Active Temperature Compensation and Calibration for MEMS Pressure Sensors with Constant Voltage

1. Description

This guide provides a simplified procedure for active temperature compensation by implementing a microcontroller (MCU) and a minimal four point calibration scheme. High accuracy applications will require additional calibration points and more complex compensation techniques. The following procedure is just one of several temperature and calibration techniques.

For additional accuracy, it is highly recommended that the system design include AutoZero during normal system operation. Autozero is a simple algorithm that recalibrates the system zero pressure point upon start-up. This simple technique will significantly improve system level accuracy.

The MEMS Pressure Sensor is basically a Wheatstone bridge with output signals in the mV range and requires amplification to interface with the microcontroller analog-to-digital converter (ADC) as shown in the system diagram below:
2. Definition of Terms

\( T_{\text{amb}} \) = Ambient Temperature (Typically 25°C)

\( T_{\text{max}} \) = High Temperature Point (Typically, 75% to 100% of the Maximum operating temperature of application) (°C)

\( P_0 \) = Ambient Pressure (psi)

\( P_1 \) = First Pressure Calibration Point (psi)

\( P_{\text{fullscale}} \) = Fullscale Pressure of sensor (psi)

\( V_{\text{out}} (T,P) \) = Output Voltage (mV)

\( V_{\text{out}}(T_{\text{amb}},P_0) \) = \( V_{\text{out}} \) at Ambient Temperature and Pressure \( P_0 \) (mV)

\( V_{\text{out}}(T_{\text{amb}},P_1) \) = \( V_{\text{out}} \) at Ambient Temperature and Pressure \( P_1 \) (mV)

\( V_{\text{out}}(T_{\text{max}},P_0) \) = \( V_{\text{out}} \) at Maximum Temperature and Ambient Pressure \( P_0 \) (mV)

\( V_{\text{out}}(T_{\text{max}},P_1) \) = \( V_{\text{out}} \) at Maximum Temperature and Pressure \( P_1 \) (mV)

\( V_{\text{zero}}(T) \) = Zero Offset Voltage (mV)

\( \Delta T \) = \( T_{\text{max}} \) – \( T_{\text{amb}} \) (°C)

\( \Delta P \) = \( P_1 \) – \( P_0 \) (psi)

\( S(T) \) = Sensitivity (mV/psi)

\( S(T_{\text{amb}}) \) = Sensitivity at Ambient Temperature (mV/psi)

\( S(T_{\text{max}}) \) = Sensitivity at Maximum Temperature (mV/psi)

\( \text{TCS} \) = Temperature Coefficient of Span (%FS/°C)

\( \text{TCZ} \) = Temperature Coefficient of Zero Offset (%FS/°C)

*Alternative temperature and pressure units can be used if kept consistent throughout equations.*
Basic Sensor Output Equation:

\[ V_{out} (T,P) = V_{zero}(T) + S(T) \cdot P \]
\[ = V_{zero}(T_{amb}) + T_{CZ} \cdot S(T_{amb}) \cdot P_{fullscale} \cdot (T - T_{amb}) + \]
\[ S(T_{amb}) \cdot (1 + T_{CS} \cdot (T - T_{amb})) \cdot P \]  
(1)

Test Equipment Requirements:

Please be aware of the following considerations when choosing suitable test equipment for calibration:

- Temperature dwell times will depend on system design and oven capacity.
- Determine appropriate dwell time by ensuring output voltage stabilizes at temperature.
3. Temperature Compensation Procedure:

**Step 1:** At Ambient Temperature and Pressure, record data:
- Ambient temperature, \( T_{\text{amb}} \)
- Ambient pressure, \( P_0 \)
- Output Voltage, \( V_{\text{out}}(T_{\text{amb}},P_0) \) (This measurement is repeated with AutoZero technique)

**Step 2:** Keep at Ambient Temperature and Raise Pressure to \( P_1 \), record data:
- \( P_1 \) of Pressure Source
- Output Voltage, \( V_{\text{out}}(T_{\text{amb}},P_1) \)

**Step 3:** Raise temperature to Maximum and adjust back to Ambient Pressure, record data:
- Maximum Temperature, \( T_{\text{max}} \)
- Output Voltage, \( V_{\text{out}}(T_{\text{max}},P_0) \)

**Step 4:** Keep at Maximum Temperature, and raise pressure to \( P_1 \) and record data:
- Output Voltage, \( V_{\text{out}}(T_{\text{max}},P_1) \)

(The four-point calibration procedure has been completed.)

**Step 5:** Calculate the zero offset and system Sensitivity at Ambient and Maximum Temperature:

\[
\Delta P = P_1 - P_0 \quad (2)
\]
\[
\Delta T = T_{\text{max}} - T_{\text{amb}} \quad (3)
\]
\[
S(T_{\text{amb}}) = \frac{V_{\text{out}}(T_{\text{amb}},P_1)-V_{\text{out}}(T_{\text{amb}},P_0)}{\Delta P} \quad (4)
\]
\[
S(T_{\text{max}}) = \frac{V_{\text{out}}(T_{\text{max}},P_1)-V_{\text{out}}(T_{\text{max}},P_0)}{\Delta P} \quad (5)
\]

For absolute sensors:

\[
V_{\text{zero}}(T_{\text{amb}}) = V_{\text{out}}(T_{\text{amb}},P_0) - S(T_{\text{amb}}) \times P_0 \quad (6)
\]
\[
V_{\text{zero}}(T_{\text{max}}) = V_{\text{out}}(T_{\text{max}},P_0) - S(T_{\text{max}}) \times P_0 \quad (7)
\]
For differential and gauge sensors:

\[ V_{\text{zero}}(T_{\text{amb}}) = V_{\text{out}}(T_{\text{amb}}, P_0) \]  
\[ (8) \]

\[ V_{\text{zero}}(T_{\text{max}}) = V_{\text{out}}(T_{\text{max}}, P_0) \]  
\[ (9) \]

**Step 6:** Calculate Temperature Coefficient of Span TCS (= sensitivity change over temperature).

\[ TCS = \frac{S(T_{\text{max}}) - S(T_{\text{amb}})}{S(T_{\text{amb}}) \Delta T} \]  
\[ (10) \]

**Step 7:** Calculate Temperature Coefficient of Zero Offset TCZ (= Offset Voltage change over temperature).

\[ TCZ = \frac{V_{\text{zero}}(T_{\text{max}}) - V_{\text{zero}}(T_{\text{amb}})}{S(T_{\text{amb}}) P_{\text{full-scale}} \Delta T} \]  
\[ (11) \]

**Step 8:** Implement Data into Basic Sensor Output Equation into MCU with following:

\[ P = \frac{\left( V_{\text{out}}(T,P) - (V_{\text{zero}}(T_{\text{amb}}) + TCZ \cdot S(T_{\text{amb}}) \cdot P_{\text{full-scale}} \cdot (T - T_{\text{amb}})) \right)}{S(T_{\text{amb}}) \cdot (1 + TCS \cdot (T - T_{\text{amb}}))} \]  
\[ (12) \]

*Note equation (12) is equation (1) solving for Pressure instead of \( V_{\text{out}} \).*

**Step 9:** AutoZero technique is recommended during normal system operation.

For additional questions, please consult sales@si-micro.com.
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