ASSESSMENT OF SAFETY FOR HYDROGEN FUEL CELL VEHICLE

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ABSTRACT

A prospective global market share of Electric vehicle (EV), Hybrid electric vehicle (HEV) and Hydrogen Fuel Cell Vehicle (HFCV) is expected to grow due to stringent emission regulation and oil depletion. However, it is essential to secure protection against high-pressure hydrogen gas and high-voltage in fuel cell vehicles and thus needs to develop a technique for safety assessment of HFCV.

In this experiment 8 research institutes, including the Korea Automobile Testing and Research Institute, Hyundai Motor Company, took part in. This project was supported by the Ministry of Land, Transportation and Maritime Affairs of the Republic of Korea.

1. INTRODUCTION

The Hydrogen Fuel Cell Vehicle (HFCV) is one of the countermeasures to solve the energy crisis and the emission problems of vehicles. Governments of various countries and Nongovernmental organizations like ISO and SAE are trying to establish the safety regulations and standards on the HFCV. In the World Forum for Harmonization of Vehicle Regulations (UN/ECE/WP.29) the development of Global Technical Regulations (GTR) for HFCV is actively being discussed. [1), 2)]

Japan has already established the regulation on the motor vehicles fueled by compressed hydrogen gas. Japanese regulation prescribes the ICHS 2011 will include thematic plenary sessions, topical lectures, and parallel oral and poster sessions of contributed papers. Each day, the conference will start with a plenary session on themes that are particularly relevant for the safe and widespread hydrogen use in society. The conference seeks to enable the near term introduction of hydrogen technologies in the market place ICHS 2011 will include thematic plenary sessions, topical lectures, and parallel oral and poster sessions of contributed papers. Each day, the conference will start with a plenary session on themes that are particularly relevant for the safe and widespread hydrogen use in society. The conference seeks to enable the near term introduction of hydrogen technologies in the market place on the hydrogen gas containers, piping systems, valves and various attachments.

Korean motor vehicle safety standard (KMVSS) needs to add the regulations on the HFCV for the future development of HFCVs. Development of a technique for safety assessment of Hydrogen Fuel Cell Vehicle(HFCV) include 3 tasks, hydrogen safety, vehicle operation safety and protection against high-voltage. [3)]

2. RESEARCH

2.1 Hydrogen safety

<u>Research for hydrogen storage and supply system</u>

The main study for hydrogen storage and supply system are as follows.

1) safety assessment of hydrogen system crash, fire

2) conformity assessment of the hydrogen leak detection sensors and system

3) safety assessment of hydrogen containers and valves, Pressure Relief Device (PRD)

4) hydrogen leakage analysis and safety evaluation

In this study, the behavior of leaking hydrogen was investigated when a vehicle was at rest, when a vehicle was moving, and after a vehicle was shut-down because of the hydrogen leakage. A hydrogen fuel cell vehicle uses hydrogen with high pressure (35 or 70 MPa) and a battery above 400 Volts. Due to this nature the safety of a hydrogen fuel cell vehicle, against the risk of fire, electric isolation failure or electric shock, should be secured in the event of a collision. There is no provision regarding the hydrogen leakage of a hydrogen fuel cell vehicle in Article 91 (Fuel System) in the Korean Motor Vehicles Safety Standards. In this study the Japanese Motor Vehicles Safety Standards (Attachment 17) and GTR Draft ware utilized to evaluate the fuel system integrity of a sport utility vehicle by measuring the pressure drop when the vehicle was impacted.

A. Leakage test for a vehicle at rest

(A) Locations of leaking points

Eleven leaking points were chosen, mainly fittings near the storage system. Eight leaking points were fittings connected directly to the storage system and three leaking points connected directly to the fuel processing system (FPS). The hydrogen flow rate was 40 liters/min which was the maximum allowable limit before the excess flow valve (EFV) began to operate.

Twelve on-board hydrogen sensors were located on the floor near the storage container. Outside the vehicle eight hydrogen sensors were lacated at 1.5 m high around the vehicle and nine hydrogen sensors were located at 3 m high around the vehicle, taking into consideration of parking area. Considering the possibility of hydrogen leakage into the passenger compartment, one near the stack, one near the FPS, one on the instrument panel and two in the interior were installed. With thirty four sensors in total the concentration of leaking hydrogen and response time were measured.

(B) Test Results of Hydrogen Leakage

Test results were collected from two areas, the underbody and engine compartment of a hydrogen fuel cell vehicle. Hydrogen leakage was simulated along the direction of hydrogen leakage at each fitting on the underbody. Figure 1 shows that hydrogen concentrations at Sensors No. 20, 31 and 32, which were measured with respect to the directions and flow rates at 8 leaking points on the underbody. It was expected that above 3 sensors were likely to detect any leakage from the underbody. Especially Sensors No. 31 and 32 were originally installed by the manufacturer and Sensor No. 32 covered any leakage from all area. Sensor No. 20 was found to detect any leakage faster and from the wider area than Sensor No. 31. [4)]

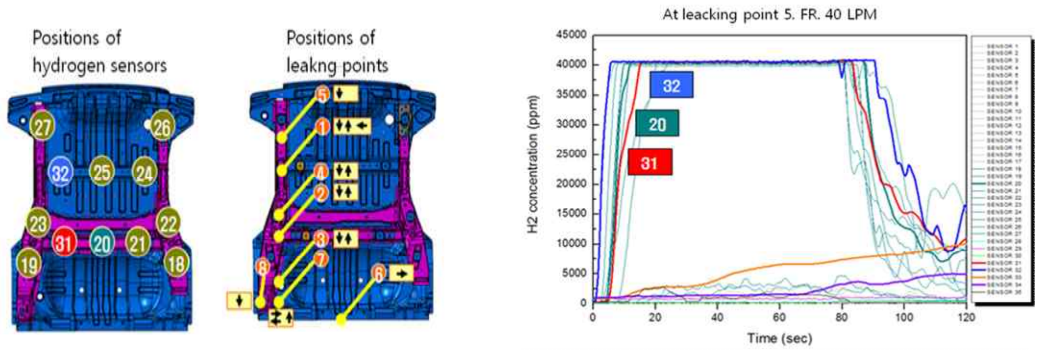

Figure 1. Hydrogen concentration at Sensors No. 20, 31 and 32, measured with respect to the directions and flow rates at 8 leaking points on the underbody.

B. Leakage test for a moving vehicle

(A) Leakage Experiment for a moving vehicle

In this experiment SUV hydrogen fuel cell vehicle was used. The head wind of 10 m/sec was blowing to the vehicle with a fan to simulate driving. Eleven possible leaking points at the storage system and delivery subsystem were shown in Figure 2. Leaking points were mainly connections. At these leaking points hydrogen was leaking with the hydrogen leakage simulation system.

To detect leaking hydrogen 34 sensors in and out of the vehicle were installed as in Figure 3. At each leaking point hydrogen leakage was controlled at 10, 40, and 131 liters/min . The flow rates were set at 10 liters/min for a low flow rate, at 40 liters/min for the onset of Excess Flow Valve (EFV), and 131 liters/min for the maximum hydrogen leakage based on the heat energy equivalent to maximum post crash leakages from gasoline vehicles specified in US FMVSS 301. The direction of leakage from each leaking point was set for the front (FF), rear (RR) and side (LH, RH).

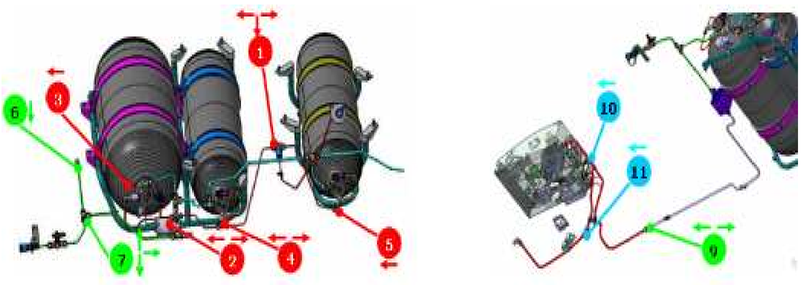

Figure 2. Possible leaking points.

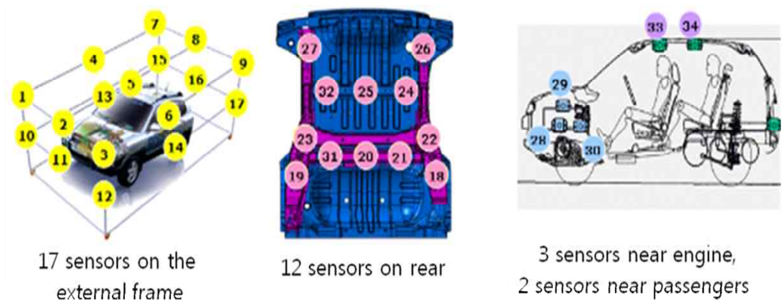

Figure 3. Locations of 34 sensors.

The test consisted of two parts. The first part was from the beginning of leakage to the point where a hydrogen concentration in air by volume reached 2 % (the onset of EFV, where the car was shut-down). Time to reach 2 % concentration was measured for this part. The second part was after the shut down. At 10 seconds and 60 seconds after the shut-down, a hydrogen concentration in air was measured. The duration period was measured, which meant the time for the hydrogen concentration in air to stay higher than 4 % after shut-down.

In case of a stationary vehicle a large amount of hydrogen was expected to leak if EFV shut-down the valve on detecting a hydrogen concentration in air of 2 %. The delay time between shut-down and detection of 2 % should be reconsidered. However, because the conditions for shut-down were related to emergency, the conditions should be reviewed from many aspects.

On detecting a hydrogen concentration in air of 2% by volume on any leaking points, the vehicle was shut-down. Though a concentration might reach 4% within 10 seconds after detecting, concentrations everywhere dropped below 4 % after one minute. The results from this study will be a ground to establish a guide for the desirable number and locations of sensors to be installed in and out of a vehicle. [4)]

2.2 Vehicle operation safety

<u>Assessment of compliance with safety standards of hydrogen fuel cell vehicle</u>

The main studies are as follows.

1) Analysis of the Applicability of safety standards

2) Fuel Economy Measurement Evaluation

3) Safety Standards of Compliance Assessment

<u>Research for fail safety mode of hydrogen fuel cell vehicle</u>

Safety evaluation studies for fail-safety mode are as follows.

1) Analysis of potential risks for HFCV

2) Self-diagnosis technology development and fail safety mode development occurs fail

3) Fail-safety evaluation technology Development

A. Crashworthiness test and Analysis [4), 5)]

(A) Verification of compliance and Analysis

(1) Overview

Article 91(Fuel System) in the Korean Motor Vehicle Safety Standard (KMVSS) applies to hybrid vehicles, electric vehicles and vehicles using gasoline, diesels and CNG. Passenger vehicles and buses with GVW of 4.5 tons or less are subject to this regulation. These vehicles shall meet fuel spillage requirements after and during the crash. In any rollover test, from the onset of rotational motion, vehicles shall meet fuel spillage requirements for the first 5 min of testing at each successive 90° increment on the longitudinal center line of a vehicle.

(2) Test procedures

Based on Article 91 (Fuel System) in the Korean Motor Vehicles Safety Standards and the Japanese Motor Vehicles Safety Standards (Attachment 17 & 100), amount of fuel leakage and body-acceleration were measured.

- Pressure sensors were installed in the test vehicle where hydrogen fuel system including the hydrogen tank was installed.
- The Fuel tank and fuel system was filled with helium gas at high (33 MPa) and low (1 MPa) pressure parts. Soap bubbles were used to test the leakage.
- The mass of test vehicle consisted of the unloaded vehicle and two dummies, equivalent to 156 kg.
- The Side impact of the moving barrier was 950kg.
- The Rear impact of the moving barrier was 1,805kg.
- Acceleration sensors were installed at the vehicle's center of mass, right and left of B-pillar and in the fuel tank.
- The hydrogen fuel storage system was filled to 90 % of nominal working pressure with helium gas.
- The degree of deformation was measured in vehicle's body and around fuel tank before and after the test.
- The temperature was measured around the test vehicle.
- High speed cameras were used when necessary.

(B) Test results

(1) The Frontal Impact Test

① Pressure measurement after test

The high (31.5 MPa) and low (0.8 MPa) pressure stayed constant showing no reduction in pressure.

② Measurement of deformation in body and area near the fuel tank

The largest deformation, 41.69 mm occurred along the longitudinal center line, which was measured the hydrogen receptacle points. In the area around the fuel tanks, brackets supporting the front fuel tank showed the largest damage, 41.38 mm.

③ Pictures showing the test

Pictures in Fig. 4 show the vehicle of frontal impact test scene. After the test, the occupant safety requirements met KMVSS article 91, 102.

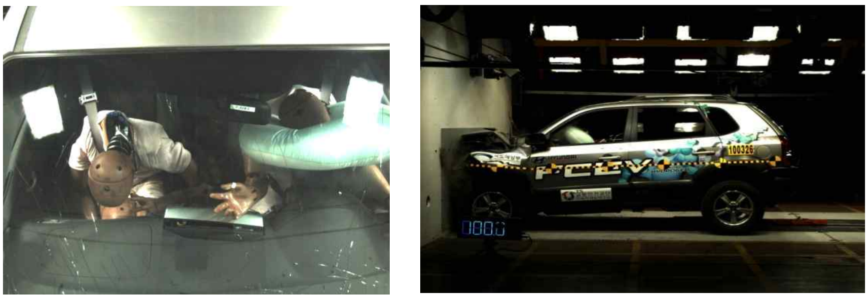

Figure 4. The test vehicle of frontal impact test.

(2) The Rear Impact Test

① Pressure measurement after test

The high (33 MPa) and low (1 MPa) pressure stayed constant showing no reduction in pressure.

② Measurement of deformation in body and area near the fuel tank

The largest deformation, 245 mm occurred along the longitudinal center line, which was measured between the mid points of front and rear bumpers. In the area around the fuel tanks, brackets supporting the rearmost fuel tank showed the largest damage, 172 mm.

③ Pictures showing the test

Pictures in Figure 5 show the vehicle before and after the test. Other than some weights to adjust the total weight of the vehicle, no additional system was installed in the engine compartment and the luggage compartment of the vehicle. After the test, the rearmost fuel tank was displaced toward the front by 172 mm, but not damaged.

Figure 5. Rear-right view of the test vehicle before and after test.

(3) The Side Impact Test

① Pressure measurement after test

The high (31.5 MPa) and low (0.8 MPa) pressure stayed constant showing no reduction in pressure.

② Measurement of deformation in body and area near the fuel tank

Around the fuel tank and body is measured the lateral deformation. The largest deformation, 168 mm occurred displacement which was measured H-point height of the baseline on the left side door and the right side door. Deformation around the fuel tank caused the most part is the fuel inlet area. Deformation in the direction perpendicular to the vehicle central longitudinal section is 39mm.

③ Pictures showing the side test

Pictures in Figure 6 show the vehicle of side impact test scene. After the test, the occupant safety requirements met KMVSS article 91, 102.

Figure 6. The test vehicle of side impact test.

B. Fail-safety evaluation

The growing interest for the deployment of electric motor driving technology has given rise to adopt the KMVSS in Acceleration Control system and to evaluate the specific safety issues of the electric motor characteristics. Electric motor control is very important to manage HEV, EV, HFCV to return to idle position for the accelerator control system. Therefore, purpose of this study is whether to adapt electric traction system to KMVSS No.87 and present a recommendation on the regulation of safety standards in electric motor drive.

(A) Test Vehicles

Table 1 shows the test vehicle's electrical power system that compares the specifications of the Prius THS-Ⅱ (Two Motor Full-Hybrid) and HEV and NEV(Neighborhood Electric Vehicle) is intended for testing and evaluation.

(B) Test methods

Test procedures and methods of KMVSS 87 and test procedure 25 conduct safety assessment in the normal state by cutting or removing the exam failed to. Prius electric-drive I / O signals to control the output of the device for cutting the production junction boxes, such as in Figure 9 are blocking the signals, a dedicated diagnostic equipment, using the measurement and analysis of test data. HEV analysis signals of junction box and ETAS INCA (ver. 5.4). EV analysis of the test data for a current meter of battery, measured with NI-PXI program developed using Labview.

Figure 9. Test vehicle and Data acquisition System

(C) Test Results

Figure 10 shows in the case of APS 1 Gnd signals cutting for the output state of the 90A and 17Nm. The test results to return to idle after 0.2 sec DC current for battery. Prius is low relative to the motor output torque and return to idle when the DC current output type, but is similar to the award.

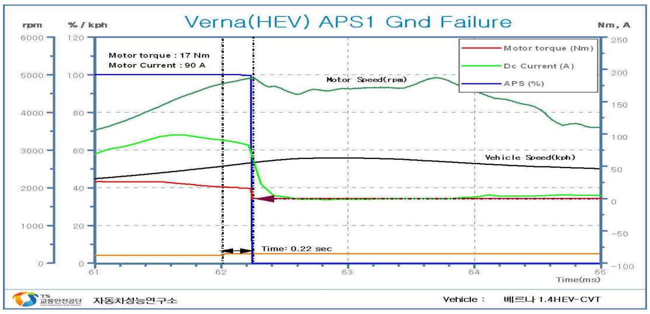

Figure 10. APS1 ground failure of HEV

Figure 11 shows that return to idle immediately when the signal was cut the motor position sensor(Resolver) in the output state of 50A and 11Nm. When the rotor position sensor occur the failure, the torque of motor blocked and the vehicle driven by the output only engine.

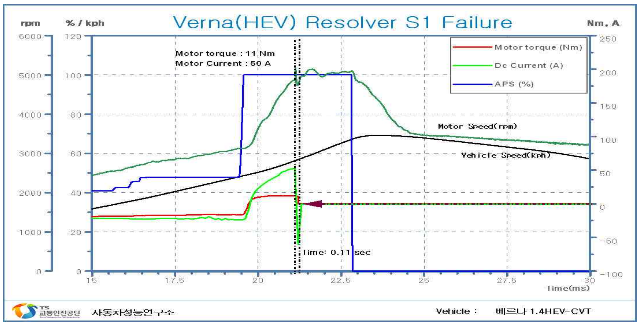

Figure 11. Failure of resolver signal

Figure 12. is a case of cutting phenomenon that motor temperature signal. Immediately after cutting, the motor power is shut off to return to idle. Failure of motor temperature sensor will work the control strategy to the system output is limited to 50%

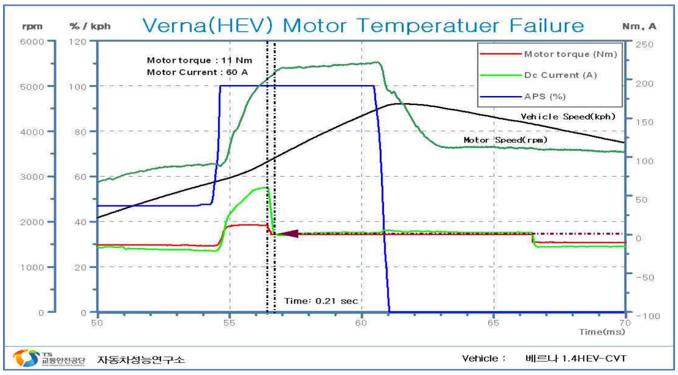

Figure 12. Failure of motor temperature sensor

2.3 Vehicle electric safety

<u>Research for electric safety of high-voltage and fuel cell system</u>

1) Assessment study and analysis of the electrical properties of the fuel cell stack
2) Analysis and evaluation methods of the high-voltage electrical characteristics
3) High voltage/current wiring system development and safety evaluation technology
4) Safety regulation for high-voltage areas draft

<u>Research for electromagnetic wave compatibility in electrical and fuel cell system</u>

1) Electromagnetic characterization for fuel cell vehicles and electronic control systems
2) Evaluation technology development for electro-magnetic fields, static electricity, electrical transient immunity performance
3) Safety regulation for electromagnetic fields areas draft

A. Electrical safety measures of post crash

Picture in Figure 13 show the insulation resistance measurement scene. After the Frontal Impact Test, 4.8 kΩ/V values for the battery and body insulation resistance measurement were to meet the criteria. (100Ω/V) [2),4)]

Figure 13. Insulation resistance measurement.

B. Electrical safety measures of in use

(A) Protection against direct contact

(1) The live parts inside the passenger compartment or luggage compartment [2),4)]

Using the IPXX D test finger, evaluation tests were carried out passenger compartment and supercapacity of luggage compartment.

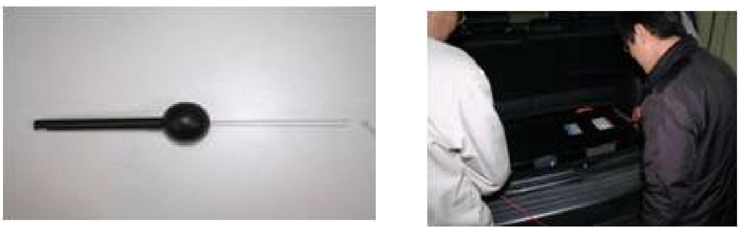

Figure 14. IPXX D (test wire) and luggage evaluation.

(2) The live parts in areas other than the passenger compartment or luggage compartment [2),4)]
Using the IPXX B test finger, evaluation tests were carried out junction box of bonnet.

Figure 15. IPXX B (test wire) and bonnet evaluation.

(3) Isolation Resistance

The minimum of electrical insulation resistance should be more than 100 Ω/V (DC), 500 Ω/V(AC). [2),4)] Insulation resistance of AC and DC input and output with both the vehicle chassis was evaluated above 1.28 kΩ /V

Figure 16. Insulation resistance evaluation.

(4) Protection against indirect contact

The test criteria of Protection against indirect contact should be less than 100 mΩ. [2),4)] The high voltage box enclosure and the Chassis was evaluated 5.4 mΩ. The supercapacitor enclosure and the chassis was evaluated 45.4 mΩ.

Figure 17. The high voltage box enclosure and the chassis evaluation.

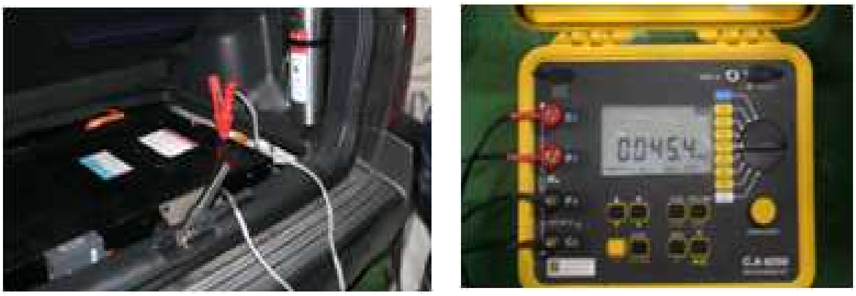

Figure 18. The supercapacitor enclosure and the chassis evaluation.

3. CONCLUSIONS

HFCV currently are not sold through mass production yet, but it is expected that mass production system will begin to meet consumer's demands in the near future.

The behavior of leaking hydrogen was investigated when a vehicle was at rest, when a vehicle was moving, and after the vehicle was shut-down because of the hydrogen leakage. The behavior of the leaking hydrogen was investigated for a moving vehicle. During the test, the head wind of 10 m/sec was blowing to the vehicle with a fan to simulate driving. Thirty four sensors were installed at points where the leaking hydrogen was expected to be trapped. The test was done at leaking rates of 10, 40 and 131 liters/min.

Next, in the frontal impact test, the test vehicle was impacted 48 km/h full frontal impact with hybrid Ⅲ 50 % male dummies. The test showed no leakage although some body deformation occurred. The electrical isolation and electrical continuity met the requirements in-use and post-crash. In case of frontal post-crash, it is not easy to measure electrical continuity because of severe damage to frontal part of vehicle.

In the rear impact test, the test vehicle was impacted form the rear by a moving barrier at the speed of 48 km/h. The test showed no leakage although some body deformation occurred.

In the side impact test, the test vehicle was impacted 50 km/h side impact with deformable moving barrier (950 kg). The test showed no leakage although some body deformation occurred. The electrical isolation and electrical continuity met the requirements in-use and post-crash.

Hydrogen fuel cell vehicles using a high-voltage electric power plant, so the failure of the device can be secured for the reliability and safety law requires that safety standards.

In this study, the main objective is to develop technology that the structure and equipment of the hydrogen fuel cell vehicles should meet the safety of the citizens to protect the lives such as hydrogen and high-voltage devices. The expected effects in this study are as follows.

1) Hydrogen fuel cell vehicle Safety Standards for the amendment
2) UN/ECE/WP.29 GTR of hydrogen fuel cell vehicle
3) Hydrogen fuel cell vehicles to minimize the risk of accidents and damage

ACKNOWLEDGEMENT

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