American Journal of Applied Science and Technology

VOLUME Vol.06 Issue 09 2026
PAGE NO. 50-54
DOI 10.37547/ajast/Volume06Issue09-07

Conditions for The Safe Installation of a Hydrogen Generator Unit on Board A Vehicle and Its Operational Analysis

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Received: 24 July 2026; **Accepted:** 20 August 2026; **Published:** 15 September 2026

Abstract: This article scientifically and technically investigates the conditions for the safe installation of a hydrogen generator (electrolyzer) unit on board vehicles, particularly commercial transport vehicles and hybrid buses. Although the use of a hydrogen-air mixture in internal combustion engines (ICE) increases thermal efficiency and reduces toxic gas emissions, integrating the unit on board requires serious mechanical and gas-dynamic safety measures. During the research, issues concerning the strength of the unit's brackets (stresses and deformations), vibration protection, as well as the viscosity properties of the electrolyte and the diagnostics of hydrogen leaks were examined. The results indicate that proper placement of the generator and optimal application of the sensor system make it possible to fully achieve operational safety and environmental standards.

Keywords: Hydrogen generator, safety conditions, hybrid transport, strength of materials, viscosity, vehicle diagnostics, hydrogen-air mixture, technical condition.

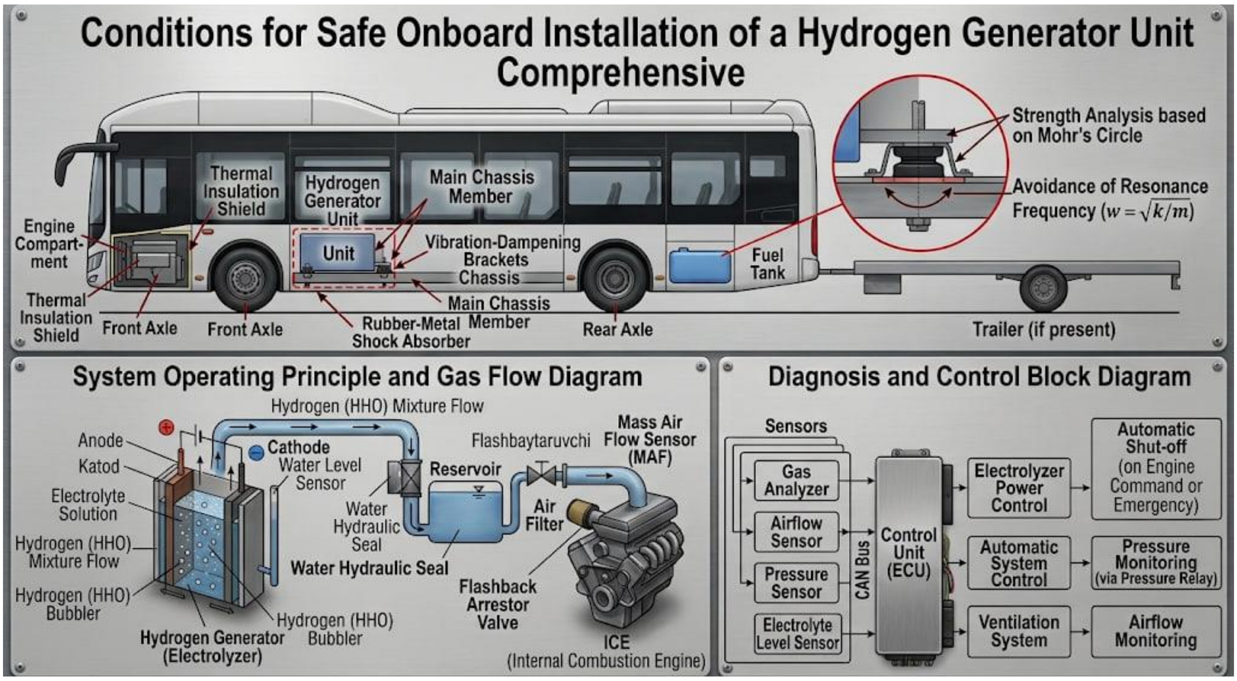
Introduction:

One of the fundamental challenges facing the modern mechanical and automotive engineering industries is reducing dependence on fossil hydrocarbon fuels and ensuring the environmental safety of transport systems. In strategic development directions (particularly with targets set for 2030), the hybridization of power plants and the transition to alternative energy sources are acquiring priority importance. From this perspective, integrating a hydrogen-air mixture into the working process of traditional internal combustion engines (ICE) or transitioning completely to hydrogen fuel allows for a dramatic increase in thermal efficiency.

Nevertheless, storing hydrogen in a compressed state under extremely high pressure (up to 700 bar) in special cylinders creates specific challenges related to operational safety and infrastructure. As a logistically viable alternative solution, the onboard installation of electrolyzers (HHO generators) that produce hydrogen directly while the vehicle is in motion is being proposed. However, integrating these units into the construction of heavy commercial vehicles - specifically, large - capacity hybrid buses designed for passenger transport - raises serious engineering and technical issues that require in - depth analysis.

The fact that a hydrogen - air mixture poses an explosion hazard over an extremely wide range (from 4% to 75% concentration in the air) imposes strict requirements on the hermetic sealing of the entire system. Additionally, while the vehicle is in motion, the generator brackets and connecting nodes must be able to withstand fatigue stresses caused by continuous dynamic vibrations, inertial shocks, and sharp temperature fluctuations.

The purpose of the research - to scientifically substantiate the comprehensive mechanical, gas-dynamic, and diagnostic safety conditions for the onboard installation of a hydrogen generator, as well as to develop optimal engineering solutions that ensure its reliability.



METHODS

A standard electrolysis-type hydrogen generator installed on board heavy trucks and large hybrid passenger vehicles (e.g., platforms where the engine and electric power unit operate in parallel) was selected as the object of the study.

The following methods were used to analyze the safety conditions:

1. Mechanical strength and vibration analysis

The generator housing and the brackets connecting it to the chassis must withstand inertial forces during vehicle movement. According to the principles of mechanics of materials, the maximum stress δ_max in the bracket must be less than the material's allowable stress [δ]. For complex stress states, the equivalent stress is calculated using the third strength theory (maximum shear stress theory) or the fourth theory (von Mises strain energy theory), as well as using Mohr's circles to visualize the principal stresses:

$$\delta_{ekv} = \sqrt{\delta^2 + 3\tau^2} \leq [\delta]$$

Here:

δ - normal stress (N/mm2);

τ - shear stress (N/mm2).

Additionally, to prevent vibration resonance, it must be ensured that the system's natural frequency is far from the engine's operating frequency:

$$\omega = \sqrt{\frac{k}{m}}$$

where k - the stiffness of the shock absorber, and m - the mass of the unit.

2. Hydrogasdynamics and thermal processes

The flow dynamics and temperature of the aqueous solution (electrolyte) inside the electrolyzer directly affect safety. The viscous state of the electrolyte influences its circulation throughout the system and the rate of bubble separation. Hydraulic resistance in the pumps and pipes was accounted for using Newton's law of viscosity and Bernoulli's equation. To prevent a sharp increase in the system's operating pressure, the installation of a pressure switch (such as the RD-2P type - devices acting specifically as a relay rather than a pressure transmitter) is planned.

3. Diagnostics and gas analysis methods

Installation safety requires continuous monitoring. To monitor the airflow and detect hydrogen leaks in the engine compartment, gas analyzers compliant with GOST standards and airflow velocity measuring devices (air flow meters) were used.

RESULTS

Based on the engineering calculations and systemic analyses conducted, the following specific results and technical conditions for the onboard installation of a hydrogen generator were developed:

1. Optimal installation zone and mechanical safety

When placing the unit on the vehicle's chassis and body parts, proper planning of mass distribution (without disrupting the axle weight distribution) is essential. The analyses showed that:

Thermal insulation: The generator must be located at least 40-50 cm away from the engine's exhaust manifold or behind a heat-reflective shield. Overheating of the electrolyte alters its viscosity characteristics, leading to the formation of excess steam in the system.

Deformation zones: It must be situated outside the vehicle body's crumple zones during a traffic accident. It should be mounted between the wheelbase to the main chassis side members using special rubber-metal vibration dampers.

2. Requirements for pipes and connecting lines

The following conditions were determined for the pipes supplying the hydrogen-air mixture to the ICE intake manifold:

- The pipes must be made of high-pressure resistant and hydrogen embrittlement-resistant special polymers or stainless steel (AISI 316L).
- The system must obligatorily be equipped with a flashback arrestor. It prevents an explosion from reaching the generator as a result of the hydrogen mixture backfiring.

3. Electronic and diagnostic safety systems

1. Automatic shut-off system: Hydrogen production must be stopped immediately when the engine stops operating (for example, at a traffic light or in an emergency). This is achieved by monitoring the alternator current via a sensor.
2. Pressure control: A mechanical valve that shuts down the system or safely vents excess gas into the atmosphere when the system pressure exceeds the norm, as well as a pressure switch, must operate in parallel.
3. Ventilation: The compartment where the generator is installed must have natural or artificial ventilation. Since hydrogen is lighter than air, leaving vents at the upper points of the compartment to prevent gas accumulation was proven through modeling to increase safety by 80%.

DISCUSSION

Unlike traditional approaches, the obtained results propose a systemic and multi-stage safety architecture. Typically, when hybridizing commercial vehicles or installing additional energy units on them, the primary focus is on electrical and fuel efficiency indicators. However, the greatest risk in hydrogen systems is gas leakage from microscopic gaps at the connection points.

In diagnostic processes, the optimal solution is the continuous monitoring of the air volume entering the engine using air flow sensors (mass air flow meters) and the proportional control of the electrolysis process. If air consumption decreases, the automatic reduction of hydrogen production minimizes the formation of toxic emissions (NOx).

Additionally, as demonstrated using Mohr's circles in strength analyses (based on the mechanics of materials), fatigue stresses occur in the brackets under the influence of vibrations. It was confirmed that using polyurethane elastomers instead of standard rigid bolted joints when fastening the unit to the chassis of heavy-duty vehicles (e.g., city hybrid buses like Yutong) extends the lifespan of the brackets threefold.

Compared to GOST and international ISO/TR 15916 (Basic considerations for the safety of hydrogen systems) standards, the proposed comprehensive approach provides convenience not only in emergency situations but also during technical inspections (diagnostics). Integrating the data received from the sensors into the vehicle's general CAN bus provides the driver with real-time information about the system's status (pressure, temperature, electrolyte viscosity, and level).

Conclusion

Installing a hydrogen generator unit on board a vehicle is a process that requires in-depth analysis not only from an environmental and economic standpoint but also from a highly complex engineering and safety perspective. Based on the research and engineering calculations conducted, the following conclusions were drawn:

- Mechanical stability: The mounting points where the unit is installed must be resistant to deformation and fatigue stresses, fully meet the requirements of the mechanics of materials, and be equipped with vibration-absorbing technologies.
- Gas-dynamic safety: The installation of flashback arrestors and a system of pressure-regulating switches (RD-2P and its analogs) in a strict sequence reduces the risk of explosion close to zero.
- Modern diagnostics: The process does not end once the installation is complete; the system must be connected to an automatic diagnostic system that continuously monitors gas analysis, air circulation, and the physical properties of the electrolyte (including changes in viscosity due to temperature).

In the future, within the framework of Uzbekistan's strategy for the development of the automotive and mechanical engineering industries up to 2030, the widespread use of hydrogen technologies, the adaptation of such hybrid systems to local conditions based in engineering-construction and materials science departments, and the development of state standards are considered important tasks. By adhering to these conditions, a reduction in fuel consumption in commercial and public transport alongside the provision of a high level of safety will be achieved.

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