Testing and Qualification of PRESSURE SENSORS for Use in Hydrogen Applications

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As the use of hydrogen increases in the processes associated with the petroleum industry, material handling, stand-by power generation, and surface transportation, new certifications and qualifications are being mandated for safe use and storage of hydrogen. Hydrogen, as the lightest element in the universe, must be handled with care, with steps taken to avoid fatality as a result of permeation and embrittlement. For safety, several industries and markets utilizing hydrogen in their processes have mandated certain testing and approvals before components, such as sensors, tubing, storage tanks, valves, regulators and fuel cells, can be used on a specific piece of equipment.

In the automotive and surface transportation applications, pressure sensors used as components for hydrogen are covered under European Integrated Hydrogen Project (EIHP), Society of Automotive Engineers (SAE) and Japanese Automotive Research Institute (JARI) mandates. For industrial applications, Underwriter Lab (UL), Canadian Standards Association (CSA), and Technischer Überwachungsverein (TUV) dictate the standards on national safety codes such as National Electrical Code (NEC), National Fire Protection Association (NFPA), and Canadian Electrical Codes (CEC). UL, CSA, and TUV can also perform the necessary testing and certification process for all markets.

Automotive and Surface Transportation Using Hydrogen Fuel

Europe has been the front-runner in regards to the use of hydrogen as a fuel carrier for cars, buses, and lights trucks. EIHP was established to help promote hydrogen technology and applications to increase the competitiveness of European companies. Since then, both SAE and JARI have adapted the EIHP practice for hydrogen safe use and storage. The first phase of EIHP included the drafting of safety-related specifications and requirements of hydrogen systems and components. Pressure sensors for 20 Bar (290 psi), 448 Bar (6500 psi) and 900 Bar (13,000 psi) systems must be tested to ECE (Draft) Regulation TRANS/WP.29/GRPE/2004/3 dated 31 October 2003 (EIHP Draft Rev. 12b) and TRANS/WP.29/GRPE/2004/3/Add.1 dated 23 March 2004 for on-board storage systems of compressed hydrogen fuel in vehicles. EIHP II is underway, with the draft becoming a permanent mandate by 24 Feb 2011. After this date, national authorities will not allow any new component into service that is not clearly marked that it has met the EIHP test and qualifications requirements.

Testing and qualifications for safe hydrogen service can be conducted by TUV SUD Automotive GmbH. The tests are performed and witnessed by TUV as shown in *Table 1*. Once testing is completed and no failures are found, TUV will issue a Type approval Reference Number that must be included on the label of the pressure sensor prior to shipment.

Table. 1 Tests Conducted to meet EIHP

No	Test	ECE Reverence Annex 8
1	Hydrogen Compatibility	B1
2	Aging Test	B2
3	Corrosion Resistance Test	B4
4	Endurance Test	B5
5	Pressure Cycle Test	B6
6	External Leakage Test	B8
7	Hydraulic Strength	
8	Isolation Resistance	
9	EMC/RFI Compatibility	

Hydrogen Forklifts

The hydrogen forklift market is expanding and will replace lead-acid batteries due to productivity and cost. Fuel cell forklifts offer many benefits over the traditional lead-acid batteries such as:

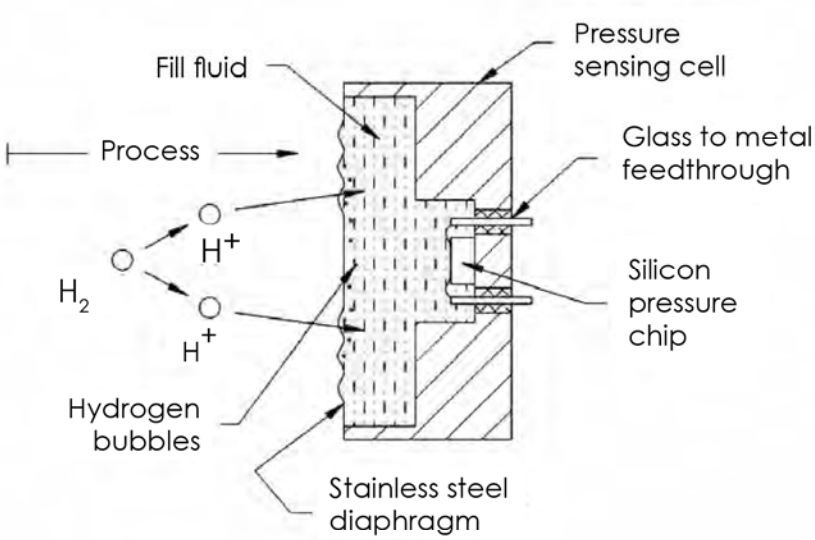
- Environmental benefit: Hydrogen fuel cell systems do not emit pollutants. For forklifts used indoors, this helps create a cleaner and healthier working environment.
- Disposal of lead-acid batteries would be eliminated, creating a cleaner environment.
- Longer life: A hydrogen fuel cell pack can last 10 to 12 years versus up to 5 years for a lead-acid battery. Maintenance costs are also expected to be lower for the fuel cell packs.
- Refueling is faster than charging: The hydrogen fueling station is easy to operate. Filling the fuel cell pack, typically 3000 to 5000 psi, takes only two to five minutes. Changing a battery can take seven minutes, and recharging and cooling it takes approximately 15 to 17 hours. A factory running 24 hours can reduce the number of required forklifts because they do not have a wait time for battery charges.
- Extended run-time between fills: A completely filled hydrogen fuel cell forklift can run for about 18 hours while the plant is in full production. A battery-powered forklift runs for approximately four to six hours before the battery must be recharged.
- Consistent and better power: As a lead-acid battery loses power, the forklift will slow down. There is no slowdown with the hydrogen fuel cell. The forklift operates at 100% power all the time, and drivers can refill the unit whenever they want.

For certifications, UL standard UL2267 or CSA HPIT 1, subject to end-user requirements, are used to certify the fuel cell truck. Pressure sensors used on the hydrogen tank and fuel cells are also tested for ordinary or hazardous location, subject to the environment where the truck will operate. If the pressure sensors are already approved from a reputable supplier with 316L stainless steel wetted parts, some of the testing can be waived due to prior approvals.

Media Compatibility of Hydrogen

Part of compliance to EIHP, TUV, UL, and CSA standards involves media compatibility because of the effects of hydrogen permeability and embrittlement. The pressure sensor manufacturer needs to select the correct, cost-effective sensor material to ensure long, trouble-free service in hydrogen. Most pressure sensors offer stainless steel wetted parts. However, it should be noted, that not all steels are compatible with hydrogen. High-strength stainless martensitic

Fig. 1 Cross section of oil-filled sensor with thin sensing membrane with hydrogen leak path



steels such as 17-4PH and 15-5PH should be avoided since they are highly embrittle in hydrogen. Austenitic steels such as 316L with low carbon content are well suited against hydrogen embrittlement. The molybdenum and high nickel content, together with high stacking fault energy, makes 316L the ideal cost effective material for pressure sensors.

Another failure mechanism in pressure sensors is permeation as a result of this sensing membrane. Oil-filled pressure sensors that employ a very thin isolation diaphragm, typically 0.025 mm (0.001") in thickness, will allow hydrogen + ions to escape through it. As thickness increases, to say 0.18 mm (0.007"), the permeation tends to stop, subject to the operating temperature. Fig. 1 shows hydrogen permeation through thin sensor membrane.

H_2-H_2S Service in the Oil & Gas Industry

The recovery of oil from bituminous sands and deep below the ground poses a challenge for pressure sensors due to the severe erosion of metals associated in the presence of temperature, Hydrogen (H_2) and Hydrogen Sulfide (H_2S). As the world runs out of low sulfur oil, oil companies are racing to develop new sources for petroleum, which is not easy to process. Here, the need for better corrosion-resistance materials and extended testing is required to withstand material erosion in the presence of H_2-H_2S. Materials with high levels of cobalt, nickel, and chromium with small quantities of molybdenum, aluminum, and tungsten are being developed to minimize erosion. While the National Association of Corrosion Engineers (NACE) specifies materials that can be used for H_2S service, there is no mention of H_2-H_2S service. While UL, CSA, and TUV can test the pressure sensors for area classifications such as Class 1, Zone 0 & 1 Groups B, C and D, the effects of material loss due to erosion must be taken into account based on the material composition, operating temperature, and concentration of H_2 and H_2S.