Status Report: 150.000 km and 3000 Operating Hours with a Daimler F-CELL Vehicle

Dr. Jürgen Friedrich[1], Bernd Günther[1], Stefan Liphardt[3], Dr. Christof Nitsche[2], Dirk Peters[2], Dr. Stefan Reiff[1], Dr. Reinhold Schamm[1], Raphael Skroza[1], Hans-Frieder Walz[1]

[1] Daimler AG, [2] MBtech GmbH (for Daimler AG), [3] SL-tecH (for Daimler AG)

1. Introduction

Daimler's passenger fuel cell car (called F-CELL) fleet (60 vehicles) is in ongoing operations around the world (Figure 1) and has accumulated more than 2.000.000 km.

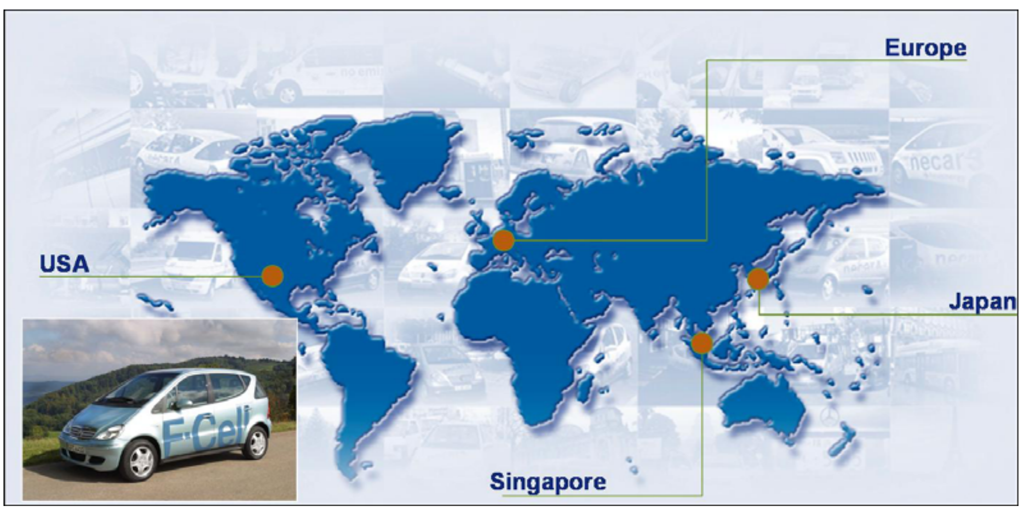

Figure 1: Worldwide F-Cell Fleet Operations

Several of the Mercedes-Benz F-CELL vehicles are used for endurance testing. In this report the findings from one of these endurance test vehicles are presented. For the endurance testing similar tests have been applied as for internal combustion engine powered vehicles. The endurance test for this vehicle was set up for 150.000 km in which the vehicle has reached roughly 3000 operating hours. The test was carried out with a single fuel cell stack and with no repair done on the stack (Figure 2). To conclude, in this work we want to present the results of this endurance test.

2. Vehicle Specifications

Figure 2: Fuel Cell Vehicle after Endurance Test

The technical specifications for this vehicle are shown in the following table:

Specifications:	
Vehicle type	Mercedes-Benz A-Class (extended version)
Fuel cell system	PEM - 72 kW (97 hp)
Drive	Electric motor Power (Continuous / Peak): 45 kW / 65 kW (87hp) Max. torque: 210 Nm (156 ft.-lb.)
Fuel	Hydrogen (350 bar / 5,000 psi)
Range	170 km (NEDC)
Max Speed	140 km/h (87 mph) limited by control
Battery	NiMh, air-cooled, Power (Continuous / Peak): 15 kW **/** 20 kW (27hp); Capacity: 6.5 Ah, 1.4 kWh

Table 1: Vehicle Specifications

The detailed setup of the propulsion system, consisting of fuel cell stack, fuel cell system, hydrogen tanks, high-voltage battery, electric traction motor and the cooling system is shown in figure 3.

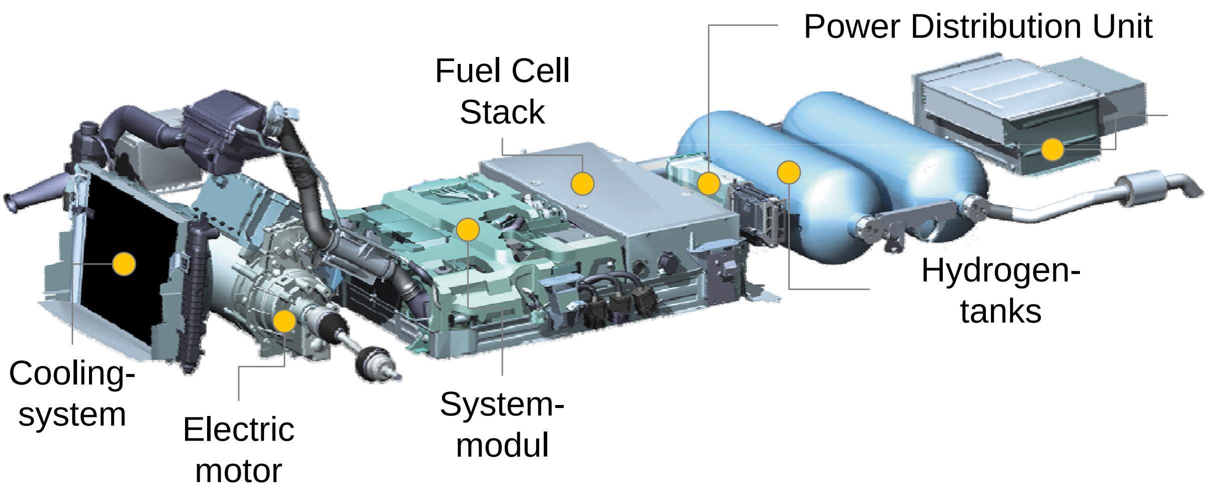

Figure 3: Fuel Cell Propulsion System

3. Fleet Data Acquisition

Since this fleet, including the vehicle used for endurance testing, is equipped with a Fleet Data Acquisition System (Figure 4), the analysis presented in this work is based on this data.

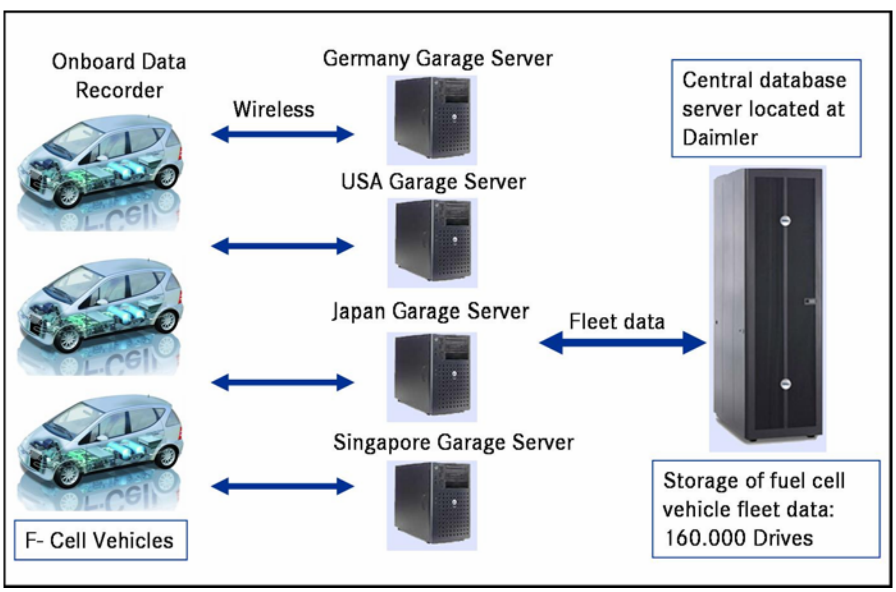

Figure 4: Fleet Data Acquisition System

4. Test Conditions

This endurance test was setup in a way that all relevant road types (highway, city…) as well as standstill are represented as shown in figure 5. The vehicle was driven for 2 years, 8 hours a day; each trip was 150 km long. In addition dynamometer tests were carried out twice a month for a detailed evaluation of the vehicle's performance.

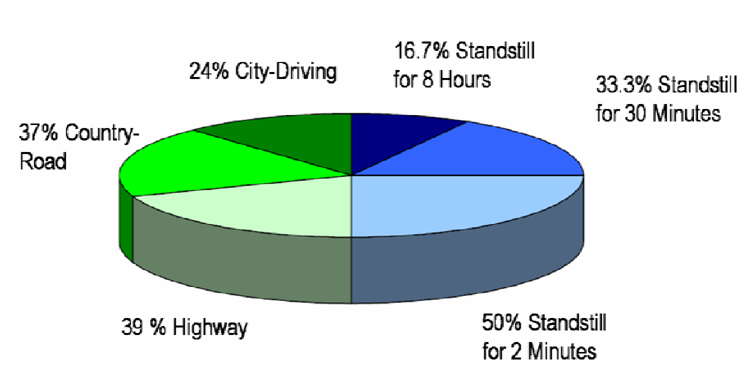

Figure 5: Timewise Distribution of Types of Roads Driven during Test

5. Lifetime Analyses

5.1 Fuel Cell Stack Degradation

The main focus of this endurance test was the fuel cell stack of the vehicle. During the whole test the vehicle was powered by one single stack, which means that the stack has not been replaced and even not been repaired. The performance of the stack was very satisfactory during the whole test.

Since this fuel cell stack consists of 440 cells divided up into 4 stack rows of 110 cells each, we were interested in the behavior of the whole stack voltage over time as well as of the individual cells over time.

Figure 6 shows the non reversible voltage degradation of the whole stack over 2500 operating hours based on drawn stack current. For example it shows a voltage degradation of 10% at maximum current and 2000 operating hours, which means that at Begin-of-Life the characteristic voltage/current curve of the stack was 10% higher at the same operating point. Figure 6 also shows that voltage degradation is higher at high currents compared to low currents, which was expected because of the higher losses on an over time increasing internal resistance. The red area underneath the degradation curves is an arbitrarily chosen voltage level of roughly 10% voltage degradation. This level was reached at around 2000 operating hours. The vehicle was still fully operational, and since this 10% loss could only be felt by very experienced drivers the test was continued until the planned 150.000 km.

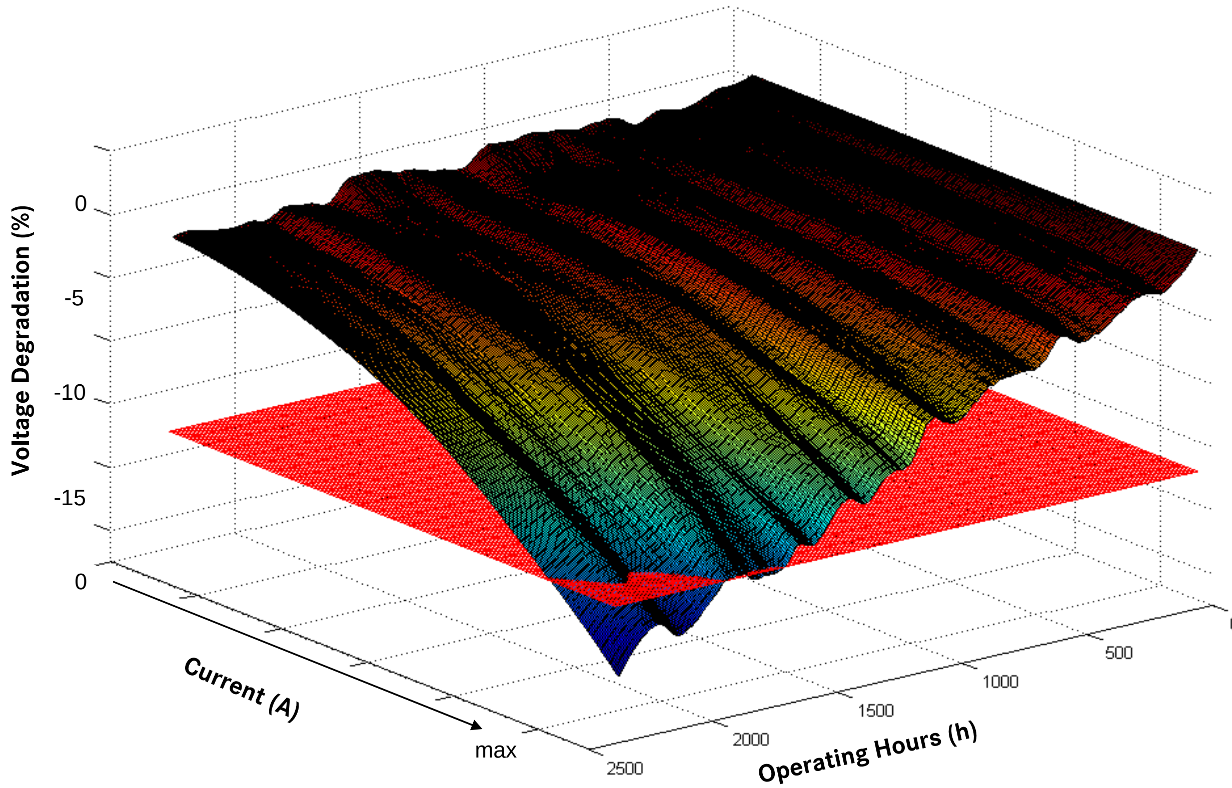

Figure 6: Voltage Degradation of Fuel Cell Stack

5.2 Single Cell Behavior

As mentioned in the previous section, in addition to whole stack performance degradation analysis we were interested in the behavior of the individual cells over time. In the following figure the number of so called Low Cell Events during the whole test is displayed based on the position of the weak cell (actually, only cell-pairs are measured) in the four rows of the fuel cell stack. We refer to a cell as Low Cell when its voltage falls below half of the average voltage of the cells in the stack. Whenever this happens, we increase the Low Cell Event Count by one.

Several things could be observed. First, the cells with the highest count are right on the edge of the rows, probably due to strong temperature gradients at the edges. Second, over the course of the endurance test, an insignificant number of Low Cell Events have occurred. And third, in row 3 a cell towards the middle of the row is affected probably due to contamination brought in by the air stream to the fuel cell stack.

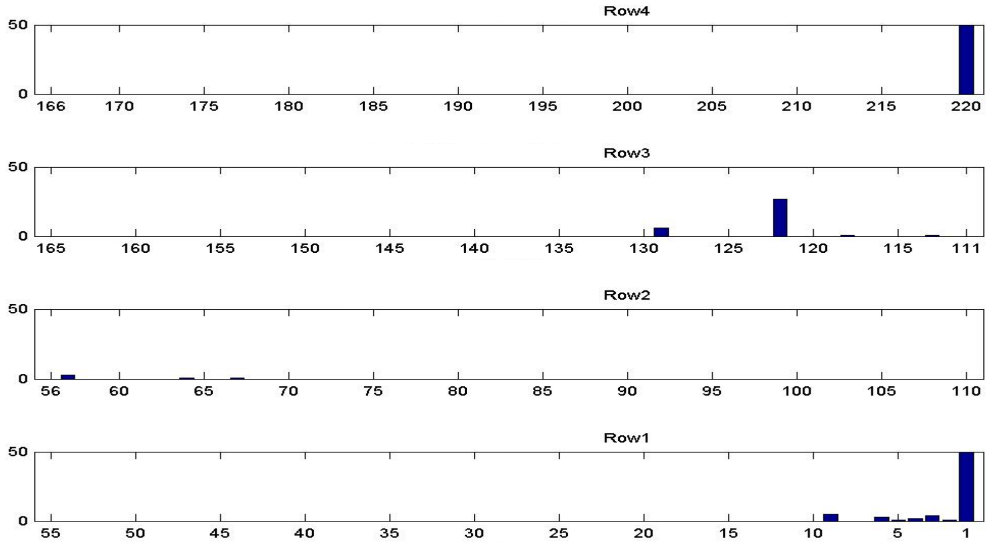

Figure 7: Location of Low Cell Events in Rows of Fuel Cell Stack

To get a better picture of such low cell events, detailed data analysis has been carried out. A snapshot of one such event at the end of the test is shown in figure 8. It shows the voltage of all cells at one point in time at moderate load. It shows that the weak cell in stack row A (top left box) is already present at moderate loads. The rest of the cells are on the same voltage level.

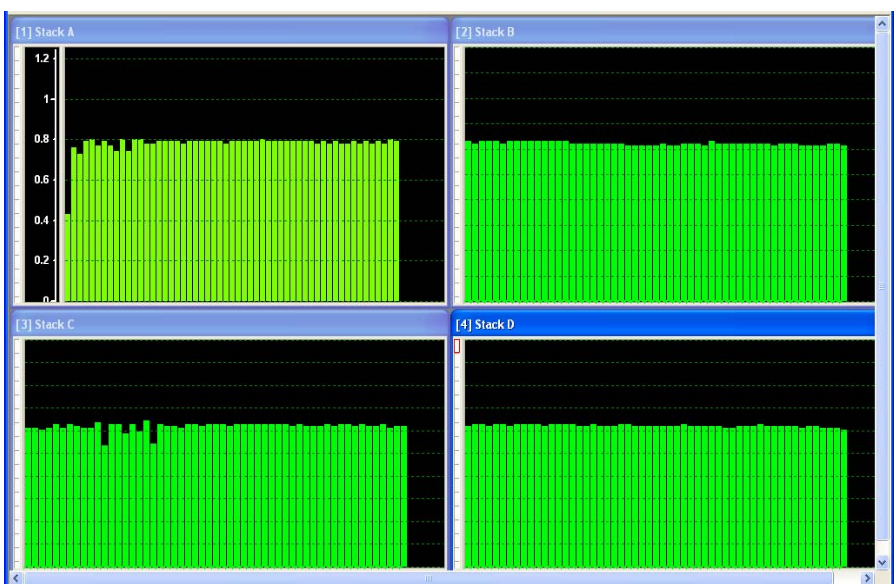

Figure 8: Voltage Distribution at Moderate Load

A similar snapshot (figure 9) was taken after increasing the load on the fuel cell stack (by stepping on the gas pedal). Now two more weak cells appear. Stack row D (bottom right box) shows a weak cell at the edge of the row, as shown earlier in figure 7. Stack row C (bottom left box) shows a weak cell at a position more towards the middle of the row (also see figure 7: row 3). These high load low cells have always disappeared after reducing the load and have not caused any trouble during the endurance test. The low cell from figure 8 in Stack row A (top left box), which is already present at low loads, did not show any significant dependence from the load and was sometimes present and sometimes not, but also did not cause any trouble during vehicle operation.

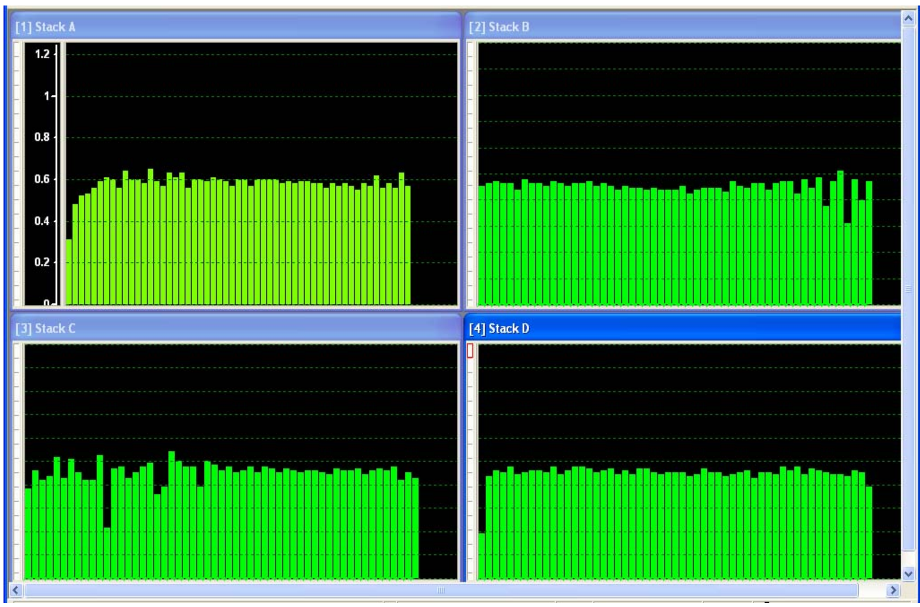

Figure 9: Voltage Distribution at High Load

6. Conclusion

This analysis of this endurance test has shown a very good reliability of the fuel cell stack and its performance. At the end of the test the vehicle was fully operational with almost the same performance levels as compared to the beginning of the test.

Whole stack voltage degradation was below 15% over the course of 3000 operating hours. Since the vehicle is operated on an average at low to moderate loads and since voltage degradation is the highest at high loads, voltage degradation does not have a noticeable influence on the vehicle's performance. For the same reason the fuel consumption stayed roughly at the same level during the whole test. In addition we experienced roughly 2-5 Low Cell Events per 10.000 km, and these events were always reversible with the exception of one edge-cell whose low voltage did not cause any influence on the vehicle's operation.

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