Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

Project number: 303445

Stack-Test

WP4: Application oriented safety / environmental test program validation report including test program report

D4.2

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Jürgen Hunger (ZSW)

Version 30/10/2015
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<th>Page</th>
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</table>
I. Introduction

This document presents the results of safety relevant Test Program validation, conducted in the second project phase of work package 4. In addition, results of Test Modules as Test Program main components are also described.

Experiences learned from the tests and derived test output were discussed in the consortium and external parties. The results were incorporated in the final Test Module and Test Program documents. The available documents are described in the respective milestone reports MS26 “Review on application safety / environmental specific Test Programs available” and MS27 “Release versions of generic safety / environmental Test Modules and application oriented Test Programs”.

II. Test Program report

In the following section, a short description of the developed and validated Test Programs is given and typical test results are presented.

II.1 General information

The consortium of work package 4 consists of following institutes:
- Zentrum für Sonnenenergie- und Wasserstoffforschung Baden-Württemberg (ZSW),
- EWE-Forschungszentrum für Energietechnologie e. V. (NEXT-E),
- JRC – Joint Research Centre - European Commission (JRC-IET) and
- Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung e.V. (Fraunhofer).

Based on the Test Modules, developed during the first project phase, specific Test Programs as listed classified in temperature, mechanical and electrical safety requirements were created and subsequently validated. The nomenclature developed in the Stack-Test project and summarised in the Stack-Test Master Document TM P-00 was consequently used in this documents and during the analysis of the validation results. Furthermore the prepared workflows for each Test Program are covered by analysing the gas leakage rates and a power analysis to identify degradation effects caused by the applied test procedures. In addition to this procedure the recommended sequence of topic-specific Test Modules is elected from less harmful to harmful.
The Test Modules can be considered as individual building blocks within specific Test Programs. Test Modules from other work packages of the Stack-Test project like e.g. “TM P-08 Polarisation Curve” from the work package 2 “Functional / performance testing” have also been used in the definition of the Test Programs as required.

An overview of safety relevant Test Programs is given in Table 1.

<table>
<thead>
<tr>
<th>final number</th>
<th>Test Program title</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP S-01</td>
<td>Mechanical Safety Analysis</td>
</tr>
<tr>
<td>TP S-02</td>
<td>Temperature Safety Analysis</td>
</tr>
<tr>
<td>TP S-03</td>
<td>Electrical Safety Analysis</td>
</tr>
</tbody>
</table>

Table 2 presents an overview of all available safety Test Modules.

<table>
<thead>
<tr>
<th>final number</th>
<th>Test Module title</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM S-01</td>
<td>Gas Leakage Test</td>
</tr>
<tr>
<td>TM S-02</td>
<td>Vibration Test</td>
</tr>
<tr>
<td>TM S-03</td>
<td>Pressure Stability Test</td>
</tr>
<tr>
<td>TM S-04</td>
<td>Freeze-Thaw-Cycling Test</td>
</tr>
<tr>
<td>TM S-05</td>
<td>Excess Temperature Test</td>
</tr>
<tr>
<td>TM S-06</td>
<td>Short-Time Rated Current Test</td>
</tr>
<tr>
<td>TM S-07</td>
<td>Dielectric Strength Test</td>
</tr>
<tr>
<td>TM S-08</td>
<td>Short-Circuit Test</td>
</tr>
</tbody>
</table>

**II.2 Test Program TP S-01: Mechanical Safety Analysis**

The aim of this Test Program is to evaluate the mechanical stack-robustness, considering specific degrees of stress compared to regular operation. Impacts caused by media pressure and vibration is analysed by initial and follow-up tests of gas leakage and electrical power. The Test Program workflow comprises the Test Modules “Vibration Test” (TM S-02), “Pressure Stability Test” (TM S-03). Changes of gas leakage rates during a Test Program are recorded by measurements based on
the Test Module “Gas Leakage Test (TM S-01). Impacts to the electrical stack performance are recorded by a nominal power test or a polarisation curve.

The mechanical stress caused by the “Pressure Stability Test” is initiated by application of pressures above the stack specifications in the reactant and coolant compartment respectively.

The simulation of mechanical impacts to the stack during transport is covered by the Test Module “Vibration Test”, where a standardised vibration profile for battery transport safety tests was adapted to fuel cell stack testing.

The test results help to improve the stack construction in a consolidated compromise of cost, power / lifetime, weight / dimensions and mechanical safety.

II.3 Test Program TP S-02: Temperature Safety Analysis

The aim of this Test Program is to evaluate the thermal stack-robustness, analysing the impact of defined temperature-stress on the fuel cell stack safety. It contains freeze-thaw cycling where the stack is in a passive state and possible excess temperature during operation. These impacts are covered in the Test Modules “Freeze-Thaw-Cycling Test” (TM S-04) and “Excess Temperature Test” (TM S-05).

Changes of gas leakage rates during a Test Program are kept track of by measurements based on the Test Module “Gas Leakage Test (TM S-01)”. Impacts to the electrical stack performance are followed by a nominal power test or a polarisation curve.

The Freeze-Thaw Cycling Test is based on a defined temperature / humidity test profile to simulate potential impacts during transport, where the stack is in a passive state.

The Excess Temperature Test considers possible system-failures like over temperature caused by a disruption or a complete breakdown of the cooling subsystem. Test outputs can provide helpful information for system integrators to configure their system.

II.4 Test Program TP S-03: Electrical Safety Analysis

This Test Program is aimed on evaluating the electrical safety of a PEM fuel cell stack exposed to induced system failure like short-circuit and electrical specified overload. Also electric shock protection demands are covered there. The Test Program workflow comprises the Test Modules “Short-time Rated Current Test (TM S-06)”, “Dielectric Strength Test (TM S-07)” and “Short-Circuit Test (TM S-08)”. Chang-
es of gas leakage rates are located by the Test Module “Gas Leakage Test (TM S-01)”. Impacts to the electrical stack performance are traced by a nominal power test or a polarisation curve.

The Short-time Rated Current Test intends to analyse the capability of conveying a specific degree of excess thermal power caused by electrical overload for a defined time.

Dielectric Strength measurements are aimed on testing isolation materials to avoid dangerous fault currents during possible human contact.

Short-Circuit measurements are aimed on measuring the maximum current coming out from the stack as basic information for system safety configuration.
III. Test Program validation

In the following, a summary of the main validation results of Test Programs is presented.

III.1 General information

An overview of individual Test Program validation by the work package 4 partners is presented in Table 3.

<table>
<thead>
<tr>
<th>Partner</th>
<th>Test Program</th>
<th>Safety</th>
<th>Test Program</th>
<th>Safety</th>
<th>Test Program</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TP S-01 Mechanical Analysis</td>
<td></td>
<td>TP S-02 Temperature Analysis</td>
<td></td>
<td>TP S-03 Electrical Analysis</td>
<td></td>
</tr>
<tr>
<td>1 Fraunhofer ISE</td>
<td>X³</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 JRC-IET</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Next Energy</td>
<td>X³</td>
<td>-</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 ZSW</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
1 only Excess Temperature
2 only Vibration / Shock
3 only Pressure Stability Test

III.2 Validation results

Subsequent validation results of the individual Test Programs are presented in this chapter. As shown in table 3 all Test Programs were able to validate even if not all work package partners could analyse all test procedures completely. Nevertheless comparable results could generate during the validation phase in the second period of the Stack-Test project.

III.2.1 Test Program TP S-01: Mechanical Safety Analysis

The workflow of the validated Test Program “Mechanical Safety Analysis (TP S-01)” is shown in
Figure 1.

The results presented are based on validation with ZSW-stacks (BZ100) equipped with 10 and 16 cells.
Gas Leakage Test
TM S-01

Start-up
TM P-00

Preconditioning
TM P-00

Fast leakage test
TM S-01

Nominal rated power
TM P-00

Stack ShutDown and Stack operation off

Alternative:
Polarisation Curve TM P-08

Pressure Stability Test TM S-03

Fast leakage test
TM S-01

Stack operation off

Nominal rated power

Vibration Test TM S-02

Subdivided tests
- Allowable Working Pressure,
- Differential Pressure Test
- Overpressure of cooling compartment

Fast leakage test
TM S-01

Nominal rated power
TM P-00

Shut-down
TM P-00

Alternative:
Polarisation Curve TM P-08

Gas Leakage Test
TM S-01

Subdivided tests
- Resonance Seeking Test
- Vibration Test

Figure 1: Test Program Mechanical Safety Analysis (TP S-01)
Results:

→ **Gas Leakage Test TM S-01**

The result of the Gas Leakage Test as the main test output is listed in Table 4. At the end of the Test Program the gas leakage rates of the specific stack compartments are comparable to initial values. A slightly increase of the external gas leakage rate of 1 ml / min is possibly caused by a minimal reduced clamping force of the stack, whereat the measurement tolerance of about ± 0.5 Nm, caused by the manual measurement, has also to be considered.

<table>
<thead>
<tr>
<th>State of measurement</th>
<th>Date of measurement</th>
<th>over-pressure (kPa)</th>
<th>gas leakage [ml/min] at the respective compartments, after a pressure-stabilisation time of 5 minutes</th>
<th>clamping torque mounting bolt [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial (Start Test-Program)</td>
<td>11.09.2014</td>
<td>51</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>End (End Test-Program)</td>
<td>12.09.2014</td>
<td>50</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

1) simultaneous pressurization of anode, cathode and coolant compartment
2) simultaneous pressurization of anode and cathode compartment

**TM - specific frame conditions and intermediate results:**

→ **Pressure Stability Test TM S-03:**

**TM S-03a : Allowable Working Pressure**

The anode and cathode compartment were interconnected to be tested simultaneously at the same pressure level on a regular equipped fuel cell test bench. After heating up to the maximum specified operating temperature of 85°C, the maximum specified reactant pressure of 300 kPa_{abs} was 1.3 times amplified to 390 kPa_{abs} by using the test gas helium. This pressure was held constant for 10 minutes.

**TM S-03b : Differential Pressure**

The anode and cathode compartment were tested separately and subsequently at the maximum specified operating temperature of 85°C again. Based on the maximum specified differential pressure of 50 kPa_{abs}, amplification with factor 1.3 resulted in a test pressure of 65 kPa_{abs} as exemplary presented in figure 2.
Figure 2: Allowable Working Pressure TM S-03b – mechanical test impact

Vibration Test TM S-02:

The vibration test was executed on a fatigue testing machine, impulsed powered by an electromagnetic vibration exciter.

Based on demands for batteries during transport, the load profile described in recommendations « UN manual of Tests and Criteria », section 38.3.4.3 was adapted to fuel cell stacks.

The vibration profile is defined by acceleration values (unit “g”) and partly additionally by amplitudes (unit “mm”). The Profile has a sinusoidal waveform with logarithmic frequency sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 minutes (see Table 3). The cycle shall be repeated 12 times for a total of 3 hours of three mutual perpendicular mounting positions of the fuel cell stack. One of the directions has to be perpendicular to the fixing plate.
Table 5: Parameters for the logarithmic frequency sweep

<table>
<thead>
<tr>
<th>frequency range [Hz]</th>
<th>peak acceleration [g, m/s²]</th>
<th>amplitude (peak to peak) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 - 18</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>18 - 50</td>
<td>1 - 8</td>
<td>1.6</td>
</tr>
<tr>
<td>50 - 200</td>
<td>8</td>
<td>-</td>
</tr>
</tbody>
</table>

Additional to the vibration load profile, a resonance sweep test (0 – 2000 Hz) was performed in the axis X, Y and Z to identify the mechanical stiffness and specific resonance spectrum of the stack.

A ready-mounted fuel cell stack on the vibration table, prepared for testing in X- direction, is presented in Figure 3.

The acceleration- and amplitude-values (fuel cell and table) of the load profile is exemplary shown in Figure 4. The red line is presenting the acceleration value on the table position (reference) and the blue line the response value on the respective fuel cell position. Additionally the corresponding amplitude values in “mm” are on the 2nd y-axis.

Figure 5 shows exemplary the result of the resonance sweep test in Z-direction. The identified response values of the fuel cell stack in specific excitation frequencies is the characteristic fingerprint of its stiffness in the respective axis of the stack.

Figure 3: Ready-mounted stack on the vibration test bench
Figure 4: Example for an excitation and response profile, excitation in Z-direction

Figure 5: Example for a resonance sweep test, excitation in Z-direction
Polarisation Curve TM P-08:

The electrical performance of the fuel cell stack before and at the end of TP S-01 is shown in Figure 6. Both polarisation curves are almost perfectly matching. Accordingly the mechanical impact of TP S-01 caused no detectible degradation to the electrical performance.

![Polarisation Curve](image)

Figure 6: Result polarisation curve at the beginning and the end of Test Program TP S-01
III.2.2 Test Program TP S-02: Temperature Safety Analysis

The workflow of the validated Test Program “Temperature Safety Analysis TP S-02” is shown in Figure 7. The Safety Test Modules Freeze-Thaw Cycling Test TM S-04 and Excess Temperature Test TM S-05 are embedded in the specific framework of a Test Program.

![Workflow of Test Program S-02]
**Results:**

→ **Gas Leakage Test TM S-01**

The result of the Gas Leakage Test as the main output parameter is listed in Table 6. At the end of the Test Program the gas leakage rates of the specific stack compartments are comparable to initial values. The gas leak rate did not deteriorate as a consequence of the test.

**Table 6: Result Gas Leakage Test of TP S-02**

<table>
<thead>
<tr>
<th>State of measurement</th>
<th>Date of measurement</th>
<th>over-pressure (kPa)</th>
<th>gas leakage rate [ml/min] at the respective compartments, after a pressure-stabilization time of 5 minutes</th>
<th>clamping torque mounting bolt [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>limit (anode)</td>
<td>external(^1) (anode)</td>
</tr>
<tr>
<td>Initial (Start Test-Program)</td>
<td>10.11.2014</td>
<td>50</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>End (End Test-Program)</td>
<td>11.11.2014</td>
<td>50</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

\(^1\) simultaneous pressurization of anode, cathode and coolant compartment  
\(^2\) simultaneous pressurization of anode and cathode compartment

**TM - specific frame conditions and intermediate results:**

→ **Freeze-Thaw Cycling Test TM S-04:**

Figure 8 presents the performed temperature / humidity profile with a cycle time of about 720 minutes (12 hours) within a temperature range of -30°C to +40°C. The cycle was 10-times subsequent repeated. The relative humidity level is set to r.H. 50 % during ambient temperature 40°C.

The instrumented stack, equipped with temperature sensors at defined positions, is shown in Figure 9.
Excess Temperature Test TM S-05:

The Excess Temperature Test is to evaluate the response time of a liquid or air cooled fuel cell stack under excess temperature conditions. The results can be valuable information for the system integrator.

The test aims at simulating two different failures of the coolant subsystem, described in following methods:
**Method A** is to measure the time of the stack under nominal operating conditions after switching the stack coolant off (complete coolant breakdown) until the minimum cell voltage drops below the specified safety limit.

**Method B** is to measure the response of a stack operating at excess stack temperature conditions caused e.g. by a lack of cooling water while other operating parameters remain unaltered. Excess temperature means stack temperature above specification.

Figure 10 shows an example of **method A**-validation. The time between shut-off of the coolant pump and the cell voltage break-down is measured. The time between coolant shut-off and reaching the minimum cell voltage limit was about 30 seconds.

Figure 11 presents an example of validation based on **method B**, performed on a regular equipped test bench without actions on the test setup during the test. The coolant inlet temperature T.Si.Cl was set to the maximum safety limit of 90°C. Depending on the degree of stack load, at rising stack load the coolant outlet temperature drifted more and more into excess temperature conditions. The polarisation curve “EXTREME” is shown compared to the polarisation curve in reference operating conditions.

![Figure 10: Validation of method A: Coolant temperature vs. stack current and stack voltage](image_url)
Figure 11: Validation of method B: Polarisation Curve

**Polarisation Curve TM P-08:**

The electrical performance of the fuel cell stack before and at the end of TP S-02 is shown in Figure 12. Both polarisation curves are almost identical. Accordingly, the thermal impact of TP S-02 caused no detectible degradation to the electrical performance.
### III.2.3 Test Program TP S-03: Electrical Safety Analysis

The workflow of the validated Test Program “Electrical Safety Analysis TP S-03” is shown in Figure 13. The Safety Test Modules Short-Time Rated Current Test TM S-06, Dielectric Strength Test TM S-07 and Short-Circuit Test TM S-08 are embedded in the specific framework of a Test Program.

![Workflow Diagram](image)

---

**Figure 13: Workflow of Test Program S-03**
Result:

⇒ **Gas Leakage Test TM S-01**

The result of the Gas Leakage Test as the main output parameter is listed in Table 7. At the end of the Test Program the gas leakage rates of the specific stack compartments are comparable to initial values. No increase in leak rate has been observed.

### Table 7: Result Gas Leakage Test of TP S-03

<table>
<thead>
<tr>
<th>State of measurement</th>
<th>Date of measurement</th>
<th>over-pressure (kPa)</th>
<th>gas leakage rate [ml/min]</th>
<th>clamping torque mounting bolt [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>at the respective compartments, after a pressure-stabilization time of 5 minutes</td>
<td></td>
</tr>
<tr>
<td>initial (Start Test-Program)</td>
<td>4-Jun-2014</td>
<td>50</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>End (End Test-Program)</td>
<td>5-Jun-2014</td>
<td>51</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

1) simultaneous pressurization of anode, cathode and coolant compartment
2) simultaneous pressurization of anode and cathode compartment

**TM - specific frame conditions and intermediate results:**

⇒ **Short-Time Rated Current Test TM S-06:**

The scope of this Test Module is to check the capability of a fuel cell stack module with autonomous cooling- and stack-control system. A specified time-limited electrical “overload” should not lead to an overheating and damaging of the stack module.

Validation on test bench level can give valuable information about the maximum thermal energy to be conveyed in a stack module or a fuel cell system. Figure 14 shows exemplary the result of a Short-Time Current Test, where an electrical overload for about 8 minutes was performed. The average and the minimum cell voltage dropped temporarily below the specified limit of 500 mV.

Compared to nominal operating conditions of 120 A, the thermal power to convey by the cooling system increased from 1400 W to 1600 W.
Dielectric Strength Test TM S-07:

The scope of this electrical safety test is to analyse the dielectric strength of the electrical insulation between active and not current leading parts of the stack. Based on the maximum OCV-voltage of about 16 V at the 16-cell ZSW-Stack, the test parameters selected are shown in the red framed row of Table 8 below.

During test execution, the stack was heated to the specified nominal temperature of 80°C.

The test is passed if the induced voltage causes in no electrical flash over and the leakage current is below the maximum specified value of 16 mA, calculated by Equation 1.

\[
I_{\text{leakage}} \leq \frac{\text{Test voltage}}{\text{no} - \text{Load voltage}} \cdot 1mA
\]

Equation 1: Calculation of maximum leakage current
An example for stack under test conditions is shown in Figure 15, whereat Figure 16 an example for a test report presents. The maximum leakage current was below the specified limit.

### Table 8: Test parameters for Dielectric Strength Test TM S-07

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCV</td>
<td>Test Voltage, AC and DC, for circuits with basic insulation and electrical protective separation</td>
<td>Test Voltage, AC and DC, for tests between electrical circuits and touchable surfaces (conducting or not conducting, but not connected to safety ground)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AC effective [kV]</td>
<td>DC [kV]</td>
</tr>
<tr>
<td>≤50 V</td>
<td>0,35</td>
<td>0,5</td>
<td>0,35</td>
</tr>
<tr>
<td>100 V</td>
<td>0,5</td>
<td>0,7</td>
<td>0,7</td>
</tr>
<tr>
<td>150 V</td>
<td>0,8</td>
<td>1,1</td>
<td>1,3</td>
</tr>
<tr>
<td>230 V</td>
<td>1,1</td>
<td>1,6</td>
<td>1,8</td>
</tr>
<tr>
<td>300 V</td>
<td>1,2</td>
<td>1,7</td>
<td>2,2</td>
</tr>
<tr>
<td>400 V</td>
<td>1,35</td>
<td>1,9</td>
<td>2,6</td>
</tr>
<tr>
<td>600 V</td>
<td>1,65</td>
<td>2,3</td>
<td>3,5</td>
</tr>
<tr>
<td>690 V</td>
<td>1,8</td>
<td>2,5</td>
<td>3,8</td>
</tr>
<tr>
<td>1 V</td>
<td>2,25</td>
<td>3,2</td>
<td>5,0</td>
</tr>
<tr>
<td>1,5 V</td>
<td>3,0</td>
<td>4,2</td>
<td>6,4</td>
</tr>
<tr>
<td>3 V</td>
<td>5,25</td>
<td>7,4</td>
<td>11,02</td>
</tr>
<tr>
<td>6 V</td>
<td>9,75</td>
<td>13,8</td>
<td>17,5</td>
</tr>
<tr>
<td>10 V</td>
<td>15,75</td>
<td>22,3</td>
<td>34,0</td>
</tr>
</tbody>
</table>
Short-Circuit Test TM S-08:

This test is aimed at determination of the short-circuit current as the maximum current coming out from the stack. An additional test output is the short-circuit voltage giving information about the internal cell resistance.

During test execution the stack was in a fully conditioned OCV-state with disconnected electrical load. The conditioning parameters stack temperature (T.Si.Cl) and reactant pressures (p.So.A and p.So.C) were set to nominal conditions of 80°C and 150 kPa$_{abs}$. Also the reactant flows were set to nominal values equivalent to 1 A/cm$^2$ at stoichiometries of 1.5 for the anode and 2.0 for the cathode conditioned to r.H. 100 %, corresponding to dewpoint values of DPT.S.A and DPT.S.C of 80°C.

The short-circuit test was carried out in two laboratories (Fraunhofer ISE and ZSW) in different ways but with the same stack (ZSW BZ100 #822, 16 cells). ZSW provoked the short-circuit by a mechanic stamp, Fraunhofer ISE by an electronic high-current conducting semiconductor device. Both measurement equipment’s were able to provide a highspeed data acquisition with sampling rates $\geq$ 50.000 Hz. The prepared test bench of Fraunhofer ISE for Short-Circuit measurements is shown in...
Figure 17; the test bench of ZSW is presented in Figure 18. Compared to the ZSW-test device, the cross section area of the load cables at the test device at Fraunhofer ISE is significantly larger.

Figure 19 presents the result of Fraunhofer ISE, where a maximum current of about 1000 A was measured. The result of ZSW is presented in Figure 20 with a maximum current of 759 A. Based on the measured values, the internal resistance of one single cell can be determined as presented in Figure 20.

The deviation of the test result is possibly caused by significant different cross-sections of the load cables as already described above, resulting in different internal resistances within the short-circuit convey which has a direct influence to the current.

Proceeding measurements above the scope of the Stack-Test project are scheduled.

---

**Figure 17**: Prepared test bench at Fraunhofer ISE
Figure 18: Prepared test bench at ZSW

Figure 19: Result Fraunhofer ISE (electronic semiconductor device)
III.3 Summary

The final revised Test Programs could be validated with viable results.

All documents include a one-page abstract as a summary of the individual Test Program. The use of Test Programs promotes the comparability of test results and deviations can be analysed in a clear and comprehensible way. It could be shown that the test procedures (work flows) developed are feasible according to the descriptions in the several documents. This includes also the decisions of the analysed Test Modules in the Test Programs from less harmful to harmful for PEM fuel cell stack lifetime under safety aspects.

Even if not all Test Programs could not be fully validated in all test laboratories (caused by the equipment, see table 3), it could be shown that the test results are comparable between the different work package partners. As examples the validation of short-circuit tests shall be given, where two test methods show the same behaviour of the results.
Furthermore it was possible to validate all Test Programs and the results identifies also ambiguous description which are caused in a successful revision of the Test Programs and partly also the included Test Modules. The finally revised documents are summarised in MS27 report.