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RESEARCH ON THE INFLUENCE OF GEOMETRIC PARAMETERS ON THE PHENOMENON OF SNAKING OF ARTICULATED VEHICLES

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Summary:

The article presents the results of own numerical research conducted to determine the influence of the differential, causing the occurrence of the non-uniform torsion of wheels on the same axle and the changes in the width of an articulated vehicle, on the changes of the angle in the turn joint leading to snaking. An attempt was also made to determine the influence of swaying on vehicle stability. The quantitative influence of the above mentioned factors has been determined. Analytical formulae are also presented.

Keywords:

snaking, articulated vehicle, movement stability, geometric parameters

INTRODUCTION

Articulated vehicles are a very large group of machines used in nearly branches of industry. Currently when they are used for special purposes, e.g. military, they move at speeds exceeding 50 km/h. Such vehicles also frequently operate in repeated cycles. The total time of a single cycle consists of simpler stages: lifting, rotation and turn gear operation, etc. Usually they do not exceed a few seconds. They can also be combined by a simultaneous turn and lifting a loader bucket. Unfortunately the time of the journey between the starting and the final point depends on the average speed achieved in a given cycle and this is the longest stage.

Achieving a high average speed means that the powertrain has to generate significant torsions so as to significantly increase acceleration.It is also important that the maximum speed is high.

A significant majority of heavy articulated vehicles uses a powertrain consisting of a torque converter (hydrokinetic), a gearbox in which it is possible to change velocity ratios under loading, differentials and wheel reduction gear. Theoretically the differentials distribute the initial torsion equally on both drive wheels. In practice, due to the existence of the internal friction torque, this distribution is not identical and a typical ratio of distributed torques is 0.55/0.45. The differences in the values of the drive torque for wheels on the same axle are not big, however, in the case of industrial vehicles with wheel reduction gear this inequality is multiplied by the velocity ratio of planetary gear (of wheel reduction gear). This results in the fact that particular wheels are driven by various values of torque and consequently there are various tangential forces at the contact place of a wheel and a surface. This irregularity of the tangential forces at both sides of a vehicle leads to the occurrence of torque which aims at turning one of vehicle frames and this results in the change of the angle in the turn joint and consequently to snaking. It can be observed that the use of the drive in the second section of a vehicle can generate torque whose direction will be the same or the opposite to the first section.

This article is an attempt to determine the influence of the differentials causing the non-uniformity of the driving torque of wheels and also the influence of using the drive of two and all wheels on the occurrence of snaking in articulated vehicles.

1. DETERMINATION OF THE UNBALANCED TORQUES OF A PROPULSION SYSTEM AND THE RESEARCH METHOD

The physical model of the vehicle and the adopted notation are presented in Fig. 1. Numerical research was conducted on the presented model while the equation of torque balance were formulated with reference to the turn joint:

$$MF = Ffcgy * xcgf - Ffcgx * yrcg +$$

$$(Fflx - Ffrx) * \frac{W}{2} + (-Ffry - Ffly) * xwfj$$

$$MR = Frcgy * xcgr + (Frly + Frry) * xwrj +$$

$$(Frlx - Frrx) * \frac{W}{2} + Frcgx * yrcg$$

$$\gamma = \frac{MF - MR}{k}$$

$$ML = (1 - Kb) * M_o$$

$$MR = Kb * M_o$$

$$Fl = \frac{MR}{r}$$

$$Fr = \frac{ML}{r}$$

where:

k = steering unit stiffness [Nm/rad];
Kb – coefficient of differential blocking [-];
ML, MR – driving torques of the left and right side of the vehicle [Nm];
M_o – driving torque set to the differential [Nm];
Fl, Fr – tangential forces exerted on the left and right wheel [N].

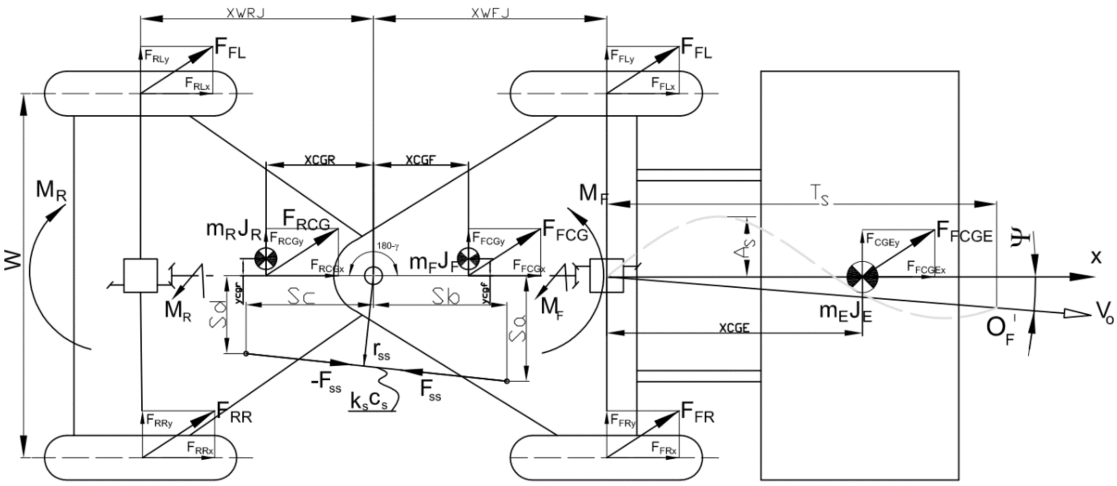

Fig. 1. Adopted notation of geometric parameters used in calculations

Source: own elaboration

The results of the presented research were analysed by the authors on the basis of the above equations. The model does not take into consideration dynamic factors related to frame inertia or interactions between wheels and the surface. The goal of the research was determining which of the tested parameters had the biggest influence on the changes of the angle of rotation in the vehicle joint. At a later stage the numerical model and research will be complemented with dynamic phenomena and the cooperation between the wheels and the surface.

2. RESEARCH ON THE INFLUENCE OF GEOMETRIC PARAMETERS ON THE CHANGES OF ARTICULATION ANGLE γ

Industrial vehicles use various types of differentials. They can be divided with regard to e.g. the type gearwheels: bevel, cylindrical or worm (e.g. TorSen). Between the rotating elements there is friction as a result of which the distribution of torques on wheels is not balanced. The internal friction torque $M_t$of traditional differentials is about 5-6%M_o. In the case of machines moving on unpaved roads increased friction constructions: M_t=25, 45, 50, 75%M_o are frequently used.It results from the fact that the decisive factor influencing the tractive forces of a vehicle is a wheel moving on a surface with a lower adhesion coefficient or smaller feed force. In an ideal differential (M_t=0) the drive torques of both wheels are equal. In reality (M_t≠0) the value of the total drive torque of one of the wheels is 0.5 M_o+ $M_t$while for the other one located on the opposite side it is 0,5 M_o-M_t. One of the wheels receives a bigger drive torque than the other whose torque is reduced by exactly the same value. It follows that the use of a differential with increased internal friction allows for the fuller exploitation of the adhesion coefficient and approximates the moment of achieving the rigid axle effect. On the other hand the use of mechanisms with a high value of M_t in vehicles contributes to a decrease in traffic safety. The differentiation of the rotational speed of wheels moving along a road-bend is possible when the value of torque difference for both the internal and external wheels is higher than M_t. Before this takes place, the wheels move with higher wheel slip.

The coefficient of differential blocking is defined as: K_b=M_2/M_1 (ratio of wheel torsion delayed to acceleration). In the case of mechanisms with bevel and spur gear K_b=1,08÷1,2, movable axes of planetary gear and a multi-disc clutch K_b~4, helical and bevel gear K_b=8÷15 [4, 5].

The results of the author’s research on the influence of the coefficient of differential blocking on the value of the angle in the turn joint is presented in Fig. 2. For the rear drive and in Fig. 3 for the front-wheel drive.

The research conducted on the rear drive showed that for typical values of K_b the change of the steering angle in the joint adopts values from 0.25^o to 1^o depending on drive torque M_o. In the case of differentials with increased internal friction, the values of the deviations of the angle in the joint are bigger. It can also be observed that the values of deviations are bigger for the acceleration phase (large M_0) and when the need for drive torque increases.

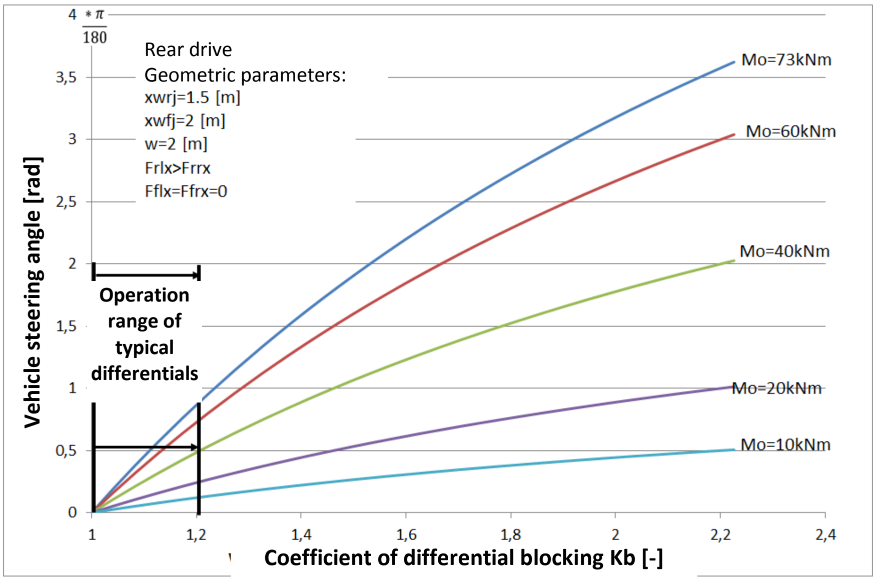

Fig. 2. Results of the research on the influence of the coefficient of differential blocking Kb depending on drive torque M_o and rear drive

Source: own elaboration

The research results for the front-wheel drive are presented in Fig. 3.

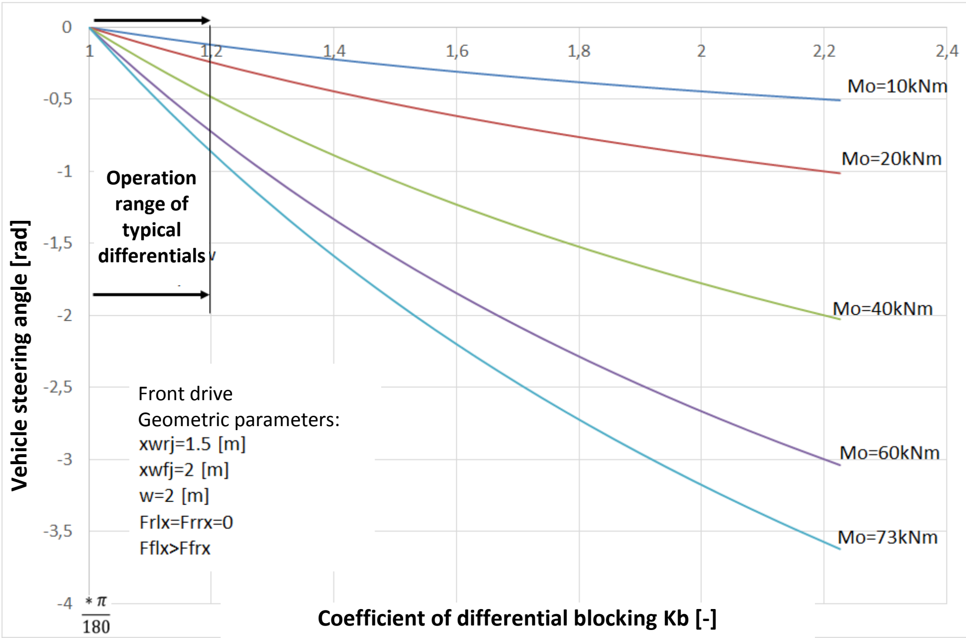

Fig. 3. Results of the research on the influence of the coefficient of differential blocking Kb depending on drive torque M_o and front-wheel drive

Source: own elaboration

The research conducted for the front-wheel drive showed a similar dependence of the steering angle deviation to the rear drive. It should also be observed that in the case when the drive torque of both front and rear wheels on the same side of the vehicle increases (and consequently it decreases on the other side), there is no increase in the steering angle of the joint. However, the vehicle tends to turn because such a situation causes the occurrence of force couple and, as a result, the rotation of the whole vehicle due to wheel skid. The use of the front-wheel drive, even in the situation when it leads to the introduction of the steering angle of the vehicle, is a more beneficial solution because the rear part of a vehicle will follow the front section and the vehicle will "straighten" in the turn joint. The research results confirm the results published earlier, e.g. in [1, 2, 3], where the front-wheel drive contributed to motion path stabilisation.

Fig. 4.presents the influence of the changes of differential blocking $K_b$in the case of a four-wheel drive.

As expected, the increase in the value of static forces of diagonally opposed wheels results in obtaining larger steering angles between vehicle sections. It can be observed that the intensity of this phenomenon grows with the value of torque M_o. For M_o=10kNm and K_b=1.2 the value of the vehicle steering angle was grew two-fold when 2x4 drive was used. It should be observed that the model did not take into account the phenomenon of power circulating which can lead to obtaining an even larger vehicle steering angle.

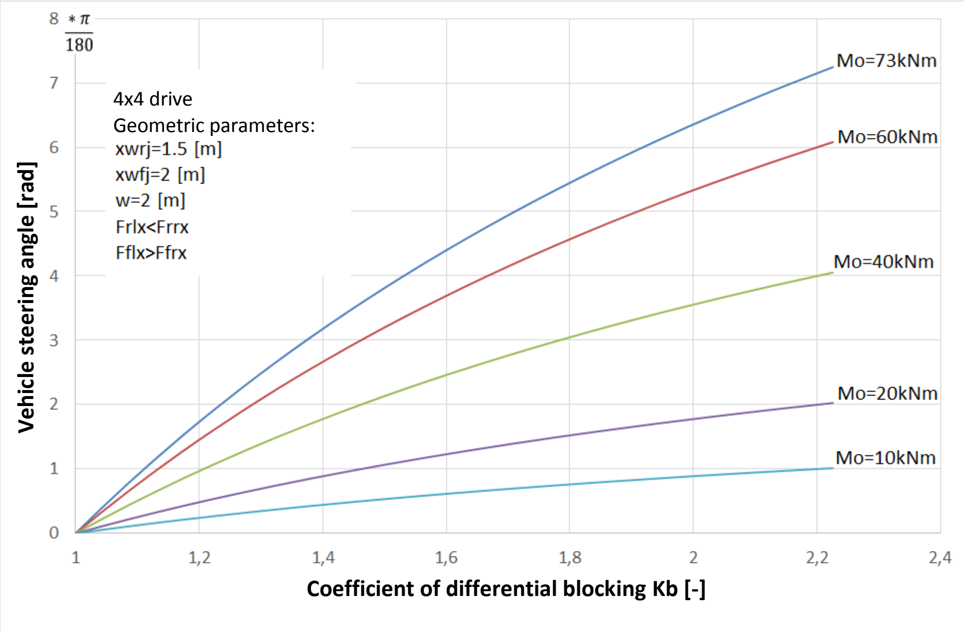

Fig. 4. Results of the research on the influence of the coefficient of differential blocking Kb depending on drive torque M_o and four-wheel drive

Source: own elaboration

Fig. 5 presents the results of the research on the influence of vehicle width and drive torque on the changes of vehicle steering angle.

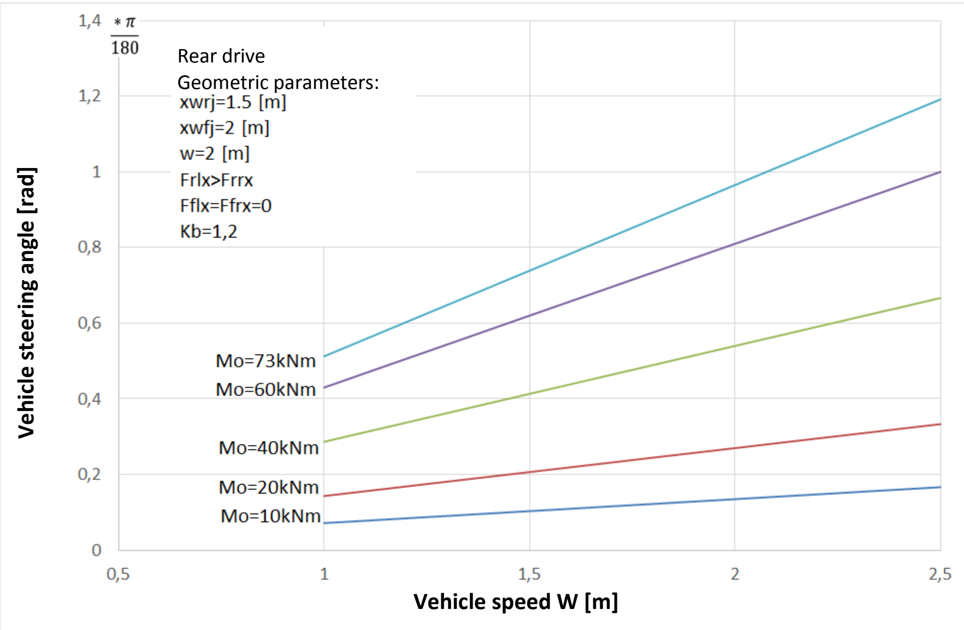

Fig. 5. Results of the research on the influence of vehicle width depending on drive torque Mo and rear drive

Source: own elaboration

The research results showed that the value of side accelerations had an influence on angle oscillations in the turn joint. Even small values of side shifts on the rubber profile of a tyre result the changes of the steering angle of a vehicle in the range of $0.5^o$to over 2.7^o and the grow with the increase in vehicle weight. In the research the assumed values of the side shift amplitude was ±5cm ($a=0.1\ m/s^2$).

The above analyses do not take into consideration the presence of transverse forces which also influence the achieved values of the vehicle steering angle. Such forces occur during the real motion of a vehicle as a result of its shifting on slopes, rough terrain, etc. Their mathematical description is complex and requires the introduction of a tyre model as well as their contact with the surface.

CONCLUSIONS

The research conducted on a simple mathematical model showed that the changes of the vehicle steering angle had a significant influence on the type of the used differential (internal friction torque) and the value of applied drive torque. Frequently there are also compromises: the use of differentials with increased internal friction allows to obtain better traction properties on unpaved roads. It leads, however, to problems in obtaining higher speeds on paved surfaces.

The research showed also that vehicle sway, caused by the use of big radius wheels and high rubber profile, introduced side acceleration. The latter ones, in turn, generate additional forces which result in the oscillation of the angle in the turn joint. This phenomenon becomes more and more intense with the increase in xwrj and xwfj lengths, i.e. the distance between the joint and the front and rear wheels.

The changes in vehicle width also have an influence on the changes of the angle in the joint. For small values of drive torque M_o =10kNm the angle differences are about 0.1^o, which is a small value, while at M_o =73kNm the value of the difference is as much as 0.7^o. It can be assumed that the increase in vehicle width contributes to the phenomenon of snaking.

However, the biggest influence on the changes of steering angle was exerted by side accelerations and here the achieved value was $\gamma=(0.5^o \div 2.7^o)$ depending on the weight of a vehicle, next the four-wheel drive for which $\gamma=(0,5^o \div 1,8^o)$ depending on M_o. The difference in the steering angle for the front-wheel and rear drive was$\gamma=(0.2^o \div 0.8^o)$ depending on the value of the drive torque. Vehicle width had the smallest influence, $\gamma=(0.1^o \div 0.7^o)$.

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BIOGRAPHICAL NOTE

Piotr DUDZIŃSKI - Prof. Dr. hab. Eng., Full Professor of the Wroclaw University of Science and Technology, Head of the Department of Machines and Industrial Vehicles Engineering, author of about 300 national and international research papers. His main areas of interest include machines and work vehicles, in particular their cooperation with any surface, and widely understood circular, track and unconventional drive systems. Member of the International Expert Group Muencherer Kreis. Author of about 30 patents including international ones: Germany, the United Kingdom, Italy, the USA and Japan, several of which were awarded with gold medals at the International Innovation Fairs in Brussels and Geneva. He cooperates with companies and institutions in Poland and abroad.

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