Benchmarking a fuel cell stack compression process

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Overview

• Background
• Compression
  • Importance
  • Literature values
  • Spring equivalent model
• Horizon fuel cell compression system performance
• Conclusion
• Proposed further work
Background

• Supporting Horizon Fuel Cell UK with fuel cell manufacturing
• Developing assembly methods and processes
• Three critical assembly processes identified
  • Alignment
  • Sealing
  • **Compression**
Assembly process criticalities

- Poor layer alignment can result in areas of mechanical stress
- Gas blockage and leakage arises from misalignment of flow field channels and gaskets
- Excessive compression can cause mechanical damage to the cell components
- Insufficient compression results in increased contact resistance between layers

Gas blockage - mass transport losses

Stack and Cell Compression

Gas leakage - efficiency losses

Gas crossover - activation losses

Layer Alignment

- Poor sealing can result in reactant and fuel gas leaking into the environment
- Combustion can also occur releasing heat that can cause damage to the catalyst

This is the most critical combination of assembly processes that cause fuel cell degradation and inevitably lead to catastrophic failure during operation.
Importance of Fuel Cell Compression

1. **Magnitude**
   - GDL - Mass transport vs. ohmic losses
   - Sealing
   - Mechanical stresses

2. **Homogeneity**
   - Hotspots

*Excessive and insufficient compression*

![Graph showing cell voltage vs. cell current with regions for activation losses, ohmic losses, and mass transport losses.](image-url)
Literature compression ratios

- GDL Compression ratio:

\[
\frac{\text{GDL Operating thickness}}{\text{Original GDL thickness}}
\]

- Trendline – coefficient of determination – 0.92
- Useful tool to help fuel cell researchers identify a ballpark figures for GDL compression
- Porosity and PTFE loading also do need to be considered
Spring equivalent model

- Gaskets sit parallel to GDL
- Effect gaskets have on GDL compression can be estimated
- Identify force required to reach compression ratio

\[ F_t = \text{total force} \]
\[ A_{GDL} = \text{SA GDL} \]
\[ E_{GDL} = \text{YM GDL} \]
\[ A_g = \text{SA gasket} \]
\[ E_g = \text{YM Gasket} \]
\[ CR = \text{GDL compression ratio} \]
\[ a = \text{ratio of gasket thickness over GDL thickness} \]

- BUT, some fuel cells use incompressible gaskets...
- AND, how does this translate to stack?...

\[ F_T = A_{GDL} E_{GDL} \left( 2 - a \frac{CR}{a} \right) + A_g E_g \left( 1 - \frac{CR}{a} \right) \]
Fuel Cell Compression System

- Horizon Fuel Cells UK designed a fuel cell compression system
- Compression characteristics are tested
- Typical methodologies for compression characteristic assessment:
  - FE Modelling
  - Piezoresistive arrays
  - **Pressure sensitive films**
Methodology

- Cut compression film to size
- Place a film between each cell in 4 cell stack
- Apply compressive force
- Wait 1 minute to settle
- Repeat at a range of compressive forces
- Scan films
- Remove films
- Wait 1 minute to settle
- Reapply force

- MATLAB code converts grayscale scan of film to contour plot
- 3 colour contour to make data easier to visualise
- Local averaging carried out so non-useful data is lost
Results and Discussion

- Non-uniform compression
- CoV through z-axis does not exceed 10%
- Good symmetry through y-axis
- Non-symmetry through x-axis
- Could be due to:
  - Compression system calibration
  - Component manufacturing tolerances
  - Stack/cell assembly tolerances

<table>
<thead>
<tr>
<th>Applied Compression (MPa)</th>
<th>10</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean compression experienced by films (MPa)</td>
<td>1.90</td>
<td>3.06</td>
<td>4.33</td>
</tr>
<tr>
<td>Mean CoV(x-y)</td>
<td>0.34</td>
<td>0.18</td>
<td>0.27</td>
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<tr>
<td>CoV (z)</td>
<td>0.09</td>
<td>0.05</td>
<td>0.01</td>
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<tr>
<td>Average error (%)</td>
<td>8.28</td>
<td>11.02</td>
<td>16.17</td>
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<tr>
<td>GDL Compression Ratio (%)</td>
<td>88</td>
<td>79</td>
<td>70</td>
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</tbody>
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Conclusion

• Optimal fuel cell compression is important
  • Potential for cheap and easy maximisation of fuel cell performance
  • Increase stack life

• BUT
  • Compression methods need to be optimised
  • Assembly processes need more rigour

• Methodology for fuel cell researchers:
  1. Estimate optimal CR based on literature values
  2. Use spring equivalent model to estimate required force
  3. Use compression system to apply force
Further Work

- Develop in process QC for ensuring uniform compression at the required magnitude
- Develop methods for testing the alignment and sealing of fuel cells
- Design a fuel cell assembly layout which accommodates
  - Product variants
  - Product traceability i.e. documentation of product birth history
  - Volume scale up
Questions

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References


