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The Problems of Dynamics of Wheeled Vehicles with Flow Able Building Cargo

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Abstract

The issues of the dynamics of the wheeled vehicles transporting free-flowing construction materials (concrete, mortar, bitumen and other construction mixes) are considered. It is proved that for the purpose of safety, the oscillations of free-flowing construction materials during the vehicle movement should be taken into account. So, in general, free-flowing construction materials are non-Newtonian fluids, i.e. their flow rheograms are non-linear. If, however, we take into account the fact that during the oscillations the deformations of non-Newtonian fluids do not occur in one plane but they do in all four coordinate planes, then the hysteresis behaviour of these rheograms is natural, which is confirmed experimentally. Then the area of the hysteresis loop allows us to perform the linearization of the problem when calculating the oscillations of the dynamic system "road-vehicle-free-flowing construction materials". The oscillation analysis methods of the wheeled vehicles with free-flowing construction materials both in transversal and longitudinal planes have been developed, as well as the recommendations for increasing the stability of the wheeled vehicles against rollover and for reducing structural loads in transient motion mode of the vehicle have been given. The research allows us to consider the dynamics of the wheeled vehicles both with free flowing and solid construction materials in general. What is more, the case with a free-flowing construction material is comprehensive and the one with a solid material is specific. The developed methodology made it possible to implement a number of design solutions which improve the structural safety of the wheeled vehicles transporting free-flowing construction materials.

Keywords: flow able cargo; safety; dynamics; rheometry; resistance; frequency; amplitude.

The problems of dynamics and as a consequence of safety during the transportation of free-flowing construction materials are extremely urgent because they are connected with people's life and health. All construction materials with inherent fluidity of different rheological characteristics are combined by one common definition "free-flowing

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materials". In reality, these can be loose substances, liquids or gases, i.e. they are in such a state that, when being subjected to small loads that can occur when the speed vector of transportation changes (acceleration, deceleration, turning movement), they are displaced provided that there is a free surface of the material, which, in turn, results in centre-of-gravity shift. All these have a detrimental effect on the transportation mode safety. Thus, a free-flowing material is a substance in which both shearing and tensile resistance is negligible, which significantly affects the magnitude and the direction of the vector of inertial loads exerted on the vehicle on which the cistern with a free-flowing construction material is mounted.

Dangerous materials are comprehensively presented and studied in the European Agreement concerning the international carriage of dangerous goods (ADR) (European Agreement concerning the International Carriage of Goods by Road (ADR) and protocol of signature, vol. 1.2) [1]. If a dangerous material is a free-flowing material which is transported and there is a free surface of the material, then the whole system "road-vehicle-free-flowing construction materials" is especially dangerous.

The increased accident rate of the mentioned wheeled vehicles intended for transportation of free-flowing construction materials is determined by the presence of a free surface of the material and its wave generation under disturbing and steering actions. The filling degree of cisterns varies widely and amounts to 40-90 %. However, the presence of even a small part of a free surface affects the whole vehicle dynamics significantly.

In fact, a special wheeled vehicle is a mechanical system with diverse connections of individual elements and the complex laws of their relative displacements. Taking into account the above, a multimass spatial theoretical model consisting of n masses connected by elastic-dissipative connections has been initially chosen.

The design features of the wheeled vehicles with free-flowing construction materials predetermine the design configuration of their dynamic systems. Since dynamic parameters (safety indicators) testing of the wheeled vehicles with free-flowing construction materials is unsafe, preliminary simulation analysis on a numerical model is required.

For the most common triaxial base chassis a spatial dynamical system is a five-mass system with elastic-damping connections. Then the formula for the kinetic energy is [2,3]:

$$\begin{aligned} T=&\frac{1}{2}\Big(mv^2+m\dot{y}^2+I\dot{\Omega}^2+m_f\dot{z}_f^2+I_{xf1}\dot{\Omega}_{x1}^2+I_{xf2}\dot{\Omega}_{x2}^2+I_y\dot{\Omega}_y^2+\\ &+m_1\dot{z}_1^2+m_3\dot{z}_3^2+m_5\dot{z}_5^2+I_{x1}\dot{\gamma}_{x1}^2+I_{x3}\dot{\gamma}_{x3}^2+I_{x5}\dot{\gamma}_{x5}^2\Big)-m_{f1}h_{k1}\left(\dot{y}\dot{\Omega}_{x1}-v\dot{\Omega}\Omega_{x1}\right)-\\ &-m_{f2}h_{k2}\left(\dot{y}\dot{\Omega}_{x2}-v\dot{\Omega}\Omega_{x2}\right)-I_{xz1}\dot{\Omega}\dot{\Omega}_{x1}-I_{xz2}\dot{\Omega}\dot{\Omega}_{x2}, \end{aligned} \quad (1)$$

where m_{f1} – mass of the sprung part acting on the front axle;
m_{f2} – mass of the sprung part acting on the bogie;
m_1 – mass of the front axle;
m_3, m_5 – mass values of the bridge axles of the bogie.

The mass of the sprung part of the chassis m_f and the mass m are expressed respectively:

$$m_f=m_{f1}+m_{f2};\ m=\sum_{i=1}^{5}m_i \quad (2)$$

Ω, y – angle of drift and lateral displacement of the chassis;
Ω_{x1}, Ω_{x2} – angles of roll of the sprung part;
Ω_y, Z_n – angle of pitch and vertical movement of the sprung part;
Z_1, Z_3, Z_5 – vertical movements of the unsprung part;
γ_{x1}, γ_{x3}, γ_{x5} – roll angles of the unsprung part;
h_{k1}, h_{k2} – heeling arms of the masses respectively, m_{n1}, m_{n2};
I_{xz1}, I_{xz2} – centrifugal torque of the inertia of the sprung part m_{f1}, m_{f2} relative to the axes 0_x and 0_z.