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# THE POWER IMPACT OF ELECTRIC POWER ASSIST IN HYBRID VEHICLE

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***Abstract***

*The current interest in the development of hybrid vehicles is a response to serious effects of road transport on the environment over recent years. In addition, vehicles equipped with this type of drive combine the advantages of a conventional diesel engine and electric motor. This results in higher system efficiency while reducing emissivity.*

*This work seeks to demonstrate the effect of electric power on the total power of a hybrid vehicle. The research on the chassis dynamometer (MAHA LPS 3000) of the hybrid sports car, Honda CRZ, has been performed in three modes of operation: normal, economical and sport. The obtained results are presented in the form of graphs of external engine characteristics, where the influence of electric power on the system is visible.*

*The tested vehicle is equipped with sixth version of Honda's Integrated Motor Assist (IMA) technology, which is the crucial system, assisting the combustion engine in order to provide higher performance and better fuel economy.*

***Keywords:*** *hybrid vehicle, Honda CR-Z, electric motor*

## 1. Introduction

The development of internal combustion engine vehicles is one of the most valued achievements of modern technology. However, the highly advanced automotive industry along with increasing number of vehicles in use around the world is the reason of serious threat to the environment and crude oil resources. Due to increasing fuel prices and introduction of new environmental standards regarding greenhouse gas emissions, more attention recently is paid to new economic propulsion configurations [12]. Among the many solutions, hybrid powertrain has become increasingly popular. Such drives are already widely used in cars, trucks and heavy-duty machines. Although hybrid vehicles have been known since the beginning of automotive development, the real breakthrough came in 1997 when Toyota started mass production of the Prius. Since then, more than a million models have been sold worldwide. High sales have confirmed the interest of users, and other car companies have also introduced hybrid vehicles to the market.

Concerns towards environment are not the only trigger leading to the development of hybrid electric automobiles. Nowadays, the focus of car manufacturers is turned to the problem of efficiency of internal combustion engines, which is rather low, especially while driving in urban conditions [2, 3, 10]. The trend is to increase vehicles' power and at the same time reduce undesirable emissions. In theory, the electric motor can be a great addition to today commonly used combustion units. It is much quieter, less complicated, produces less energy loss and has a high torque from the lowest turn [5, 8, 9,].

## 2. Vehicle tested

The vehicle under test was Honda CR-Z, the model from production year 2010, equipped with manual transmission. Honda CR-Z is a sport compact hybrid electric automobile manufactured by

Honda since 2010. The CR-Z is a combination of a hybrid powertrain with elements of a traditional sport car. It is regarded as the successor to the second generation of Honda CR-X. On October 23, 2007, at the Geneva Motor Show, the car was introduced as a concept vehicle. In January 2010, at the North American International Auto Show, Honda introduced the production model of CR-Z.

The CR-Z uses the sixth version of Honda's Integrated Motor Assist (IMA) technology. It is powered by a 1.5 litre i-VTEC SOHC inline-4 engine with 16 valves [6, 11, 12]. The engine has a 10.4:1 compression ratio and it displaces 1.497 cc. The underbore arrangement has a bore and stroke that measures 73 mm x 89 mm, respectively. A narrow, 30-degree angle between the intake and exhaust valves in the head of cylinders contributes to the engine's overall compact size.

By introducing IMA system, Honda aimed to reduce fuel consumption by combining a more advanced conventional ICE with electric powertrain technology, offering a hybrid electric vehicle as a result. The Honda CR-Z uses the sixth generation IMA system, which is so far the most powerful and efficient.

All of the Honda IMA systems are built of the same parallel hybrid powertrain configuration. The engine and the electric motor, both, deliver power to the wheels [1]. The IMA system is built of an ultra-thin DC brushless electric motor, which is situated between the combustion engine and the transmission, and an Intelligent Power Unit (IPU), which stores electric power in a compact battery box and steers the electricity flow to and from the motor.

The electric motor is designed to deliver up to 13 HP (10 Kilowatts) at 1500 RPM and 58 lb-ft. of torque at 1000 RPM, contributing to the combustion engine output. The motor assists primarily during acceleration and some steady-state driving situations. It can act also as a generator, capturing kinetic energy and recharging the batteries. The ultra-compact motor measures 61 mm in case width and is an AC synchronous three-phase electric motor.

The power of IMA system is controlled by the Intelligent Power Unit (IPU). The IPU includes the module of energy storage (battery), Power Control Unit (PCU), motor Electric Control Unit (ECU), and an airflow cooling system. In order to use the space effectively, the IPU is situated beneath the rear cargo area, which has a minimal influence on the interior area. The nickel metal hydride (Ni-MH) battery system is built of seven modules. The battery system includes 84 individual D-sized 1.2 Volt cells which gives an overall battery output of 100.8 volts and capacity of 5.75 ampere-hours [1].

The CR-Z is equipped with 3-mode drive system, so the driver is allowed to select between each individual mode of performance. These possible driving styles include Sport, Normal and Economy mode. Desirable option can be activated through three backlit buttons located to the left of the steering wheel.

First option to select, looking from the top, is the Sport mode. It enhances variety of car systems for performance, among which are the engine throttle responsiveness, electric power steering effort, the power assist of electric motor and CVT gear ratio (if available). Switching the Sport Mode on influences the following systems (if compared to Normal Mode) [1]:

1. More electrical power available during acceleration (does not occur in the 6MT model).
2. More direct and firmer steering assist.
3. DBW throttle angle is optimized giving boosted acceleration feel.
4. In CVT models transmission ratios are made lower to keep higher engine RPM and faster acceleration.

By turning on the Normal Mode, standard settings for steering, engine response, motor assistance and air conditioning are provided. This mode is default so at start-up the vehicle will be switched to it, regardless the previous selection. Normal Mode is characterized by [1]:

1. Normal steering assist.
2. DBW throttle angle optimization for linear acceleration feel.
3. In CVT models, transmission ratios are set up for greater economy.

While vehicle is driving under the Econ Mode, the engine's reaction is adjusted for optimal economy. What is more, the electric motor assist gives priority to fuel efficiency. By pushing the Econ button, range of functions is initiated [1]:

1. DBW throttle angle is adjusted for smoother acceleration and keeps the engine RPM the lowest is possible.
2. The automatic climate control blower fan speed is reduced and air conditioning compressor engagement minimized whenever possible.
3. Transmission ratios of the CVT (if equipped) are optimized higher (relatively to the engine RPM) to achieve better economy.
4. Power and torque is limited by approximately 4% (full responsiveness is provided in case of wide-open throttle).
5. A smaller throttle-opening angle is managed by the cruise control, whenever possible.
6. Normal steering assist operation.

## 3. Test procedure

Laboratory measurements were conducted using the chassis dynamometer. As a result, engine external characteristics were obtained, namely the engine power and torque curves. Then examination station used for this purpose was the MAHA LPS 3000.

The car was positioned on the test setup and mounted to the ground using set of fastening belts attached to the front and back of the car. In the next step, the car computer was connected to a dynamometer using OBD II cable. There was also a thermocouple immersed in engine oil to control the temperature. To prevent the car from overheating, a cooling fan was set in front of the hood. At the same time, exhaust gas extraction hose was connected to the back of the car to remove all of the exhaust gases. The test stand is presented in Fig. 1 and Fig. 2.

The laboratory examination included three separate measurements for different vehicle operation modes, that is: normal, eco and sport mode. Each measurement consisted of the same, two steps:

- acceleration of the car starting from 0 km/h up to around 190 km/h by shifting from 1st gear up to 5th gear,
- recording of the data while reduction of the velocity to 0 km/h.

Before conducting the tests, the engine was heated up at low RPM to ensure proper temperature. Each mode was measured three times and the presented data are averaged results. Between each measurement, the battery was charged.

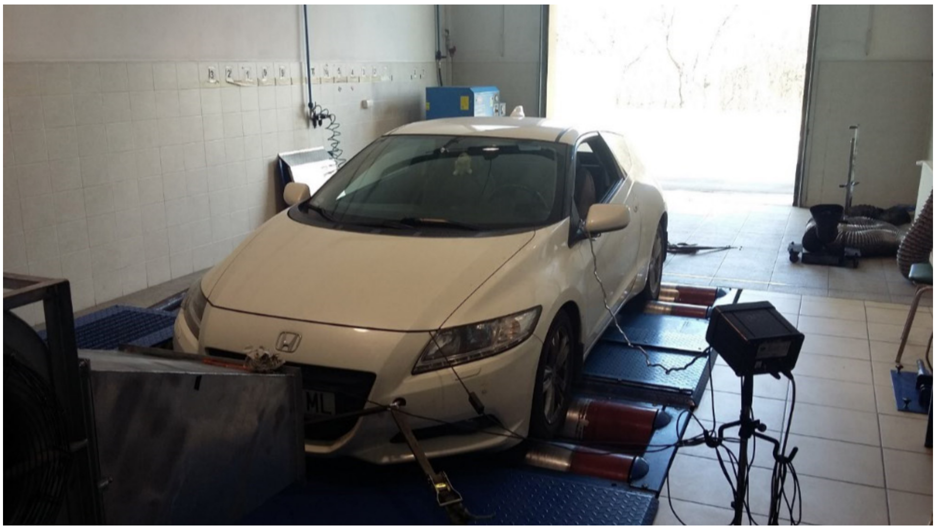

*Fig. 1. Vehicle test stand (front)*


*Fig. 2. Vehicle test stand (back)*

## 4. Results

Based on the data received, appropriate graphs were plotted. Fig. 3 presents torque and power curves for Normal mode, Fig. 4 and Fig. 5 for Eco and Sport modes, respectively. Fig. 6 represents the collective power representation for all modes, whilst Fig. 7 does the same according to torque. All of the presented figures refer to combined, combustion engine and electric motor output.

Graphs presented in Fig. 6 and Fig. 7 allow for a convenient comparison of overall performance in each mode, therefore showing how the electric motor assistance influences the values in each case. The first impression after looking at the graph in Fig. 6 is that two sections of waveforms behaviour can be distinguished – first one, from the beginning till around 3000 RPM, the second one over the span from around 4000 RPM till the last record and the midpoint with the area around 3500 RPM. In the first section, significantly high at the beginning is the power characteristic for Sport mode, which then, after 2000 RPM reaches values close to Normal mode results. The smallest values are recorded for Eco mode, what proves the lowest contribution of electric motor assist in order to save energy. The assistance in Normal mode is rather neutral, while a real boost of power is possible after switching to Sport. In this situation, the contribution of electric power assist is visible. The assistance allows for better dynamics including faster acceleration of the car, which could not be such satisfying with the operation of combustion engine alone. Another interesting behaviour can be observed around midpoint. Just before 3000 RPM, the values drop down in Sport mode and the same happens for Normal mode but slightly later, at around 3250 RPM. It can be assumed, these are the points where electric assistance is lowered by the control unit due to specific discharge of the battery. What is more, both curves at these moments are behaving nonlinearly, what could prove this assumption. It is logical, that the electric power assistance is reduced faster in the Sport mode, as the initial contribution of the electric motor is greater and as a result, the battery discharge happens quicker. However, there are no sudden discharges observed on the Eco mode curve. It is presumably thanks to the moderate contribution of electric power. In the second section, it is clearly seen that Sport performance is characterized by the lowest output, what is connected to previous significant battery discharge. Also, the power graph lines were approximated linearly and the angular coefficient "***a***" was determinate, as following:

1. Normal mode power curve coefficient ***a*** equal 0.0204.
2. Eco mode power curve coefficient ***a*** equal 0.0224.
3. Sport mode curve coefficient ***a*** equal 0.017.

From the obtained numbers it can be seen that overall increment of values is the lowest in

Sport mode. That means that, despite the initial boost, discharge of the battery was most significant among the three mode settings.

All these considerations are valid for the torque graph presented in Fig. 7, as the horsepower values are calculated based on measured values of torque. According to the graph, the greatest range of high torque occurs during Normal mode operation. This provides good vehicle dynamics among this span. Even better acceleration is given when switched to Sport, but that is only during the initial range of RPM. Eco mode torque distribution proves that the control unit is focused on fuel savings and smooth vehicle operation, where speed performance and dynamics are in the background.

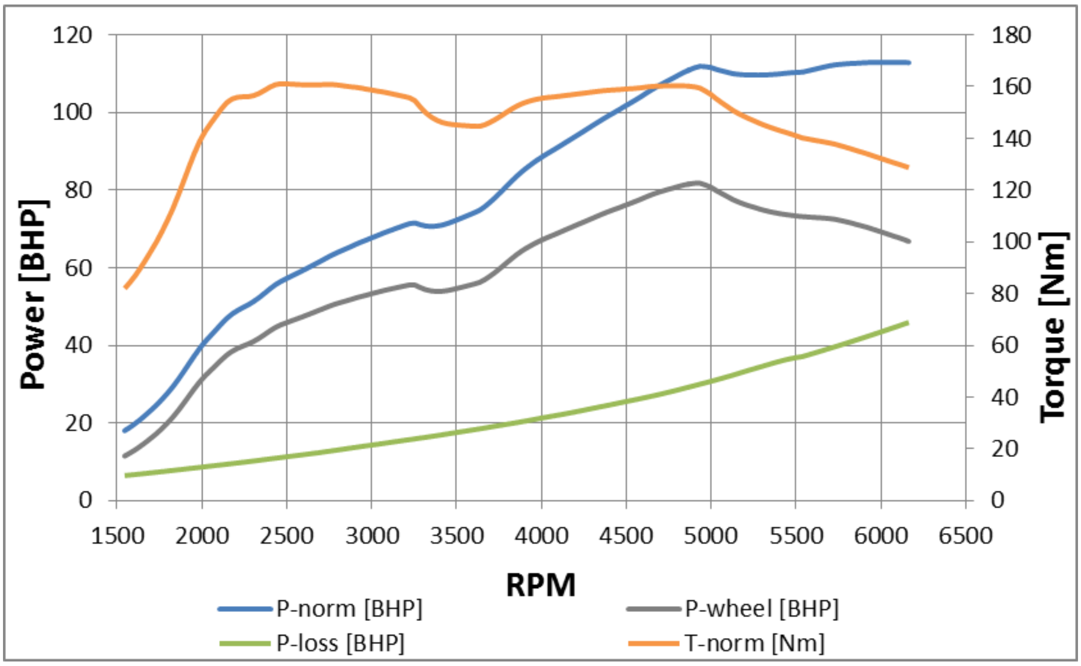


*Fig. 3. External characteristics graph for Normal mode*

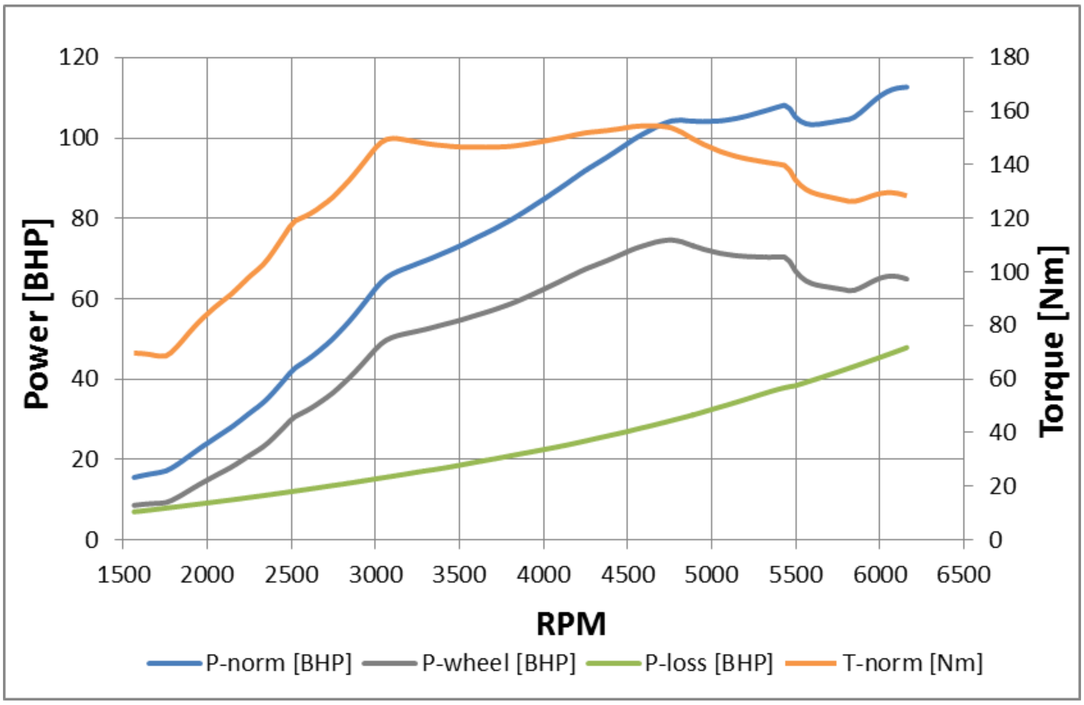


*Fig. 4. External characteristics graph for Eco mode*

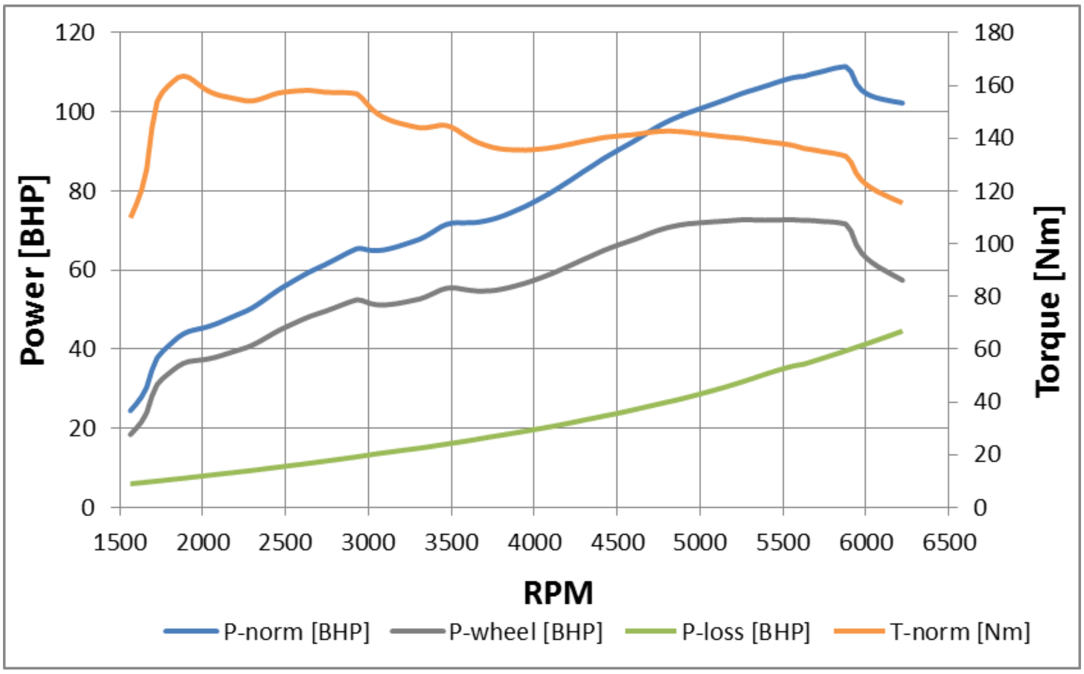


*Fig. 5. External characteristics graph for Sport mode*

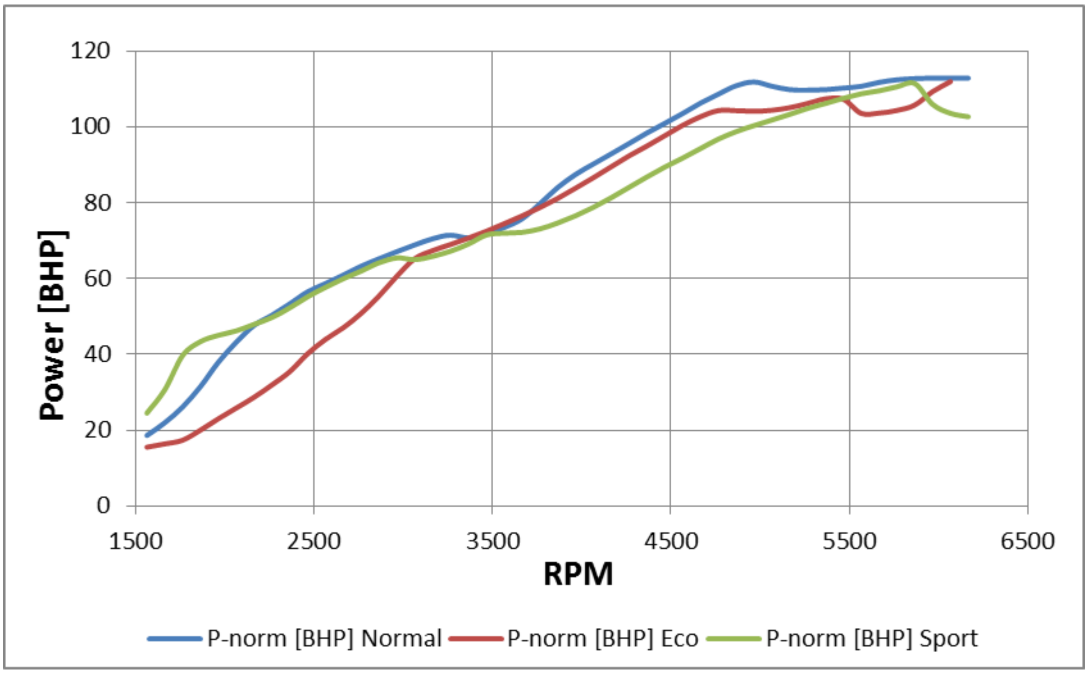


*Fig. 6. Power characteristics graph for all of the three modes*

## 5. Conclusion

The way in which electric motor shapes the total output is clearly visible when comparing different driving modes, where the Power Control Unit performs the task of appropriate power distribution. From the graphs, it can be seen that the greatest electric power assist is dedicated to the Sport mode, as the torque is desired to be high, offering great dynamics. Normal mode is set to obtain neutral performance; however, motor assist has a significant impact on the torque, providing decent powertrain efficiency, which would not be possible using only the combustion engine [13, 14]. Eco mode, however, is designed for smooth operation during which the fuel consumption is reduced and at the same time, efficiency of the system is satisfactory.

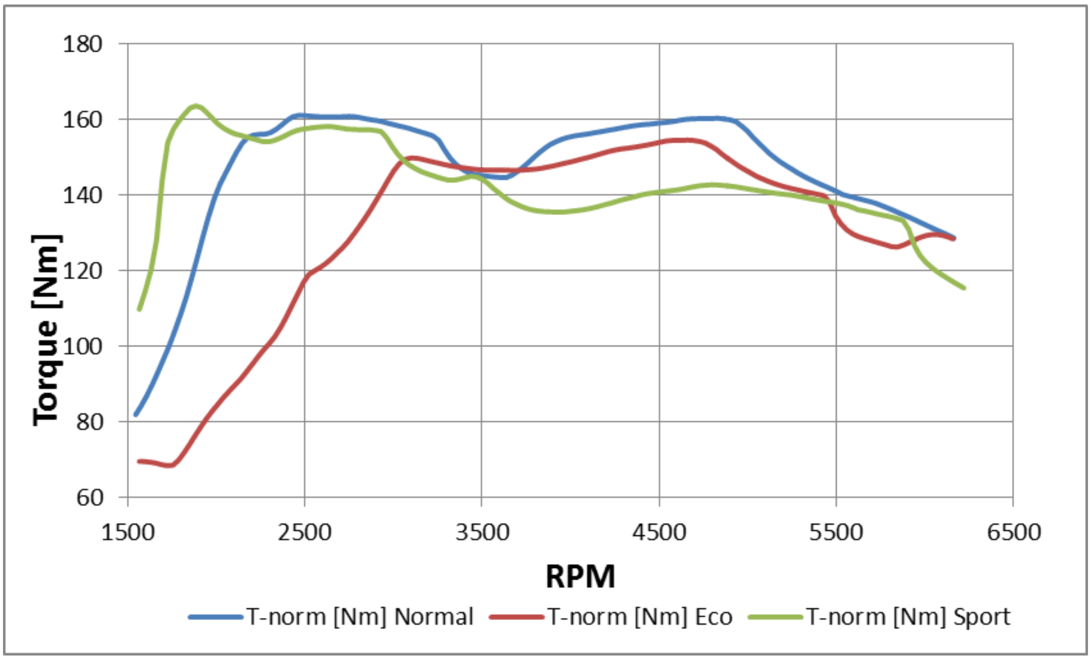


*Fig. 7. Torque characteristics graph for all of the three modes*

One of the obstacles for hybrid vehicles is the battery performance. Looking at the results once more, it is visible that the battery is being discharged quite quickly, especially for the Sport mode where the maximum power is desired from the initial operation. However, the vehicle was designed to have small total weight and considering that the contribution of electric assist is limited in mild hybrids, still the assist system fulfils its task.

It is noticeable that the electric power assist shapes the overall vehicle powertrain performance. With such a small combustion engine capacity, it gives pretty decent output. These are satisfactory results, given the 1.5 litre capacity.

Presented vehicle performance which is obtained by combining both energy sources, proves that hybrid vehicles can become even more popular in the future. The solution allows compensating the drawbacks of internal combustion engine, ensuring improved, higher overall efficiency of the entire system.

## References

[1] *Car Ecology, New Technological and Ecological Standards in Automotive Engineering*, http://www.ae.pwr.wroc.pl/filez/20110606094111_HEV_Honda.pdf.
[2] Cienciała, M. Haller, P. Jankowski, A. Kardasz, P.: *Water – fuel microemulsions influence on fuel consumption and exhaust gas emissions* Journal of KONES, Vol. 20, No. 4, s. 111-116, 2013.
[3] Haller, P., Jankowski, A.: *Impact Analysis of Internal Catalyst Converter on Operating Parameters of VW 1.9 TDI Engine,* Journal of KONES, Vol. 21, No. 1, s. 99-106, 2014.
[4] Honda CR-Z, https*://en.wikipedia.org/wiki/Honda_CR-Z.*
[5] *Honda CR-Z: Powertrain*, http://news.honda.com/newsandviews/article.aspx?id=5488-en, 2011.
[6] Merkisz, J., Pielecha, I., *Układy mechaniczne pojazdów hybrydowych*, Wydawnictwo Politechniki Poznańskiej, Poznań 2015.
[7] Mi, C., Abdul Masrur, M., Wenzhong Gao, D., *Hybrid Electric Vehicles, Principles and Applications with Practical Perspectives*, Wiley, 2011.
[8] *The Honda Hybrid System: the engine is the main power source*, http://world.honda.com/automobile-technology/IMA/ima03/.

[9] Jankowski, A., Kowalski, M., *Environmental Pollution Caused by a Direct Injection Engine,* Journal of KONES, Vol. 22, No. 4, pp. 113-138, Warsaw 2015.

[10] Jankowski, A., *Reduction Emission Level of Harmful Components Exhaust Gases by Means of Control of Parameters Influencing on Spraying Process of Biofuel Components for Aircraft Engines,* Journal of KONES, Vol. 18, No. 3, pp. 129-134, Warsaw 2011.

[11] Jankowski, A., *Test Stand for Modelling of Combustion Processes of Liquid Fuels,* Journal of KONES, Vol. 21, No. 2, pp. 121-126, Warsaw 2014.

[12] Kaźmierczak, U., Kulczycki, A., Dzięgielewski, W., Jankowski, A., *Microemulsion Fuels for Piston Engines,* Journal of KONBiN. Volume 21, Issue 1, pp. 131–140, 2012.

[13] Zurek, J., Jankowski, A.: *Experimental and Numerical Modelling of Combustion Process of Liquid Fuels under Laminar Conditions,* Journal of KONES, Vol. 21, No. 3, pp. 309-316, 2014.

[14] Zurek, J., Kowalski, M., Jankowski, A., *Modelling of Combustion Process of Liquid Fuels under Turbulent Conditions,* Journal of KONES, Vol. 22, No. 4, pp. 355-364, Warsaw 2015.