06

H_2 fuel cell for transport

Maintenance of a fuel cell vehicle

Index

Objectives

- To know the specific working conditions. What is different in a workshop where fuel cell vehicles will be maintained?
- To have an overview of the main safety rules
- To know the regular maintenance items on a fuel cell vehicle
- To interpret a block diagram of a real system and to be able to analyse it and identify the possible causes of malfunctions

Introduction

An urban myth has been circulating for several years that maintenance on an electric vehicle is no longer needed and therefore that technicians are no longer needed. In reality, maintenance operations may be fewer but more technical, they must be performed in a suitable environment with utmost precaution.

Safety aspects become an integral part of the maintenance. Therefore, the preparation work for ordinary vehicle maintenance becomes essential and will last much longer than today. Finally, fuel cell vehicle maintenance will require the same amount of work than for a conventional vehicle, but it will be broken down into four major operations: **safety aspects**, vehicle and workshop preparation, diagnostic operation and the replacement of consumables or sometimes the repair or replacement of components.

With replacement of consumables, there will still be the need to change the different filters. There will be, however, more delicate tasks like the replacement of high pressure tanks in the event of damage to the system. Replacing components from the high-voltage system also requires special precautions.

Among the diagnostic operations there will also be new activities like checking the level of hydrogen concentration in the working environment and testing the performance of:

- Hydrogen sensors placed in the garage
- Hydrogen sensors located in the vehicle
- The hydrogen detector worn by the worker

These detectors will be chosen relative to the activity performed as described in Table 1 partially presented in unit 2. The top of the table concerns manufacturing and process i.e. industry. The technician in a garage will be mainly concerned with the numbers in the yellow cells of the table. All of the detectors and sensors must be calibrated regularly and the expiration date of the calibration must be checked before use.

Table 1 Reminder, estimation of hydrogen gas concentrations in the working environment

H2 concentration high (ppm)	H2 concentration low (ppm)	Safety topic	Measuring equipment & Safety action related
1	0,001	strict leakage requirements, permeation	bubble counter
1	0,01	manufacturing, assembly	pressure decrease test
1	0,1	manufacturing, assembly	spray test, leak rate sensor
10	0,1	general safety	measuring concentration in air
100	1	process control	gas analysis
1000	1	maintenance work	personal safety devices
10000	100	personal safety	alarms, system failure
10000	100	avoid imminent danger	automatic ventilation increase
10000	1000	built-in safety measures (also check of)	automatic shutdown
100000	10000	combustion, toys, explosion	danger, effects on human body

The type and brand of vehicle will determine whether a diagnostic box can be used during troubleshooting. In both cases, knowledge of the system based on a block diagram is essential to understand how each component interacts with one another. If the diagnostic box is present, it will help to locate the faulty components; otherwise the technician must be able to analyse the symptoms and consider several failure scenarios.

This unit will first describe the maintenance activity of a hydrogen PEM fuel cell vehicle and will highlight items that will require special attention. A block diagram of a vehicle already on the market will also be introduced.

1.1. Teaser

1.2. Introduction to warning signs and maintenance

Working on a fuel cell vehicle requires a rigorous approach which is summarised and illustrated by the flow chart below [1].

1. Provide adequate local ventilation

↓

2. Eliminate static electricity and wear protective equipment

↓

3. Ensure safety when working on high voltage components

↓

4. Verify the tightness of the high pressure hydrogen tanks

↓

Maintenance and/or Repair
5. + Ensure safety during bodywork activities

↓

6. Check for leaks after working on the components of the hydrogen circuit

Each point can be explained as follows:

1. The dedicated workshop.

As of yet, there are no European standards, however, a consulting inspection company can provide advice.

The room must be equipped with good ventilation based on the principle of cross flow. This means, for example, that the air inlet grille is located down in the left wall and the air exhaust fan is located high in the right wall. With this configuration, the air flow moves the hydrogen leak away from its source as illustrated in Figure 1.

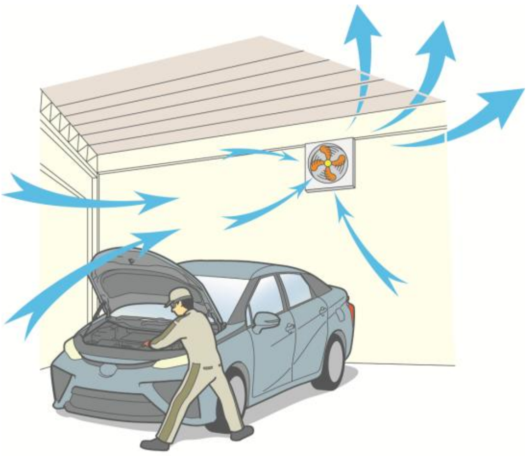

Figure 1 Illustration of the ventilation purpose in a garage (Source, Toyota [1]).

The garage must be equipped with hydrogen detectors which should increase the automatic ventilation in the event of a leak. Alternatively, they also should trigger the automatic opening of vents and doors in order to obtain maximum air flow. The sensors must be calibrated regularly. Before starting the maintenance work the following must be checked:

- The expiration date of the calibration
- The accuracy of the sensor by using a special spray containing a calibrated mix of H_2 in air at a concentration of 0.9 % - 1.6 %

The soil can be covered with an antistatic coating. Depending on the brand, the garage will be equipped with special tools, essential for the replacement of heavy sensitive components like the fuel cell and the tanks.

2. The worker must wear personal protective equipment including specially designed gloves, glasses and H_2 detector as illustrated in the Figure 2. Before disconnecting a component capable of releasing hydrogen, the worker must discharge static electricity by touching a metal conductor connected to earth.

Figure 2 Illustration of personal protection equipment (Source, Toyota [1]).

3. A worker who must perform tasks on the high voltage system must have professional certification related to this work. They must be aware of the technology and associated risks (level 1) and must also know the procedures to:

- Isolate the high voltage system from the battery and from the fuel cell. Where the service plugs are located and how to remove them among other operations described by the manufacturer (level 2)
- How to perform measurements under safe conditions during diagnostics (level 2 diagnostic)

In addition to this, a technician performing diagnostics must also analyse the architecture of the high voltage electrical system, such as the one shown in Figure 3 of the Toyota Mirai. The technician must understand the working and functional principles of major components and be aware of the associated dangers. These certifications are already organised for workers who may ensure maintenance on hybrid and electric vehicles.

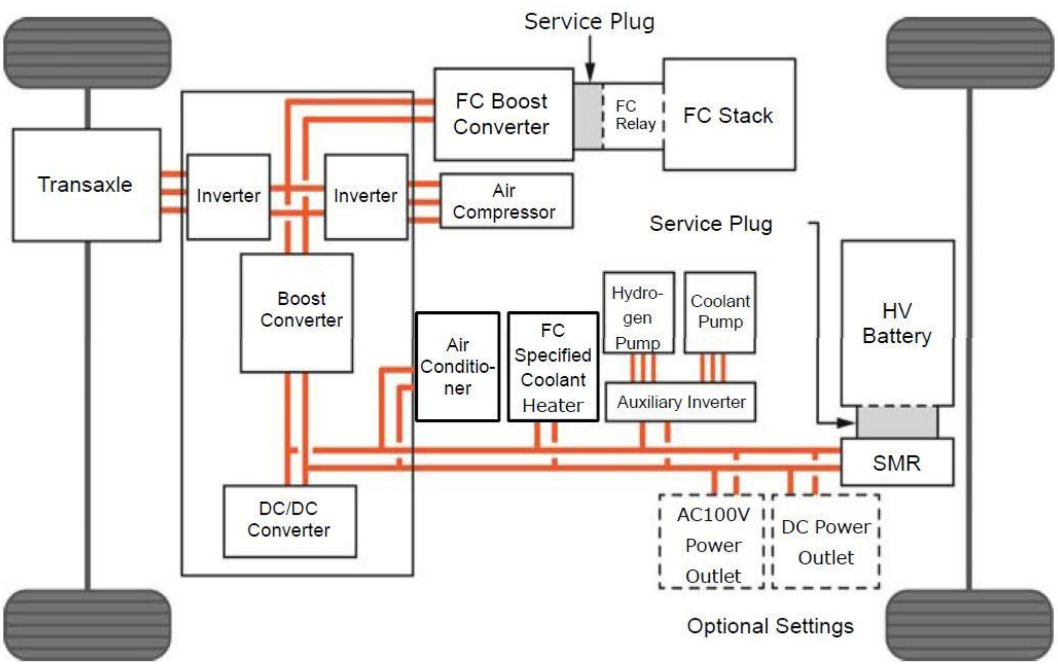

Figure 3 Example of a FCV high-voltage system (source, Toyota [2]).

4. Before working on the hydrogen circuit, ensure that the solenoid valves and manual valves of the tanks are closed. Then depressurise the hydrogen circuit and check the pressure difference with the environment. For example, no noise must be audible when lightly loosening the connector. If it is safe, start removing parts and installing new components in the system.

5. For workers who must perform common tasks on a special vehicle, like a body repairer for example; it is absolutely necessary that they follow some training (level 1) in order to be aware of the specialised components found in a fuel cell vehicle. Being aware of what to do and what not do during maintenance is vital such as:

- Check the double closing of hydrogen tanks, manual closing and via the solenoid valve
- Do not expose the leak detectors to paint solvents
- Do not weld near the hydrogen tanks, remove them if necessary
- Do not expose hydrogen tanks to a flame, solvents or sparks
- Do not expose hydrogen tanks to a temperature greater than 85 °C
- Do not expose hydrogen pipes & components to a temperature greater than 85 °C
- Do not use infrared heating near hydrogen pipes because the temperature is not easily controlled
- Check for hydrogen leak before placing the vehicle in painting booth

6. After conducting any maintenance or repair work to parts of the hydrogen circuit, check the pipes and components for leaks by using a professional foam spray and an electronic detector placed near the potential source. In case of leakage, the foam sprayed on the connections will produce visible bubbles. If a portable electronic detector is used near the source, the leakage will be detected when a H_2 concentration greater than the recommended threshold is observed, for example 100 ppm suggested by Toyota.

In the case of the tank replacement, inspection is more complex because the filling line must be checked before opening the manual valve of the tank and using hydrogen. This operation is then performed in two steps.

- The first step consists of checking the tightness of the filling line by connecting a pressurised tank of nitrogen gas and measuring the pressure decrease.
- The second step consists of measuring leakages with a detector after filling the tank with hydrogen under the conditions prescribed by the manufacturer.

1.3. Maintenance of components

1.3.1. The electric motor

The electric AC motor requires no maintenance except to check the electrical connections for any loosening due to vibration. In the case of some niche products, one can meet DC motors with an average power less than 10 kW. In this case the periodical replacement of the brushes is essential. This operation is accompanied by the cleaning of both rotor and stator by means of compressed air in order to eliminate wear particles which are electrically conductive.

1.3.2. Batteries/Supercapacitors

The battery ventilation system must be checked to see if it is functioning properly, because the battery pack is very sensitive to heat. It presents a high risk of thermal runaway beyond 100 °C. Many videos circulating on the web are showing this type of Ni-MH battery burning. They show evidence that this type of fire is not extinguished easily. The thermal runaway process is able to resume after the flame is initially extinguished (Animation 1).

Animation 1 Battery fire restarts after being extinguished (Source, T. Coppens).

Regarding the peak power systems (PPS), the measurement of the full-charge voltage enables a quick check of the pack and possible failure diagnosis of one or more cells. In both cases, the voltage at full load is known and must be measured. The BMS normally provide this information.

1.3.3. Fuel cell auxiliary components

Replacing the intake air filter

In a PEM fuel cell hydrogen vehicle, the outside air is sent into the stack trough dedicated auxiliaries (filter, compressor & intercooler) in order to provide oxygen for the redox reaction. In parallel, we know that it is important to prevent external particles from entering the stack through the air flow and reaching the electrodes. Indeed, the contamination of the electrodes by dust will lead to a reduction in the active surface and will bring down the production of electricity for the same quantity of hydrogen consumed at the anode. In addition, these dust particles may also damage the compressor as mechanical clearances between parts are very small in this kind of machine. It is therefore appropriate to monitor the cleanliness of the air filter and change it periodically following the manufacturer's instructions (Figure 4).

Figure 4 Replacement of the air filter (source, Toyota [2]).

Replacement of the coolant

In a hydrogen vehicle, the cooling of the fuel cell is a critical element for the membrane material which cannot be exposed to more than 100 °C. For high power fuel cells, cooling is achieved by means of a circuit using a liquid coolant which flows through the stack between the bipolar plates. This coolant must not be electrically conductive because electricity will leak, reducing the stack efficiency. To avoid this phenomenon, the coolant is continuously filtered by a resin which retains the positive ions H^+ and negative ions OH^- produced in the cells. It is therefore not necessary to change the coolant regularly. However, the replacement of a component of the cooling system may require draining the circuit. In this case, the coolant is replaced making sure to use the special fluid recommended by the manufacturer. This fluid has a low conductivity and contains antifreeze; **you cannot use a conventional coolant**.

Replacement of the ion exchanger

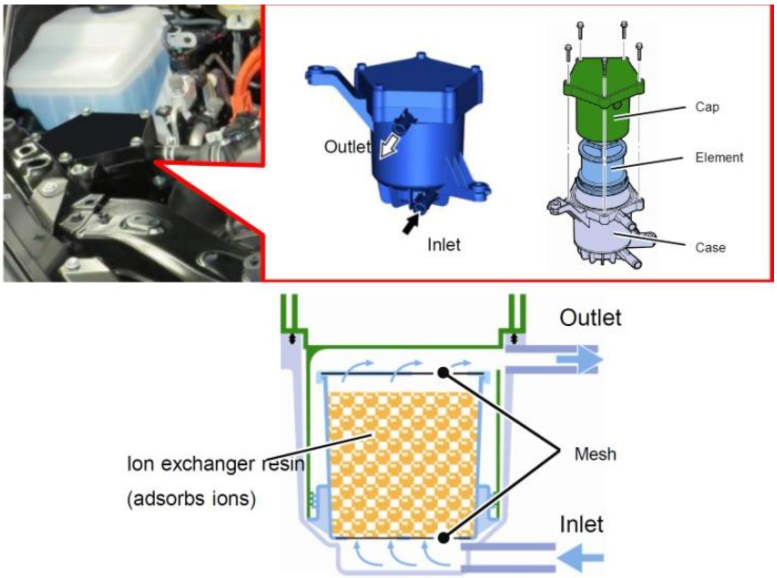

Figure 5 Ion exchange filter (source, Toyota [2]).

If the coolant should not be changed periodically, it is the case of the ion exchange filter whose role is to retain ions from the coolant.

It is emphasised that the cooling fluid passes through the stack becomes progressively charged with ions. The coolant becomes, therefore, an electrical conductor and a part of the electricity produced by the fuel cell will leak through the coolant. This is not acceptable. It is therefore the role of the resin filter to avoid this by adsorbing the ions. Nevertheless, there is a time limit of ion exchange resin (filter) performance, so it is necessary to replace it periodically. An example of the location of the filter and a description of this operation is provided in Figure 5.

1.3.4. Power electronics

This work of verifying the components of the high voltage circuit is equivalent to the operations performed to maintain or repair hybrid or electric cars. The diagnostics of HV components must often be done when the system is on. One can measure the voltage as a first check and then the complete signal for more precise information. In these conditions, compliance with safety rules is essential; this is ensured through adequate training officially approved by a sector certification.

1.3.5. Hydrogen system

A first measure consists in a visual inspection to observe the absence of damages to the pipes and tanks. Typical, damage which is normally visible is a crushed pipe and a scratched tank. This visual inspection could also detect unscrewed connectors, particularly after maintenance work.

A second measure consists of checking if the hydrogen system is free of any leaks. This is carried out using a portable detector. Taking into account that hydrogen disperses, the portable detector must be located near the potential leakage sources. A measurement of 100 ppm or less is acceptable.

This double inspection must be periodic. It should ideally be carried out when the tank is full since this is when the pressure is at a maximum.

The vehicle also includes hydrogen leak detectors (Figure 6) connected to the ECU which will ensure the closing of the various solenoid valves of the hydrogen system in case of leakage detected. The technician must periodically test the sensors and verify that the relevant safety emergency operations are executed, including the warning LED on the driver dashboard. To do so, the technician will use a professional spray containing hydrogen with a concentration between 0.9% and 1.6%. This spray will be used where the sensors are located, for example near the tanks and under the bonnet.

Figure 6 Hydrogen sensor (source, Toyota [2]).

The hydrogen tanks are large and heavy, manufacturers will therefore place them at the rear of the vehicle and as close as possible to the ground. Risk of contact with the ground is not negligible and if it happens the scratches must be examined to determine the depth of the damage. In the case of 3 layered tanks shown in Figure 7, the decision to change the tank is taken if the second layer made of carbon fibres is breached by the scratch. In this case, the black colour clearly appears.

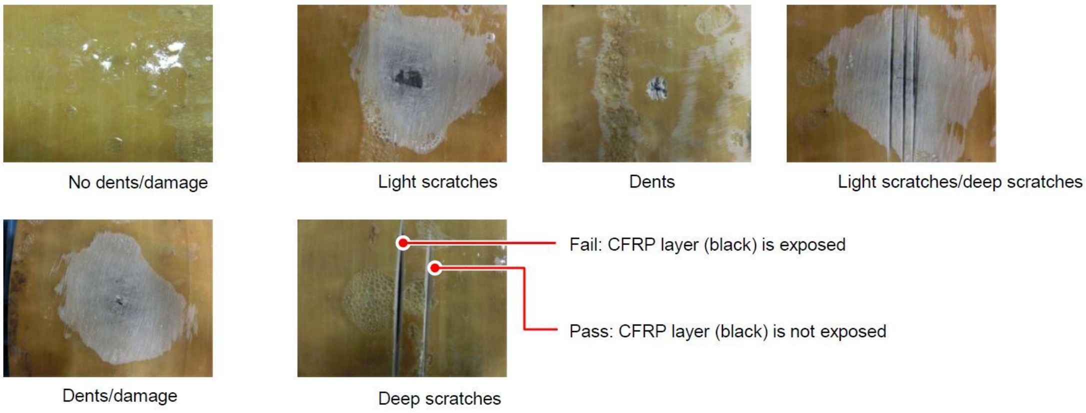

Figure 7 Different kind of scratches on a tank surface (source, Toyota [2]).

If the decision is taken to replace a tank with a new one, one must follow the manufacturer's procedure and especially use special tools like the one shown in Figure 8.

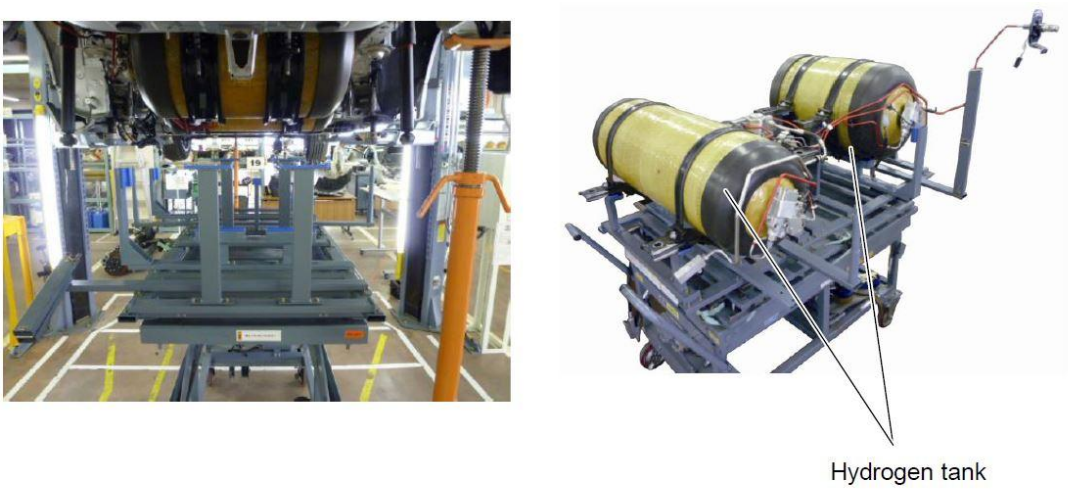

Figure 8 Special tooling (source, Toyota [2]).

If a hydrogen pipe is damaged, it must be replaced. This is also the case if a pipe was disassembled to replace a component because the connector works by deforming the pipe significantly. There are also connectors using removable soft seals like a copper or rubber ring, in this latter case only the spare parts must be changed.

In all cases, before the reassembly, it is essential to <u>check surfaces</u> and ensure that there is neither dust nor damages. It is also essential to <u>use the correct torque</u> to tighten the connector.

1.3.6. ECU - controller

The ECU diagnostic is usually performed by means of an interface provided by the manufacturer. However, the technician will consider possible causes of failures with the support of the block diagram corresponding to the vehicle up for maintenance. As an example, Figure 9 shows a block diagram dedicated to activation and shutdown procedures. The technician will check the system step by step. He will especially check that the switch signal produces the desired actions. For example that the battery and fuel cell relays are closing, that the solenoid valves of the tanks are opening, that the hydrogen pump and the air compressor are rotating... After this functional inspection he will determine if the failure comes from the ECU or from the component.

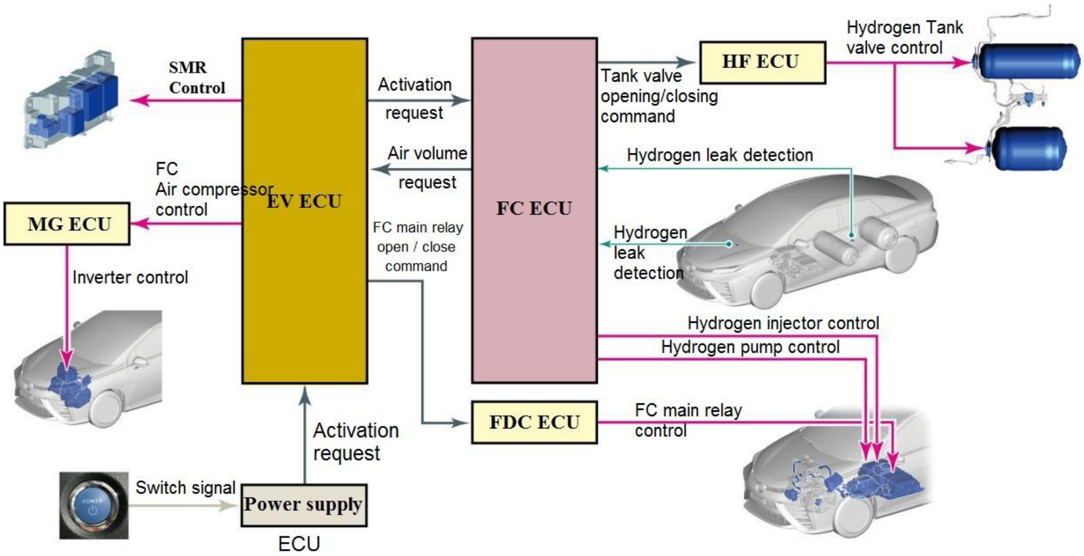

Figure 9 Block diagram and role of ECU (source, Toyota [2]).

Based on Figure 9 one can understand for example the activation procedure. The main switch sends a request to the ECU which closes the main relay of the fuel cell and the safety relays of the battery. The ECU also opens the solenoid valves of the hydrogen tanks unless leak detectors send a positive warning signal. The idle operation is then obtained through the control of both air compressor and H_2 injectors.

In operation, the pedal request of the driver is sent to the ECU which transforms it in a setpoint for the inverter. In parallel, instructions are sent to the H_2 pump, H_2 injectors and air compressor to achieve the current demand. This type of control is described in Figure 10.

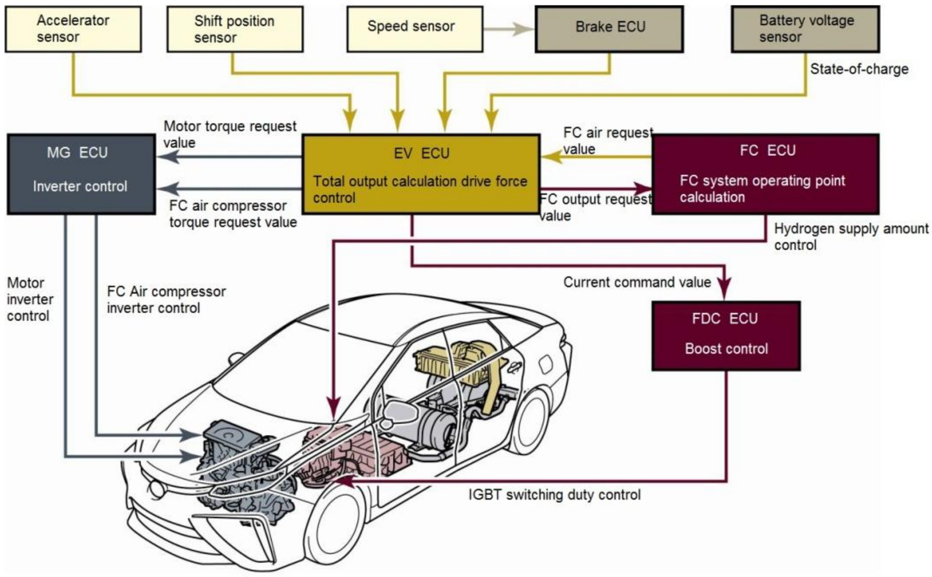

Figure 10 Block diagram for the system output control (Source, Toyota [2]).

The speed sensor is able to control the brake ECU and therefore recover kinetic energy in the HV battery. The state-of-charge of the battery is monitored so that the EV ECU can decide to charge if necessary.

1.4. Troubleshooting

In this particular case, it is known that the car is not working properly or at all, so the cause of this malfunction must be sought. The technician may be interested in this case in the fuel cell or, more likely, in the role of the sensors and in the efficiency of the auxiliaries.

1.4.1. Measurement of the I-V curve

The efficiency of the fuel cell is a key indicator of performance. This measurement is indirect since it simultaneously monitors the hydrogen consumption and the electric power produced. The calculation is quite easy and can be explained during a practical exercise.

The main difficulty of this method is that the fuel consumption is not easily determined, except for a test bench. Therefore, a more direct and affordable method must be used to check the fuel cell.

The measurement of the I-V curve will give a good idea of the system status and will enable a comparison with measurements given by the manufacturer's technical specifications. The following will accurately be measured and compared:

- the open circuit voltage
- the voltage decrease during operation

Manufacturers often give the I-V curve for one cell so therefore it is necessary to multiply the voltage by the number of cells in series. Figure 11 shows an example of an I-V curve for a single cell. The polarization (I-V) curve is in blue while the power is in red.

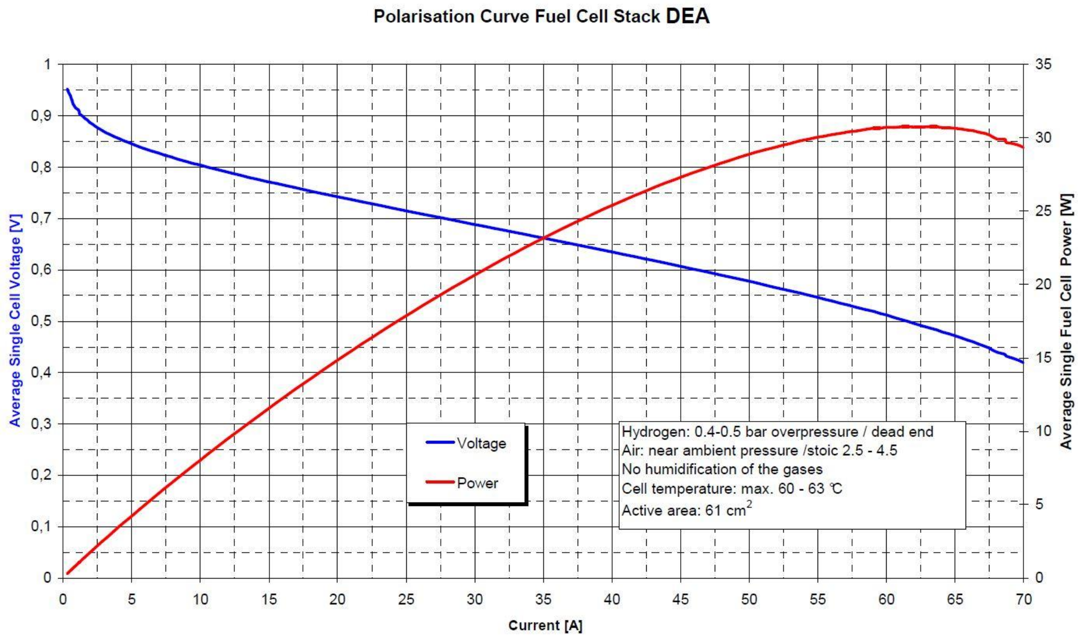

Figure 11 Example of an I-V curve from a fuel cell (Source, MES-DEA).

1.4.2. Torque measurement of the wheels

One method is to place the vehicle on a chassis dynamometer and measure the torque. This helps to check that the electric motor provides the desired torque which will ensure the vehicle acceleration specified by the manufacturer. Indeed, in the case of electric motors, one can always say that the torque depends on the current I (Amperes) and the rotational speed depends on the voltage V (Volts) associated with the frequency f (Hertz) of the electric signal. In the absence of a chassis dynamometer, an acceleration road test will provide the same information with less precision.

1.4.3. Troubleshooting based on block diagrams

Thanks to the support of Toyota, it is possible to show the functional diagram of the Mirai presented in Figure 12. It clearly shows the interaction between subsystems and in each block between the components. The subsystems are as follows:

- Fuel Cell (central)
- Hydrogen supply (red)
- Air supply (green)
- Cooling circuit (blue)
- High voltage electrical circuit (orange)

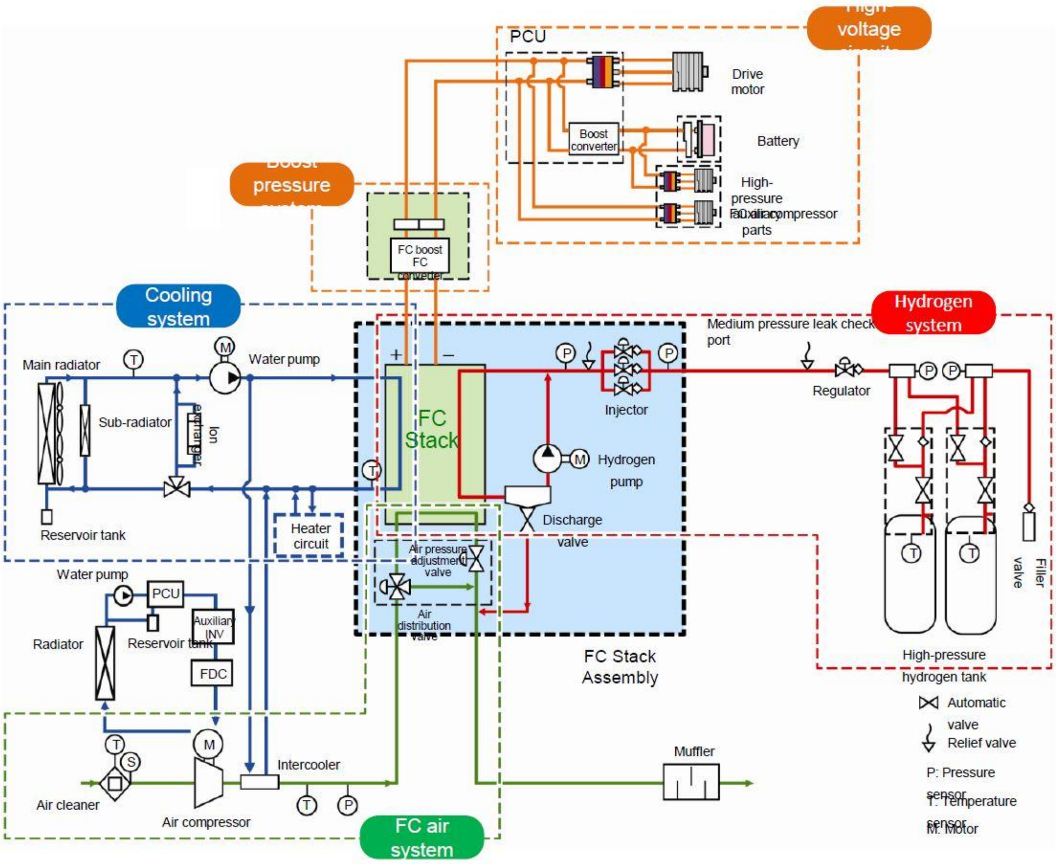

Figure 12 Functional scheme of the Toyota Mirai (Source, Toyota [2]).

<u>Power loss</u>

- The air filter is dirty and the fuel cell does not receive enough air, the redox reaction does not occur normally
- Water management is not good and the membrane tends to dry
- The resin filter of the cooling circuit needs to be changed, electricity is leaking from the fuel cell
- The injectors do not provide a sufficient hydrogen flow
- The management of the pressure within the fuel cell is not good, check the counter pressure valve at the oxygen (air) side

- The battery or super capacitors (PPS) are no longer providing additional energy to ensure the nominal acceleration specified by the car manufacturer
- The membrane of the battery is contaminated at the hydrogen side, a purge with hydrogen must be performed
- The air compressor does not work properly

Vehicle cannot be started

- Hydrogen leak detected
- Hydrogen leak detectors faulty or damaged
- Fuel cell main relay remains open (electrical circuit open)
- Solenoid valves closed down (check the reasons)
- PPS safety relay remains open (electrical circuit open)
- Faulty inverter

In any case, compliance with procedures and instructions given by the manufacturer overrides this general approach.

[1] Safety Guidance for FCV, Toyota Motor Corporation

[2] Mirai Technical Training manual, Toyota Motor Corporation

Summary

A hydrogen vehicle also requires maintenance, unlike the urban myth that claims an electric vehicle should never be verified. The most important point concerns the **safety of workers**: the workshop infrastructure and guidelines to follow.

First of all the garage must be **well ventilated and equipped with hydrogen leak sensors**. There is still no standard but one can already apply the standards for hazardous gases and follow the advice of an external inspection company.

The safety rules must be followed when working on the hydrogen high pressure circuit or the high voltage circuit. The technician must wear personal protective equipment, including a personal H_2 detector. The technician must isolate any dangerous parts before disconnecting components, this is ensured by:

- Removing the fuel cell & battery service plugs before working on the high voltage system
- Closing the manual valve of each hydrogen tank before working on the H_2 system.

During maintenance one must use specific tools and follow certain rules:

- Use specific tools such as insulated tools and voltage detector in order to work on the high voltage system
- Use a portable hydrogen detector for checking the tightness of critical areas near potential leakage sources.
- Use handling tools for the replacement of sensitive heavy parts like the tanks and the fuel cell. This equipment is designed to avoid shocks and falls.
- Follow safety rules when disconnecting H_2 connectors (listen for any audible leakage sounds) or when connecting (ensure that there is no dust and no damage to the sealing surfaces and use the correct torque to tighten the fitting nuts)
- Follow all other rules described in this document and in the manufacturer maintenance guide

In short, the regular maintenance of a fuel cell vehicle consists mainly of:

- **Assuming safety aspects (equipment & behaviour)**
- Checking the whole H_2 system for leaks
- Carry out a visual inspection of sensitive points like hydrogen pipes and tanks
- Change the air filter and the resin ion exchanger

In short, the extraordinary maintenance consists mainly of:

- **Assuming safety aspects (equipment & behaviour)**
- The diagnosis of malfunctions followed by the repair or replacement of components. In this case, the use of a manufacturer's diagnostic tool (OBD) is ideal; otherwise it is necessary to refer to block diagrams to consider fault scenarios.