. Such a presentation of solutions of equations of the system (1) in the study of passing of resonance zone by rotor exciters, when the manifestation of Sommerfeld effect takes place and, respectively, the frequency of rotor rotation $\dot{\varphi}_i$ changes relatively slowly, seems legitimate. We use the method of direct separation of movements in its traditional form , ie we shall find approximate decision of equations of quick movements (2), using all usually simplified input supplies the main of which is that when decision equations (2) all slowly variables can be considered as the constant.

In that case in the approximation it is not difficult to get the equation of slow movements of rotor exciters when passing resonance zone in the form got in [1]

$$I_i \dot{\omega} = L_i(\omega) - R_i(\omega) + V_i(\omega), \tag{3}$$

where

$$V_i(\omega) = \frac{m_i \varepsilon_i \omega}{2\pi} \int_0^{2\pi/\omega} \ddot{x} \sin \omega t d\tau. \tag{4}$$

Here $V_i(\omega)$ – so called vibration moment [1].

We shall stress that Sommerfeld effect as well as phenomenon of self-synchronization of inertial exciters is explained by the appearance of vibration moments in the vibration systems, while obtaining equation (3) linearization of expressions $L_i(\dot{\varphi}_i)$, $R_i(\dot{\varphi}_i)$ is done, as in [1], near to value $\dot{\varphi}_i = \omega$ (where ω – frequency “jam” of rotor at running start).

4 Features of the running start of vibration machines with two vibration exciters

Let the parameters of exciters are equal and they rotate in resonance zone in the same direction with the same angular velocity and shift of phases equal to zero, ie $\varphi_i = \omega t$. Then taking into consideration (4), the formula for braking vibration moment which operates on the rotor of each of exciters when passing resonance zone, is depicted in the form

$$V_1(\omega) = V_2(\omega) = -\frac{1}{2} F_1 A_1 \sin \gamma_1 = -\frac{(m\varepsilon\omega)^2}{2M} \frac{n_x}{(1-\lambda_x^2)^2 + 4n_x^2} = \frac{1}{2} V, \tag{5}$$

where

$$m\varepsilon = 2m_i\varepsilon_i; F_i = m_i\varepsilon_i\omega^2; A_i = \frac{A}{2} = \frac{m\varepsilon}{2MB_x}; B_x = \sqrt{(1-\lambda_x^2)^2 + 4n_x^2};$$
$$n_x = \frac{\beta_x}{2M\omega}; \lambda_x = \frac{p_x}{\omega}; p_x = \sqrt{\frac{c_x}{M}}; \sin \gamma_1 = -\frac{2n_x}{B_x}.$$

Here V – vibration moment got in [1] for the case of vibration system with one exciter having static moment $m\varepsilon$. Value A_i presents amplitude of forced fluctuations of the bearing body at even rotation of exciters described by expression $x = 2A_1 \cos(\omega t + \gamma_1)$.

Thus, naturally, in the case of a drive of vibration machine of two in-phase rotating equal exciters the maximum load on rotor of each of electric engine at its start will be two times less, then when using of only one exciter with dual static moment, ie at the same amplitude of forced oscillations. In doing so, of course, summary dynamic load and, respectively, necessary power of the electric drive in both cases is the same. We shall note, that all main regularities of system behavior when passing resonance zone will stay unchanged[1, 6].

Suppose at the same other conditions some start small shift of the phases $\alpha_{12} = \alpha_1 - \alpha_2$ takes place between the rotors of exciters , ie $\varphi_1 = \omega t$, $\varphi_2 = \omega t - \alpha_{12}$. Let us stress that before start of electric engine imbalances take maximum lower vertical place herewith the shift of the phase between them (if it occurs) may be only small enough.

In this case, taking into consideration the solutions of equations of oscillations of bearing body (2) in the form of $x = A_1 \cos(\omega t + \gamma_1) + A_2 \cos(\omega t + \gamma_2 - \alpha_{12})$, (here $A_1 = A_2$, $\sin\gamma_1 = \sin\gamma_2$) and considering that angle α_{12} is small, we obtain expressions for vibration moments, which influence on advanced and lagging rotor exciters in form of

$$V_{1,2} = \frac{1}{2} V (1 \mp \Delta), \tag{6}$$

where

$$\Delta = \frac{1}{2}\alpha_{12} \cot\gamma_1; \quad \cos\gamma_1 = \frac{\lambda_x^2 - 1}{B_x}.$$

We shall note, that in accordance to the results of the modeling of the process of running start , “jam” of the speed of rotors of both vibration exciters is occurring at the same moment of time, in this very period of rotor exciter running start angle γ_1 is close to 90^0.

It is not difficult to show that in case where angle speeds of rotor exciters are some few different between themselves, it can be rolled to previous result – to the expressions for vibration moments in the form (6). We shall note, that the difference between the speed of exciters may be only small enough , since usually when you install several self-synchronized exciters , their options, as well as options of electric engines are chosen to be maximum identical.

Thus, from (6) follows that in the case of small phase shift or slight differences between the rates of vibration exciters, before the resonance ($\omega < p_x$, $\gamma_1 < 90^0$) on the leading exciter will act somewhat higher vibrational torque than in the absence of phase shift, and the exciter, which falls short – a little smaller. After resonance ($\omega > p_x$, $\gamma_1 > 90^0$) – contrary: to leading – the smaller, the lagging – more.

Thus, in the case of a small phase shift or little difference between speeds of exciters a bit less vibration moment will influence on advanced exciter then in absence of phase shift, and on the lagging exciter – a bit greater. What is natural, the lagging vibration exciter feels the implications of the passage of resonance zone by the advanced exciter – with lagging exciter we already have “excitation” of the vibration system. Herewith, as more valuable is the phase shift between the rotors, the more noticeable is the difference in the values of vibration moments: the advanced exciter will slow down less and the lagging one – all the more. Due do this, the amplitude of resonance fluctuations of the bearing body and the duration of transition process grow.

Summarizing the results for the case of vibration system with several degrees of freedom, you can conclude , that interrelated personal frequencies are preferably to be chosen close in the meaning, and in that way to decline consequences of the process of “excitation” of the system on running start of exciters , in cases where starting phase shift between exciters (for example, because of rotor exciters axes location in the plane inclined to the horison) we can recommend the start of one of the engines with small delay the duration of which is easy to be determined modeling the processof running start of given vibration machine.[9].

Presentation of vibration moment (5) through amplitude of forced fluctuations A makes evident the fact that in the case of first start of electric engine with static moment $m_1\varepsilon_1 = m\varepsilon/2$ the resonance vibration moment which will brake its rotor will turn two times less than in case of simultaneous start of both exciters, ie $V_1(\omega) = \frac{1}{4}V$. Consequently, power of the first engine chosen of conditions of start, may be taken two times less. Also, since only one engine is starting the starting current in the feeding circuit will be significantly smaller then (nearly 2 times) than in the case of simultaneous start of both set engines.

After the set regime's choice for the first engine movement and at the following inclusion of the second maximum moment which will break its rotor, will also have value $V_2(\omega) = \frac{1}{4}V$ (in given approximation), ie will be two times less than in case of simultaneous running start of both exciters. Herewith, again, since only one electric engine is started the starting current in the net will be significantly less, then in the baseline variant. We shall note, that with consideration of the following approximations the extra terms to the vibration moment appear which influence on the rotor of the second exciter. However their values are small enough and, therefore, they will not change the general picture of the running start noticeably.

We shall notice that in the case of separate start of electric engines for the facilitation of the passing of resonance zone by the second exciter the fluctuations of the bearing body can be successfully used [8].

5 Comparison with the results of computer modeling

The performed analytical study has found good consistency with the results of numerical modeling. Modeling is completed in program environment Maple with accounting of dynamic model of asynchronous electric engine used the work [9].

In Fig. 2 the changes during the running start of electric engine moments, forces of resistance to rotation and vibration moment for vibration system with one imbalance exciter with parameters: $M = 300kg$; $m = 30kg$; $\varepsilon = 0.044m$; $I = 0.172kg \cdot m^2$; $c_x = 75 \cdot 10^4 N/m$; $\beta_x = 1120kg/sec$; three-phase asynchronous shortly closed engines series 4A with synchronous rotation frequency $n_c = 1500prm$, $P = 2.2kW$ were used. Action of gravity forces on the rotor and the own dynamic of electric engine is not taken into consideration.

According to the shown graphics, while passing resonance zone ($t = 0.15 - 0.42sec$) dynamic load on electric engine rotor significantly grows, so mean value of breaking vibration moment grows approximately to $25Nm$, maximum – to $58Nm$ (pay attention, that starting point for engine is $41Nm$). For vibration machine with two completely equal self-synchronized exciters ($m_1 = m_2 = m/2$, $I_1 = I_2 = I/2$, $P_1 = P_2 = P/2$) all the rest parameters of system are former) vibration moments impacting the rotor engines are the same (Fig. 3, curves 1, 2 coincided), herewith their values compared with moment at Fig.2, declined approximately twice.

From comparison of curves 1, 2 with curve 3 (Fig. 3) it follows that in the case of the start of one of the engines at first the value of vibration moment decreases nearly two times more. Thus mean value of breaking vibration moment approximately is $6Nm$, maximum – only $14Nm$, ie nearly four times less, then for the drive of machines from one strong electric engine.

According to Fig. 4, at $\omega > p_x$ in the case of small initial small phase shift at the advanced exciter in resonance zone the less breaking vibration moment influences (curve 1,

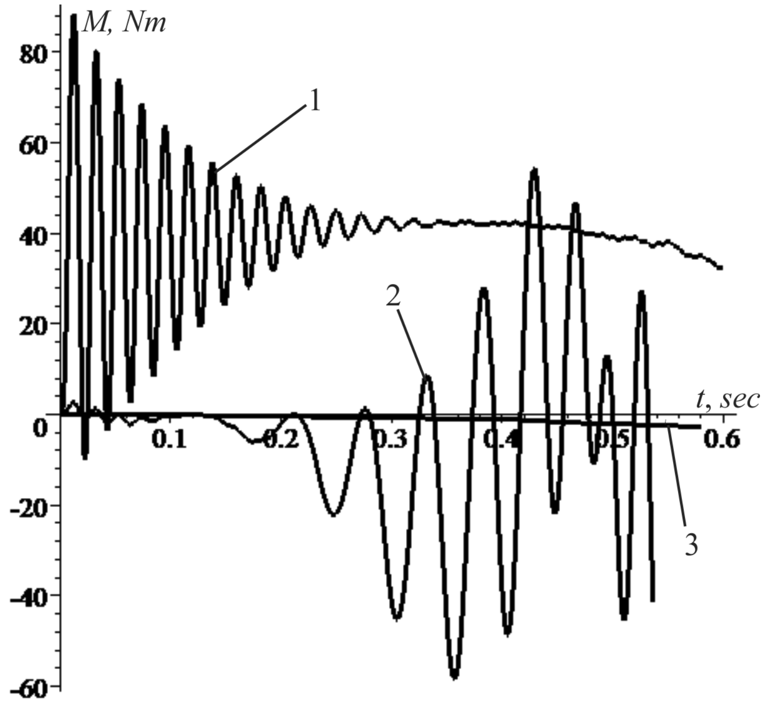

Figure 2: Changing in time for vibration machine with one exciter: 1 – moments of engine; 2 – vibration moment; 3 – resistance forces rotation

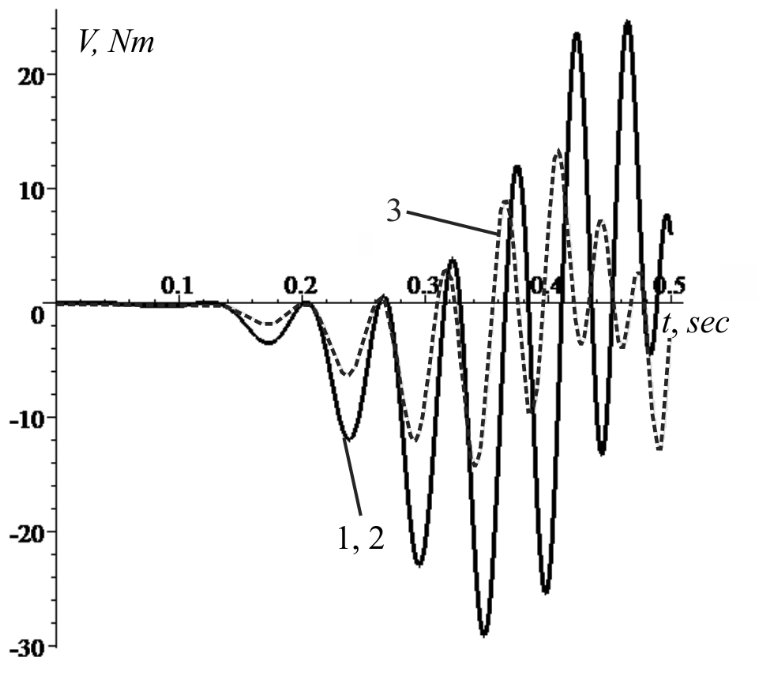

Figure 3: Changing in time of vibration moments for vibration machines with two exciters: 1, 2 – at simultaneous start; 3 – at one of them start

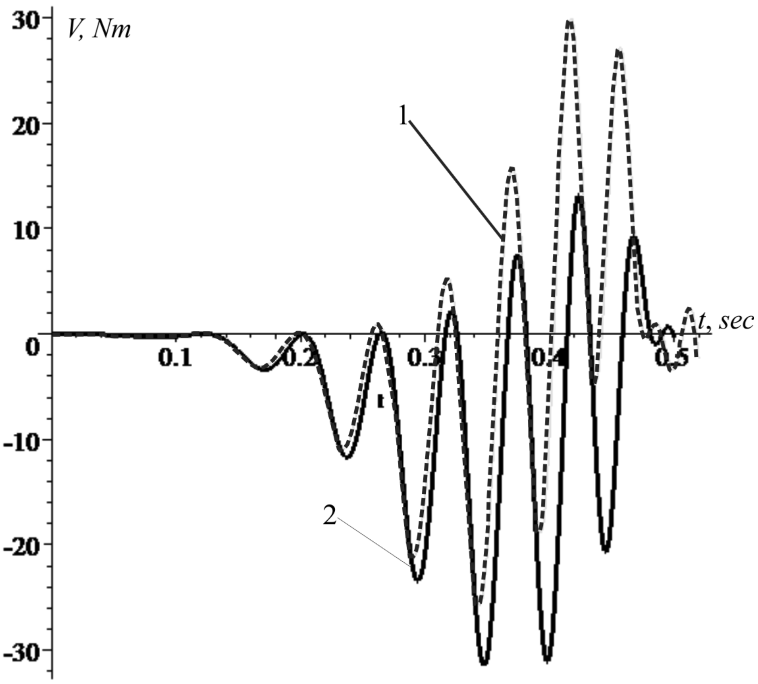

Figure 4: Changing of vibration moments for vibration machine with two exciters in the case of small initial shift of phases: 1 – advanced exciter; 2 – lagging exciter.

$V_{\max} = 25Nm$) the exciter which lags – greater (curve 2, $V_{\max} = 32Nm$). The increase of Initial phase shift (or differences between parameters of exciters, engines) lead to increase of the difference between values of moments, herewith the amplitude of resonance fluctuations of bearing body and duration of transition process grows a bit (Fig. 5).

6 Conclusion

It is found that a slight phase shift, as well as a small difference between the angular speeds, lead to a deterioration in the process of starting vibration machines with self-synchronized exciters. Consequently, the best in terms of the dynamics of running start, is providing of equality of speeds of exciters and lack of phase shift between them, ie parameters of exciters and their electric engines should be maximum similar and in the case of more than one degree of freedom of vibration system, it is desirable that the exciters were symmetrically arranged. For such systems, interconnected own frequencies are recommended to be chosen like-to for reducing the impact of the consequences of "swing" of the passage of the exciters of the lowest frequency for passing the higher frequencies.

It is shown that the separate running start of electric engines should significantly reduce engine power, but also significantly reduce the inrush current impact in the feeding circuit.

The possibility of reducing the power and size of electric engine inrush current are additional important advantages of using the phenomenon of self-synchronization of mechanical exciters in vibration machines and devices.

References

[1] Blekhman I.I. Vibrational mechanics, Fizmatlit, Moscow – 400 (in Russian). English

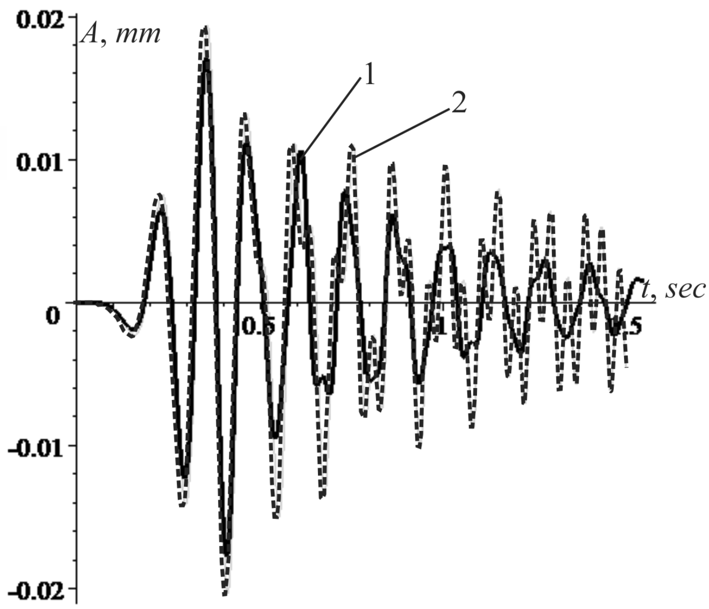

Figure 5: Changing of the amplitude of resonance fluctuations of the bearing body in the case of: 1 – common mode rotation of exciters; 2 – availability of phase shift between exciters.

translation : Vibrational mechanics. Singapore, world Scientific, 2000. – 509p. (in Russian).

[2] Blekhman I.I., Blekhman L.I., Dresing H., et al. Selected Topics in Vibrational Mechanics/ Edited by Blekhman I.I. – Singapore et al: World Scientific Publishing Co., 2004. – 409p.

[3] Blekhman I.I. Synchronization in Science and Technology.–New-York: ASME Press, 1988. – 255p.

[4] Michalczyk J. Influence of collisions with a material feed on cophasal mutual synchronisation of driving vibrators of vibratory machines / J. Michalczyk, P. Czubak // Journal of theoretical and applied mechanics. 48.1 Warsaw. – 2010. – P.155-172. – Bibliogr.: p. 172.

[5] Fildin A. Nonlinear Oscillations in Mechanical Engineering. Berlin, Heidelberg. Springer-Verlag. 2006. – 358 p.

[6] Blekhman I.I., Indieytshev D.A., Fradkov A.I. Slow motions in systems with inertial excitation of oscillations // Problems of machine building and reliability of machines, No.1 2008. 25-31. (in Russian).

[7] Blekhman I.I. Transition regimes in inertially excited trans-resonant vibration devices with several degrees of freedom of the carrier system / I.I. Blekhman, Yaroshevich N.P. - Nonlinear problems of theory of oscillation and theory of control Vibrational Mechanics. – SPb.: Nauka, 2009. – Bibliogr.: P. 237-238. (in Russian).

[8] Tomchin D.A., Fradkov A.I. Control of rotor passing through the resonance zone on the basis of the method of velocity gradient// Problems of machine building and reliability of machines, No5 2005. 66-71. (in Russian).

[9] Yaroshevich N.P. Simulation of double start-up of vibrational machines inertial excitation of oscillations // N.P. Yaroshevich // Nonlinear problems of theory of oscillation and theory of control. Vibrational Mechanics. – SPb.: Nauka, 2009. – P. 476-486. Bibliogr.: P.485-486. (in Russian).

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