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Towards in process control of polymer injection moulded micro components

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Abstract
In the last decade the number of applications of micro components has increased steadily. In order for Europe to maintain its leading role in the polymer micro-fabrication industry there is a need of expansion for processes capabilities for mass manufacture. The present study focuses on the design of a fast-integrated inspection method aimed at part quality monitoring and tolerance conformance verification. The proposed approach investigates as product case study the optimization of polymer (VECTRA® E820i) passive micro microwave components. A focus variation 3D optical high-speed metrology system was employed to perform the measurements on the produced polymer parts. Automated measuring routine allowed fast dimensional quality mapping of the functional sub-mm features integrated in the plastic frame of the final microwave component. Design of experiment (DOE) was adopted to quantify significant factors affecting the final replication quality of the produced critical features. Measurement results have shown product conformance varying with the distance from the gate and features orientation with respect to the polymer flow direction.

Injection moulding, optical metrology, in-line quality control

1. Introduction

Volume production at industrial scale of miniaturized components still offer important challenges not only in terms of precision manufacturing [1-3], but also in terms of process chains integration of different technologies reducing so production time and costs. In this direction, the present study investigates replication quality of functional flanges sections produced by injection moulding (IM) integrated in microwaver components for point-to-point communications. An automated measuring routine was customized, for the present product features topography, to assess produced part quality within product specification (design tolerance ± 11 µm). Three-dimensional measuring capability with sub-µm resolution was guaranteed with the required measuring time compatible with moulding cycle time. DOE aimed at identifying process parameters that decrease process disturbance and product rejection, that guarantee process performance with respect to tolerance requirements was adopted.

2. Experimental set-up

Injection moulding experiments were carried out on an Engel 50 tons (EVC 80/50) injection moulding machine with screw diameter of 22 mm. Screening experiments were run to define process parameters related to filling phase enabling complete filling of the cavity and part demoulding within reasonable short cycle time. Preliminary experiments defined a process window that avoided material degradation, effective air evaluation and premature solidification during filling of the cavity. Finally, considering machine capabilities and material physical properties different injection machine settings were selected for the statistical design of experiment, see table 1.

Table 1. Injection moulding process settings.

Injection moulding process parameters	Low level (-)	High level (+)
Inj. Flow Rate	22,5 cm^3/s	47,5 cm^3/s
Holding Pres.	175 bar	275 bar
Mould Temp.	90°C	110°C
Barrel Temp.	330°C	340°C

A DOE based on 3 repetitions of a full factorial design (2^5) including a total of 96 moulding experiments was run.

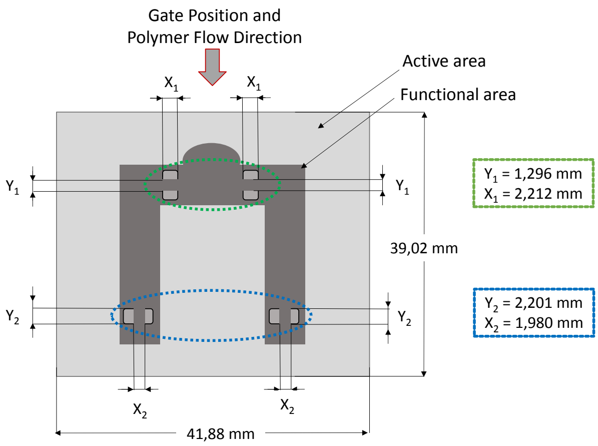

Figure 1. Schematic view of the final polymer component. Dotted areas indicate the different measurands design dimensions and position from the gate (green=position close to gate; blue=position far from the gate).

Effects of the different injection moulding process combinations on the final replication quality were quantified. Moreover the study analysed the effects of the critical geometries positions in respect of their locations from the gate, see figure 1. Aimed at better understanding the polymer behaviour the study examined and quantified the replication quality of different features orientations with respect of polymer flow direction.

3. Measurement strategy

Measuring routine aimed to future in-line injection moulded part quality assurance was developed. A samples holder was manufactured to accommodate 16 different polymer parts at the time. 96 produced polymer parts were measured with a focus variation optical microscope, three times each in all the 8 positions indicated in figure 1 (total of 2304 measurements). Each critical feature, figure 1, 3 a) and b), was measured in less than 10 s by stitching of two different acquisitions with 50% overlapping before moving automatically to the next measurement location. Data capturing and following analysis is performed by the script that ultimately store the measurement results as absolute distance between the two flanges at the different positions.

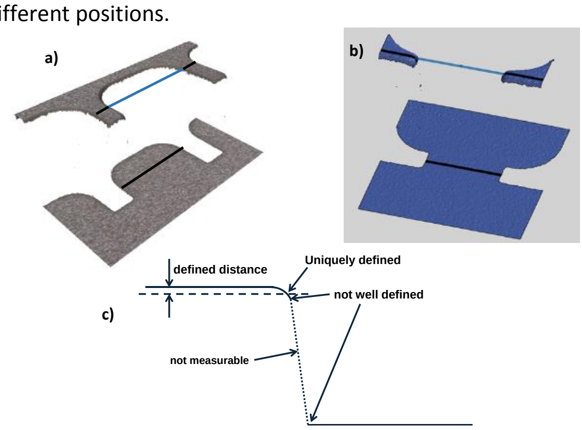

Figure 2. Data acquisition and data analysis of the different measurands. a) Critical geometry oriented along the y-direction with respect of the polymer flow direction; b) Critical geometry oriented along the x-direction with respect of the polymer flow direction; c) identification scheme of measurement alignment procedure in the project script.

Stored data are subsequently used to obtain for each measurement output the width deviation calculated as following $W_{dev} = (W_{polymer} - W_{mould})$. The deviation quantify the degree of replication from an ideal full replication between calibrated mould (master) and polymer (replica) geometries on the corresponding mirrored positions. Experimental measuring uncertainty (Uexp) calculated including instrument calibration, measurements repeatability and process reproducibility was equal to Uexp = ± 1,2 µm.

4. Results and discussion

The results are summarized in the main effects plots of figure 3 and 4. W_{dev} mean values of the different geometries, figure 1, are calculated and grouped based on their orientation with respect to the flow direction. The main result of the analysis is the significant effect on the final replication quality of the flanges dependent by their location/distance from the gate. Different product variations were quantified for the different features orientations. Nevertheless a general common trend can be identified for both the features orientation. Larger product deviation from ideal master/polymer replication was measured for the geometries closest to the gate. Moreover, if absolute mean values W_{dev} for features located far from the gate are considered, similar variation (within a range of ± 3 µm) is measured. Otherwise, the same statement is not valid for the features close to the gate whereas the measured variations have different magnitude and sign. Considering as ideal full replication $W_{dev} = 0$ different features orientation close to the gate present different behaviour once the polymer part is ejected from the mould cavity. The analysis shows that the polymer has the tendency to expand (negative value of W_{dev}) if the flanges are oriented along the Y direction and to shrink (positive value of W_{dev}) if oriented along the X direction.

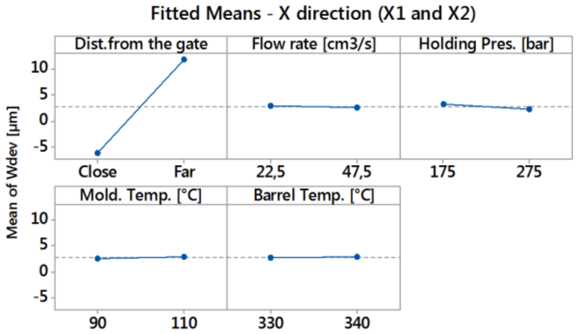

Figure 3. Main effect plot of Wdev calculated for flanges oriented orthogonally to flow direction (X-direction).

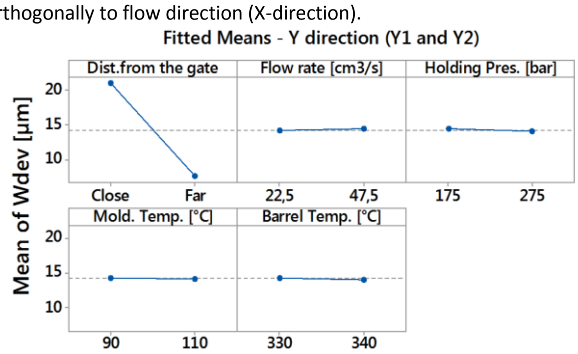

Figure 4. Main effect plot of Wdev calculated for flanges oriented parallel to flow direction (Y-direction).

5. Conclusion

The possibility to integrate fast, precise and cost effective solutions within precision engineering of miniaturized polymer components will ultimately reduce manufacturing costs and enable high quality production and cheaper process chains. Towards total quality in line process control, in the present study a fast-integrated inspection method was designed and developed. Results of injection moulding process optimization based on part quality assessment of critical functional geometries integrated on a passive microwave component were presented. A 3D optical high-speed metrology system was employed to assess quality conformance of the produce parts. Measurement results expressed as deviation from calibrated mould master geometries were statistically evaluated. Product variation dependent on the feature location and orientation within the same active moulding area was detected and quantified.

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