

Developing Safety Standards for FCVs and Hydrogen Vehicles

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ABSTRACT

The SAE FCV Safety Working Group has been addressing fuel cell vehicle (FCV) safety for over 8 years. The initial document, SAE J2578, was published in 2002. SAE J2578 has been valuable to FCV development with regard to the identification of hazards and the definition of countermeasures to mitigate these hazards such that FCVs can be operated in the same manner as conventional gasoline internal combustion engine (ICE)-powered vehicles. J2578 is currently being updated to clarify and update requirements so that it will continue to be relevant and useful in the future.

An update to SAE J1766 for post-crash electrical safety was also published to reflect unique aspects of FCVs and to harmonize electrical requirements with international standards.

In addition to revising SAE J2578 and J1766, the Working Group is also developing a new Technical Information Report (TIR) for vehicular hydrogen systems (SAE J2579). The initial focus of this document is compressed hydrogen, as most FCVs currently use this form of storage. Systems-level, performance-based requirements are being established to demonstrate that hydrogen can be safely contained within the storage system for the life of the vehicle. It is envisioned that the TIR will serve as a basis for verification of the test methodologies and then, after a couple years, the document can be upgraded and published as a Recommended Practice. The objective of this approach is to address long-term real-world system safety while still facilitating rapid advances by the industry.

DESIGN FOR SAFETY

The automotive industry is applying design practices developed over the past 100 years to ensure that FCV development and commercialization is successful and safe. Under normal and anticipated driving and vehicle scenarios, the vehicle and associated subsystems are designed with the objective that foreseeable single-point hardware or software failures do not result in an unreasonable safety risk to any person or uncontrolled vehicle behavior. As a result, potential single-point failures are managed with fail-safe designs, redundancy, and/or additional safety margins to provide reasonable assurance that a component will not cause a hazardous situation.

SAE J2578 and J2579 recommend use of risk analyses tools such as failure mode and effects analysis (FMEA) to investigate the impact of potential faults. Foreseeable single-point failures that could result in a hazardous situation should be detected and mitigated. When necessary, a staged warning and shutdown procedure is to be implemented to mitigate potential hazards by isolating vehicle propulsion systems and occupants from the stored hydrogen and high voltage electrical energy.

ADDRESSING COMPRESSED HYDROGEN STORAGE ON VEHICLES

Since isolation of stored hydrogen is a key aspect of failure management, the SAE Safety Working Group identified components that form the primary pressure boundary for the stored compressed hydrogen. For the example illustrated in Figure 1, the subsystem (defined as the Compressed Hydrogen Storage System or CHSS) includes the thermally-activated pressure relief device (PRD), the fuel shutoff, and the fill check valve in addition to the hydrogen container (tank) itself.

The CHSS isolates hydrogen by --

- 1) closing the container isolation valve and preventing flow to downstream systems and the fuel cells,
- 2) preventing leakage through the PRD(s) and fill check valve(s), and
- 3) minimizing over-board leakage and permeation from the hydrogen container(s) as well as all other components and interconnections in the CHSS.

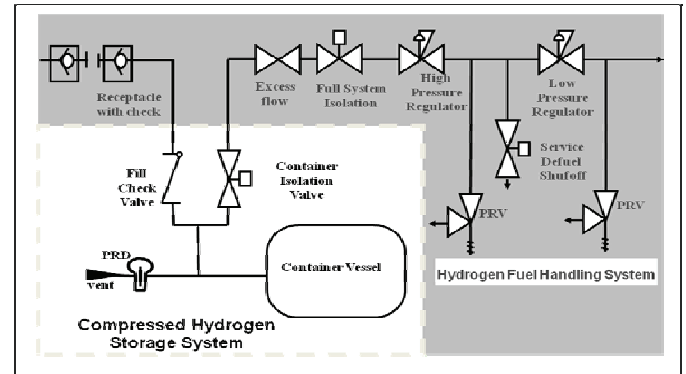


Figure 1. Example of a Compressed Hydrogen Storage System (CHSS)

SYSTEMS-LEVEL, PERFORMANCE-BASED REQUIREMENTS FOR THE COMPRESSED HYDROGEN STORAGE SYSTEM

The Compressed Hydrogen Storage System (CHSS) should be designed to provide acceptable leakage/permeation without burst throughout the vehicle's expected service life.

Performance requirements for the CHSS are derived from a systems-level understanding of vehicle requirements. The SAE Safety Working Group is cooperating with CSA in North America and the Japanese Automobile Research Institute (JARI) to integrate the new perspective with tests developed by compressed natural gas (CNG) and compressed hydrogen experts to provide a robust and comprehensive set of verification tests. The verification tests are organized to evaluate --

- 1) system performance over expected service conditions,
- 2) durability under harsh conditions and extended use, and
- 3) the absence of rupture under service-terminating conditions.

In order to qualify CHSS, the system should be manufactured in a manner that is representative of normal production. The entire CHSS should be evaluated unless a specific test specifies otherwise or, in the case of multiple container systems, there are repeating elements that would necessitate verification of only one of these elements.

The verification test to evaluate performance over expected service conditions includes both pressure cycling over the full range of ambient temperature (from -40°C to +50°C) and long static holds at full pressure and elevated temperature representative of radiant heating on hot days (+85°C). By so doing, both cycle fatigue and stress fatigue phenomena are evaluated. Additionally, the tests are conducted with hydrogen as the test gas so the full impact of adiabatic compression heating during rapid fuel fills and de-compression cooling during prolonged acceleration are included as part of the accumulated exposure.

The test sequence for evaluation of expected service life is as follows:

- Routine Production Quality Tests
 - Extreme-Temperature Gas Cycling (Evaluating Fueling/Operation)
 - Extended Static High Pressure Gas Test (Evaluating Parking)
 - Extreme-Temperature Gas Cycling (Evaluating Fueling/Operation)
 - Extended Static High Pressure Gas Test (Evaluating Parking)
 - Gas Leak/Permeation Test
 - Pressure Proof Test at 180% NWP
 - Residual Strength Burst Test

Following the pressure cycling and static hold stress testing, hydrogen leakage/permeation, proof pressure capability, and residual burst pressure capability tests are performed to demonstrate acceptability of the system over the expected service life.

The verification test to evaluate durability under harsh conditions and extended use includes exposure to mechanical and chemical “abuses” followed by pressure cycling. The pressure cycling is conducted hydraulically so that a large number of cycles (at least 3 times expected) can be evaluated in a short period of time. The test sequence is as follows:

- Routine Production Quality Tests
 - Drop Test
 - Surface Damage & Chemical Exposure
 - Ambient Temperature Pressure Cycling Tests
 - Proof Pressure Test at 180% NWP
 - Residual Strength Burst Test

As with the expected service tests, a proof pressure test and a residual strength burst test are conducted after “abuses” and pressure cycling to demonstrate acceptability.

The following service-terminating tests are currently planned:

- 1) engulfing fire (bonfire) to demonstrate that the PRD(s) can protect the CHSS system from burst,
- 2) penetration tests to demonstrate robustness of the wrap, and
- 3) burst (and perhaps other) tests to show consistency within the verification batch and to future production.

In summary, as illustrated in Figure 2, the purpose of the tests is to demonstrate that the *capability* of the CHSS exceeds the *demands* of vehicle service such that the probability of failure is unlikely. The test methodologies will be evaluated globally by development partners such as JARI, automobile and equipment manufacturers, and test laboratories using a combination of private and government funding. In North America, the US Department of Energy (DOE) is funding a test program to demonstrate the practicality and verify the appropriateness of the new systems-level, performance-based test methodologies. Following verification, SAE J2579 will be updated and re-published as a recommended practice.

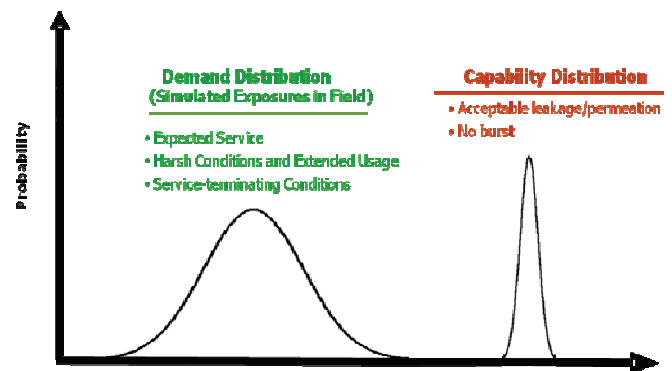


Figure 2. Verification of the Compressed Hydrogen Storage System

CRASH

Electrical and fuel system hazards in FCVs need to be managed in a manner similar to other vehicles. When an accident is detected by the vehicle crash sensors, fuel flow should be automatically shutoff and high voltage electrical