Comparing Cavity Pressure Sensor Technologies Using In-Mold Data

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Abstract

Three cavity pressure sensor configurations were used to compare data from direct and indirect, piezoelectric and strain gage sensors. The indirect button style sensors tended to read slightly lower peaks than direct flush mount sensors, and data decayed slightly later. Also, the piezoelectric sensors tended to respond approximately 5 ms faster than the strain gage sensors. However, data from all sensor types correlated very well with one another. For all practical purposes, there is no distinguishable difference in the data utility between one sensor type and another.

Introduction

Today, only two types of cavity pressure sensors have been widely accepted in the injection molding industry. The first of these, typically referred to as strain gage sensors, uses strain gages mounted to a diaphragm or column to convert force exerted by the plastic into a voltage output. The second technology, typically referred to as piezoelectric sensors, uses piezoelectric crystals which emit charge when loaded.

These sensors can be further classified by the location of the sensors inside the mold. Direct, or flush mount sensors, are positioned with the sensor directly in contact with the cavity. On the other hand, indirect sensors, typically in the form of a button, are placed behind an ejector pin which transmits pressure from the plastic to the sensor.

Over the years, practitioners of each of these forms of cavity pressure sensing technology have argued the merits of each type of sensor. Some of these benefits have been well documented, such as the superior high-temperature performance of piezoelectric sensors and the lower cost of strain gage sensors. Other claims, such as the response time, accuracy, and potential for misinstallation, have been based on theoretical assumptions but have not been well documented.

The purpose of this study is to directly compare the data from strain gage and piezoelectric sensors, as well as from direct and indirect sensors. This comparison will be accomplished through the use of several unique sensor installations that provide direct comparison between sensors using in-mold data. It is hoped that this comparison will provide greater insight into the true strengths and weaknesses of each technology.

Experimental

Three sensor installations were used to facilitate comparison of sensors.

Configuration 1, shown in Figure 1, utilized a flush mount sensor mounted in a moving ejector pin. This ensures that any pressure applied to the flush mount sensor is applied to the indirect sensor beneath the ejector pin as well, although there is additional pressure from the exposed end of the ejector pin as well. This installation was positioned near the last point of fill in a standard 165 mm (6.5”) test bar mold with a wall thickness of 3.18 mm (1/8”)..

Configuration 2, shown in Figure 2, used a button sensor mounted behind the support sleeve of a flush mount sensor. The advantage of this configuration is that the same contact surface is used to load both sensors. However, the indirect sensor installation is not truly representative of a typical application. This installation was located approximately 30 mm from the last point of fill in a rectangular 127 mm x 32 mm x 1.47 mm (5” x 1.25” x 0.058”) two cavity mold.

Configuration 3, also shown if Figure 2, used an indirect sensor mounted behind an ejector pin directly opposite a flush mount sensor. The ejector pin was 4.76 mm (3/16”) diameter, and the installation was located approximately 10 mm from the last point of fill in the same mold used for Configuration 2.

The sensors used for the study included a LS-B-127-2000 9 kN (2000 lb) strain gage button style (indirect) sensor from RJG, Inc., a 6157 piezoelectric flush mount (direct) sensor from Kistler, Instruments, and a 9204 10 kN piezoelectric button style sensor from Kistler. Data was collected using an eDART™ system from RJG, Inc. Effective data sampling rates of approximately 250 samples/sec were used.

The studies were run on an Arburg 320S 500-150 press. The material was a natural polypropylene with intermediate viscosity. For each sensor configuration, a standard series of 10 tests were performed in which fill speed, transfer position, pack speed, and hold pressure were varied. Mold temperature was maintained at 21^o C (70^o F), except in Configuration 3, where additional data was taken at 43^o C (110^o F).

Results

Configuration 1 Results: Figure 3 shows a comparison of the data for a single shot using Configuration 1 (direct sensor in a pin). Here, the flush mount piezoelectric sensor and the indirect button sensor track closely, although the piezoelectric direct sensor reads a peak approximately 3 bar (50 psi) higher and decays approximately 0.2 seconds sooner than the strain gage button. Also, by zooming in on the "dogleg" in the curve where the cavity finishes filling and is rapidly pressurized, it is seen that the button sensor data lags the flush mount sensor by approximately 3-5 ms.

When the strain gage button is replaced by the piezoelectric button, the results are very similar. The flush mount sensor again reads slightly higher and decays slightly faster than the button sensor. However, the doglegs from both sensors are very closely aligned, with virtually no difference between the two.

This suggests that the differences between the peak pressures and decay rates are due to the sensor location (flush mount vs. indirect) rather than the sensor technology (piezoelectric vs. strain gage). However, the piezoelectric style sensor does seem to respond approximately 3-5 ms faster than the strain gage sensor during the packing portion of the curve.

Further analysis of the differences between sensor location and sensor technology is seen in Figure 4. Here, the difference between the peak flush mount pressure and the peak button pressure is plotted as a function of the time required to fill the cavity. At low fill times (fast injection rates), the difference is rather small (approximately 5-7 bar), while at longer fill times, the difference rises to 14 - 17 bar (200 – 250 psi). Both the strain gage and piezoelectric sensors follow the same trend, and the differences between the two are within their calibration error.

Correlation analysis was used to compare the relative agreement of each sensor type. Figure 5 shows the strong relationship between peak flush mount pressure and peak button pressure. Similarly, Table 1 shows correlation coefficients for flush mount vs. button data for each configuration. The high correlation for both peak and cycle integral (area under the entire cavity pressure curve) for all configurations illustrates how each of these sensor types is equally capable of measuring pressure changes within the cavity.

Configuration 2 Results: In Figure 6, the difference between the peak flush mount pressure and the peak button pressure is plotted as a function of the time required to fill the cavity. The data from Configuration 2 is comparable to the data from Configuration 1; the flush mount sensor's peak cavity pressure is approximately 11 bar higher than the strain gage button sensor's, and its decay is approximately 0.08 sec sooner. This is further illustrated in Figure 7, which shows data from a single shot using Configuration 2.

Also similar to Configuration 1's results, the strain gage sensor lags the piezoelectric sensor by approximately 3-5 ms during packing. Finally, Table 1 shows again a strong correlation between the peak cavity pressure and cycle integral for the two sensors.

Configuration 3 Results: Figure 6 also shows the difference between the peak flush mount pressure and the peak button pressure for Configuration 3 at both 21^o C and 43^o C. Unlike Configuration 1 and 2, the flush mount sensor reads lower than the strain gage button by approximately 18 bar (250 psi) at the 21^o C mold temperature.

Closer examination of the data for a single shot shows that the difference between the two sensors grows throughout the cycle, peaking following the end of injection forward (Figure 8). Also, a significant amount of mold deflection is noted in the cavity pressure data at the end of injection forward. Since the flush mount sensor is located in the fixed half of the mold, which has better support than the moving half of the mold where the button sensor is located, it is likely that mold deflection effects the two sides of the mold differently. Thus, higher pressures seen on the button sensor may be due to the effects of mold deflection exerting additional pressure on the moving half of the mold. This is supported by data from the flush mount sensor from Configuration 2, also shown in Figure 8, which is also mounted in the moving half of the mold and tracks very closely to the button sensor from Configuration 3 at most injection rates.

Interestingly, the difference between the peak flush mount pressure and the peak button pressure shifts to 25 bar (350 psi) at the 43^o C mold temperature (see Figure 6). This may be attributable to increased mold deflection, since pressures at 43^o C were higher than at 21^o C.

Finally, correlation data for the two Configuration 3 sensors, as seen in Table 1, again shows strong correlation between the direct and indirect sensors. It is interesting that this correlation is maintained despite the differences in mold deflection on the two sides of the mold.

Discussion

While there are measurable differences in the behavior of each type of sensor, it is unlikely that the data from any of the sensor types provides greater utility than any of the other types. This is because the differences in sensor behavior are rather minor, and the strong correlation between the direct and indirect sensors suggests that either sensor will provide the same information to processors using the technology. For example, an increase in peak cavity pressure would be detected equally well by any of the sensors tested. In other words, it is the relative change in cavity pressure with process changes, not the absolute value, that is most important.

In instances where the cavity pressure sensor is used to control the press (e.g. transferring to 2nd stage pressure via a cavity pressure setpoint), the response time of the sensor during packing could affect the overall response of the press. However, the difference in response time between the piezoelectric and strain gage sensors was only 3-5 ms, compared to the overall response time of approximately 20 – 120 ms required for most presses to transfer once they receive a transfer signal. Thus, it is unlikely that the faster response rate of the piezoelectric sensor would result in improved process control capability.

Conclusion

While there are subtle differences in the performance of direct and indirect, strain gage and piezoelectric sensors, the usefulness of any of these sensor types is equal for purposes of process control and process monitoring. Perhaps more important distinguishing characteristics of these sensor types are their relative cost, ease of proper installation, and robustness in a manufacturing environment.

Acknowledgements

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Configuration 1	Cycle Integral Correlation	Peak Correlation
Piezo Direct - Strain Gage Button	100.0%	99.9%
Piezo Direct - Piezo Button	99.7%	99.7%
Configuration 2		
Piezo Direct - Strain Gage Button	99.9%	99.9%
Configuration 3		
Piezo Direct - Strain Gage Button 21^{o} C	99.9%	99.8%
Piezo Direct - Strain Gage Button 43^{o} C	99.9%	100.0%

Table 1: Correlation of Peak and Cycle Integral Data for All Experimental Conditions

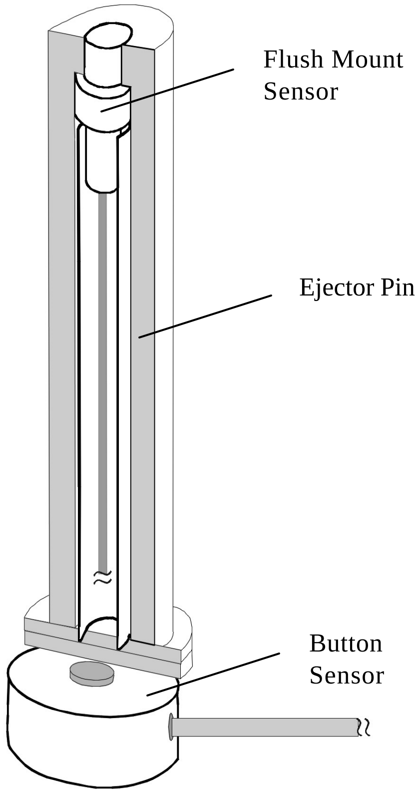

Figure 1: Illustration of Configuration 1: Direct Sensor Installed in Moving Ejector Pin

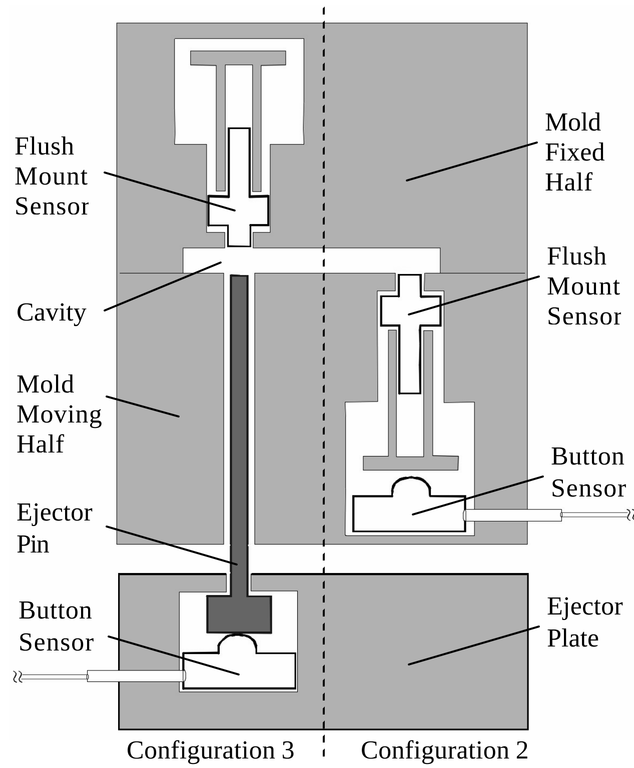

Figure 2: Illustration of Configuration 2 (Button Beneath Direct Sensor) and Configuration 3 (Direct Sensor Across from Moving Ejector Pin)

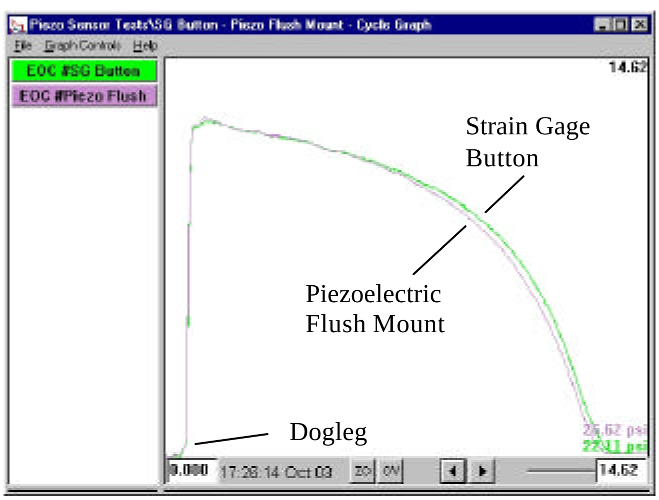

Figure 3: Example of Cavity Pressure Profiles: Configuration 1

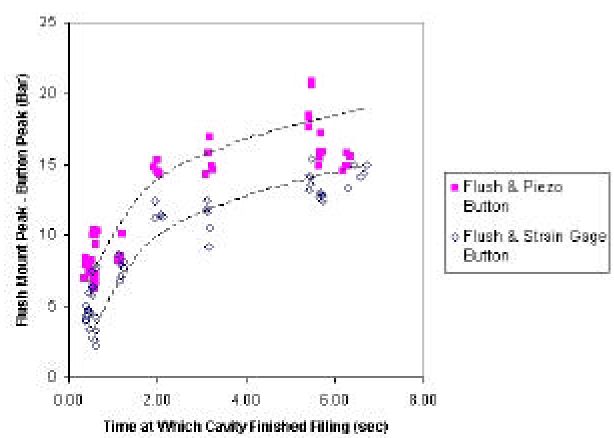

Figure 4: Differences in Peak Data Between Sensors Using Configuration 1

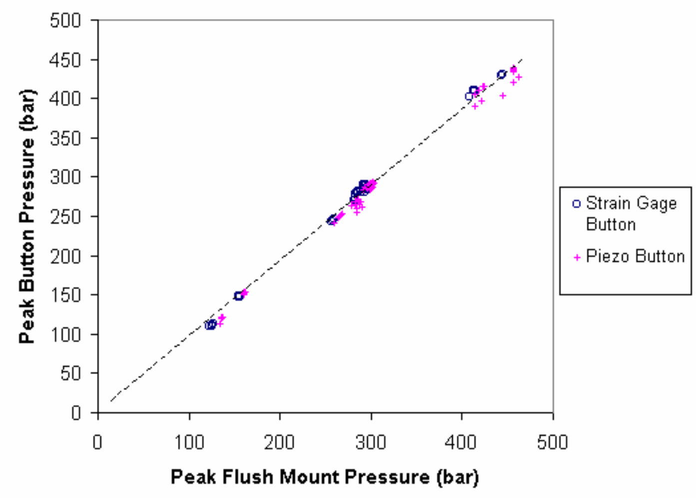

Figure 5: Correlation of Peak Cavity Pressure Data Using Configuration 1

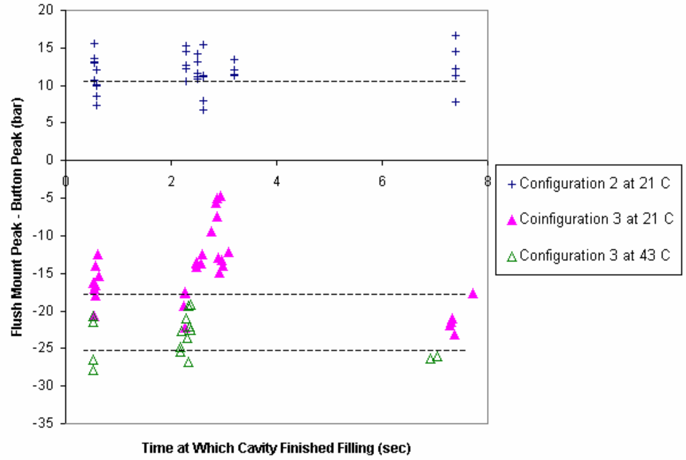

Figure 6: Difference in Peak Data Between Sensors Using Configuration 2 and Configuration 3

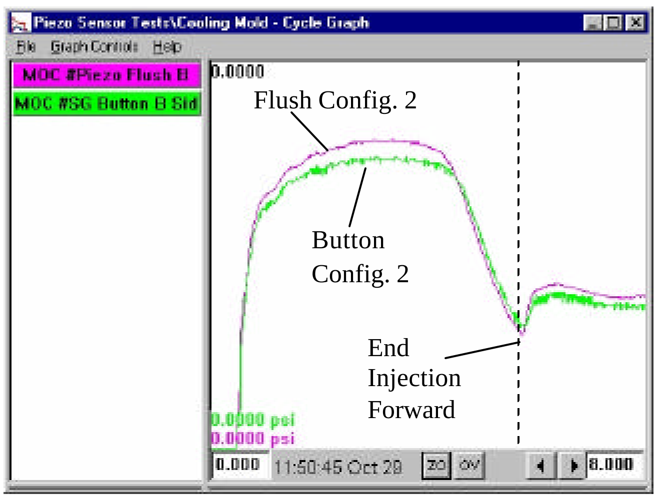

Figure 7: Example of Cavity Pressure Profiles Using Configuration 2

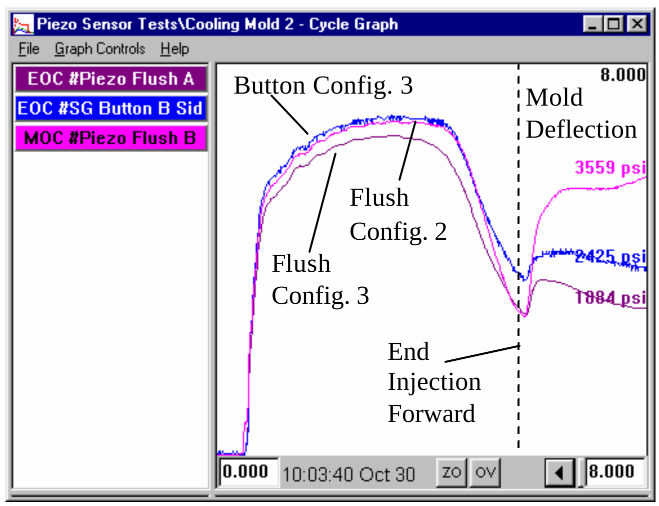

Figure 8: Example of Cavity Pressure Profiles Using Configuration 3