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Development of Technical Regulations for Fuel Cell Motorcycles in Japan—Hydrogen Safety

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Abstract: Hydrogen fuel cell vehicles are expected to play an important role in the future and thus have improved significantly over the past years. Hydrogen fuel cell motorcycles with a small container for compressed hydrogen gas have been developed in Japan along with related regulations. As a result, national regulations have been established in Japan after discussions with Japanese motorcycle companies, stakeholders, and experts. The concept of Japanese regulations was proposed internationally, and a new international regulation on hydrogen-fueled motorcycles incorporating compressed hydrogen storage systems based on this concept are also established as United Nations Regulation No. 146. In this paper, several technical regulations on hydrogen safety specific to fuel cell motorcycles incorporating compressed hydrogen storage systems are summarized. The unique characteristics of these motorcycles, e.g., small body, light weight, and tendency to overturn easily, are considered in these regulations.

Keywords: fuel cell; hydrogen; motorcycle; standardization

1. Introduction

Recent environmental and energy safety issues have resulted in a significant change in the transportation sector: The replacement of fossil fuels by alternative energy sources. As a clean fuel and energy carrier, hydrogen is a promising alternative energy source. Hydrogen fuel cell vehicles (HFCVs) are expected to play an important role in the future and thus have improved significantly over the past years [1,2]. The first commercial hydrogen fuel cell car was launched in 2014 in Japan [3].

However, hydrogen fuel cell motorcycles are still in their developmental stages. Since battery-powered electric motorcycles have already been provided by several manufacturers and are rapidly becoming popular in recent years [4], commercialization and widespread use of fuel cell motorcycles are also expected. Several concepts for fuel cell motorcycles have been designed. Metal hydride canisters are widely used for hydrogen-fueled scooters in Taiwan [5,6]. The canisters are designed with quick connectors to allow easy replacement. A hybrid scooter with a plug-in battery and a hydrogen fuel cell has been researched in the UK [7]. Two metal-hydride canisters are used for the hybrid scooter.

Alternatively, small containers for compressed hydrogen gas have been researched and developed in Japan. Recently, a fuel cell motorcycle incorporating a compressed hydrogen storage system has been developed by Suzuki [8]. The fuel cell motorcycle, equipped with an air-cooled fuel cell unit, obtained Japanese type approval in August 2016. It is the first vehicle of its type in Japan. The fuel cell motorcycle was tested on the public roads of Japan [9] and the UK [10]. Figure 1 shows the fuel cell motorcycle being refueled with compressed hydrogen gas at a hydrogen station in Japan. In this case, Japanese hydrogen fueling regulation JPEC-S 0003(2012) was applied to refuel the motorcycle after

the fueling safety has been confirmed [8]. Furthermore, a new hydrogen fueling method for fuel cell motorcycles incorporating compressed hydrogen storage systems is under development [11].



Figure 1. A fuel cell motorcycle at a hydrogen station in Japan.

To make fuel cell motorcycles commercially available all over the world, it is important to establish appropriate technical regulations for these vehicles. Although the technical regulations for the electrical safety of motorcycles have been published as United Nations Regulation (UNR) No. 136, the technical regulations for hydrogen safety of motorcycles have not been published. Additionally, Global Technical Regulation (GTR) No. 13 and UNR No. 134, which are international technical regulations for hydrogen-fueled vehicles incorporating compressed hydrogen storage systems, excluding motorcycles, have been published. Most of these regulations are considered to be applicable to fuel cell motorcycles incorporating compressed hydrogen storage systems. However, there are parts of these regulations that cannot be safely applied to fuel cell motorcycles due to some characteristics that are unique to these vehicles. It is necessary to modify these regulations for fuel cell motorcycles.

The characteristics unique to motorcycles include their small body, light weight, and tendency to overturn easily. National regulations taking these characteristics into account have been established in Japan. A new international regulation on hydrogen-fueled motorcycles incorporating compressed hydrogen storage systems based on Japanese regulations was also established as UNR No. 146 in 2019. In this paper, several technical regulations specific to motorcycles which are different from UNR No. 134 are summarized.

2. Regulations

In this section, some technical regulations different from that for four-wheeled vehicles are summarized. These regulations were established in Japan after discussions with Japanese motorcycle companies, stakeholders, and experts.

2.1. Capacity of Hydrogen Containers

It is clear that a small vehicle, e.g., a motorcycle, must have hydrogen container(s) smaller than that of four-wheeled vehicles. Considering the container capacity of conventional gasoline motorcycles, the reasonable maximum container capacity for fuel cell motorcycles is considered to be around 20 L.

Additionally, the hydrogen volumetric concentration inside a garage caused by permeation from the container should be maintained to be less than 1%, as stated in the rationale of GTR No. 13. Therefore, it is necessary to consider a small garage for motorcycles instead of using a large garage for four-wheeled vehicles.

According to survey results, the smallest garage used to house motorcycles is approximately 3.56 m³. This garage is 2.2 m in length, 0.9 m in width, and 1.8 m in height. The upper limit of permeation rate per liter from a compressed hydrogen storage system (P_l) and the lower volumetric air exchange rate for a garage per hour (r) are 46 mL/h/L and 0.03 /h, respectively, which are obtained from GTR No. 13. These values are used to calculate the capacity of 330 L in GTR No. 13. It is reasonable to

use the same procedure for a fuel cell motorcycle with a similar compressed hydrogen storage system. Therefore, the following equation holds to maintain the volumetric concentration in the smallest garage to be less than 1%:

$$V_m < \frac{rV_g}{100P_l} \cong 23.2L, \quad (1)$$

where V_m is the compressed hydrogen storage capacity for a fuel cell motorcycle and V_g is the smallest garage capacity (3.56 m³). Therefore, it is a reasonable requirement that 23 L is the maximum capacity for fuel cell motorcycles. This requirement is stated in Japanese regulations.

2.2. Types of Hydrogen Containers

Compressed hydrogen containers can be categorized into four types [12,13]. Type I and II are traditional steel containers that are primarily used for storing natural gas. Type III and IV are carbon fiber full-wrapped cylinders which have been developed and researched for use in HFCVs because their maximum allowable pressure is higher than that of Type I and II containers. Hydrogen gas stored in Type III and IV containers can be compressed up to 70 MPa, thereby enabling long-distance driving and making HFCVs comparable to conventional vehicles in this regard. Type III and IV containers will also be useful for the commercialization of fuel cell motorcycles.

It is necessary to complete refueling of the hydrogen gas within few minutes for user convenience. However, the pressure in the container increases to 70 MPa from several MPa in few minutes. Such a high-pressure ramp rate induces a rapid increase in the temperature of the hydrogen gas inside the container. To avoid compromising the structural integrity of the hydrogen gas storage system, the temperature of this gas must be restricted to less than 85 °C [14,15].

To avoid temperatures higher than 85 °C inside the container during the refueling process at hydrogen stations, the supplied hydrogen gas needs to be pre-cooled. The temperature of the supplied hydrogen gas is gradually decreased by the pre-cooled system due to heat exchange through pipes, nozzles, hose, and other components in the hydrogen gas supply line. Therefore, the hydrogen gas at an initial filling is not sufficiently cooled. The ratio of the initial filling to the total filling inevitably becomes large in a small container. Therefore, there is great concern that the hydrogen gas temperature in a small container rises significantly compared to the gas temperature in a large container.

Hiraki et al. experimentally investigated the temperature changes inside small Type III and IV containers during hydrogen filling [16]. The liner materials of the Type III and IV containers are metal and plastic, respectively. Since the heat capacity of the metal liner is large, an increase in the temperature of the hydrogen gas in Type III containers is moderate compared to the increase in the temperature of the hydrogen gas in Type IV containers. These experimental results show that the Type III container (with the metal liner) has a considerable thermal advantage with regard to hydrogen filling. It is difficult to refuel Type IV containers with hydrogen gas in a few minutes under high ambient temperature while maintaining the temperature of the hydrogen gas below 85 °C.

From a safety point of view, it is appropriate to use Type III containers in fuel cell motorcycles for now. Therefore, Japanese regulations only permit Type III containers for use in fuel cell motorcycles.

2.3. Thermally Activated Pressure Relief Device

To immediately discharge compressed hydrogen gas in the event of a fire accident, it is required to install a thermally activated pressure relief device (TPRD) on the containers of HFCVs. Installing a TPRD is necessary for small and large containers. When the TPRD is activated, a hydrogen flame is formed immediately in the discharge direction. Therefore, it is important for first responders to identify the direction of the hydrogen gas discharge from the TPRD. In UNR No. 134 excluding motorcycles, the direction of the hydrogen gas discharge from the TPRD is specified. The hydrogen gas discharge to forward from the vehicle, or horizontally (parallel to road) from the back or sides of the vehicle is not permitted by UNR No. 134.

However, motorcycles are generally overturned in accidents. Thus, it is necessary to further restrict the discharge direction. The direction of the hydrogen gas discharge is specified in Japanese regulations. The hydrogen gas discharge from a TPRD attached to a fuel cell motorcycle shall not be directed in any orientation other than perpendicularly outward from the bottom of the body of the vehicle, as shown in Figure 2.

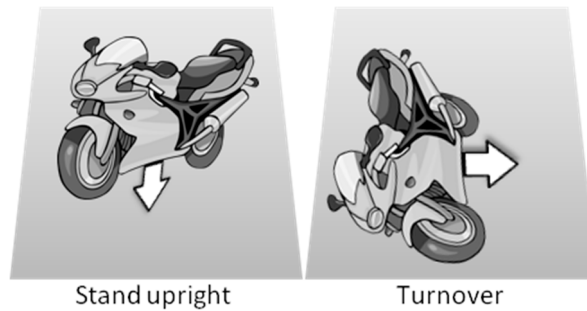


Figure 2. Direction of gas discharge from a thermally activated pressure relief device.

2.4. Protection of Hydrogen Containers

If a fuel cell motorcycle incorporating a compressed hydrogen storage system encounters an accident, it is important to appropriately protect the onboard container to avoid container rupture. If a motorcycle overturns, there is concern that its container might come into direct contact with something.

Therefore, Japanese regulations state that the container shall not be in contact with the road surface, or even in direct contact with any other component of the vehicle (with the exception of protective devices), in the event of a crash, rear-end collision, etc.

Post-crash fuel system integrity is required for hydrogen-fueled vehicles incorporating compressed hydrogen storage system, excluding motorcycles, which is stated in UNR No. 134. In case, that the vehicle crash tests are not applicable to the vehicle. The vehicle fuel system shall instead be subject to the relevant alternative accelerations. Crash tests are not necessary for motorcycles, therefore it is appropriate to apply an alternative acceleration test.

The strength of the attachment of the container shall be verified by the alternative acceleration test, where a specific acceleration is applied to the container attached to the vehicle on a loading platform. The container shall remain attached to the vehicle with a minimum of one attachment point and stay within the installed location after the acceleration test. The acceleration values used in the test were obtained from the frontal and lateral collision tests shown in Figure 3. In the frontal collision test, a motorcycle collided with the side of a car. In the lateral collision test, the car collided with the side of the motorcycle. The collision speed indicated in the figure is based on accident statistics involving motorcycles in Japan over the past 10 years.

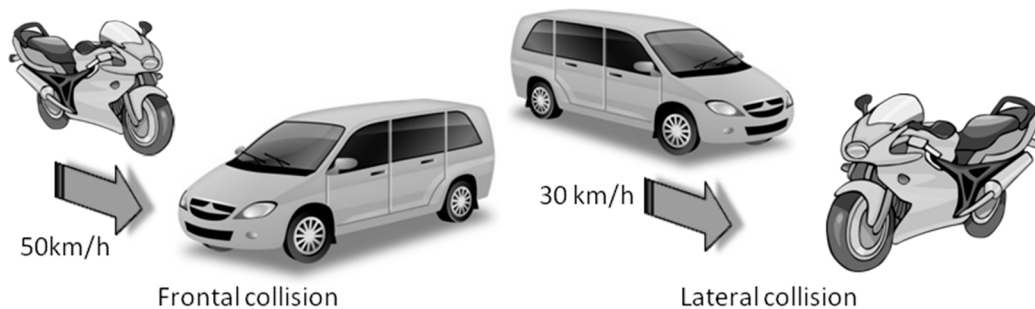


Figure 3. Collision tests between motorcycles and cars.

The collision tests provided the acceleration values to verify the strength of container attachment. The acceleration values in the direction of travel (forward and rearward direction) and in a direction

that is horizontally perpendicular to that of travel (left and right) were 426 (43.5 g) and 617 (63 g) m/s², respectively. These acceleration values are considerably large because motorcycles are light in weight. In UNR No. 134, acceleration values in the direction of travel and in a direction that is horizontally perpendicular to that of travel are 20 g and 8 g, respectively, for vehicles of category M1, which are power-driven vehicles having at least four wheels and used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.

3. Conclusions

The Japanese technical regulations for hydrogen-fueled motorcycles, which are different from those for four-wheeled vehicles, were summarized. The unique characteristics of motorcycles, such as their small body, light weight, and tendency to overturn easily, were considered in these regulations.

After thorough consideration, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) enacted and published safety regulations for hydrogen fuel cell motorcycles in February 2016 [17]. Then, the Ministry of Economy, Trade and Industry (METI) enacted and published technical regulations for compressed hydrogen containers for motorcycles in May 2017 [18]. Technical regulations on hydrogen safety for fuel cell motorcycles, including those mentioned above, have been proposed internationally. After the discussion, the new UNR No. 146 (Hydrogen and fuel cell vehicles of category L) was enacted in January 2019 [19].

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