DYNAMIC ASCENT OF A MINING DUMPER ON A ROAD WITH LONGITUDINAL SLOPE

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ABSTRACT. The dynamic ascent is achieved via an initial (reached), sufficiently high, velocity. By using the inertial force, the ascent of relatively short sections with a higher slope becomes possible without the risk of flipping over backwards. The ascent of a mining dumper truck travelling with a constant acceleration along an inclined section of a road without bumps is investigated. The truck is described using a one-mass dynamic model with one degree of freedom. The differential equation of the longitudinal angular vibrations is derived and solved analytically. It is assumed that a rear overturn happens when the angle of rotation reaches a maximum and the normal force of the road on the front set of wheels reaches zero. The critical inclination that can cause an overturn is calculated.

Keywords: dynamic ascent, mining dumper truck

ДИНАМИЧНО ИЗКАЧВАНЕ НА РУДНИЧЕН САМОСВАЛ ПО НАКЛОНЕН ПЪТ

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РЕЗЮМЕ. Динамичното изкачване се реализира с предварително развита (достигната) достатъчно висока скорост. С помощта на инерционната сила става възможно изкачването на по-стръмни наклонени участъци със сравнително малка дължина без опасност от преобръщане на автомобила назад. Разглежда се изкачване на рудничен самосвал с постоянно ускорение по наклонен участък от пътя без неравности. Той е представен посредством едномасов модел с една степен на свобода, извършващ надлъжни ъглови трептения. Диференциалното уравнение на малките трептения е получено и решено аналитично. Приема се, че преобръщането на самосвала назад настъпва когато ъгълът на завъртане е максимален и реакцията на пътя върху предните колела стане равна на нула. Така се определя критичния наклон на пътя, при който е възможно да настъпи преобръщане.

Ключови думи: динамично изкачване, рудничен самосвал

Introduction

Mining dumpers are used under very harsh conditions. The technological roads in open-pit mines are characterised by extreme unevenness, longitudinal and transverse gradients. The mining dumper truck can climb evenly (at a steady speed) on an inclined road only under the action of the engine thrust. The distance travelled in this case may be unlimited. But overcoming the slope can also be done by pre-accelerating and reaching a high enough speed to enter the slope. The gas supply is then discontinued and the dump truck ascends with the help of inertial forces. Thus, in addition to the thrust of the engine, the accumulated kinetic energy is also used. In this case it is possible to climb steeper sections of the road with a shorter length and it is gaining popularity as a dynamic overcoming of slopes. This increases the capacity of the mining dumper in extreme conditions.

Figure 1 (Vahlamov, 2006) shows the stages of a dynamic ascent. In the first section AB, the driver supplies gas, the dump truck increases its speed, and acceleration is observed. Thus, a sufficiently safe speed is reached in section BC, with which the mining dumper enters section CD that represents the ascent itself. Then the speed starts to decrease (section CD) and deceleration occurs. There is an inertial force whose direction coincides with the direction of movement. It is opposed to a possible roll over of the mining dumper truck. This makes it possible to overcome larger slopes.

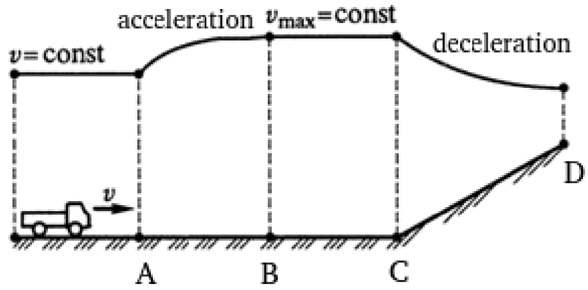

Fig. 1. Stages of a dynamic overturn

Dynamic model

We consider the climbing of a mining dumper (Fig. 2) along a section of the road with an inclination α without unevenness (Pulev, 2012). The deceleration a is constant and the direction of inertial force

$$\Phi = ma$$

coincides with the direction of movement. The following inscriptions have been made:

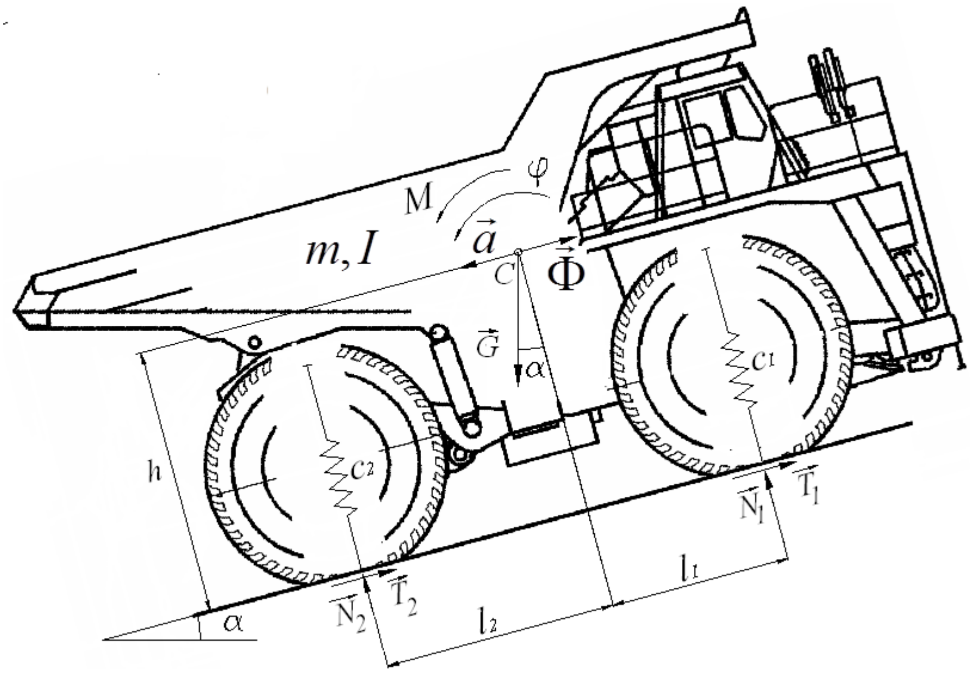

Fig. 2. Dynamic model

I - moment of inertia of the mining dumper truck relative to the transverse axis passing through the centre of gravity;

m – aggregate mass of the mining dumper;

c_1, c_2 - elasticity of front and rear suspension;

N_1, N_2 – normal road reaction to the front and rear wheels respectively;

T_1, T_2 – tangential road reaction on the front and rear wheels respectively;

h – height of the centre of gravity of the mining dumper;

l_1 - distance from the front suspension to the centre of gravity;

l_2 - distance from the rear suspension to the centre of gravity.

As a generalised coordinate, the rotation angle φ of the mining dumper around the transverse axis passing through the centre of gravity is introduced. The vertical oscillations are neglected because there are no vertical external disturbances. It is assumed that the mining dumper is symmetrical, i.e. there is no connection between jumping and galloping.

In the position of static equilibrium, in both springs static deformations $\delta_{1,0}$, $\delta_{2,0}$ and elastic forces $c_1.\delta_{1,0}$, $c_2.\delta_{2,0}$ occur. The equations

$$c_1.\delta_{1,0} = \frac{l_2 mg\cos\alpha}{L} \quad \text{and} \quad c_2.\delta_{2,0} = \frac{l_1 mg\cos\alpha}{L}$$

$(L = l_1 + l_2)$ are obtained from the equilibrium conditions.

At any moment of the movement, the elastic forces in the two springs are respectively

$$c_1(\delta_{1,0} - l_1.\varphi) \quad \text{and} \quad c_2(\delta_{2,0} + l_2.\varphi).$$

In order to have an equilibrium in the area of contact of the wheels with the road, the normal reactions must be equal to the elastic forces in the springs, i.e.

$$N_1 = c_1(\delta_{1,0} - l_1.\varphi) = \frac{l_2 mg\cos\alpha}{L} - c_1.l_1.\varphi\ , \tag{1}$$

$$N_2 = c_2(\delta_{2,0} + l_2.\varphi) = \frac{l_1 mg\cos\alpha}{L} + c_2.l_2.\varphi.$$

The tangential reactions T_1 and T_2 act in the opposite direction to the possible slip of the mining dumper on the inclined road. The equation

$$T_1 + T_2 = G\sin\alpha - \Phi.$$

is a condition for the equilibrium of tangential forces. The forces on both sides form a couple with an arm h and a moment

$$M = h(G\sin\alpha - \Phi) = hm(g\sin\alpha - a).$$

The differential equation of the longitudinal angular oscillations of the mining dumper is obtained using the second order Lagrange equation and has the form

$$\ddot{\varphi} + \frac{c_1.l_1^2 + c_2.l_2^2}{I}.\varphi = \frac{hm(g\sin\alpha - a)}{I}. \tag{2}$$

This is a non-homogeneous second-order differential equation with constant coefficients. Its common solution is the sum of the solution of the homogeneous equation and a particular solution.

The solution of the homogeneous equation is

$$\varphi_0 = C_1 \cos kt + C_2 \sin kt,$$

where C_1 and C_2 are integration constants, and the own frequency of longitudinal angular oscillations is

$$k = \sqrt{\frac{c_1.l_1^2 + c_2.l_2^2}{I}}.$$

A particular solution of the following kind is necessary:

$$\eta = A,\ \dot{\eta} = \ddot{\eta} = 0.$$

After substituting η in the differential equation (2), the following equation is obtained

$$A = \frac{hm(g\sin\alpha - a)}{c_1.l_1^2 + c_2.l_2^2}.$$

The general solution of the differential equation (2) is

$$\varphi = \varphi_0 + \eta = C_1 \cos\sqrt{\frac{c_1.l_1^2 + c_2.l_2^2}{I}}t + \\ + C_2 \sin\sqrt{\frac{c_1.l_1^2 + c_2.l_2^2}{I}}t + \frac{hm(g\sin\alpha - a)}{c_1.l_1^2 + c_2.l_2^2}$$

Under zero initial conditions for integration constants is found that:

$$C_1 = -\frac{hm(g\sin\alpha - a)}{c_1.l_1^2 + c_2.l_2^2} \text{ and } C_2 = 0.$$

Therefore, the law on transverse angular oscillations is given by the following expression:

$$\varphi = \frac{hm(g\sin\alpha - a)}{c_1.l_1^2 + c_2.l_2^2}\left(1 - \cos\sqrt{\frac{c_1.l_1^2 + c_2.l_2^2}{I}}t\right).$$

It is known that

$$-1 \le \cos\sqrt{\frac{c_1.l_1^2 + c_2.l_2^2}{I}}.t \le 1.$$

Then, the maximum value of the coordinate is obtained when the expression in the brackets of the law for transverse angular oscillations becomes equal to 2. It is

$$\varphi_{\max} = \frac{2hm(g\sin\alpha - a)}{c_1.l_1^2 + c_2.l_2^2}. \tag{3}$$

A rear overturn happens when the tipper deviates as much as possible from the static equilibrium and the front wheels lose contact with the road. The following conditions must be met:

$$\varphi = \varphi_{\max} \text{ and } N_1 \le 0. \tag{4}$$

The normal reaction (1) of the road in contact with the front wheels is determined by the expression

$$N_1 = \frac{l_2 mg\cos\alpha}{L} - c_1.l_1.\frac{2hm(g\sin\alpha - a)}{c_1.l_1^2 + c_2.l_2^2}. \tag{5}$$

The critical inclination $\alpha_к$ that can cause an overturn is determined by the equality

$$\frac{l_2 mg\cos\alpha_к}{L} - c_1.l_1.\frac{2hm(g\sin\alpha_к - a)}{c_1.l_1^2 + c_2.l_2^2} = 0. \tag{6}$$

After mathematical transformations, the equation (6) acquires the following form:

$$2hgLc_1l_1\sin\alpha_к - l_2g\left(c_1.l_1^2 + c_2.l_2^2\right)\cos\alpha_к = \\ = 2hLc_1l_1a \tag{7}$$

If the substitutions are made

$$\sin\psi = \frac{2hLc_1l_1}{\sqrt{4h^2L^2c_1^2l_1^2 + l_2^2\left(c_1.l_1^2 + c_2.l_2^2\right)^2}},$$

$$\cos\psi = \frac{l_2\left(c_1.l_1^2 + c_2.l_2^2\right)}{\sqrt{4h^2L^2c_1^2l_1^2 + l_2^2\left(c_1.l_1^2 + c_2.l_2^2\right)^2}},$$

$$\sin\varphi = \frac{2hLc_1l_1a}{g\sqrt{4h^2L^2c_1^2l_1^2 + l_2^2\left(c_1.l_1^2 + c_2.l_2^2\right)^2}},$$

the equation (7) becomes:

$$\sin(\alpha_к - \psi) = \sin\varphi.$$

The solution to this trigonometric equation, which is of practical significance, is

$$\alpha_к = \varphi + \psi. \tag{8}$$

The value of deceleration has the determinant influence on the critical inclination $\alpha_к$. The size of the load transported also influences it. The higher the load, the greater the height h of the centre of gravity and the probability of an overturn increases. The increasing of h requires a reduction of $\alpha_к$. It's also different for the different dump models.

Numerical experiment and discussion

Using the formula (8) obtained, the critical inclination α_κ value can be calculated for a mining dumper with the following characteristics:

$L = 5.3\ m$, $l_1 = 3.551\ m$, $l_2 = 1.749\ m$,
$c_1 = 10.93\text{x}10^5\ N/m$, $c_2 = 22.2\text{x}10^5\ N/m$,
$h = 5\ m$.

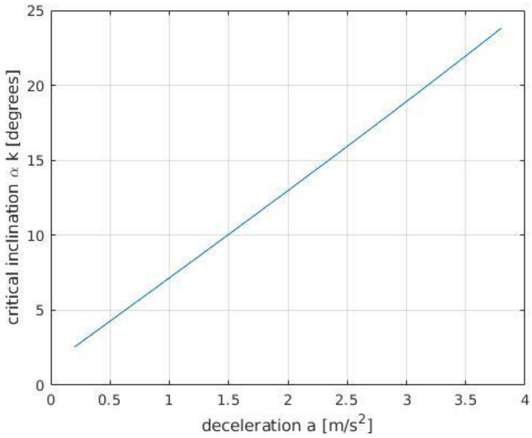

Fig. 3. Influence of deceleration on critical inclination

Figure 3 shows changes of the critical inclination α_κ depending on the deceleration values. Acceleration values of 1.5 m/s^2 to 3.5 m/s^2 are recommended.

The dynamic ascent of a mining dumper ensures safe climb of steeper sections of the road with a shorter length. It mostly depends on the driver's abilities, skills, experience, wisdom and quick responses.

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