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Feasibility study on integrated process/product quality assurance framework for precision injection moulding based on vibration monitoring

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Abstract

Quality control and assurance has a major involvement in manufacturing of injection moulded components, especially when the effectiveness and capability of precision injection moulding needs to be established and ensured. Quality control through the traditional metrological inspection approach has been known to require a considerable amount of time, limiting the number of parts that can be measured and assessed. In a process such as in injection moulding with very short cycle times, the large time required for metrological inspection includes the risk of detecting that the production is out of tolerance late, causing an increased production scrap rate. The current paper presents a feasibility investigation on a quality control system that incorporates multiple inputs such as signals from external and machine regulating sensors (process conditions data) and part measurements to establish process quality indicators ("Process Fingerprint"). It is presented that the process quality indicators derived from the sensors signals and process data profiles follow a similar trend with the part dimension throughout the duration of the production run. The process quality indicators can be calibrated for the specified process conditions and provide a fast quality monitoring system based on machine data that will detect production variations. Therefore, such a system could decrease the required intensive metrological efforts for the approval of injection-moulded parts

Keywords: Precision injection moulding, Quality Control, Process monitoring

1. Introduction

Injection molding is a process that is increasingly adopted as the manufacturing process of more products as is can ensure a cost efficient production with short cycle times.

To ensure the quality and capability of the precision injection moulding a metrological investigation is essential. However, such an investigation requires significant amount of time and researchers are working towards developing new methodologies with the use of sensing technology that could decrease the intensive metrological efforts for the approval of the injection-moulded parts.

Multiple research studies have been conducted with different approaches based on the function requirement of the product. Mould separation (MS) monitoring with the use of LVDT's, is one of those that can provided a reliable indicator for of part weight and thickness [1]. Gao et all [2] have used an approach where a custom designed multivariate sensor (MVS) was used to monitor the quality on the injection-moulded parts based on the assumption the part quality indicators (dimensions) can be tightly controlled and the in-mould process parameters are known. Indirect process parameter data were also utilized in an online multivariate optimization system developed Johnston et al for the optimization and control of the process [3].

The aforementioned approaches consider the case of a tightly controlled and optimised process, but do not consider the dimensional control of the injection-moulded components directly. The quality of the parts though is the essence of any quality assurance system. It is thus required to consider the dimensional accuracy of the parts together with the sensor data. This research work presents an alternative approach to process and part quality monitoring and control utilizing machine and external sensor data monitoring or "Process Fingerprint".

2. Experimental setup and Instrumentation

The use of vibrations as a quality tool is not unknown in the manufacturing world and particularly in machining.The use of accelerometers in injection moulding to monitor and control the process is not yet established and the potential of using accelerometers in injection moulding is investigated experimentally. The accelerometers transducers have a positioning advantage, as they do not required mould modifications for in-mould placement, keeping tooling costs stable and avoiding surface impressions on the part.

An Engel e-motion 110 electrical injection-moulding machine was used for the experiment. The mould used is a multiple-cavity mould and the manufactured geometry is a part of a mechanism assembly. No further information is available though, due to confidentiality. The experiment was conducted based on a pressure-controlled, high-pressure injection moulding process, which run for three hours with constant process conditions. Moulded parts from each cavity were collected every 60 cycles for dimensional and weight measurements and consequent comparison to the vibrational and machine process data. The machine process data were directly recorded from the machine controller.

For the acquisition of vibrational data, three types of commercial accelerometers from Brüel & Kjær, were considered. Based on expected frequency content and vibration magnitude, accelerometer Types 4394 and 4397-A (sensitivity 10mV/g) were used in order to avoid overloading due to the motion of the ejection system. Whereas the more sensitive Type 4507 accelerometers (sensitivity 100 mV/g) were positioned in the stationary platen of the machine in order to record smaller changes. Figure 1 presents the relative position of the transducers in the machine's working space. A Type 3050, sixchannel data acquisition module was used to record acceleration signals close to the mould.

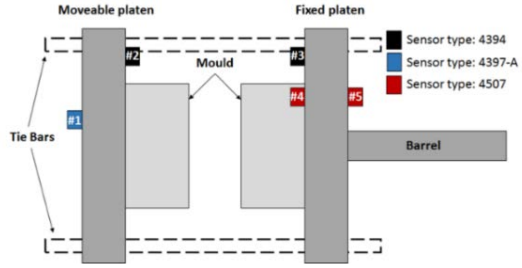

Figure 1. Accelerometer types and placement positions. Each number represents the relative channel.

3. Methodology and Experimental Evaluation

The vibration data are recorded as a continuous signal throughout the experimental moulding process, leading to the development of methodology for data manipulation and analysis. The trigger signal, corresponding to the beginning each moulding cycle of the process was used to section it to the relevant cycles and the maximum cross correlation of those sections to align the vibration signal from each cycle in a common time axis. The resulting alignment error of each cycle to the reference signal is calculated with equation 1 and is illustrated by the grey area in figure 2. Equation 2 is consequently used to calculate the Integrated Squared Error (ISE) as a quantification of the deviation. The "ISE" procedure is used for both the external sensor vibrational data and the machine process data in order to compare them.

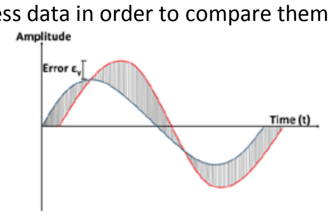

Figure 2. Alignment error

$$\varepsilon(t) = y(t) - y^{*}(t - \tau) \qquad (1)$$

$$\mathrm{ISE} = \int \varepsilon(t)^{2} dt \qquad (2)$$

The feasibility of a vibration based process-monitoring system can be evaluated by the comparison of the vibrational and machine process data to the dimensional data. A Zeiss 850 OMC tactile machine was used to measure the collected samples. The circular feature (Diameter 1) of the samples was selected as measurand, with each part to be measured five times.
However the three data types are not directly comparable. The data are consequently standardized with the use of equation 3.

$$Zscore = \frac{x-\mu}{\sigma} \qquad (3)$$

Where, "x" the x^{th} observation, "μ" the mean value and "σ" the standard deviation of all observations per signal.

3.1. Data Analysis

The following section focuses on the comparison of the process data for the collected data. The standardized signal ISEs and circle diameter values (Z-scores) facilitate a comparison among the three sources of data in figures 4 and 5. The section of the signals associated with only the injection and packing phases of the process is under consideration. Figure 3 presents an example of the vibration measurement for channel #1.

All channels of vibrational data follow a similar increasing trend to the process and part data, the data of channel #1 though are worthy of special attention. A clear relationship of the signal from channel 1 with the weight of the parts is illustrated in figure 4 leading to the conclusion that it is feasible to use accelerometers in position #1 to monitor part weight, as both data follow a similar varying trend.

Furthermore, when the part diameter measurand (Diameter1 Cavity2) from the second cavity of the mould is plotted with the Injections Speed's standardized signal in figure 5 it is evident that they follow a similar trend. However, the values from Channel1 do not closely follow the same trend, even though they follow the increasing trend of the process. Thus the use of accelerometers for process quality assurance is feasible, though more suitable for weight that dimension measurands.

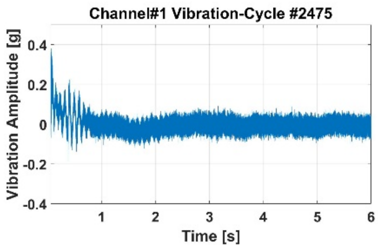

Figure 3. Example of vibration (Cycle #2475) in time domain

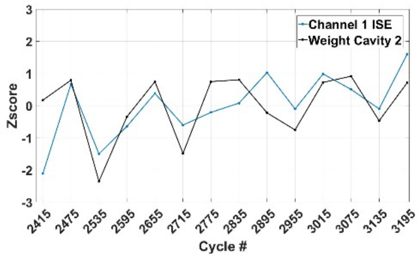

Figure 4. Plot of standardized values (Zscore) of Vibration ISE (Ch1 ISE: Channel 1 ISE) and part weight values.

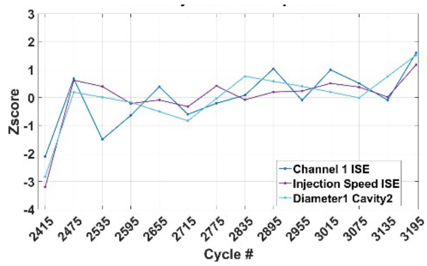

Figure 5. Plot of standardized values (Zscore) of Vibration ISE (Channel 1 ISE), Injection Speed ISE and Diameter1 values.

5. Conclusion

This paper presents a feasibility study in the use of accelerometers and vibrational data in an integrated process/product quality assurance framework for the injection moulding process. The workspace of the machine is monitored by five accelerometers with process and part data to be collected for the evaluation of the vibrational data. A methodology of data manipulation and comparison was develop to access the data, leading to the conclusion that the use of accelerometers and vibrational data in a quality assurance framework together with process data is feasible for the used process parameters.

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