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CONTINUING A VEHICLE FITTED WITH RUN FLAT TYRES

Summary. Modern vehicles are equipped with many systems that monitor the security of driving. An example is the tyre pressure monitoring system that shows a fault if the tyre pressure is lowered. Low tyre pressure or no pressure at all (0 kPa) means that continuing driving may lead to a dangerous situation. Prolonged driving of the vehicle at 0 kPa in the tyre ends with tyre burst, rim damage, or even loss of stability. Therefore, on the automotive market, manufacturers offer Run Flat tyres adapted to emergency driving with a pressure of 0 kPa. This article presents the results of an experimental research in the field of vehicle dynamics, continuing driving a vehicle with a loss of tyre pressure. These tests were carried out not only to confirm the data provided by tyre manufacturers and to verify the vehicle's driveability but also to analyse the effectiveness of stopping vehicles equipped with this type of tyres using, for example, police studs, especially when vehicles are used for crimes or terrorist activities.

Keywords: tyre, Run Flat, vehicle, driving with 0 Pa pressure

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1. INTRODUCTION

Increasingly, motor vehicles are used by terrorists for attacks. In recent years, there have been over a dozen attacks in which many people were injured using cars. In the case of using a vehicle equipped with Run Flat tyres, which, according to the manufacturers' declaration, despite the lack of air pressure (for an attempt of a forced stop of the vehicle by the Police, it will be adequate to run into a road stud or overshoot), it is possible to continue driving. This article presents preliminary comparative tests of a Run Flat tyre and a standard construction tyre in terms of the possibility of effective long-distance driving in the event of loss of tyre shade.

2. TYPES OF RUN FLAT TYRES

The history of Run Flat tyres began before World War II. The development of the technology took place during World War II, and further work in this direction was carried out after its end. Tyres of this type have been used on a larger scale since the end of the 1980s. Currently, the Run Flat technology is becoming increasingly popular. There are more cars on the market equipped with this type of tyres, which allow driving for a distance of 80 km after tyre damage (pressure 0 kPa) at a speed of about 80 km/h. Run Flat tyres can generally be divided into three segments:

- with reinforced structure,
- self-sealing,
- with support ring.

Reinforced construction – there is a rubber insert in the sidewall of the tyre, which helps to absorb pressure loss. The tyre bead, directly adjacent to the rim, is also reinforced. The applied solutions make the sudden loss of pressure almost imperceptible for the driver. Hence, the necessity to use pressure measuring sensors. The scheme of operation of such a solution is presented in Figure 1.

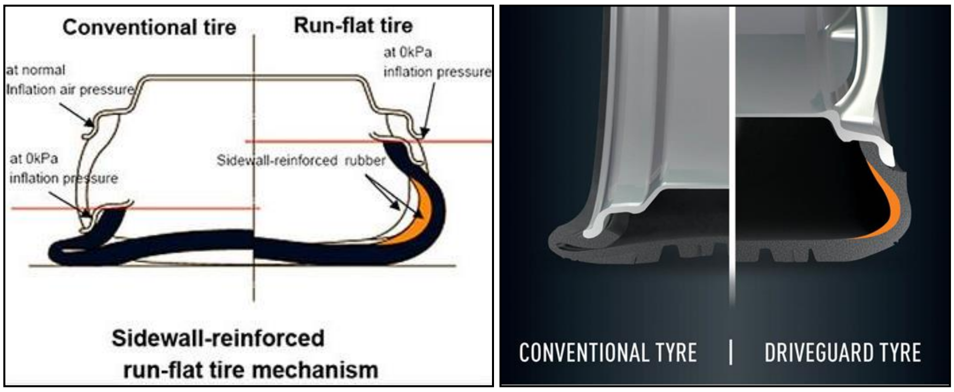

Fig. 1. Functional diagram of the operation of a Run Flat tyre
Source: http://bridgestonesamericas.com

Self-sealing – the structure of the tyre uses an additional internal sealing layer, just behind its tread, which fills the places where the air leakage caused by the damage has occurred. The resulting hole is filled on the inside of the tyre with a sticky, gluey substance. This solution allows the regeneration of the tyre with a maximum puncture diameter of 5 mm. Compared to the classic solution, the weight of the tyre is 15-20% higher. An example of this solution was proposed by Pirelli Seal Inside presented in Figure 2.

Fig. 2. Diagram of the operation of a self-sealing Run Flat tyre
Source: http://www.opony-samochodowe.com/blog/tag/seal-inside

With a support ring – this is technology uses a special ring inside the tyre. A special part is mounted inside the tyre, acting as a support, thus prevents the tyre from slipping off the rim. This solution was introduced by the Michelin concern in a PAX tyre in 1997, shown in Figure 3.

Fig. 3. The Michelin PAX tyre
Source: http://photo blog.netcar.pl

2.1. Comparison of the possibility of continuing a ride for a RUN FLAT tyre and a standard tyre

Fig. 4a. Run Flat Bridgestone TURANZA ER300 RFT tyre
Source: http://www.sklepopon.com

Fig. 4b. Bridgestone TURANZA ER300 tyre
Source: http://www.sklepopon.com

The tests were conducted for the Bridgestone TURENZA ER300 tyre in the standard version and the RFT tyre, size 205/55r16, with the same tread pattern shown in Figure 4a,b. The tyres are mounted on the rear axle of the vehicle, with an actual weight of 1,320 kg. The vehicle was loaded with an additional ballast to obtain a rear axle load (on which the tested tyres were mounted) of 600 kg, which resulted in a vertical load of a single tyre of 2.94 kN, that is, approx. 50% of the nominal load permitted by the manufacturer. Figure 5 shows the static radius of the tyres mounted on the vehicle during the tests (at a pressure of 0 kPa).

Fig. 5a. Static radius for the Run Flat Bridgestone TURANZA ER300 RFT tyre (pressure 0 kPa)
Source: authors' study

Fig. 5b. Static radius for the Bridgestone TURANZA ER300 tyre (pressure 0 kPa)
Source: authors' study

2.2. Description of the phenomenon

The basic concepts of the wheel dynamics presented in this paper are derived from the driven wheel that is in non-steady state conditions, which is the most general case.

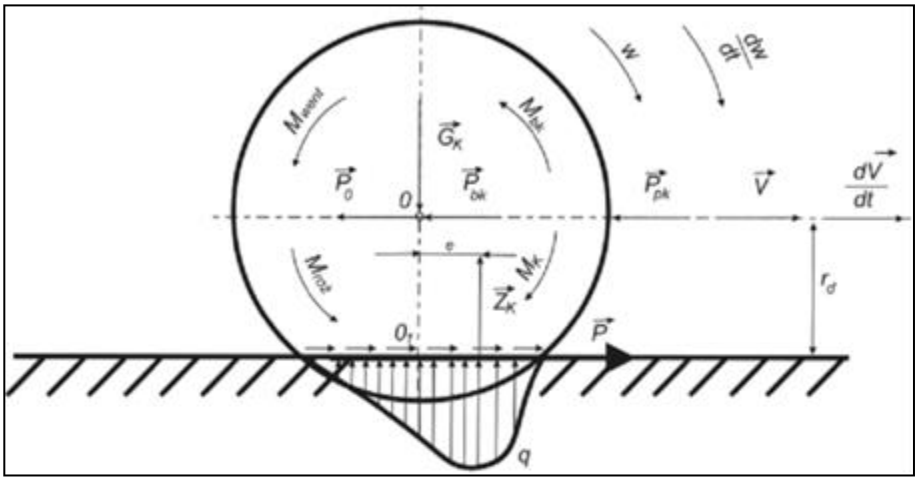

Fig. 6. Forces and moments influencing the driven wheel of
a vehicle driving on a rigid road surface
Source: authors' study

The diagram of forces and moments influencing such wheels is shown in Figure 6. The resultant force between the tyre and the road surface acting in point 0_1 may be decomposed into two components: P, Z_k. Here, it is anticipated that the location of point 0_1 is known. The case is, therefore, analysed formally.

It is known that the forces and moments acting on the wheel (including inertial forces and moments) must be balanced. Therefore, the following three equations may be formulated:

$$\vec{P}_0 + \vec{P}_{bk} + \vec{P}_{pk} + \vec{P} = 0 \quad (1)$$

$$\vec{G}_k + \vec{Z}_k = 0 \quad (2)$$

$$\vec{e} \times \vec{Z}_k + \vec{r}_d \times \vec{P} + \vec{M}_k + \vec{M}_{lo\dot{z}} + \vec{M}_{went} + \vec{M}_{bk} = \vec{0} \quad (3)$$

After having considered the directions of forces and moments, the presented vector equations may be presented as the following algebraic equations:

$$P = P_0 + P_{bk} + P_{pk} \quad (4)$$

$$G_k = Z_k \quad (5)$$

$$M_k = eZ_k - r_d P - M_{lo\dot{z}} - M_{went} - M_{bk} \quad (6)$$

and

$$P_{bk} = m_k \cdot \frac{dV}{dt} \tag{7}$$

$$M_{bk} = I_k \cdot \frac{d\omega}{dt} = \frac{I_k}{r_t} \cdot \frac{dV}{dt} \tag{8}$$

where:
m_k - mass of the wheel;
I_k - inertia momentum of the wheel in relation to its axis of rotation.

From (5) and (6), we calculate M_k

$$M_k = eG_k + P_t r_d + M_o + M_w + M_e \tag{9}$$

product of eG_k we call the rolling resistance torque, that is:

$$M_t = eG_k = eZ_k \tag{10}$$

The rolling resistance torque M_t expressed by formula (10) is an abstract notion.
After dividing (9) by r_d, we obtain:

$$\frac{M_k}{r_d} = \frac{e}{r_d} G_k + P_t + \frac{M_o}{r_d} + \frac{M_w}{r_d} + \frac{M_e}{r_d} \tag{11}$$

The ratio of driving torque M_k and dynamic tyre radius r_d is defined as driving force p_n. Therefore:

$$P_n = \frac{M_k}{r_d} \tag{12}$$

Equation (12) is especially important in providing the basis for the vehicle's stability. The driving force provided by the driven wheel depends on the driving torque supplied by the power train and tyre radius. It is anticipated that the driving torque is evenly distributed between all driven wheels.

3. TEST DESCRIPTION

This study aimed to determine the possibility of continuing driving a vehicle at a pressure of 0 kPa, equipped with the Run Flat Bridgestone Turanza ER300 RFT tyres and the Bridgestone Turanza ER300 tyres.

The research was conducted on roads excluded from public use. To record the longitudinal speed of the vehicle and accelerations, the Race Technology DL1 recorder was used with the speed and position sampling frequency of 20 Hz, and other parameters (acceleration and gyroscope) of 100 Hz.

Fig. 7. View of the measuring apparatus used during the tests
Source: authors' study

The tests were conducted under the following weather conditions:

- temperature 20°C,
- pessure 1010 hPa,
- wind speed 2.6 m/s,
- pavement dry asphalt [-].

The vehicle was subjected to a controlled air release to a pressure of 0 kPa in the rear axle wheels. Then the driver covered a measuring distance of about 1000 m from a speed of about 70 km/h, after which the vehicle was stopped, and the condition of the tyres was checked until one tyre was deformed or completely damaged, preventing further driving without permanent damage to the vehicle body by defragmentation of the tyre.

4. DISCUSSION OF RESEARCH RESULTS

The longitudinal speed of the vehicle during the test was about 70 km/h and was kept at a constant level (Figure 8). The displayed speed moments, amounting to 0 km/h, resulted from the need to periodically stop and verify the technical condition of the tyres.

The temperature distribution on the sidewall of the tyres presented in Figure 9 was made as a mean measurement with a manual pyrometer at a distance of about 0.025 m from the rim flange. Measurement was made for solid rubber elements. In the case of the degradation of the tyre, the exposure of metal elements (belting the tyre) was noticed, and the steel elements were characterised by a slightly higher temperature, however, the average value for solid pieces of rubber was still considered as the tyre temperature.

After covering the distance of 3,000 m, the degradation process of the Bridgestone Turanza ER300 sidewall was noticed. The successive phases of damage to the tyre wall are shown in Figure 10.

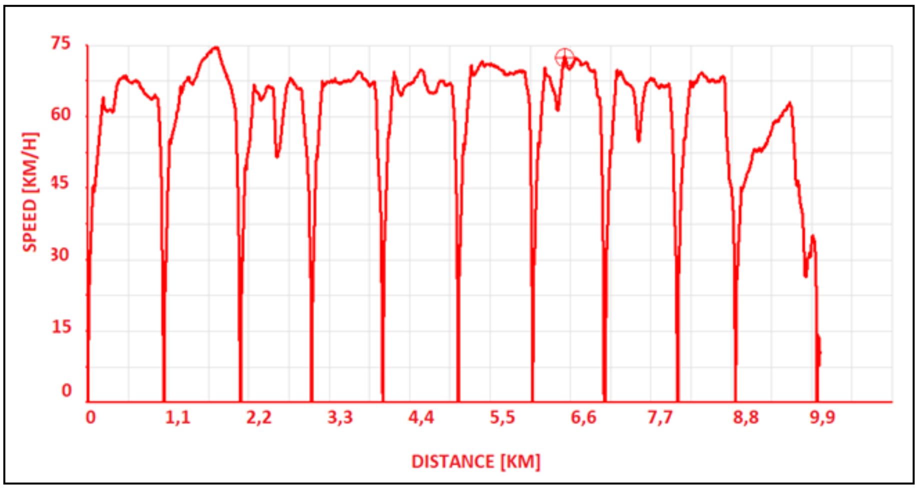

Fig. 8. Characteristics of the vehicle speed in [km/h] over the distance of 10 km
Source: authors' study

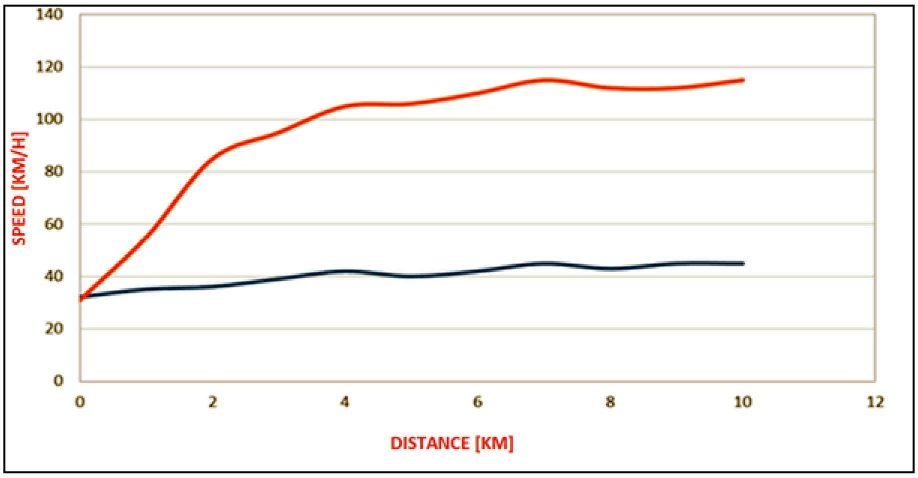

Fig. 9. Temperature distribution on the tyre sidewall while driving at 70 km/h:
blue colour - Run Flat Bridgestone Turanza ER 300 RFT,
red colour Bridgestone Turanza ER 300
Source: authors' study

After covering a distance of 9,700 m, with a pressure of 0 kPa in the Bridgestone TURANZA ER300 tyre, the sidewall was abraded. Continued driving with the tyre in this condition resulted in the occurrence of vibrations in the suspension system, and fragmenting elements from the damaged tyre caused the risk of damaging the body and suspension components (for example, breaking the brake lines).

The distance of 9,700 m that was covered by the Bridgestone Turanza ER300 tyre at a pressure of 0 kPa, loaded with a pressure of 2.9 kN should be considered relatively long. If the tyre was loaded to its full extent, the dynamics of vehicle movement were varied (braking delay, loss of lateral adhesion), the process of destruction would take place much faster. The experience of the sports research team shows that tyres operated at a pressure of 0 kPa during, for example, sports trials, are completely destroyed after covering about 2000-3000 m (Figure 12).

Fig. 10. Phases of damage to the Bridgestone Turanza ER300 tyre sidewall during the tests
Source: authors' study

Fig. 11. View of the process of cutting the sidewall of the Bridgestone Turanza ER300 tyre while covering the test distance: on the left, the initial phase of the belting damage on the right, complete cutting of the sidewall of the tyre
Source: authors' study

The Run Flat Bridgestone Turanza ER300 RFT tyre, after covering the test distance of 9,700 m, showed no signs of damage. It was decided to continue the research at a longer distance. The tests were completed after covering a distance of 30,000 m. During the tests, it was found that it is possible to continue driving without any noticeable difference in the road tyres. This was especially true for straight-ahead driving.

RFT (Bridgestone Run Flat Tyre) technology stiffens the sidewall of the tyre. Compared to the first generation RFT tyres produced in 1987-2004 and currently available on the market, a 60% decrease in the temperature increase index can be observed, as well as an increase in the comfort of selecting unevenness because the tyre in question has only about 105% higher stiffness compared to classic tyres.

Fig. 12. View of the destructed rubber collecting inside the tyre while driving at a pressure of 0 kPa
Source: authors' study

In juxtaposition with similar constructions from previous years, the discussed model of the tyre has an improved structure of the sidewalls for better comfort when selecting unevenness, and additionally, has improved cooling of the sidewalls.

Apart from a much greater distance that can be covered, RFT tyres are characterised by a much lower rolling resistance at a pressure of 0 kPa. Therefore, even with all tyres punctured, the vehicle can move with the driving dynamics.

For the Run Flat Bridgestone Turanza ER300 RFT tyre and the Bridgestone Turanza ER300 tyre, the runway test shown in Figure 13 was performed. The presented characteristics show that the Run Flat Bridgestone Turanza ER300 RFT tyre generates a lower rolling resistance of over 50% compared to the Bridgestone Turanza ER300 tyre while driving with a pressure of 0 kPa.

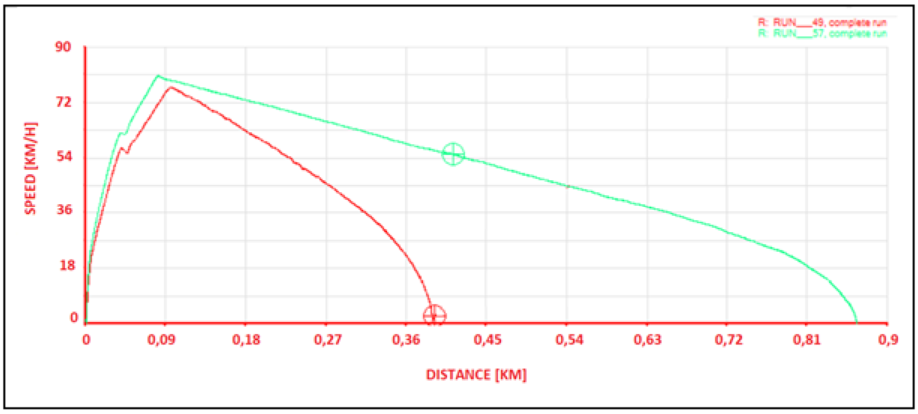

Fig. 13. Determination of vehicle rolling resistance using the coast-down method :
green - the Run Flat Bridgestone Turanza ER300 RFT tyre,
red - the Bridgestone Turanza ER300 tyre
Source: authors' study

During the use of the Run Flat Bridgestone Turanza ER300 RFT tyre, the parameters related to the longitudinal dynamics of the vehicle do not deteriorate, while the parameters responsible for the lateral dynamics deteriorate. Because of pressure loss and increased lateral acceleration, the bead may slide off the rim edge. Therefore, an effective method of stopping this type of vehicle may be to use another vehicle as a measure of direct coercion and ram such a vehicle.

During the tests, basic braking efficiency tests were carried out for the series tyre and RFT without pressure. The vehicle maintains a relatively high deceleration during braking, however, reduced lateral stability must be considered. Interestingly, it results, of course, directly from the structure of the RFT tyre (the loads in the event of pressure loss are transferred by reinforced sidewalls) during the braking process with blocked wheels, and is particularly visible. For the Run Flat Bridgestone Turanza ER300 RFT tyre, high pressures (a clear trace) are visible only in the area of the tyre wall with the road surface, while for the series tyre in a wider footprint.

Fig. 14. View of the emergency braking marks (blocked wheels) for the Run Flat Bridgestone Turanza ER300 RFT tyre with a pressure of 0 kPa (right) and the road tyre (left)
Source: authors' study

4. CONCLUSIONS

According to the manufacturers' declarations, Run Flat tyres enable effective driving with a pressure of 0 kPa. This can make it difficult to stop a vehicle equipped with this type of tyre. In connection with the above, it is reasonable to start research on the possibility of forced stopping of this type of vehicles by law enforcement officers. Standard methods that have been used so far, such as the spike, may be ineffective, and the vehicle, after colliding with it, can still travel for many kilometres, with high dynamics. In addition, training in not only effective but also safe stopping of this type of vehicles by the Police, especially in urban traffic conditions, should be considered.

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