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

Nikolaos Giannekas¹, Rene Gammelby¹, Guido Tosello¹, Dmitri Tcherniak², Yang Zhang¹
¹ Department of Mechanical Engineering, Technical University of Denmark, ²Brüel & Kjær Sound and Vibration Measurement A/S

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 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 (QI) 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.

Objective and experimental set up

• Objective ⇒ To study the replication and quality correlation of moulded parts to external sensors and machine process signals in order to connect product quality data to process quality indicators.
• Equipment ⇒
  • Engel e-motion 110 electrical injection-moulding machine was used for the experiment
  • Brüel & Kjær Instruments
  • Accelerometers – chosen based on expected frequency content and vibration magnitude
    • Types 4394 and 4397-A (sensitivity 10mV/g) to avoid overloading
    • Type 4507 accelerometers (sensitivity 100 mV/g)
  • Data acquisition module ⇒ Type 3050
• Production stability experiment
• Constant process conditions in ABS material
• 1 part per cavity was collected every 60 cycles
• Weight measurements
• Diameter measurements – 10 replications using a Zeiss 850 OMC tactile CMM

Methodology

• Continuous signal handling ⇒ Chopping of signals per cycle based on trigger signal.
• Alignment of signals ⇒ Maximum cross correlation signals per cycle ⇒ Alignment error (Equation 1) ⇒ Grey area in figure 3
• Integrated Squared Error (ISE) (Equation 2) ⇒ quantification of the deviation.
  • For external sensor vibrational data and the machine process data comparison.

\[
\text{e}(t) = y(t) - y'\left(t - \tau\right) \quad (1)
\]

\[
\text{ISE} = \int e(t)^2 dt \quad (2)
\]

\[
\text{Zscore} = \frac{x - \mu}{\sigma} \quad (3)
\]

Where:
"x" the xth observation (cycle),
"\mu" the mean value and
"\sigma" the standard deviation of all observations per signal.

Conclusions
A number of accelerometers were positioned on the injection moulding machine’s platen in order to measure the vibration close to the mould during a production run. The vibration data, part weight and dimensional data were assessed and a number of process quality indicators were derived. It is presented that the sensor signals and process data profiles follow a similar trend with the part dimensions 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 it is setting the foundation for a system that could decrease the required intensive metrological efforts for the approval of injection-moulded parts.

References

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Fig. 1: Accelerometer positions

Fig. 2: Vibration example as recorded from sensor #1 after the mould closed and during the injection and packing phases of the process

Evaluation

Fig. 3: Alignment Error

Fig. 4: Plot of standardized values (Zscore) of Vibration ISE (Channel 1 ISE) and part weight values. The weight of the part from cavity 2 presents a clear trend to the Channel 1- ISE (vibration) showing that the vibration signals can follow the deviation in part weight for the chosen process conditions

Fig. 5: Plot of standardized values (Zscore) of Vibration ISE (Channel 1 ISE), Injection Speed ISE and Diameter1 values. Similarly to fig. 4 the diameter of the part from cavity 2 presents a clear trend to the Channel 1- ISE (vibration) showing that the vibration signals can follow the deviation in part weight for the chosen process conditions

Fig. 6: Plot of standardized values (Zscore) of Vibration ISE (Channel 1 ISE), Injection Speed ISE and Diameter1 values. Similarly to fig. 4 the diameter of the part from cavity 2 presents a clear trend to the Channel 1- ISE and Injection Speed ISE showing that for the vibration signals and inj. speed machine signals can follow the deviation in part diameter for the chosen process conditions. This trend presents two viable options for process QIs: Channel 1 ISE and Injection Speed ISE.