

## Analysis of The Effect of Different Gearbox/Transmission Types on Driveline Friction Losses by Means of Gt Suite Simulation Programme

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### Abstract

Selection of transmission systems of motor vehicles used on highways is highly important in terms of fuel consumption and vehicle efficiency. In this study, effect of using 3 different gearboxes in a passenger car (automatic gearbox, CVT gearbox and manual gearbox) on driveline friction losses and engine operation interval by means of GT SUITE vehicle modelling programme. The vehicle model formed has been simulated in 3 different driving cycles (WLTP, HFET and US06) and transmission system losses have been compared. In WLTP driving cycle in which speed changes and average speed are low, frictions resulting from the load constitute a significant part of total frictions; on the other hand, in driving cycles in which driving mode is aggressive and the average speed is high, frictions resulting from lubricant and sealing elements constitute a significant part of total frictions. Gearbox and related clutch mechanism selection have changed operation interval of the engine during driving cycle.

Keywords: Driving cycle, GT SUITE, transmission losses, lock-up clutches

### Research Article

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## 1. Introduction

Usage of driveline (clutch, gearbox, drive shaft, differential and axles) is a requirement when moving force and power need of the vehicles using internal combustion engines are analyzed. Today, driveline in automobiles using fossil fuel is designed to reduce CO<sub>2</sub> emission and to provide fuel economy. Different clutch and transmission forms, attached to the same internal combustion engine, create significant emission and fuel economy changes in vehicle performance. CO<sub>2</sub> emission of the vehicle can be decreased by 60% by optimizing the vehicle's chassis and driveline [1]. Gearboxes regulating the chassis of the vehicle during the cruise play an important role in driving comfort and fuel economy [2]. Usage of gearboxes in vehicles primarily started with three-speed gearboxes and has become widespread by development of four-speed gearboxes [3]. Today, field of use, desired number of speed levels, cost, comfort and performance parameters come to the forefront in selection of gearbox type.

In automotive terminology, the term "driveline" is used for a

power transmission group transferring the moving force obtained from the engine into road surface, water or air [4]. The most basic gearbox technology is the manual transmission (MT). MTs provide torque and speed changes which are complying with the requirements of the vehicle by using gear groups that have different transmission ratios. Synchromesh mechanism is used in order for easy and silent coupling of the gears. Automobile manufacturers have produced automatic transmission (AT), continuously variable transmission (CVT), dual clutch transmission (DCT), automated manual transmission (AMT), and electrically variable transmission (EVT) in order to decrease exhaust emission and fuel consumption [5]. A large part of power losses occurring in AT and CVT transmission results from the torque converter used by both transmissions. Although lack of torque converter usage in MT transmissions is seen as an advantage, it is compulsory for the driver to shift gear in such transmissions at the most suitable times.

The gearboxes controlling the clutch mechanism by means of electromagnetic or hydraulic actuators are called as automated transmission ((automated manual transmission (AMT)) [6].

In the literature, dynamic simulations have been made by using ADAMS, MapleSim and Matlab/Simulink programmes in order to reduce the cost and time loss with relation to the driveline [7]. The studies carried out have generally focused on formatting of simulations by means of making analytic models of driveline. Overall researches are related to modelling and control of MT, AT and CVT-IVT-DCT gearboxes [8-15]. In such studies, formulation methods and programme techniques related to dynamic modelling of driveline in vehicles and simulation of gearbox control have been used in general terms; transmission losses have not been examined. Numerous studies deal with total losses of both automated and manual vehicle transmissions [16–24]. An evaluation of different driving cycles on a map-based loss calculation is given in [16] and an evaluation of synchronizer losses is given in [15]. In this study, a passenger type automobile model has been formed by using GT SUITE vehicle simulation programme and gearbox losses in different driving cycles have been examined. MT, AT and CVT gearboxes have been selected.

**2. Material and Method**

In this study, model of simulation vehicle has been formed firstly. In Fig. 1, the transmission model formed by means of GT SUITE programme is shown. Such model is composed of ECU (Electronic Control Unit), TCU (Transmission Control Unit), Driver, Engine, Transmission and Vehicle elements. In the model, only transmission type has been changed and transmission losses in 3 different driving cycles have been examined. The transmission types used are automatic transmission (AT), CVT (Continuous Variable Transmission) and manual transmission (MT). While AT and CVT gearboxes use lock-up clutch, MT uses frictional dry-

type single clutch. Gear ratios of the selected gearboxes are shown in Table 1.

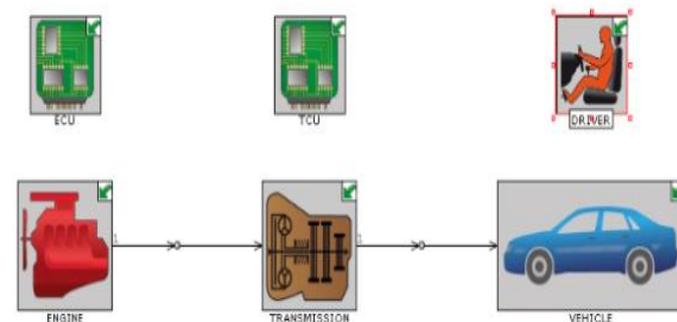


Fig. 1. GT SUITE engine transmission model

Table 1. Technical specification of transmission

	Gear Ratio		
	AT	CVT	MT
1	2.393		2.393
2	1.45		1.875
3	1		1.45
4	0.677		1
5			0.677

In Fig. 2, average effective pressure (BMEP) change depending on the speed of test engine is seen. By increasing the engine speed, a throttle opening of 80-100% and BMEP of 11.14 bars at 1980-3750 rpm interval are obtained. BMEP value decreases in all engine speed and throttle opening changes except for the stated speed and throttle opening.

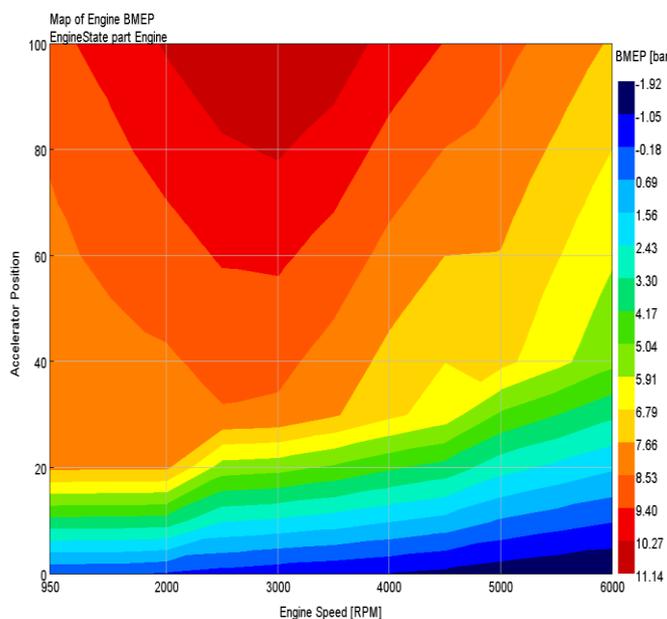


Fig. 2. Map of engine BMEP

## 2.1 Driving Cycles

3 driving cycles widely used recently have been selected in order to evaluate inner-city, inter-city and acceleration performances of vehicles to examine clutch and transmission losses (Fig. 3).

### WLTP driving cycle

WLTP (Worldwide Harmonized Light-Duty Vehicles Test Procedure) is a recent driving cycle used in approval of the sale of vehicles within European Union borders. All light-duty vehicles sold since September 2018 have been tested according to this cycle. Such cycle reflecting real driving cycle has a length of 23.24 km and is realised at 4 dynamic stages. Average speed in 46.5/h, and maximum speed is 131 km/h (Figure 3-a).

### HFET driving cycle

This a chassis dynamometer driving cycle developed by EPA of USA in order to determine fuel economy of light-duty vehicles.

The cycle activates twice with an interval of maximum 17 sec.; in the first activation, conditioning of the vehicle is carried out, and in the second activation, emission is measured. The cycle lasting for 765 sec. in total has a road length of 16.45 km and its average speed is 77.7 km/h (Figure 3-b).

### US06 driving cycle

US06 Supplemental Federal Test Procedure (SFTP) has been developed in order to make up the deficiencies of FTP-75 test cycle in representation of aggressive, high-speed and/or high-accelerated driving behaviour, rapid speed fluctuations and driving behaviour after start-up. The cycle has a road length of 12.8 km; its average speed is 77.9 km/h and its maximum speed is 129.2 km/h (Figure 3-c).

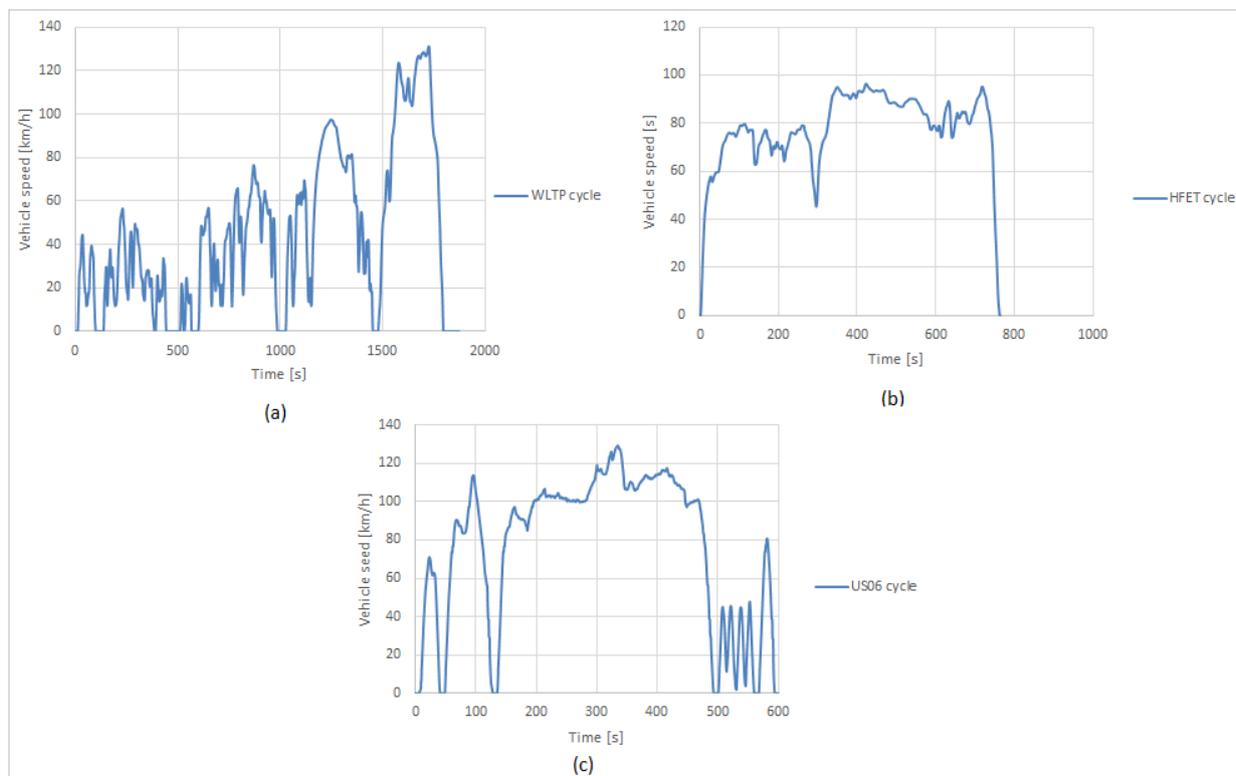


Fig. 3. Driving cycles used in simulations

## 3. Findings

In Fig. 4, BMEP change depending on engine speed has been given for driving cycle. In WLTP driving cycle, the engine using AT has functioned at 945-3200 rpm interval, the engine using CVT has functioned 945-3800 rpm interval, and the engine using MT has functioned at 945-5000 rpm interval. Operation of

the engine at larger speed range has increased friction and fuel consumption of the vehicle using MT. Transmission and the selection of clutch that can function in compliance with such transmission has operated internal combustion engine (ICE) at different speed range as per the same driving cycle.

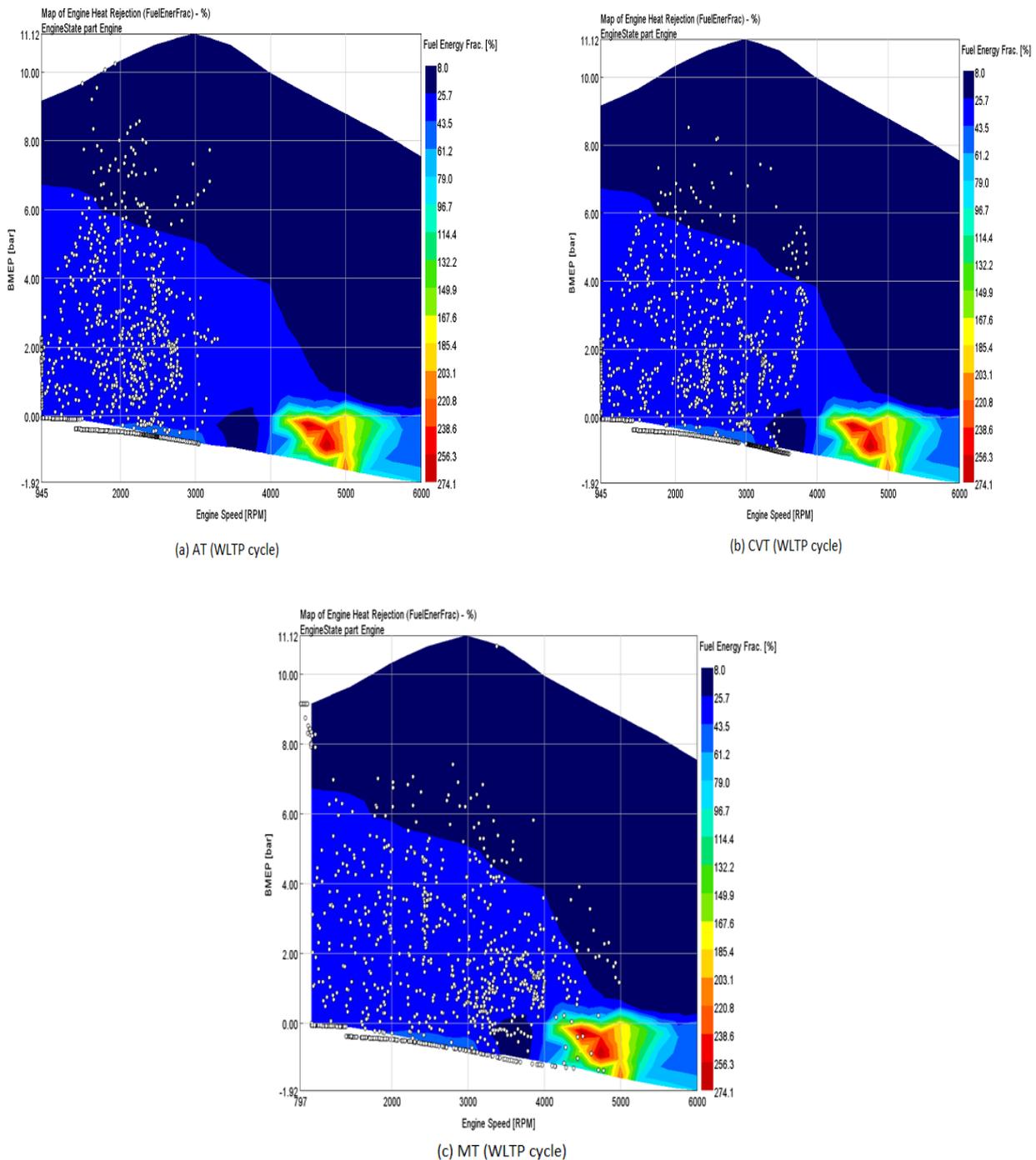


Fig. 4. BMEP change depending on engine speed for WLTP driving cycle

Transmission losses are generally divided into 4 categories as gear losses, bearing (ball and roller bearing) losses, sealing element losses and other losses [14]. In Table 2, transmission losses selected according to WLTP driving cycle are given. When the losses are examined, it is seen that MT transmission losses are much more. MT transmission has 5 forward speed capacities. Therefore, in such gearbox, there has been more losses than other gearboxes, dependent on and independent from engine

load. Transmission losses which are dependent on engine load are the basic determinant of the losses especially at lower vehicle speeds [15], as at lower vehicle speeds, higher speed changes and torque increases are provided when compared to higher speeds. WLTP cycle uses lower vehicle speeds compared to other cycles, and its average speed is lower than other cycles. AT and CVT transmissions use torque converter and a lock-up clutch in order to increase efficiency of the torque converter.

When such clutch is activated, converter pump and turbine parts are locked completely, accordingly power loss of the converter is reduced and it operates more efficiently [16]. Therefore, operation frequency of such clutch is of great importance for the efficiency of the torque converter. Graphic of lock-up clutch loss, obtained from GT SUITE programme, is shown in Fig. 5. According to such graphic, lock-up clutch of the torque converter of CVT transmission has operated less than AT lock-up clutch in WLTP cycle. In time interval of the cycle between 0-650 sec., lock-up clutch of CVT transmission has operated only once. It is understood that such situation results from less amount of lock-up clutch losses. For WLTP cycle, CVT lock-up clutch has

caused a total power loss of -0.12338 kJ, and AT lock-up clutch has caused a total power loss of -2.71047 kJ. Although this situation is considered as an advantage for CVT transmission, such gearbox has experienced much loss in torque converter and transmission. Torque converter loss in CVT transmission has been calculated as -1475.14 kJ, and as -1258.77 kJ in AT transmission. Moreover, when all driveline elements are taken into consideration, it is seen that driveline with CVT transmission has consumed more energy than other transmissions in WLTC cycle.

Table 2. Driveline losses according to WLTP driving cycle

	AT (kJ)	CVT (kJ)	MT (kJ)
Clutches	-2.71047	-0.12338	-300.343
Torque Converter	-1259.77	-1475.14	0
Transmission and Gears	-308	-313.015	-332.893
Differential, Transfer Case	-400	-403.906	-432.549
Total	-1970	-2192.18	-1065.785

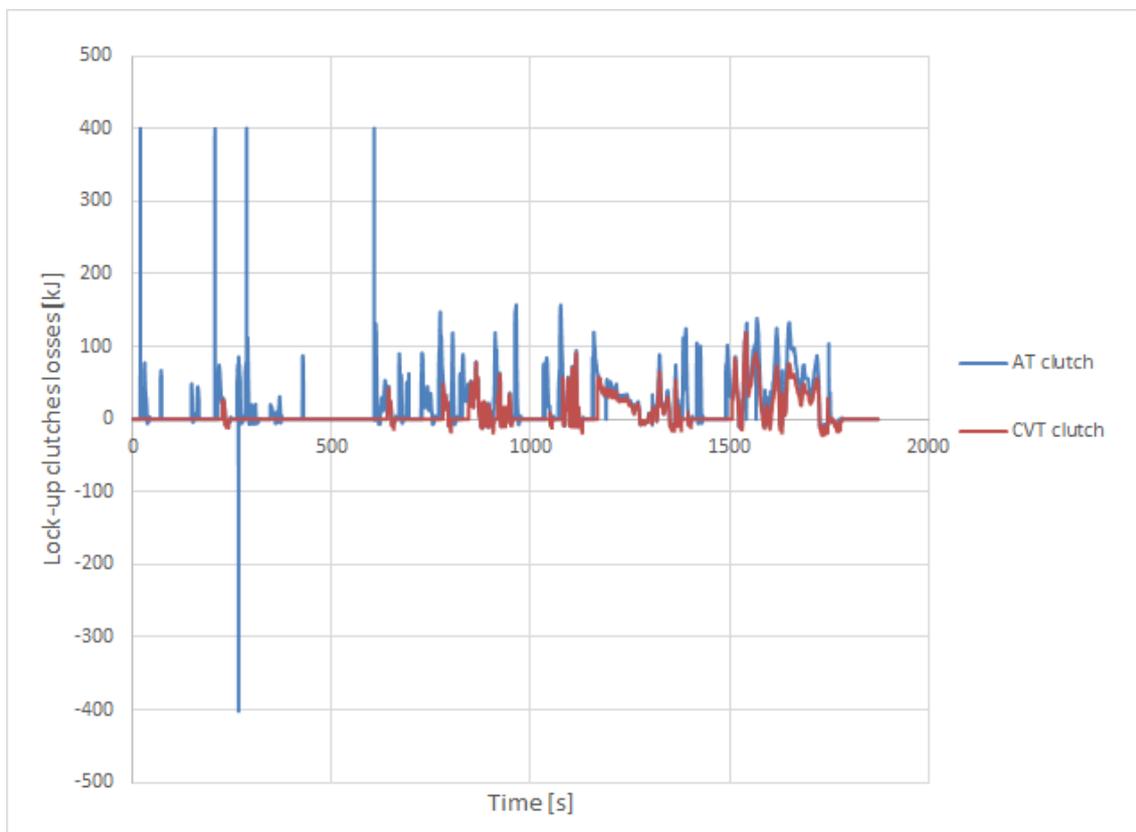


Fig. 5. Graphic of the lock-up clutch loss of transmission according to WLTP driving cycle

In Fig.6, BMEP change depending on engine speed has been given for HFET driving cycle. In HFET driving cycle, the en-

gine using AT has operated at 2000-3300 rpm interval, the engine using CVT has operated at 2500-3300 rpm interval, and the engine using MT has operated at 2700-4000 rpm interval.

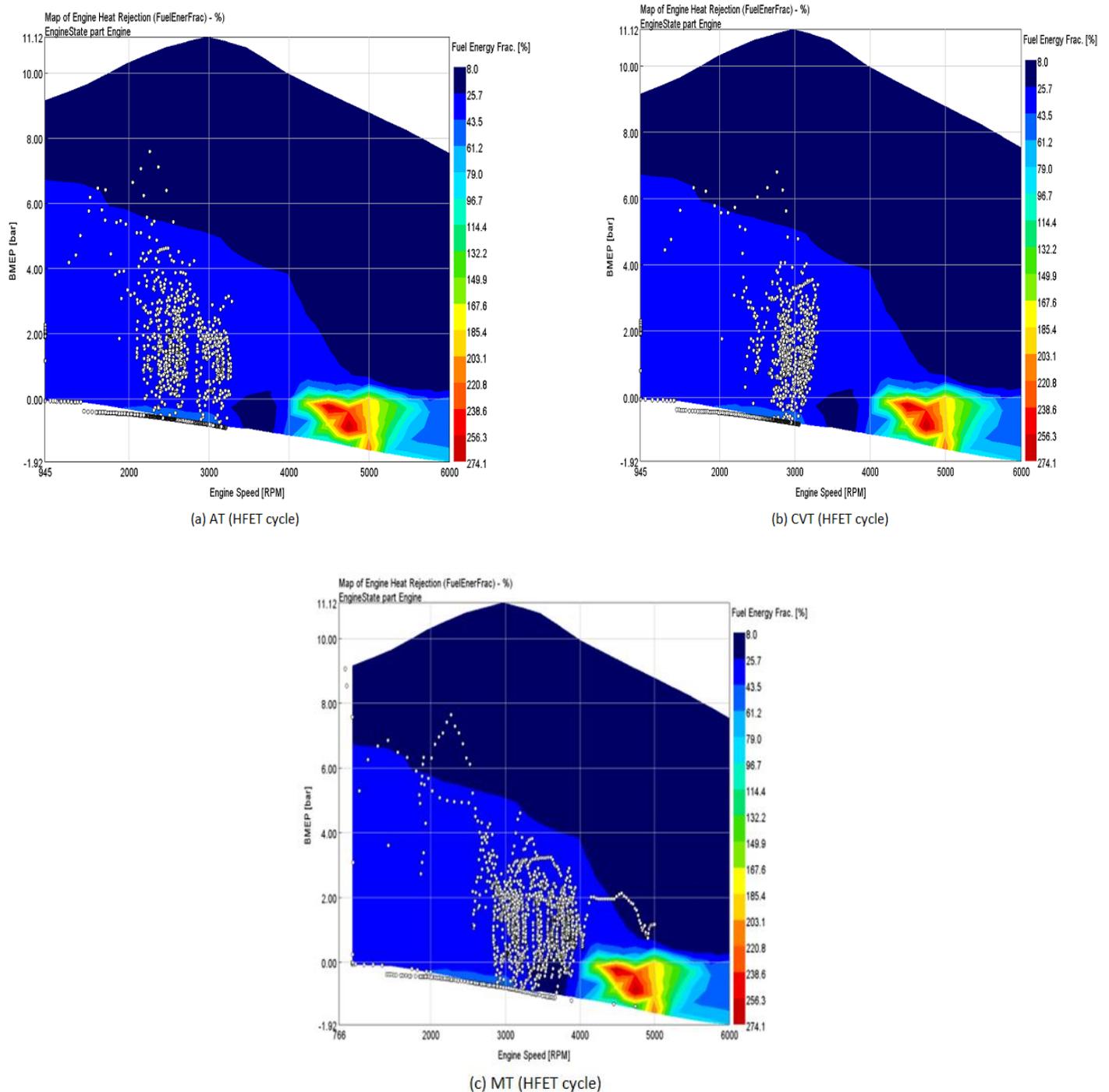


Fig. 6. BMEP change depending on engine speed in HFET driving cycle

In Table 3, driveline losses have been given according to HFET driving cycle. HFET cycle includes higher average speed and less speed change when compared to WLTP driving cycle. Therefore, total transmission losses are much less. As clutch

mechanisms of CVT and AT are lock-up clutches, it has consumed less energy than MT clutch. The torque converter with CVT transmission has consumed 48.7% more energy compared to the torque converter with AT transmission.

Such situation is related to frequency of lock-up usage. Increase in average speed of cruise cycle and decrease in speed changes have resulted in close figures of transmission losses. Furthermore, differential losses have decreased approximately by half compared to WLTP cycle. When all driveline elements are taken

into consideration, the highest driveline loss has occurred in CVT transmission system in HFET driving cycle (-410.385 kJ). After such transmission system, the highest driveline loss has occurred in MT transmission system (-392.2 kJ).

Table 3. Driveline loss according to HFET driving cycle

	AT (kJ)	CVT (kJ)	MT (kJ)
Clutches	-0.286711	-0.0618062	-36.1776
Torque Converter	-38.6852	-56.5778	0
Transmission and Gears	-153.675	-154.131	-155.081
Differential, Transfer Case	-198.836	-199.625	-200.944
Total	-391.482	-410.385	-392.20

Graphic of the lock-up clutch loss obtained from GT SUITE programme is shown in Fig. 7. Although lock-up clutch of CVT has operated more in this cycle when compared to WLTP cycle, lock-up clutch of AT has operated more effectively in HFET

cycle. Such situation is the reason of 31.62% less energy consumption of AT torque converter. Moreover, the engine to which CVT transmission is attached has operated at higher speeds. Such situation has increased torque converter losses.

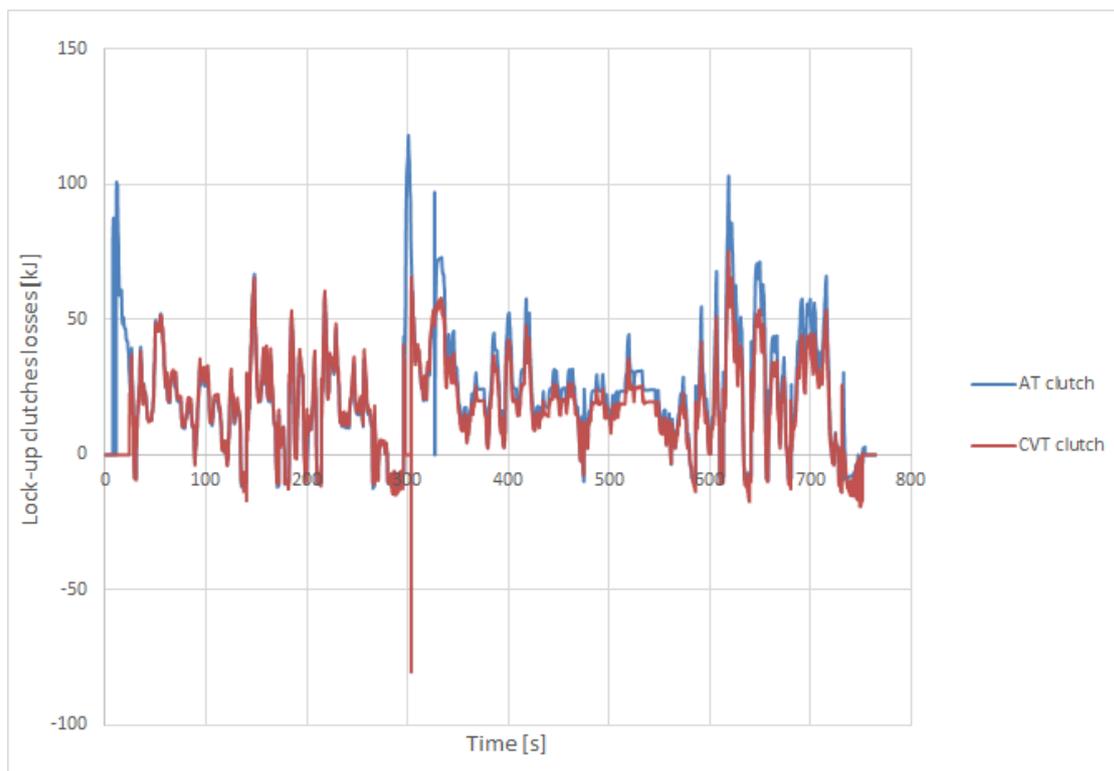


Fig. 7. Graphic of transmission lock-up clutch loss according to HFET driving cycle

In Fig. 8, BMEP change depending on engine speed has been given for US06 driving cycle. In US06 driving cycle, the engine using AT has operated at 3000-4000 rpm interval, the engine using CVT has operated at 2000-3000 rpm interval, and the engine using MT has operated at 2000-4000 rpm interval. In such

driving cycle, the engine with MT transmission has operated at the widest cycle range. Internal combustion engines increases fuel consumption outside optimum operation region.

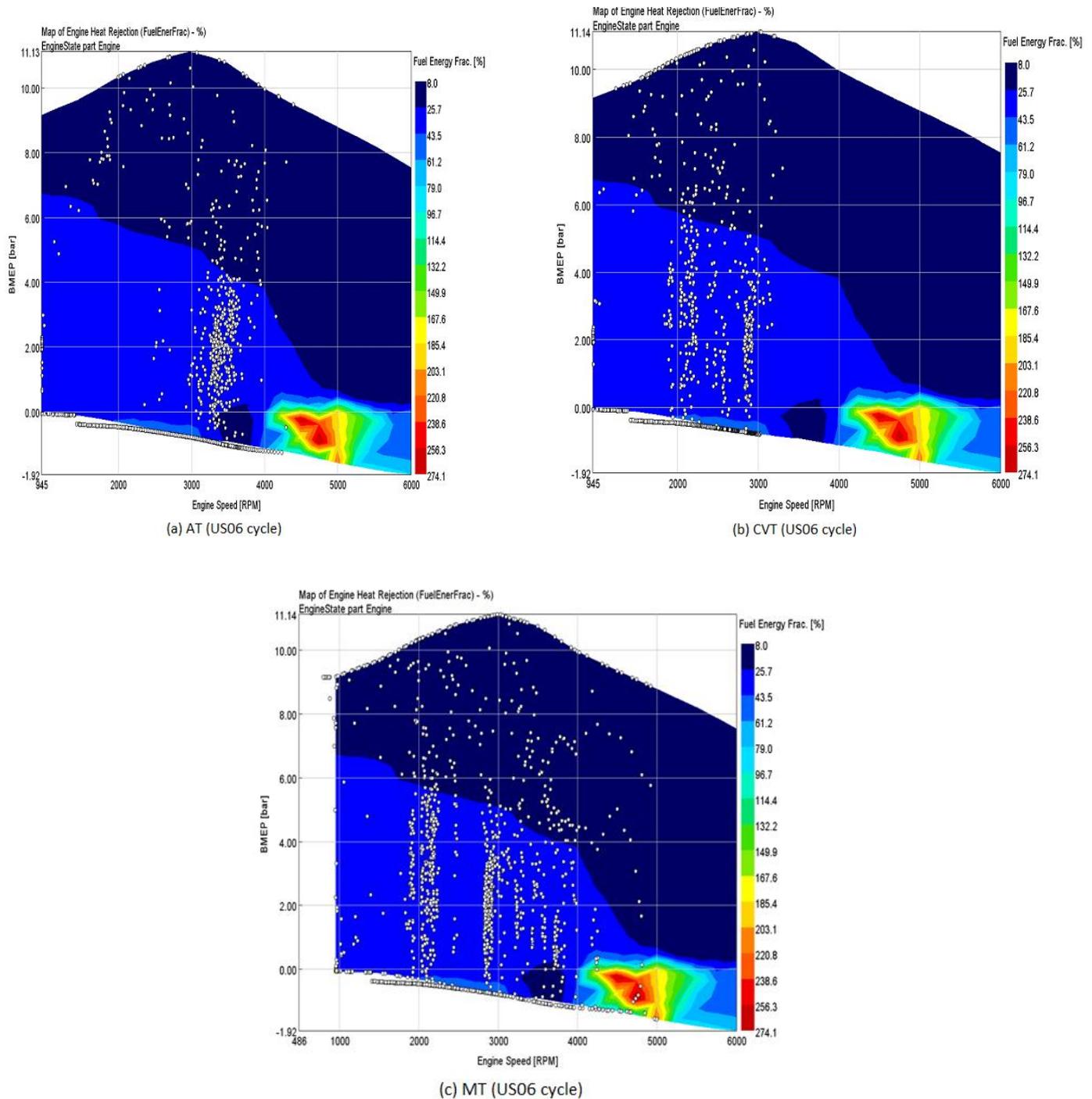


Fig. 8. BMEP change depending on engine speed for US06 driving cycle

In Table 4, driveline losses have been given according to US06 driving cycle. US06 driving cycle is aggressive and has high speed and rapid speed fluctuations. Therefore, general transmission losses are higher than HFET driving cycle even though their average speeds are close to each other. The change of driving style from normal to aggressive has increases total transmission

losses. Lock-up clutch of CVT transmission has not operated at 487s-579s intervals. Such situation has increased torque converter losses. Aggressive characteristic of driving cycle has increased speed-based losses in transmission and differential resulting from agitation and fluctuation of lubricant, and sealing elements. (Fig. 9)

Table 4. Driveline losses according to US06 driving cycle

	AT (kJ)	CVT (kJ)	MT (kJ)
Clutches	-27.3082	-0.21871	-241.988
Torque Converter	-293.086	-484.318	0
Transmission and Gears	-208.279	-215.073	-211.715
Differential, Transfer Case	-270.379	-277.306	-275.158
Total (kJ)	-799.05	-976.91	-728.86

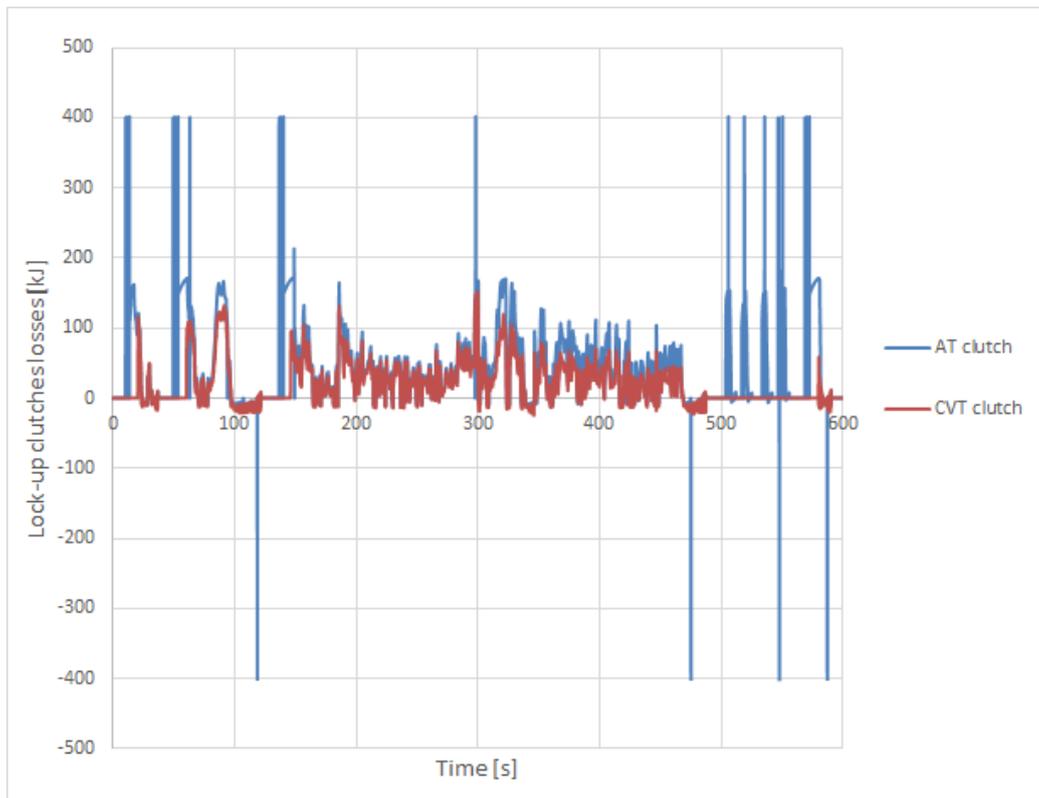


Fig. 9. Graphic of transmission lock-up clutch loss according to US06 driving cycle

### 3. Conclusion

Driving style has significant effects on fuel consumption and transmission losses in vehicles. In driving styles in which speed changes are dense and average speed is low, transmission losses depending on load increase significantly. In case of selection of aggressive driving style, agitation of lubricant and frictions resulting from sealing elements increase. Such situation is observed in transmission losses in HFET and US06 driving cycles. Selection of CVT and AT as gearboxes requires usage of torque converter and lock-up clutch.

Usage of such clutches decreases energy losses of the related gearbox. In addition, the internal combustion engines to which such gearboxes are attached provide less cycle fluctuations. This situation shall decrease engine frictions and fuel consumption as well. In all driving cycles, losses of transmission systems with AT gearbox are less than the losses of transmission systems with

CVT gearbox. The basic reasons of such situation are operational structure of gearboxes and operational frequency of lock-up clutch. Although it is observed that losses of transmission systems with MT gearbox are less in all driving cycles, the engine to which such transmission system is attached has operated at the widest speed range and speed fluctuation. This shall increase engine losses and fuel consumption.

### Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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