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IMPACT OF PRESSURE LOSS IN STEERABLE TYRE WHEEL ON STEERABILITY OF FOUR-AXLE SPECIAL PURPOSE VEHICLE

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The authors of this paper took a part in a government research project on the behavior of a military AFV after an explosive damage to its tires, which inter alia aims to assess its motional abilities, also in terms of ensuring the safety of the crew. The results presented hereto refer to a part of preliminary experimental studies on a four-axle vehicle with a total weight of 22,000 kg and a length of 8m, carried out in the situations of a substantial or complete loss of tire pressure in the first steerable wheels axle. A significant influence of the total pressure loss in the drivability of the vehicle has been proven.

Keywords: *AFVs, tires, pressure, damage, steady state circular test, steerability characteristics, double lane change, loss of lateral stability*

INTRODUCTION

A partial or complete loss of pressure in the vehicle tires undoubtedly and in certain way influences the motional properties of the vehicle. In extreme conditions, there may be a sudden loss of tire pressure, commonly called a tire blow-out. Such an emergency situation could pose a big threat to the safety of the driver and the passenger crew of the vehicle. This condition may occur in both civilian and military vehicles. In all the cases described herein, the driver, despite his surprise, must master the vehicle and perform appropriate maneuvers so as not to lead to the vehicle roll-over or another dangerous in its consequences accident, associated with an unexpected, self-change of the motion trajectory.

Statistical data on civilian vehicles, published, for example, in the United States of America, indicate a high number of road accidents caused by a tire blow-out that killed or injured many thousands of people. In many countries, such statistics are not maintained, although they would provide the basis for presentation of the severity of the problem on a global scale.

The topics of research studies on car traffic in extreme conditions are considered by inter alia North American centers, mostly the University of Michigan (UMTRI) [1], road accidents research associations and dynamics studies [2], [3], [5], as well as German centers (e.g. Daimler-Benz).

Many studies were published in 1960-1980. Later works include materials published in those years. The paper [1] focuses on comprehensive issues related to tire blow-outs in heavy trucks. A comprehensive analysis of professional literature has been carried out, which indicates a relationship between the actual accidents and defective drivable wheel tires, causing a major disruption in directional stability. Accidents of articulated vehicles happen more often when the left wheel tire blows out, and while this type of the defect in the right front wheel tire is more likely the reason for single-car accidents.

Simulation studies are also carried out. For instance, such studies for a model of a large passenger car with about 15 degrees of freedom are presented in [2]. The EDVSM simulator program was used. The results were compared with the experiment. Experimental studies were performed at speeds of about 102 km/h (63 mph and 65 mph) while driving straight ahead and on the curve.

The authors of this paper participated in the government research project on the behavior of a military AFV after an explosive damage to its tires, which aims to assess its motional abilities and also to ensure the safety of the crew. The results presented in the body of the paper are part of the preliminary experimental studies of this type of vehicle, carried out in the situations of a substantial or complete loss of pressure.

1. DESCRIPTION OF EXPERIMENTAL TESTS CONDUCTED

A four-axle special purpose vehicle with a length of 8 m and a weight of 20 250 kg, with dimensions of a multi-purpose tire at 14.00R20, with a nominal internal pressure of 5.3 bar. The outside axles spacing is 4.55 m. The mass distribution among individual axles: the first (steering) x the second (steering) x the third x the fourth = 6100 x 5200 x 4960 x 3990 kg.

Fig.1 illustrates a state of emergency of the left wheel of 1st steering axle with a part of the suspension. A two-parameter head of the Correvit contactless system was also presented for measuring the velocity vector components at the point close to the center of the contact with the road, thus allowing to determine the wheel slip angle. The heads were mounted to both wheels. However, in the event of research studies on the loss of pressure, only the head at the opposite wheel was kept, because of the apparatus security.

The steady state circular test using a fixed control method [9] and a test of a double lane change, based on the procedure of NATO Allied Research Procedures [11] were performed.

Diagram of the track is illustrated in Fig. 2, and the dimensions in Table 1.

The following quantities were inter alia measured and recorded during the tests: longitudinal and lateral components of the velocity vector of the vehicle center of inertia (V_{LV}, V_{QV}), the vehicle yaw velocity ($d\psi/dt$), roll velocity ($d\varphi/dt$), steering wheel angle (δ_H), moment on the steering wheel ($M_{\delta H}$), longitudinal and lateral components of velocity vectors of 1st steerable wheels axle (V_{Lrw}, V_{Llw}, V_{Qrw}, V_{Qlw}, respectively). In addition, components of linear accelerations vector of the vehicle center of inertia, the other components of the angular velocity vectors and the vehicle position angle.

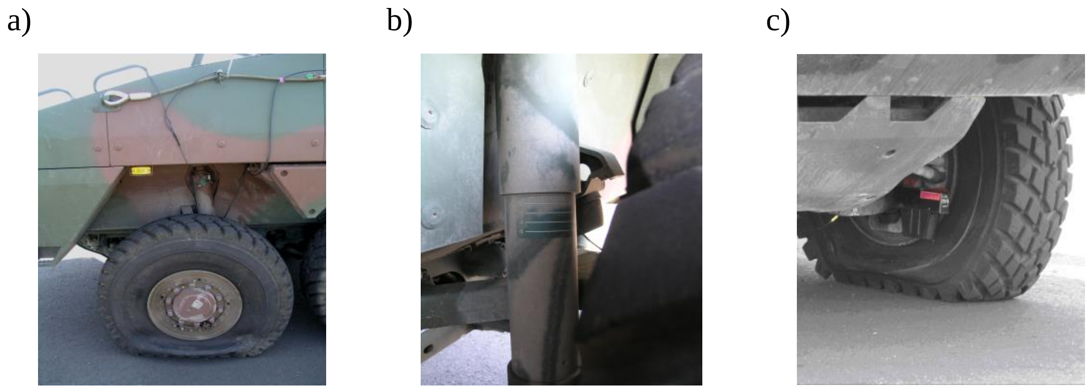

Fig. 1. State of the failure of the left wheel of 1st steering axle, following the total loss of pressure: a) side view, b) view of the hydro-pneumatic column of wheel suspension, c) view of two-parameter head of the Correvit system, mounted to the wheel swivel axle to directly measure the wheel drift angle

Source: Own elaboration

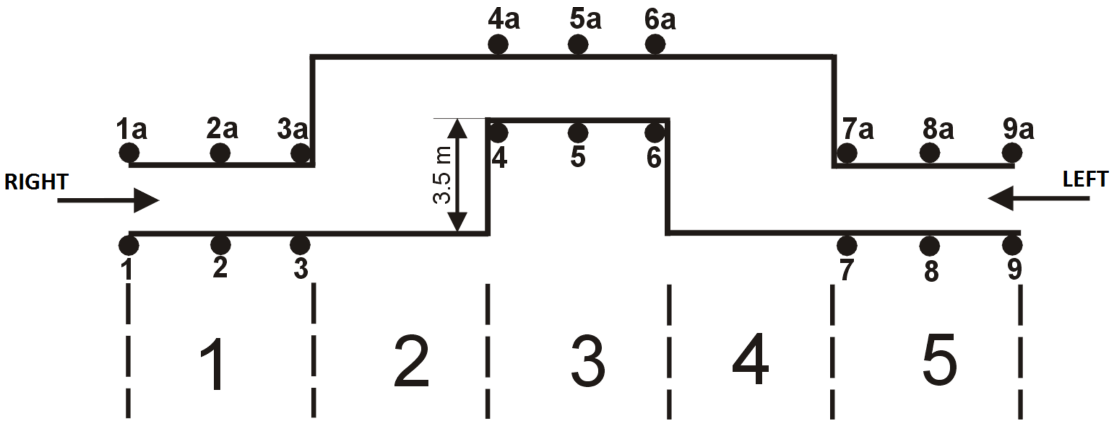

Fig. 2. Diagram of the track to the double lane change maneuver

Source: [11]

Table 1. Diagram of the track

Section Number	Length	Width	Remarks
1	15 m	1.1 x B + 0.25 m	B – AFV width L – AFV length (overall vehicle length measured at 0.5 m above the ground)
2	L+24		
3	25	1.2 x B +0.25 m	
4	L+24		
5	15 m	1.1 x B + 0.25 m	

Source: Own elaboration

Here are the measuring instruments used: 3002 RT Inertial and GPS Navigation System, two-parameter steering wheel MSW-2 S/N 103-4243 Datron-Messtechnik, the CORREVIT system heads (for contactless measurement of the velocity vector components of a selected point in the vehicle), wire transducers for a system to measure the turn angles of the wheels. The quantities were recorded in the GPS system device and in the recorder HIOKI 8847 Memory HiCORDER.

2. PERFORMANCE TEST RESULTS AND THEIR ANALYSIS

The relation of the steering wheel turn angle changes in the lateral acceleration function was determined indirectly by using changes in a radius of the center-of-inertia track. Assuming that the radius of the track is much higher than the distance between outer axles, the following formula may be provided for the simplified flat model:

$$\text{deltaH-deltaHA}=(\text{deltaH0})\cdot(1-(\text{Ro}/\text{R}))[\text{rad}] \qquad (1)$$

where:

deltaHA – the steering wheel angle at lateral acceleration a_y=0, referred to as the Ackermann angle,

(deltaH$_0$) – constant angle of the steering wheel,

R0 – initial radius of the track,

R – running radius of the track.

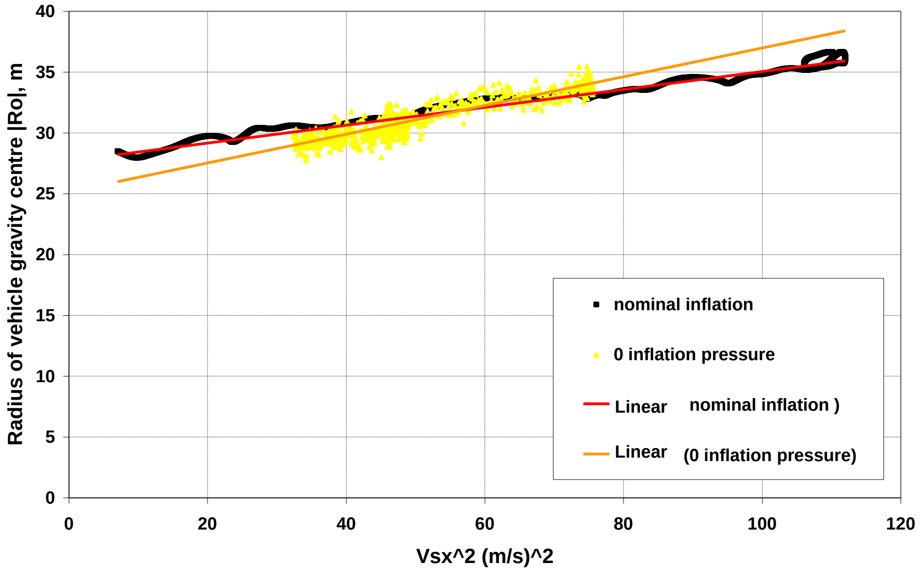

Fig. 3a. The results of steady state circular test. Right side turn. The calculated and approximated runs of radiuses (R$_0$) of vehicle center-of-inertia trajectory for nominal and 0 inflation pressure in left front axle wheel. Vsx – x component of vehicle's velocity in intermediate axis system.

Source: Own elaboration

The runs of radiuses of trajectory of vehicle center-of inertia (Fig. 3a) indicate a change in vehicle steering characteristic. When there is a lack of pressure in the left wheel tire of the front axle than the upper mentioned radius increases. The slope of the straight line approximating the run of radius is almost twice as big as for a vehicle with nominal pressure in that wheel. It means that the vehicle understeering increases (see Fig. 4).

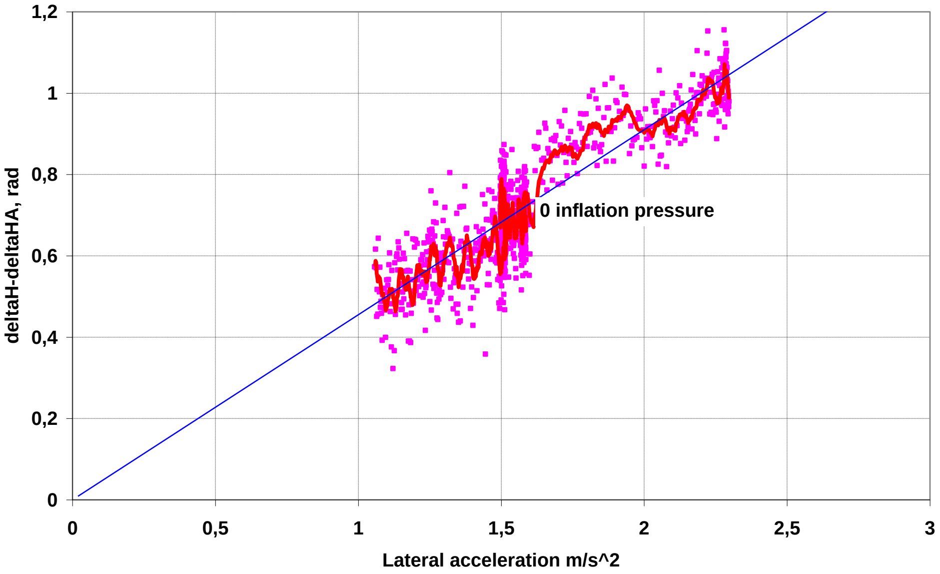

Fig. 3b. The steering wheel angle increase processes as lateral acceleration function for the vehicle with no pressure (0 inflation pressure) in the front axle left wheel tire.

Source: Own elaboration

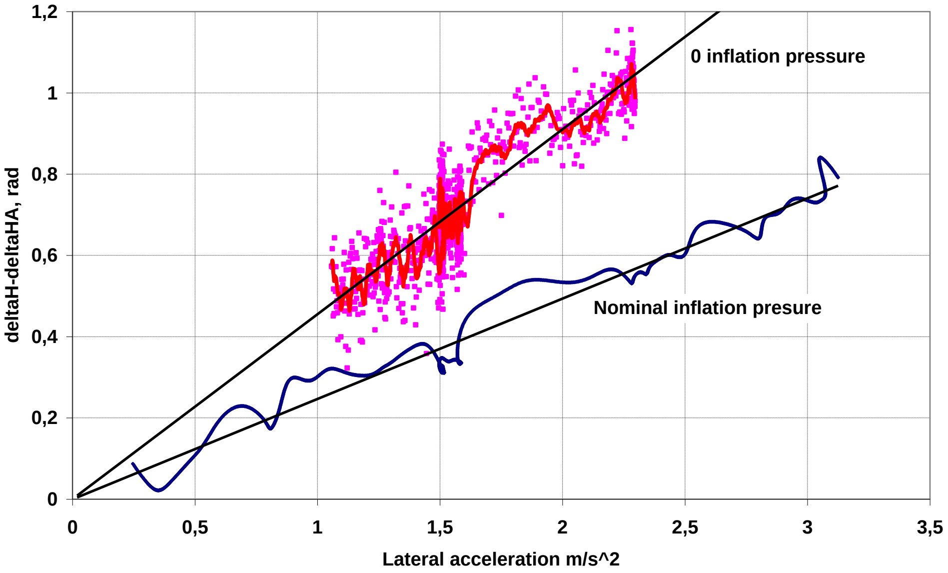

Fig. 4. Comparison of the steering wheel angle increase processes in the lateral acceleration function for the roadworthy vehicle (nominal inflation pressure-bottom lines) and for vehicle with no pressure in the wheel tire (upper lines).

Source: Own elaboration

Changes of radiuses of trajectory of vehicle center-of inertia require corrections of the vehicle’s motion on the path. These corrections must be performed by the driver with the steering wheel in order to keep the vehicle on the desired curvilinear motion path. It is shown on Fig. 4. Attention must be drawn to the fact that when there was a lack of pressure in left wheel tire only a part of the run was shown. It is due to the fact that both in the initial stage of motion as well as when the lateral acceleration was higher than 2.5 m/s^2 the vehicle was unstable.

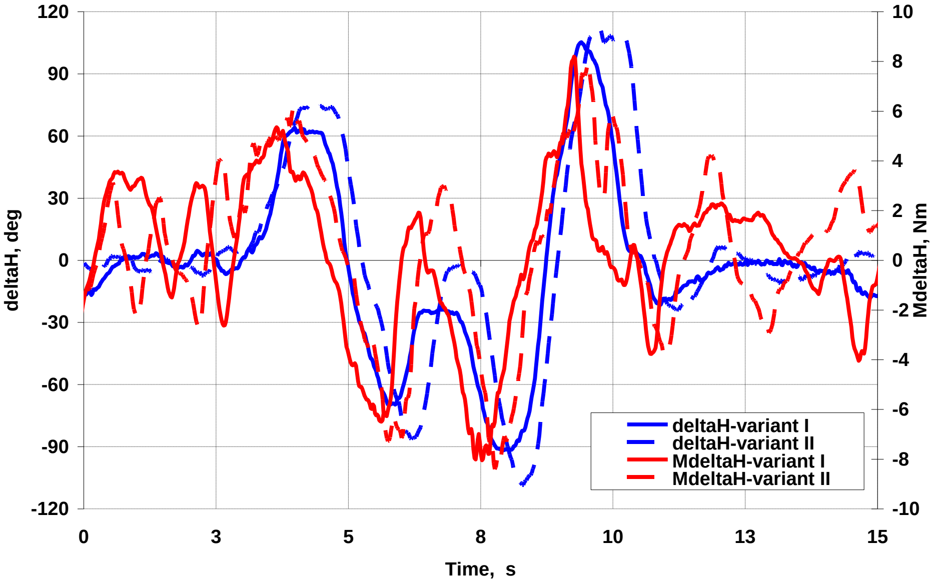

Fig. 5. Comparison of the steering wheel angle increase processes and the response of moment on the steering wheel in time function. Variant I-nominal inflation pressure, Variant II-inflation pressure 2.0 bar

Source: Own elaboration

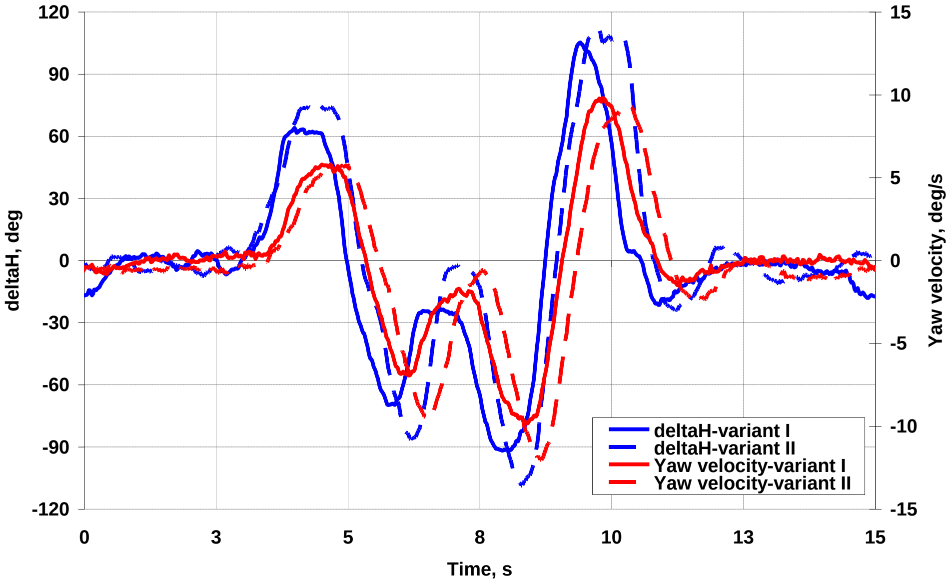

Fig. 6. Comparison of the steering wheel angle increase processes and the response of yaw velocity of the vehicle in time function.

Source: Own elaboration

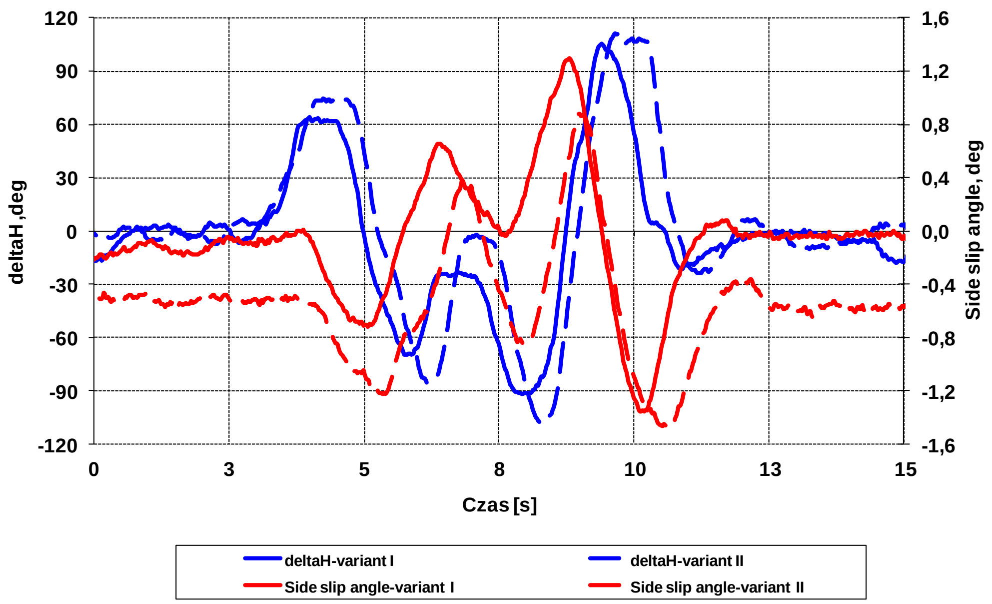

Fig. 7. Comparison of the steering wheel angle increase processes and the response of side slip angle of the vehicle in time function.

Source: Own elaboration

Dynamic runs are shown in Fig. 5-7. Double lane change manoeuver was performed with the speed of 50 kmph. After comparing the runs of the adequate quantities a conclusion can be drawn that the change of pressure in a tire (variant II) caused difficulties in driving the vehicle along the section 5 of the path (see Fig. 2) The driver had to perform correction movements with the steering wheel in order to make the vehicle move along a straight path. Fig. 5 and 6 show the oscillations of runs of steering wheel angle, steering wheel moment and yaw velocity, corresponding to this section of trajectory. Fig. 7 shows the side slip angle in both variants of the research.

CONCLUSIONS

The following conclusions can be drawn on the basis of the performed research.

1) For the vehicle with the left wheel of first axle after the loss of pressure, the understeering significantly increased. For lateral acceleration higher than 2.5 m/s^2 the vehicle was unstable. In reality such a value of acceleration is seldom reached by vehicles of this type. It is possible only during fast driving along sharp curves.

2) The tests of the vehicle in variant II during double lane change manoeuver (which was the simulation of overtaking manoeuver on a road) showed some difficulties in making the vehicle move straight ahead after the second change of a lane. The driver had to perform additional correction movements with the steering wheel.

3) The general assessment of the vehicle's behaviour in an emergency situation is positive. After the loss of pressure in one of the wheels of the front axle, the vehicle doesn't cause any major difficulties for a driver as well as for its crew.

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REFERENCES

1. Bareket Z., Blower C., *Blowout Resistant Tire Study for Commercial Highway Vehicles,* Final Technical Report for Task order no. 4, UMTRI-200-28, August 2000.
2. Blythe, W., Day, T., Grimes, W., *3-Dimensional Simulation of Vehicle Response to Tire Blow-outs,* [in:], „SAE Technical Paper", paper no 980221, 1998, doi:10.4271/980221.
3. Aurell H.E., Nordmark S., *Truck driver behaviour in critical situations and the impacy of surprise. A Pilot study of a sudden blow-out of the front axle of a heavy truck.* Proceedings of DSC Conference Driving Simulation Conference. Paris, France. October 4-6, 2006, p. 285-294.
4. Pieniążek W., *Indicators of the lateral stability of heavy articulated vehicles,* AUTOPROGRES 2006, Conference Materials.
5. Pieniążek W., (co-authors. Z. Bielecki i W. Grzegożek), *Experimental Research of the Movement of Multiaxle Vehicles*, [in:] „Papers of the Symposium MVM '90", Kragujevac 1990.
6. Motrycz G., Stryjek P., *Problems in assessment of parameters of 8x8 vehicles in the circular motion method*, [in:] „Logistics Magazine", no. 2/2010, p.1929-1938.
7. Motrycz G., Stryjek P., *Problems in assessment of stability and drivability of AFVs during the double lane change maneuver,* [in:] „Logistics Magazine", no. 4/2010, p.1929-1938.
8. Simiński P., *Experimental studies of the 8x8 vehicle in circular motion and for the double lane change maneuver*, [in:] „Technical Magazine", no. 6/2008, Publication of the Cracow University of Technology, p. 85-95.
9. ISO 14792 *Road vehicles – Heavy commercial vehicles and buses – Steady state circular test,* First edition 2003-09-01.
10. ISO 14793 *Road vehicles – Heavy commercial vehicles and buses – Lateral transient response test methods*. First edition 2003-02-15.
11. AVTP 03-160 W – „*Dynamic Stability of Motion" Allied Vehicle Testing Publication part I NATO AC 225* (panel II/WGE 3).
12. Motrycz G., Stryjek P, *Influence of the wheeled AFV (KTO) structural design changes on the lateral dynamic stability of the motion,* [in:] „Journal of Science of the gen. Tadeusz Kościuszko Military Academy of Land Forces", no 1/2012, Wroclaw 2012, p. 192-203.

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WPŁYW UTRATY CIŚNIENIA W OGUMIENIU KOŁA KIEROWANEGO NA KIEROWALNOŚĆ CZTEROOSIOWEGO POJAZDU SPECJALNEGO

Streszczenie

Autorzy niniejszej pracy uczestniczyli w rządowym projekcie badawczym dotyczącym problemu zachowania się transportera wojskowego po eksplozyjnym uszkodzeniu ogumienia, który miał na celu, między innymi, ocenę jego możliwości ruchowych, w aspekcie zapewnienia bezpieczeństwa załogi.

Przedstawione wyniki dotyczą fragmentu wstępnych badań eksperymentalnych pojazdu czteroosiowego o masie całkowitej 22.000 kg i długości 8m, przeprowadzonych w sytuacjach znacznej lub całkowitej utraty ciśnienia w ogumieniu koła pierwszej osi kierowanej. Wykazano znaczny wpływ całkowitej utraty ciśnienia na kierowalność pojazdu.

Słowa kluczowe: *transportery opancerzone, opony, ciśnienie, uszkodzenia, ustalona jazda po okręgu, podwójna zmiana pasa ruchu, charakterystyki kierowalności, utrata stateczności poprzecznej*

BIOGRAPHICAL NOTE

Grzegorz MOTRYCZ, MSc, Eng, – graduated from the Military University of Technology. Over the last years he has been involved in the safety and steering ability of vehicles. He is an author of numerous articles and a co-author of a monograph concerning the steering ability of military vehicles. Last time he was the main executive of several research and development projects related to the dynamics of military vehicles.

Wiesław PIENIĄŻEK, PhD, – was a research scientist and lecturer at Cracow University of Technology for many years. A specialist in vehicular road measurements. He participated in many research projects concerning steerability and stability of automobiles. He is the author of significant publications in the field of measurements and result analysis of vehicular dynamics. He cooperates with many leading institutions within motor industry.

Piotr STRYJEK, MSc, Eng, – graduated from the Warsaw University of Technology. He is currently employed at the Military Institute of Armour and Automotive Technology. Head of the Laboratory of Combat Armored Vehicles. Over the last years he has been involved in research and development projects and tests of military vehicles. An author or a co-author of several articles and a monograph concerning military and special purpose vehicles. He is a member of the National Standards Body in Poland: the Technical Committee of Tires and Vehicles.