Available onlinewww.ejaet.com

European Journal of Advances in Engineering and Technology, 2021, 8(11):86-90

Research Article ISSN: 2394-658X

Enhancing Safety and Efficiency: Technical Study of On-Tank Valve (OTV) for Hydrogen Fuel Cell Electric Vehicles (FCEVs)

Vinay Nagarad Dasavandi Krishnamurthy

Software Engineer
Bosch USA
Michigan- USA
vinayndk9@gmail.com

ABSTRACT

The efficient storage and utilization of hydrogen as a clean energy source necessitates advanced tank valve systems that ensure safety, reliability, and practicality. This abstract delves into the intricate design, operation, and optimization of tank valve mechanisms tailored specifically for hydrogen storage applications. Drawing from interdisciplinary research in materials science, mechanical engineering, and hydrogen technology, it examines key factors such as valve material compatibility, leakage prevention, and pressure regulation techniques.

Keywords: OTV, FCEV, Emergency flow valve, TPRD

INTRODUCTION

The transition to hydrogen as a clean energy source necessitates not only advancements in production and utilization but also in the safe and efficient storage of this highly versatile fuel. Central to this endeavor are the on-tank valves (OTVs), critical components that manage the flow of hydrogen within fuel cell electric vehicles (FCEVs). This paper presents a comprehensive technical exploration of OTV systems tailored explicitly for hydrogen storage applications. By delving into the intricate design, operation, and optimization of OTVs, this study aims to contribute to the ongoing efforts to realize the full potential of hydrogen as a sustainable energy carrier.

The burgeoning interest in hydrogen as a key player in the transition towards a low-carbon economy underscores the urgency of developing robust and reliable OTV systems. These valves serve as the interface between the hydrogen storage tank and the vehicle's fuel cell system, regulating the flow of hydrogen with precision and safety. Given the unique properties of hydrogen—its high flammability, propensity to embrittle materials, and susceptibility to pressure fluctuations—designing OTVs that can withstand the demands of real-world applications is a multifaceted challenge.

Drawing from interdisciplinary insights in materials science, mechanical engineering, and hydrogen technology, this paper navigates through the myriad considerations that underpin the design and implementation of OTV systems. From material selection and pressure regulation techniques to safety features and regulatory compliance, each aspect is meticulously ex amined to elucidate the complexities involved in achieving optimal performance and reliability.

Key to the design of OTVs is the seamless integration of safety features and operational efficiency. The adoption of advanced materials, such as aluminum alloys, and innovative sealing mechanisms, like metal-to-metal and O-ring seals, ensures compatibility with hydrogen and enhances durability under demanding operating conditions. Moreover, the incorporation of pressure relief valves, thermal protection systems, and fail-safe mechanisms safeguards against over-pressurization and other potential hazards, thereby bolstering the safety profile of FCEVs.

LITERATURE REVIEW

A. Working of On-Tank Valve The basic working principle of an on-tank valve (OTV) for hydrogen involves the controlled opening and closing of the valve to regulate the flow of hydrogen from the storage tank to the fuel cell system of a vehicle. A solenoid is commonly used to actuate the valve, and its energization and de-energization play a pivotal role in this process. Here's an overview of the basic working of an OTV with solenoid actuation:

[1].Initial State (Valve Closed):

When the OTV is in its default or closed state, the solenoid is de-energized, and the valve mechanism remains sealed, preventing the flow of hydrogen from the storage tank.

[2].Energization of Solenoid:

To initiate the flow of hydrogen, an electrical signal is sent to the solenoid, causing it to energize. The energized solenoid generates a magnetic field, which exerts a force on the valve mechanism, typically a plunger or piston, overcoming any spring tension or other mechanisms that keep the valve closed. As a result, the valve mechanism is lifted or moved, creating an opening that allows hydrogen to flow from the storage tank through the valve and into the fuel cell system.

[3].Hydrogen Flow:

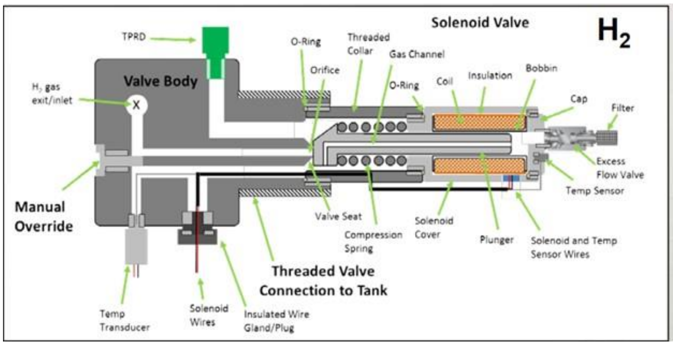

Figure 1: Basic Structure of On-Tank Valve

With the valve opened by the energized solenoid, hydrogen flows through the valve and into the fuel cell system, where it undergoes chemical reactions to produce electricity for powering the vehicle's motor or other applications.

[4].De-energization of Solenoid: –

When the flow of hydrogen is no longer required, the electrical signal to the solenoid is interrupted or reversed, causing it to de-energize. As the solenoid de-energizes, the magnetic field dissipates, and the force holding the valve mechanism open diminishes. Depending on the design of the valve, there may be additional mechanisms such as springs that assist in closing the valve once the solenoid is de-energized. The valve mechanism returns to its default position, sealing off the flow of hydrogen from the storage tank, thereby ensuring safety and preventing leaks.

[5].Safety Features:

In addition to solenoid actuation, OTVs often incorporate safety features such as manual overrides, temperature/pressure relief devices (TPRDs), and excess flow valves to enhance operational safety and reliability. These safety features provide redundancy and fail-safe mechanisms to mitigate risks associated with hydrogen handling, such as over-pressurization, temperature fluctuations, or sudden increases in flow rate.

DESIGN CONSIDERATIONS OF OTV

The design of an on-tank valve for hydrogen is a crucial component in ensuring the safe and efficient storage and utilization of hydrogen fuel. Here are some intricate details that are typically considered in such a design:

[1]. Material Selection: The valve must be constructed from materials that are compatible with hydrogen, resistant to embrittlement, and capable of withstanding high pressures.

[2]. Pressure Rating: The valve must be designed to handle the specific pressure range of the hydrogen storage system, which can vary depending on the application (e.g., automotive, industrial).
[3]. Sealing Mechanism: A reliable sealing mechanism is essential to prevent leaks, which is particularly important given the potential flammability and volatility of hydrogen. This may involve the use of specialized seals or gaskets.
[4]. Flow Control: The valve design should allow for precise control of hydrogen flow rates, enabling efficient refueling or distribution of hydrogen to the fuel cell or other end-use devices.
[5]. Safety Features: Various safety features may be incorporated into the valve design, such as pressure relief valves to prevent over-pressurization, thermal protection to mitigate the risk of overheating, and fail-safe mechanisms to ensure shut-off in case of emergencies.
[6]. Compatibility with Tank: The valve design must be compatible with the specific type of hydrogen storage tank being used, whether it's a high-pressure tank (e.g., carbon fiber reinforced composite tank) or a cryogenic tank (e.g., liquid hydrogen storage).
[7]. Integration with Fuel System: The valve should be designed for seamless integration into the overall hydrogen fuel system, considering factors such as size, weight, and interface compatibility with other system components.
[8]. Durability and Reliability: Given the harsh operating conditions and potential vibration and shock loads experienced in automotive or industrial applications, the valve must be designed for long-term durability and reliability.
[9]. Regulatory Compliance: The design must adhere to relevant safety standards and regulations governing the handling, storage, and transportation of hydrogen, such as those established by organizations like the International Organization for Standardization (ISO) or the National Fire Protection Association (NFPA). UN/ECE R134, HGV 3.1
10.] Maintenance and Serviceability: Consideration should be given to ease of maintenance and serviceability, including access for inspection, repair, or replacement of components over the valve's lifecycle.

Overall, the intricate design of an on-tank valve for hydrogen involves a careful balance of technical considerations to ensure both safety and performance in the storage and delivery of hydrogen fuel.

COMPONENTS OF OTV

There are many components within OTV as shown in figure 1 [5]. Some of the important components will be covered below.

A. Manual override

Manual override in an on-tank valve for hydrogen is a crucial safety feature that allows for manual control or emergency shut-off of the valve in situations where automated or electronic control systems may fail or become inaccessible. Here are some key aspects of manual override mechanisms in such valves.

[1]. Emergency Shut-off: The manual override allows operators to quickly shut off the flow of hydrogen in emergency situations, such as detecting leaks, fires, or other hazardous conditions. This manual intervention can be critical for preventing accidents or mitigating risks.
[2]. Mechanical Actuation: Manual override mechanisms typically involve a mechanical actuation system that bypasses or overrides the automated control system. This may include levers, knobs, or handles that can be manually operated by personnel.

B. TPRD: Thermal Pressure Relief Device

TPRD stands for "Thermal Pressure Relief Device." It is an essential safety feature incorporated into the design of on-tank valves for hydrogen storage systems. The primary function of the TPRD is to prevent over-pressurization of the storage tank, especially in situations where the temperature of the hydrogen inside the tank rises significantly. Here are some key aspects of TPRD in on-tank valves for hydrogen:

[1]. Functionality: The TPRD is designed to automatically release excess pressure from the hydrogen storage tank when the internal pressure surpasses a predetermined threshold. This helps prevent

catastrophic failure of the tank due to over-pressurization, which could result from factors such as ambient temperature changes or heat generation during hydrogen refueling or usage.

[2]. Operating Principle: TPRD devices typically utilize a combination of thermal and pressure-sensitive elements to activate the pressure relief mechanism. When the temperature or pressure inside the tank exceeds the set limits, the TPRD opens, allowing hydrogen to vent safely to the atmosphere until the pressure returns to a safe level.

[3]. Design Considerations: TPRD devices must be carefully designed and calibrated to ensure reliable operation and accurate pressure relief under varying operating conditions. Factors such as the desired relief pressure, temperature sensitivity, response time, and flow capacity are taken into account during the design process.

[4]. Integration: TPRD devices are integrated into the on-tank valve assembly, often as an integral part of the valve or as a separate component closely connected to the tank. This integration ensures that pressure relief occurs directly at the point where excess pressure is most likely to occur, minimizing the risk of damage to the tank or surrounding components.

C. EFV: Excess flow valve

An excess flow valve (EFV) is an important safety feature incorporated into the design of on-tank valves for hydrogen storage systems. Its primary function is to automatically shut off the flow of hydrogen in the event of a sudden increase in flow rate beyond a predetermined threshold. Here's a detailed overview of the excess flow valve and its role in on-tank hydrogen valve design:

[1]. Functionality: The excess flow valve is designed to activate when there is an unexpected surge in hydrogen flow, such as a ruptured hose or a damaged connection. This sudden increase in flow rate triggers the valve to close rapidly, effectively stopping the flow of hydrogen and preventing further release.

Table I: Some of the Key Features of OTV

Height of OTV	150mm to 250mm
Seal types	Metal-to-metal, O-ring, PEEK, Composite
Operating temperature	-40 to +85 °C
Nominal operating pressure	700 bar
Maximum allowable working pressure	875 bar
Body materia	Aluminum, Stainless steel
TPRD activation temperature	80°C to 120°C

[2]. Safety Mechanism: The EFV acts as a critical safety mechanism to mitigate the risk of hydrogen leakage in the event of an accident or system malfunction. By shutting off the flow of hydrogen during abnormal conditions, it helps to minimize the potential for fire, explosion, or other hazards associated with uncontrolled hydrogen release.

[3]. Design Considerations: The design of the excess flow valve must be carefully engineered to ensure reliable operation while minimizing false activations. This involves selecting appropriate materials, optimizing flow path geometry, and incorporating robust sealing mechanisms to withstand the high-pressure hydrogen environment.

[4]. Threshold Setting: The EFV is typically calibrated to activate at a specific flow rate threshold, which is determined based on factors such as the maximum allowable release rate, system pressure, and application requirements. The threshold setting ensures that the valve responds appropriately to abnormal flow conditions without impeding normal operation.

CONCLUSION

In conclusion, the study of on-tank valves (OTVs) for hydrogen fuel cell electric vehicles (FCEVs) has provided valuable insights into the intricate design, operation, and optimization of these critical components. By drawing from interdisciplinary research in materials science, mechanical engineering, and hydrogen technology, we have explored key factors such as valve material compatibility, leakage prevention, and pressure regulation techniques. Key features such as the height of the OTV, seal types, operating temperature, and pressure ratings highlight the technical specifications necessary to meet the demanding requirements of FCEV applications.

In particular, the discussion on manual override mechanisms, TPRDs, and excess flow valves underscores the critical role of these safety features in mitigating risks associated with hydrogen handling and ensuring the integrity of the storage system under various operating conditions.

REFERENCES

[1]. Zhang, Caizhi, et al. "Review on the safety analysis and protection strategies of fast filling hydrogen storage system for fuel cell vehicle application." Journal of energy storage 45 (2022): 103451.

[2]. Klopciˇ c, Nejc, et al. "Refuelling tests of a hydrogen tank for heavy- ˇ duty applications." International Journal of Hydrogen Energy 49 (2024): 1237-1249.

[3]. Yamashita, Akira, et al. Development of high-pressure hydrogen storage system for the Toyota "Mirai". No. 2015-01-1169. SAE Technical Paper, 2015.

[4]. Barthel´ emy, Herv ´ e. "Compatibility of metallic materials with hydrogen ´ review of the present knowledge." (2007).

[5]. Molkov, Vladimir, Mohammad Dadashzadeh, and Dmitriy Makarov. "Physical model of onboard hydrogen storage tank thermal behaviour during fuelling." International Journal of Hydrogen Energy 44.8 (2019): 4374-4384.

[6]. https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/ review14/st100 james 2014 o.pdf?Status=Master