Next Generation Quartz Pressure Gauges

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Quartzdyne

Houston, TX – March 2, 2016
Outline

• Quartz Pressure Gauge Introduction

• Gauge Size Reduction

• Long Term Pressure Drift Characterization

• Error Reduction During Transient Events

• Summary
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• Summary
Quartz Transducer Components
Quartz Thickness Shear Mode Operation

- Frequency determined by thickness and stiffness
- Motion at center of resonator, but not at edge
- Very low loss (high Q) allows very stable resonance (7.2 MHz)
- Reactions to external stimuli controlled by crystal cut (anisotropy)
- Simple manufacturing process
  - Slice/Turn/Contour resonator
  - Plate electrodes
  - Mount
- Mature technology that has been around for 60+ years
Quartz Pressure Sensor Operation

• Resonator sealed between two endcaps
• Crystal cut chosen to maximize pressure and minimize temperature sensitivities
• Sensor “floats” in fluid behind fluid isolation device
• Applied pressure creates in-plane compression of resonator
• Compression causes quartz stiffness and frequency to change accordingly
• Sensitivity around 2 Hz / psi
• Resolution less than 0.01 psi
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• *Gauge Size Reduction*

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• Error Reduction During Transient Events

• Summary
Gauge Size

• Reducing gauge size enables new applications
  – Smaller spaces for a variety of applications
  – Completions – Wire feedthrough
  – Tubing conveyed
  – Annulus monitoring without expensive mandrels
• Quartzdyne past offerings were 3/4”, 7/8” and 1”. Each uses a similar sized sensor.
• New ½” gauge now available!
• All components re-designed to fit smaller envelope
  – Pressure Sensor
  – Temperature and reference crystals
  – Electronics
  – Packaging
Half Inch Transducer
DHB104-XX-YYY

Circuit
- Enhanced pin placement
- Updated seal design
- ASIC optimized for size and performance

Temp / Ref Crystals
- Smaller packaging

Pressure Crystal
- Complete re-design (2+ years)
- Smaller
- Similar performance to standard

Packaging
- ½” Outside Diameter
- 4.38” length
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Sensor Drift

- Drift (or creep) defines the amount a sensor’s accuracy degrades over time
- Specified assuming operation at max pressure and temperature
- Customers need typical drift at intermediate pressures and temperatures
Sensor Drift

• Customers more interested in drift performance recently
• Concerned about drift at intermediate temperatures and pressures (not max P/T)
• Applications include
  – Interference tests between wells need time for pressure to transmit to second well
  – Formation tests and logging applications
  – Distinguish pressure changes due to production in permanent installations
  – Flow monitoring where drift can imply more / less flow
  – Applications where true accuracy is critical
# Specified Drift Performance

## Pressure Performance

<table>
<thead>
<tr>
<th>Pressure (kpsi) - YY</th>
<th>05</th>
<th>10</th>
<th>16</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pressure Range</strong></td>
<td>0 to 5,000</td>
<td>0 to 10,000</td>
<td>0 to 16,000</td>
<td>0 to 20,000</td>
<td>0 to 25,000</td>
<td>0 to 30,000</td>
<td>0 to 35,000</td>
</tr>
<tr>
<td>(psia</td>
<td>bar)</td>
<td>0 to 344</td>
<td>0 to 660</td>
<td>0 to 1,100</td>
<td>0 to 1,380</td>
<td>0 to 1,725</td>
<td>0 to 2,070</td>
</tr>
<tr>
<td><strong>Available Calibration Temperature Ranges (°C)</strong></td>
<td>25 to 150</td>
<td>25 to 150</td>
<td>25 to 150, 177, 200</td>
<td>25 to 150, 177, 200, 225</td>
<td>25 to 177, 200, 225</td>
<td>25 to 177, 200, 225</td>
<td>25 to 177, 200</td>
</tr>
<tr>
<td><strong>Accuracy</strong> (%)</td>
<td>0.02</td>
<td>0.015</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.025</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Typical Accuracy</strong> (%)</td>
<td>0.015</td>
<td>0.012</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
<td>0.02</td>
<td>0.025</td>
</tr>
<tr>
<td><strong>Accuracy (%)</strong></td>
<td>0.04</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.03</td>
<td>0.035</td>
<td>-</td>
</tr>
<tr>
<td><strong>Achievable Resolution</strong> (psi * sec)</td>
<td>&lt; 0.006</td>
<td>&lt; 0.006</td>
<td>&lt; 0.008</td>
<td>&lt; 0.008</td>
<td>&lt; 0.010</td>
<td>&lt; 0.010</td>
<td>&lt; 0.010</td>
</tr>
<tr>
<td><strong>Repeatability (%)</strong></td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td><strong>Nominal Sensitivity</strong> (Hz / psi)</td>
<td>2.8</td>
<td>2.8</td>
<td>2.5</td>
<td>2.5</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Frequency Output Range</strong> (kHz)</td>
<td>10 to 70</td>
<td>10 to 70</td>
<td>10 to 75</td>
<td>10 to 80</td>
<td>10 to 90</td>
<td>10 to 100</td>
<td>10 to 100</td>
</tr>
<tr>
<td><strong>Response Time to FS Step (for 99.5% FS)</strong></td>
<td>&lt; 1 sec</td>
<td>&lt; 1 sec</td>
<td>&lt; 1 sec</td>
<td>&lt; 1 sec</td>
<td>&lt; 1 sec</td>
<td>&lt; 1 sec</td>
<td>&lt; 1 sec</td>
</tr>
<tr>
<td><strong>Gravity / Orientation Effect</strong></td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Acceleration Sensitivity</strong> (psi / g – any axis)</td>
<td>&lt; 0.02</td>
<td>&lt; 0.02</td>
<td>&lt; 0.02</td>
<td>&lt; 0.02</td>
<td>&lt; 0.02</td>
<td>&lt; 0.02</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td><strong>Drift at 14 psi and 25°C</strong> (% FS / year)</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Drift at Max. Pressure and Temperature</strong> (% FS / year)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.025</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**0.02% FS / year in most cases**
Drift Experimentation

- Data captured over several days / weeks
- Intermediate pressure / temperatures
- Must test all sensor designs
- Challenging to hold known pressure for long times (>2 weeks)
- True pressure calculation
  - Equipment temperature
  - Barometric pressure
- Long term drift projected to one year

\[ \text{Creep} = A_1 \left( e^{-\frac{t}{\tau_1}} - 1 \right) - A_2 \ln \left( \frac{t}{\tau_2} + 1 \right) \]
## Drift Results

### 10K Sensors 1-Year Predicted Drift (%F.S.)

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>6000</td>
<td>0.0015%</td>
<td>0.0047%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8000</td>
<td>0.0026%</td>
<td>0.0043%</td>
<td>0.0048%</td>
<td>-</td>
</tr>
<tr>
<td>10000</td>
<td>0.0063%</td>
<td>0.0057%</td>
<td>0.0021%</td>
<td>0.0017%</td>
</tr>
</tbody>
</table>

### 20K Sensors 1-Year Predicted Drift (%F.S.)

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>125</th>
<th>150</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>0.0021%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12000</td>
<td>0.0042%</td>
<td>0.0010%</td>
<td>0.0021%</td>
</tr>
<tr>
<td>14000</td>
<td>0.0022%</td>
<td>0.0011%</td>
<td>0.0027%</td>
</tr>
<tr>
<td>16000</td>
<td>0.0034%</td>
<td>0.0025%</td>
<td>0.0156%</td>
</tr>
<tr>
<td>18000</td>
<td>0.0040%</td>
<td>0.0017%</td>
<td>0.0116%</td>
</tr>
<tr>
<td>20000</td>
<td>-</td>
<td>0.0055%</td>
<td>0.0025%</td>
</tr>
</tbody>
</table>

*Results demonstrate typical performance. Performance not guaranteed!*

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2016 SPWLA Formation Testing SIG
Drift Results and Future Work

• Typical performance usually just a fraction of the maximum specification

• Published specifications written for worst case scenarios
  – Must account for worst possible performance even though typical performance much better
  – Uncertainty in extrapolation from days / weeks to full year

• Future improvement by experimenting with manufacturing parameters
  – Experimentation underway
  – Modern manufacturing control systems could enable improvement
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Transient Error

- Pressure measurement error due to temperature and pressure variations

Applications
- Drilling formation testing
- Logging formation testing
- Logging gradient surveys
- Other tests where anything is moving in the wellbore

- Pressure change induces temperature variation

- Errors can be large (>10’s psi)

- Several minutes in static conditions required for equilibrium

- Inaccurate temperature compensation due to distance between sensors
Transient Error

Temperature Step: 25°C to 140°C
Liquid Plunge at Atmospheric Pressure

Pressure Drop: 5 kpsi to 0 psig
In Liquid Bath at 175°C
Transient Error Countermeasures

- Transducer modifications to couple pressure and temperature sensors

- Place temperature sensor in oil with pressure sensor

- Dual mode sensor
Dual Mode Sensors

- It is possible to have two or more frequencies running in one quartz resonator
- Orthogonal resonance motion
- Each mode reacts differently to external stimuli (see table below)
- Two sensors in one!

<table>
<thead>
<tr>
<th>Mode</th>
<th>Temperature Sensitivity</th>
<th>Pressure Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Dual Mode Sensor Performance

- Two Experiments
  - Plunge into 140°C bath
  - Ramp 140°C to 175°C at 2 kpsi
- Transient performance improved substantially
  - Some error still occurs due to gradient induced stress
  - Not commercially available but science is proven

**Temperature Step: 25°C to 140°C**
- Liquid Plunge at Atmospheric Pressure

**Temperature Ramp: 140°C to 177°C**
- At Constant Pressure of 2 kpsi

### Performance Table

<table>
<thead>
<tr>
<th>Type</th>
<th>Max Error</th>
<th>Inaccuracy</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Plunge</td>
<td>Ramp</td>
</tr>
<tr>
<td>Standard</td>
<td>200 psi</td>
<td>9 mins</td>
<td>Always</td>
</tr>
<tr>
<td>Dual</td>
<td>9.8 psi</td>
<td>3.8 mins</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Error Chart

- Standard QD
- Ramp Rate (°C / min)
- Dual Mode
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• Quartzdyne is focusing on several areas to address market needs / desires
  – Size
  – Drift performance
  – Transient performance
• Smaller transducer built to enable new opportunities for instrumentation downhole
• Drift understanding and improvement give petroleum engineers confidence in data over the long term
  – Data shown to be much less than published specifications
  – Potential future improvement through experimentation
• Transient error reduction enables faster responses to conditions downhole saving rig time and cost
  – Dual mode technology a significant improvement over current quartz sensors
  – Technology proven, but not commercialized
• Always considering new ideas (½” OD Dual Mode Gauge?? )
QUESTIONS?