# SHOCK ABSORBER EFFICIENCY MEASUREMENT IMPACT OF TYRES TYPES AND PRESSURE

**KRISTINA KEMZŪRAITĖ[1], VIDAS ŽURAULIS[2], DARIUSZ WIĘCKOWSKI[3]**

Vilnius Gediminas Technical University, Automotive Industry Institute (PIMOT)

## Summary

The paper offers analysis of the effect of different types of tyres and tyre inflation pressure on the measurements of shock-absorber efficiency. Testing was carried out in accordance with the EUSAMA method for testing shock-absorbers' efficiency using test stand "Safeline 400/800". Literature review presents a survey of the most up-to-date studies regarding the topic under consideration in this particular paper. For the purpose of research, heavily used summer tyres and slightly worn winter tyres were selected. The effect of air pressure in tyres (varied in range of [1.6 … 3.0] bar) on the variation of shock-absorber efficiency has been assessed. The correlation between vibration inducing platform and vertical acceleration of the wheel has been examined. Findings obtained through research are depicted graphically. Results about shock absorbers efficiency variation because of the tyres types and pressure and wheel's replication of the vertical acceleration of the vibrating test plate are summarized and conclusions are drawn at the end.

**Keywords:** correlation, efficiency, EUSAMA, shock absorber, tyres, tyres pressure

## 1. Introduction

A vehicle suspension encompasses fundamental components of an automobile and represents a highly vulnerable part in the structure of a vehicle. The structure of the vehicle suspension is supposed to ensure sufficient features of tyre grip between the wheel and road surface, driving comfort and traffic safety.

The critical function of a suspension is to dampen body (sprung mass) vibrations coming through wheels from the surface of a road. The shocks continuously occurring due to roughness and irregularities of a road, cause damage to conjunctive components of a suspension, whereas suffered huge loads lead to decreased lifetime of resilient components. The condition of suspension parts determines not only driving comfort

[1] Vilnius Gediminas Technical University, Department of Automobile Transport, J.Basanavičiuas 28, 03-224 Vilnius, Lithuania, e-mail: kristina.kemzuraite@vgtu.lt

[2] Vilnius Gediminas Technical University, Department of Automobile Transport, J.Basanavičiuas 28, 03-224 Vilnius, Lithuania, e-mail: vidas.zuraulis@vgtu.lt

[3] Automotive Industry Institute (PIMOT), ul. Jagiellońska 55, 03-301 Warsaw, Poland, e-mail: d.wieckowski@pimot.org.pl, tel. +48 22 777 70 92

but also operating safety of a vehicle. Almost all modern cars have a suspension of a specific structure built in that includes components featuring particular rigidity and damping characteristics. For this reason, the body including all its built-in equipment, as a sprung mass, has a particular freedom of movement with respect to the suspension components and wheels. Although shock-absorbers are usually considered to serve as main damping components, the prime part of a vehicle that responds to roughness of a road and dampens shocks delivered to its body is tyres inflated with pressurized air. Consequently, when examining variation in efficiency of a vehicle shock-absorber as of a component of a vehicle, while restraining from disassembling the object under research, it is highly important to simulate the actual operation of a suspension on a road as precisely as possible.

Generally speaking, determination of shock-absorber efficiency uses several different methods for shock-absorber testing.

Method of swinging [1]. This method is good for determination of only approximate condition of shock-absorbers. It is based on the measurement of velocity of shock-absorber movement while simulating swings of a vehicle. However, this method is neither precise nor good. It is more suitable for the subjective assessment of the condition of shock-absorbers.

Drop test. This method uses a mechanism of car dropping that simulates a damping of a single axle of a vehicle when overcoming a single obstacle. Based on this, the condition of a suspension is determined afterwards, i. e., this method is used to assess how fast oscillations of the suspension cease.

Method of comparison of resonant amplitudes. This one is absolutely different from those previously mentioned methods. Each wheel of a vehicle is being moved separately at the frequency of 15 Hz, and motion path is recorded on the round-shaped paper disk. Assessment of the suspension condition is strictly linked to the comparison of data of each wheel. For this reason, it is necessary to make sure that components of the suspension (springs, tyres, and shock-absorbers) have not been modified or, if modified, that they feature the same characteristics.

EUSAMA and BOGE represent the most popular methods for testing of shock-absorber efficiency. They facilitate the assessment of technical state of shock-absorbers in terms of reliability – good or bad. The core of EUSAMA testing method is safety of a vehicle, which is usually defined in terms of tyre grip on road surface. In a course of testing, EUSAMA value is measured as a minimum percentage of remnant vertical tyre contact force between the tyre and the vibration platform during vertical oscillation of the wheel.

When assessing shock-absorber efficiency based on EUSAMA method, the component of a vehicle in contact with the vibrating platform is considered to be an unsprung mass (tyre). As it was mentioned above, vibrations occurring due to road surface are mainly received through tyres and only afterwards transferred into suspension and body. Depending on the air pressure in tyre, this structural component may respond differently to wheel contact force under both actual driving conditions and during testing. The novelty of this research involves assessment of tyre damping and is aimed at examining the effect of air pressure in tyre on the EUSAMA measurement results of shock-absorber efficiency.

## 2. Literature review

Majority of researchers are involved in examining noise issues caused by tyres. For example, analysis of the noise caused by tyre oscillations and its propagation due to the tyre surface response to the roughness of a road [2]. Paper [3] presents an ordinary 3D method for forecasting random tyre vibrations, consequently, both internal and external noise caused by these tyre/road excitations. Road roughness is modelled from the spectral density of a common road profile supposing the road to be an isotropic surface. Paper [4] characterizes critical parameters of road roughness having the effect on the vibrations of tyre tread, and offers information regarding reduction of noise caused by tyre/road excitations. The effect of road roughness on tyre vibrations is evaluated in detail using the model of a contact between the tyre and road.

Reviewing the established studies on a tyre vibration shows that they have studied the plane vibration characteristics of the inflation pressured tyre by assuming the movement of tyre to be a round shaped shell [5].

Scientific literature also examines natural vibration frequencies of different types of tyres and their damping in the vertical direction. Modal parameters of tyres in the vertical direction were found using a method of frequency response function. Air pressure in tyres was varied. To achieve the theoretical natural frequency of oscillation and shape of the form, the plane of the tyre vibration has been modelled in a round shape. Results showed that experimental conditions can be considered to be criteria changing the natural frequency of oscillation and damping coefficient [6].

Vibration characteristics of the vehicle tyre driving over the obstacle (plate) have also been analyzed. The model of vehicle tyres has been verified using digital analysis and experimentally. The tyre of a car is assumed to be a 7 degrees of freedom system. The effect on the proposed tyre design factor is considered. This analysis result proved that the proposed tyre design factor reduced tyre and wheel vibration energy [7].

Based on the EUSAMA investigation method, Polish scientists [8], [9] examines the importance of dry friction force in suspension. A quarter-car model is proposed. Visual simulation was implemented in MATLAB-Simulink environment. Reported results of the scientific simulation model prove the influence on simulation results of EUSAMA method. Consequently, it is highly important to include such a damping into models intended for diagnostics of shock-absorbers condition.

It has also been studied the dynamic wheel load and rear axle vibrations of tyre inflation pressure and tractor velocity on. The experiments were conducted on an asphalt road and a sandy loam field at different combinations of tractor forward speeds and rear tyre inflation pressures [10].

The study of [11] investigates the effects of tyre inflation pressure and tractor forward speed on tractor vibrations. Investigation involves a tractor travelling at varied forward speeds with different tyre inflation pressures at different soil moisture contents. During experiments, using 3 accelerometers, accelerations of vertical vibrations were measured in front and rear axle as well as accelerations of tractor body vibrations in three axial directions. Results showed that vibrations were found to be particularly depended on the variation in tractor forward speed and rear tyre inflation pressure.

## 3. Model of the research

Fig. 1 presents the principal model of EUSAMA method. Using this method, wheel contact forces are measured in both directions (compression and decompression) enabling to evaluate the condition of a vehicle suspension more objectively. Adhesion is the property of a suspension to deliver the pressure on to the road or on vibrating plate. It is denominated [N] when travelling on a road or simulating road conditions.

The coefficient of relative damping effectiveness of shock-absorbers is expressed as follows:

$$WE = \frac{W_{\min}}{W_{st}} \cdot 100 \ \ [\%], \tag{1}$$

where: $WE$ – damping effectiveness; $W_{min}$ – minimal value of apparent wheel load on the plate during testing; $W_{st}$ – static value of the wheel load on the plate.

The state of shock absorbers is assessed based on the following principle:

$WE > 60\%$ – very good; $40\% < WE < 60\%$ – good; $20\% < WE < 40\%$ – adjustments required and additional check-up afterwards; $WE \leq 20\%$ – shock-absorbers must be replaced.

Tyres represent a highly important part of any vehicle. Tyres serve to dampen shocks received from road surface, support the weight of a vehicle, maintain or change the direction of a vehicle and transfer driving force and breaking.

The improper inflation pressure of tyres accounts for as much as 98 percent of defects. Insufficiently inflated tyres support lower vehicle weight by the air pressure present inside of them. The load on such a tyre is a reason for occurrence of higher contact area resulting in higher friction and heat.

Over- inflated tyres cause too much of the vehicle weight to be supported by the air pressure present inside of them. In this case the vehicle is bouncy and more difficult to control. The reason behind this is a small contact area of a tyre when practically only a central part of a tyre is in contact with the road surface.

In case of correctly inflated tyres approximately 95 percent of a vehicle weight is supported by the air pressure present inside of a tyre, and only 5 percent – by the tyre itself.

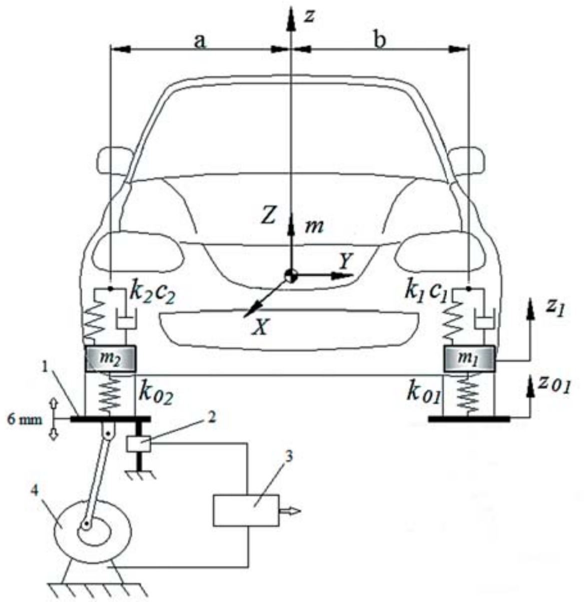


**Fig. 1. A half-car model for dynamic analysis and principal mode of EUSAMA method (on the left side): 1 – pad of the plate, 2 – tension sensor, 3 – data processing, 4 – vibration generator**

Analysis of a car vibration loads uses a dynamic half-car model (Fig. 1). This model takes into consideration vertical motions of unsprung ($m_1$, $m_2$) and sprung masses ($m$), respectively $z_1$ and $z$. Oscillations $z_{01}$ of the vibrating plate simulating irregularities of the road are passed to wheels. A dynamic half-car model can be assigned the following equations:

$$m_1\ddot{z}_1 - c_1\left(\dot{z} - \dot{z}_1\right) - k_1(z - z_1) + k_{01}(z_1 - z_{01}) = 0, \tag{2}$$

$$m_2\ddot{z}_1 - c_2(\dot{z} - \dot{z}_1) - k_2(z - z_1) + k_{02}(z_1 - z_{02}) = 0, \tag{3}$$

$$m\ddot{z} + c_1(\dot{z} - \dot{z}_1) + c_2(\dot{z} - \dot{z}_1) + k_1(z - z_1) + k_2(z - z_1) = 0, \tag{4}$$

where: $k_i$, $c_i$ – coefficients of suspension stiffness and damping on the respective sides of a car, $k_{0i}$ – stiffness coefficients of respective tyres in the direction $z$.

This model takes into consideration damping of tyre. Vertical force of a tyre can be calculated following linear function that takes into consideration deviations $\Delta z$, measured at the centre of the tyre:

$$F_z = k_{0i} \cdot \Delta z, \tag{5}$$

where: $F_z$ – vertical tyre force, $\Delta z$ – difference in vertical motion.

Stiffness of a tyre can be influenced by many different parameters. The most effective one is the pressure of tyre inflation. Whereas the stiffness, according to formulas, has the effect not only on the dynamics of a vehicle but presumably on measured effectiveness of shock-absorbers, too.

## 4. Research methodology

Testing was performed on the test stand "Safeline 400/800" intended for measurement of shock-absorbers effectiveness (Fig. 2). The Toyota Avensis car built in 1999 of the excellent working order has been selected for the research. The car had a McPherson strut type front suspension and was fitted with the 195/60R15 tyres. To assess the effect of different types of tyres on the measurements of shock-absorbers efficiency, winter tyres "BF Goodrich" non-intensively used for two seasons have been selected with the tyre tread depth of 7 mm, and relative hardness of rubber compound of 54 units in the scale of up to 100 limit (Fig. 3). Another selection included the set of summer tyres "Michelin Energy E3A" used for 7 seasons with the tyre tread depth of 3 mm, and relative hardness of rubber compound of 72 units (Fig. 4). Consequently, the tyres featuring different characteristics, age and wear-off level were selected for the research (yet suitable for exploitation). Before the testing, defect investigation of the tyre on the wheel rim was performed (Fig. 5). Tyres characteristics are shown as information, but the main subject-matter is tyre pressure.

Vertical acceleration of the wheel (unsprung mass) was measured using "Kistler 8395A" sensor with the measurement range of ±50 g, and sensitivity of 80 mV/g, ±5 %. Vertical

**Fig. 2. On the left – on the test stand "Safeline 400/800" intended for measurement of shock-absorbers effectiveness. On the right – measurement of the car suspension travel**

Fig. 3. Winter tyre tread depth and rubber hardness


Fig. 4. Summer tyre tread depth and rubber hardness

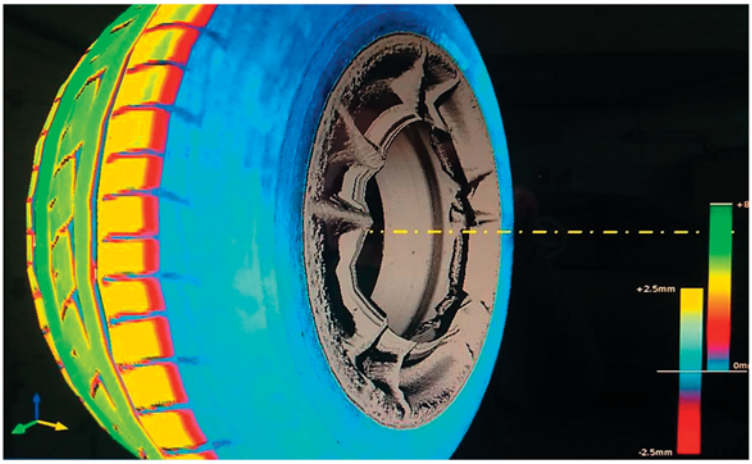


Fig. 5. Measurement of quantitative and qualitative parameters of a tyre using laser technique

acceleration of the body (sprung mass) was measured using "Kistler TANS" sensor with the measurement range of ±3 g, and sensitivity of 666 mV/g, ±1 %. Data were simultaneously acquired from sensors and processed by synchronizing at frequency of 100 Hz using "Corrsys-Datron DAS3" unit.

The pressure was varied on the front right side (FR) at steps of 0.2 bar in range of 1.6 – 3.0 bar each time when taking measurements of the shock-absorbers efficiency. The pressure on the front left side (FL) was held constant.

## 5. Discussion of research results

Analysis of obtained findings and results was followed by the comparison of the effects of air pressure in winter and summer tyres on the measurements of shock-absorber efficiency. Under variable air pressure in the tyre, similar trend of variation in shock-absorbers efficiency was observed in case of a car fitted with winter and summer tyres (Fig. 6): with increasing pressure the damping efficiency was observed to decrease, on the average, by 2.6 percent per 0.2 bar for summer tyres, and by 3.1 percent per 0.2 bar for winter tyres. It can be explained by the variable stiffness and damping of the tyre. The increasing pressure in a tyre causes its damping to decrease which in turn effects measurement of the total damping of a quarter-car.

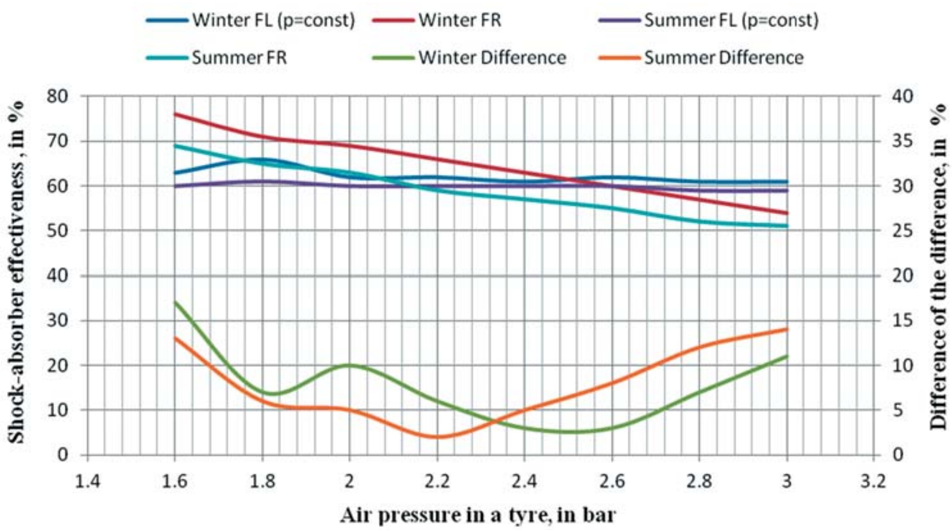


**Fig. 6. Dependency of the shock-absorber effectiveness on air pressure in winter and summer tyres**

When evaluating effectiveness of damping for winter tyres in comparison with summer tyres, it was found to be higher under any air pressure (Table 1). On the average the difference of 8.64 percent was obtained when compared to summer tyres used for a long period of time.

**Table 1. Effectiveness of damping when fitted winter tyres are compared to summer tyres**

| Pressure, bar | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 | 2.8 | 3.0 | Average difference |
|---|---|---|---|---|---|---|---|---|---|
| Winter FR | 76 | 71 | 69 | 66 | 63 | 60 | 57 | 54 | |
| Summer FR | 69 | 65 | 63 | 59 | 57 | 55 | 52 | 51 | |
| Difference, % | 9.21 | 8.45 | 8.70 | 10.61 | 9.52 | 8.33 | 8.77 | 5.56 | 8,64 |

To find out the effect of tyres with different air pressure on damping of the induced vertical oscillations, the correlation between the shock-absorber test plate and vertical acceleration of the wheel has been evaluated (Fig. 7).

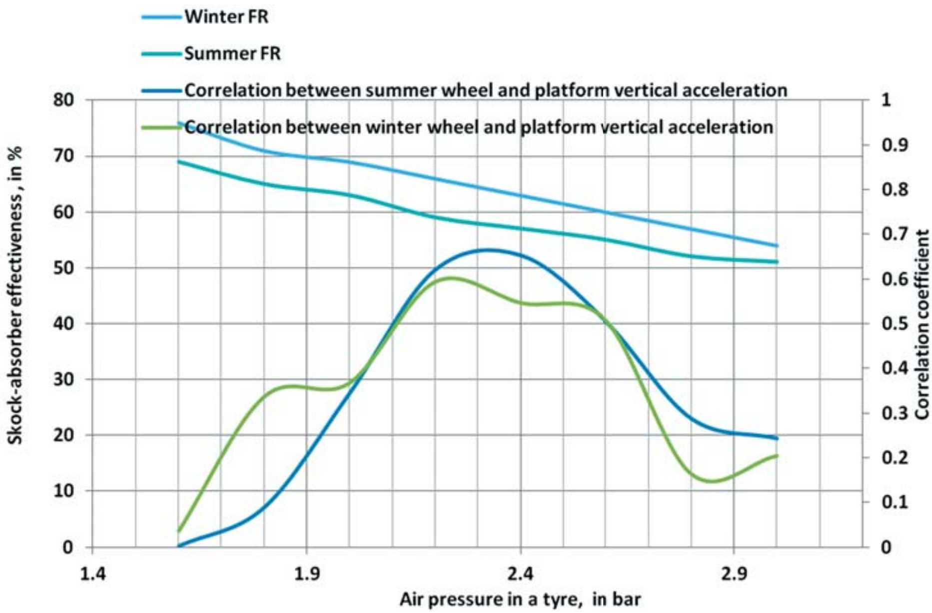


**Fig. 7. The effect of air pressure in different types of tyres on damping of induced oscillations**

Variation in correlation coefficient evidences that the wheel replicates vertical acceleration of the vibrating test plate most accurately under the tyre inflation pressure of 2.2–2.6 bar. Such a result might be associated with the tyre inflation pressure indicated by the automotive manufacturers. Under low tyre inflation pressure, the characteristic of tyre damping becomes close to the one of the shock-absorber, resulting in better total effectiveness of the suspension. Under the tyre inflation pressure above 2.6 bar, the tyre replicates induced vibrations inconsistently resulting in impaired suspension damping.

## 6. Conclusions

Variable stiffness and damping of the tyre because of the inflation pressure determine shock-absorbers efficiency variation.

Shock-absorbers efficiency decreases with increasing the inflation pressure in tyres. In general decreased efficiency is 29 percent for winter tyres and 26 percent for summer tyres in a pressure range of [1.6 … 3.0] bar.

Analysing effectiveness of damping for different types of the tyres it was found that less used winter tyres have better damping efficiency on all occasions. The difference of 8.64 percent has been obtained when compared to much time used summer tyres.

The correlation coefficient shows that the wheel with summer tyre replicates vertical acceleration of the vibrating test plate more exactly compared with winter wheel. Both wheel replicate vertical acceleration most accurately under the inflation pressure range of [2.2 ... 2.6] bar. Suspension damping decreases in case of the inflation pressure above the 2.6 bar.

## References


[1] GARDULSKY, J.: *Testing methods for vehicle shock absorbers.* Diagnostics, Lenkija, 2009, nr. 3(51), 3(53), s. 93-100.

[2] KINDT P., SAS P., DESMET W.: *Measurement and Analysis of Rolling Tire Vibrations.* Optics and Lasers in Engineering, 2009, nr 47, s. 443-453.

[3] RUSTIGHIE E., ELLIOTT S.J., FINNVEDENS S., GULYASK K., MOCSAIT T., DANTI M.: *Linear Stochastic Evaluation of Tyre Vibration due to Tyre/Road Excitation.* Journal of Sound and Vibration, 2008, nr 310, s. 1112-1127.

[4] FUJIKAWA T., KOIKE H., OSHINO Y., TACHIBANA H.: *Definition of road roughness parameters for tire vibration noise control.* Applied Acoustics 66 (2005), s. 501-512.

[5] TIELKING J.T.: *Plane Vibration Characteristics of a Pneumatic Tire Model.* SAE Technical Paper, 1965, nr 650492.

[6] BYOUNG S.K., CHANG H.C., TAE K.L.: *A Study on Radial Directional Natural Frequency and Damping Ratio in a Vehicle Tire.* Applied Acoustics, 2007, nr 68 , s. 538-556.

[7] TAE K.L., BYOUNG S.K.: *Vibration Analysis of Automobile Tire due to Bump Impact.* Applied Acoustics, 2008, nr 69, s. 473-478.

[8] LOZIA Z., ZDANOWICZ P.: *Dry Friction Force in Suspension vs. Testing Result of Shock-Absorbers Mounted in Vehicle. Elementy diagnostyki maszyn roboczych i pojazdów,* red. Żółtowski B, Wydawnictwo Naukowe Instytutu Technologii Eksploatacji – PIB, Radom. Uniwersytet Techniczno-Przyrodniczy im. J. i J. Śniadeckich w Bydgoszczy. ISBN 978-83-7204-823-3. 2009r. Str. 334¸339. ISBN 978-83-7204-823-3.

[9] STAŃCZYK T.L.: *Usage of the angle for diagnostic axamination of damping properties of schock absorbers nounted in a vehicle.* Materiały konferencyjne. Rozwój techniki samochodowej, a ubezpieczenia komunikacyjne. II Konferencja Naukowo-Techniczna, Radom, 16-17 czerwca 2004, s. 310-326.

[10] GUYEN V.N. , IANBA S.: *Effects of Tire Inflation Pressure and Tractor Velocity on Dynamic Wheel Load and Rear Axle Vibrations.* Journal of Terramechanics, 2011, nr 48, s. 3-16.

[11] DO M.C., SIHONG Z., YUE Z.: *Effects of Tyre Inflation Pressure and Forward Speed on vibration of an Unsuspended Tractor.* Journal of Terramechanics, 2013, nr 50, s. 185-198.