

# Development of New Hydrogen Fueling Method for Fuel Cell Motorcycle

Kiyoshi Handa, Shigehiro Yamaguchi, and Kazuya Minowa  
 Honda R&D Co., Ltd.

Steven Mathison  
 Honda R & D Americas Inc.

## ABSTRACT

A new hydrogen fueling protocol named MC Formula Moto was developed for fuel cell motorcycles (FCM) with a smaller hydrogen storage capacity than those of light duty FC vehicles (FCV) currently covered in the SAE J2601 standard (over than 2kg storage). Building on the MC Formula based protocol from the 2016 SAE J2601 standard, numerous new techniques were developed and tested to accommodate the smaller storage capacity: an initial pressure estimation using the connection pulse, a fueling time counter which begins the main fueling time prior to the connection pulse, a pressure ramp rate fallback control, and other techniques. The MC Formula Moto fueling protocol has the potential to be implemented at current hydrogen stations intended for fueling of FCVs using protocols such as SAE J2601. This will allow FCMs to use the existing and rapidly growing hydrogen infrastructure, precluding the need for exclusive dispensers or stations.

**CITATION:** Handa, K., Yamaguchi, S., Minowa, K., and Mathison, S., "Development of New Hydrogen Fueling Method for Fuel Cell Motorcycle," *SAE Int. J. Alt. Power*, 6(2):2017, doi:10.4271/2017-01-1184.

## 1. INTRODUCTION

Hydrogen Fuel Cell Vehicles (FCVs) have the potential of being simultaneously a Zero Emission Vehicle (ZEV) with long driving ranges and short fueling times, similar to conventional vehicles. Honda's newly developed Clarity FCV for instance has a range of 366 miles/ 589 km (as per US EPA Certification) and can be fueled using established standardized protocols in 5 minutes or less. However, there are ranges of storage sizes for other vehicles classes such as motorcycles which are not yet covered in standards. The purpose of this paper is to provide a proposal for a protocol and methodology for Fuel Cell Motorcycle (FCM) fueling based on analytical work and real world fueling testing.

Standards such as SAE J2601 [1] (and the accompanying communications standard SAE J2799 [10]) and JPEC S0003 [2], establish a safe and effective means of high-pressure hydrogen fueling to light duty passenger fuel cell vehicles (FCV). These standards are applicable to hydrogen tank volumes from 50 to 250 L (equivalent to a hydrogen storage amount of between 2 and 10 kg at 70 MPa). The construction of hydrogen fueling stations using these standards is also proceeding at a rapid pace.

At the same time, the development of FCMs is under way [3],[4],[5]. Because the bodies of FCMs are smaller than those of FCVs, the volume of the hydrogen storage tanks are restricted to around 10 to 25 L (equivalent to a hydrogen storage amount of between 0.4 and 1 kg at 70 MPa). Conventional motorcycles also have tank sizes that are a fraction of those utilized in conventional gasoline powered passenger

vehicles, however, because fueling with gasoline is conducted at a constant flow rate, the difference between passenger vehicles and motorcycles is only a reduction in the fueling time. This is due to the fact that fueling a tank with liquid hydro-carbon fuel at a constant rate is easily metered and controlled. There are no adverse effects to gasoline fueling light duty vehicles, including motorcycles, at a constant flow rate, however it should be noted that heavy duty vehicles are generally fueled at a much faster rate (generally twice as fast).

In the case of hydrogen, however, compression heat is generated in the tank during fueling. As the ANSI standards [6], among others, stipulate that the hydrogen temperature shall be no more than 85°C, hydrogen fueling stations therefore pre-cool their hydrogen to around -40°C. Additionally, current standard hydrogen fueling protocols use a pressure ramp rise rate to fuel vehicles in the relatively the same fueling times as gasoline powered passenger vehicles [7], [11]. If a hydrogen tank is fueled using a constant mass flow rate, the rate of pressure increase (the ramp rate), and the rate of gas temperature rise become higher as the tank volume becomes smaller [14]. To help avoid this issue, the abovementioned hydrogen fueling standards specify the use of pressure ramp-rate control, which allows a variety of tank volumes to be fueled at a similar rate. The gas temperature is maintained by adjusting the ramp rate in response to the ambient temperature, the pre-cooling temperature, and the volume of tank.

The Fueling Interface Standardization Working Group, through a project of the New Energy Development Organization (NEDO) supervised by the Japan Automobile Research Institute (JARI), has established a small-volume Fueling Task Force to develop and

establish a hydrogen fueling method for FCMs. Under this development process, numerous issues were identified. The new FCM hydrogen fueling method described herein addresses these issues, the details of which are presented in the sections which follow.

## 2. CLASSIFICATION OF ISSUES

### 2.1 Start-Up Issues

In order to measure the initial pressure of a vehicle fuel tank, a small quantity of hydrogen is introduced to the tank at the initial connection, referred to as a connection pulse. The connection pulse is essentially an equalization of the small amount of hydrogen pressurized in the fueling line downstream of the storage with that in the vehicle tank. After the connection pulse, a small quantity of hydrogen can also be introduced to the tank in order to measure its internal volume. SAE J2061[1] defines the connection pulse and volume measurement as the startup sequence and limits the amount of hydrogen which can be dispensed during this sequence to 200 g (Figure 1).

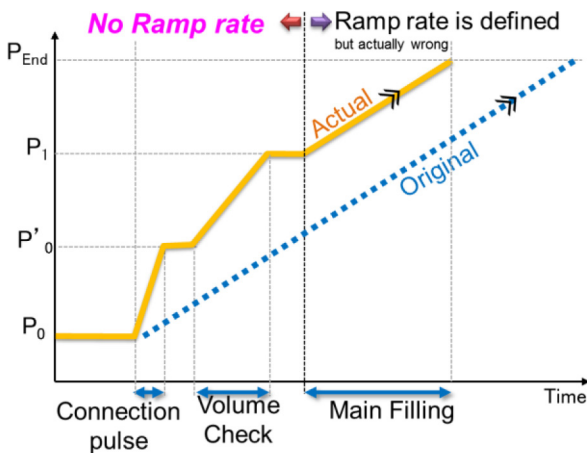


Figure 1. Example of constant ramp rate filling

In the case of a small FCM tank, for example one with a storage volume of 10 liters, it is possible for the state of charge (SOC), from an initially nearly empty condition, to reach 50% simply as a result of start-up sequence. For higher initial pressure conditions, it might also be possible for the tank to become full. In either of these cases, there is also the potential for the hydrogen to reach an excessive temperature (especially for tanks with plastic liners of type IV construction), merely as a result of start-up sequence prior to the start of the main portion of the fueling.

The dotted line in Figure 1 shows an example of fueling at a constant-pressure ramp-rate from an initial pressure of  $P_0$ . In hydrogen fueling standards, the ramp rate is set to help ensure that the hydrogen temperature does not exceed 85°C from the minimum pressure to the end-of-fill pressure,  $P_{End}$ . More rapid fueling than this might excessively increase the hydrogen temperature. The solid line in Figure 1 shows a case in which a small FCM fuel tank is filled at the same pressure ramp rate. Start-up fueling increases the pressure from  $P_0$  to  $P_1$ . Following this, when fueling is conducted using a constant-pressure ramp-rate method, the fueling time becomes lower than that

shown by the dotted line. The average pressure ramp rate is greater than that shown by the dotted line, and there is a possibility that the hydrogen temperature will increase. Because the fuel tank in the FCV is large, the pressure increase due to start-up fueling is comparatively small, and can be absorbed within the tolerances for pressure control. However, the pressure increase cannot be absorbed in the same way in the case of the small FCM tank.

### 2.2 Issue of Low Flow Rate

Because the volume of FCM tanks are smaller than FCV tanks, the mass flow rate is relatively small when using a constant-flow-rate fueling method. If the mass flow rate is below the lower-limit value for a hydrogen fueling station, it is possible that the control would not function as intended. In the same way, if the mass flow rate dropped below the lower-limit flow rate for the measurement range of a hydrogen flowmeter, measurement accuracy might also decline, making the sale of hydrogen for FCMs problematic. SAE J2601[1] regulates that a maximum mass flow rate is 60g/s. If the minimum controllable mass flow rate is 5% of 60g/s, it is 3g/s. However 3g/s flow can approximately make 30MPa/min in 0.4kg FCM tank. In other word, FCM pressure ramp rate needs to exceed 30MPa/min always to control the flow correctly. SAE J2601[1] lookup table doesn't have such a high pressure ramp rate table to avoid an overheating in the tank.

### 2.3 Issue of Increase in Temperature of Pre-Cooled Hydrogen

The hydrogen tube between the station and the vehicle is exposed to the ambient temperature prior to fueling. When fueling starts, the pre-cooled hydrogen passes through the interior of the tube and the hose. At this time, the temperature of the hydrogen increases due to the thermal mass of the hydrogen tube itself and heat exchange with the environment through the walls of the tube. Because the thermal mass of tubes is fixed, the increase in temperature becomes more pronounced the lower the mass flow rate of the hydrogen during fueling.

### 2.4 Issue of Fueling Time

Current hydrogen fueling stations employ a look-up table (L/T) fueling method specified by SAE J2601 [1]. This method basically determines the pressure ramp rate exclusively via the pre-cooling temperature, the ambient temperature, and the volume of the hydrogen tank. In order to increase the fueling speed, the pre-cooling temperatures of most hydrogen stations today are in the lowest category (T40), and it is necessary for the temperature of the hydrogen to be within the range of -40 to -33°C within the first 30 sec following the start of fueling. It can be considered that at the hydrogen flow rate used for a FCM, it would be challenging to bring the temperature within this range. In this case, the higher-temperature pre-cooling categories T30 or T20 are used, and the fueling speed slows considerably. When fueling time is extended, more heat enters the tubes and other components from the environment, and there is a further increase in hydrogen temperature. In other words, these factors create a negative feedback loop. In addition, if the hydrogen temperature exceeds the upper limit or the T20 category (-17.5°C), fueling stops.

## 2.5 Issue of Integrated Fueling Control

The degree of increase in the temperature of the pre-cooled hydrogen upstream of the measurement point just before the breakaway fitting is dependent on the hardware used in each hydrogen fueling station, e.g., the length of tubing and the status of insulation. Because the flow rate when fueling a FCM is low, the effect is even greater. Fueling control for FCMs therefore necessitates greater flexibility in relation to the issue of increase in the temperature of the pre-cooled hydrogen than is the case for FCVs. Taking other factors such as response to the start-up issue into consideration, this makes integrated control necessary. However, this could not be realized using the conventional L/T fueling method.

## 2.6 Issue of Dedicated Dispensers

Based on these issues, it was considered that the fueling of FCMs using a hydrogen dispenser designed for FCVs would not be possible. It was projected that it would be necessary to produce dedicated dispensers for FCMs, featuring flow control valves and flow meters designed for low flow rates, tube systems with reduced thermal mass, and a reduced start-up fill quantity. While technologically feasible, it would entail a major infrastructure investment for the installation of new dedicated FCM hydrogen dispensers. Failure to proceed with the installation of the infrastructure would impede the further diffusion of FCMs. However, if hydrogen dispensers for passenger vehicles could also be used to fuel motorcycles, it would be possible to make use of existing hydrogen fueling stations, doing away with the necessity for new investment while promoting the diffusion of FCMs. A new fueling technology that would make it possible to use hydrogen dispensers to fuel both FCVs and FCMs would therefore be required.

It is generally known that because heat absorption by the thermal mass of the aluminum liners of Type 3 tanks makes it possible to control the increase in the temperature of the hydrogen, a higher-pressure ramp rate is allowable than is the case when using Type 4 tanks, which have plastic liners. Suzuki Motor Corporation conducted a test in which a 10 L Type 3 tank with an aluminum liner was filled at an extremely high pressure ramp rate (60 MPa/min), and presented the results to the Taskforce discussed above. This test produced the major finding that even when the tank was filled at a pressure ramp rate approximately twice the maximum rate stipulated by SAE J2601 (28.5 MPa/min), the hydrogen did not reach excessive temperatures. If FCM hydrogen tanks were restricted to Type 3 tanks, it would be possible to set high-pressure ramp rates and increase the mass flow rate. If it were possible to increase the hydrogen flow rate to the same level as employed in fueling FCVs, the outlook would be positive towards addressing the issues of low flow rate and increase in the pre-cooling temperature. Motorcycle OEMs in Japan discussed about this and conducted. A difference of the weight between Type 3 and Type 4 is actually tiny in such small volume tanks. To eliminate Type 4 is more beneficial in the actual hydrogen world because to build completely new dispensers just only for FCM is unrealistic.

However, this method would not address the start-up issue and the issue of integrated fueling control. The authors have conducted many years of research concerning hydrogen fueling technologies [7]–[9]. The MC Formula fueling method for FCVs, adopted into the SAE J2601 standard in 2016, makes it possible to flexibly control the

pressure ramp rate in real time even when the temperature of the pre-cooled hydrogen fluctuates. It was considered that this flexibility would be of benefit in addressing the issues of increase in the temperature of the pre-cooled hydrogen and the realization of integrated control for FCMs. In addition, a fill control method for FCMs was newly devised by adding a method of addressing the start-up issue to the MC Formula fueling protocol. The developed fueling method was named the MC Formula Moto fueling protocol.

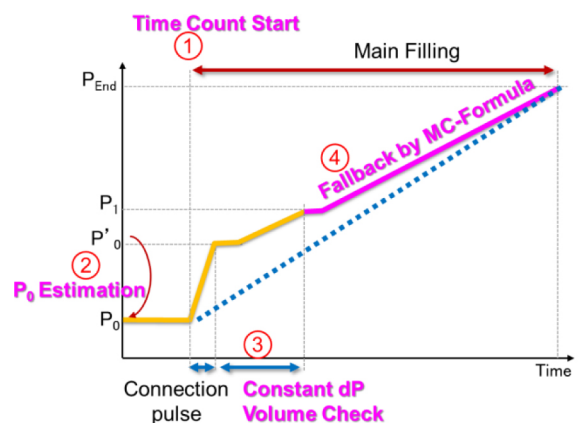
## 3. DEVELOPMENT GOALS

The hydrogen fueling method for FCMs was developed based on the following goals:

1. Providing the ability to fuel FCMs using hydrogen dispensers for FCVs; and
2. Able to be realized by modifying software, without the need for modification of hydrogen fueling station hardware.

The authors analyzed the issues discussed above. These analyses indicated that the most essential issue was the fact that the fill quantity at start-up was ignored by the overall fill control, and was not incorporated in ramp rate control (Figure 1). Accordingly, as shown in Figure 2, it was considered that the projected desired ramp rate (dotted line), including start-up fueling, should be realized at the completion of fueling. Fueling control is applied as discussed below, based on this fundamental concept.

FCM hydrogen tanks are restricted to Type 3 tanks in order to realize a higher pressure ramp rate. FCVs and FCMs are differentiated by the dispenser using an infrared (IR) communication interface as an essential condition. If FCM refuels at non-communication station, the station may use FCV's pressure ramp rate which is smaller than FCM. There is no concern about over heating in FCM tank.



$P'_0$  : gas pressure of vehicle tank after Connection pulse  
 $P_1$  : gas pressure of dispenser after volume check  
 $P_{End}$  : gas pressure of dispenser when fueling ends

Figure 2. Image of the new control

The time count from the start of the fill is changed from after start-up fueling to before the connection pulse (1). The initial pressure in the FCM tank before the connection pulse,  $P_0$ , is estimated (2). When