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Effects of resistive loads and tire inflation pressure on tire power losses and CO_2 emissions in real-world conditions ☆

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HIGHLIGHTS

- Study of tire power losses due to rolling resistance and slip is performed.
- Test conditions are chosen to comprise the change of resistive loads.
- Slip power loss is the determining factor when tractive force is significant.
- In some cases the minimum tire power loss obtained when the tire is under inflated.
- The variations of the tire power losses and CO_2 emissions are similar.

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ABSTRACT

Considerable portion of energy losses in a vehicle traced to tire. Energy losses in a tire are due to tire longitudinal slip as well as rolling resistance. Hence, both of aforementioned factors must take into the consideration to study the tire energy loss. Present paper aims to investigate the power losses in tires and to examine influence of road conditions and tire inflation pressure on them. To cover the real-world conditions, experiments were done on a gasoline-fueled passenger vehicle on an urban highway along two routes with same length and opposite gradients to comprise the change of road conditions. Then, by use of engine performance model which is prepared in dynamometer laboratory, the power losses in drive and driven wheels are conducted separately. According to the results, either in driven wheels or when cruising in negative gradient, the power loss due to rolling resistance is primary and as a result the tire power losses would be decreased as inflation pressure increases. But when the tractive force is significant, for instance in positive gradient, the role of slip power loss becomes substantial in drive wheels so that the sum of rolling resistance and tire slip losses must be evaluated. Results show that in positive gradient, the least tire power losses in drive wheels would be obtained when the tire is under inflated. In addition, CO_2 emissions during the tests obtained and it is seen that a reduction in tire power losses leads to decrease of CO_2 emissions.

1. Introduction

More than 50% of petroleum productions used in transport sector in 2011, according to IEA[1] statistics [1]. Furthermore, the largest share of energy use within the transport sector comes from road transport and as it shown in Fig. 1, the share of road transport was nearly constant during last decades. Therefore energy efficiency in vehicles is an important factor to global energy use.

In a vehicle, driving resistance can be categorized as: tire resistance, air drag, gradient resistance, and acceleration resistance. More resistance leads to reduce efficiency and increase energy consumption as well. Also, tire as the final element of the powertrain is the part which tractive force and relevant torque is applied to. Hence, tires play a crucial role in the energy efficiency and fuel consumption of a vehicle as well as other characteristics such as ride comfort, stability, acceleration, braking, and handling. Power loss in tires can be listed as rolling resistance losses and losses due to tire slip. When the subjective of a study is to perform energy

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Nomenclature

f	coefficient
F	force (N)
H	center of gravity height (m)
k	tire stiffness (N/m^2)
l	length (m)
L	longitudinal distance to center of gravity (m)
p	tire inflation pressure (kPa)
r	tire radius (m)
R	rolling resistance force (N)
s	tire slip
T	torque (N m)
v	linear velocity (m/s)
W	weight (N)
δ	deviation of normal load (m)
θ	grade angle (°)
λ	longitudinal deformation prior to contact patch (m)
μ	coefficient of friction
ω	rotational speed (rad/s)

Subscript

c	characteristics
dyn	dynamic
f	front axle
p	peak value
R	rolling resistance
r	rear axle
S	longitudinal slip
t	tangential
V	vehicle
w	wheel
x	longitudinal
z	vertical

efficiency in tire, it is necessary to consider both rolling resistance and tire slip power losses to attain accurate results.

One of the tire parameters that routinely undergoes change is the inflation pressure which then affects several factors such as power losses. The public perception is that power losses increase by decreasing the tire inflation pressure and this is mainly because of considering rolling resistance one-sidedly. Also, in most of the studies conducted into the influence of tire inflation pressure, the longitudinal slip has been neglected [2,3]. While, change occurring in tire pressure affects both rolling resistance and longitudinal slip and relevant power losses consequently. Therefore, variation of several parameters such as rolling resistance and tire longitudinal slip must be considered when making any judgment about the effects of tire inflation pressure on other characteristics e.g. fuel consumption and gas emissions.

Most of the previous researches have been conducted in rolling resistance dependency to tire inflation pressure, while the simultaneous effect of tire longitudinal slip has been neglected. This is mainly due to measuring the rolling resistance by a laboratory test of a single tire, not with a fuel consumption test on a car [4]. However, studying of vehicle energy efficiency and GHG emissions is of interest to engineering and management investigations. Making use of new technologies is found to be one of the most effective methods to improve fuel efficiency. For instance using a HCCI[2] engine and a driving assistance system resulted in 21% and 10% better fuel efficiency respectively [5,6]. Also, Electrification of the powertrain (EV, HEV, and PHEV) could represent considerable reduction in fuel consumption and CO_2 emissions. Damiani et al. [7] simulated a hybrid powertrain and consequently achieved 23% fuel saving and 27% reduction in CO_2 emissions through urban, extra-urban, and highway cycles compared to basic powertrain. Nevertheless, Bishop et al. [8] concluded that utilizing advanced combustion technologies (e.g. GDI) are more cost-effective than EVs and fuel cell PHEVs. They studied the cost effectiveness of conventional and alternative powertrains of passenger vehicles and it is shown that the ownership costs of EV and fuel cell PHEV in all SMMT classes and series HEV and Parallel PHEV for some classes are greater than the base case vehicle. Although the utilization of technologies have considerable effect on fuel efficiency, the influence of ambient and/or performance conditions is a matter of importance. Changes of ambient pressure and temperature have significant influence on CO_2 emissions and fuel consumption [9–11]. Traffic flow rate has a major influence on CO_2 emissions and fuel consumption too. Results of a case study show that the fuel consumption of a passenger car increases by the amount of 70% in heavy traffic comparing to a free traffic flow [12].

Fuel consumption and CO_2 emissions in real-world conditions have been the objective of several studies because of different results in comparison to that of standards test procedure. Kudoh et al. [13] investigated real fuel consumption of petrol-fueled vehicles in Japan based on the voluntarily reported fuel consumption. They also estimated CO_2 emissions and the results show that there is a gap between real fuel consumption and Japan 10.15 mode fuel consumption. In addition, it is seen that real fuel consumption differs noticeably by geographical, social aspects, and even month of the year. Millo et al. [14] performed a method to minimize CO_2 emissions of a mid-size PHEV through four different driving cycles. Also, minimization of end user's cost is selected as an alternative target. A backward simulator was presented in order to obtain fuel consumption and CO_2 emissions in which performance maps of IC engine and electric machines in steady state conditions were located. Results show that by considering the CO_2 related to both IC engine and electricity, measured CO_2 emissions in NEDC and WLTP cycles is significantly different to that of obtained from the European Union test procedure. However, it is concluded that proposed method for CO_2 minimization has the ability to achieve minimum of the energy costs. Huo et al. [15] examined fuel consumption of passenger cars in China based on labeling policy and real world voluntarily reported by users namely drivers on the internet. One of the most important points of this research is that there is a considerable different between fuel consumption rate in a laboratory with fuel consumption rate in the real world. This shows that designing and implementing some suitable real world driving cycles and calibrated for the position where the fuel consumption would be measured is inevitable. Because of the impact of driving cycles on fuel consumption rates, they adopted the International Vehicle Emission (IVE) model. Based on the results of the research, IVE model has closer results to the real world condition. Zhang et al. [16] calculated fuel consumption and CO_2 emissions by measuring on-road emissions for 60 light-duty passenger vehicles (LDPV) including 41 gasoline LDPVs, 16 diesel LDPVs and 3 LPG-fueled LDPVs in three China's cities. They employed SEMTECH-DS PEMS (Sensor Inc.) and GPS to measure on-road CO_2 emissions, vehicle speed, and altitude data. Their results show that there is a strong correlation between relative fuel

[2] Homogenous Charge Compression Ignition.

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