TESTING CAPACITY EXTENSION THROUGH USING SYSTEMS INSTALLED AT CUSTOMER SITES

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ABSTRACT

In an attempt to enlarge its testing capacity and to verify results from the laboratory, Sulzer Hexis used its base of 100 installed 1 kW pre-series systems (HXS1000 PREMIERE) at customer sites (1), for a number of well-defined test runs. These “Design of Experiments” tests were performed to assist quality control of stack production and evaluate specific design variations for the continuous improvement process. Careful data analysis revealed new correlations between stack design (applied compression force) and top cell set-up (number of Ni mesh, electrolyte choice), with degradation rate and performance. Using scandia-doped electrolytes for the top three cells, the power degradation rate could be reduced by 62% (from 32.5 W/1000 h to 20 W/1000 h). In addition, higher applied force resulted in 7.3% better electrical output (from 828 W to 892 W). It was shown that degradation rate and power output were combined.

INTRODUCTION

Fuel cell companies are always short of testing capacity. The nearly twenty system test-rigs in the laboratory at the Hexis facility are busy in fulfilling the basic needs of the development departments (System Development, Electronic Development and Stack Development) of Sulzer Hexis. Additional testing capacity is needed to verify achievements and to support the production departments (System Production and Stack Production) to assure quality. While increasing production volume, meeting quality is one of the major challenges Sulzer Hexis is facing on its way to the market.

Being aware of this challenge, the option of using the systems installed at customer sites for additional testing is very attractive. Nearly 100 units of the 1 kW pre-series System HXS1000 PREMIERE are already installed and in operation (1). These units can be used for matrix tests to support production or simply to verify the latest developments.

One of the initial problems is to find appropriate systems for the tests. Operating conditions and infrastructure must be well known and must be similar to laboratory conditions in order to avoid unknown parameters that might influence the results. The systems must be equipped with additional instruments to measure important parameters. To have better and faster control of the system in case of irregular failure, they should be located close to the Hexis facility. Nevertheless the customer’s operating comfort should not suffer under the special testing conditions.
Matrix tests or a Design of Experiments help to support production. A defined number of factors are deliberately varied. The quality characteristics are affected by interaction of the factors. The response measurements must be sensitive enough to reflect changes in the factor levels in order to determine how the factors interact towards each other. This tool allows the identification of critical parameters and furthermore an evaluation of possible solutions can be obtained.

For the first so called “DoE1” (Design of Experiments No. 1) matrix test, the object of concern has been the performance of the top-layer cell inside a Hexis-Stack during operation. The top-layer cell is placed between a limiting top-interconnect and a normal “Repeat-Element”-interconnect. The thickness, thermal expansion and bending of these two different interconnector designs vary. Furthermore the thermal gradients, mechanical force and contact area of the top-layer cell are different from other cells and change with time and temperature. Short laboratory tests could only detect this phenomenon but it has not been precisely investigated.

![Performance; Top-Layer Cell; 5-Cell Test-Rig](image)

**Figure 1. Performance of the top-layer cell and a repeat-element cell in a standard 5-cell test-rig; 1000 hrs operation at 200 mA/cm², 950°C.**

The example in Figure 1 displays the degradation rate of a top-layer cell in a 5-cell test-rig (46.2%/1000 hrs, voltage degradation) which is significantly higher compared to the degradation rate of a standard repeat-element cell (1.1%/1000 hrs). In the 5-cell test-rig this behaviour is allocated to the different bending of the interconnectors. The contact-area of the top-layer cell decreases and therefore the contact-resistance increases. In a system stack the performance of the top-layer cell is additionally influenced by several other factors, i.e. stack operation mode (CV instead of CC), temperature and gas distribution (not homogenous), higher compression force and different force insertion into the stack.
To improve the performance of the top-layer cell in a stack, three options were evaluated. The reduction of the stack compression force from 900 N to 600 N (at RT) could have an effect on the bending of the interconnectors. The use of two nickel meshes rather than one could improve the contact between the top-layer cell and the interconnectors. And the use of high-performing cells that are based on a ScSZ-electrolyte rather than a standard YSZ-electrolyte (2) could improve the performance of the top-layer cell inside a stack.

Table 1. Realized combination types of the DoEl in order to investigate the performance of the top-layer cell inside a system stack.

| Combination type No. | 1   | 2   | 3   | 4   |
|----------------------|-----|-----|-----|-----|
| Compression Force RT [N] | 900 | 600 | 600 | 900 |
| Number of Ni-Meshes   | 2 x | 1 x | 2 x | 1 x |
| Art of the electrolyte | ScSZ| ScSZ| YSZ| YSZ |

For all three factors, there are eight different combinations in total. For the DoEl, only four possible combination-types were realized (Table 1). This half-factorial variation has an inaccuracy in significance. That means that although interaction of combined factors is possible only important effects of single factors are reviewed in the results. This can cause misinterpretation if significant factors affect the result through interaction. However for each combination-type five stacks were built and tested to have more reliable statistical data, which gives a total of twenty stacks for DoEl.

![Figure 2. Development of the ASR-value of the top-layer cell during operation.](image)

The performance of the top-layer cell during operation was analysed. Calculating its ASR was difficult. Only at the start of stack operation the OCV could be obtained. Therefore a change of OCV is not displayed in the data. On the other hand systematic errors were made by creating short-circuits while measuring the voltage. Nevertheless there is a clear tendency, that the ASR of the top cell is reduced during operation (Fig. 2). The lowest ASR-values of 0.7 Ω cm² were obtained with ScSZ cells. The best YSZ cells reached ASR-values of 1.0 Ω cm² which is reasonable compared to the other cells of the stack. The change of ASR has been too small to have a statistical influence on the overall stack performance inside the test-matrix.
The starting ASR of the top-layer cell was most likely influenced by the stack compression force and by the number of Ni-meshes used. A higher compression force of 900 N resulted in a lower ASR-Value of the cell which is reasonable because a higher compression force increases the contacting. The use of two Ni-meshes decreased the ASR in the beginning while after 3000 hrs of operation the ASR of cells with 2 Ni-meshes has been higher than those with one. The lower ASR in the beginning of stack operation could be due to a better contacting that has been achieved by using two Ni-meshes. The higher ASR after 3000 hrs of operation could not be explained by simple contacting-effects. Further analysis of this behaviour is needed.

The overall tendency of a decrease in ASR during system stack operation is contrary to the one observed in a 5-cell test-rig. This can be explained by the fact that the operation of a system stack is different than that of a 5-cell stack. The bending of the interconnectors in the system seems more strongly related to oxidation kinetics during the heat-up phase. In a system the amount of air put on the stack is several times higher than in a 5-cell test-rig where no air is needed while heating up. Furthermore reducing gas is put at lower temperatures on the system stack. This could cause oxidation on one side of the interconnector which could explain bending. Therefore it seems that the bending is very high at the beginning of system stack operation while the contacting of the top-layer cell seems to be increased during operation. Influences other than contacting seemed not to influence the behaviour of the top-layer cell but the overall stack performance.

Analysis of the operation data revealed that the overall performance of the stacks was not following a Gaussian distribution. Three of the stacks were facing a fast descent in electrical power output. This was due to bad quality of one cell inside the stacks, as disassembling of the stacks revealed after being returned from the customers. By eliminating these three stacks from the analysis data, a comparison between the stack performances was possible (Fig. 3).

![Summary for degradation (W/1000h) after 3000h of operation](image)

**Figure 3. Distribution of the stack degradation rate; p-Value 0.423; Mean degradation rate 27.5 W/1000 hrs.**
Using ScSZ-electrolytes for the top three cells has a positive influence on the degradation (Fig. 4), (3). The reduction of the degradation rate from absolute 32.5 W/1000 hrs to 20 W/1000 hrs was bigger than expected. This performance correlates to the fact that the highest degradation rate is most often seen at the stack endings for the HXS1000 Stack because of higher operating demands. With high performing Sc-doped cells the degradation rate could be reduced. The other factor influencing stack performance is the compression force. A high compression force has a positive influence on the maximum power output of the stack (Fig. 5). This could be explained by an improvement in the contacting. The stacks with lower compression force display also a higher distribution of the maximum power output which is a negative aspect regarding reproducibility. The average maximum power of all stacks has been 850 W (dc). Stacks with a high compression force displayed an increased degradation rate. The average degradation of all stacks was 27.5 W/1000 hrs which equals 3.2%/1000 hrs. A correlation between maximum power output and degradation rate revealed that two factors have an influence on the degradation rate (Fig. 6). On the one hand a high maximum power leads to faster
Figure 6. Comparison of the stack degradation rate to the maximum stack power.

degradation. It is not clear yet whether the compression force or the high power output is causing the increased degradation. On the other hand, faster degradation is caused by low starting power; stacks with a low starting power might have damages, caused by i.e. assembling, transportation, failure in starting procedure, that are causing faster degradation.

Design of Experiments - Series No. 2

The second test-row called DoE2 was started with the intention to verify improvements under real field conditions that have already been demonstrated in the laboratory. The DoE2-series consisted of 16 stacks. Most of the stacks were started from mid February 2004 to the beginning of April 2004. As the HXS1000 System is heat controlled most of the stacks were facing a reduction of gas input (Part-Load Operation) -even some were completely shut down- because of the low heat demand in the summer months. Therefore the electrical efficiency was best suited to compare the performance of the stacks as this is the only parameter with low sensitivity to variations of the gas-input (Fig. 7).

Figure 7. Efficiency of the DoE2 stacks (average of 16 stacks) and the Reference-stacks (average of 4 stacks) after 6000 hrs of operation.
After 3500 hrs, the efficiency of the field units displays a significant drop because of several shut-downs and system failures due to summer operation. Nevertheless, the DoE2 has been a success, demonstrating highly reproducible and reliable electrical efficiency for several thousand hours with a SOFC system under real conditions.

CONCLUSIONS

Results revealed that an extension of the testing capacity while using systems installed at customer sites is possible, although for getting reliable data the operation conditions should be static. In summer months, this is not true because of the low heat demand of some systems. Even with reliable data the history and performance of each stack must be verified to prevent misinterpretation. The method of matrix-tests has been proven effective while stack reproducibility is not sufficient in this phase of pre-market entry. The verification of recent developments turned out to be difficult under real conditions. Eventually the testing cycle in the laboratory should be optimized to cover more of the performance at customer sites.

Performance of the top-layer cell in a stack could be mostly explained by changes in contacting, although there are differences in performance between a system stack and a short stack that have to be further investigated.

The use of scandia doped electrolytes at the stack-end turned out to be effective for reducing degradation. Unfortunately, scandia doped electrolytes are more expensive than yttria doped ones. The gain in lifetime has to be compared to the additional cost. A high stack compression force leads to a higher maximum power but also to higher degradation rates while running the stack at full load.

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