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MECHANICS
MEHĀNIKA

MOTION OF VIBRATING PENDULUM WITH ADDITIONAL INNER SIDE-BLOCK

VIBRĒJOŠA SVĀRSTA AR PAPILDU IEKŠĒJO BLOKU KUSTĪBA

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1. Introduction

Investigation include mechanical model of side-block 2 that move in relative motion along of pendulum *1* groove (Fig. 1.). Side-block and pendulum is connected together with spring and have bumper. System may be excited by kinematics motion of pendulum axe in two directions *Ox* and *Oy*. Additional forces moment around pendulum rotation point may be added. System investigation may include two tasks: - possibility of pendulum vibrating motion damping; - use of system for technological needs. Pendulum vibrating motion is investigated for case when kinematics motion of axe is harmonically. In this case many kinds of nonlinear motions of system exist that is known in nonlinear dynamics. By choice of systems parameters (gap, stiffness of spring, mass of side-block and initial position of side-block location) efficiency of pendulum vibrating motion damping may be obtained. For technological needs system was evaluated by shock interaction between side-block and pendulum. It is shown that additional forces moment around pendulum axe gives positive effect.

2. Description of mechanical system

The investigated system in vertical plane has two degree of freedom: rotation motion φ of pendulum *1* (together with side-block) around point *O* and additional relative translation motion r of side-block *2* mass centre C_2.

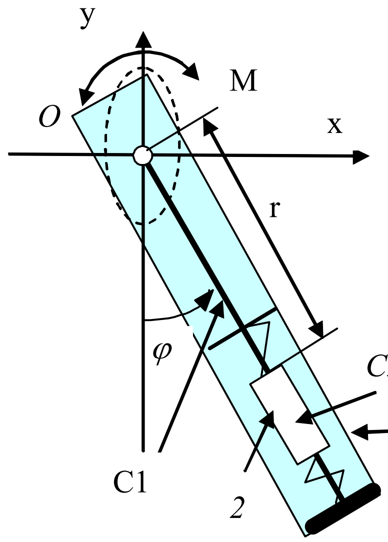

Fig. 1. Scheme of system

The equations of motion are next (1), (2) [1, 2]:

$$Jo(t)\cdot\ddot{\varphi} = -K_{12}(t)\cdot\left[(g+\ddot{\eta})\cdot\sin\varphi + \ddot{\varsigma}\cdot\cos\varphi\right] - 2\cdot m_2\cdot\dot{\varphi}\cdot\dot{r}\cdot r - b\cdot\dot{\varphi} + M_O^{(e)}; \quad (1)$$

$$m_2\cdot\ddot{r} = -f_{12}(r,\dot{r}) + m_2\cdot\dot{\varphi}^2\cdot r + m_2\cdot(g+\ddot{\eta})\cdot\cos\varphi - m_2\cdot\ddot{\varsigma}\cdot\sin\varphi. \quad (2)$$

Here

$$Jo(t) = Jc_1 + m_1\cdot L^2 + Jc_2 + m_2\cdot r^2; \quad (3)$$

$$K_{12}(t) = Jc_1 + m_1\cdot L^2 + Jc_2 + m_2\cdot r^2. \quad (4)$$

Were $\dot{\varphi},\ddot{\varphi}$ - angular velocity and angular acceleration both objects; $\dot{r},\ddot{r}$ - derivation in time of distance r (or relative velocity and relative acceleration of axe – box mass centre); m_1, m_2 - masses; Jc_1, Jc_2 - axial moments around centre of masses; L - constant distance from masse centre C_1 to pendulum vibrating point O; g - acceleration of free fall; $\ddot{\varsigma},\ddot{\eta}$ - horizontal and vertical acceleration components of vibrating pendulum axe; b - constant of linear damping; $M_O^{(e)}$ - external additional forces moment around pendulum axe; $[-f_{12}(r,\dot{r}]$ - internal interaction forces from technological process. Example of internal interaction inside free motion modeling block is shown in Fig. 2, Fig. 3.

3. Motion simulation

First series of modeling was made as free motion to check main model without excitation. Results of investigations are shown in Fig. 2. - Fig. 5. Comments are given under any picture.

$$\begin{bmatrix} r_{n+1}\\ v_{n+1}\\ \varphi_{n+1}\\ \omega_{n+1}\end{bmatrix} := \begin{bmatrix} r_n + s\cdot v_n \\ v_n + \frac{s}{m2}\cdot\left[\left[m2\cdot r_n\cdot(\omega_n)^2 + m2(g)\cdot\cos(\varphi_n)\right] - c\cdot(r_n-\Delta) - c2\cdot(r_n - \Delta 1)\cdot\left(0.5 - 0.5\cdot\frac{\Delta 1 - r_n}{|\Delta 1 - r_n|}\right)\cdot\left(0.5+0.5\cdot\frac{v_n}{|v_n|}\right)\right] \\ \varphi_n + s\cdot\omega_n \\ \omega_n + \frac{s\cdot\left[-(m1\cdot L + m2\cdot r_n)\cdot\left[(g)\cdot\sin(\varphi_n)\right] - 2\cdot m2\cdot\omega_n\cdot v_n\cdot r_n - b\cdot\omega_n\right]}{Jc1 + m1\cdot L^2 + Jc2 + m2\cdot(r_n)^2}\end{bmatrix}$$

Fig. 2. Example of internal interaction inside modeling block

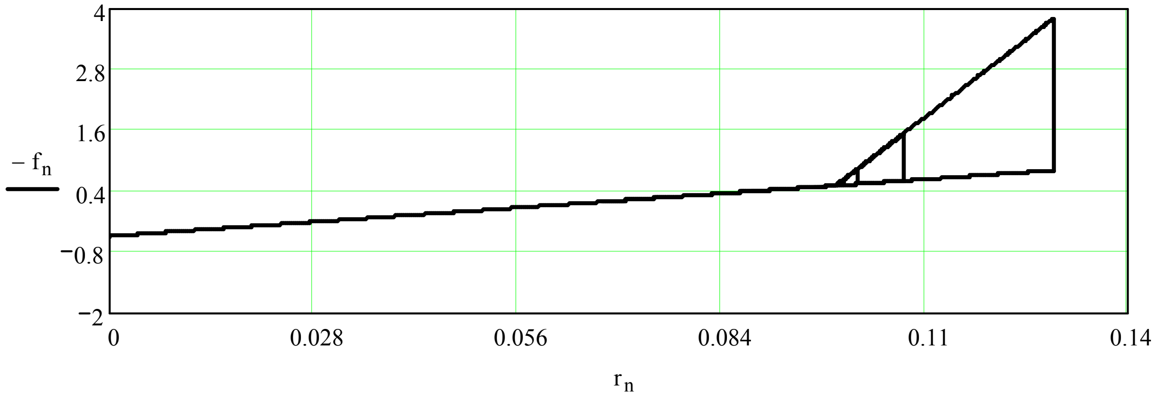

Fig. 3. Graphic of internal interaction and displacement.
Interaction depends of displacement and velocity as linear loop

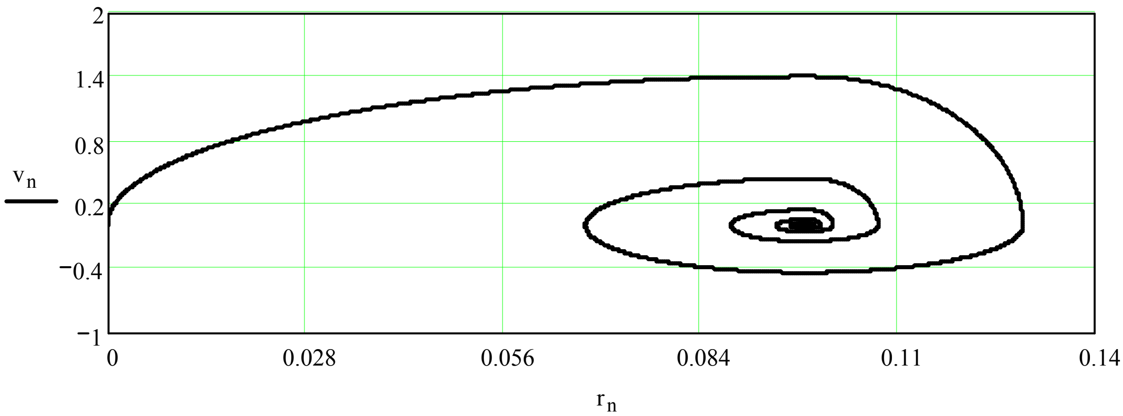

Fig. 4. Side-block damping motion in phase plane.
After three impacts internal interaction is stopped

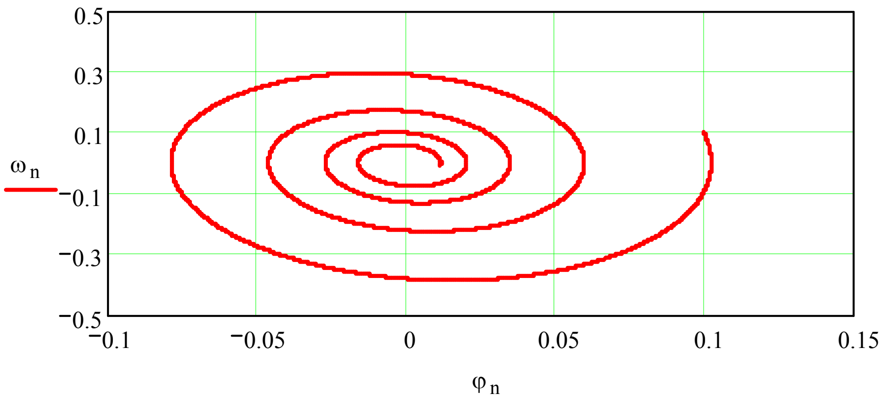

Fig. 5. Motion of pendulum in phase plane by linear damping

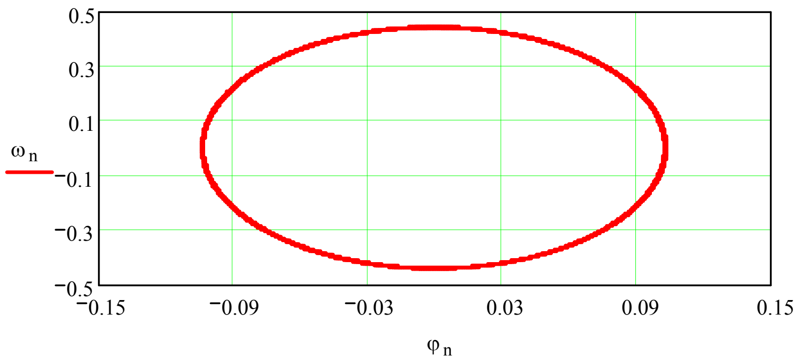

Fig. 6. Motion of pendulum in phase plane with out external damping (b = 0).
Carioles force practically does not damped motion

Second series of modeling was made for only vertical harmonica excitation. Results of modeling are shown in Fig.7 – Fig. 11.

$$\begin{bmatrix} r_{n+1} \\ v_{n+1} \\ \varphi_{n+1} \\ \omega_{n+1} \end{bmatrix} := \begin{bmatrix} r_n + s \cdot v_n \\ v_n + \frac{s}{m2} \cdot \left[\left[m2 \cdot r_n \cdot (\omega_n)^2 + m2 \cdot (g + Ay \cdot \sin(k \cdot n \cdot s)) \cdot \cos(\varphi_n) \right] - c \cdot (r_n - \Delta) - c2 \cdot (r_n - \Delta 1) \cdot \left(0.5 - 0.5 \cdot \frac{\Delta 1 - r_n}{\left| \Delta 1 - r_n \right|} \right) \cdot \left(0.5 + 0.5 \cdot \frac{v_n}{\left| v_n \right|} \right) - b1 \cdot v_n \right] \\ \varphi_n + s \cdot \omega_n \\ \omega_n + \frac{s \cdot \left[-(m1 \cdot L + m2 \cdot r_n) \cdot \left[\left[(g + Ay \cdot \sin(k \cdot n \cdot s)) \cdot \sin(\varphi_n) \right] \right] - 2 \cdot m2 \cdot \omega_n \cdot v_n \cdot r_n - b \cdot \omega_n \right]}{Jc1 + m1 \cdot L^2 + Jc2 + m2 \cdot (r_n)^2} \end{bmatrix}$$

Fig. 7. Equation for modeling with vertical harmonica excitation

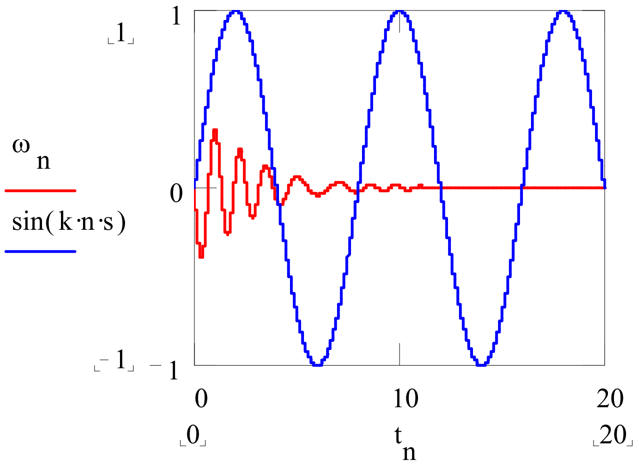

Fig. 8. Angular velocity of pendulum compare with harmonica in time domain

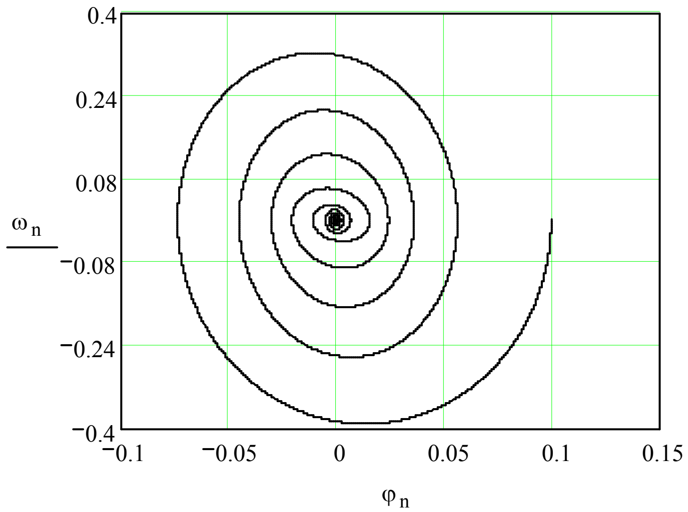

Fig. 9. Motion in phase plane for pendulum (see Fig. 8)

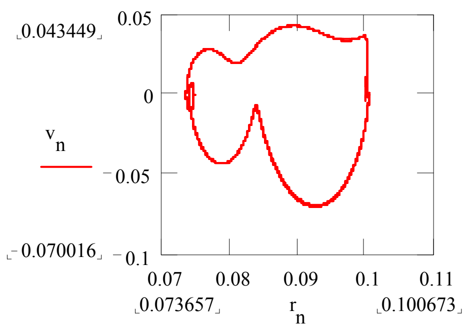

Fig. 10. Motion of side-block in phase plane (see Fig. 11)

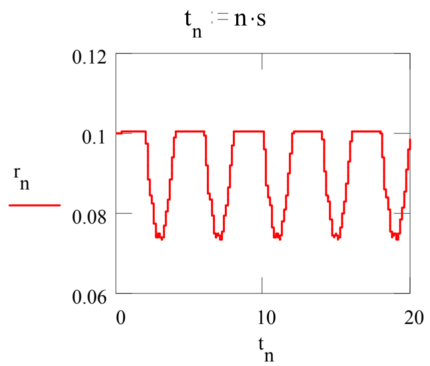

Fig. 11. Displacement of side-block in time domain. Stick moment with bumper is seeing (see Fig. 10)

Third series of modeling was made for common vertical and horizontal harmonica excitation. Results of modeling are shown in Fig.12 – Fig. 15.

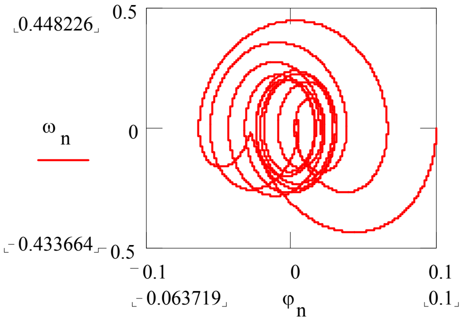

Fig. 12. Motion of pendulum in phase plane when two external components acted

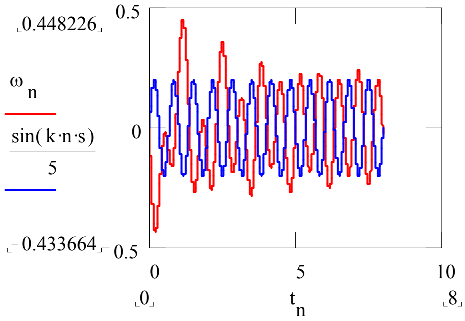

Fig. 13. Angular velocity in time domain and harmonica of excitation

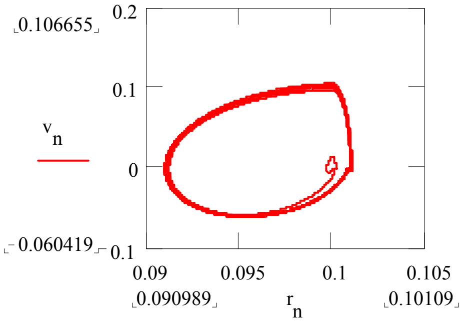

Fig. 14. Relative motion of side-block in phase plane. Periodic cycle is very stable. It means that this regime may be used for technological processes

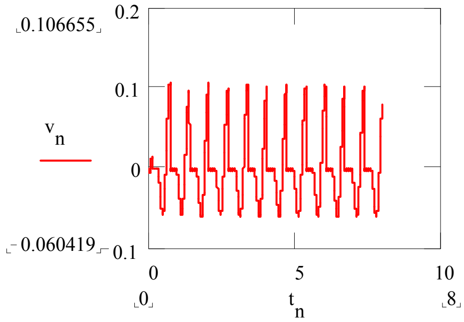

Fig. 15. Relative velocity of side-block in time domain when two external components are added (see Fig. 12 – Fig. 14)

Fourth series of modeling was made for common vertical and adaptive moment ($M_O^{(e)} = M \cdot \frac{\dot{\varphi}}{|\dot{\varphi}|}$) excitation. Results of modeling are shown in Fig.16 – Fig. 19.

Final series of modeling was made for only horizontal excitation (Fig. 20 – Fig. 21) and only adaptive moment excitation (Fig. 22, Fig. 23).

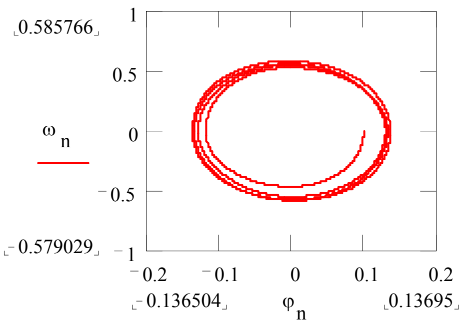

Fig. 16. Motion of pendulum in phase plane when vertical excitation exists and additional adaptive moment ($M_O^{(e)} = M \cdot \frac{\dot{\varphi}}{|\dot{\varphi}|}$) is added

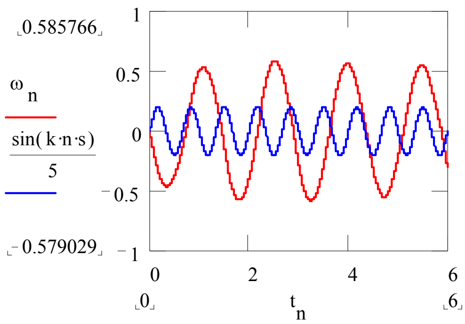

Fig. 17. Motion of pendulum in time domain when vertical excitation exists and additional adaptive moment ($M_O^{(e)} = M \cdot \frac{\dot{\varphi}}{|\dot{\varphi}|}$) is added

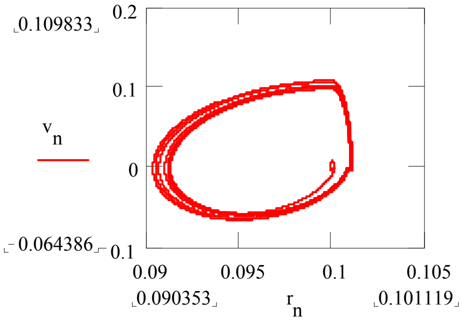

Fig. 18. Relative motion of side-block in phase plane when vertical excitation exists and additional adaptive moment is added

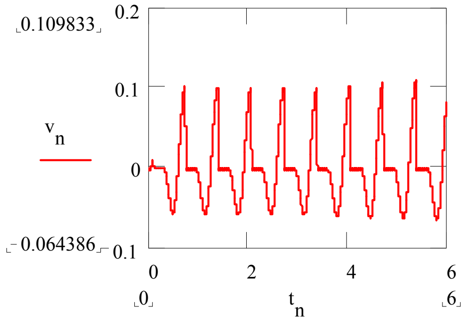

Fig. 19. Relative velocity of side-block in time domain when vertical excitation exists and additional adaptive moment is added (see Fig. 16 – Fig. 18)

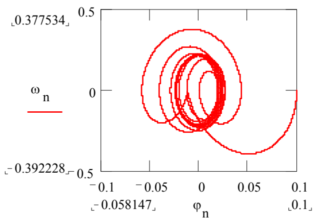

Fig. 20. Motion of pendulum in phase plane when only horizontal excitation exists. System is useless for technological processes

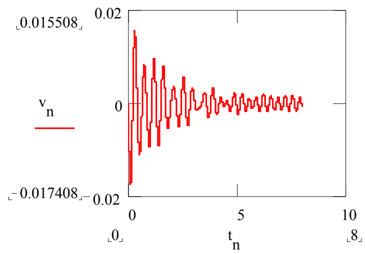

Fig. 21. Motion of side-block in time domain when only horizontal excitation exists. System is useless for technological processes

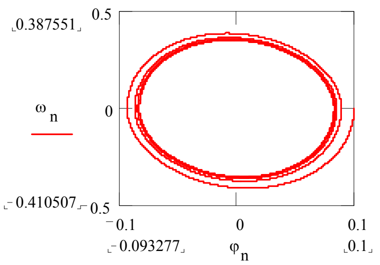

Fig. 22. Motion of pendulum in phase plane when only moment of excitation exists. System is useless for technological processes

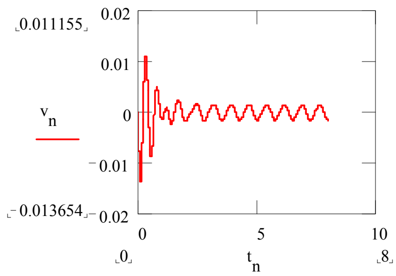

Fig. 23. Motion of side-block in time domain when only moment of excitation exists. System is useless for technological processes

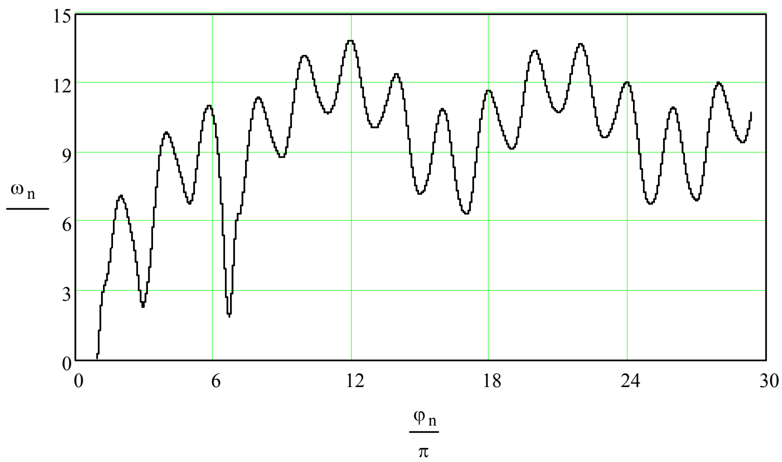

Fig. 24. Rotation ahead: $\varphi/\pi >> 1$

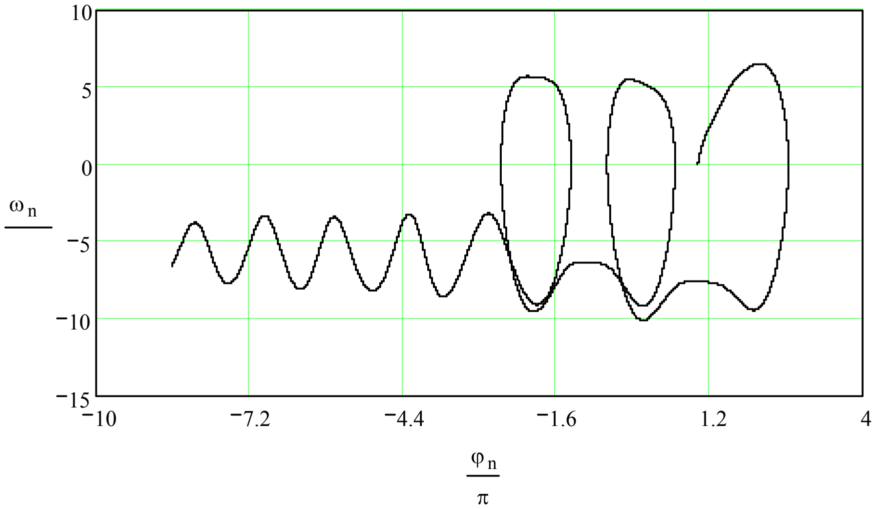

Fig. 25. Rotation back: φ/π << - 1

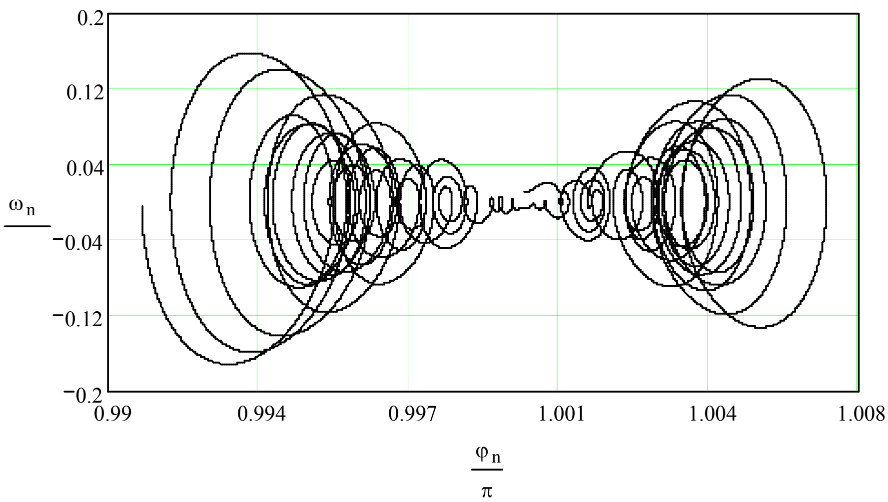

Fig. 26. Vibration regime around vertical position φ/π ≈ 1

At the end of motion modeling was checked up special kinds of motion when pendulum rotate ahead and back or move in vibration regime around vertical position φ/π ≈ 1 (see Fig. 24-26). Its means that system is very complicated.

4. Conclusion

Pendulum vibrating motion is investigated for the case when kinematics motion of axe is harmonically and additional force moment may be added. For technological needs vertical exciting together with horizontal exciting or force moment must be used. Case with only one excitation is small efficiency. Modeling shows that there are special kinds of motion when pendulum rotates ahead and back or move in vibration regime around vertical position. It means that system is very complicated. Task of damping possibility needs more additional investigations.

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Panovko G., Mjalo E., Vība J. Vibrējoša svārsta ar papildu iekšējo bloku kustība

Izpētīts papildu bloka mehāniskais modelis, kura relatīvā kustība vērsta pa svārsta gropi. Papildu bloks un svārsts ir savstarpēji saistīti ar atsperi, un tam ir amortizators. Svārsta vibrācijas kustība ir izpētīta gadījumam, kad ass kinemātiskā kustība ir harmoniska. Šajā gadījumā pastāv vairāki sistēmas nelineāru kustību veidi, kas ir zināmi nelineārajā dinamikā. Modelēšana parāda, ka ir speciāli kustību veidi, kad svārsts svārstās uz priekšu un atpakaļ vai kustās vibrēšanas režīmā ap vertikālo stāvokli. Sistēmas izpētei var būt divi uzdevumi: svārsta vibrācijas kustības slāpēšana un sistēmas pielietojums tehnoloģiskām vajadzībām. Mainot sistēmas parametrus (gropes garumu, atsperes stingumu, papildu bloka masu un papildu bloka novietojuma sākuma stāvokli) var panākt svārsta vibrāciju kustības bremzēšanas efektivitāti. Tehnoloģiskām vajadzībām novērtēta sistēmas papildu bloka un svārsta trieciena savstarpējā mijiedarbība. Parādīts, ka papildu spēku moments ap svārsta asi sniedz pozitīvu rezultātu.

Panovko G., Myalo J., Viba J. Motion of vibrating pendulum with additional inner side-block

Mechanical model of side-block that moves in relative motion along of pendulum groove is investigated. Side-block and pendulum is connected together with spring and have bumper. Pendulum vibrating motion is investigated for case when kinematics motion of axes is harmonically. In this case many kinds of nonlinear motions of system exist that is known in nonlinear dynamics. Modeling shows that there are special kinds of motion when pendulum rotates ahead and back or move in vibration regime around vertical position. System investigation may include two tasks: possibility of pendulum vibrating motion damping and use of system for technological needs. By choice of systems parameters (groove length, stiffness of spring, mass of side-block and initial position of side-block location) efficiency of pendulum vibrating motion damping may be obtained. For technological needs system was evaluated by shock interaction between side-block and pendulum. It is shown that additional forces moment around pendulum axes gives positive effect.

Пановко Г. Я., Мяло Е.В., Виба Я. Движение вибрирующего маятника с дополнительным внутренним блоком

В данной работе исследована механическая модель дополнительного блока, относительное движение которого направлено вдоль паза маятника. Дополнительный блок и маятник связаны между собой при помощи пружины и имеет амортизатор. Вибрационное движение маятника исследовано для случая гармоничного кинематического движения. В этом случае существует много видов нелинейных движений системы, которые известны в нелинейной динамике. Моделирование показывает, что существует специальные виды движений, когда маятник качается вперёд и назад или движется в вибрационном режиме вокруг вертикального положения. Выбирая параметры системы (длину паза, жёсткость пружины, массу дополнительного блока, начальную позицию дополнительного блока) можно достичь эффективности гашения вибрационного движения. Для технологических нужд сделана оценка ударного взаимодействия между дополнительным блоком и маятником. Показано, что дополнительный момент сил вокруг оси маятника приводит к положительному эффекту.