VIBRATION DAMPING OF CARGO LIKE PENDULUM INSIDE VEHICLE HULL

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Abstract. A model is proposed to study the dynamic response of cargo like pendulum vibration under three dimension vehicle hull motions. A nonlinear two degree-of-freedom model of the cargo inside vehicle hull is developed and analyzed. Equations of pendulum motion are obtained by first order Lagrange equations using Lagrange multiplier for constrained system with one constraint equation. One or two independent bumpers of the securing cargo are considered in the model. In model of two bumpers between them is right angle. Bumpers forces are represented by a special stiffness and damping as a function of the displacement and motion velocity. Investigation was made for three kinds of pendulum motion: transient motion from free initial conditions without hull vibrations; stationary motion exciting from constrained string or hull bumpers vibrations; jointly transient and exciting motion. The investigation was made for one, two and tree component harmonica motion of hull. Additional investigation of motion with random excitation was observed. From mathematical modeling the optimization of geometric parameters like length of string and gap between bumpers and pendulum was made. It is found out that processes of transient motion are very short when gap is "negative". In additional is found out that by special harmonica frequency start vibro shock motion with large amplitude. Recommendation of investigation may be used for cargo fasten inside trailer, ship or airplane.

Keywords: cargo pendulum motion, vehicle hull vibrations, nonlinear vibrations, vibroshock motion, transient motion of pendulum.

Introduction

During transportation cargo's are subjected to various vibrations and acceleration forces. These forces are caused by many factors from road vehicles engine and transmission systems, uneven roads, the shunting of rail cars, cargo handling at terminals and docks and the pitching, yawing and rolling of a ship at sea [1].

One of the important kinds of cargo vibration system is pendulum motion that imitates ship-mounted cranes. Simulation and experimental results of the special controlled cranes for different operating conditions and payload masses are investigated in many works, for example [2 - 4]. Analysis of publications shows that motion of cargo with additional shocks is not so completely investigated [5]. It is investigated in this report where traditionally models as a simple pendulum, with rigid hoisting cable and a lumped mass at the end of cable are observed (Fig. 1).

Equations of pendulum motion

Pendulum relative motion along sphere as mathematical point has constraint (1):

$$f(x,y,z)=0 \text{ or } x^2+y^2+(H-z)^2-L^2=0, \tag{1}$$

where L – length of cable OA;
H – z coordinate O_1O of pendulum rotation point (Fig. 1.).

For motion investigation it is convenient to use first form of Lagrange differential equations with Lagrange multiplier λ. For this reason normal reaction N of constraint is equal (2):

$$\overline{N}=\lambda\cdot grad(f(x,y,z)), \text{ or } \overline{N}=\lambda\cdot\begin{Bmatrix}\dfrac{\partial f}{\partial x}\\ \dfrac{\partial f}{\partial y}\\ \dfrac{\partial f}{\partial z}\end{Bmatrix}, \quad \overline{N}=\lambda\cdot\begin{Bmatrix}2x\\ 2y\\ -2(H-z)\end{Bmatrix}. \tag{2}$$

Differential equations of motion are:

$$m(\ddot{x}+A1)=B1(x,\dot{x})\cdot 0.5\cdot(1-sign(x+\Delta 1))+2\cdot\lambda\cdot x;$$

$$m(\ddot{y}+A2)=B2(y,\dot{y})\cdot 0.5\cdot\big(1-sign(y+\Delta 2)\big)+2\cdot\lambda\cdot y\,; \qquad (3)$$

$$m(\ddot{z}+A3)=-m\cdot g-2\cdot\lambda\cdot\big(H-z\big),$$

where m – mass;
g – acceleration of free fall;
$A1$, $A2$ and $A3$ – translation acceleration of reference system along x, y, z axis (Fig. 1.);
$B1(x,\dot{x})\cdot 0.5\cdot(1-sign(x+\Delta 1))$ – reaction of bumper interaction along x axe;
$\Delta 1$ – gap along x axe;
$B2(y,\dot{y})\cdot 0.5\cdot(1-sign(y+\Delta 2))$ – reaction of bumper interaction along y axe;
$\Delta 2$ – gap along y axe.

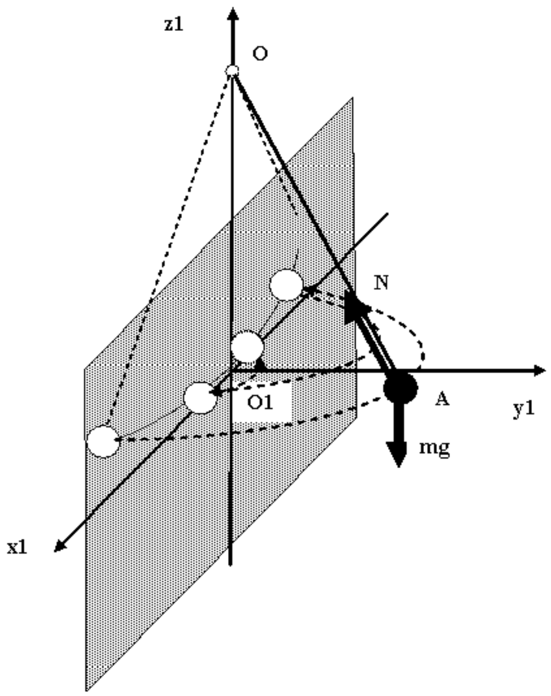

Fig. 1. **Mathematical model of pendulum with one bumper:** x1,y1,z1,O1 – absolute reference system; m – mass of pendulum; g – acceleration of free fall; AO – length of pendulum; $H = O_1O$ – z coordinate of pendulum rotation point O; x1O1y1 – bumper parallel plane

Pendulum has two degree of freedom. To use x and y like independent coordinates from Equation (1) must be finding:

$$x\cdot\dot{x}+y\cdot\dot{y}-\big(H-z\big)\cdot\dot{z}=0\,;$$

$$\dot{x}^2+x\cdot\ddot{x}+\dot{y}^2+y\cdot\ddot{y}+\dot{z}^2-\big(H-z\big)\cdot\ddot{z}=0\,. \qquad (4)$$

Therefore from equations (1), (3) and (4) accelerations $\ddot{x}$, $\ddot{y}$ may be finding in form:

$$\ddot{x}=\ddot{x}(x,\dot{x},y,\dot{y},t)\,;$$

$$\ddot{y}=\ddot{y}(x,\dot{x},y,\dot{y},t)\,. \qquad (5)$$

One bumpers pendulum model

For one bumpers model results of investigation (5) are shown in Fig. 2. – Fig. 5. Modeling results analysis gives that (for vibration damping) bumper must be soft and gap negative (then vibration damping is efficiency).

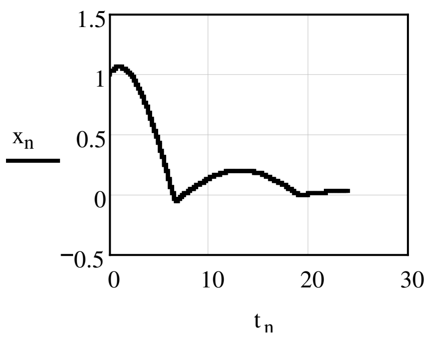

Fig. 2. **Displacement x_n of mass along x axe in time t_n domain without hull vibration in SI**

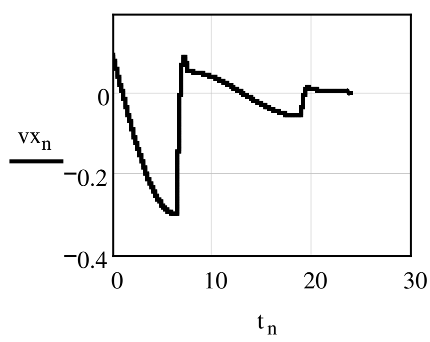

Fig. 3. **Velocity vx_n of mass along x axe in time t_n domain without hull vibration in SI**

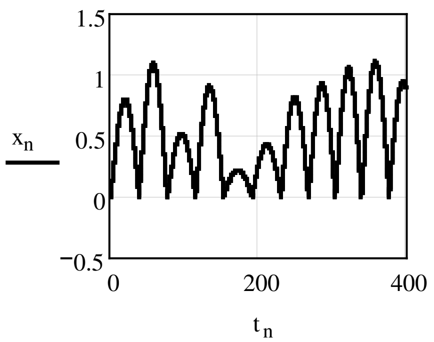

Fig. 4. **Displacement x_n of mass along x axe in time t_n domain with hull vibration in SI**

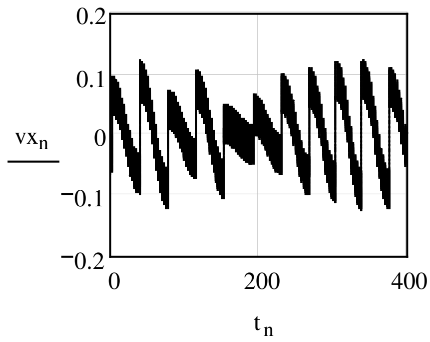

Fig. 5. **Velocity vx_n of mass along x axe in time t_n domain with hull vibration in SI**

Two bumpers pendulum model

Two bumper models are shown in Fig. 6. It includes two independent bumpers with gaps Δ1 and Δ2.

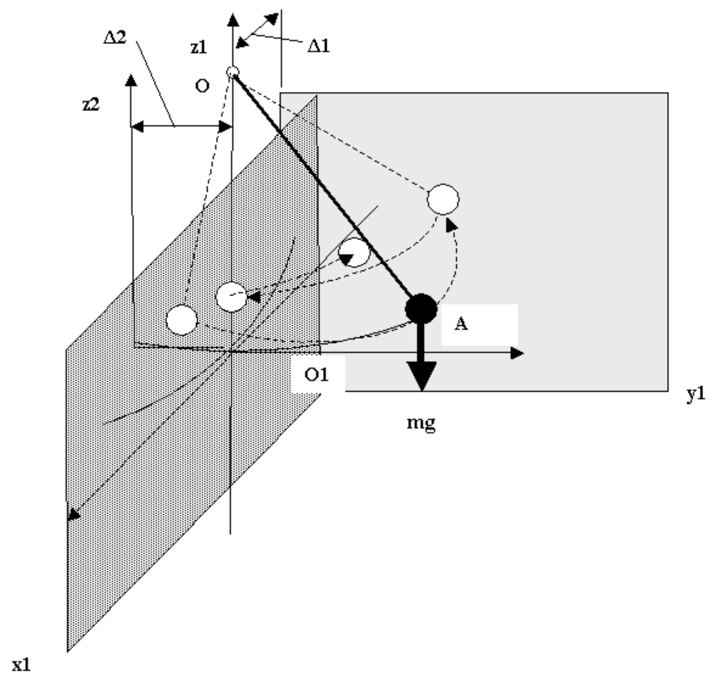

Fig. 6. **Mathematical model of pendulum with two bumpers:** x1,y1,z1,O1 – absolute reference system; m – mass of pendulum; g – acceleration of free fall; AO – length of pendulum; H = O_1O – z coordinate of pendulum rotation point O; Δ1, Δ2 – bumpers gaps

Between bumpers is right angle and forces are represented by a special stiffness and damping function like equations (3). Results of modeling are shown in Fig. 7. – 10.

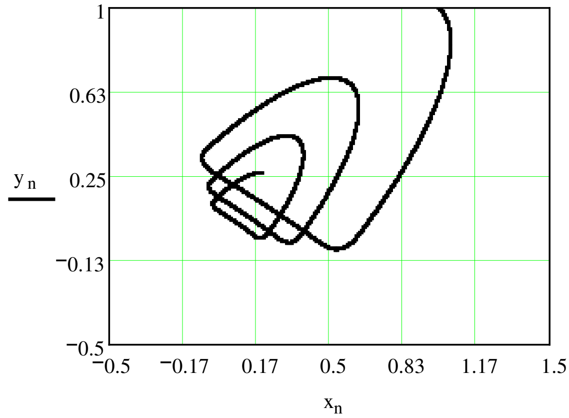

Fig. 7. **Transient motion in plane *x-y* in SI**

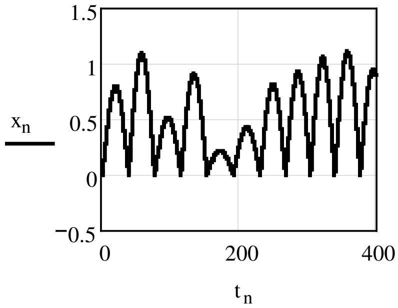

Fig. 8. **Displacement x_n along x axe in time t_n domain (in SI)**

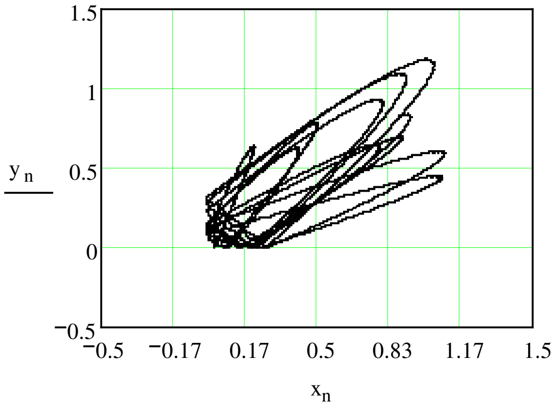

Fig. 9. **Motion in plane *x-y* with bumpers harmonica vibration SI**

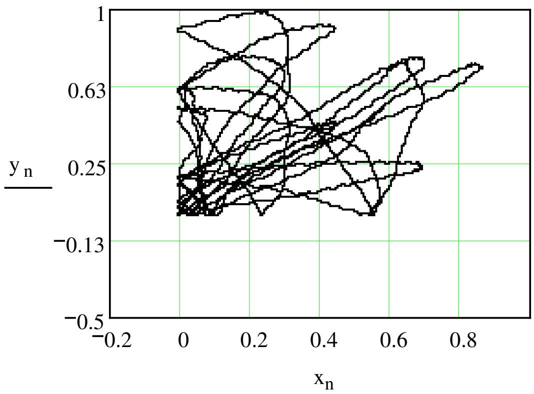

Fig. 10. **Motion in plane *x-y* with bumpers random vibration in SI**

Conclusions

From mathematical modeling the optimization of geometric parameters like length of string and gap between bumpers and pendulum is found out that processes of transient motion are very short when gap is “negative”. In additional is found that by special harmonica frequency can start vibro shock motion with large amplitude. Recommendation of investigation may be used for cargo fasten inside trailer, ship or airplane.

References

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