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Analysis of positioning parameters at glazing of pressure measurement cells

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Summary:

Glazing is increasingly used to join the silicon measuring cell to the steel diaphragm in pressure sensor production. This study examines the glazing process at ETO SENSORIC (Germany) using statistical analysis. The objective was to identify key positioning parameters that optimize signal yield. High sensor sensitivity and low deviation of the characteristic curve are maintained. A multivariable regression was performed with the measuring cell signal as the response. The analysis was extended with a µCT study of parts with unexplained signal deviations.

Keywords: pressure sensor, glazing, piezo resistive cell, steel membrane, statistic

Introduction

Glazing is a particularly sensitive process that directly affects the signal quality. During glazing, several objectives must be optimized, including the positioning of the measurement cell (strain gauge), thermal parameters, material selection, and process cost. This study aimed to determine the relationship between positioning parameters and both the signal level (sensitivity) and the piecewise variation of the characteristic lines [1]. These features, which characterize glazing quality, can easily be quantified using the measurement cell's signal. The cell contains four resistors forming a Wheatstone bridge, measured in the laboratory with a pressure-controlled measurement system.

Additionally, samples that deviated from the regression model were analysed using µCT to reveal the effect of bubble distribution in the glazing.

Samples

For the investigation, CiS set up steel measuring cells with differently positioned silicon strain gauges – 200 bar relative pressure sensor. Complete assemblies of pressure sensors with a steel diaphragm and a piezo resistive measuring cell joined by a glazing were produced in 46 functional parts, 28 of which were OK-calibrated (OK parts).

In the following section, only the OK parts were included in the analysis, but in the last sections. The variants (Tab.1) include test specimens with glass layer thicknesses of 50 µm and 150 µm and standard positioning (1.5 mm from the centre of the steel membrane at 0° rotation). The final three variants were produced with a 50 µm glass layer and an initial 45° rotation, followed by centre distances of 1 mm and 2 mm. The positioning parameter is set to the default value at the theoretical limits of the technology, showing no indication of a design of experiments (DoE).

Tab. 1 Variants of samples

	Thick. glass [µm]	Disp. centre/ mm	Angle / °	Functional parts	Calibration Ok
Thick. glass 50 µm	50	1,5	0	17	13
Thick. glass 150 µm	150	1,5	0	10	5
Angle 45°	50	1,5	45	7	0
Displacement 1 mm	50	1	0	5	4
Displacement 2 mm	50	2	0	7	6

Basic statistic of the signal

The raw values were extracted from the complete measurement protocol at specific temperatures (-25 °C, 20 °C, and 120 °C) and pressures (0 bar, 100 bar, and 200 bar) for further analysis. The standard deviation of these values for a given positioning parameter indicates the coherence of the derived characteristic curves. Fig. 1 and 2 display three pressure cycles for each temperature - cycle 1 at -25 °C, cycle 2 at 20 °C, and cycle 3 at 120 °C - with each cycle rising to 200 bar and falling back to 0 bar.
In Fig. 1, parts with a 150 µm thickness show very low deviation and raw values in contrast to those pieces with a 50 µm layer, indicating that a stable, functional sensor can be produced with a 150 µm layer. Additionally, Fig. 1 shows that the "50 µm" configuration with a 2 mm displacement exhibits the same deviation as the basic "50 µm" displacement (1.5 mm), while the "Angle 45°" configuration displays extremely large deviation throughout. The median value indicates sensor sensitivity; according to Fig. 2, all settings except "Angle 45°" are suitable for measurement, as a 45° rotation causes the resistors to cancel out the signal, and both scatter and median decrease with increasing temperature.

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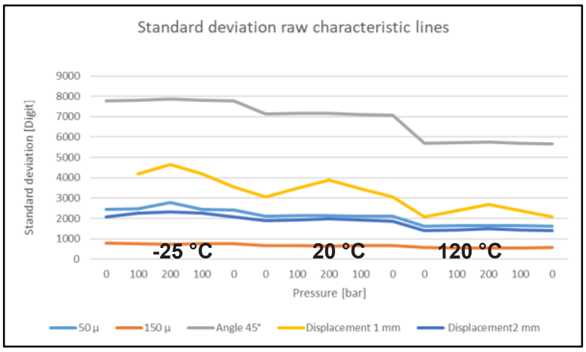

Fig. 1. Standard deviation of raw characteristic line vs. pressure

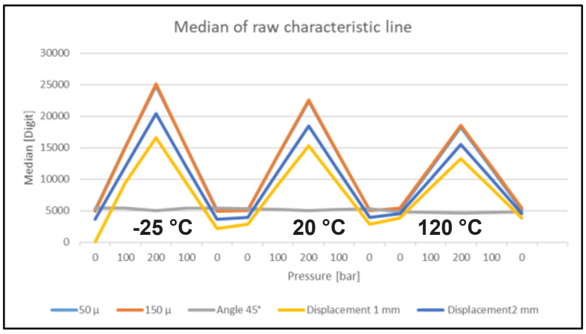

Fig. 2. Median of raw characteristic line vs. pressure

Variables of measuring cell positioning

To determine the parameters, several planes were first defined. The surface of the steel membrane was chosen as the reference plane (plane 0). The four bond pads on the strain gauge were designated as planes 1, 2, 3, and 4, while the surface of the strain gauge was assigned as plane 5 and the glazing surface as plane 6. Based on these planes, 11 geometric and positioning parameters were developed, covering features from the cross-section of the glass pad to the heights of the strain gauge cell elements. These variables were measured using a Keyence 4th Generation measuring microscope.

Analysis of measuring cell positioning

The following section analyses the influence of the glazing's geometric parameters on the raw values of the characteristic lines. A multivariable regression analysis was performed using MiniTab. Parts with a 50 µm layer thickness yielded significantly worse EMC results compared to those with a 150 µm layer; therefore, we focused on the 150 µm test specimens. Regression analyses were conducted over all temperature ranges (-25 °C, 20 °C, 120 °C) and pressure ranges (0 bar, 100 bar, 200 bar). For the 150 µm layer, the coefficients of determination were consistently high (>80%), though the significant variables varied. The influence of different parameters on the sensor signal was sometimes contradictory, suggesting other factors may also be at play.

A µCT analysis was then carried out to investigate whether bubbles or cracks in the glass solder could affect the results [2].

Deviation in trend

The NOK parts generally exhibit lower raw values than the OK parts, except for NOK part No. 29, whose raw value falls within the expected range for OK parts. The analysis of geometric parameters revealed no abnormalities, suggesting that other factors may be influencing the results. Four samples were therefore sent for µCT analysis. The selected samples included the conspicuous test piece No. 29, an OK part with a 50 µm layer (No. 16), a NOK part with a 150 µm layer (No. 25), and an OK part with a 150 µm layer (No. 38). Test piece 16 shows almost no bubbles in the glass pad (Fig. 3) and has an acceptable signal. In contrast, test piece 25 exhibits many large bubbles in the glass solder, especially beneath the strain gauge, resulting in significantly lower raw values. Test sample 29 has a large bubble beneath the strain gauge - though smaller than in test piece 25 - which places it just outside the acceptable range. Test sample 38, like test sample 16, displays only a small bubble beneath the strain gauge and shows no abnormalities in its characteristic curve.

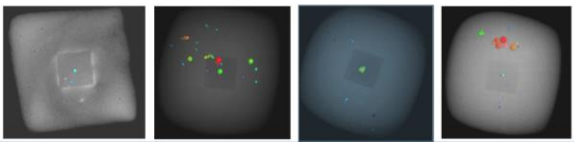

Fig. 3, µCT image of No. 16 IO/50µm; No. 25 NIO/150µm; No. 29 NIO/150µm; No. 38 IO/150µm;

Result and discussion

- A significant deviation from the ideal strain gauge positioning substantially affects the raw values and the consistency of the signal lines.
- Using a 150 µm layer thickness, sensitive sensors can be produced with a lower standard deviation than those with a 50 µm layer.
- The regression analysis of production parameters versus raw values yielded contradictory results, indicating that some factors were overlooked; hence, a µCT scan was performed.
- Bubbles in the glass beneath the strain gauge directly influence its raw signal values.
- A design of experiments (DoE) is currently underway to investigate the factors influencing bubble formation in glazing.

References

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