ESTIMATION OF ERRORS AND CALIBRATION OF THE FREESCALE PRESSURE SENSORS

Abstract:

This report provides information to estimate the pressure reading error and to perform additional calibration to Compensated and IPS pressure sensors by the customer to improve the accuracy of the output.

Discussion:

The errors of the Freescale IPS (integrated pressure sensors) and compensated pressure sensors are minimized by calibration and compensation done after assembly, and before the gel fill operation. However, the accuracy is limited by the following errors:

1. Offset (ε_1);
2. TCO (temperature coefficient of Offset) (ε_2);
3. Linearity error(ε_3);
4. Span(ε_4);
5. TCS (temperature coefficient of Span) (ε_5);
6. Temperature hysteresis (ε_6);
7. Pressure hysteresis (ε_7).

The total accuracy (or error budget) can be calculated as:

Accuracy [%]= (ε_T /VFSS)*100;

Where VFSS is the full scale span and ε_T is the total error;
$\varepsilon_T = \sqrt{\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2 + \varepsilon_4^2 + \ldots + \varepsilon_7^2}$

Calculation of the errors:

1. Offset (ε_1) [mV]= Offset $_{actual}$-Offset $_{nominal}$.

2. TCO: The greatest of the two TCO's
   TCO_1 (ε_{21}) [mV] = Offset $_{actual}$ @ 25°C- Offset $_{actual}$ @ 0°C,
   TCO_2 (ε_{22}) [mV] = Offset $_{actual}$ @ 85°C- Offset $_{actual}$ @ 25°C.

   Sometimes specified in [μV/kPa]units:

   TCO_1 (ε_{21}) [μV/°C] = (Offset $_{actual}$ @ 25°C- Offset $_{actual}$ @ 0°C)* 10^6/(25°C-0°C)

3. Linearity error (ε_3) [mV]=[Vout $_{actual\ @\ half\ scale\ reading}$- (Offset $_{actual}$+ +Sensitivity $_{actual}$*pressure $_{@\ half\ pressure\ range}$)];

   Sometimes specified in % VFSS:
   Linearity error (ε_3) [%]=[Vout $_{actual\ @\ half\ scale\ reading}$- (Offset $_{actual}$+ +Sensitivity $_{actual}$*pressure $_{@\ half\ pressure\ range}$)]*100/VFSS $_{actual}$

   Where: Sensitivity $_{actual}$ [mV/kPa] = VFSS/pressure range.

4. Span (ε_4) [mV] = Full-scale output $_{actual}$- full scale output $_{nominal}$.

5. The greatest of the two TCS's:
   TCS_1 (ε_{51}) [mV] = Span $_{actual}$ @ 25°C- Span $_{actual}$ @ 0°C,
   TCS_2 (ε_{52}) [mV] = Span $_{actual}$ @ 85°C- Span $_{actual}$ @ 25°C.

6. The greatest of the two hysteresis;
   Temp hysteresis (ε_{61}) [mV] = (Offset @ 1st 25°C – Offset @ 2nd 25°C)
   Temp hysteresis (ε_{62}) [mV] = (Offset @ 2nd 25°C – Offset @ 3rd 25°C)

   The temperature loop for these V offset's is: 25°C, 85°C, 25°C, 0°C, 25°C
   For an absolute part, any pressure point can be used.

7. The greatest of the two hsyteresis:
   Press hysteresis (ε_{71}) [mV] = (Vout@ 1st $_{mid\text{-}range\ pressure}$ - Vout@ 2nd $_{mid\text{-}range\ pressure}$)
   Press hysteresis (ε_{72}) [mV] = (Vout@ 2nd $_{mid\text{-}range\ pressure}$ -Vout@ 3rd $_{mid\text{-}range\ pressure}$)

   The pressure loop for the V output's @ 25°C is: mid-range pressure, max pressure, mid-range pressure, min pressure, mid range pressure.

Calibration of the part to minimize error:

Typically, the Offset is the biggest error, followed by TCO, TCS, linearity and Span. Temperature hysteresis and pressure hysteresis errors are small and can be neglected. There are three options to increase the accuracy of the part. These options are described below.

Equations a, b and c will be used for the calibrations:

a. Vout= Vcc*a*P+Vcc*b
b. Vout = s*P+ Offset
c. Vcc*a=slope= $V_{\text{full scale output}}$-Offset/Pmax-Pmin=s

Where a=sensitivity, b= y-axis intercept.

1) Nominal error (e_1):

Using sensitivity and offset from datasheet, and using a linear equation to determine pressure:

$P=(Vout_{nominal}-Offset_{nominal})/s$

$Vout_{nominal}= s*P+ Offset_{nominal}$

e_1 [kPa] = $(Vout_{actual}-Vout_{nominal})/s_{nominal}$

e_1 [%]= $(Vout_{actual}-Vout_{nominal})*100/VFSS$

Figure 1 shows an example of error correction using e_1

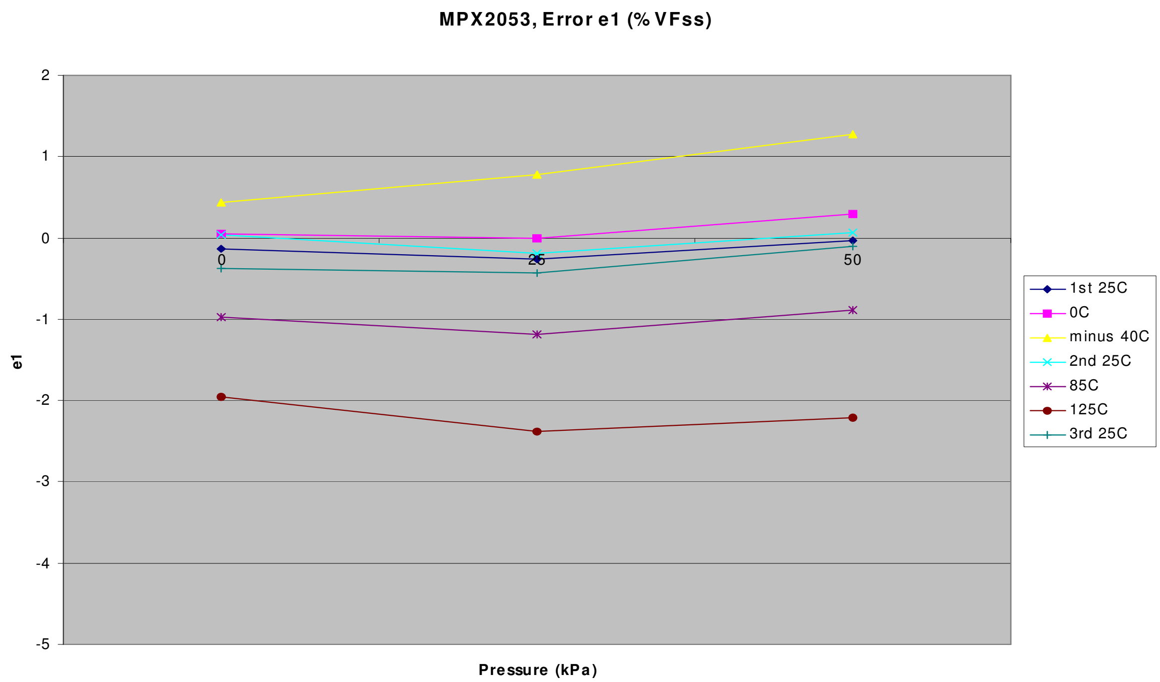

Fig 1

2) **Auto-Zero (e_2):**

Offset error and TCO ($\Delta(Voff)/\Delta T$) are reduced.

e_2 [kPa]= [Vout $_{actual}$-Vout $_{nominal}$-Offset $_{actual}$)]/s $_{nominal}$

e_2 [%]= [Vout $_{actual}$-Vout $_{nominal}$-Offset $_{actual}$)] * 100/VFSS

Figure 2 shows a graph of the errors obtained using e_2.

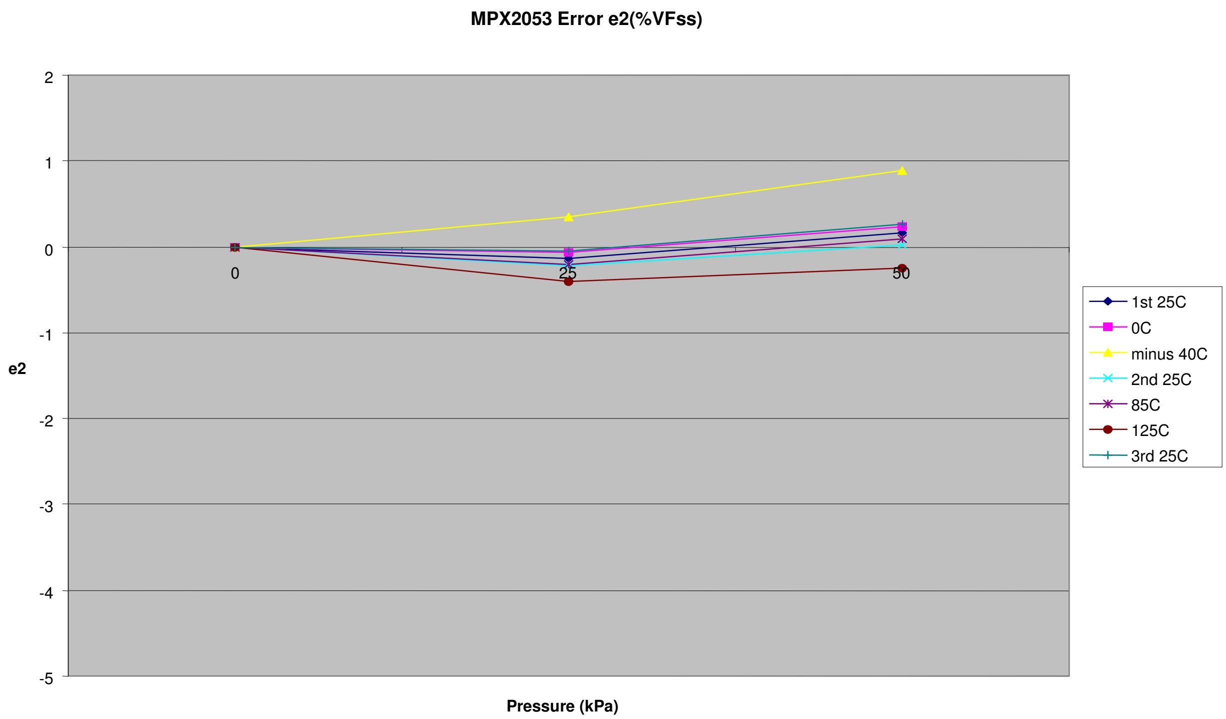

Fig 2

3. Error using auto-zero and a two-point calibration in the factory (e_3):

e_3 [kPa]= [Vout $_{actual}$-s $_{actual}$*P-Offset $_{actual}$]/s $_{actual}$

Where s $_{actual}$= V $_{full\ scale\ output}$ –Offset $_{actual}$/Pmax-Pmin

e_3 [%]= [Vout $_{actual}$-s $_{actual}$*P-Pff]/VFSS

Figure 3 shows a graph the errors using e_3.

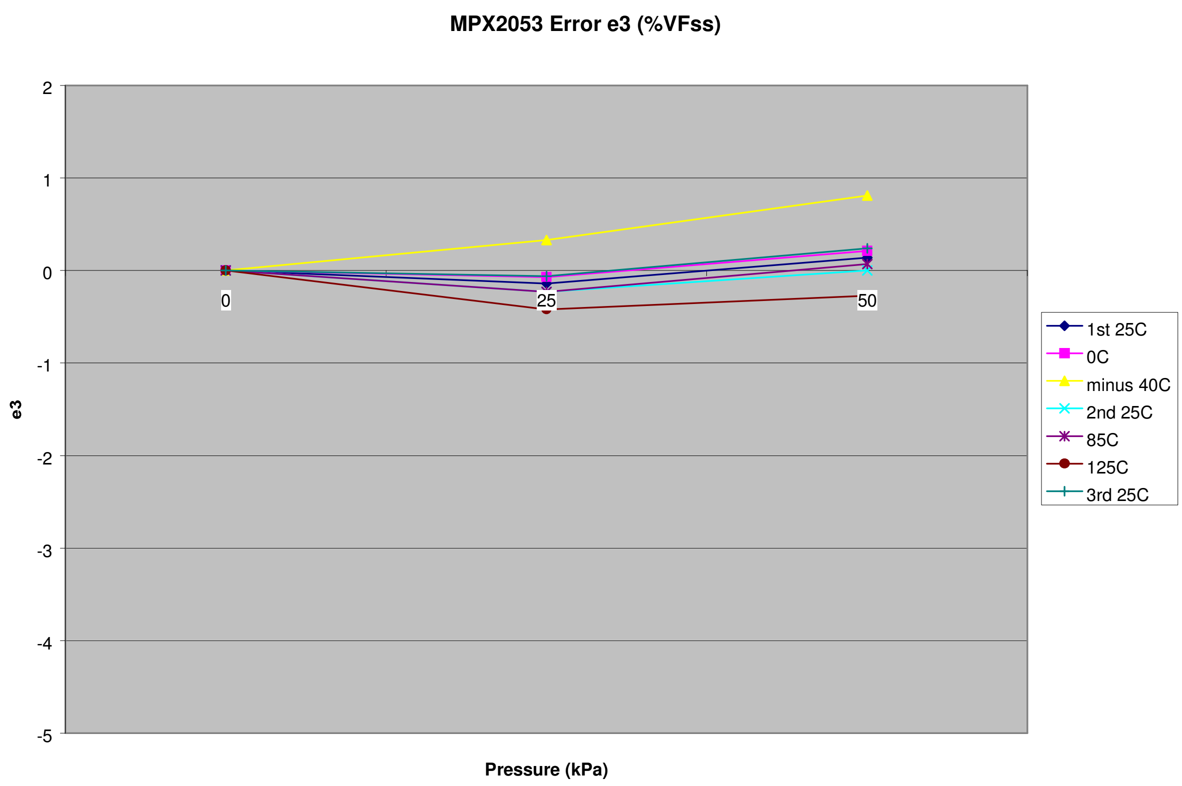

Fig 3