Tyres influence on vehicle fuel economy

A Șoica, A Budală and I S Comănescu
Automotive and Transport Engineering Department, Transilvania University of Brașov, RO
E-mail: a.soica@unitbv.ro

Abstract. The development of technologies and the need for rationally use of the available energy resources, continuously leading to the implementation of tyre construction solutions that ensure low fuel consumption. Recent studies, from various sources, have demonstrated the potential for reducing vehicle consumption and emissions by using premium tyres, with fuel efficiency class "A". Moreover, for electric vehicles, tyres with low rolling resistance coefficient have been developed in order to increase driving autonomy. In this paper, the influence of tyres on fuel consumption is indirectly established. Using a function and performance chassis roller dynamometer, the RRC variations for different types of tyres and their rolling conditions were determined. Having statistical data on the influence of the power lost through the rolling resistance of the wheels, some correlations were made regarding the influence of the tyres and the speed of the vehicle on the fuel consumption.

1. Introduction
The European Union (EU) replaced NEDC cycle with the newly developed WLTP in 2017. The new procedure will deviate in some details from the current one, which will have an impact on the determination of the official EU type-approval emission values. This also has consequences on the NEDC-based CO₂ passenger cars’ emission target for 2020-2021 (95 g CO₂/km), which will need to be adapted to the new testing procedure [1].

Energetic optimization of the engines doesn’t compete alone to reduce CO₂ emissions. Among the possibilities of optimizing the performance of a vehicle can be found the efforts of the tyre manufacturers, which develop types of tyres with low RRC. Various studies (e.g. Stelwagen et al., 2015) have shown that the use of fuel-efficient tyres with "A" label can lead to substantial savings and reduction of carbon emissions in the atmosphere [2].

Due to the vehicle load, the tyre is deformed in the contact area with the road surface. This deformation induces internal losses, same as a rubber ball falling down that does not rebound as high as it was launched. As a rule of thumb, reducing RR (Rolling Resistance) by 6% decreases fuel consumption by 1% for passenger cars. Many other factors contribute to vehicle fuel consumption: aerodynamics, vehicle weight, type of engine, auxiliary systems like air-condition, slope of the road, tyre pressure level, personal driving style, accelerations or general traffic conditions [3].

The inflation pressure of the wheels [2] should be mentioned as one of the factors that that influence RRC and relates exclusively with the operation of the vehicle.

For the calculation of the impact of correct tyre pressure maintenance, the relation between tyre pressure and rolling resistance is required. This relation has been extensively studied by several tyre manufacturers and is described by [4]:

...
Thus, the effect of tyre pressure on RRC is equal for all vehicles for the same relative difference from the recommended tyre pressure.

Table 1 shows Stelwagen's and others' studies on fuel-saving possibilities in Rotterdam, if all vehicles would be equipped with Class "A" label tyres and would have swollen wheels at the right pressure.

Table 1. Fuel-saving possibilities, source [2].

| Tyre class | Vehicle category                  | Driving Behaviour | Fuel savings potential |
|------------|-----------------------------------|-------------------|------------------------|
|            |                                   | [%] urban / [%] highway | summer | winter | average |
| C1         | Cars and vans (petrol/diesel)     | 39 / 61           | 6.3       | 7.1    | 6.7     |
|            | Distribution truck (diesel)       | 32 / 68           | 4.3       | 5.2    | 4.8     |
|            | Heavy duty (diesel)               | 17 / 83           | 5.0       | 5.0    | 5.0     |

Another important factor is the degree of tyre wear. Yet, substantially worn tyres are more frequent on our roads and streets than new or almost new tyres. Only a few investigations have addressed the basic problem of how and to what extent tyre wear influences tyre/road noise.

The results of the rolling resistance measurements at BASf facilities are shown as a comparison between the tyres in new condition and in fully worn condition (2 mm remaining tread depth). The value shown is the RR coefficient expressed in percentage of the vertical load, figure 1. It appears that the RR coefficient decreases substantially with wear. The average reduction from new condition is 17 [%] [5].

Figure 1. Rolling resistance coefficient variation with wear (source: [5]).

The paper presents a method that indirectly estimates the influence of RRC on fuel consumption using a MAHA LPS 3000 R100/1 roller dynamometer and statistical data from [3].

2. Testing method
Coast-Down Methods: The coast-down method pinpoints all significant contributions to driving resistance, not merely the rolling resistance. The principle in coast-down measurement is to accelerate
a vehicle to a certain speed and then let it roll freely in neutral gear or clutch down [6]. This method does not yield any direct results on rolling resistance, but must be fitted to a mathematical model by, e.g., estimating parameters with least squares regression. The formulation and complexity of the model may vary depending on the experimental setting, sources of data, and so on [7].

Chassis performance dynamometer: In order to determine the rolling resistance coefficients through an indirect method, tests can be performed on a MAHA LPS 3000 R100/1 roller dynamometer. The working procedure is identical to that of determining the performance of a vehicle, with the mention that the trials are done up to the maximum speed allowed by the tyre, and main interest is focused on the roll-out phase in which the $P_{\text{drag}}$ power is measured.

The lost power $P_{\text{drag}}$ is composed of the lost power by rolling the wheels on dyno and the power lost in the drivetrain. For this paper only the drag power (see figure 2) is subject of interest.

![End power measurement](image)

**Figure 2.** Example of recorded data on MAHA roller dynamometer.

We mention that that up to 50 kph the stand is set not to record any parameter. Successive tests are performed at specific time intervals in the gear where the maximum admissible speed for the tested tyres is obtained. Finally, a regression curve for the $P_{\text{drag}}$ powers for all tested tyres has been determined.

3. **Theoretical approach**

From the foregoing the $P_{\text{drag}}$ power is the sum of the powers lost in the drivetrain - $P_{\text{drive}}$ and that of the rolling wheels - $P_r$:

$$P_{\text{drag}} = P_r + P_{\text{drive}}$$  \hspace{1cm} (2)

In case we do not have exact data on the RRC variation depending on the speed, for all the analyzed tyres, it is enough to know this variation for a single type of tyre, considered as a reference. Through indirect method it can be determined, with enough accuracy, the RRC variations for the tested tyres. It should be mentioned that the trials must be done with the same vehicle.

The relation (1) can be particularised as:

$$P_{\text{drag,ref}} = P_{r,\text{ref}} + P_{\text{drive,ref}}$$  \hspace{1cm} (3)
\[ P_{\text{drag, use}} = P_{\text{use}} + P_{\text{drive, use}}. \]  

(4)

For the same vehicle, regardless of the type of tyre, could be write:

\[ P_{\text{drive, use}} = P_{\text{drive, ref}} = P_{\text{drive}}. \]  

(5)

\[ P_{\text{drive}} = P_{\text{drag, use}} - P_{\text{use}} = P_{\text{drag, ref}} - P_{\text{ref}}. \]  

(6)

As we use one vehicle for the research, the power lost in the transmission is the same for both the test and reference tyres, see the relation (5).

\[ P_{\text{drag, use}} - P_{\text{drag, ref}} = P_{\text{use}} - P_{\text{ref}}. \]  

(7)

\[ P_{\text{drag, use}} = P_{\text{use}} + P_{\text{ref}}. \]  

(8)

From relation (8) it can be obtain the RRC for test tyres:

\[ K = (f_{\text{use}} - f_{\text{ref}}).m \cdot g \cdot v \]  

(9)

where "m" is the vehicle equivalent mass on front axle and "v" is vehicle speed

\[ f_{\text{use}} = f_{\text{ref}} + \frac{K}{m \cdot g \cdot v} \]  

(10)

\[ f_{\text{use}} = f_{\text{ref}} - \frac{K}{m \cdot g \cdot v} \]  

(11)

The rolling resistance coefficients according [8], [9] and [10] could be expressed by the 4th degree polynomial law.

Rolling resistance measurement procedure for passenger car is described in Standard SAE J1269 and ISO 28580:2018 [13], [14]. Using MAHA LPS 3000 R100/1 dynamometer, by the proposed model it can be determined the RRC variation with enough precision.

For a type of tyre, considered as reference were available experimental data on the variation of RRC depending on the speed. Thus, on the dynamometric facility \( P_{\text{drag}} \) powers were determined, with different types of tyres, in order to determine, through the comparative method, the rolling resistance coefficients. For the tyre from “T” class of speed the test was conducted up to 180 kph. Five different tyre models were used, as shown in table 2.

| No | Tyre | Speed class/Type of tyre |
|----|------|--------------------------|
| 1  | T1   | H                        |
| 2  | T2   | V                        |
| 3  | T3   | T - winter                |
| 4  | T4   | H                        |
| 5  | T5   | V                        |

These are from different speed and energy efficiency classes, with varying degrees of tread wear. The values of the RRC coefficients obtained according to the vehicle speed are shown in figure 3.

4. Results and discussion

In the paper, from the experimental determinations, for different types of tyres, the power lost by the rolling resistance of vehicle was determined, figure 3. By the proposed model, power losses in the vehicle drivetrain are eliminated. The powers lost by rolling the wheels were determined by the relation (12). For vehicle speed of 50, 90 and 180 kph these powers are shown in table 3.
\[ P_r = f \cdot m \cdot g \cdot v \]  

(12)

Table 3. Values of RRC.

| Tyre no. | 50 km/h | 90 km/h | 180 km/h |
|----------|---------|---------|----------|
|          | RRC %   | Pr [kW] | RRC %    | Pr [kW]  | RRC %    | Pr [kW] |
| T2       | 0.008     | 100.00% | 0.0083   | 100.00%  | 0.0113   | 100.00% |
| T1       | 0.0081    | 101.25% | 0.0095   | 114.46%  | 0.0138   | 122.12% |
| T3       | 0.0093    | 116.25% | 0.0113   | 136.14%  | 0.0183   | 161.95% |
| T4       | 0.0089    | 111.25% | 0.0098   | 118.07%  | 0.0165   | 146.02% |
| T5       | 0.0087    | 108.75% | 0.0093   | 112.05%  | 0.016    | 141.59% |

Figure 3. The values of the RRC coefficients obtained according to the vehicle speed.

Studies in [11] showed that for a middle-class car, the influence of rolling resistance ranges between 25% and 46% of the total resistances that act on the vehicle, depending on the travel regime. The highest weight of rolling resistance is in the urban traffic regime, which is confirmed on figure 4 [15].

The high percentage of power loss by rolling wheels in urban mode is due to the fact that the vehicle's engine runs at low partial loads. These values fall between 5.10 and 5.92 kW for the analyzed tyres, table 3.

It is noticed that in urban driving at a speed of 50 km/h, RRC for winter tyres, in the T speed category, represents 116.25% of the RRC value for reference tyre 1. This trend is compounded by the increase in travel speed, RRC reaching over 162% of the reference tyre 1 value at 180 km/h (see table 3).

Tyres with speed index "V", (T2 and T5), belong to two different energy efficiency classes, and they have lower RRC values than type "H" tyres (T1 and T4), which are also from different energy efficiency classes. For "V" class tyres, it has to be noted that, in the field of high speeds, the RRC increase is slower than the "H" and "T" type of tyres.

The tyres in speed class "T" have the highest RRC (T3), being for winter season.

According to Berge [12], even the tyres belong to the same energy efficiency class they admit RRC increases between the upper and lower limits. For example, tyres of category "C" admit an increase
with 15.3%, depending on the destination of the tyre (summer/winter/all-season) and the manufacturer, as shown in table 4.

![Diagram](https://via.placeholder.com/150)

**Figure 4.** The influence of rolling resistance of the total resistances that act on the vehicle (source: [15]).

| Tyre label | Coefficient of rolling resistance (RRC) [in kilograms per ton] |
|------------|---------------------------------------------------------------|
| A          | RRC ≤ 6.5                                                   |
| B          | 6.6 ≤ RRC ≤ 7.7                                             |
| C          | 7.8 ≤ RRC ≤ 9.0                                             |
| D          | Empty                                                        |
| E          | 9.1 ≤ RRC ≤ 10.5                                            |
| F          | 10.6 ≤ RRC ≤ 12.0                                           |
| G          | 12.1 ≤ RRC                                                  |

**Table 4.** Values of RRC *(source: EC 1222/2009).*

5. **Conclusions**

The efforts of tyre manufacturers are focused on decrease of the RRC values, in order to obtain small CO₂ vehicle emissions. In line with the EU Tyre Labelling Regulation 1222/2009, a reduction of RRC with 6% can lead to a 1% decrease in fuel consumption for vehicles.

By using low energy-efficient class tyres, fuel consumption increases by approximately 2.5% at 50km/h, 6% at 90 km/h and by more than 10% compared to medium class tyres (ex "C" class) at 180 speeds km/h.

The difference at high speeds also results from the speed class of the tyres. The tyres with the speed index "T" are designed for economy at the usual speeds, but at high speeds they have pronounced RRC increases, compared to those of the speed class "H" or "V".
6. References

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