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Analysis of Engine and Powertrain Losses of a Passenger Type 4-Stroke Gasoline Vehicle in 4 Different Driving Cycles with GT-SUITE Vehicle Simulation Program

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Abstract

Vehicle simulations have a very important place in the automotive R&D process. These simulations provide automotive companies with the benefits of saving money on model creation and the user changing many parameters throughout the vehicles as soon as possible. In this study, the engine and powertrain energy losses of a 4-stroke gasoline passenger car were analyzed in FTP75 (Federal Test Procedure), HFET (Highway Fuel Economy Test), US06 and WLTC (Worldwide Harmonized Light Vehicles Test Cycles) cycles. Analyzes were examined and tested with the help of GT-SUITE vehicle simulation program in urban and intercity road conditions. According to the analysis results, the lowest CO_2 emission (127.58 g/km) and average fuel consumption (5.29 l/100km) were obtained in the HFET driving cycle. While the transmission and gear friction values were close to each other between the driving cycles, the lowest loss in terms of torque converter losses was obtained in the HFET driving cycle (0.2%).

Keywords: Driving Cycle, Friction Losses, Gasoline Engine, GT-SUITE, Powertrain Elements

Research Article

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1. Introduction

A vehicle's fuel economy, efficiency, and the amount of emissions it emits to the environment are highly influenced by factors such as road conditions, traffic, driving style, and environmental conditions. Therefore, it is not a useful method to evaluate the fuel economy, losses and emissions of vehicles depending on the actual values measured on the roads. In order to solve this problem, automakers and governments have developed standardized driving tests to compare vehicles with each other in a standard way and to measure fuel consumption and emissions of the vehicle under repeatable conditions. These tests are called the driving cycle and these tests are used as the standard driving cycle in all new car designs [1]. Driving cycles are usually defined according to vehicle speed and gear selection as a function of time under standard conditions [2]. Simulation is defined as the study of how a system works by modeling it in a computer environment. After the model is created in the simulations, the parameters and elements are changed and predictions can be made about the behavior of the system for different conditions. Automobile companies perform simulations to verify the design at the beginning of the design process, to identify problems early, to increase their economic gains by reducing the number of design cycles and trials. Many popular programs are used in vehicle simulations. The most commonly used among these simulations are MATLAB/Simulink [3-4], ADVISOR [5], PSAT [6] and Gamma Dec. GT-SUITE [7] programs are prepared by. Model analysis studies on transmission losses mostly related to modeling and control of MT, AT and CVT-IVT-DCT gearboxes [8-15]. In this article, the engine and powertrain losses of a passenger-type gasoline car in 4 different driving cycles using the GT-SUITE simulation program are examined.

2. Models Description

The model was created with the created vehicle GT-SUITE simulation software. GT-SUITE is a product of Gamma Technologies (GTI), which produces engine and vehicle technology software

[16]. In the modeled vehicle, the engine, powertrains, tires and aerodynamic characteristics were first defined, and then the driving cycles were selected. The selected driving cycles are the most used driving cycles in vehicle emission and performance evaluations in the last 10 years. The data of the vehicle used in the modeling are given in Table 1. The model used a gasoline engine with an engine volume of 1998 cc. In the model, the ICE (Internal Combination Engine) controller is used to simulate engine control functions such as idle and fuel cut-off. This controller is recommended for applications where it is important to maximize fuel economy. "Driver Controller" is a model-based controller used for dynamic driving cycle analysis. The driver module was created by combining the vehicle path and the accelerator pedal during gear shifting, the brake pedal and the gear state to simulate the behavior of the controlling driver. The model has a feed-forward component that calculates the engine load torque required to correlate the desired vehicle speed or acceleration. For this calculation, the driver-controller receives important information from the powertrain with the help of a controller. A Transmission Controller is used to simulate the use of automatic transmission control in gear selection. This controller (Transmission Controller) is used to determine the desired gear state and to recall the transmission gearshift action. In the model, a Lock-up clutches connection was used to model the movement of the friction clutch used for fuel economy in the torque converter. An environmental module was used to determine the ambient weather conditions that affect the aerodynamic resistance force on the vehicle. The environmental module has several parameters for determining air density, including relative humidity, ambient air temperature and pressure. Effective tool-the wind speed and direction can also be changed in this model to determine the air speed. Density and effective air velocity are used in the calculations of aerodynamic drag force and aerodynamic lift force. The input parameters of the vehicle and the engine used in the modeling of the vehicle are given in Table 1. In addition, the GT-SUITE vehicle model created is shown in Fig. 1.

Table 1. Vehicle model parameters

Engine type, fuel	4 stroke, gasoline
Engine displacement (cc)	1998
Transmission type	Automatic
Gear ratio	3.393 (Gear 1), 1.45 (Gear 2), 1 (Gear 3), 0.677 (Gear 4)
Vehicle mass (kg)	1320
Passenger and Cargo mass (kg)	0
Vehicle drag coefficient	0.29
Vehicle frontal area (m^2)	2.2311
Tire rolling radius (m)	0.35
Tire rolling resistance coefficient	0.01
Ambient air temperature ($°C$)	20
Ambient weather	Dry, sunny

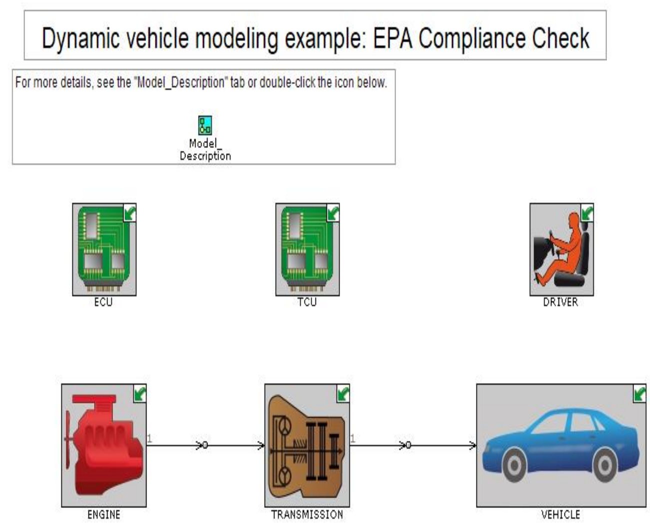


Fig. 1. GT-SUITE vehicle model

The BMEP (Brake Mean Effective Pressure) map of the selected engine depending on the engine speed is given in Fig. 2. According to the figure, the highest BMEP was obtained in the range of 2000-4000 rpm engine speed at a accelerator position of 80%-100%.

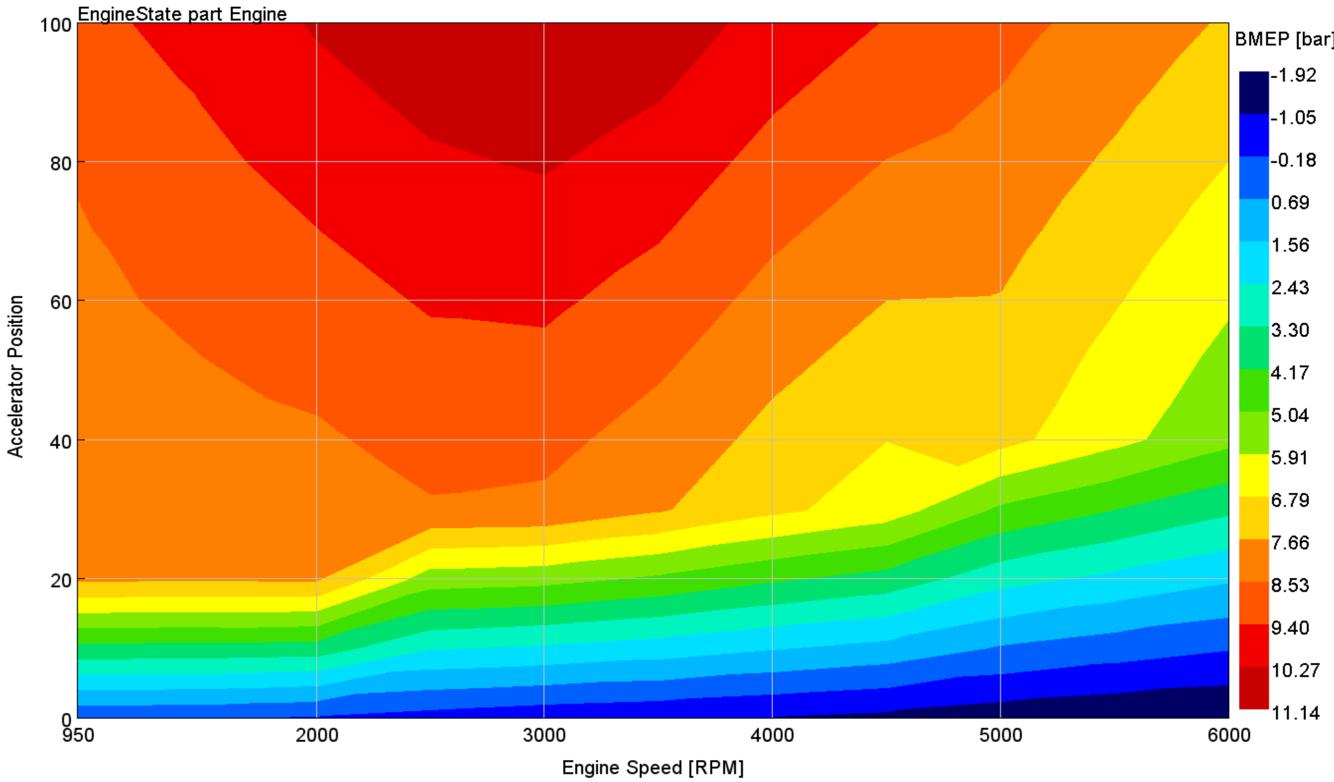


Fig. 2. Conventional vehicle model

2.1 Driving Cycles

Driving cycles should best represent the actual driving conditions applicable to the vehicle type and region defined in a given time period [17]. Considering these features, FTP75, HFET, US06 and WLTP cycles were selected as the driving cycle. The time dependent vehicle speed changes of the selected driving cycles are shown in Fig. 3.

FTP75 Driving Cycle

FTP Cycle (Federal Test Procedure) is a driving cycle created by the US Environmental Protection Agency (EPA, Envirometal Protection Agency), taking into account the stopping frequency, high speed use, and urban usage conditions. Its total distance is 17.77 km, its duration is 1874 s and its average speed is 34.1 km/h.

HFET Driving Cycle

The HFET (Highway Fuel Economy Test) cycle is a driving cycle that allows measuring fuel economy under high speed driving conditions. Its total distance is 16.45 km, its duration is 765 s and its average speed is 77.7 km/h.

US06 Driving Cycle

The US06 driving cycle is a driving cycle with speeds higher than 80 mph (130 km/h) and in which aggressive driving behaviors with high accelerations are taken into account.

WLTP Driving Cycle

It is a new driving cycle used to approve the sale of vehicles within the borders of the European Union [18]. The average speed of the WLTP driving cycle, which is a test model that reflects the real driving experience, is 46.5 km/h and the maximum speed is 131 km/h.

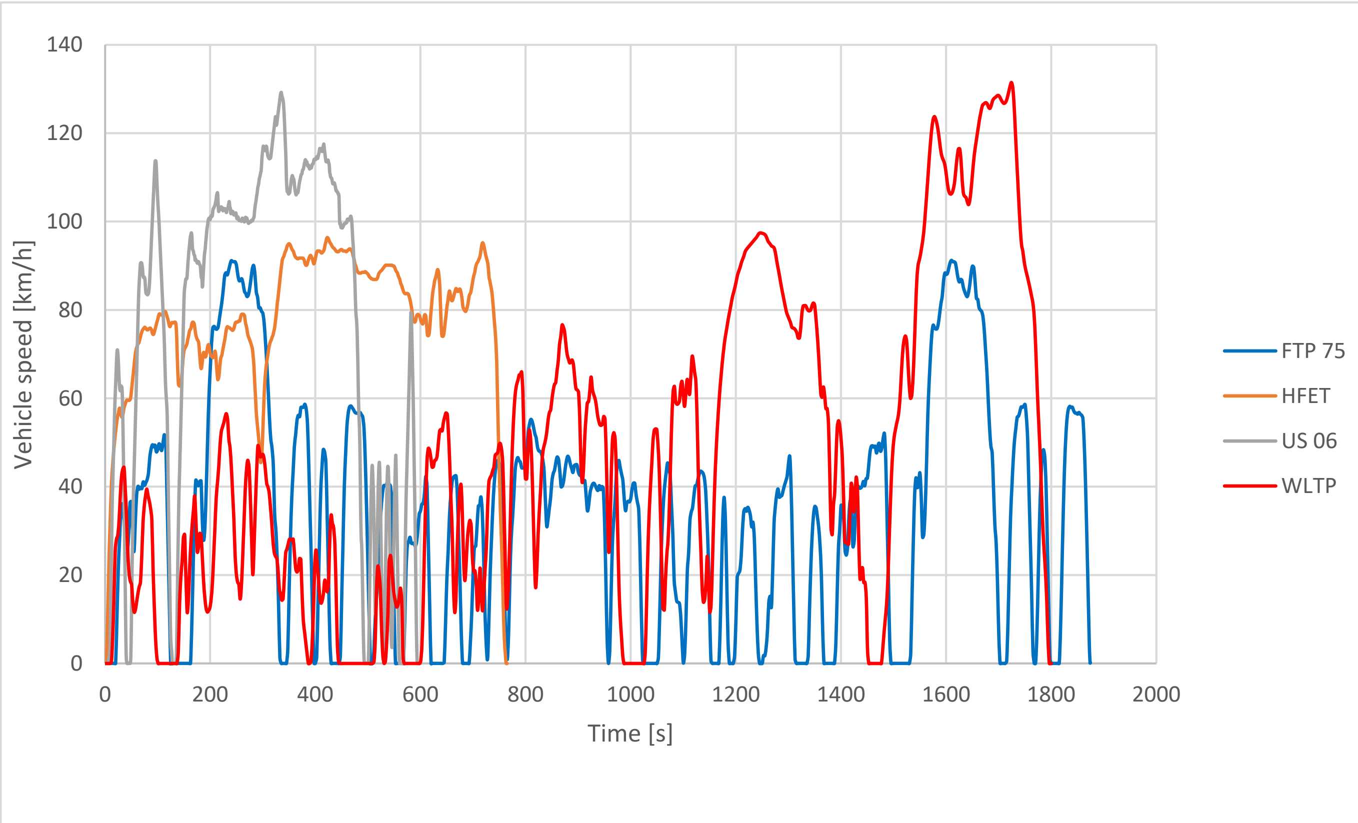


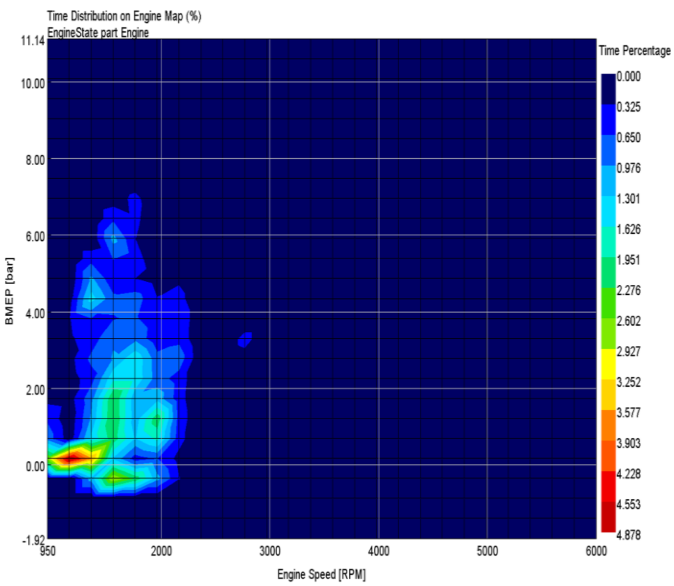
Fig. 3. Driving cycles used in modeling

3. Findings and discussion

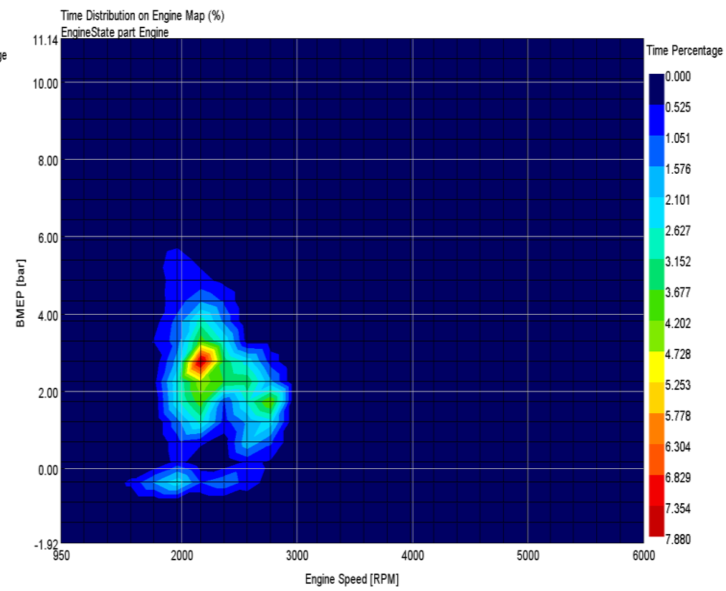
Fig. 4 shows the intensity map of the change in BMEP according to the driving cycles. According to the graphs obtained, the test engine is most intensely used at 950-1350 rpm in FTP75 cycle, 2100-2300 rpm in HFET cycle, 1500-1700 rpm in US06 cycle, and 950-1100 rpm in WLTP cycle in engine speed ranges. Because of the FTP75 driving cycle is a cycle designed for urban use,

BMEP values were mostly below 1 bar pressure. HFET driving cycle is a cycle performed at higher speeds than other cycles. Therefore, BMEP values of the driving cycle occurred in the pressure range of 2-4 bar. Although the US06 driving cycle is prepared for high speed driving, vehicle speed changes are very high in this cycle. This is the reason why BMEP values generally remain at low values. Although the WLTP driving cycle was the longest driving cycle, it was the driving cycle with the narrowest variation in terms of both engine speed and BMEP change interval.

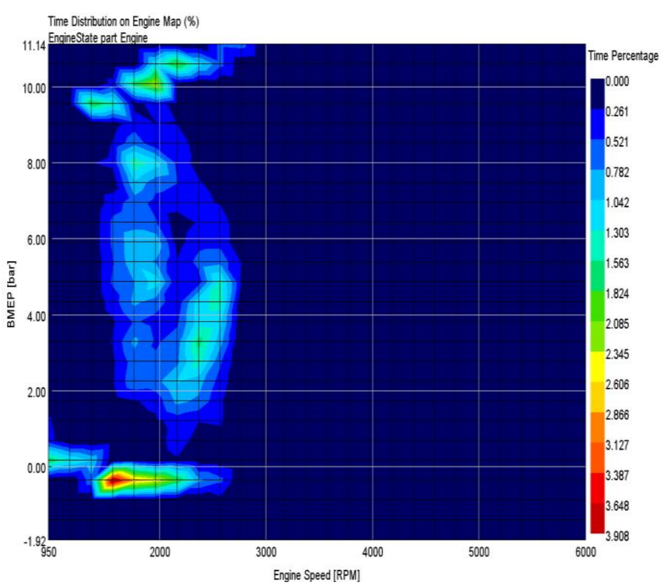
In Table 2, the distance traveled, average fuel consumption and CO_2 emission table are given according to the driving cycles. The highest average fuel consumption by distance traveled occurred in FTP75 (7.627 l/100 km) and WLTP (7.047 l/100 km) cycles. These cycles are driving cycles with high usage intensity at low and medium speeds. At the same time, these driving cycles are the driving cycles with the highest acceleration times (Table 3). The amount of fuel consumed during acceleration significantly increased the average fuel consumption. The high speed variability of the internal combustion engine also negatively affects the combustion efficiency in the engine combustion chamber. As a result, CO_2 emissions have increased. Among the driving cycles, the highest CO_2 emissions were gained in the FTP75 (183.95 g/km) and WLTP (169.95 g/km) driving cycles.



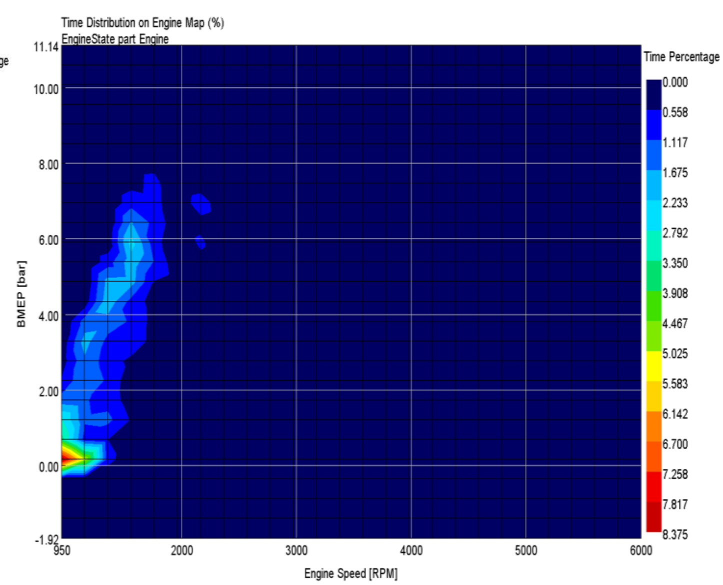
FTP75



HFET



US06



WLTP

Fig. 4. Motor speed dependent BMEP change intensity map

Table 2. Driving cycle distance, fuel consumption and CO_2 emissions chart

	FTP 75	HFET	US06	WLTP
Total distance traveled (km)	17.684	16.496	12.751	23.192
Average fuel consumption (l/100km)	7.627	5.29	6.935	7.047
Average distance specific CO_2 (g/km)	183.95	127.58	167.26	169.95

Table 3. Drive cycle characteristics

	FTP 75	HFET	US06	WLTP
Average vehicle speed (km/h)	33.97	77.63	76.51	46.38
Average vehicle acceleration (m/s^2)	0.483	0.175	0.592	0.398
Time to maximum acceleration (s)	1345.04	8.17	49.54	607.55
Time to maximum deceleration (s)	1682.13	763	165.08	567

In Fig. 5, the energy distribution of the internal combustion engine according to the driving cycle is given. According to the energy distributions, the highest effective efficiency of the internal combustion engine was gained in the US06 driving cycle (28.4%). The US06 driving cycle is the driving cycle with the lowest cooling and engine friction among other driving cycles. High BMEP values are gained at wide accelerator pedal openings in internal combustion engines. In these operating conditions, the amount of mixture taken into the cylinders increases and the combustion efficiency increases. According to the simulation results, 21.1% effective efficiency was obtained in FTP75 driving cycle, 22.1% in HFET driving cycle, 28.4% in US06 driving cycle and 25.1% in WLTP driving cycle. In addition, when examined in terms of waste heat recovery, the US06 driving cycle, which causes the highest exhaust waste heat loss, has the highest waste heat recovery potential.

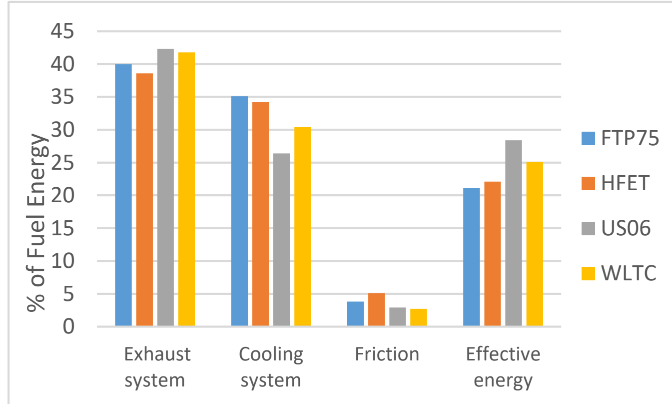


Fig. 5. Engine energy losses distribution

In Fig. 6, the vehicle energy distribution according to the driving cycle is given. Of all resistace forces, the overall largest amount of resistance loss is aerodynamic resistace loss. When analyzed according to the driving cycles, the aerodynamic resistance losses were 11.2% in the HFET driving cycle, 8.3% in the WLTP driving cycle, 5.4% in the US06 driving cycle, and 3.8% in the FTP75 driving cycle. The rolling resistance losses were 7.3% in the HFET driving cycle, 5.5% in the WLTP driving cycle, 5.1% in the US06 driving cycle, and 5.1% in the FTP75 driving cycle. Rolling and aerodynamic resistance losses have also occurred in driving cycles with high braking and speed changes. Transmission and differential losses are very close to each other and below 1%. In terms of torque converter losses, the FTP75 and US06 driving cycles are the highest. The lowest torque converter loss was obtained as 0.2% in the HFET driving cycle. This is due to the fact that the HFET driving cycle has the highest average speed among other driving cycles and the effective use of the Lock-up clutch, which provides fuel economy in torque converters.

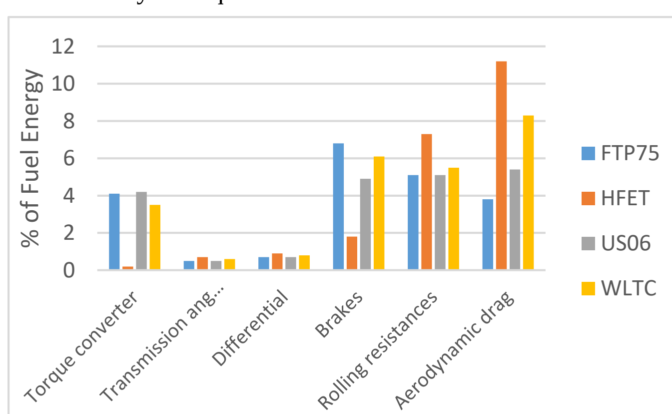


Fig. 6. Vehicle and driveline energy losses

4. Conclusions

According to the analysis results, the highest BMEP value in the driving cycles occurred in the HFET driving cycle. High cruising speed and less engine speed revolutions were effective in obtaining a high BMEP value. Lower CO_2 emissions and average fuel consumption were obtained in the HFET driving cycle compared to other driving cycles. According to the simulation results, the highest aerodynamic resistance occurred in the HFET driving cycle. This relates to average cruise speed and cycle time. In terms of transmission and differential losses, values close to each other were obtained for all driving cycles. The most important factor in torque converter losses is the effective use of the Lock-up clutch. A small number of actuation of the lock-up clutch reduces torque converter efficiency and increases its losses.

Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

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