Pressure sensors for automotive HVAC systems

Tom Kwa, PhD
CTO
DunAn Sensing LLC

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Outline

• The need for automotive A/C and the need for a new pressure transducer technology
• A/C fundamentals
• Traditional configuration of automotive A/C
• The developing need for pressure transducers in automotive A/C
• Available media-isolated pressure transducer technologies
• DURAsense™ pressure transducer technology and performance
• Summary
The need for automotive A/C
Other needs for automotive A/C
The need for a new pressure transducer technology

- Piezoresistors or metal film deposited on ceramic diaphragm
- Strain gauges bonded to stainless steel diaphragm
- MEMS chip in stainless steel package with metal diaphragm and silicone oil

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Functions of automotive A/C

- It must cool the air
- It must circulate the air
- It must purify the air
- It must dehumidify the air
The principle of natural A/C
The fundamentals of mechanical refrigeration

\[ \Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq 0 \]  \hspace{1cm} (2^{nd} \text{ Law of Thermodynamics})

or, heat flows from hot to cold

\[ \ln \left( \frac{P_1}{P_2} \right) = \frac{\Delta H_{\text{vap}}}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right) \]  \hspace{1cm} (Clausius-Clapeyron Equation)

or, boiling temperature increases with pressure

\[ \frac{P_1}{T_1} = \frac{P_2}{T_2} \]  \hspace{1cm} (Charles’ Law)

or, compression of a gas raises its temperature
Simplified A/C loop – flow sequence

- Temperature increases with increasing pressure.
- Boiling temperature increases with pressure.
- Refrigerant releases heat.
- Heat flows from hot to cold.
- Lower refrigerant temperature.
- Temperature decreases with decreasing pressure.
- Boiling temperature decreases with pressure.
- Refrigerant absorbs heat.
- Heat flows from hot to cold.

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Simplified A/C loop – component configuration
Temperature-pressure chart of R-134a

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>Pressure kPa</th>
<th>Temp. °C</th>
<th>Pressure kPa</th>
<th>Temp. °C</th>
<th>Pressure kPa</th>
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320-335kPa/46-48psig (PCS)  
1400kPa/200psig (HPS)  
3000kPa/430psig (HPS)  

170-180kPa/24-26psig (PCS)
A/C system in a car
with combustion engine
Pressure Cycling Switch (PCS) for A/C control – expansion valve system
Pressure Cycling Switch (PCS) for A/C control – orifice tube system
Functions of the PCS

• To control the temperature
  • Enables and disables the compressor

• To help protect A/C system from damage
  • Excessively high pressure in the loop can cause line rupture
  • Excessively low pressure resulting in freezing at evaporator surface
  • Activate max speed of condenser fan at pre-set refrigerant pressure
Locations of other pressure switches in automotive A/C systems

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PCS-controlled A/C

- Limited comfort (too hot, too cold)
- Reduced efficiency (system wear and tear, increased fuel consumption/fewer miles per charge)
Benefits of A/C control using a pressure sensor over a PCS

• Enables constant monitoring of pressure instead of only upper and lower (cut-in/cut-out) points
  • More accurate control
  • Faster response
  • Better efficiency
  • Easier to diagnose problems
Challenges for automotive A/C refrigerant pressure sensors

• Chemically compatible with refrigerants (R-134a, R-1234YF, R-744); refrigeration oils; acids formed due to moisture contamination
• High operating temperature (-40°C to 140°C)
• High reliability (>10,000,000 pressure cycles)
• Automotive, therefore must be low cost
Technologies suitable for use in automotive A/C refrigerant pressure sensors

- Piezoresistors or metal film deposited on ceramic diaphragm
- Strain gauges bonded to stainless steel diaphragm
- MEMS chip in stainless steel package with metal diaphragm and silicone oil

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Media-compatible pressure sensor using DURAsense™ oil-free and weld-less MEMS packaging technology

Unique features:
- No oil fill
- No stainless steel diaphragm
- No welds
- No organic-adhesive die attach

Resulting in:
- Compatibility with refrigerant fluids
- Wider temperature range
- Higher reliability
- Improved manufacturing cost
Construction of DunAn Sensing’s DURAsense™ media-compatible MEMS pressure sensor

U.S. Patent Application Nos.: 14/170,355; 14/170,387

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Qualification testing methods and protocols

- Pressure cycling: 0 to FS, >10,000,000 cycles
- Temperature cycling: -40°C to 140°C
- Media-compatibility: automotive refrigerants
- Vibration: 4.5g’s, 20Hz to 200Hz
- Temperature shock: -40°C to 140°C
- Mechanical shock: 100g’s
- EMI
- ESD
- *Et cetera*
Achieved accuracy equal to or better than any other HVAC transducer on the market that meets the automotive cost target

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Performance – before and after qualification

**Samples:** 96  
**Temperatures:**  
- -40, 0, 25, 100, 140 °C  
**Pressures:**  
- 0.05, 0.66, 1.28, 1.89, 2.5 MPa  
**Overall Duration**  
- 3 months

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<th>Final</th>
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<td>Cpk</td>
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Average Shift of ~ 0.4%FS
## Characteristics/capabilities of current technologies

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<th>Technology</th>
<th>Metal thin-film sensor</th>
<th>Microfuse sensor</th>
<th>Oil-filled sensor</th>
<th>Ceramic thick-film sensor</th>
<th>DURAsense™ MEMS pressure sensor</th>
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<tbody>
<tr>
<td>Measurement of absolute pressure</td>
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<td>NO</td>
<td>YES</td>
<td>OK</td>
<td>YES</td>
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<td>YES</td>
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<td>Long-term stability</td>
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<td>High temperature &gt;100°C</td>
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<td>HIGH</td>
<td>HIGH</td>
<td>MEDIUM</td>
<td>LOW</td>
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**NOTE:**
- Requirement fullfilled: Yes / Good
- Requirement partly fullfilled: OK / Maybe
- Requirement not fullfilled: No / Bad

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Summary

Introduction of **DURA sense™**, an *innovative MEMS packaging technology* which *eliminates the need for* the traditional method of *metal diaphragm welding and oil-fill* to achieve media-compatibility and...

...can achieve an *accuracy* equal to or better than any other HVAC transducer currently on the market

...that meets the *cost target* for automotive

...is *compatible* with refrigerant fluids

...has a *wide* *temperature* *range*

...has a *high* *reliability*
Contact

DunAn Sensing LLC
1953 Concourse Drive
San Jose, CA 95131
USA
Phone: +1-408-613-1015
Website: www.dunansensing.com