INFLUENCE OF RETREADED TYRES ON VEHICLE ACTIVE SAFETY – RESULTS OF STEADY-STATE CIRCULAR TESTS AND SEVERE LANE-CHANGE MANOEUVRE

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Abstract

The aim of the article is to present the results of road tests of original and retreaded tyres, analysed in the aspect of vehicle active safety. The tests covered steady-state circular tests and severe lane-change manoeuvre. The tests were performed in summer conditions. Original Michelin tyres and Michelin tyres retreaded with summer and winter rubber compounds were used. The results of the tests proved that vehicle active safety is affected by retreaded tyres. The curved trajectory tests revealed that, compared with brand new tyres, the majority of retreaded tyres showed a lower cornering stiffness and strongly non-linear steering-wheel angle change.

Key words

retreaded tyres, road holding ability, steerability

1. INTRODUCTION

One of the forms of utilisation of worn car tyres is to retread them. In this process the tread pattern of the used tyre is reconstructed by placing a layer of a rubber compound. The recently improved quality of tyre retreading together with lower prices of retreaded tyres as compared with brand new ones have made such tyres used fairly frequently. Vehicles with retreaded tyres often take part in road collisions and accidents. In reconstructing an event information on the contribution of the properties of retreaded tyres in traffic safety is very important. What is of particular interest is the knowledge of the effect of tyres on road holding ability and vehicle manoeuvreability.

There is no up-to-date data available in literature that determine the influence of the properties of retreaded tyres on vehicles active safety. That is why research was undertaken at the Institute of Forensic Research in Cracow the aim of which was to compare car motion parameters obtained when retreaded tyres were used with corresponding parameters obtained for original tyres. The other aim was to determine the effect of the tread rubber compound composition and type of tread pattern of retreaded tyres on car motion parameters.

The tests performed covered steady-state circular test and severe lane-change manoeuvre. Steady-state circular test is one of the basic quasi-static tests in vehicle road holding ability and manoeuvreability tests. Severe lane-change manoeuvre is a dynamic test useful in assessing vehicle road holding ability and manoeuvreability, similar to defensive manoeuvre of by-passing an obstacle, often occurring in road traffic. Severe lane-change manoeuvre can be described as a type of vehicle anticipatory steering which helps to establish the response of the driver – vehicle system in traffic emergency [3, 5].

2. SUBJECT OF RESEARCH

The tests were done on a Renault Megane Classic car. The tests were carried out for new and retreaded tyres. The new tyres were manufactured by Michelin, with XH1 tread (Photo 1).

The retreaded tyres used in the tests were hot retreaded. Since the tyres selected for retreading were worn Michelin tyres, the carcass structure of all the tested tyres was the same. The retreaded tyres used in tests differed in rubber compound. Besides three summer compounds, marked with symbols A, B and C, tyres with two different winter compounds, marked with D and E, were tested. Four types of tread were selected for tests: two summer treads – Energy and Sport, and two winter treads – MK770 and MK790. The Energy tread was modelled on the Michelin Energy XH1 tyre tread, while the Sport tread corresponded with the Michelin Pilot Sport tyre tread. Two winter treads MK770 and MK790 were modelled on Continental 770 and Continental 790 (Photo 1).

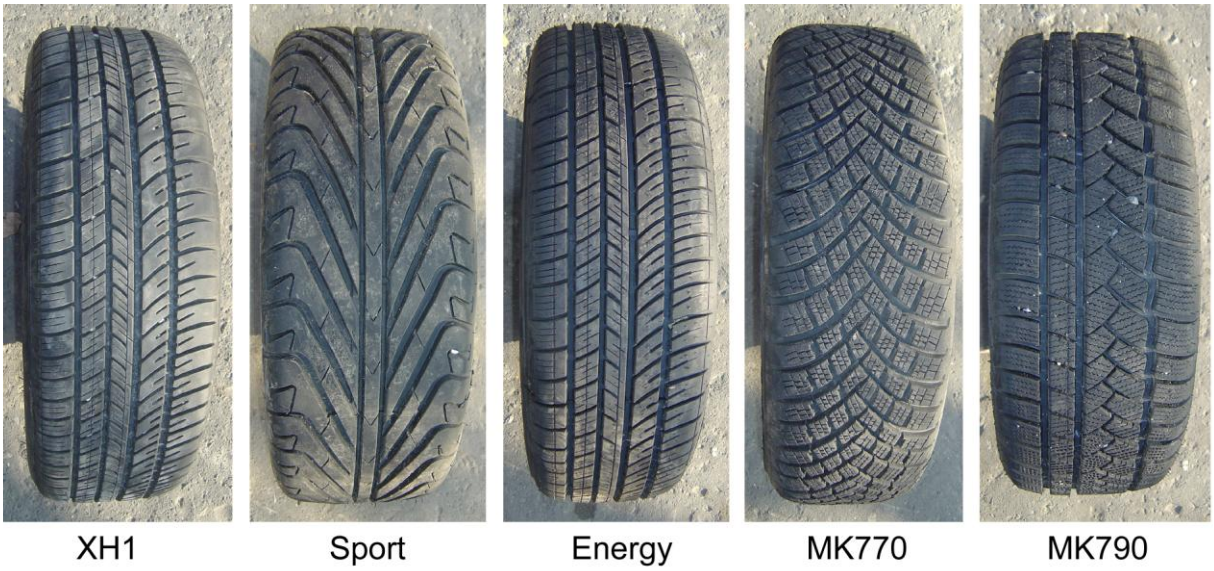

Photo 1. Tread patterns of tested tyres.

Three sets of tyres of different rubber compounds (A, B, C) and the same tread pattern (Energy), and two sets of tyres of identical rubber compound (C) and different tread patterns (Energy, Sport) were prepared (Table 1). Separate tests were done for winter tyres (D, E).

Tread pattern	Rubber compound	Size of tyre	Marking
XH1	Michelin	185/60 R15	XH1-Michelin
Energy	A	195/65 R15	Energy-A
Energy	B	195/65 R15	Energy-B
Energy	C	195/65 R15	Energy-C
Sport	C	195/50 R15	Sport-C
MK790	D	195/50 R15	MK790-D
MK770	E	195/65 R15	MK770-E

Table 1 Specification of tyres according to tread pattern and type of rubber compound

3. INSTRUMENTATION

The following instrumentation was used in tests (Table 2):

– CORREVIT S-CE head for non-contact measurement of longitudinal v_L and lateral v_Q components of the vector of car selected point velocity,

– piezoelectric vibratory gyroscope MURATA ENV 05A for measurement of yaw velocity $\dot{\psi}$,
– converter of steering wheel angle for measurement of steering wheel angle δ_H.

Instrument	Quantity	Marking	Measurement range	Measurement accuracy
Correvit Corrsys® S-CE head	Longitudinal velocity	v_L	0 ÷ 350 km/h 0 ÷ 97 m/s	0,03 m/s
	Lateral velocity	v_Q	± 225 km/h 0 ÷ 62 m/s	0,03 m/s
Gyroscope Murata Gyrostar ENV-05A	Yaw velocity	$\dot{\psi}$	± 90 °/s	± 0,1 °/s
Converter potentiometric MU 161	Steering-wheel angle	δ_H	± 300 °	1°

Table 2 Specification of instrumentation used in tests

4. COMPARATIVE STUDIES IN THE RANGE OF STEADY-STATE CIRCULAR TESTS

4.1. Methodology of steady-state circular tests

Due to the available test track, the steady-state circular test, with the constant radius of the circle (*R*=const.) was selected [2, 4]. A circle of radius of 20 m was marked on the roadway. During the test the drive drove the car along the circle, making corrections of the ride trajectory so that any deviation off the marked circle did not exceed 0.3 m each side. The travelling speed at a given gear was changed from the lowest possible to such at which the driver was still able to drive the car along the assigned trajectory. The car travelling speed was changed at a constant rate at the acceleration not larger than 0,5 km/h/s.

The constant quantity that was determined prior to the tests was the position of centre of gravity relative of the vehicle axis. The quantities measured during the experiments, used in calculations and the quantities calculated on the basis of the recorded histories have been shown in Fig. 1.

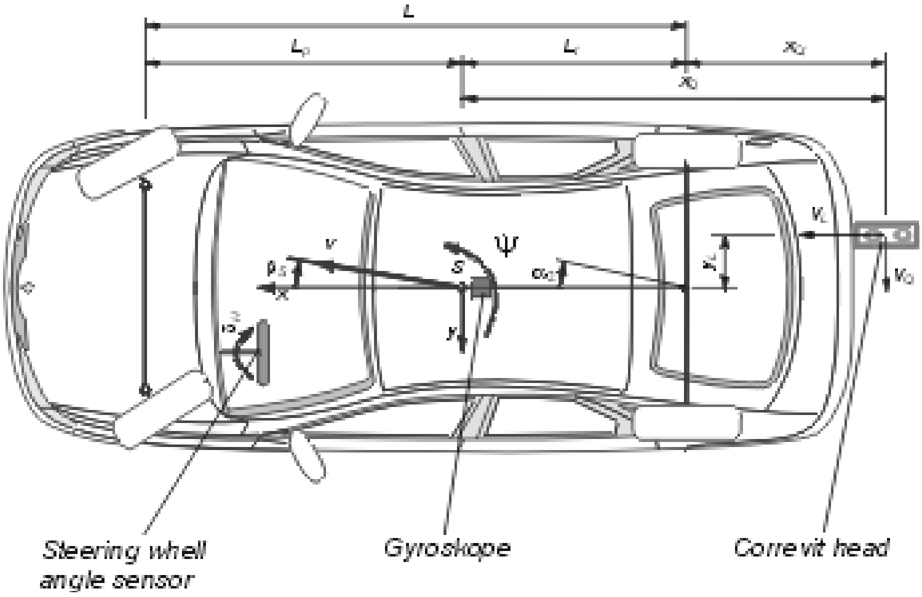

Fig. 1. Location of instrumentation in the tested car and scheme of quantities measured in tests, used in calculations and calculated.

The steady-state circular tests were performed in summer conditions. The car was loaded with the instrumentation, the driver and the instrumentation operator. The mass distribution during tests did not differ from that during regular operation.

4.2. Test results

The recorded results were processed using the software of the Institute of Automobiles and IC Engines, Cracow University of Technology together with programmes working in Matlab environment [6]. The histories of yaw velocity $\dot{\psi}$, longitudinal velocity v_L and lateral velocity v_Q were filtered with Butterworth low-pass filter. The recorded data were used in calculations of (Fig. 1):

– cog longitudinal velocity: $v_{Sx} = v_L + y_L \cdot \dot{\psi}$
– cog lateral velocity: $v_{Sy} = v_Q + x_Q \cdot \dot{\psi}$
– lateral acceleration: $a_y = v_{Sx} \cdot \dot{\psi}$
– rear axle slip angle: $\alpha_2 = arctg\left(\dfrac{-v_Q + x_{Qt} \cdot \dot{\psi}}{v_{Sx}}\right)$

Examples of dependencies of steering-wheel angle and rear axle slip angle as a function of lateral acceleration for brand new tyres and Energy-A retreaded tyres have been shown in figures below (Fig. 2, 3).

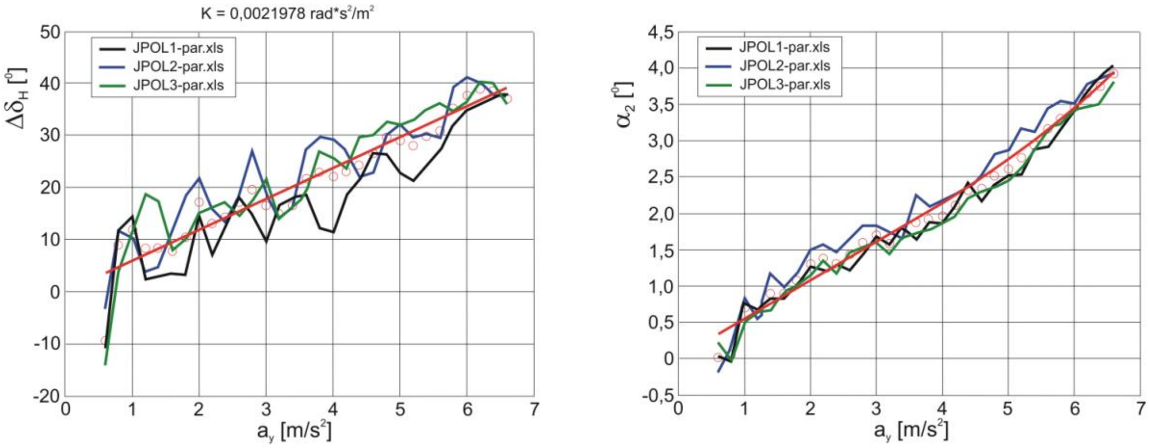

Fig. 2. Dependencies of steering-wheel angle on lateral acceleration (left) and rear axle slip angle on lateral acceleration (right) – XH1-Michelin tyres.

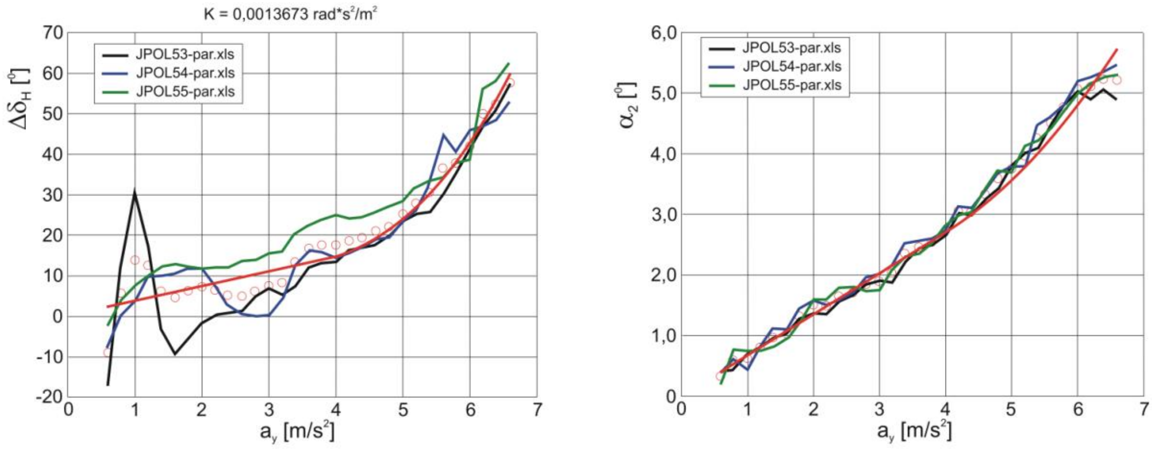

Fig. 3. Dependencies of steering-wheel angle on lateral acceleration (left) and rear axle slip angle on lateral acceleration (right) – Energy-A tyres.

On the basis of motion parameters of the tested car the steer coefficient K [s^2/m^2] was calculated:

$$K = \frac{A_{\delta H}}{i_s \cdot l}$$

where:

$A_{\delta H}$ – steering-wheel angle gradient (derivative of steering-wheel angle δ_H relative of lateral acceleration a_y, defined from the diagram made on the basis of road experiments),
i_s – steering system transmission ratio of the tested car,
l – axle base of the tested car.

From a series of several steady-state circular tests the mean value of steer coefficient K was determined (Table 3).

Tyres	**K [s^2/m^2]**
XH1-Michelin	0,0022
Energy-A	0,0014
Energy-B	0,0021
Energy-C	0,0020
Sport-C	0,0025
MK790-D	0,0028
MK770-E	0,0027

Table 3 Specification of mean values of steer coefficients for particular sets of tested tyres

The car steerability characteristics was determined from dependence [3]:

$$i_s \cdot l \cdot \left(\frac{\dot{\psi}}{\delta_H}\right) = \frac{v_{Sx}}{1 + K \cdot v_{Sx}{}^2}$$

For the tested car boundary acceleration of linearization range 4 m/s^2 was adopted [3, 7].

On the basis of measurements of car motion parameters during steady-state circular tests repeated many times steerability characteristics at lateral acceleration of 4 m/s^2 was determined for each set of tyres (Fig. 4).

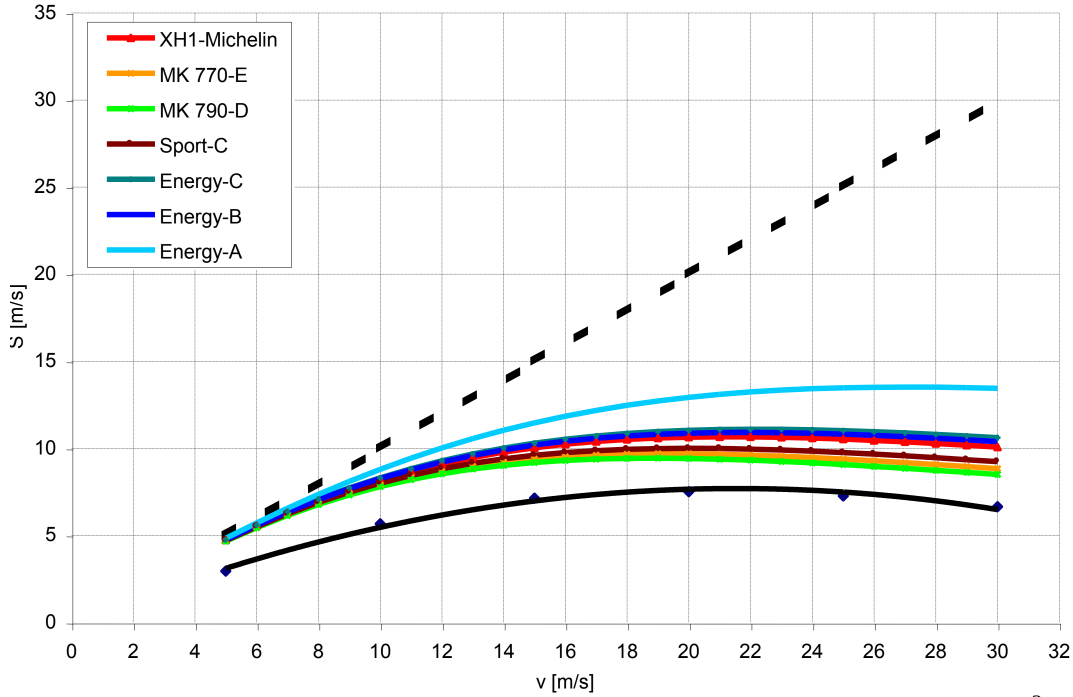

Fig. 4. Characteristics of tested car steerability for different tyres (for a_y = 4 m/s^2) where $S = i_s \cdot l \cdot (\dot{\psi}/\delta_H)$ and $v = v_{Sx}$

The experiments with all the tested tyres proved the car to have favourable steerability characteristics – moderate understeer (all the characteristics in Fig. 4 are within the characteristics band for a safe car RSV[1], restricted with the black lines: fine and broken).

4.3. Conclusions from steady-state circular tests

In case of XH1-Michelin tyres, treated as model ones, the dependence of steering-wheel angle and rear axle slip on lateral acceleration was almost linear. The lateral wheels slip occurred at lateral acceleration exceeding 6,5 m/s^2.

Nearly all the retreaded tyres (except Energy-B) have lower cornering stiffness. During experiments the highest values of rear axle slip angle, even up to 5,2° (for MK790-D tyres) were reached at lateral acceleration of ca. 6 m/s^2, i.e. higher by ca. 1,1÷1,7° in comparison with XH1-Michelin tyres.

In case of Energy-A, Energy-B, Energy-C, Sport-C and MK790-D tyres the characteristics of steering-wheel angle change was observed to be strongly non-linear. This non-linearity points to poorer manoeuvreability in the range of lateral acceleration higher than 4 m/s^2.

As far as car steerability is concerned, Energy-A tyres change car properties the strongest and due to a significant rear axle slip angle they reduce understeerability as compared with a car with model XH1-Michelin tyres. At lateral acceleration higher than 4 m/s^2, the effect of retreaded tyres properties on car steerability can be even more pronounced. It should be noticed, however, that an ordinary driver rarely decides to negotiate a turn at lateral acceleration higher than 4 m/s^2, but such values are usually reached at undertaking defensive manoeuvres.

5. COMPARATIVE STUDIES OF TYRES IN SEVERE LANE-CHANGE MANOEUVRES

5.1. Research methodology

The severe lane-change manoeuvre is a dynamic procedure of fast transition from the initial straight trajectory to the parallel laterally shifted one, which is next followed by the return to the trajectory identical with the initial one. The test track on which the severe lane-change manoeuvre tests were performed was determined according to ISO/TR 3888-1975 standard [1]. The car speed during tests was constant, about 80±3 km/h. The experiments were run under load identical with that during the steady-state circular tests. During the tests the concrete pavement of the test section was dry. The car motion parameters recorded during tests were a basis for determination of time histories of steering-wheel angle and yaw velocity.

5.2. Presentation and discussion of results

To assess car behaviour during tests with different tyres two factors were adopted:

- gain – as maximum yaw velocity to maximum steering-wheel angle ratio in first lane-change manoeuvre,
- car response time – as time difference between reaching maximum yaw velocity and maximum steering-wheel angle reached.

[1] RSV – Research Safety Vehicle

The notation of respective quantities has been shown in Fig. 5. The values of gain and car response time are determined by the following dependencies:

$$W = \frac{X_{\dot{\psi},max}}{X_{\delta_H,max}};$$

$$t_{rs} = T_{\dot{\psi},max} - T_{\delta_H,max}$$

where:

$X_{\delta_H,max}$ – maximum steering-wheel angle to the left in the first lane-change manoeuvre (turn to the left),

$X_{\dot{\psi},max}$ – maximum value of yaw velocity in the first lane-change manoeuvre (turn to the left),

$T_{\delta_H,max}$ – time necessary to reach maximum value of steering-wheel angle in the first lane-change manoeuvre (turn to the left),

$T_{\dot{\psi},max}$ – time necessary to reach maximum yaw velocity in the first lane-change manoeuvre (turn to the left).

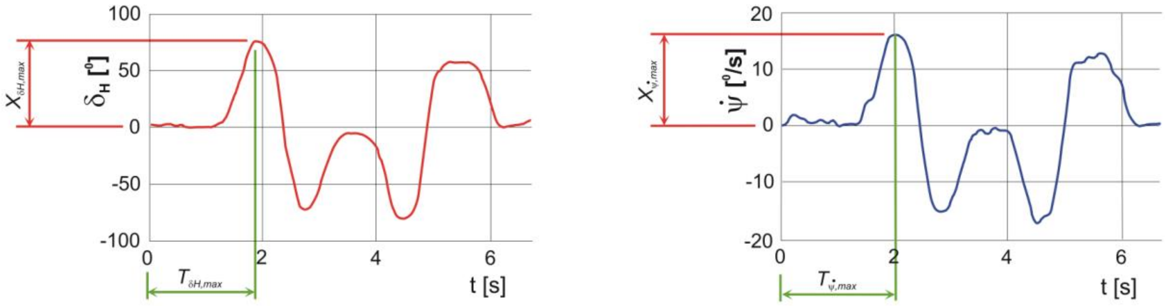

Fig. 5. Quantities necessary to determine car gain and response time.

Examples of steering-wheel angle and yaw velocity curves as time function have been shown in Fig. 6, 7. Fig. 8 shows the values of gain and response time for all the sets of tyres.

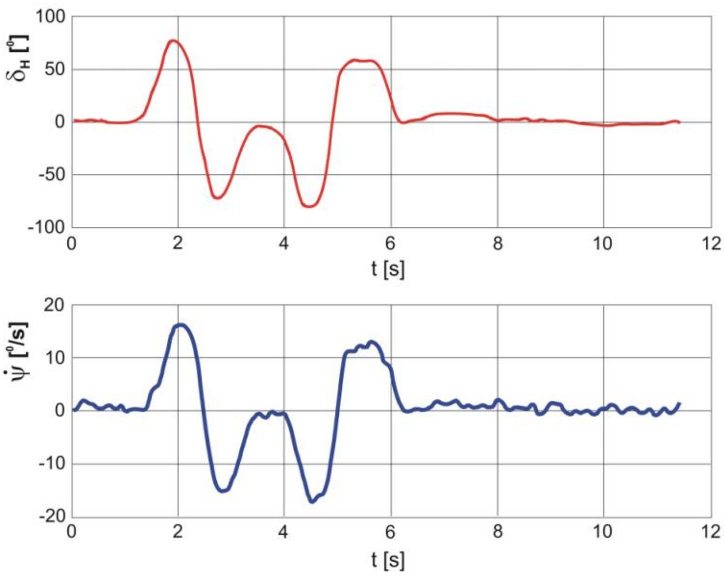

Fig. 6. Time histories of steering-wheel angle and yaw velocity for XH1-Michelin tyres.

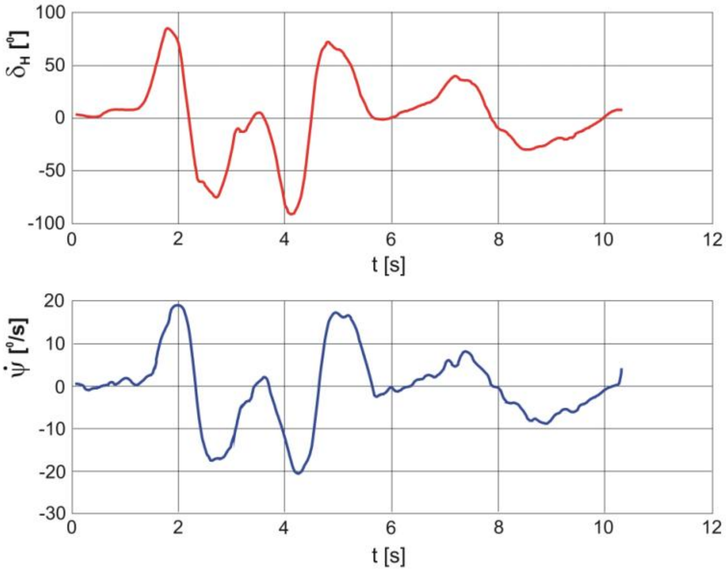

Fig. 7. Time histories of steering-wheel angle and yaw velocity for Energy-A tyres.

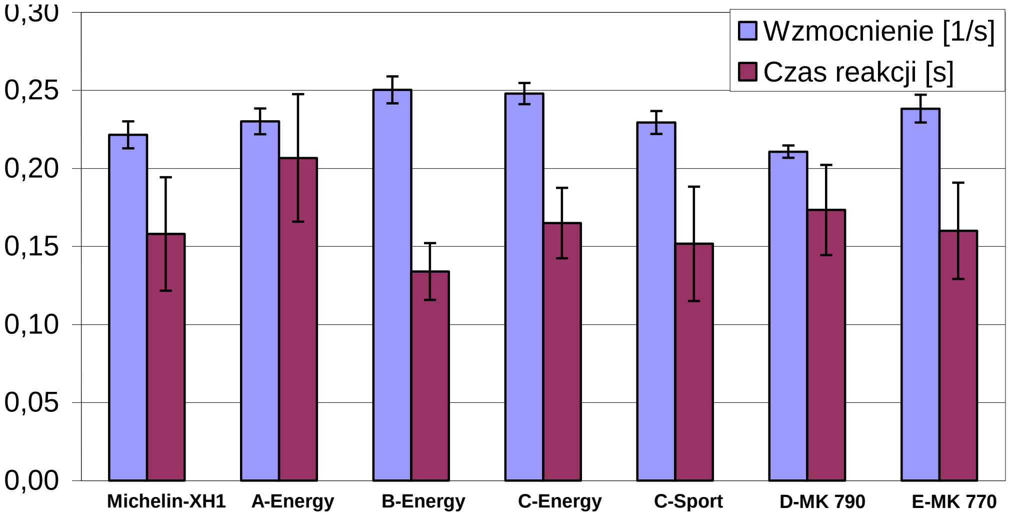

Fig. 8. Car gain and response time for all sets of tyres.

5.3. Conclusions from severe lane-change manoeuvre tests

The results of tests prove that the differences in the manner of driving a car with alternative tested tyres are relatively insignificant, particularly in reference to “gain” defined as maximum yaw velocity to steering-wheel angle ratio in the first stage of severe lane-change manoeuvre. The maximum relative differences of gain do not exceed 12% of the value obtained for model XH1-Michelin tyres. The highest value of gain, indicating lateral elasticity of tyres, was observed in Energy-B tyre. Similar values were obtained for Energy-A, Energy-C, Sport-C and MK770-E tyres. The lowest values of gain, on the other hand, were noticed for MK790-D tyres, but the difference in reference to model tyres (XH1-Michelin) did not exceed 5%.

The time of car response to steering-wheel angle can be considered a certain indicator for manoeuvreability assessment. The faster the response, i.e. the shorter the response time, the better manoeuvreability of the car (it follows the driver’s manoeuvres). During the experiments the vehicle response time for six sets of tyres (including the model XH1-Michelin tyre) was approximately 0,15÷0,17 s and only in the case of Energy-A tyre the response time exceeded 0,20 s and was longer by ca. 31% compared to the model tyres. Taking into account the value of gain it can be stated that Energy-A tyres had the best lateral elasticity. With these tyres the driver found it most difficult to keep the straight trajectory after completion of the severe lane-change manoeuvre.

6. FINAL CONCLUSIONS

The curved trajectory tests revealed that, compared with brand new tyres, the majority of retreaded tyres showed a lower cornering stiffness and strongly non-linear steering-wheel angle change. It can be stated, then, that the effect of retreaded tyres on vehicles active safety is noticeable.

The experiments with all the tested tyres proved the car to have favourable steerability characteristics – moderate understeer.

The results of tests prove that the differences in the manner of driving a car with alternative tested tyres are relatively insignificant, particularly in reference to “gain” defined as maximum yaw velocity to steering-wheel angle ratio in the first stage of severe lane-change manoeuvre

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