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THE FLOW METER-BASED MEASUREMENT OF HYDROGEN CONSUMPTION IN FUEL CELL ELECTRIC CARS

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Abstract - *Energy consumption plays a crucial role in assessing the competitiveness of fuel cell electric vehicles. An integral aspect in measuring energy consumption is the evaluation of hydrogen utilization, which can be accomplished through methodologies like the mass approach, the pressure/temperature approach, and the flowmeter approach. The flowmeter approach has garnered significant attention due to its straightforward operation, cost-effectiveness, and reliable real-time functionality. Recent studies have demonstrated the precision of the flowmeter approach under certain conditions. However, various factors in real-world scenarios, such as unintended vibrations, ambient temperatures, and the calibration of onboard hydrogen capacity, can impact the test results. Additionally, researchers have explored the use of a shortcut technique as an alternative to the depletion method to enhance testing efficiency. To determine whether the flowmeter approach, incorporating the shortcut technique, can accurately represent the hydrogen consumption of an actual vehicle, we conducted experiments and trials on both the New European Driving Cycle (NEDC) and the China Light-Duty Vehicle Test Cycle (CLTC) using the same vehicle. The findings revealed that the shortcut technique can reduce the test duration by at least 50% compared to the depletion method. The error margin of the shortcut technique, based on the flowmeter, was found to be below 0.1% for the NEDC operational condition and 8.12% for the CLTC operational conditions. By integrating a throttle valve and a 4L buffer tank, the error margin was reduced from 8.12% to 4.76%. These test results underscore the importance of tailoring appropriate approaches for measuring hydrogen consumption based on the flowmeter and shortcut technique in line with specific circumstances.*

Key Words: fuel cell electric vehicles, hydrogen consumption measurement, flowmeter, thermal flow sensor, onboard vehicle systems, emerging trends.

1.INTRODUCTION

Fuel cell electric vehicles (FCEVs) are a promising option for those looking to move away from traditional internal combustion engine vehicles. These vehicles operate by utilizing hydrogen fuel cells to power their engines, resulting in zero harmful emissions being released into the environment. Unlike battery electric vehicles (BEVs) that rely on storing electricity in batteries, FCEVs produce electricity through a chemical reaction between hydrogen and oxygen, with the only byproducts being water vapor and heat. This innovative technology boasts numerous advantages, such as quick refueling times and impressive driving ranges, making FCEVs a viable alternative to conventional gasoline-powered vehicles in terms of convenience. Moreover, the hydrogen fuel used in FCEVs can be sourced from renewable sources, contributing to a significant reduction in greenhouse gas emissions linked to transportation. Despite the promising aspects of FCEVs, there are still some hurdles that need to be overcome for widespread adoption. Challenges like the limited availability of hydrogen refueling stations and the high production costs associated with FCEVs are currently impeding their popularity. However, ongoing research and development efforts are dedicated to enhancing the efficiency, affordability, and accessibility of FCEVs, with the ultimate goal of creating a more sustainable and diverse transportation landscape for the future. Through continued innovation and advancements in technology, FCEVs are poised to play a significant role in shaping the future of transportation towards a cleaner and greener direction.

1.1.Architectural diagram of fuel-cell electric vehicles (FCEVs)

The architectural diagram of fuel cell electric vehicles (FCEVs) is a complex system that consists of several integral components working together harmoniously to facilitate the vehicle's functionality. At the heart of this diagram is the fuel cell stack, which is made up of individual fuel cells stacked on top of each other. These fuel cells receive hydrogen gas from high-pressure tanks located on the vehicle. Oxygen, on the other hand, is sourced from the surrounding air and supplied to the cathode side of the fuel cell stack. Inside each fuel cell, hydrogen molecules undergo a process where they split into protons and electrons at the anode. The protons then move through an electrolyte membrane to the cathode, while the electrons travel through an external circuit, generating electricity that powers the vehicle's motor. When the protons and electrons reunite with oxygen at the cathode, water vapor is produced, along with the release of heat as a byproduct.

The fuel cell stack, there are other supporting systems in place to ensure the optimal performance and efficiency of FCEVs. These include cooling mechanisms, power electronics, and control units that work in tandem to regulate the vehicle's operations. Moreover, FCEVs are equipped with hydrogen storage systems, usually high-pressure tanks, which store and deliver hydrogen to the fuel cell stack as needed. The electric motor of the vehicle is powered by the fuel cell stack, with additional systems in place to manage power distribution and enhance overall performance. The architectural diagram of FCEVs showcases a sophisticated integration of various components that ultimately enable the vehicle to operate efficiently, cleanly, and sustainably, highlighting the future of transportation technology.

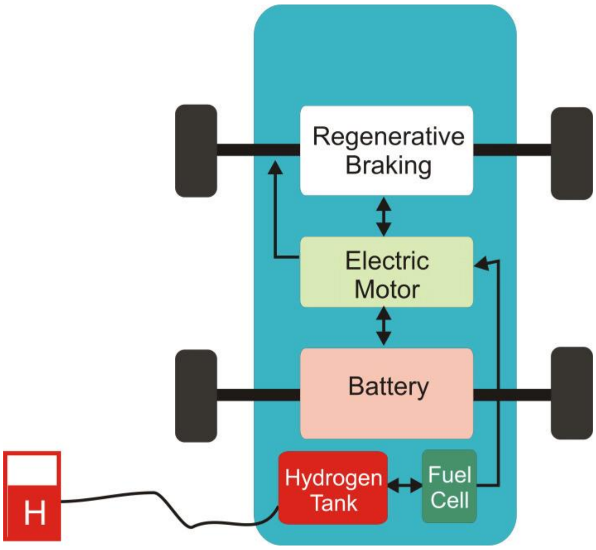

Figure-01: Architectural diagram of fuel cell electric vehicles (FCEVs)

1.2.Principle of Fuel cell electric vehicles

Fuel cell electric vehicles (FCEVs) are a type of vehicle that operates by converting the chemical energy stored in hydrogen fuel directly into electricity through an electrochemical process. This process is made possible by the fuel cell stack, which is made up of multiple individual fuel cells. Each fuel cell consists of an anode and a cathode that are separated by an electrolyte membrane. When hydrogen gas is supplied to the anode, it undergoes a reaction that splits it into protons and electrons. The protons then move through the electrolyte membrane to the cathode, while the electrons travel through an external circuit. This movement of protons and electrons generates an electric current that powers the vehicle's motor.

Once at the cathode, the protons and electrons combine with oxygen from the air, resulting in the production of water vapor and the release of heat as byproducts. Unlike traditional internal combustion engines, FCEVs do not emit any pollutants or greenhouse gases. The only emission from FCEVs is water vapor, making them a very environmentally friendly option. This efficient and clean process of converting hydrogen fuel into electricity makes FCEVs a promising solution for reducing carbon emissions and decreasing our dependence on fossil fuels in the transportation sector.

2.ACCURATELY MEASURING HYDROGEN CONSUMPTION

Precisely quantifying hydrogen consumption in fuel cell electric vehicles (FCEVs) is essential for comprehending vehicle performance, enhancing efficiency, and effectively managing fuel utilization. Various methodologies are utilized to achieve accurate measurements. A key approach involves incorporating flow meters into the vehicle's hydrogen delivery system. These meters directly gauge the rate of hydrogen gas supplied to the fuel cell stack, offering real-time data on consumption. By continuously monitoring the flow rate over time, the total hydrogen consumption by the vehicle can be precisely determined. Advanced onboard sensors and instrumentation are utilized to oversee parameters such as temperature, pressure, and voltage within the fuel cell system. These sensors offer valuable data for calculating hydrogen consumption and evaluating the general condition and operation of the system. Calibration and validation processes are frequently carried out to ensure the precision of the measurement systems. This may entail comparing flow meter readings with theoretical computations or conducting controlled experiments under laboratory conditions. In research and development environments, sophisticated testing facilities equipped with specialized apparatus are employed to conduct thorough analyses of hydrogen consumption under diverse operational circumstances. These facilities empower researchers to refine measurement methodologies and acquire deeper insights into the factors influencing hydrogen consumption in FCEVs. Precisely quantifying hydrogen consumption in FCEVs demands a blend of advanced instrumentation, stringent testing protocols, and meticulous calibration to guarantee dependable data collection and analysis. This information is imperative for enhancing vehicle performance, propelling fuel cell technology forward, and facilitating the widespread adoption of hydrogen-powered transportation.

3.FLOWMETER MEASUREMENT METHOD

The Flowmeter Measurement Method is a crucial technique utilized to precisely measure the rate at which hydrogen is consumed in fuel cell electric vehicles (FCEVs). This method involves the installation of flow meters within the hydrogen delivery system of the vehicle to directly track the flow rate of hydrogen gas that is supplied to the fuel cell stack. These flow meters generate real-time data regarding the volume or mass of hydrogen that passes through them per unit of time, typically measured in liters per minute (L/min) or kilograms per hour (kg/hr). By continuously monitoring the flow rate over a specific duration, it becomes possible to accurately calculate the total amount of hydrogen consumed by the vehicle. The utilization of the Flowmeter Measurement Method provides a dependable approach to quantifying hydrogen consumption, making it a valuable tool for performance assessment, efficiency enhancement, and effective fuel management in FCEVs. Moreover, these flowmeter measurements can also serve for calibration and validation purposes to ensure the accuracy and reliability of hydrogen consumption data obtained through alternative methods. This contributes significantly to the continuous progress and evolution of hydrogen fuel cell technology. In essence, the Flowmeter Measurement Method plays a fundamental role in improving the overall performance and sustainability of FCEVs by enabling precise measurement and analysis of hydrogen consumption.

4.SHORT-CUT METHOD

The shortcut method is a simplified technique used to estimate the amount of hydrogen consumed by fuel cell electric vehicles (FCEVs) without the need for direct flowmeter measurements. This method relies on mathematical models or equations that take into account various factors such as vehicle speed, distance traveled, power output of the fuel cell system, and efficiency of the hydrogen fuel cell stack. By inputting these parameters into the model, an estimation of hydrogen consumption for a specific driving scenario can be calculated. Although not as precise as flowmeter measurements, the shortcut method offers a convenient and practical way to estimate hydrogen usage, especially for real-time monitoring or predictive analysis. It allows for quick assessments of fuel consumption trends, enabling drivers and operators to make well-informed decisions regarding refueling schedules and overall vehicle performance. Moreover, the shortcut method can be a valuable tool in research and development efforts, providing valuable insights into the factors that influence hydrogen consumption and contributing to the continuous improvement of FCEV technology. This method serves as a useful resource for understanding and optimizing the efficiency of hydrogen fuel cells in the automotive industry.

5.MINIMIZE THE CONSUMPTION OF HYDROGEN FUEL IN ELECTRIC VEHICLE

Reducing the consumption of hydrogen fuel in electric vehicles is a critical step towards promoting sustainable transportation. One effective strategy is to improve the efficiency of hydrogen fuel cells, ensuring that the conversion of hydrogen into electrical energy is done with minimal waste. This can be accomplished by making advancements in fuel cell technology, such as developing more efficient catalysts and membrane materials to enhance electrolysis and decrease energy losses. Furthermore, optimizing the vehicle's powertrain and aerodynamics can also play a significant role in improving efficiency, making sure that the energy stored in hydrogen is used efficiently to propel the vehicle forward. Utilizing renewable energy sources for hydrogen production can help reduce the environmental impact of fuel generation, leading to a more sustainable transportation system. Ultimately, a comprehensive approach that combines innovation in technology, infrastructure development, and sustainable energy practices is crucial for achieving the goal of minimizing hydrogen fuel consumption in electric vehicles. This holistic approach is essential for creating a more sustainable and eco-friendly transportation ecosystem for future generations.

6.MODELLING OF THE VEHICLE

In order to effectively evaluate the performance and efficiency of fuel cell systems and power batteries, it is essential to gather voltage and current readings from both components. Moreover, when employing the short-cut method, it is imperative to also document hydrogen flow data. It is crucial to emphasize that all data should be collected at a sampling frequency of 5 Hz. This meticulous process plays a vital role in the thorough assessment of fuel cell systems and power batteries, ensuring accurate and reliable results.

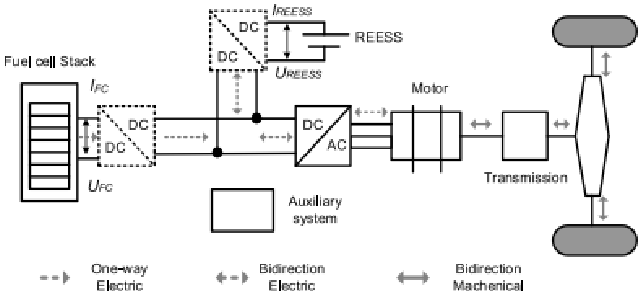

Figure-02: Modelling of the Vehicle

In the field of hydrogen storage and vehicle technology, there is a common method known as the run-out approach used to determine the capacity of onboard hydrogen in a vehicle. This method involves measuring the pressure and temperature before and after conducting a cylinder test in order to calculate the quantity of hydrogen that can be stored on the vehicle. However, a new and improved methodology has been introduced by Zheng Jinyang, which focuses on calculating the compression factor and hydrogen mass more accurately within this process. Moreover, in order to further analyze and evaluate the potential driving range of a hydrogen-powered vehicle, researchers often rely on chassis dynamometer testing. This type of testing allows researchers to determine the distance a vehicle can travel on a single tank of hydrogen fuel. By conducting these tests, it becomes possible to calculate the hydrogen consumption per hundred kilometers, providing valuable insights into the efficiency and performance of hydrogen-powered vehicles on the road.

7.ANALYSIS OF RESULT

In this particular part of the analysis, we will be examining the outcomes that have been derived from the evaluation of the hydrogen fuel vehicle. This assessment was carried out utilizing both the flow-meter and the short cut method. Through this detailed examination, we aim to gain a deeper understanding of the performance and efficiency of the hydrogen fuel vehicle. By utilizing these specific techniques, we can accurately measure and analyze various aspects of the vehicle's operation, ultimately leading to valuable insights and conclusions regarding its overall functionality and potential for widespread use in the future of transportation.

7.1.HYDROGEN COMSUMPTION IN NEDC FOR BOTH METHOD

Upon examination of the data, it is apparent that the NEDC abbreviated technique exhibits a more balanced distribution in comparison to the CLTC abbreviated technique. Conversely, the latter displays a greater aggregate of data recorded by the flowmeter in contrast to measurements obtained through the run-out method. It is intriguing to observe, nonetheless, that there are no discernible and uniform trends in hydrogen consumption for either approach. Notwithstanding these discoveries, additional scrutiny is imperative to completely grasp the fundamental factors influencing these outcomes and their significance for subsequent research and practical implementations.

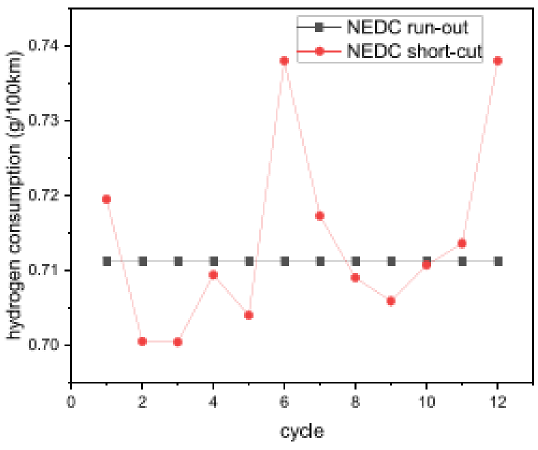

Figure-03: Hydrogen Consumption for NEDC in Short Cut and Run Out Method.

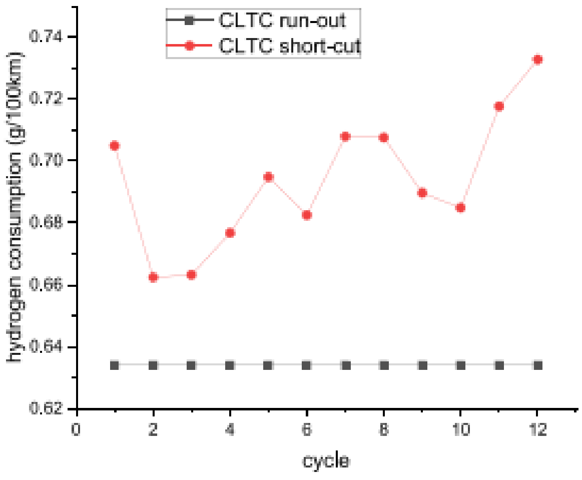

Figure-04: Hydrogen Consumption for CLDC in Short Cut and Run Out Method.

7.2.IMPROVEMENT OF THE FLUCTUATION

In hydrogen fuel vehicles, the reservoir tank plays a crucial role, aiding in the storage and regulation of hydrogen gas. Its main purpose is to maintain a consistent pressure of hydrogen that is supplied to the fuel cell stack, the core of the vehicle's power generation system. By storing hydrogen at high pressure, the reservoir tank allows the vehicle to carry enough fuel for a satisfactory driving range between refueling stops. Furthermore, it ensures a seamless and steady flow of hydrogen to the fuel cell stack, enhancing the vehicle's performance and efficiency. Safety measures are incorporated into the reservoir tank design to reduce risks related to high-pressure storage, protecting against leaks or ruptures. Moreover, some reservoir tanks are equipped with thermal management systems to control hydrogen temperature, further improving efficiency and stability. Essentially, the reservoir tank serves as a fundamental component of hydrogen fuel cell vehicles, playing a vital role in their operational dependability, safety, and overall performance.

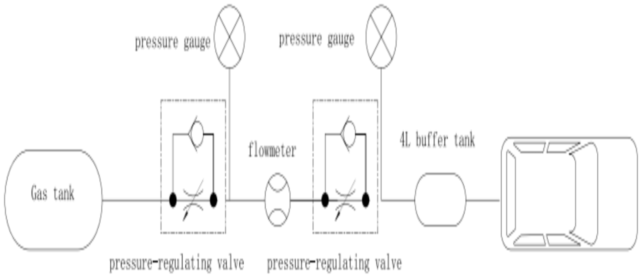

Figure-05: Buffer Tank for Improvement of Fluctuation.

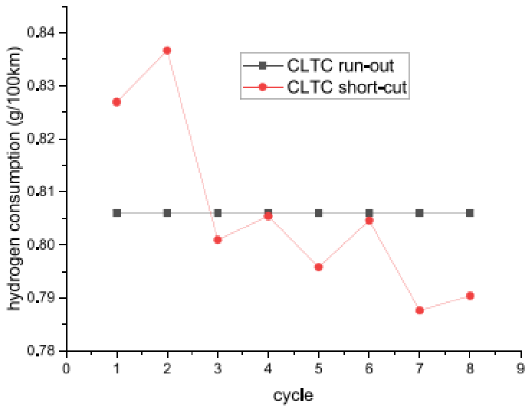

Figure-06: Enhanced expeditious approach under California Lighting Technology Center (CLTC) conditions.

8.CONCLUSION

We have developed an innovative testing methodology utilizing a flowmeter as a shortcut technique, which we have validated by comparing it to the standard run-out method under NEDC and CLTC operating conditions on the same vehicle. This novel approach has demonstrated a substantial 50% reduction in testing duration compared to the conventional method. In terms of measurement precision, our proposed technique exhibits an error margin of less than 0.1% under NEDC conditions. However, this margin increases to 8.12% in CLTC settings. To mitigate this discrepancy, we have integrated a throttle valve and buffer tank into the system, resulting in a decreased error margin of 4.76%. An important observation is that regardless of whether the NEDC or CLTC approach is employed, hydrogen consumption remains constant throughout the testing cycles. This uniformity presents a challenge in determining the optimal number of cycles required for accurate outcomes when utilizing the shortcut method. This underscores the significance of further research and enhancement of our methodology to ensure dependable and precise testing results.

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