

# Removal of Grounding Cable from Hydrogen Fueling Process

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## ABSTRACT

Hydrogen, which is used for fuel in fuel cell vehicles, has the characteristic of being easy to ignite. Because of this characteristic, prior to fueling, static electricity from the vehicle body should be dissipated. Industry practice to mitigate this risk has been to connect a grounding cable to the vehicle to remove the static electricity from the vehicle body prior to connection of the fueling nozzle. However, this complex procedure is not user-friendly, nor is it fail safe as it depends on the user to implement.

Our research<sup>(1)</sup> shows that the maximum grounding resistance that will allow static electricity to be safely dissipated before the fueling nozzle can be connected is 100 MΩ. Two favorable fueling pad surfaces were found to be conductive paint applied on asphalt, and concrete. After application, the separate grounding cable connection is no longer necessary, and as a result, safe and user-friendly fueling is now possible. The practice of grounding through the tires is now being adopted by hydrogen stations, and surface resistance requirements have been written into the latest revisions to the International Code Council (ICC) International Fire Code (IFC).

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## 1. Introduction

The fuel cell shows much promise as a clean power plant of the next generation because of its potential to displace the use of fossil fuels and reduce emissions, including those associated with global warming. In addition to developing fuel cell vehicles, it is important to study how hydrogen is supplied to fuel cell vehicles, as hydrogen supply will influence the appeal and marketability of fuel cell vehicles in the future.

## 2. Background

Hydrogen, which is used for the fuel in fuel cell vehicles, has some properties that make it quite unique from other vehicle fuels. The most common fuel in use today is gasoline, with natural gas (consisting primarily of methane) fueled vehicles a distant second. Table 1 compares some properties of these fuels<sup>(2)</sup>. Gasoline has the narrowest range of ignitable fuel/air ratio and relatively high minimum ignition energy. Methane has a slightly wider ignitable fuel/air ratio, and even higher

minimum ignition energy than gasoline. Hydrogen has a very wide range of ignitable fuel/air ratio and a very low minimum ignition energy of 0.016mJ, approximately 1/12<sup>th</sup> that of gasoline. It should be noted, however, that the minimum ignition energy in Table 1 is for stoichiometric mixtures (29% for hydrogen). At the lower flammability limit (LFL), the minimum ignition energy of hydrogen is nearly the same as that of methane.

In regards to the manner in which these fuels are dispensed, both hydrogen and natural gas are dispensed to the vehicle in a closed system designed to prevent leaks, whereas gasoline dispensing utilizes an open system where vapors can escape near the interface of the nozzle and receptacle. Additionally, the presence of natural gas and gasoline is easily detected by the user from their distinct odor, whereas hydrogen has no smell and no odorants currently exist.

The hydrogen fueling coupling and associated hydrogen storage system on vehicles is designed as a closed system in which hydrogen does not leak either

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Table 1 Ignition properties of hydrogen, methane and gasoline

| Properties              |         | Hydrogen | Methane | Gasoline |
|-------------------------|---------|----------|---------|----------|
| Minimum ignition energy | (mJ)    | 0.02     | 0.29    | 0.24     |
| Ignition limits in air  | (Vol %) | 4-75     | 5.3-15  | 1.0-7.6  |

during fueling or operation of the vehicle. However, potential ignition sources should be removed or mitigated as much as possible for safe fueling in the event that a failure of the system results in a fueling leak. Because gasoline and methane have narrower ranges of ignition limits and much higher minimum ignition energies, and leaks can be easily detected by smell, this is not as high a concern when fueling these vehicles.

Static electricity can build up on the vehicle chassis during driving, and this static electricity may be a potential ignition source during fueling. Therefore, it is important to dissipate this static charge from the chassis before fueling the vehicle. Under current industry practice, a fuel cell vehicle user connects a grounding cable (referred to as GND cable) to the vehicle first, before connecting the separate hydrogen fueling hose/nozzle (Fig. 1). The opposite side of the GND cable is connected to earth. This sequence allows the vehicle to discharge the static electricity before the fueling hose is connected and fueling begins. This practice has been implemented at nearly all hydrogen stations in the U.S. to date, as a precautionary requirement.

When fueling the test fuel cell vehicle used in this study, first the user opens a lid containing the GND connection receptacle, then connects GND cable to the GND connection receptacle. After this, the user pulls a knob in the GND lid, which then opens a separate lid containing the fueling receptacle (Fig. 1). This sequence

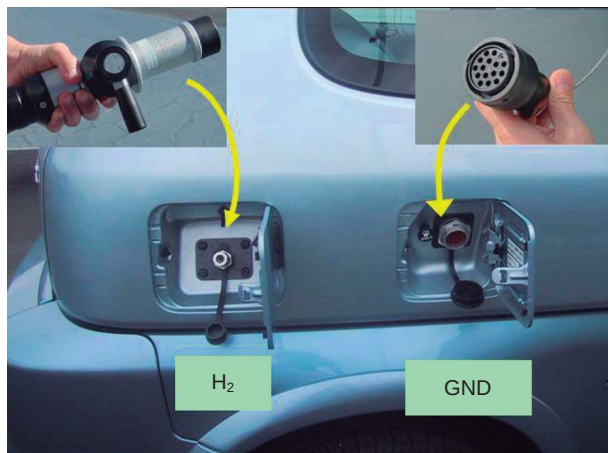


Fig. 1 Grounding cable connector/receptacle and H<sub>2</sub> nozzle/receptacle

is devised to remind the user to connect the GND cable before fueling, as a means to increase the safety of the fueling operation. However, if the user forgets to connect the GND cable or the connector isn't tightly connected, the GND cable can not work to remove the static electricity. This GND cable also increases the complexity of the fueling operation, and is not convenient for the user. Therefore, some other method to remove the static electricity surely and consistently without using the GND cable is necessary.

Although it is outside the scope of this paper, another important safety consideration when fueling a hydrogen vehicle (or even gasoline and CNG vehicles) is to help ensure that the user has discharged his / her body prior to connecting or disconnecting the nozzle. Many hydrogen stations require the user to touch a grounded conductive part on the dispenser before the nozzle can be released. Because a weak electrostatic spark from a human body releases about 10 mJ of energy (above the minimum ignition energy of all three fuels), grounding the user prior to connecting and disconnecting the nozzle is very important.

### 3. Requirements for adequate dissipation of static charge

Because the GND cable is not a reliable means of removing static charge from the vehicle chassis prior to fueling and because it is cumbersome to the user, we looked to an alternative, which is to use the existing contact between chassis and ground, i.e. the vehicle tires, as a means to removing the static charge. To help ensure that no ignition can occur, even if hydrogen is present, the grounding resistance, through the tires to earth ground, was calculated which will dissipate the static charge to a safe level within a short period of time after stopping the

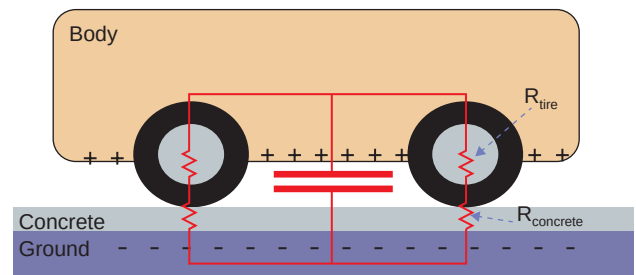


Fig. 2 Equivalent circuit of static electricity on vehicle

vehicle on the fueling pad surface. To make this calculation, an equivalent circuit of the static electricity on the vehicle is shown in Fig. 2.

The capacitance of the test vehicle was calculated to be approximately 0.5 nF by using Eq. 1. However, there may be numerous sizes of the vehicles in the future, some larger than the test vehicle. Therefore, a capacitance of 1 nF was used as a more conservative value. The literature also supports the use of 1nF as typical vehicle capacitance<sup>(3)</sup>.

$$C = \varepsilon \frac{A}{d} \quad (1)$$

C: Capacitance [F]  
d: Pole interval [m]  
 $\varepsilon$ : Aerial permittivity [F/m]  
A: The pole area [m<sup>2</sup>]

If the energy of the capacitor is smaller than the minimum ignition energy of hydrogen, hydrogen will not ignite. The capacitor's energy can be calculated from Eq. 2.

$$W = \frac{1}{2} CV^2 \leq 0.016mJ \quad (2)$$

V: Voltage of Capacitor [V]

When solving Eq. 2 for the condition of C=1nF, the answer is shown in equation 3.

$$V_t < 180V \quad (3)$$

Next we should consider the maximum voltage of the static electricity on the vehicle. There is a report which describes that a maximum of 2kV can be generated by the fuel pump in a conventional ICE vehicle<sup>(4)</sup>. Of course, on a fuel cell vehicle, because there is no fuel pump, the static electricity must be generated by a different mechanism. Because any given regional area may not be suitable to measuring the maximum static electricity voltage because of the high levels of atmospheric humidity, the 2kV value from the literature<sup>(4)</sup> was adopted as a maximum potential for the vehicle.

$$V_0 = 2000V \quad (4)$$

For a capacitor, the voltage when discharging is shown by Eq. 5.

$$V_t = V_0 \times e^{-\frac{t}{RC}} \quad (5)$$

As a result, the resistance R can be calculated from Eq. 6.

$$R = \frac{t}{C \cdot \ln \left( \frac{V_0}{V_t} \right)} \quad (6)$$

To determine the required resistance, one must first establish how much time can be allowed for the static charge to dissipate to a safe level. If the static electricity is discharged to a safe level within 1 second after the vehicle stops at the station, there is no way fueling can be initiated before a safe condition is present, so this time value was chosen.

$$t < 1sec \quad (7)$$

When solving equation 6 for the above conditions,

$$R \leq 410M\Omega \quad (8)$$

Because this resistance value is considered under ideal conditions, it may be possible that the resistance between the vehicle chassis and ground could increase due to contaminants on the vehicle tires or on the fueling pad surface. Therefore, a four times safety factor was applied to the value in Eq. 8, resulting in a maximum grounding resistance requirement as shown in Eq. 9.

$$R \leq 100M\Omega \quad (9)$$

Also SAE J2578<sup>(5)</sup> recommends that “the grounding resistance of the vehicle through the tires of the fuel cell vehicle should not exceed 25 M $\Omega$ ” while it refers to literature<sup>(3)</sup>. Therefore, if the vehicle tires meet the SAE J2578 recommended practice, the fueling pad surface itself should have a resistance of less than 75 M $\Omega$ .

#### 4. Tests conducted to validate grounding through the tires

As discussed earlier, the goal of our research is to discharge the static electricity through the tires without the

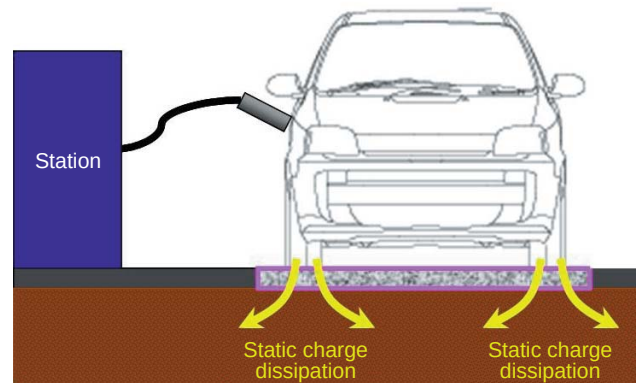


Fig. 3 Static charge dissipation through vehicle tires

use of a GND cable. If it is possible to discharge directly from the chassis through the tires to the Earth, the GND cable becomes unnecessary and it reduces the possibility of human error or negligence (Fig. 3). For this to occur, the grounding resistance of the vehicle chassis through the tires, including the parking surface, should be less than 100 M $\Omega$  as shown in Eq. 9. However, a tire is made of rubber (an inherently isolative material), and fueling pad surfaces at hydrogen stations are often made without any consideration for conductivity. Therefore, we conducted some validation tests as shown in the next section.

## 5. Validation Testing

### 5.1. Testing the basic resistance of the vehicle

In this test, we measured the resistance of the FC test vehicle on steel plates. The four tires of the test vehicle were placed on four steel plates which were connected in parallel electrically. We then measured the resistance between the steel plates and the chassis (Fig. 4). The result was a resistance of 1.7 M $\Omega$ . Because this resistance is much lower than the required resistance (100 M $\Omega$ ), the test vehicle itself has enough low resistance to discharge the static electricity to the ground.

Next, we measured a number of conventional vehicles in the same way to understand the influence of tire selection. There were large differences in the results, ranging from 30 k $\Omega$  up to 370 M $\Omega$  (Table 2). The resistance was measured at a number of different locations on the chassis, and found to be the same, which indicates that nearly all of the resistance is contributed to by the tires themselves. An observation from our measurements is that high profile tires tend to have higher resistance values than low profile tires.

### 5.2. Testing the grounding resistance on asphalt

We measured the grounding resistance of the the FC test vehicle on an asphalt surface. The measurement result was 800 M $\Omega$ , which is much higher than the required resistance (100 M $\Omega$ ). Therefore, an asphalt fueling pad

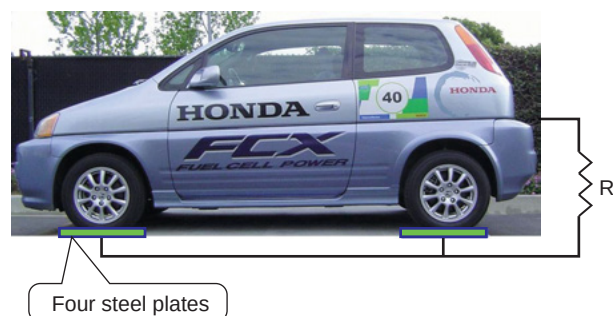


Fig. 4 Measuring resistance through tires parked on steel plates

Table 2 Resistance measurements for various cars and tires

| Vehicle                | Tire       | Resistance      |
|------------------------|------------|-----------------|
| Fuel cell test vehicle | 205/60R15  | 1.7 M $\Omega$  |
| Passenger car 1        | 195/60R15  | 35 M $\Omega$   |
| Passenger car 2        | -          | 51 M $\Omega$   |
| Passenger car 3        | 245/40R18  | 8.3 M $\Omega$  |
| Passenger car 4        | 275/40R19  | 10.7 M $\Omega$ |
| Mini Van               | 225/60R16  | 19 M $\Omega$   |
| SUV 1                  | 235/55R18  | 200 M $\Omega$  |
| SUV 2                  | 235/65R17  | 370 M $\Omega$  |
| SUV 3                  | 235/55R17  | 19 M $\Omega$   |
| SUV 4                  | 245/75R16  | 1.2 M $\Omega$  |
| Sports car 1           | 255/40ZR18 | 1.3 M $\Omega$  |
| Sports car 2           | 255/40R17  | 0.03 M $\Omega$ |

surface is not suitable to discharge the static electricity through the vehicle tires.

### 5.3. Testing the grounding resistance on concrete

At conventional gasoline stations, the fueling pad surface is usually made of concrete to protect from oil spills and other chemical contaminants. To see how this conventional surface performed, we measured the grounding resistance of the FC test vehicle on a concrete pad. This concrete was constructed using common construction methods, had no paint or coating on the surface, and the reinforcing bars were grounded to the earth. The result was a resistance value of 2.3 M $\Omega$  (Fig. 5). Therefore, a concrete fueling pad surface is suitable to safely discharge the static electricity through the vehicle



Fig. 5 Measuring resistance through tires parked on concrete test pad

Table 3 Resistance of FC test vehicle on various fueling pad surfaces

| Steel          | Concrete       | Conductive Paint |
|----------------|----------------|------------------|
| 1.7 M $\Omega$ | 2.3 M $\Omega$ | 2.5 M $\Omega$   |

tires. Of course, there is a possibility that the resistance value would increase if paint or other coatings were applied to the surface.

#### 5.4. Testing the grounding resistance on conductive paint

When installing a hydrogen station, asphalt may already be in place, or can be applied as the fueling pad surface much less expensively than with concrete. Replacing the asphalt fueling pad surface with concrete to remove static electricity may not be economical. Floor paint with high conductivity to remove static electricity is commonly marketed and available for semiconductor industries and other uses where it is important to minimize static electricity. We applied a conductive paint<sup>(6)</sup>, which was grounded to the Earth, onto the asphalt. We then measured the grounding resistance of the FC test vehicle. The result was a resistance of 2.5 M $\Omega$  (Fig. 6). Incidentally, because we could not find conductive paint specified for outdoor use, an indoor specification conductive paint was used.

Table 3 shows a summary of the resistance measurement results of the FC test vehicle on various surfaces.



Fig. 6 Measuring resistance through tires parked on conductive painted test strip

Table 4 Resistance of FC test vehicle on concrete under adverse conditions

| Sand           |                |                | Snow            | Rain            |
|----------------|----------------|----------------|-----------------|-----------------|
| 3 mm           | 10 mm          | 20 mm          | 20 mm           | N/A             |
| 8.4 M $\Omega$ | 8.4 M $\Omega$ | 8.0 M $\Omega$ | 0.39 M $\Omega$ | 0.08 M $\Omega$ |

#### 5.5. Testing the influence of environmental factors

Because a vehicle should operate in a variety of weather and environmental conditions, we cannot assume that fueling will occur under clean, dry conditions. Therefore, we measured the grounding resistance of the concrete fueling pad surface under a variety of adverse real world conditions, including dry sand, snow, and rain (Table 4).

In the case of dry sand, the resistance was somewhat dependent on the depth, but 8.4 M $\Omega$  was the maximum value measured (Fig. 7). We measured the resistance in snow in the northeastern part of the US, and the result was 0.39 M $\Omega$  (Fig. 8). And finally, in the case of rain, the measured result was the lowest, with a resistance of



Fig. 7 Measuring resistance through tires with sand between tire and concrete pad



Fig. 8 Measuring resistance through tires with snow between tire and concrete pad



Fig. 9 Measuring resistance through tires on rain soaked concrete pad

only  $0.08 \text{ M}\Omega$  (Fig. 9). In all cases, the grounding resistance values were less than the required resistance ( $100 \text{ M}\Omega$ ). Therefore, for all weather and environmental conditions we tested for, we found the ability of the concrete fueling pad surface to safely discharge the static electricity was not affected.

As the results of the above five test regimes show, the use of conductive paint applied onto an asphalt surface, or the use of commonly constructed concrete for the fueling pad surface at a hydrogen fueling station can safely remove the static electricity from the FC test vehicle without the use of a GND cable.

## 6. Application of Results

To put our testing results into practice, we constructed two different static electricity discharging fueling pad surfaces at hydrogen stations in Torrance, CA. We applied the conductive paint to the asphalt in front of one of the fueling stations. Two grounding copper bars were embedded in the asphalt and bonded to the conductive paint. After installation, the grounding resistance was measured to be  $2.5 \text{ M}\Omega$  (Fig. 10).

At the second station, we installed a concrete fueling pad surface. After installation, the grounding resistance was measured to be  $2.3 \text{ M}\Omega$  (Fig. 11).

Because of the low measured resistance values at both hydrogen stations, it is no longer necessary to use the GND cable when fueling the FC test vehicle, or any other fuel cell vehicle meeting the SAE J2578 recommended practice for tire resistance, at these stations.

## 7. Durability and Other Factors

One downside to using the conductive paint fueling pad surface is that it can be quite slippery when it is wet, or when a user walks on it with wet shoes, so care should be taken when it is raining. Also, after six months of use, we found the paint to be peeling-off in an area where there is a low spot and rain water collects. This demonstrates that the durability of this conductive paint against rain water is insufficient. As mentioned earlier, the paint we used is specified for indoor use. Therefore,



Fig. 10 Conductive paint fueling pad surface in front of hydrogen station



Fig. 11 Concrete fueling pad surface in front of hydrogen station



Fig. 12 Deterioration of conductive paint due to rain water pooling

for this application, a non-slip outdoor spec paint is desired. Of course, in the case of concrete, it is neither slippery when wet, nor does it suffer from any durability issues.

Despite the durability issues with the conductive paint, both the conductive paint surface and concrete surface sustain good grounding resistance values over time, as measurements taken after six months were nearly the same as the initial measurements.

## 8. Expansion of Research to the Real World

Applying our findings to the two hydrogen stations used in this study has made the fueling process user friendly and safer. However, to benefit the end user and future customers, this practice should be accepted and applied to all hydrogen stations. A tendency in the industry is to be conservative when it comes to safety practices, and our findings show that it is actually safer to ground the vehicle through its tire contacts rather than through a GND cable. Our research and that of others has been studied and considered within code development organizations (CDOs) and standard development organizations (SDOs), as well as industry groups such as the California Fuel Cell Partnership. It is now generally accepted that safe hydrogen fueling can be accomplished by grounding the vehicle through its tires. At stations with concrete fueling pad surfaces, the requirement for connection of the GND cable has, in many cases, been eliminated. Also, in the 2006/07 I-code revisions to the International Code Council (ICC) International Fire Code (IFC), it states, “2209.5.1.1 Vehicle fueling pad. The vehicle fueling pad shall be constructed of a non-coated concrete pavement or shall have a resistivity not exceeding criteria of 1 megohm as measured using the methodology specified in EN 1081.”<sup>(7)</sup> With this

addition to the IFC, it will now be a permitting requirement for hydrogen stations to have a conductive fueling pad surface.

## 9. Conclusion

The aim of our study was to find a way to safely dissipate the static electric charge from the fuel cell vehicle chassis without the use of a GND cable before fueling with hydrogen. To this end, we conducted research on discharging the static electricity through the tires. The results of this research showed that if the grounding resistance of the fuel cell vehicle on the fueling pad surface is less than 100 MΩ, it is possible to safely discharge the static electricity through the tires. The FC test vehicle used in this study has a resistance of 1.7 MΩ on steel plates, 2.3 MΩ on the concrete fueling pad surface, and 2.5 MΩ on the conductive paint fueling pad surface applied onto asphalt. With these highly conductive fueling pad surfaces, the grounding resistance mainly comes from the tires. The resistance of the concrete and the conductive paint fueling pad surfaces are sufficiently small to safely fuel the FC test vehicle, even when surface contaminants of sand, snow, and rain are present. Rain and snow actually reduce the grounding resistance, while dry sand slightly increases the grounding resistance, but not to a level that affects the discharging.

Our research has thus demonstrated that the GND cable connection is unnecessary if the hydrogen station has a concrete or grounded conductive paint fueling pad surface, and the resistance of the tires on the fuel cell vehicle are less than 25 MΩ, in accordance with SAE J2578. As a result, safe and user-friendly hydrogen fueling is now possible. Furthermore, the industry is now recognizing this safe practice and other hydrogen stations are incorporating the use of low resistance fueling pads. With the latest revision to the ICC IFC now specifying both a resistance value and test method for hydrogen fueling pads, the practice of grounding through the vehicle tires will become standard practice at all hydrogen stations in the future.

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