Hydrogen and Fuel Cell Vehicles UN Global Technical Regulation No. 13: Latest Updates Reflecting Heavy Duty Vehicles

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Abstract

This paper provides a detailed technical description of the United Nations Global Technical Regulation No. 13 (UN GTR #13), 1998 Agreement and contracting party obligations, phase 2 activity and safety provisions being discussed and developed for heavy duty hydrogen fuel cell vehicles.

Background

The development of the UN GTR #13 for Hydrogen and Fuel Cell Vehicles [1] occurred within the World Forum for Harmonization of Vehicle Regulations (WP.29) of the Inland Transport Committee (ITC) of UNECE. The goals of this document are to develop and establish a GTR for hydrogen-fueled vehicles that: (i) attains or exceeds the equivalent levels of safety of those for conventional gasoline fueled vehicles; and (ii) is performance-based, data driven and does not restrict future technologies.

The GTR is being developed in two phases:

(a) **Phase 1** (completed): GTR was established in 2013 for light duty (LD) hydrogen-fueled vehicles based on a component, system and vehicle-level requirements. The GTR specifies in-use and post-crash safety provisions for compressed gaseous hydrogen and liquified hydrogen systems.

1. Performance requirements for hydrogen storage systems, high-pressure closures, pressure relief devices, and fuel lines;
2. Electrical isolation, safety and protection against electric shock (in use); and
3. Performance and other requirements for subsystem integration in the vehicle.

(b) **Phase 2** (on-going): Amend the GTR to maintain its relevance with new findings based on new research and the state-of-the-art technology beyond phase 1. Phase 2 also includes other vehicle classes, specifically, heavy duty (HD) vehicles.

Nikola Motor is producing the world's first commercial, zero-emission hydrogen heavy duty Class 8 fuel cell electric trucks that have the same fast fueling, long driving range, and power performance as conventional diesel trucks. Nikola is supportive of the GTR phase 2 activities and has been an active member of and contributor to the GTR development process.

The 1998 Agreement and Contracting Party Obligations

The purpose of the 1998 Agreement is to establish a global process by which Contracting Parties (CPs) from all regions of the world can jointly develop GTRs regarding the safety, environmental protection, energy efficiency, and anti-theft performance of wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles. The GTR will establish high levels of safety and reduce technical barriers to international trade. In developing GTRs, objective consideration is given to the analysis of best available technology, science and performance-based, data driven, and relative benefits and cost effectiveness. The GTR development process is transparent.

A Contracting Party that votes in favor of establishing a global technical regulation under Article 6 of the 1998 Agreement shall be obligated to submit the GTR to the process used by that Contracting Party to adopt such a GTR into its own laws or regulations and shall seek to make a final decision expeditiously. The European Union has already taken this step by adopting phase 1 into a regulation (UN ECE R134) [2].

GTR Phase 1 Requirements

Hydrogen Storage System

The GTR applies to hydrogen storage systems (storage and primary valves) having nominal working pressures (NWP) of 70 MPa or less, with an associated maximum fueling pressure of 125 per cent of the NWP. Systems with NWP up to 70 MPa include storage systems currently expected to be of commercial interest for vehicle applications. In the future, if there is interest in qualifying systems to higher NWPs, the test procedures for qualification will be re-examined.

The GTR applies to fuel storage systems securely attached within a vehicle for usage throughout the service life of the vehicle. It does not apply to storage systems intended to be exchanged in vehicle fueling.

The performance test requirements for all compressed hydrogen storage systems in on-road vehicle service are specified in paragraph 5.1 of the GTR. The performance-based requirements address documented on-road stress factors and usages to assure robust qualification for vehicle service. The qualification tests were developed to demonstrate capability to perform critical functions throughout service including fueling/defueling, parking under extreme conditions, and performance in fires without compromising the safe containment of the hydrogen within the storage system. These criteria apply to qualification of storage systems for use in new vehicle production.

Hydrogen Fuel System

The GTR provides in-use requirements for the vehicle's fuelling connection point (fueling receptacle) and labelling. It also sets requirements to prevent over pressure in the low-pressure system due to the possible failure of the pressure regulator. Vent lines of storage discharge systems (TPRDs and PRVs) must be protected by a cap to prevent blockage by intrusion of objects such as dirt, stones, and freezing water and the discharge itself cannot be ignitable. In addition, the GTR specifies that any single failure downstream of the main hydrogen shut off valve shall not result in any level of hydrogen concentration in air anywhere in the passenger compartment. Furthermore, the vehicle is required to provide a warning if unintended leakage of hydrogen reaches flammable concentrations.

The GTR provides allowable post-crash leakage for fuel system integrity in vehicle post-crash conditions but does not specify vehicle crash conditions. Contracting Parties to the 1998 Agreement are expected to execute crash conditions as specified in their national regulations.

Electric Safety Requirements and Safety Needs

In-use electrical safety requirements which must be considered when the fuel cell vehicle is engineered are specified to avoid any electric hazard to passengers of an electric vehicle. The requirements focus on the electric powertrain operating on high voltage as well as the high voltage components and systems which are galvanically connected. To avoid electrical hazards, it is required that live parts (conductive part(s) intended to be electrically energized in normal use) are protected against direct contact.

The GTR establishes post-crash safety conditions for high voltage components including rechargeable batteries and fuel cells. These safety conditions are based on international standards and regulations.

GTR Phase 2 Requirements: Heavy Duty Vehicles

The GTR phase 2 goals include modifications of requirements and improvements of test procedures based on available test data and current technology. The GTR scope will expand to include HD vehicles in which some of the significant safety requirements being considered consist of container durability and on-road performance, permeation, fire safety, container harness and fueling receptable. Wherever possible the HD requirements for safety will be aligned with those for LD vehicles. The following discussion identifies the latest approaches being considered and should, therefore, not be construed as the final resolution to the new requirements related to HD vehicles.

Container Durability and On-Road Performance

Although the durability performance test requirements for hydrogen fuel systems for HD vehicles will not likely deviate from those specified for LD vehicles, there are a few performance metrics that will require adjustment to account for the unique duty cycles of HD vehicles. For example, HD vehicles will refuel more frequently than LD vehicles due to the commercial aspects of their role.

In phase 1 of the GTR, fueling frequency data from LD personal use cars and fleet vehicles such as taxis were used to determine fuel system (vehicle tank) pressure cycle life [3]. The minimum requirement for demonstration of resistance to leakage was determined to be 5,500 cycles. This was based on a 6 sigma value of lifetime fuelings (1,833 fills) multiplied by a safety factor of 3. An analysis of vehicle fleet data (taxis) yielded maximum lifetime fueling of 3,100 to 6,000 fills, which correlate well with the 5,500 pressure cycle life assumption based on light duty frequency [4]. Phase 1 also allows CPs to select a minimum pressure cycle life of 5,500, 7,500 or 11,000 cycles because of the potential differences in the expected worst case lifetime vehicle range and fueling frequency in different jurisdictions. Note the 11,000 cycle minimum represents a 6 times factor of safety for LD personal use vehicles, and a 2 times factor of safety for LD vehicles operating in a commercial environment. The former safety factor is an astoundingly high bar, and may be considered excessive and design restrictive against certain metal-lined composite tanks. This is particularly unfortunate because onboard vehicle fuel tanks never fail in service via leakage.

For the case of HD vehicle applications where usage is expected to be commercial in nature involving similarly high filling frequencies, the current thinking for phase 2 pressure cycle life is 11,000 cycles.

As indicated earlier, the evaluation of vehicle fuel systems is based on hydraulic and pneumatic test procedures which simulate a lifetime of stressors on the tank. The final end-of-life requirement for the hydraulic test sequence involves a demonstration that the single tank exhibit a minimum 1.8 times safety factor on burst integrity. For the case of the pneumatic test sequence, instead of testing a single tank, the entire fuel system is evaluated through a sequence of 500 hydrogen gas cycles at different ambient temperatures. Since LD fuel systems typically contain less than 10 kg of hydrogen, the gas cycle filling and emptying sequence can be accomplished in a reasonable amount of time (less than 3 months). This is not the case for HD vehicles, which contain upwards of 80 kg of hydrogen. Filling and emptying such a system in a reasonable period of time is extremely challenging. Very few test labs in the world have the capability to fuel such systems to 87.5 MPa in 10 -15 minutes. For this reason, phase 2 is considering the addition of specific language which will allow manufacturers to evaluate a smaller subsystem as defined by the concept of repeating elements. In other words, if the HD fuel system is comprised of numerous identical tanks filled in parallel, then the pneumatic sequential test may be conducted on a single tank fuel system.

Fuel System Permeation

Hydrogen gas is expected to permeate through the walls of plastic materials such as the tank liners of all-composite tanks and through O-rings seals. Fuel system permeation is defined to eliminate the risk factor for fire hazards in confined spaces such as vehicle garages. The permeation limit is defined to restrict the hydrogen concentration from exceeded 25% of the lower flammability limit by volume (1% concentration in air). Using a low air exchange rate of 0.03 volumetric air exchanges per hour (assuming a tight vehicle garage consisting of a tight wood frame structure), the resultant permeation limit is determined to be 46 ml/h/L water capacity for each tank in the fuel system.

Although HD vehicles will have significantly larger volume fuel systems, it is believed that the same permeation limit as LD vehicles is conservatively scalable to HD vehicles. Since HD vehicles are expected to be operated in more open (naturally-ventilated) or mechanically-ventilated spaces, the 46 m L/h/L water capacity requirement for fuel system tanks provides reasonable margin in the event of mechanical ventilation failures.

Fire Safety

Phase 1 vehicle fire safety is validated using a localized/engulfing fire test methodology that confirms the LD fuel system's ability to vent its entire contents during exposure to a representative flame temperature profile v. time. The flame temperature v. time profile was specifically developed for LD vehicles as it was based on LD vehicle fire test data from the Japanese Automobile Research Institute and U.S. vehicle manufacturers [5]. One of the key issues with the specified flame temperature profile is that it does not consistently guarantee the same heat input for each fuel system configuration. There has been reported lab-to-lab test result variability with the current test procedure. Accordingly, phase 2 considerations may include specifying heat flux in addition to flame temperature v. time, and/or completely defining the test apparatus including fuel flow rate, burner tip diameter, etc. Other considerations specific to HD vehicles will include extending the size of the fire exposure and increasing the duration of the test to be more in line with larger HD fuel system installations.

Tank Installation/Crash Testing

Fuel system and tank installation requirements related to geometric positioning were not specified in phase 1 of the GTR since they can be restrictive, not performance-based and provide no additional benefit to crash safety. Phase 2 will carry over the same rationale.

The phase 1 GTR specifies that each CP will use its existing national crash tests where LD vehicle crash tests are required. Currently, there are no crash-worthiness requirements in the US and Europe for HD vehicles, and so phase 2 is hesitant to consider adopting new requirements for crash testing. There is discussion at phase 2 regarding the use of simulation to replace compliance tests, but some CPs do not utilize simulations to confirm compliance. For example, the Department of Transportation National

Highway Traffic Safety Administration [6] and Transport Canada [7] conducts compliance tests based on test procedures that are well-defined for repeatability. Vehicle manufacturers in these jurisdictions are under the self-certification process and can self-certify their vehicles using simulation or analysis and therefore do not necessarily need to conduct an actual crash test.

Fueling Receptacle

The fueling receptacle profile for LD vehicles is defined in standards ISO 17268 and SAE J2600. These documents ensure that LD FCEVs of higher NWP can be fitted with fueling station nozzles operating at NWPs equal to or lower than the vehicle being fueled and not vice versa. In addition, this approach ensures that vehicles fueled by other gaseous fuels are not fueled by hydrogen filling stations. The phase 1 GTR recognizes these safety requirements. In order to consider new connector technologies that will be required to fuel HD vehicles (up to 80 kg in 10-15 minutes), the phase 2 GTR is considering the addition of language that will allow a different receptacle geometry if it can be shown that the new design provides, at a minimum, the same level of safety and interoperability as the design shown in the aforementioned connector standards. Although it is likely that ISO 17268 and SAE J2600 documents will be modified to account for new HD (high flow) receptacle designs, the proposed language allows for the use of these solutions until these documents are updated.

Conclusions

The GTR #13 phase 2 activity is currently on-going with a mandate of completion date by end of 2021. The scope of the GTR has been expanded to include HD vehicles. The working group is developing provisions to ensure safe operation of HD vehicles while maintaining the principles of the GTR. Due to components that have similar function and operation, some of the requirements for HD vehicles are being adopted directly from those of LD vehicles. However, remaining requirements are still being discussed and developed. Additional research and test data might be required to ensure the requirements are well-justified with objective and repeatable test procedures. The GTR working group is expected to make significant progress in the next year in order to meet the challenging GTR mandate. The presentation at the 8th International Conference on Hydrogen Safety will provide an update on the progress of the GTR working group.

References

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6. United States – Federal Motor Vehicle Safety Standard (FMVSS) No. 301 - Fuel System Integrity.
7. Transport Canada – Canadian Federal Motor Vehicle Safety Standard (CMVSS) No. 301 – Fuel System Integrity.