Advanced Sealing Components for Automotive Lithium Battery Systems

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<table>
<thead>
<tr>
<th><strong>&gt;7.5bn EUR Sales 2015</strong></th>
<th><strong>4.2% R&amp;D Ratio</strong></th>
<th><strong>100% Family Ownership</strong></th>
<th><strong>60 countries Global Presence</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>522m EUR</strong> 7% Operating Profit</td>
<td><strong>2bn of Sales with New Products &lt;4 Years</strong></td>
<td><strong>Established 1849</strong></td>
<td><strong>&gt;40,000 Employees</strong></td>
</tr>
<tr>
<td><strong>Moody's INVESTORS SERVICE</strong></td>
<td></td>
<td></td>
<td><strong>A3 Stable Outlook</strong></td>
</tr>
</tbody>
</table>
Freudenberg = More than 70 years of battery experience!

Freudenberg Performance Materials
- Longtime supplier to the battery industry (since 1950ies)
- Separator supplier for Lead-acid, NiCd & NiMH systems
- Li-ion Separator activities since 2002
- Nonwoven-based Ceramic Separator with unique safety features (esp. thermal stability & puncture resistance)

Freudenberg Sealing Technologies
- Global key player for sealing components both for automotive and industrial industries
- “Low Emission Sealing Solution” (https://less.fst.com) including components for E-mobility
- Serial Lithium Battery Seal production e.g. for diverse Automotive OEMs
Sealing Components for Lithium Battery Systems
FST Products for Lithium Batteries

- Overpressure Valves
- Pressure-regulating Elements
- Housing gaskets
- Pouch Cell Fixation
- Thermally conductive Materials
- Safety Concept
- Vibration-control systems
- Pressure Compensation Elements
- Plug Seals & Cable Bushings
- Connector Seals for Cooling Cycles
- Tubes for Cooling Cycles
- Cell Seals for Round / Prismatic Cells
Lithium Cell Seals

Elastomers for future needs…
Lithium Cell Seals

Elastomeric Cell Seals considering future requirements

- Swelling & shrinking of the cell housing @ cycling [new chemistries!]
- Increasing inner overpressure with cell lifetime
  !! Thermoplastic seals may fail !!

FST’s Approach (under development)

(1) Elastomeric O-ring seals made from Polyolefinic rubber
    -> ultra-pure grades avoiding leaching
    -> permeation-optimized grades

(2) Elastomer + Thermoplastic Carrier

(3) USIT Ring: Elastomer + Metallic Carrier
    (2) and (3) creating a reliable mechanical end stop
        -> avoiding seal damage
        -> reducing free cross section
Housing Gaskets

The optimum solution for serial & prototype production
Battery Housing Gaskets – the Challenge

- Under normal operation, large Automotive Battery Systems are exposed to
  - vibrations
  - mechanical deformations (twisting…)

- Trends for light-weight housings will result in higher deformation and thus larger gaps during operation

- In general, the system is highly exposed to contamination

The main challenge of the housing gasket is to provide an optimum tolerance compensation and thus sealing function over lifetime
# Battery Housing Gaskets

<table>
<thead>
<tr>
<th></th>
<th>Puzzle Seal</th>
<th>P2G Profile-to-Gasket</th>
<th>Profiled Flat Gasket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical production volumes</td>
<td>Prototypes to small series</td>
<td>Mid series (50…5.000)</td>
<td>Large series (&gt; 5.000)</td>
</tr>
<tr>
<td>Assembly effort</td>
<td>Medium-high</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Max. Size</td>
<td>No limitation</td>
<td>No limitation</td>
<td>Approx. 2.000 x 1.200 mm²</td>
</tr>
<tr>
<td>Tool costs</td>
<td>None (one standard dimension available)</td>
<td>Low</td>
<td>Mid-high</td>
</tr>
<tr>
<td>Functionality</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Status</td>
<td>One dimension in serial</td>
<td>One dimension in serial</td>
<td>Serial</td>
</tr>
</tbody>
</table>
Cooling Cycle Components

Vibration resistant & modular
Cooling Cycle Components – the Challenge

- Cooling cycle components are exposed to mechanical deformations & vibrations
- Modular designs require a large amount of connectors & sealing parts
- Low heat loss & low flow resistance are desired for the thermo-management system

The main challenge of cooling cycle components is to provide an optimum tolerance compensation and thus sealing function over lifetime
Battery Cooling Cycle Seals - Overview

- Connector pieces ("Plug & Seal")
  - Highly reliable due to **axial & radial sealing** function
  - Catalogue products available
  - Individual designs possible

- Multi-port Connector Pieces
  - Designs for reduced flow resistance

- Integrated Functionality
  - Sensors (T, p, …)
  - Valves

- Plastic Tubes
  - Free-form design
  - Smooth inner surface
Thermally Conductive Thermoplasts

- Main motivation for plastics vs. Aluminum: „unlimited“ tool endurance“
- Special-grade polyamide
- Thermally & electrically conductive fillers
- Anisotropic heat conductivity
- **Thermal conductivity** (ASTM E1461)
  - $3-5 \text{ W/}[\text{m*K}]$ through the plane
  - $15-20 \text{ W/}[\text{m*K}]$ in the plane
- **Product design allows** to “control” the anisotropy an thus allows an **intelligent heat management** (directed thermal flow)
- Products show fire resistance (UL94: V0/3mm)
- Direct bonding of Silicon rubber seals
- Products possess shielding properties (EMC)
Thermally Conductive Flexible Materials

- Material as enabler for improved products
- Ensure / improve heat transfer between cells and
  -> Housing
  -> Cooling channels
- Applicable to all kinds of cells; most suitable for
  prismatic cells (side cooling)
- Round cells could be cooled from the bottom
- Flexible & soft sheets / elements ensure
  form-fit and thus an optimum heat transfer
- For most applications, electric conductivity is
  undesired
- Approach:
  Consider of our intelligent materials
  !! Under development !!
Cable Feedthrough Seals & Bellows

- Cable feedthrough seals with all possible dimensions
- Multi-lip design for highest reliability
- Multi-pole seals are possible
- Tiny cable feedthroughs
- Embedding of electrical contacts / flexible circuit boards

- Elastomeric Bellows & Dust Covers for highest robust applications
Pressure Regulating & Control
## Pressure-regulating & Control - Overview

<table>
<thead>
<tr>
<th></th>
<th>Pressure Regulating</th>
<th>Overpressure Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occurrence during…</td>
<td>Normal Operation</td>
<td>Emergency</td>
</tr>
<tr>
<td>Occurrence frequency</td>
<td>Always</td>
<td>Only once</td>
</tr>
<tr>
<td>Caused by…</td>
<td>• Atmospheric p &amp; T variations</td>
<td>Cell Venting</td>
</tr>
<tr>
<td></td>
<td>• Up- &amp; downhill driving</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Transport (plane, rail)</td>
<td></td>
</tr>
<tr>
<td>Typical Δp</td>
<td>+/- 0.2 bar</td>
<td>&gt;&gt; 2 bar (only inner overpressure)</td>
</tr>
<tr>
<td>Typical volume exchange rates</td>
<td>1 l in 1 min</td>
<td>100 l in &lt;&lt; 1 min</td>
</tr>
<tr>
<td>Exchanged media</td>
<td>Atmospheric air</td>
<td>Decomposed electrolyte</td>
</tr>
</tbody>
</table>
Pressure-regulating & Control - Overview

- **Pressure-regulating Elements** (nonwoven-based)
  - high robustness
  - high air permeability / low space requirements
  - tolerates water-head up to 100 mm

- **Overpressure Valve**
  - secures a safe exhaust gas management in case of a venting cell

- **Pressure Compensation Concepts**
  - Avoidance of condensate & contamination inside the battery housing
  - Enable an inert gas atmosphere inside housing

- **Next Generation Pressure Control**
  - high air permeability AND
  - IP67+ protection class AND
  - integrated overpressure function

<table>
<thead>
<tr>
<th>PR*</th>
<th>OR**</th>
</tr>
</thead>
<tbody>
<tr>
<td>●</td>
<td>○</td>
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</tbody>
</table>

*PR = Pressure Regulating  **OR = Overpressure Release*
## Pressure-regulating Elements

<table>
<thead>
<tr>
<th></th>
<th>Micro Porous PTFE Foil</th>
<th>FST Functionalized Nonwoven</th>
<th>FST Next Generation Pressure Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative air permeability</td>
<td>0.1 ... 1</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Required cross section</td>
<td>100</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Mechanical Strength (e.g. puncture...)</td>
<td>low</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Contamination susceptibility (“plugging by particles”)</td>
<td>Very high</td>
<td>Low</td>
<td>low</td>
</tr>
<tr>
<td>Water repellance</td>
<td>Very high Water head &gt; 1.000 mm</td>
<td>Splash water Water head 100 mm</td>
<td>Very high Water head &gt; 1.000 mm</td>
</tr>
<tr>
<td>Oil repellence</td>
<td>poor</td>
<td>Medium ... good</td>
<td>Medium ... good</td>
</tr>
<tr>
<td>Exhaust gas management</td>
<td>limited</td>
<td>limited</td>
<td>yes</td>
</tr>
</tbody>
</table>
Pouch Cell Fixation Concepts
Li Batteries / Pouch Cells

**INNER CONSTRUCTION**
- Thin-film stack (typ. > 100 layers)
- Electrodes & Separator

**CURRENT CONNECTORS**
- Anode & Cathode each 0.1 - 0.2 mm thick metal sheets

**SEALED SEAM**
- Aluminium foil, which is coated with plastic at both sides

**FOIL HOUSING**
- FREUDENBERG SEALING TECHNOLOGIES
- FREUDENBERG INNOVATING TOGETHER
FST has developed two concepts for embedding Pouch Cells:

- **Pouch Cell Frame Seal:**
  - Each Cell is placed in an individual “frame”
  - A compressible, surrounding seal protects the cell from external damage
  - Safety grooves allow exhaust gas management in case of cell venting
  - The cells & frames are assembled to stacks
  - Concept has proven its basic functionality in a pre-development project

- **Pouch Cell Profile Seal:**
  - Cells border are placed in an elastomeric Profile Seal
  - The Profile Seal design also allows a soft embedding of the cells
  - Main Motivation: fast solution for Customers!
  - Project currently is on a Concept State
  - One profile dimension is available
Innovation 1:
Sealing profile
Secures a safe cell sealing at cell overpressures of 3 bars *cell typically opens at 0.5 bar*

Innovation 2:
Cell „Embedding“

Innovation 3:
Metallic Inserts to adjust constant distance

Innovation 4:
Current Collector Feedtrough with higher compressibility
Compensates the „locally thicker“ Pouch Cell Seam

Innovation 5:
Cooling Cycle Connectors
Allowing a perpendicular flow of cooling fluid
Strict separation of cooling fluid & electrical circuit

Innovation 6:
Safety Channel
Conducts out-gasing electrolyte in case of malfunction
Pouch Cell Fixation Concepts / Profile

Basic Approach:
Two neighbored profiles embed the seam of the Pouch Cell

100%-embedding of cells possible

Safety Channel can be implemented
# Pouch Cell Fixation Concepts / Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pouch Cell Frame Gaskets</th>
<th>Pouch Cell Profile Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Embedding</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Adjust / distance between cells</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Vibration Protection</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Assembling time</td>
<td>++</td>
<td>0</td>
</tr>
<tr>
<td>Implementation of Cooling</td>
<td>++ (liquid) + (indirect) 0 (air)</td>
<td>- (liquid) + (indirect) + (air)</td>
</tr>
<tr>
<td>Exhaust gas handling</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Adaption to different designs</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Effort for development</td>
<td>1 year</td>
<td>2 months</td>
</tr>
<tr>
<td>Typical volumes [cells]</td>
<td>500,000 p.a.</td>
<td>&gt; 1,000,000 p.a.</td>
</tr>
</tbody>
</table>
Safety Approach

Emergency Cooling Concept
Safety of Batteries – the Challenge

- Trends in battery development
  - increased energy density on cell & system level
  - ultra-fast charging requirements

…result in future safety challenges

Freudenberg has developed a concept to prevent a thermal runaway

The concepts uses a CO$_2$-based mobile air conditioning system as “emergency cooling reservoir”
Lithium Battery – Safety Concept

Basic Idea:

- Use pressurized CO$_2$ – the medium of future mobile air conditioning systems – for emergency cooling
- When a cell becomes overheated, CO$_2$ can expand through a nozzle to rapidly cool-down the cell
- Prevention of a thermal runaway
- Concept has been proven in lab scale [cooperation with ZSW, Ulm]
Lithium Battery – Safety Concept

Project currently is on a Concept State
We are looking for partners for industrialization
Summary

- Freudenberg is a world-wide key supplier of sealing components both for automotive and industrial industries.
- With our long-term battery experience, we have the system know-how to actively support our customers & partners.
- Our battery sealing components are addressed to:
  - > long-term reliability
  - > safety
  - > system cost reduction
- Sealing components are developed in close cooperation with our customers.
- Besides this, we have developed concepts for improvement of future battery systems.

For questions:

Thanks a lot & keep your SoH!