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INNOVATIVE METHODS OF MOTION STABILITY IMPROVEMENT IN ARTICULATED RIGID FRAMES VEHICLES ON WHEELED CHASSIS

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Abstract

One of the last trends concerning articulated rigid frame vehicles is to increase velocity of their movement beyond 50-60 km/h. Significant differences in construction chassis system this kind of vehicles to distinguish automotive vehicles, makes that it is difficult to follow stragight path course by operator. It is caused for example by a very low equivalent stiffnes of hydraulic steering system, the contact method of large size wheels and others. While constructing articulated rigid frame vehicles a very few parameters could be changed. Both numerical and experimental examination shows a crucial influence of stiffnes steering system on trajectory of this kind vehicles. In this article a various methods of construction steering system are examined to improve their stiffnes. The value of equivalent stiffnes of actuators steering system is measured on a real articulated vehicle. The simulations are made in MSC ADAMS environment.

The present paper will include an analysis of the impact of the steering system geometry on the achieved motion trajectory. The virtual and physical model of the investigated articulated industrial vehicle researches are put as well as the comparison between considered variants of the steering system.

Keywords: *vehicle, wheeled chassis, simulation, innovative method*

1. Introduction

Articulated rigid frames vehicles, owing to their numerous advantages, are used in many industries. These advantages include high manoeuvre ability and a simple structure of the chassis system. One of the current trends concerning this group of machines is the increase of their mobility, which is understood as the increase in the velocity beyond 50-60 km/h. Meeting these requirements has resulted in several previously unknown dynamic issues. Unfortunately, it is impossible to directly apply the results of numerous studies on classic automotive vehicles, due to the significantly too large differences in the structure of chassis systems. In case of articulated rigid frame vehicles one can distinguish the following chassis systems: with front, rear or all steering wheels, with an articulated frame steering system, or systems which are their combinations. The differences also involve the contact method of large-size wheels of industrial vehicles, which feature significant inertia.

It is impossible to achieve higher velocities of industrial vehicles due to their limited motion stability that is ‘porpoising’ and snaking. ‘Porpoising’ (Fig. 1) is the longitudinal oscillations in relation to the central centre of gravity.

They may lead to a temporary loss of contact with the ground and thus to the lack of the possibility to change/adjust the direction of the motion by the operator. These oscillations also decrease the comfort of driving the vehicle and pose a threat of losing the load from the work device.

Articulated vehicles move along a trajectory of a certain amplitude and the frequency of occurrence referred to as snaking (Fig. 2).

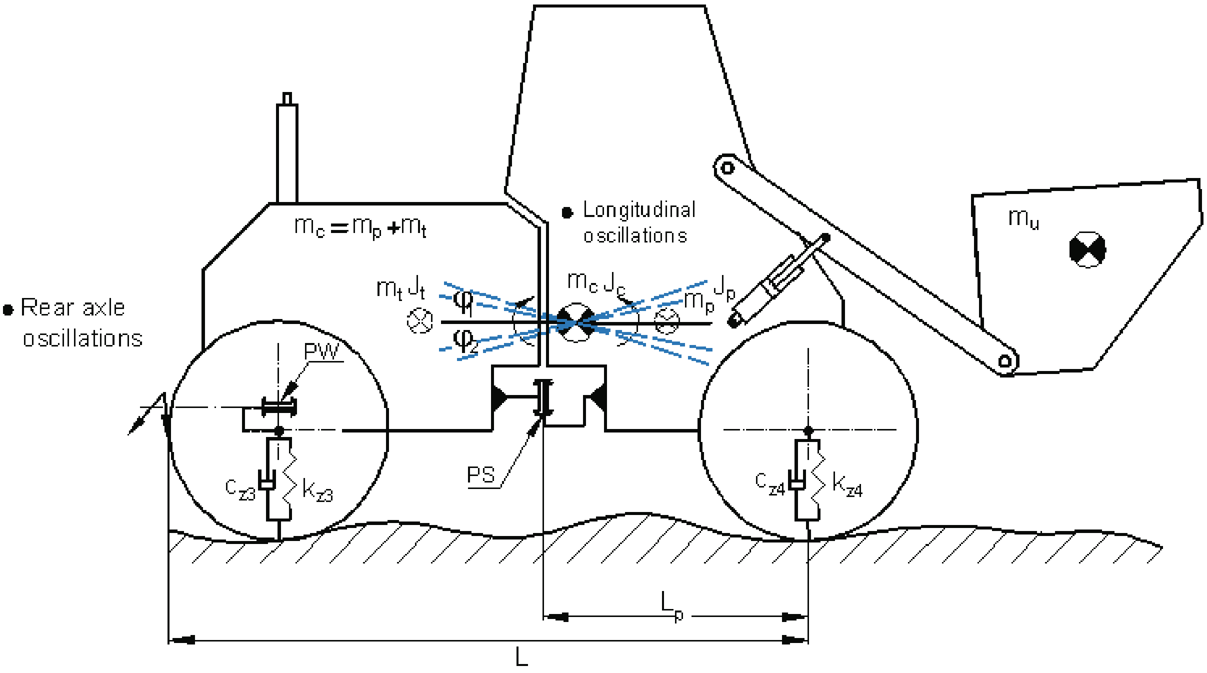

Fig. 1. Porpoising of articulated rigid frame vehicles

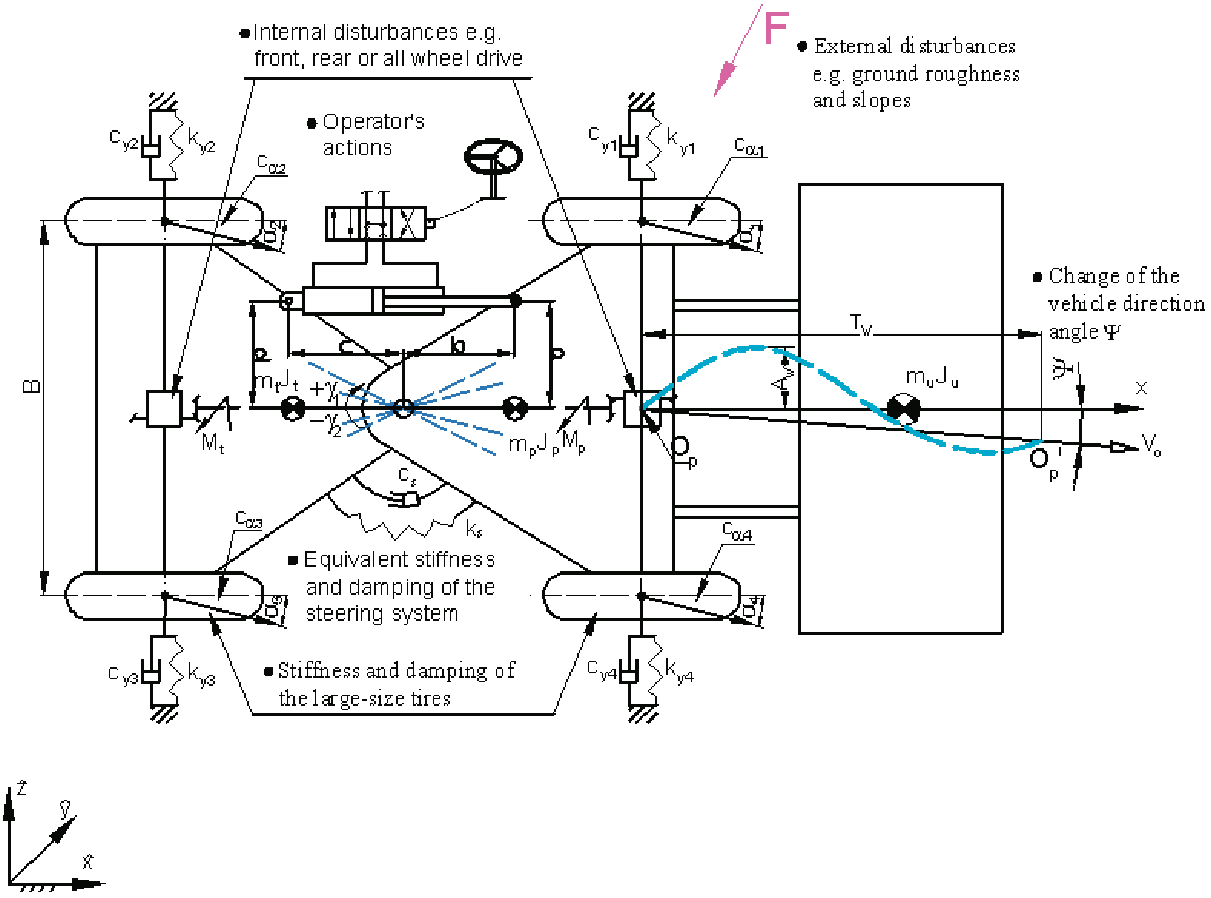

Fig. 2. Snaking of industrial vehicles

It is caused primarily by the insufficiently low equivalent stiffness of the steering system, which results in oscillations of the sections of the front and rear frames thus changing the direction of the motion. Moreover, the low lateral stiffness of large-size tires is the cause of significant transverse displacements of the vehicle. The inability to return autonomously to the rectilinear direction of the motion also affects the snaking of articulated vehicles.

The vehicle moves in changing operational conditions, which disrupt the direction of the motion desired by the operator. These include: surface roughness, the impact of the lateral forces or the vehicle drive type, which affect the parameters connected with the structure of the vehicle, for instance the location of the centres of gravity of the vehicle sections, the wheelbase and the track, the steering geometry and the stiffness and damping of the steering system and the tire elasticity and damping, the presence of the rear swing axle, the velocity etc. The factors mentioned above affect the motion trajectory that the articulated vehicle achieves. It is crucial to recognize which of them particularly limit the motion stability of articulated vehicles. Research of this type is conducted in the Department of Utility Machines and Industrial Vehicles Engineering [1].

While developing the documentation of new articulated rigid frame vehicles designers can influence the majority of the parameters of a vehicle, but only to a limited extent. Some of them such as the track, wheelbase depend primarily on the intended use of the vehicle and cannot be selected freely. Also heavy elements of the drive system, due to structural considerations, are located possibly close to one another thus there is no significant possibility to influence e.g. the location of the centres of gravity of the vehicle sections. The studies on the snaking of articulated rigid frame vehicles have demonstrated that the equivalent stiffness of the steering system has a particular impact on the motion trajectory. Its value is determined by factors which include the geometry of the steering system, the diameters of the pistons and piston rods of hydraulic cylinders, the pressure in the system, the length of the hydraulic line and the connected volume of the working fluid, the type of hydraulic hoses, the system gain coefficient and others. In this case the designers may significantly influence the achieved steering system stiffness. Unfortunately, any guidelines regarding their development are missing from the literature. The present paper will include an analysis of the impact of the steering system geometry on the achieved motion trajectory. Due to the great complexity of the issue in question the simulation investigations were conducted using the MultiBody software.

2. Simulation investigations of the motion stability in an articulated vehicle on a wheeled chassis

The simulation investigations of the loader were conducted using the MSC. Adams environment. The masses and the inertia of all the components of the vehicle were determined by means of specialized software and the machine documentation obtained from the manufacturer. This model takes into account the elements of the drive system: reduction gears and differentials. The equivalent stiffness of the steering was also determined experimentally. For this purpose pressure sensors, hydraulic cylinder stroke sensor and the turning angle sensor were mounted in the steering system. The turning of the vehicle sections was forced with the measured force. The diagram of the system is shown in Fig. 3. This system was divided into 3 variants: 1^{o} the factory system, 2^{o} the system with isolated distribution valve 3^{o} the system with cut –off distribution valve and without hydraulic hoses and the achieved characteristic of the equivalent stiffness was $k_s = \partial M / \partial j = Nm / rad$. The operation of the hydraulic steering in the MSC Adams was modelled, in this case, as an equivalent linear spring with constant elasticity 2780N/mm and damping 6 Ns/mm. The aim of such a simplification of the steering system is to achieve its constant impact on the sections of frames in the case of the conducted simulations for the improvement of the motion stability of articulated vehicles. A comparison of the virtual and the real objects is shown in Fig. 4.

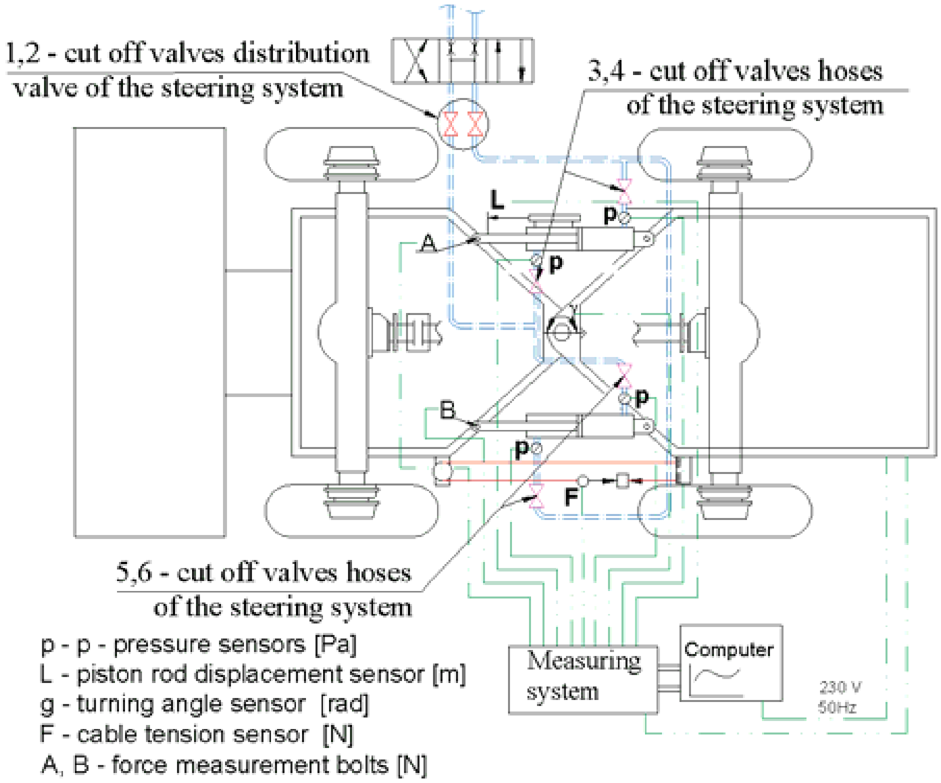

Fig. 3. A diagram of the measuring system and the method of the experiment

Fig. 4. The virtual and the physical model of the investigated articulated industrial vehicle (Ł220 loader)

The steering system of articulated vehicles is subject to particular standardized tests [4]. It is required, among other things, that the steering system should enable the motion of the vehicle tires on a rectilinear section of a road of the width equal to 1.2 of the outside track and 100 m long at the maximum velocity. In the case of the investigated vehicle the lateral displacement, at which the standardized motion area will be left, is 0.27 m. During simulation investigation the input constituted a single obstacle affecting only the front wheel of the vehicle. The motion of the rear wheel provides the second input to the system, which may cause an increase or a decrease of the amplitude of the oscillations of the vehicle sections which introduces difficulties in the interpretation of the obtained results. The investigations were conducted for five geometric variants of the steering system, which are shown in Fig. 5. The difference between variants 1 and 2 is the increase of the CD distance between the mounting of hydraulic cylinders. Variants 3, 4 and 5 have equal distances of the AB and CD sections, however they differ with regard to the location of the steering joint P.

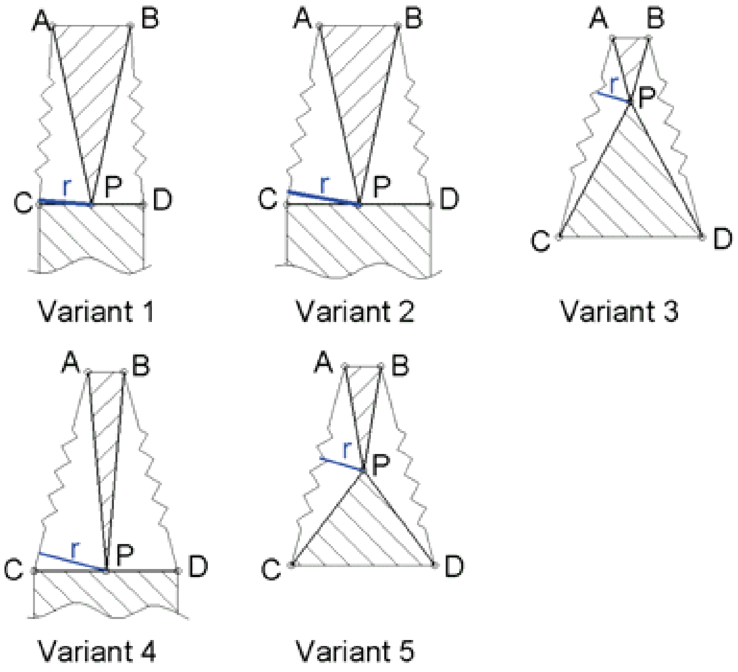

Fig. 5. Various geometric variants of the steering systems assumed in the computations

The simulation was conducted at the velocity of v=38 km/h and the rear wheel drive. Fig. 6 presents the obtained angle oscillations between the sections of the articulated vehicle. The oscillations of the turning angle in variant 3 were not shown due to exceedingly high amplitudes reaching the maximum of ± 6^o.

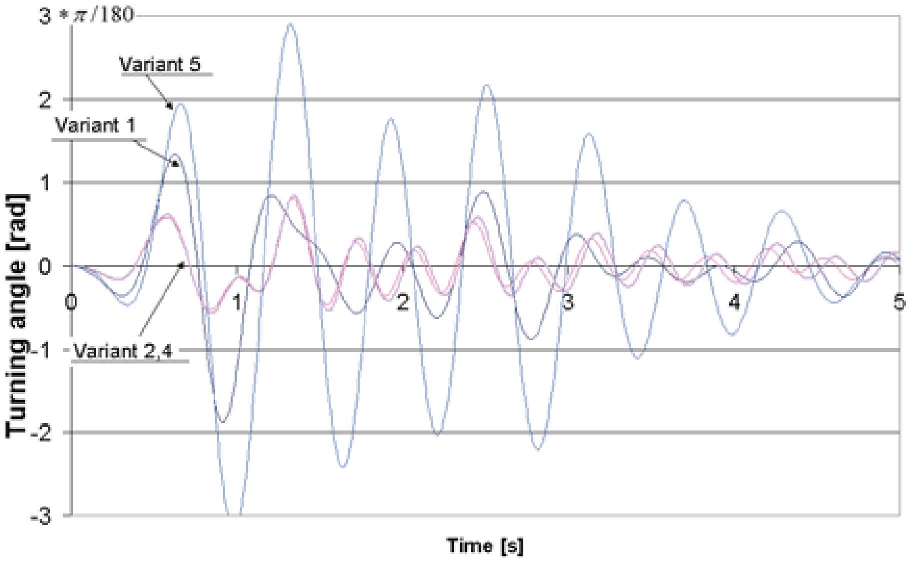

Fig. 6. Oscillations of the turning angle of the elements of an articulated vehicle depending on the variant of the steering system geometry

The conducted simulations demonstrate those variants 3 and 5 reached unfavourable and the highest amplitudes of the oscillations. The geometry of the steering mechanism in variants 2 and 4 differs slightly – by the length of the AB section and they yielded similar results. Oscillations in the steering joint have a significant impact on the motion trajectory of an articulated vehicle. Fig. 7 presents the motion trajectory of the geometric centre of the vehicle front axle.

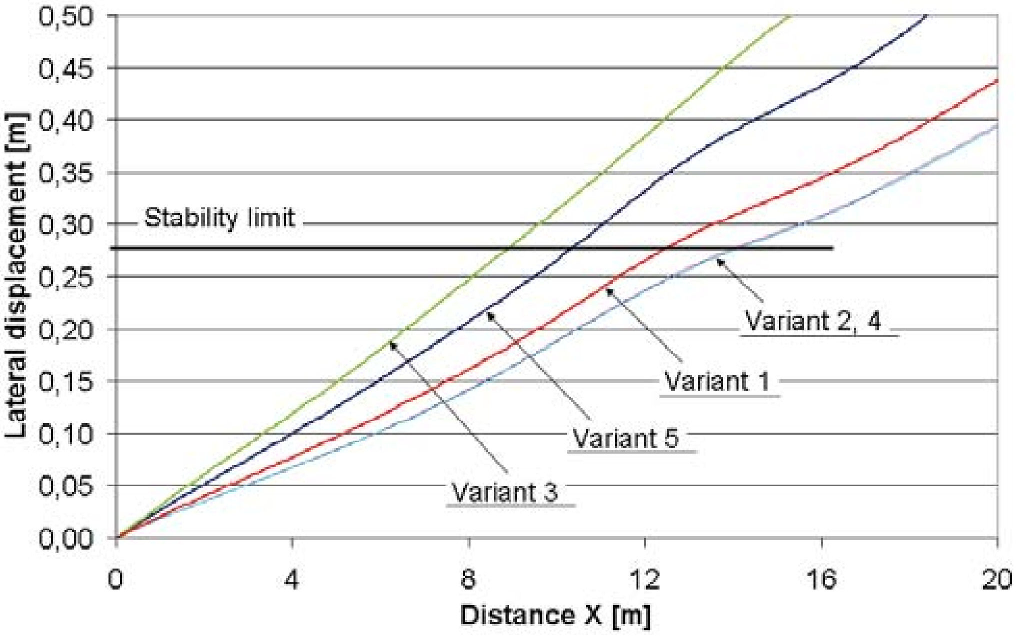

Fig. 7. The achieved motion trajectory of the vehicle depending on the steering system type

The investigation demonstrated that the longest distance, in the standardized area, was covered by the vehicle with the steering system of variants 2 and 4. It also reached the smallest oscillation amplitudes of the elements assuming identical simulation conditions. This proves the impact of the steering system geometry on its equivalent structural stiffness. It may be noted that the amplitude of oscillations decreases as the force arm of steering hydraulic cylinders marked with the symbol r in Fig. 5 increases. The steering systems of articulated vehicles should be designed in such a way that the force arm should be as long as possible.

An important task performed by steering systems of vehicles, besides the stabilization of the sections of the vehicle for motion forward, is also the possibility to give a new direction of motion. Changing the direction of the motion is possible only when steering cylinders transform their progressive motion into the mutual circumvolution of the sections. Such investigations are shown in [2]. In order to achieve this purpose the ground resistance forces when turning have to be overcome. The available torque, generated by the steering cylinders, depends among other things on their mutual placement, which changes as the turning angles of the elements increase. Increasing the turning angle to the maximum value (complete turning of the vehicle) decreases the available torque while turning resistance moments often increase. The improvement investigation of the articulated frame steering systems [2] demonstrated that the greatest available torques possible to be achieved occur at the geometry of the steering system which is a trapezoid ABCD (Fig. 5) with a possibly large difference between the bases. The system designed in this way provides the possibility to achieve large ratio angles CAP and DBP, which minimize the forces necessary to ensure the possibility to steer within the full range of the vehicle turning.

3. Summary and conclusions

The proper selection of the geometry of the steering system is crucial both to achieve the rectilinear direction of the motion of articulated vehicles (stabilization of significant masses of the front and rear sections) and to give a new direction of the motion of the vehicle (achievement of relatively large turning moments).

Many structural parameters of the vehicle affect the horizontal motion stability of an articulated vehicle. Many of them can be adjusted at an early stage of the vehicle design.

Investigations demonstrated that the change of the steering system geometry significantly affects the achieved equivalent stiffness of the entire steering system. The geometry of the steering system has to be selected in such a way that the difference between the bases of the trapezoid ABCD is the largest. It is also crucial that the revolute joint of vehicle sections is located in such a position that the force arms are the longest. It has been demonstrated that the stiffness of the steering system significantly affects the oscillation of the elements and the motion trajectory of the vehicle.

References

[1] Skurjat, A., *Modelowanie procesu stabilizowania ruchu pojazdu przegubowego na podwoziu kołowym*, praca doktorska, Instytut Konstrukcji i Eksploatacji Maszyn, Politechnika Wrocławska, 2009.

[2] Dudziński, P., *Lenksysteme für Nutzfahrzeuge*, Springer-Verlag, 2005.

[3] Dudziński, P., Skurjat, A., *Badania wirtualne i eksperymentalne procesu stabilizowania ruchu przegubowego pojazdu przemysłowego na podwoziu kołowym*, Problemy Maszyn Roboczych, z. 32, 2008.

[4] PN-EN 12643+A1: *2009 Maszyny do robót ziemnych. Maszyny na kołach z ogumieniem. Wymagania dotyczące układu skrętu,* 2009.