JOURNAL OF MECHANICAL AND TRANSPORT ENGINEERING
Vol. 70, no. 3 2018
DOI 10.21008/j.2449-920X.2018.70.3.06

Ireneusz PIELECHA*
Kinga FLUDER*
Wojciech CIEŚLIK*

(Received 20 Mar 2018, Received in revised form 7 Jan 2019, Accepted 11 Mar 2019)

ANALYSIS OF THE USE OF A HYBRID DRIVE SYSTEM IN URBAN TRAFFIC CONDITIONS

The continued reduction of fuel consumption by vehicles leads to an increase in the share of hybrid and electric vehicle drives in the automotive market. There are many approaches, such as to focus only on the introduction of electric vehicles, however, using this type of drive requires additional infrastructure, reconstruction of many systems and has a long charging time, with which consumers are not entirely satisfied. Therefore, one of the leading types of passenger car drives is currently a hybrid drive. It does not require reconstruction of the entire infrastructure, only changes in vehicle drive systems. The costs related to this are relatively small compared to, for example, the construction of a network of new charging stations. Knowing the electric drive operating share in a vehicle with a hybrid system is used as a determinant of the profitability of using electric drives. The article estimated the share of electric and hybrid mode operation in urban traffic conditions. The research object was a Toyota C-HR vehicle equipped with a fourth generation hybrid drive. The analysis of the drive's operation allowed to determine the conditions of energy flow and determine the share of electric mode operation in the total driving time and in relation to the distance travelled.

Keywords: hybrid vehicle, drive modes, energy flow

1. INTRODUCTION

Emission limits of toxic and harmful compounds from exhaust gases currently being introduced pose a challenge for car manufacturers. They have to meet not

*Poznan University of Technology

only these legal requirements, but also the expectations of customers in relation to the comfort of driving and operating the vehicle. In addition, solutions that can minimize the use of conventional fuels in transport have been sought after for a long time. Such solutions are observed in various branches of transport, including in road, rail or air transport [Marciniak 2010, Bogusz et al. 2017]. Analyzing only land transport in the European Union in 2010-2015, the share of road transport oscillated around 75% (Fig. 1).

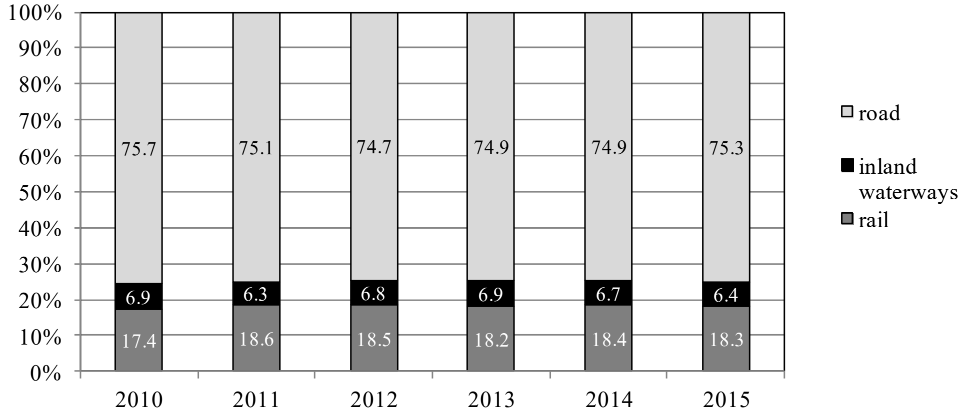


Fig. 1. Freight transport in the EU modal split of inland transport modes [Eurostat 2016]

Such a significant share of road transport relative to land transport means that measures aimed at limiting the emission of harmful compounds to the environment should begin with this type of transport. The more it is possible to reduce emissions from vehicles, the greater the effect of measures to protect the environment will be globally.

Using a hybrid drive reduces fuel consumption and as a result the emission of harmful and toxic compounds to the environment. A hybrid drive is one that has a minimum of two power sources and two drive sources. Most often this system is an internal combustion engine and an electric motor. A vehicle with a hybrid drive system is characterized by the fact that it has, among others, the ability to recover and accumulate energy from braking, which can be used at a later stage of driving, instead of being lost and wasted. The operation of the hybrid system, in the case of insufficient electric power supply, is supported by the combustion engine [Alvarez and Muñoz, 2016]. According to the International Energy Agency, the sale of light-duty vehicles is expected to increase year by year (Fig. 2).

The first commercial vehicle with a hybrid drive was a Toyota Prius [Buczaj 2006]. This brand was the first to focus on the production of hybrid vehicles and is still at the forefront of sales of this car type. One of the latest products of this company is the Toyota C-HR hybrid version.

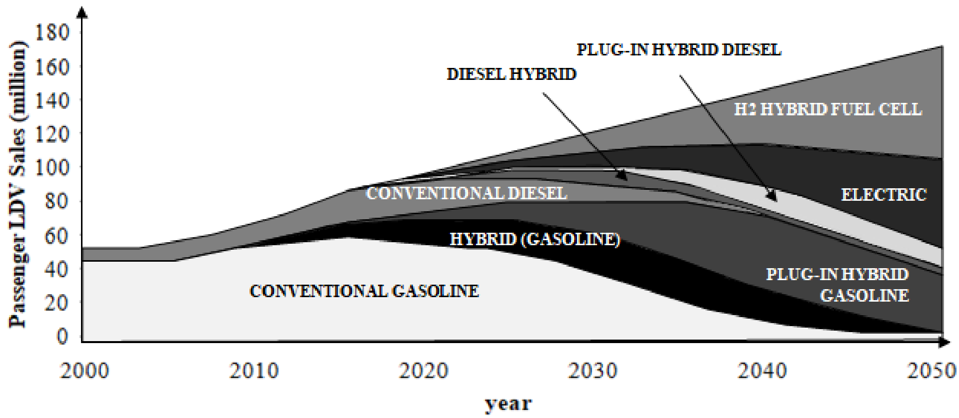


Fig. 2. Annual light-duty vehicles sales [International Energy Agency]

2. AIM OF THE RESEARCH

Currently, the aim of using a hybrid drive is such that the share of the system's operation in electric mode is continuously increased, which has a positive effect on fuel consumption in urban driving mode. This means an increased share of electric motor operation in the total operating time of the hybrid drive system [Cieślik et al. 2015]. In order to determine the share of electric mode operation, tests in urban driving conditions were conducted. The practical goal of the conducted research was to analyze the energy flow of the latest generation hybrid drive system based on the example of Toyota C-HR.

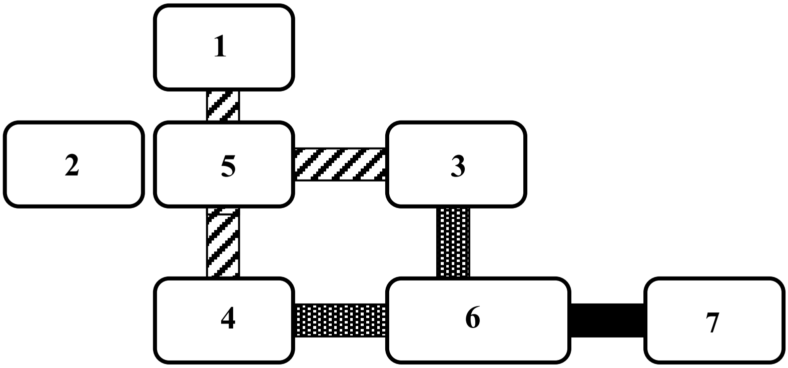
3. TEST OBJECT

The Toyota C-HR vehicle, which was used to test the hybrid drive system in urban driving conditions, has a propulsion system with a characteristic construction similar to that of the Toyota Prius. The basic parameters of the drive system components are shown in Table 1.

The Toyota C-HR is equipped with a fourth-generation hybrid drive. The hybrid drive is a mixed system solution (series-parallel) [Merkisz and Pielecha 2015]. It consists of a Ni-MH battery (7), an inverter (6), a planetary gear (5), a generator (3), an electric motor (4), a differential gear (2) and an internal combustion engine (1) (Fig. 3).

Table 1. Test vehicle technical data

Combustion engine	
Fuel injection system	electronic multi-point injection
Displacement [cm^3]	1798
Compression ratio [–]	13:1
Max power [kW] at speed [rpm]	72/5200
Max torque [Nm] at speed [rpm]	142/3600
Emission standard	Euro 6
Hybrid drive system	
Total hybrid drive power [KM]	122
Maximum speed [km/h]	170



	Electric Power Path (AC)	3	Motor Generator MG1
	Mechanical Power Path	4	Motor Generator MG2
	Electrical Power Path (DC)	5	Planetary Gear
1	Engine	6	Inverter with Converter Assembly
2	Hybrid Vehicle Transaxle Assembly	7	HV Battery

Fig. 3. Diagram of Toyota C-HR hybrid drive along with the locations of data collection devices [toyota-tech.eu]

Hybrid drive is a good solution for specific road conditions. Frequent changes in acceleration, braking or traffic congestion are circumstances in which the use of a hybrid drive makes the most sense – it is most used, and as a direct result – the most effective. For this reason, a test was carried out in real traffic conditions while driving in the city center.

4. RESEARCH METHODOLOGY

The tests of the hybrid drive were carried out in Warsaw in real traffic conditions on a work day with moderate traffic congestion. The length of the route (Fig. 4) was 12.4 km, and the total time of the test was about 34 minutes. The average travel speed was 21.72 km/h. A large number of complete vehicle stops (32) resulted from typical high traffic in main communication routes and road congestion (mainly primary congestion).

Fig. 4. Map of the route used for road tests

The tests were performed in the typical vehicle driving mode (the EV mode was not forced, as it would prefer driving with the smallest possible share of the internal combustion engine operation).

In order to record vehicle movement parameters and hybrid drive operation conditions, a diagnostic system was used to read data from the hybrid drive system monitor. The following values were recorded in the test: vehicle speed (v), combustion engine speed (n), battery state of charge (SOC) and battery current (IB). In addition, a second, independent device determined the geographical position of the vehicle (GPS) in order to determine the route.

To determine the contribution of the electric drive mode, sections of the route with certain defined parameters have been selected. Thus, modes of operation of the hybrid drive system were determined, i.e.: driving, acceleration and braking during operation of the hybrid drive (HV), vehicle stop, and driving, acceleration and braking in the electric mode (EV). The adopted criteria are included in Table 2.

The flow of energy in the system was also determined in the article using the formula:

$$\Delta E = U \cdot I \cdot \Delta t \qquad (1)$$

where:
U – voltage [V]
I – current [A]
Δt – time span [h].

Table 2. Criteria for selecting individual modes during the test

Tryb	Parametry
HV drive	a = 0, n > 600, v > 0
EV drive	a = 0, n < 600, v > 0
HV acceleration	a > 0, n > 600, v > 0
EVacceleration	a > 0, n < 600, v > 0
standstill	v = 0
breaking	a < 0, v > 0, n > 600
EV breaking	a < 0, v > 0, IB > 0, n < 600

Analyzes of individual driving modes (battery discharging, charging and recuperative braking) were made taking into account the equation (1) as well as the criteria from Table 2.

5. RESULTS ANALYSIS

The data was recorded on a 12.4 km route. The initial state of charge of the high voltage battery was 58.03%. The use of data recorded during the trip along with the selected analysis in accordance with Table 2, allowed the determination of EV, HV driving modes and vehicle stops.

The results of these analyzes are shown on the speed profile in Fig. 5.

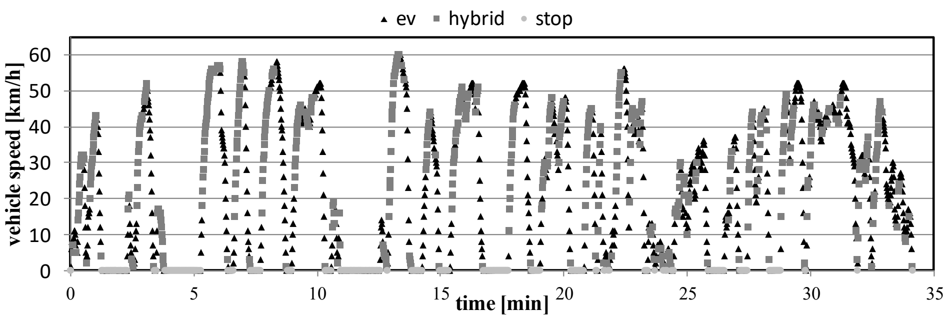


Fig. 5. Division of the driving test into sections travelled in hybrid and electric drive modes as well as vehicle stops

Table 2 was used to calculate the operating time share of all vehicle modes. The results were compared in terms of both the time and the distance traveled (the apparent differences are a result of vehicle stops).

The summary of this data is included in Table 3, which includes the distance and time in relative terms.

Table 3. Percentage share of individual driving modes based on the time and distance travelled

	Stop	HV drive	EV drive	HV acceler.	EV acceler.	Breaking	EV breaking
Distance	0.00%	5.96%	20.21%	32.03%	11.39%	4.30%	26.11%
Time	22.80%	2.93%	14.21%	19.35%	16.07%	5.76%	18.88%

Using the formula (1), the energy flow rates were calculated. The battery charging, discharging and regenerative braking conditions were taken into account. The calculated total energy flow (0.18 kWh) includes charging the battery (0.35 kWh), discharging (–1.03 kWh) and energy recovery during regenerative braking (0.86 kWh). These results have been included in Fig. 6. The energy flow rate is influenced by both the initial and final battery state of charge. The changes of SOC during the test are shown in Table 4.

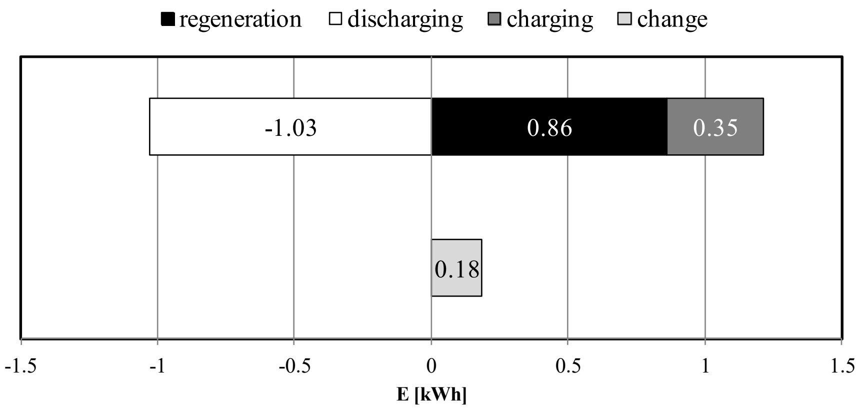


Fig. 6. Energy flow to/from the battery in a hybrid drive in urban operating conditions (negative values mean discharging the battery)

Table 4. Parameters characterizing the changes in energy flow in the system

SOC	Value [%]
initial SOC	58.03
final SOC	63.13
ΔSOC	+5.10

Based on the above analyzes, the percentage share of time (and distance travelled) of the electric mode operation was determined. This was done by adding the EV system mode operation duration, i.e. driving and acceleration without the participation of the internal combustion engine, as well as braking with energy recovery without the participation of the internal combustion engine. The obtained results are depicted in Fig. 7.

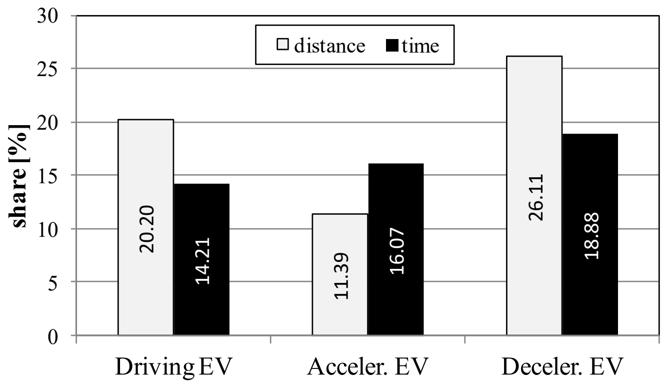


Fig. 7. The share of the electric mode operation when dividing between different modes

After summing up the shares of each particular vehicle drive sections performed in electric mode, the proportion of using the EV mode was determined as a whole (Fig. 8).

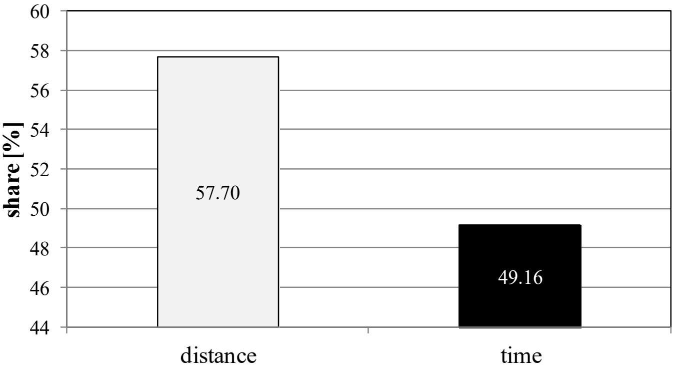


Fig. 8. The share of electric mode operation in urban traffic conditions in relation to the distance and time of vehicle operation

The percentage share of the electric mode operation was 58% of the distance travelled and about 49% of the total test time duration (the tested vehicle was equipped with a nickel-metal hydride battery with a capacity of 6.5 Ah). It should be taken into account that the tested vehicle was not equipped with a plug-in system. Vehicles with such an energy accumulation system have an increased capacity of Li-Ion batteries and for such a case the share of EV mode operation would be much larger.

6. CONCLUSIONS

The obtained results allow to conclude that the latest Toyota C-HR vehicle is characterized by a large share of operating time spent in electric mode (EV). The percentage share of electric mode was almost 58% of the total distance travelled and about 49% of the total test time. The final percentage value is influenced by many factors, including the road conditions, vehicle load, initial high-voltage battery charge level, idle time spent at intersections with traffic lights, driving style or the number of passengers in the vehicle.

As a result of the test performed in urban conditions, the battery state of charge (SOC) increased by +5.1% (Table 3), while the total battery power increased by +0.18 kWh. This indicates the efficiency of recuperative braking energy recovery and indicates the correct energy flow direction (charging the battery) in the hybrid drive system.

Considering such a large operating share of the electric mode, one should consider whether investing in purely electric vehicles is economically justified at all. A hybrid vehicle does not require the construction of an expensive infrastructure, such as the charging points necessary for charging the batteries in electric vehicles.

It should also be noted that in many countries electricity is still obtained from traditional coal-fired power plants that emit pollutants into the environment, so using electricity to drive vehicles does not have as large an environmental impact as one would expect.

Recuperative braking, a significant share of electric drive operation, reduction of operating costs, lower emissions of harmful and toxic compounds into the environment without significant extra financial costs are undoubtedly arguments that speak in favor of hybrid drives.

The hybrid propulsion system is somewhat self-sufficient, which is of great importance in large urban agglomerations, where the air pollution rates have been rising significantly over the years [Analiza wybranych…, 2016].

Current vehicle owners also value the convenience of using a vehicle with certain drive types. The use of a hybrid drive does not require long charging times, unlike in the case of electric vehicles. The number of petrol stations is much higher than the charging station for electric vehicles, which is also an advantage for the use of hybrid drives.

REFERENCES

Alvarez A., Muñoz E., 2016, Associated controls systems development application via parallel post transmission rear wheel drive for plug in hybrid electric vehicle, SAE Technical Paper, 2016-01-2154.

Analiza wybranych epizodów wysokich stężeń pyłu PM10 z lat 2013-2016, Etap II. Epizody z lat 2015-2016, powietrze.gios.gov.pl (access on 06.12.2017).

Bogusz P., Korkosz M., Prokop J., Wygonik P., 2017, Theanalysis of generating operation of brushless machine with permanent magnets for hybrid unmanned aerial vehicle, Maszyny Elektryczne – Zeszyty Problemowe, nr 3.

Buczaj M., 2006, Wykorzystanie alternatywnych źródeł zasilania pojazdów w świetle norm i dyrektyw w UE na przykładzie Polski, MOTROL.

Cieślik W., Pielecha I., Szałek A., 2015, Indexes of performance of combustion engines in hybrid vehicles during the UDC test. Combustion Engines, nr 160(1), p. 11–25.

Eurostat Statictics Explained, 2017, Freight transport statistics – modal split.

International Energy Agency, www.iea.org/roadmaps.

Marciniak Z.,2010, Hybrydowe układy napędowe lokomotyw spalinowych, Logistyka, nr 4.

Merkisz J., Pielecha I., 2015, Układy elektryczne pojazdów hybrydowych, Wydawnictw Politechniki Poznańskiej, Poznań.

Toyota Service Information, toyota-tech.eu (access on10.10.2017).

ACKNOWLEDGEMENTS

The authors would like to thank Mr Andrzej Szałek – representatives at Toyota and Lexus Academy in Toyota Motor Poland Company Sp. z o.o. in Warsaw, Poland for their provision of an vehicle for testing.

The study presented in this article was performed within the statutory research 05/52/DSPB/0246.

ANALIZA WYKORZYSTANIA UKŁADU NAPĘDU HYBRYDOWEGO W WARUNKACH RUCHU MIEJSKIEGO

Streszczenie

Ograniczanie zużycia paliwa przez pojazdy prowadzi do zwiększenia udziału napędów hybrydowych i elektrycznych w rynku pojazdów. Istnieje wiele pomysłów, aby skupić się tylko i wyłącznie na wprowadzeniu pojazdów elektrycznych, jednakże ten rodzaj napędu wymaga dodatkowej infrastruktury, przebudowy wielu systemów oraz charakteryzuje się długim czasem ładowania, z czego nie do końca zadowoleni są konsumenci. Dlatego obecnie jednym z wiodących rodzajów napędów pojazdów osobowych jest napęd hybrydowy. Nie wymaga on przebudowy całej infrastruktury, jedynie zmian w układach napędowych pojazdów. Koszty z tym związane są relatywnie małe, w porównaniu do np. do budowy sieci nowych stacji ładowania. Znajomość udziału pracy napędu elektrycznego w pojeździe z układem hybrydowym jest wyznacznikiem opłacalności stosowania napędów elektrycznych. W pracy oszacowano udział pracy trybu elektrycznego i hybrydowego w warunkach ruchu miejskiego. Obiektem badawczym był pojazd marki Toyota C-HR wyposażony w napęd hybrydowy czwartej generacji. Analiza pracy napędu pozwoliła na określenie warunków przepływu energii oraz ustalenie udziału pracy trybu elektrycznego w całkowitym czasie jazdy oraz w odniesieniu do przebytej drogi.

Słowa kluczowe: napęd hybrydowy, tryby jazdy, przepływ energii