Investigation of Vehicle Energy Demand considering the Modified Tire Power Loss

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ABSTRACT

Owing to current status of global energy consumption and greenhouse gases emission, investigation of energy demand in different sectors seems to be necessary. Meanwhile, International Energy Agency (IEA)'s reports imply that a considerable share of global energy use is consumed in transport sector. Thus, conducting the vehicle energy demand and influential parameters has become a demanding topic, especially in the recent years. Current study investigates the vehicle energy demand considering the power losses due to tire slip. To achieve this, vehicle resistant powers are rewritten by taking the modified tire power loss into account and after that, two different passenger vehicles are chosen and simulations are performed in three well-known driving cycles. Energy demand of the selected vehicles significantly increases in a more aggressive driving cycle which comprises of higher levels of longitudinal acceleration and speed. According to the results, considering the power loss due to tire slip would improve the calculation accuracy of tire losses up to 6 percent and in case of a more aggressive driving cycle and/or increased resistant forces, energy loss due to tire slip would be increased.

KEYWORDS

Energy demand, Vehicle, Tire dissipation, Tire slip, Rolling resistance.

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1. Introduction

Excessive consumption of fossil fuels, emitting relevant pollutants, and greenhouse gas emissions have become a serious crisis in today's world. Transportation is one of the most energy consuming sectors in the world and according to the report of International Energy Agency in 2011, it accounted for about 55% of global energy consumption [1]. Therefore, relevant organizations have enacted various laws to control the emission of pollutants and greenhouse gases of vehicles. For example, European Union has set a target of achieving 95 g /km carbon dioxide emission for passenger cars by 2021 [2].

Tire rolling resistance, as one of the main resistances against vehicle longitudinal motion, plays a crucial role in fuel and energy consumption and emissions. It consists of about 20 to 25 percent of the consumed energy and fuel in NEDC driving cycle for a typical passenger car. Accordingly, developing tires with lower levels of rolling resistance is one of the treatises that reduces the consumed energy by the tires and consequently improves the fuel efficiency [3]. Another approach is to adjust the inflation pressure of the tires, as outlined in [4], in order to reduce tire resistance in different conditions.

In summary, the effect of tire rolling resistance on vehicle fuel and energy consumption has been extensively studied in the previous works, nevertheless, the power loss due to longitudinal slip of the tire has been neglected. In 2015, experimental study conducted by Sina et al. [5] showed that the power loss due to tire slip largely affects the vehicle fuel consumption. Accordingly, authors in [6] have proposed a modification to tire power loss, which in addition to rolling resistance, includes longitudinal slip of the tire too. Neglecting the tire slip loss in the analysis of vehicle dynamics would demote the validity of the results, and therefore in recent versions car simulation software packages, e.g. Carsim, have been considered.

The present paper examines the vehicle energy demand by considering modified tire power loss in NEDC, FTP and WLTP driving cycles. One of the main contributions of the study is considering the modified tire power loss, which in addition to rolling resistance that has been studies in previous works, includes the loss due to longitudinal slip of the tire as well. Bearing the importance of studying vehicle energy demand to improve the fuel efficiency and reducing greenhouse gas emissions in the mind, the proposed modification to power loss would enhance the accuracy and validity of the results.

2. Modification to tire power loss

In the literature, rolling resistance has been known as the primary source of dissipation in tires, which usually is described as a function of the normal force given by Eq. (1).

$$F_R = f_R F_z \tag{1}$$

Where f_R is rolling resistance coefficient. Although rolling resistance, which originates from viscoelastic property of the tire, characterizes dissipation in tires, longitudinal slip leads to power loss in tires as well. Longitudinal slip is the inevitable consequence of applying a torque to the wheels. In case of a drive torque, as shown in Figure 1, transitional speed of the wheel is less than its peripheral speed as a result of the sliding speed of the contact patch, i.e. v_s. Tire slip can be formulated as:

$$\lambda = \frac{r_{dyn}\omega_w - v_x}{r_{dyn}\omega_w} \tag{2}$$

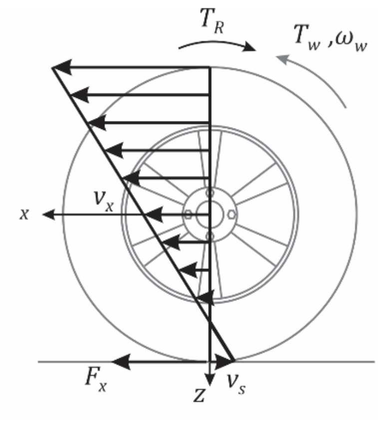

Figure 1. Free body diagram of the wheel

According to Figure 1, differential of the slip work is given by:

$$dW_S = \vec{F}_x \cdot d\vec{r}_s \tag{3}$$

Owing to opposite directions of the sliding speed and tractive force, the resultant power can be expressed as:

$$P_S = -F_x v_S = -F_x \lambda r_{dyn} \omega_w \tag{4}$$

Where P_S is the power loss due to longitudinal slip. Therefore, the modified tire power loss includes both rolling and slip losses and can be given by Eq. (5).

$$P_t = P_R + P_S = \left(f_R F_z + F_x \lambda\right) r_{dyn} \omega_w \tag{5}$$

3. Results and Discussion

Figure 2 and Figure 3 illustrate energy demand and share of each resistance in different driving cycles for a B-class and a D-class vehicle, respectively. The energy demand in WLTP cycle is much higher than that of in NEDC and FTP cycles and this is the fact in both vehicles. This increase is due to the aggressiveness of WLTP cycle so that it provides higher levels of longitudinal acceleration and speed than the other driving cycles. It should be noted that WLTP cycle is organized to diminish the gap between standard cycles and real world conditions and is therefore more consistent with the actual driving patterns.

Consumed energy due to rolling resistance in different cycles does not change considerably and is about 76 kJ/km and 114 kJ/km for B-class and D-class vehicles, respectively. Energy loss due to tire slip depends upon tractive force and tire slip. Consequently, energy loss due to tire slip increases significantly in an aggressive driving cycle. Moreover, resistant and tractive forces are greater in D-class sedan which increases the consumed energy due to tire slip.

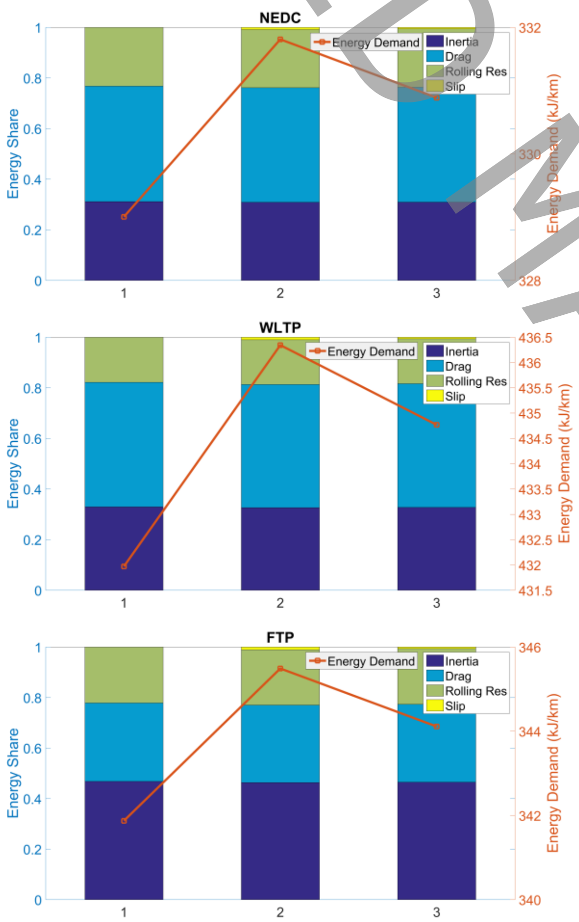

Figure 2. Energy demand and share of each resistance for compact B-class sedan, 1: neglecting the slip loss, 2: considering the slip loss using physical tire model, and 3: considering the sip loss using verified tire model

Tire slip loss in the simulated driving cycles is less than 1.1% of the total energy demand, and at the first glance it may seem reasonable to ignore it in obtaining the energy demand. However, tire slip is the inevitable result of the applied drive torque to the wheel, and considering the resultant loss improves the accuracy of calculation. The role of considering the slip loss becomes more important when the focus is on tire loss calculation. Results show that the modified tire power loss is capable of improving the accuracy of prediction of tire loss by about 6% in the simulated driving cycles.

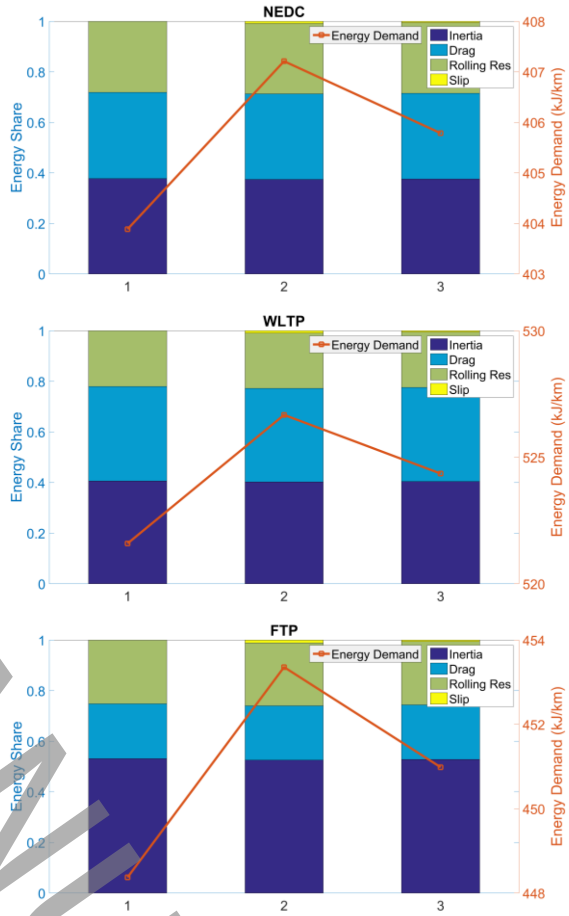

Figure 3. Energy demand and share of each resistance for mid-size D-class sedan, 1: neglecting the slip loss, 2: considering the slip loss using physical tire model, and 3: considering the sip loss using verified tire model

4. Conclusion

In the present paper, vehicle energy demand is studied by considering the modified tire power loss, which includes the slip loss as well as rolling resistance. Accordingly, neglecting the slip loss would affect the accuracy and validity of the modeling and simulation process. The lost energy due to tire slip consists about one percent of total energy demand in different conditions. Although this amount may seem negligible, it is capable of improving the accuracy of tire loss prediction by about 2 to 6 percent in the selected driving cycles. Therefore, considering the effect of tire slip in the tire dissipation term, especially in the studies focusing on tires and their influence on vehicle energy consumption, is essential in order to obtain the desired accuracy. In more aggressive driving cycles and/or by increasing the traction force, the slip loss would be increased. The results also show that energy demand per kilometer in the WLTP driving cycle is significantly higher than that of in the FTP and NEDC driving cycles, which should be taken into consideration by automotive design experts and energy policymakers.

5. References

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