Experimental Results of the Hybrid Electric Vehicle Energy Efficiency in Urban Transportation

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Abstract: *The development of internal combustion engine vehicles, especially automobiles, is one of the greatest achievements of modern technology. Automobiles have made great contributions to the growth of modern society by satisfying many of its needs for mobility in everyday life. The automotive industry and the other industries that serve it constitute the backbone of the word's economy and employ the greatest share of the working population. However, the large number of automobiles in use around the world has caused and continues to cause serious problems for the environment and human life. Air pollution, global warming, and the rapid depletion of the Earth's petroleum resources are now problems of paramount concern [1]. A hybrid vehicle combines any type of two power (energy) sources. Possible combinations include diesel/electric, gasoline/fly wheel, and fuel cell (FC)/battery. Typically, one energy source is storage, and the other is conversion of a fuel to energy. The most modern hybrids are powered by a combination of traditional gasoline power and the addition of an electric motor. However, hybrid still use the petroleum-based engine while driving so they are not completely clean, just cleaner than petroleum only cars. This enables hybrid cars to have the potential to segue into new technologies that rely strictly on alternate fuel sources [2,3].*

This paper considers the experimental result obtained from HEV energy efficiency researching in urban transportation in the town of Sofia.

Keywords: *HEV, FUEL FLOW, METERING, METHODOLOGY*

1.Introduction

The hybrid electric vehicles (HEV) are equipped both with internal combustion engine (ICE) and electric motor (EM) which is powered by energy storage unit i.e., battery (B). The ICE used in a HEV is, of course, downsized compared to an equivalent vehicle engine. The ICE in combination with the EM provide an extended range for HEV and bring down pollution. The HEV energy efficiency is the main factor for its advantage and evaluating and depends directly on the HEV both fuel consumption and electricity consumption. Moreover, the city traffic conditions determine the quantity of the energy consumed by the HEV, so it is very important to measure the fuel consumption in accurate manner and with suitable equipment to obtain the correct results.

2.Object

As object of experimental researching of the hybrid electric vehicle energy efficiency (HEVEE) can be selected various HEV models which can be researched and evaluated. At this paper is selected Honda CR-Z [4] which common view is shown on figure 1.

Fig.1 *Researched HEV (Honda CR-Z)*

The selected HEV is of the mild class hybrid. The HEV propulsion system is known as Integrated Motor Assistance [4]. The EM is linked rigidly with the ICE and serve as assistant motor as well as the starter motor. The HEV technical data are shown in table 1.

Table 1: HEV technical data

Quantity	Designation	Dimension	Value
Engine	1.5 SOHC i-VTEC		
Max. Power (Engine)		kW/PS/rpm	84/114/6100
Max. Torque (Engine)		Nm/rpm	145/4800
Max. Power (Electric Motor)		kW/PS/rpm	10/14/1500
Max. Torque (Electric Motor)		Nm/rpm	78.4/1000
Max. Power (Combined)		kW/PS/rpm	91/124/6100
Max Torque (Combined)		Nm/rpm	174/1000-1500
Fuel system	Honda PGM-FI Electronic Injection		
Fuel rating	Unleaded		95 RON
Maximum design total mass	m_{HEV}	kg	1520
Frontal area	A	m^2	2,43
Drag coefficient	C_d		0,30
Gear ratios	i_n	1st 2nd 3rd 4th 5th 6th	3.142 1.869 1.303 1.054 0.853 0.688
Final drive ratio	i_o		4.111
Transmission efficiency	η_t		0,9 [6]
Tyres	195/55R16		
Rim diameter	D	mm	406,4mm (16in)
Tyre aspect ratio	H/B	%	55
Coefficient of the wheel inertia	δ_1		0,04
Coefficient of the powertrain inertia	δ_2		0,0025
Air density	ρ_a	kg/m^3	1,25
Fuel density	ρ_f	kg/m^3	710

The metering equipment is Bosch KTS 560 interface [5] which is shown on the figure 2. The test-bench can be programmed and managed by the Flowcode 7 software [6], which ensures adjustment to the real work mode of the fuel injectors in the modern automobiles and HEVs.

Fig. 2 *Common view of the metering interface [5]*

The selected interface is connected to the HEV OBD-2 diagnostic plug and receive the data from the HEV electronic control unit (ECU) via ISO 15765-4 protocol [6]. The measuring quantities are as following:

- Discharging current I_{disch}, A;
- HEV required power P_{HEV}, W;
- EM speed n_{EM}, min^{-1};
- Battery voltage under load U_B, V;
- Driving speed υ_d, km/h;
- Electric motor phase current, A.

The fuel consumed is determined by the difference in the HEV fueling volume before and after researching test. The initial fuel volume is equal to the full HEV fuel tank volume. The difference is metered by the fuel equipment in the gas station in accuracy 0.5% according to the OIML R 117-1 [7].

The researching is carried on in the town of Sofia according to the route which is tracked and measured by the GPS navigation system NMEA Monitor for windows Ver 3.79 [8]. The recorded route is shown on the figure 3. The total travelled distance is 53 km.

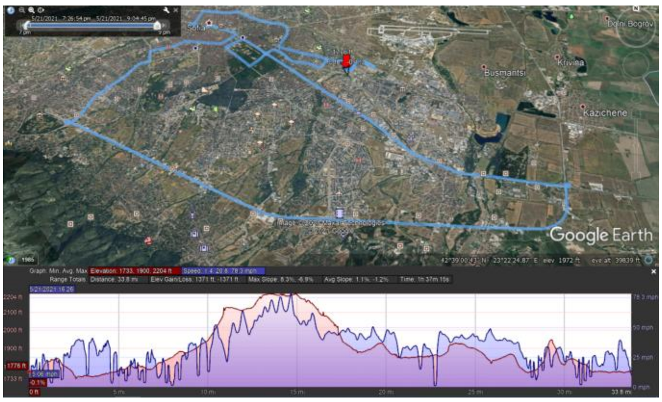

Fig. 3 *The travelled route*

The fig.3 contains the map of the route, the elevation characteristic of the route and the driving speed characteristic. These data correspond to the Bosch KTS 560 clock and are used to experimental determining the parameters of HEVEE. The average road inclination is 1%.

During the experiments, the HEV driving modes are selected as follows:

0-1700 s – Normal mode

1700-3200 s – Sport mode

3200-3800 s – Eco mode.

These modes are determined by the IMA system and cannot be modified. The specific energy efficiency during these modes is evaluated in point 4.

3.Results

After the performed experiments is obtained the following results, which are displayed in graphic diagrams. A fig.4 to fig.7 displays the energy characteristic of the Normal mode. Fig.4 presents the discharging current I_{disch} and the battery voltage under load U_B. The maximum value of the I_{disch} is 98,63 A. The maximum value of the driving speed υ_d is 70 km/h.

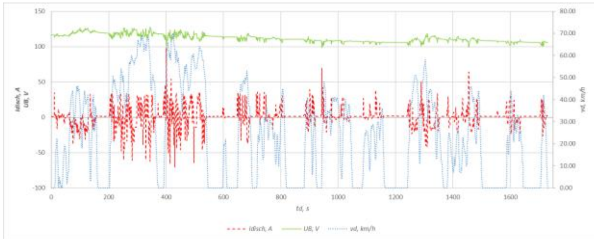

Fig.4 Normal mode: *Characteristic of the discharging current I_{disch} and battery voltage under load U_B*

At the next fig.5 is displayed the electric motor phase current. The maximum value of the EM phase current is 98,9 A.

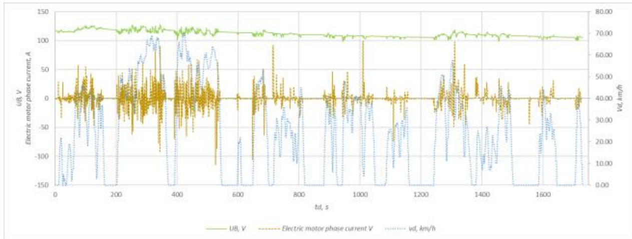

Fig.5 Normal mode: *Characteristic of the electric motor phase current and battery voltage under load U_B*

The HEV required electrical power P_E is displayed on the fig.6. The required power P_E is determined by the IMA system and is part of the whole required driving power. The maximum P_E = 9773 W. The maximum n_{EM} = 3048 min^{-1}.

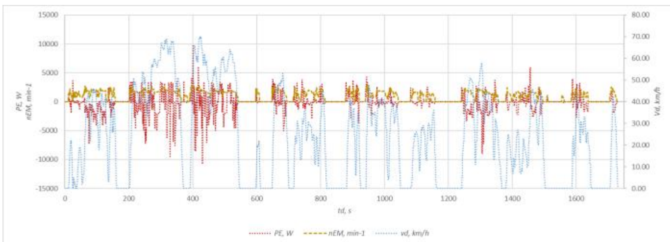

Fig.6 Normal mode: *Characteristic of the HEV required electrical power P_E*

The electricity consumed Q_{disch} and electricity regenerated Q_{regen} is shown on fig.7. The electricity consumed Q_{disch} = 0,183 kWh. The electricity regenerated Q_{regen} = 0,235 kWh.

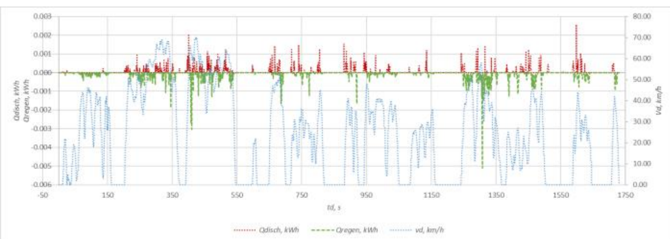

Fig.7 Normal mode: *Characteristic of the HEV electricity consumed Q_{disch} and electricity regenerated Q_{regen}*

A fig.7 to fig.10 displays the energy characteristic of the Sport mode. Maximum I_{disch} = 109,37 A. Maximum driving speed υ_d = 135 km/h.

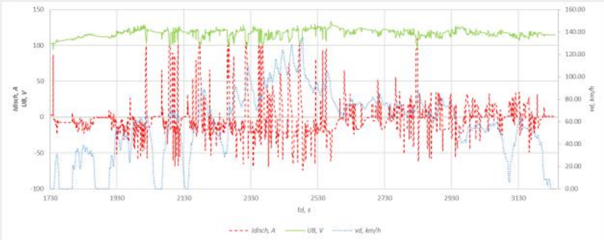

Fig.7 Sport mode: *Characteristic of the discharging current I_{disch} and battery voltage under load U_B*

Maximum EM phase current is 116,3 A.

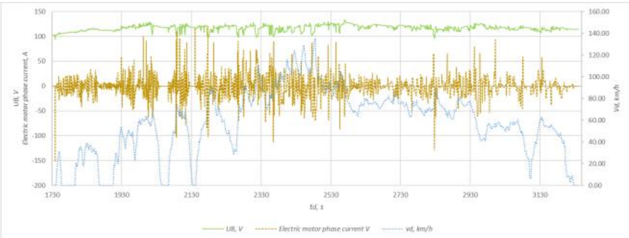

Fig.8 Sport mode: *Characteristic of the electric motor phase current and battery voltage under load U_B*

Maximum P_E = 10262 W. Maximum n_{EM} = 4015 min^{-1}.

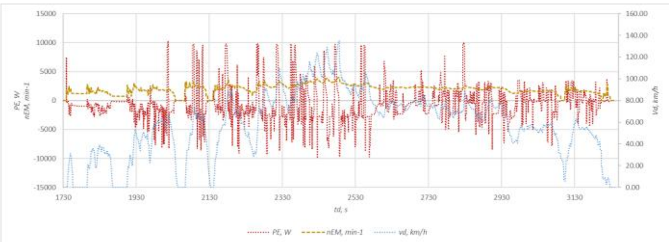

Fig.9 Sport mode: *Characteristic of the HEV required electrical power P_E*

The electricity consumed Q_{disch} = 0,316 kWh. The electricity regenerated Q_{regen} = 0,566 kWh.

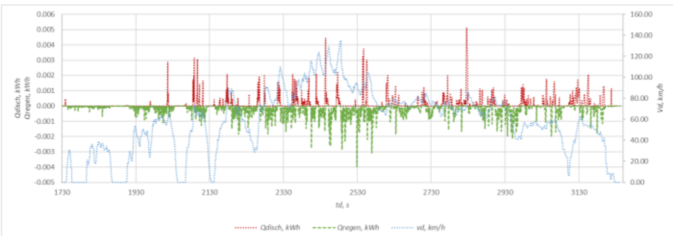

Fig.10 Sport mode: *Characteristic of the HEV electricity consumed Q_{disch} and electricity regenerated Q_{regen}*

A fig.11 to fig.14 displays the energy characteristic of the Eco mode. Maximum I_{disch} = 100,09 A. Maximum driving speed υ_d = 68 km/h.

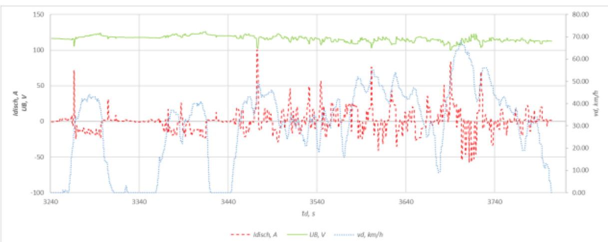

Fig.11 Eco mode: *Characteristic of the discharging current I_{disch} and battery voltage under load U_B*

Maximum EM phase current is 91,75 A.

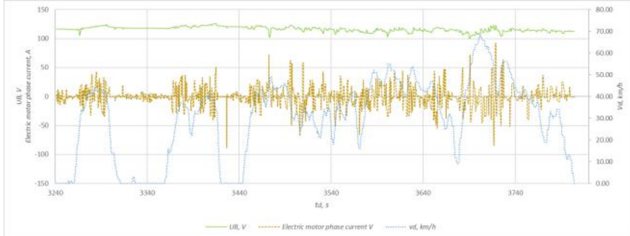

Fig.12 Eco mode: *Characteristic of the electric motor phase current and battery voltage under load U_B*

Maximum P_E = 9858 W. Maximum n_{EM} = 2996 min^{-1}.

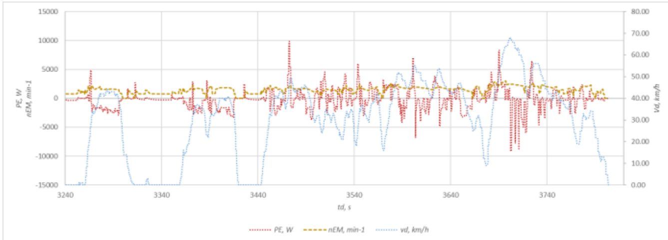

Fig.13 Eco mode: *Characteristic of the HEV required electrical power P_E*

The electricity consumed Q_{disch} = 0,082 kWh. The electricity regenerated Q_{regen} = 0,107 kWh.

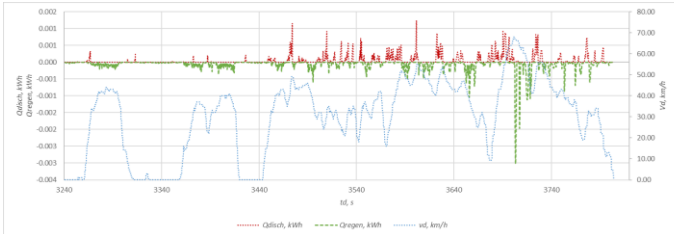

Fig.14 Eco mode: *Characteristic of the HEV electricity consumed Q_{disch} and electricity regenerated Q_{regen}*

On all characteristics the battery has stable voltage with maximum value 132,89 V and minimum value 93,99 V.

The subtotal electricity consumed Q_{disch} = 0,58 kWh. The subtotal electricity regenerated Q_{regen} = 0,91 kWh.

Because of the state of charge of the HEV battery and recharging limitation by the IMA system $Q_{regen} > Q_{disch}$, i.e. this is the case with recharged HEV battery, which has decreased lifetime.

The total fuel consumed Q_f = 3,73 l.

4.Evaluation

According to the evaluation criteria [2,9] is obtained data which is represented in table 3. The selected HEV is not rechargeable and in this case the Q_{rech} = 0.

Table 2: *Evaluation data.*

Mode	Distance criterion		Mass criterion		Combined criterion	
	Fuel consumed $Q_{D,f}$ l/100km,	Electricity consumed $Q_{D,e}$, kWh/100km	Fuel consumed $Q_{M,f}$, l/kg	Electricity consumed $Q_{M,e}$, kWh/kg	Fuel consumed $Q_{DM,f}$, l/kgkm	Electricity consumed $Q_{DM,e}$, kWh/kg.km
Normal	6.22896	-0.46989	0.00046	0.00003	0.00518	-0.00039
Sport	8.16227	-1.02218	0.00132	-0.00016	0.03224	-0.00404
Eco	5.65222	-0.13823	0.00068	-0.00002	0.01235	-0.00030

The official data for the researched HEV [4] are as follows: Urban 6.1 l/100km; Extra Urban 4.4 l/100km; Combined 5.0 l/100km. The obtained data in the table 2 include official data and give the detailed HEV energy efficiency evaluation. The outreaching of the data is because of the decrease battery resource.

Conclusion

The experimental researching of the hybrid electric vehicle is carried on and the real data according to traffic condition in town of Sofia and selected hybrid model are obtained.

The evaluation of the obtained data make clear the real energy efficiency of the selected HEV and estimate its real technical condition.

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