DEGRADATION ANALYSIS OF CFY-STACKS MK35X
A GUIDE FOR EXACT MEASUREMENT

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Overview

- Introduction
- Experimental setup
  - Test protocols, stack unit, test rig
- Results
  - Test methods
  - Performance test
  - Long term stability and uncertainties
- Conclusion
Introduction: The Fraunhofer-Society at a glance

Applied research for the immediate benefit of the economy and society

- Nearly 28,000 employees
- 74 institutes and research units

Finance volume

2019

- € 2.8 billion
- € 2.3 billion

- Major infrastructure capital expenditure and defense research
- Almost 30% is contributed by the German federal and Länder Governments.
- More than 70% is derived from contracts with industry and from publicly financed research projects.
**Introduction: Fraunhofer IKTS**

<table>
<thead>
<tr>
<th>Personnel (full-time equivalents)</th>
<th>613</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall budget in million €</td>
<td>64.3</td>
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<tr>
<td>Industrial revenues in million €</td>
<td>22.9</td>
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(Latest update: December 31, 2019)

**Institute Director:**
Prof. Dr. Alexander Michaelis
Introduction: Fraunhofer IKTS
Complete Value Chain - „From Powder to Power“

Materials and Processes
- Powders, Pastes, Foils
- Protective Coatings
- Characterization

Cell and Stack Components
- Electrodes, MEAs
- Contact Layers
- Glas Sealings

SOFC and SOEC Stacks
- CFY Mk35x, 10-40E
- HotBox-Integration
- Test & Characterization

Reactors and System Components
- Reformer, Burner, HEX
- Membrane Reactors
- Sensors

Production Planning, Pilot Manufacturing
- Design to Cost
- Production Planning
- Pilot Manufacturing

System Engineering and Demonstration
- Proof-of-Concept
- System Prototypes
- Safety Concept, CE

Customized Test-Rigs and Validation
- Customized Test-Rigs
- Assembly, Commissioning and Operation

CAD and Simulation
- System Concepts
- 2D, 3D CAD
- Process+ Component Models
Introduction: Hurdles on the way of commercialization of SOC

- Cost reduction
  → Target 500-3000 €/kW

- Lowering degradation
  → Target: $\frac{\Delta P}{P_0} < 0.5\ %/1000\ h$
    ($\Delta ASR < 16\ m\Omega cm^2/1000\ h$)
Introduction: Test protocols

- IEC 62282, SOCTESQUA, VDMA

Test methods and rated conditions standardized and validated.

Source: Solid Oxide Cell and Stack Testing, Safety and Quality Assurance, Test Module 09: Temperature sensitivity, 2017
Experimental setup: Test rig and stack measurement

Schematic test rig

Real test rig at IKTS

→ Infrastructure and equipment is very different
→ Rated test conditions must be known and monitored

Source: Solid Oxide Cell and Stack Testing, Safety and Quality Assurance, Test Module 00: General SOC Testing Guidelines, 2017
Experimental setup: Stack unit MK352

- Cover plate
- Bipolar plate
- Protective layer
- Cell with 10ScSZ electrolyte and contact layer
- Anode contact
- Stamped glass sealing
- Ground plate with current plug
- Interface to adapter plate

Active area: 127 cm²

Biggest CFY interconnect 130x150 mm

Air

Fuel
Results: Test methods MK35x stacks

- Temperature distribution of a middle stack layer in hotbox @35 A, $\eta_{FU}=75\%$, 40\% H$_2$ in N$_2$

- Results:
  - Test methods MK35x stacks
  - $P_{el}=28.5$ W/cell
  - $\Delta T<50$ K
  - Reference temperature defined at air outlet

- Position of thermocouples
Results: Test methods MK35x stacks

- Temperature distribution of a middle stack layer in hotbox @35 A*, $\eta_{FU}=75\%$, 40 % H$_2$ in N$_2$

> Operation modes and measuring test parameters has a direct affect to stack power and degradation

> Test conditions needs to be comparable

*35.6 A
Results: Performance test of MK352 stacks

- 30-cell MK352 stack in hotbox, 40% H₂ in 5% H₂O and N₂, η_{FU}=75%, Air=100 NL/min

→ Rated power measurement for stack characteristic
Results: Uncertainties of equipment

- Influence of uncertainties of instruments for test of 10 cell stack test MK352

→ Temperature affect initial stack power with 0.1 W/cell
→ Low impact of summarized theoretic uncertainties (0.3 W/cell ≈ 1%)
Results: Long term stability and uncertainties of MK352 stacks

- Degradation of selected 10 cell MK352 stacks

\[ \Delta P \approx 5 \text{ W} \quad \rightarrow \quad \Delta P_{\text{max}} \approx 3 \text{ W from equipment} \]

\[ \Delta P/P_0 = 0.7\%/1000 \text{ h} \]

- Reproducable values due to rated conditions and low drifts of measurement over time
- Increased degradation \( \rightarrow \) Indication of equipment or integration issues
Results: Degradation of equipment and influence to degradation

- Measured drift of thermocouples and sensors projected to degradation of stack

→ Thermocouples must be referenced and frequently replaced
→ Maintained sensors leads to low drifts and valid measuring values over time
Conclusion

- Proofed stack technology MK35x for SOFC and SOEC operation
  - Degradation: $\Delta P/P_0 = 0.7\%/1000\ h (>20,000\ h @35\ A, 835\ ^\circ C)$

- Guide for exact measurement:
  - Stable rated power points
  - OCV at dry $H_2$ in $N_2$ for tightness check
  - Definition of reference temperature
  - Temperature measurement with referenced thermocouples „Type N“
  - Maintenance of mass flow controller
  - …

- Measurements $\Delta P/P_0 < 0.5\%/1000\ h$ needs high accuracy measurements and well equipped infrastructure
THANK YOU FOR YOUR ATTENTION

SOFC Testing and Laboratory Infrastructure at IKTS