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RESEARCH OF THE SUSPENDED MONORAIL SIDE-SWAY

Summary. In the article there has been developed the dynamic model of the suspended monorail side-sway. There have been received the motion equations, carried out the analysis and determined the frequencies and amplitudes of rolling stock side-sway. During the rolling stock motion along the monorail there appears the crew side-sway relative to suspension centre. The following parameters influence onto the side-sway amplitude: traverse speed, coefficient of stiffness of the crew suspension, distance from the centre of mass till the points of the suspension of the carriage with the crew and cargo mass. Crew side-sway causes the efforts changes in the suspension system.

ИССЛЕДОВАНИЕ БОКОВОГО РАСКАЧИВАНИЯ ПОДВЕСНОЙ МОНОРЕЛЬСОВОЙ ДОРОГИ

Аннотация. В статье разработана динамическая модель бокового раскачивания подвесной монорельсовой дороги. Получены уравнения движения, проведен их анализ, определены частоты и амплитуды бокового раскачивания подвижного состава. Во время движения подвижного состава по монорельсу возникает боковое раскачивания экипажа относительно точки подвеса. На амплитуду бокового раскачивания влияют следующие параметры: скорость движения, коэффициент жесткости подвески экипажа, расстояние от центра масс до точек подвеса рамы с экипажем и масса груза. Боковое раскачивания экипажа приводит к изменению усилий в системе подвески.

1. INTRODUCTION

At monorail motion in real-life environment there inevitably appear oscillations of its components [1, 2]. Rolling stock, besides efficient motion along monorail axis, makes small oscillations of the complex structure. Remaining small by amplitudes they can be accompanied by secondary forces effecting onto the monorail, driving and running wheels [3]. The force increase causes the heightened runout, track deformation and therefore leads to safety decrease.

Between stock structure, its design parameters and operating conditions there exists indissoluble connection. Transporting cargo mass, track profile, track watering and dustiness and another operating conditions greatly influence onto stock work which proves the necessity of the many-sided taking into account of these conditions at monorail projecting and exploitation.

2. RESEARCH AND RESULTS

Let's study the crew plane motion consisting of material particle of mass m and imponderable bar of length l, on which one this particle is suspended, in the field of gravity. With this, suspension point isn't fixed and can move along some (given or chosen) trajectory. It is supposed the absence of any friction and resistance forces. The crew position will be determined by angle φ. Let's give some position $\varphi_0 \in \left[-\frac{\pi}{10}; \frac{\pi}{10}\right]$ in which it is situated at initial time with zero angular speed. The task is to find the law of motion of suspension centre $(x(t), y(t))$, which does not allow crew to change the position with time, i.e. to provide the solution existence $\varphi(t) = \varphi_o$.

Motion equation (fig. 1) at suspension centre motion by law $(x(t), y(t))$ is

$$\ddot{\varphi} + \frac{g}{l}\sin\varphi + \frac{\ddot{x}(t)\cos\varphi + \ddot{y}(t)\sin\varphi}{l} = 0. \qquad (1)$$

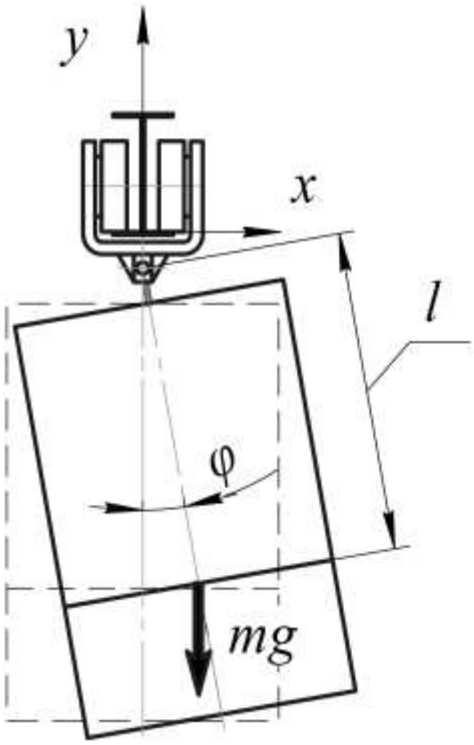

Fig. 1. Design diagram of crew motion
Рис. 1. Расчетная схема раскачивания экипажа

The important particular case appears when suspension centre oscillates along some axis forming angle α with the gravity direction. Having marked the suspension centre displacement along this axis $s(t)$, we have

$$x(t) = s(t)\sin\alpha, y(t) = -s(t)\cos\alpha \qquad (2)$$

and crew oscillations equation (1) turns into

$$\ddot{\varphi} + \frac{g}{l}\sin\varphi + \frac{\ddot{s}(t)}{l}\sin(\varphi - \alpha) = 0. \qquad (3)$$

As upper $\varphi_o = \frac{\pi}{10}$ and lower $\varphi_o = 0$ crew verticals are equilibrium positions at fixed suspension $(x(t) \equiv y(t) \equiv 0)$, so let's delete them from further studying and let's suppose that $\sin\varphi_o \neq 0$. Let's only mention that for keeping vertical positions of crew equilibrium the suspension centre can move only along the $\sin\varphi_o \neq 0$. As it is followed from [4], upper position becomes stable at suspension oscillations along the vertical with the frequency higher than $\sqrt{2gl}/\alpha$, where α - amplitude of these oscillations.

Let's find out such suspension centre motion $(x(t), y(t))$ as $\varphi(t) = \varphi_o = const \neq k\pi, k \in Z$. Functions $x(t)$ and $y(t)$ can be regarded as directions in equation (1). As class of permissible directions let's study continuous twice differentiable functions. So taking into account $\dot{\varphi} = \ddot{\varphi} = 0$ the equation (1) let's turn into

$$(g + \ddot{y}(t))\sin\varphi_o + \ddot{x}(t)\varphi_o = 0.$$

Whence

$$y(t) = -x(t)ctg\,\varphi_o - \frac{gt^2}{2} + c_1 t + c_2, \tag{4}$$

where c_1, c_2 – some constants which are determined from initial values of speed and position of crew suspension.

Have chosen $x(t)$ in random way from the class of permissible directions from (4) we'll get $y(t)$, have determined in such way suspension centre motion in full. Thereby we have family of directions $x(t)$, $y(t)$, providing inclined equilibrium of crew. Let's find out if there exist limitable ones among them.

Let it be that $x(t)$ is limitable on half-interval $[0, +\infty)$ function. Then at $t \to \infty$ under the limitation $x(t)$ the value $|y(t)|$ according to (4) goes to infinity. Therefore the suspension motion at $\sin\varphi_o \neq 0$ can't be limitable at both coordinates. Nevertheless there can be the traffic condition limited at y and unlimited at x, allowing the crew to remain in inclined position

$$x(t) = -\frac{gt^2}{2}tg\,\varphi_o, y(t) = 0.$$

Let's simplify now suspension motion trajectory. We'll move the suspension centre along the line (2), but let's extend the class of permissible functions $s(t)$. This class will include functions, the first derivatives of which (speeds) can have discontinuities of the first kind in some points at the intervals between these points functions $s(t)$ will be as before twice differentiated. In the given points of discontinuity regarded mechanical system will be undergone to pulse action.

Further dependence calculation is described [5], hence we have that at $\Omega \to 0$ $sign\Delta v$ coincides with $sign\frac{\sin\varphi_o}{\sin(\varphi_o - \alpha)}$, and at $\Omega \to 0-$ with $sign\cos(\varphi_0 - \alpha)$. These signs are different as it is made an in equation $\sin\varphi_o ctg(\varphi_0 - \alpha) < 0$.

So under continuous dependence Δv on Ω there exists some value $\Omega = \Omega_o$ at which the speed increase during period T will be zero.

Now let's study increase $s(t)$, it will be $\int_0^t \dot{s}(t)dt$. Obviously that depending on speed initial value v_o we can get different increases Δs. Let's choose initial speed in such way that this increase is equated to zero. Let's mark $\Delta v(t) = \int_0^t \ddot{s}(t)dt$. Then have chosen initial speed v_o equated to $-\frac{1}{T}\int_0^T \Delta v(t)dt$, we'll get that increase $s(t)$ will be zero.

Such values of frequency Ω and initial speed for $s(t)$ that suspension coordinate $s(t)$ and its speed during the period return to initial values. Therefore at these values suspension motion $s(t)$ will be periodic and continuous at *t* and crew will oscillate relative to position φ_o by law

$$\varphi(t) = \varphi_o + \varepsilon\cos(\Omega t + \delta).$$

Let's take the distance from the mass centre point till points of stock suspension l = 10 long and let's study its horizontal position $\varphi_o = \pi/4$. Let it be that axis along which suspension point oscillates angles $\alpha = 2\pi/4$ with gravity direction. Diagrams of suspension point motion providing harmonic oscillations of tractive equipment at horizontal position with some small amplitude ε and diagram of frequency dependence Ω on ε at periodic motion $s(t)$ suspension points are shown in fig. 2.

In fig. 2a it is given the diagram of Ω frequency dependence on ε at periodic motion $s(t)$ of suspension point. From it we see that frequency $\Omega(\varepsilon)$ increases unlimitedly at amplitude ε decrease.

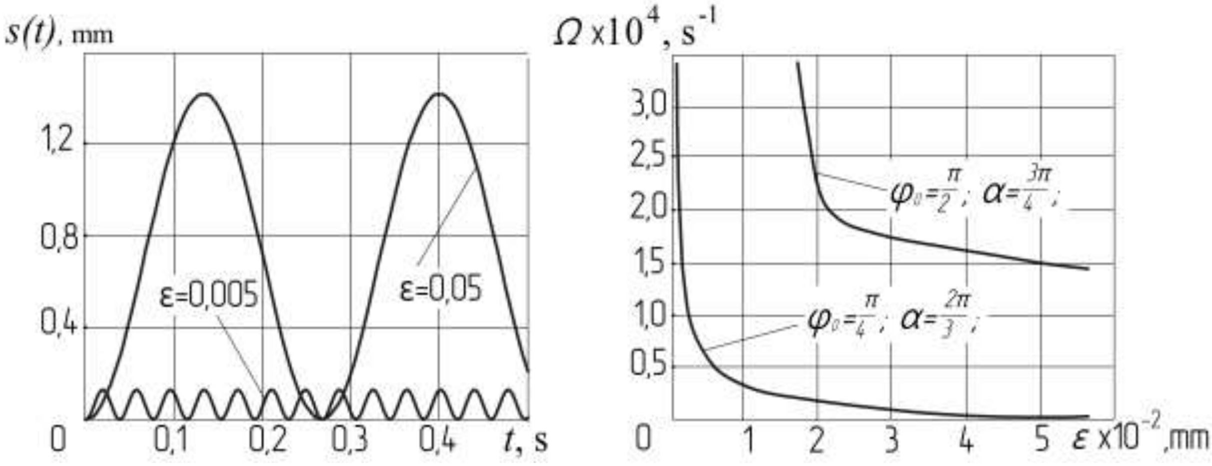

Fig. 2. Suspension motion: a) $s(t)$ at $\varphi_0 = \pi/4, \alpha = 2\pi/4$; b) frequency diagram $\Omega = f(\varepsilon)$

Рис.2. Движение подвеса a) $s(t)$ при $\varphi_0 = \pi/4, \alpha = 2\pi/4$; b) график частоты $\Omega = f(\varepsilon)$

In the fig. 2b for $\varphi_O = \pi/4$, $\alpha = 2\pi/4$ there have been given for comparison diagrams of suspension speed $v(t) = s(t)$ at $\varepsilon = 0{,}5$. With this it was found out that the maximal speed values $v(t)$ precede to maxima of harmonic speeds and minima lag.

3. CONCLUSIONS

Practical value of given work consist in possibility of wider application of monorail transport for odd works in all spheres of transport carriage and increase of speed of crews motion. On the ground of carried analysis of equation of crew oscillations at motion along monorail it follows the biggest influence onto the side declinations is provided by transporting cargo mass, coefficient of stiffness of holding down device and distance from mass centre till suspension points of driven carriage. Another parameters of tractive device and monorail have less considerable influence. There exist periodic by time oscillations of suspension centre at which crew declinations from given fixed inclined position will be as small as is wished.

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