

HYBRID VEHICLE DIAGNOSTICS

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Abstract

The history of hybrid vehicles has started between the 19th and the 20th century because then the first project of a hybrid vehicle was constructed. The first man who manufactured a front hub mounted electric propulsion connected with a generator powered by a spark ignition engine was Ferdinand Porsche. This vehicle was called the Lohner-Porsche Electromobile. The first mass-produced hybrid vehicle was the first generation Toyota Prius. The model premiere was in 1996 and the production started one year later. The vehicle was equipped with a 1.5 dcm 58 hp spark ignition engine and with the added electric propulsion. It generated 40 mechanical hp. Since 2000, a 72 hp spark ignition engine and a 44 hp electric generator were mounted. Fuel consumption of this model was 5 litres per 100 km. In the early 2000s, 95% hybrid vehicles were the Toyota Prius. The biggest competitor to the Toyota Prius was the Honda Insight. Lexus and Mercedes started manufacturing hybrid vehicles few years later. The most popular car brands that sell hybrid vehicles are Toyota and Lexus from Toyota Motor Corporation. This article describes an example of diagnostic possibilities for the hybrid vehicle system. The construction of vehicle models that use two propulsion systems (spark ignition engine and electric generator) results in the development and increase in control system devices. The measurements were made using various diagnostic devices, e.g. a diagnostic scanner, mustimeter, megohm-meter and oscilloscope. The reading of fault codes is not enough so it is necessary to use a mustimeter or a megohm-meter to examine the signal characteristics, which is presented in this article.

Keywords: hybrid vehicle diagnostics, sensors, actuator technology, oscilloscope signal characteristics

1. Introduction

A modern hybrid car is a technical system that is constructed using the latest achievements in many field of science, primarily in mechanical engineering, electrical engineering, electronics, information technology, and chemistry [2].

An increase in exhaust emission requirements for internal combustion engines and a dynamic development of electrical engineering and electronics favour the introduction of vehicles with two-propulsion or electric drive on a broad scale. The availability of ever more powerful electronic circuits resulted in the use of these circuits in the systems that control different operating parameters of the hybrid systems consisting of an internal combustion engine and an electric motor. The system efficiency that can be achieved with a given hybrid power train solution depends primarily on the control system.

The higher-level hybrid power train control system coordinates the operation of the entire drive, while the individual components have their own control functions. In addition to controlling the components, hybrid power train control includes operational strategy, which optimises the mode of system operation. This strategy affects the functions that determine reduction of the fuel consumption and the emission of toxic exhaust components by a vehicle [2, 6, 7].

2. Test object

A 2009 Toyota Prius 1.8 HSD car was selected as a test object; it is a hybrid vehicle with Hybrid Synergy Drive technology. It combines an internal combustion engine 2ZR-FXE with an

electric generator (MG1) and an electric motor (MG2) in a P410 transaxle, being presented in Fig. 1. This system uses a high-voltage battery with a DC voltage of 201.6 V and a converter that boosts the voltage to the working voltage, which is approximately 650 V. The maximum total power is 100 kW, which, after conversion, is about 136 horsepower.



Fig. 1. Test object – a Toyota Prius 1.8 HSD car and a P410 transaxle

In order to achieve the adopted scope of the study, the diagnostic devices were used, such as:

- a multimeter – Brymen BM 338,
- a megohm-meter – ABATRONIC AB-5500,
- an oscilloscope – Magneti Marelli, and
- a diagnostic tester – Mega Macs 66.

The objective of the study was to present the methods and problems in diagnosing electric and electronic equipment in two-propulsion vehicles using different devices and, based on the results, examine the correct or incorrect operation of a given element, and evaluate the possibilities of diagnostic equipment.

Internal combustion engine 2ZR-FXE – 1800CC 16-VALVE DOHC EFI:

- capacity – 1798 cm³,
- maximum power – 73 kW / 5200 rpm,
- maximum torque – 142 Nm / 3500 rpm.

Electric generator (MG1):

- AC motor-generator with a permanent magnet rotor,
- generates electric voltage and serves as the starter of internal combustion engine.

Electric motor (MG2):

- AC motor-generator with a permanent magnet rotor,
- serves as the main electric motor with high torque,
- maximum power – 60 kW / 13500 rpm,
- maximum torque – 207 Nm.

3. Toyota Prius 1.8 HSD power train

In the 3rd generation Prius, the series-parallel system with a power split was used. The propulsion system consists of an internal combustion engine, transaxle, electric drive, and batteries.

The internal combustion engine used in this system, coded 2ZRFXE, works in the Atkinson cycle. The Atkinson cycle is characterised by different piston stroke during the fuel-air mixture compression and expansion. In terms of construction, it is difficult to achieve because it would be necessary to change the entire engine design but Toyota has applied a simple and well-known method to bypass this problem by changing the valve timing. Consequently, the system can control

the opening time of intake and exhaust valves. This cycle, compared to the Otto cycle, uses the expansion process and thus the efficiency of the engine cycle increases. In addition, in the internal combustion engine with the Atkinson cycle, the maximum engine speed has been reduced and solutions associated with the drive timing have been changed by reducing the friction force resistance. Among others, in the 3rd generation Toyota Prius, the air conditioning compressor and the water pump are driven by electric motors. This allowed a significant reduction in fuel consumption [2].

Electronic Continuous Variable Transmission (eCVT) is a step-less gearbox having an planetary gear connected to the internal combustion engine and electric engines MG1 and MG2, as well as to the differential gear. The electric motor MG1 has two functions. The first one is the role of a generator that charges the battery during energy recovery when the vehicle brakes or at a standstill when the internal combustion engine drives the rotor. Its second function is the role of a starter to start the internal combustion engine. The electric motor MG2 acts as a drive. It is worth noting that both devices are three-phase electric motors. The voltage on which MG2 operates is 650 V AC. The satellite yoke is connected directly to a friction clutch, which is permanently disengaged, i.e. is connected to the shaft of the internal combustion engine. It is not possible to disconnect the drive shaft from the eCTV gearbox through the clutch. The solar wheel is connected to the rotor of electric motor MG1. The ring wheel is connected to the rotor of electric motor MG2.



Fig. 2. Electronically controlled continuously variable transmission (eCVT)

The electrical system consists of electric motors MG1 and MG2, a frequency inverter, and high voltage cables. The frequency inverter is intended to change 201.6 V DC to 650 V AC and vice versa, as well as to control the speed of electric motors. The fact that the current flow is controlled by a computer is means of power transistors shows that this system must be cooled due to large current flow. However, these transistors cannot exceed the temperature of 65 degrees centigrade and therefore the petrol engine cooling system cannot be used. An additional cooling system has been used in the form of a plate on which power transistors are mounted. The cables through which high voltage flows from the battery to the frequency inverter are bright orange in colour. This way one can immediately identify whether given component, such as a compressor or water pump, are supplied with high voltage.

A high voltage (HV) nickel-metal hydride (NiMH) battery with the rated voltage of 201.6 V is composed of 28 cells with a total capacity of 6.5 Ah and a maximum power of 27 kW and is characterised by a high density of the stored energy. The alkaline electrolyte contained in it does not participate in the reaction with electrodes as it happens in the most commonly used lead-acid batteries. In addition, the battery can work even when it is partially charged, which does not affect its overall service life. It has a high charging and discharging efficiency, which is crucial in the vehicles of that type. This battery has a temperature sensor and its own cooling system in order to maintain optimum working temperature, especially during the high load. Another important element of the battery is the channels that drain out the hydrogen escaping from the cells in the case of critical battery status [6].

Each individual component of the power train has its own controller that is independent of the other ones; whereas all controllers are monitored by the hybrid power train controller (Fig. 3) to which, for example, the accelerator pedal is directly connected.

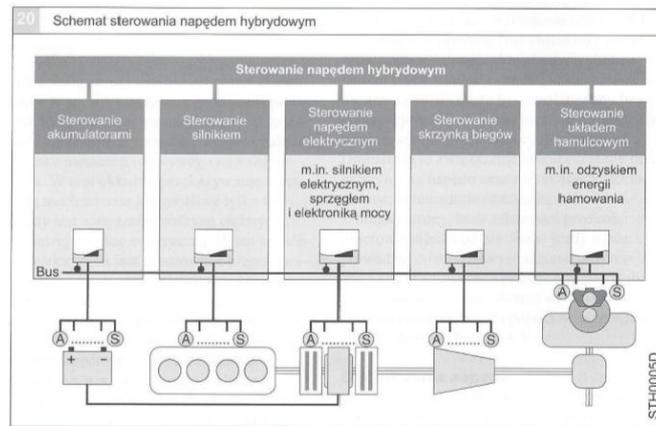


Fig. 3. Hybrid power train control system [2]

4. Power train diagnostics

Practically, all controllers, except the control system located in the frequency inverter, as well as in the battery, operate at 12 V. All types of electric components (operating at 12 V) can be examined with a multimeter with the impedance of minimum 10 k Ω . The manufacturer does not provide for testing of the hybrid system that operates at the voltage to 650 V AC with the measuring instrument other than a diagnostic tester.

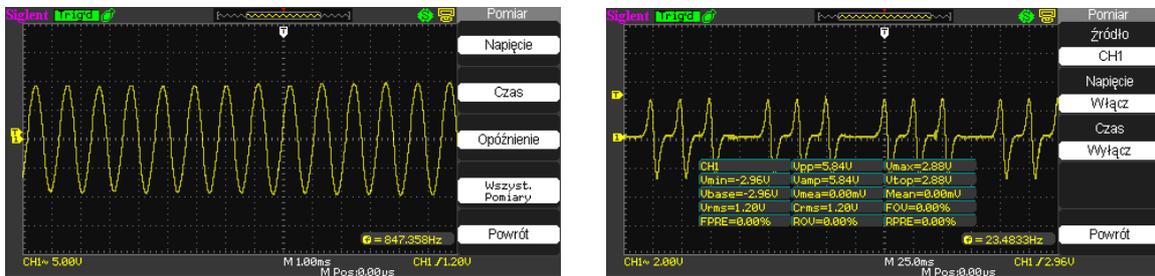


Fig. 4. Oscilloscope graphs for the crankshaft and camshaft sensors

During the diagnostic work, it is often required to connect the oscilloscope to individual sensors in order to examine their correct operation. When analysing the technical documentation being made available by Toyota, there are no contraindications to test the measuring elements. For safety, it is necessary to make sure before making measurements. There is a voltage of approximately 12-14.5 V, in the cable, to which we want to connect [8].

By virtue of their individual systems working at a high voltage, hybrid vehicles can be very dangerous, even for trained workers if they do not observe appropriate safety procedures.

According to regulations, any works on hybrid vehicles can take place after completing the appropriate training on live voltage working to 1000 volts, and such a person must be equipped with appropriate equipment, which will ensure his / her safety. The training that will grant a licence for working with such vehicles is called the SEP training (acronym from the Association of Polish Electrical Engineers). Such a licence is valid for 5 years. After this period, the licence should be renewed.

All the works with the propulsion system operating at a high voltage are always carried out with the power being disconnected.

The testing of electric motors MG1 and MG2 may be made using an ordinary multimeter. Such examination is being made to control the resistance and continuity of the winding of each electric motor. This measurement consists in setting the multimeter to resistance testing range and connecting it to the winding terminals as shown in Fig. 5.

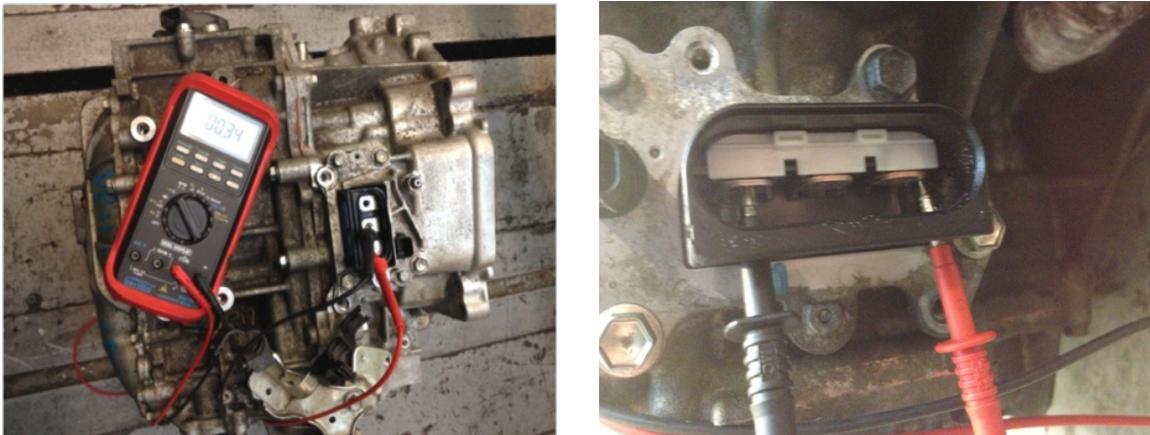


Fig. 5. Measurement of MG1 generator and MG2 motor winding continuity resistance

In order to perform the measurement and the diagnostics, the tested value should be examined for each winding connections with two other. This means that three measurements must be performed, at least two times, in order to reduce the possibility of any potential human error (in connection or in reading). Tab. 1 presents the test results for the electric motor and electric generator being used in the 3rd generation Toyota Prius transaxle.

Tab. 1. Results of the measurement of winding insulation resistance for electric generator MG1 and electric motor MG2

Winding	Electric generator MG1		Electric motor MG2	
	Measurement I	Measurement II	Measurement I	Measurement II
1-2	0.40 Ω	0.41 Ω	0.34 Ω	0.33 Ω
1-3	0.42 Ω	0.41 Ω	0.35 Ω	0.35 Ω
2-3	0.39 Ω	0.40 Ω	0.35 Ω	0.34 Ω

Unfortunately, Toyota Motor Corporation does not provide data on the resistance values which the tested elements should have but considering that these elements operated in the working vehicle before dismantling and that each of the analysed measurements showed the value similar to other ones (for a given motor), it can be stated that the windings are not damaged. In the case of possible damage, a considerable deviation in these values would be visible.

The next test, which can be performed, is the measurement of motor winding insulation resistance. Such examination is aimed at inspecting if there is no passage of voltage between the windings and the chassis ground (gearbox housing). This measurement is made with an instrument being called an insulation resistance tester. It consists in connecting one of the device probes to the winding terminals, while the second one to the housing, which is shown in Fig. 6. Tab. 2 presents the results of winding insulation resistance for the electric motor and electric generator being used in the vehicle.

After the test, it is possible to see that in the case of range set to 200 MΩ – 500 V the tester showed the infinite values. This is due to the fact that the range of 500 V is a too small value because the rated voltage of the elements being tested is beyond this value as it amounts to approximately 650 V. In the case of the test of that type, Toyota Motor Corporation does not

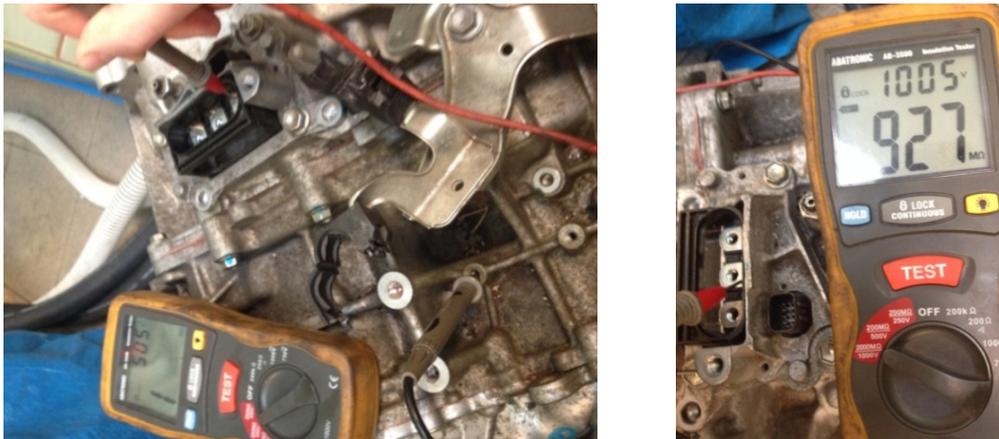


Fig. 6. Measurement of MG1 generator and MG2 motor winding insulation resistance

Tab. 2. Results of the measurement of winding insulation resistance for electric generator MG1 and electric motor MG2

Winding	Electric generator MG1		Electric motor MG2	
	Range 200 MΩ – 500 V	Range 2000 MΩ – 1000 V	Range 200 MΩ – 500 V	Range 2000 MΩ – 1000 V
I	∞ MΩ	798 MΩ	∞ MΩ	923 MΩ
II	∞ MΩ	777 MΩ	∞ MΩ	927 MΩ
III	∞ MΩ	756 MΩ	∞ MΩ	931 MΩ

provide data on the respective values that demonstrate the system efficiency either. After analysing almost identical measurement values for each of the elements, it is possible to state that the winding insulation probably is not damaged.

Examination of the status of each traction battery cell can be easily performed using a Mega Macs 66 diagnostic tester. It is a versatile tester for diagnosing the vehicles of a diverse range of car brands with service data software (HGS Data) being installed connecting to the vehicle via a data link connector (DLC). After connecting to the vehicle, we select the parameter we want to examine and read the value from the sensors in real time. In the case being analysed, this is the voltage of individual HV battery cells in the 3rd generation Toyota Prius with an internal combustion engine 2ZR-FXE. Fig. 7 presents the programme screenshot at the time of running the test.

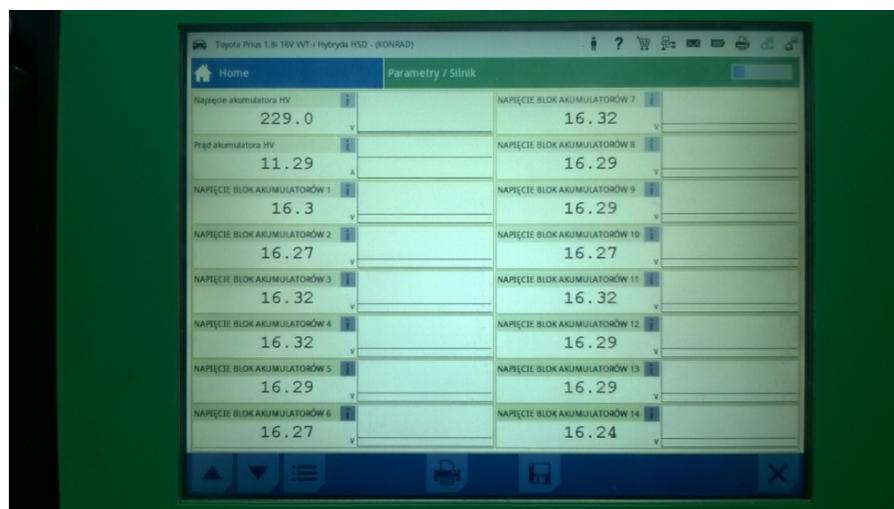


Fig. 7. The current parameters of HV battery

Conclusions

The primary objective of the tests being described in this article was to present the diagnostic and measurement methods for the elements of hybrid vehicle propulsion system when searching for their defects. Moreover, interpretation of some test results was undertaken.

A mustimeter was used to measure the resistance of the winding continuity of electric generator MG1 and electric motor MG2, with the measurement results being presented in Tab. 1. In the case of the resistance of the winding insulation, this measurement is sufficient to determine its efficiency status. The measurements of continuity and insulation resistance being made allowed showing whether the resistance changes for the respective windings, as well as identifying the correct values for this system in the absence of manufacturer's data.

Using the Mega Macs 66 interface, it was examined whether error codes had been saved in the controller's memory. Next, the current parameters were observed. This function allows determining whether the sensors generate the correct signals. And finally, the test of electronic actuators was performed which, in the case of the engine being analysed, was limited to the electric water pump, fuel pump, EGR valve, throttle controller, and the fan motor. During the test, the operation of the above elements was heard.

An oscilloscope was used to diagnose the following sensors: inductive sensor, Hall sensor, fuel pressure sensor, and intake manifold negative pressure sensor.

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