

# 413. Increase of rail transportation safety with use of nonlinear dynamics methods and the modern catastrophe theory

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**Abstract.** The number of unexpected crashes, breakdowns and catastrophes in mechanical nonlinear dynamical systems stays very large. The paper deals with the increasing of rail transportation safety using nonlinear dynamics methods and the modern catastrophe theory. The original method of complete bifurcation groups is suggested for systematical prediction of dangerous motion regimes.

**Keywords:** catastrophic regimes, railway transport safety, rare attractors, complete bifurcation analysis

The number of unexpected crashes, breakdowns and catastrophes in mechanical nonlinear dynamical systems stays very large. Among such engineering systems working in dynamical conditions, there are nonlinear flexible suspensions, offshore oil systems, bridges, switches, valves, gear boxes, metalcutting lathes, vibro-impact systems, machines for deep drilling, and many others. The modern mechanical engineering systems are essentially nonlinear systems. Recent global dynamics' investigation of typical nonlinear systems shows that there are several new common mechanisms leading to dangerous phenomena. Different chaotic attractors and multiplicity of stable regimes; dangerous bifurcations, escape phenomena with complex finger-like basins of attractions, fugitive subharmonics; rare attractors (RA), complete bifurcation analysis, complex protuberances are good examples for such mechanisms [1-2]. Now it is clear that in archetypal dynamical systems, which describe railway transport dynamics, there are rare important dynamical phenomena of new types, which are common for different mechanical systems with nonlinear elastic-dissipative elements. For example, the system with usual bilinear or trilinear elastic suspension designed to suppress large amplitude oscillations may have unpredictable dangerous regimes, or even catastrophic. Sometimes in nonlinear dynamical systems the unexpected dangerous regular or chaotic vibrations appear in such unusual way: after decreasing of the amplitude of excitation (or after some damping

increasing) maximum vibrations in the system become greater (so called the converse effect). Therefore the development of new engineering methods for systematically prediction and quenching all possible dangerous regimes in nonlinear dynamical systems, including dangerous rare stable regimes (rare attractors), is very important for modern mechanical engineering systems.

The main goal of railway transport is to provide the effective transportation process without cargo and passenger health losses and rolling stock damages. The prevention of railway transportation accident always was and remains among the branch prior problems [3-8]. The traffic safety is mostly defined by level of rolling stock and train maintenance. At the solution of traffic safety problem the attention of the theory and practice is, first of all, directed to:

- working out of modern control systems of train motion and its motion safety provision;
- assuring the improved dynamic characteristics of railway vehicles and increase of their critical speed by the development of modernised running gears;
- development of ways of vehicles derailment prevention and means of locomotives and cars protection at trains collision and train riding into an obstacle;
- development of on-board means for on-line diagnostics of railway vehicles.

Railway transport operating experience testifies that the considerable part of accidents on railways is accompanied by car derailment, car riding onto another car or different obstacles, cars self-uncoupling also may take place. The analysis railway accidents has allowed to draw conclusions, that presence of cars transporting dangerous cargoes in the train is the reason of over half of all the accidents. Accidents with freight trains at the transportation of dangerous and especially dangerous cargoes lead to considerable destructions, area contamination and mass affection by toxic substances. It is necessary to carry out the complex of nature-conservative measures at the liquidation of such incidents besides the organisation of medical assistance. Nowadays the great attention is paid to safe transportations of ecologically dangerous cargoes by railway cars including cars-tanks in all CIS countries. Tendencies of world practice on increase of safety of dangerous cargoes railway transportation are directed not only to elimination of accident reasons and development of improved technical requirements of car safe operation, but also to their design improvement by the equipment with coupler absorbing devices of increased capacity and special protection means.

Dynamic qualities of railway rolling stock units including transportation safety indices are substantially determined by cars design and running gears parameters. Research of locomotives and cars dynamics shows that it is possible to improve their dynamic characteristics by the corresponding choice of stiffness and dampers parameters of spring suspension and of running gears bearing elements joints between each other and with the car body. Besides, the rail/wheel rolling surfaces geometry is very important for the rolling stock dynamical characteristics. To increase freight trains motion safety, especially when there are empty cars in the train, it is necessary to exclude cases of frictional dampers wedges release in cars spring suspension at operation.

Rolling stock derailments are force majeure for railways. As numerical research shows, their direct technical reasons are wheel flange climbing onto a head of a rail and rails thrust because of dynamic forces action from the wheelsets to the track [9-18]. Dynamical wheel unloading, wheel flange climbing onto a switch blade, presence of big track irregularities, cross levels and vertical profiles can be the reasons of wheel climbing. More often wheel climbing occurs in sharp curves and in switches in a zone of transitive curves where lateral forces are very high because of wheel flange climbing to the outer rail. Among the factors leading to this phenomenon is the increase of the contact angle between a wheel and a rail for the worn out lateral side of an outer rail head. At a curve entrance and exit, the most probable reason of derailment is track gauge widening because of rails overturning. High longitudinal compressing forces also can become the reason of derailment of cars at small radius curves negotiation or in the switch zones. At carrying out emergencies examinations on the CIS railways, it is established that from 14 cases of cars derailment 7 has

occurred in curves of small radius and on abrupt descents. Empty or almost empty cars located in the middle part of a train were derailed. As world experience of trains operation shows, the derailment can occur even in the case when each separate index of car traffic safety is within the established limits. The fact is that all the mentioned above parameters are closely connected to each other and often strengthening each other lead to the accident.

The analysis of head-on collisions made by the commission of the European Railway Research Institute (ERRI) and carrying out classification of safety violence have revealed three kinds of the most typical emergency impacts of rolling stock: with a flying extraneous subject; collision with the car or a large animal; collision with other rolling stock [19, 20]. The last type of collision is one of the heaviest and serious incidents on railways and it causes the heaviest consequences. Quite often they are expressed in full or partial destruction of rolling stock, considerable damage of track, transported cargoes and human victims. For example, money damages from the accident having place in Germany in 1997 and caused by collision of a passenger train with a freight one consisting of 22 tank-cars were 30 million German marks. Besides, 20 thousand liters of fuel has got into soil. Considerable part of worst case situations is made by rolling stock collisions at maneuvering caused by braking of cars moving from humps, excess of motion speed, technical devices failure. The main violation of technical operation rules is the deviation from requirements on one of the main factors – the speed of cars collision. The analysis of speeds of cars collision at their motion from humps has shown that regulated speed is exceeded 2-3 times.

It is possible to solve the problem of increase of transportation safety of using theoretical methods of mathematical modeling of accidents. Theoretical models of separate vehicles and trains dynamic characteristics calculations should be developed and used for this purpose.

One of the most complicated problems occurring at the solution of the problem of particular vehicle dynamics is the problem of mathematical models setting which adequately reflect properties of investigated systems and irregularities. For their setting systems of rigid bodies connected by elastic, viscous or frictional elements are used [21]. All non-linear elements of the system should be taken into account. They are: forces of wheel and rail interaction, interaction forces in automatic couplers elements, dry friction forces, nonlinear profiles of wheel and rail rolling surfaces. For the objects containing tanks partially filled with liquid, movement of a liquid mobile part can influence essentially design elements dynamic response at transition regimes of motion. Therefore liquid cargo vibration can be considered on the basis of pendulum analogy. Thus an equivalent rigid body with mathematical pendulums is accepted as the mechanical analogue of a tank-car tank with liquid cargo. From the mathematical point of view, multibody models obtained finally represent systems of nonlinear differential equations of rather high order.

Developed mathematical models allow studying many cases of rolling stock behaviour in standard situations. Among them are motions of the railway vehicle with constant speed along the track of arbitrary shape in plan and profile, motion of tank-cars with different levels of liquid cargo filling, motion of trains on grades and complicated track profile at different transition regimes like acceleration and braking. Some emergency situations also can be investigated with the models developed: locomotives and cars dynamic response at trains collisions or a train riding into an obstacle, estimation of cars safety level at their motion along the track with random vertical and horizontal irregularities with taking into account different factors lead to derailment [22-26].

The aim of this work is to show the possibility of applying of new nonlinear dynamics methods and the modern catastrophe theory for systematically prediction and quenching possible dangerous regimes in railway transport, including dangerous rare stable regular and chaotic regimes, and to deepen the fundamental understanding of global driven dynamics of nonlinear systems.

This work is the result of scientific collaboration of Ukrainian and Latvian scientists and specialists on increasing of transportation safety of liquids, bulk cargo and other ecologically dangerous cargos. Increase of rail transportation safety with use of nonlinear dynamics methods and the modern catastrophe theory will allow, in our opinion, to increase capacity of railway transport.

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