APPLICATION NOTES

Tilt / Inclination sensing

The TS9001.D is the highest resolution Sensor from Colibrys

Introduction

Low g Colibrys accelerometers are ideal products to measure tilt angle, using the earth's ground plate as reference. Tilt or inclination measurement is required in a wide variety of markets such as Energy, Mil/Aerospace, and Industrial & Instrumentation. Typical examples of applications are:

- Indication of pitch and roll of vehicles, sailing boat or aircraft
- Monitoring of boom angle
- Distance or height measurement
- Measuring drilling angle in well-logging
- Platform or antenna stabilization
- Compass correction
- High speed tilting train control
- Weapon security system

Colibrys MEMS accelerometers

The Colibrys products dedicated to tilt and inclination are MEMS capacitive accelerometer based on a bulk micro-machined silicon element, a low power ASIC for signal conditioning, a micro-controller for storage of compensation values and a temperature sensor.

Tilt measurements are quasi static measurement requiring typically ±1g or ±2g accelerometers with a low bandwidth. The TS9001.D and TS9002.D products are certainly the best tilt sensor from the complete family of Colibrys products. They operate from a single power supply voltage (between 2.5V and 5.5V) with a low current consumption (< 0.5mA at 5V). The output is a ratiometric analog voltage that varies between 0.5V and 4.5V for the full-scale acceleration range at a voltage supply of 5V.

The sensors are fully self-contained and packaged either in a 48-pin LCC ceramic housing (TS8002.D Fig 1) or in a 20-pin LCC ceramic housing (TS9001.D), thus insuring a full hermeticity. They operates over a temperature range of –55°C to 125°C and can withstand shocks up to 6000g without performance degradation.

The Colibrys tilt sensing accelerometer products from Colibrys are:

- TS8002.D Traditional tilt sensing product, Cost effective – 40°C to +85 °C
- TS9001.D Latest product designed for tilt applications, low range
- TS9002P Highest accuracy, highest stability

Fig 1: Open view of a TS8002.D product
Principle of operation
The accelerometer is using the effect of terrestrial gravity (1g) on the seismic mass as input acceleration to determine the inclination (Fig 2). The inertial mass is the center wafer, supporting the proof mass through the spring. The accelerometer output signal “Vout” is a ratiometric analog voltage following the next equation:

\[ V_{out} = Bias + (Scale \, factor \times Acceleration) \]

where:
- The Bias [V] is the output voltage at 0g acceleration
- The Scale factor [V/g] is the sensor sensitivity
- The Acceleration [g] is the earth acceleration (1g) applied through the sensitive axis

The angle \( \phi \) is calculated using the following equation:

\[ \phi = \arcsin \left( \frac{V_{out} - Bias}{1g \times Scale\_factor} \right) \]

where \( \phi \) is in degrees.

Variable capacitance accelerometer used as tilt sensor
The accelerometer rotated through the gravity acceleration produces a sinusoidal output signal. The figure 3 shows a schematic example of the accelerometer under various earth acceleration.

Example of tilt measurements using +/- 2g Range
In this example, the accelerometer is rotated 360° around the X or Y axis. The corresponding angle [°], the acceleration through the sensitive axis [g], the output signal [V] and the resolution [mg/°] are presented in the Table 1. When representing the resolution vs. the angle, we can clearly see that even if the accelerometer will provide signal over 360°, the best working domain is a linear and symmetric zone of ±30° around 0° and 180°.

<table>
<thead>
<tr>
<th>Tilt angle [°]</th>
<th>Sensitive axis acc. [g]</th>
<th>Vout [V (2g)]</th>
<th>Vout [V (1g)]</th>
<th>Resolution [mg/°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>2.5</td>
<td>2.5</td>
<td>17.452</td>
</tr>
<tr>
<td>30</td>
<td>0.5</td>
<td>3</td>
<td>3.5</td>
<td>15.038</td>
</tr>
<tr>
<td>60</td>
<td>0.866</td>
<td>3.366</td>
<td>4.232</td>
<td>8.594</td>
</tr>
<tr>
<td>90</td>
<td>1</td>
<td>3.5</td>
<td>4.5</td>
<td>-0.152</td>
</tr>
<tr>
<td>120</td>
<td>0.866</td>
<td>3.366</td>
<td>4.232</td>
<td>-8.858</td>
</tr>
<tr>
<td>150</td>
<td>0.5</td>
<td>3</td>
<td>3.5</td>
<td>-15.190</td>
</tr>
<tr>
<td>180</td>
<td>0</td>
<td>2.5</td>
<td>2.5</td>
<td>-17.452</td>
</tr>
<tr>
<td>210</td>
<td>-0.5</td>
<td>2</td>
<td>1.5</td>
<td>-15.038</td>
</tr>
<tr>
<td>240</td>
<td>-0.866</td>
<td>1.634</td>
<td>0.768</td>
<td>-8.594</td>
</tr>
<tr>
<td>270</td>
<td>-1</td>
<td>1.5</td>
<td>0.5</td>
<td>0.152</td>
</tr>
<tr>
<td>300</td>
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<td>1.634</td>
<td>0.768</td>
<td>8.585</td>
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<tr>
<td>330</td>
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<td>15.190</td>
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<td>360</td>
<td>0</td>
<td>2.5</td>
<td>2.5</td>
<td>17.452</td>
</tr>
</tbody>
</table>

Value are defined for 5V Power supply @20°C
Selection of a tilt sensor

Various specifications have to be considered to select the best accelerometer for a tilt sensing application. Short term and long term stability, hysteresis, repeatability and low noise output are the key parameters to consider for the best accuracy of a tilt measurement. Colibrys TS9001.D and TS9002P accelerometers are among the best products in term of short term and long term stability (1) with typical 0.15 mg for a ±1g full scale range. This represents bias stability better than 0.0086° over one year. Excellent bias temperature coefficient without compensation (typically 50µg/°C or 0.0028°/°C), low hysteresis and high repeatability are also provided by these products. Finally, the combination of noise and bandwidth determine the resolution or smallest measurable angle of the tilt sensor. Colibrys products present a low noise level (typ. 18 µg/√Hz for a ±2g sensor or typ. 9 µg/√Hz for a ±1g sensor) and therefore enable to measure angles with a typical resolution of 0.001° for ±2g sensor or 0.0006° for ±1g sensor (RMS noise for 1Hz bandwidth).

Conclusion

Colibrys accelerometers are qualified and integrated successfully since several years as tilt sensors in various applications such as compass correction, platform stabilization, transport and drilling instrumentation. The success of these integrations confirm Colibrys as a leader in the market for high-resolution tilt and inclination sensing.