
Use the Computed Tomography for the Automatic Tool Correction of the Mould Injection Process

Katharina Richter¹, Natalia Grozmani¹, Martin Peterek¹, Robert H. Schmitt¹

¹RWTH Aachen - WZL

K.Richter@wzl.rwth-aachen.de

Abstract

Currently many iterations and an experienced operator are necessary to achieve a high product quality for injection moulding parts. Therefore a partly automatic mould correction is needed which is intimately connected with metrology in order to reduce correction loops dramatically. Several different methods are used to attain high product quality in injection moulding. The basic method is the design of the mould under consideration of the production parameters, for example the shrinkage of the plastic can be taken into account. An alternative method uses modification of the production parameters based on simulation processes (for example a mould flow analysis). Despite such complex simulations the required product quality is not always reached. Further improvements can be attained by iterative modification of the moulds.

The mould correction consists of three major sub-processes: the design of the mould, the injection moulding process and the quality control of the workpieces and / or moulds. All three areas are tightly interconnected. Both the moulds and the production parameters directly influence the quality of the workpiece. The workpiece measurement data defines the process quality which then influence the correction process.

The process begins with the design and production of a moulding injection tool based on the nominal geometry of the workpiece. The first produced workpiece is measured using computed tomography. The difference between the measured geometry and the nominal geometry is calculated using the measurement results. These are mirrored around the nominal geometry. A new corrected CAD surface is generated using the mirrored measurement points. Complicated manual methods to correct surfaces are not necessary. Errors emanating from the operator are almost eliminated. This guarantees the high quality of the CAD model and results in a correction process with only a few iterations. The methods allow the different processes to be carried out at geographically different sites. Data Exchange of CAD models and point clouds can be done via Intranet or Internet. This is Industry 4.0 in practice.

Metrology, Computed tomography, Industry 4.0, Control

1. Introduction

Injection Moulding is a production process where formless material is transformed into a solid part with a geometric shape. It is most frequently applied in plastics processing. Plastics are often used in industry due to their low specific weight, the possibility of integrating various functions and their simple processing [1]. Here, a tool is designed and manufactured regarding the demanded CAD model. By using simulations, for example, production-related shrinkage can be taken into account. The production parameters during the injection process, such as the temperature of the plastic or the injection pressure significantly affect the quality of the workpiece produced. In the case of large quantities the costs of tooling is redeemed quickly, making injection moulding a well-established and an affordable manufacturing process with a high reproducibility [2].

2. Adherence of tolerances for injection moulding

The design of the mould CAD model is driven by the desired geometry of the workpiece. Although production influences like shrinkage and mould flow are taken into account during the design process of demanding features, the produced parts' geometric dimensions generally don't lie within their given dimensional tolerance in the first instance [3]. Generally the desired geometry cannot be sufficiently achieved only by an

optimization of the process parameters which is the basic approach. As the workpiece geometry is not influenced only by the process parameters but also by the geometry of the mould another method for the correction of the workpiece geometry is a targeted modification of the mould. This is achieved by capturing the three dimensional geometry of the sample part with a coordinate measuring machine (CMM) using optical or tactile sensors. This CAD correction method involves the use of measurement data to manually modify individual model patches to achieve the desired part dimensions. This process is very labor intensive and generally requires several iterations to achieve meaningful results. In this paper we focus on a new method where CAD models are modified automatically using computed tomography (CT) measurement data (Fig. 1). The approach is aimed to achieve the desired geometry within a single iteration. A complete integration of the mould correction into the WinWerth® measuring software provides powerful measure- and alignment functions. Furthermore the correction result is a modified CAD model in a standard format like step or iges. Therefore a smart interface is established between the measuring software and the CAD / CAM systems. This makes the use of separate reverse engineering methods and other software unnecessary. [4]

Instead an altered workpiece CAD model is created directly, this new model can be manipulated in the CAD / CAM system as before. Data exchange between specific subprocesses beyond the measurement laboratory is possible via network

2. Mould correction using computed tomography data

Sample parts are first measured with computed tomography. This process allows a rapid measurement of all internal and external structures with high point density. In order to achieve a higher product quality raw measuring data must be transferred into smart data. Once the measured point cloud is aligned to the CAD model the deviation vectors for each measurement point to the model are calculated and stored (Fig. 2).

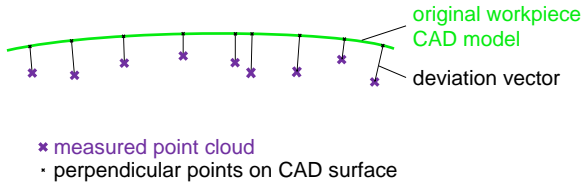


Figure 2. Determination of dimensional deviations of manufactured part to original CAD model.

From here, the deviation vectors are inverted on the appropriate the CAD model patch (Fig. 3). It is necessary to associate the deviation vectors to the correct CAD patches. To ensure patch corrections are as small as possible, the measuring software is used to precisely align the point cloud with the CAD model. If needed, additional local coordinate systems can also be created.

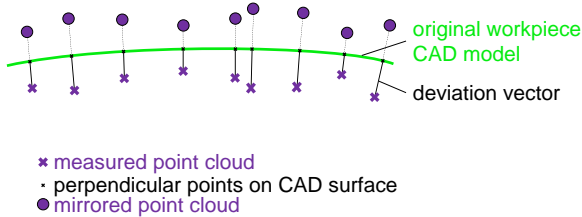


Figure 3. Inversion and transfer of deviations to original CAD model.

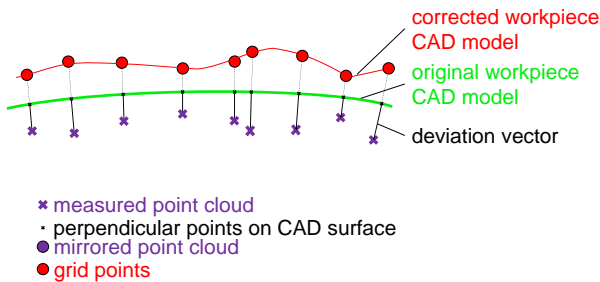


Figure 4. Modification of the original CAD model

Using the original CAD model and the inverted deviations new grid points are generated with an appropriate algorithm. These form the basis for the modified CAD patches (Fig. 4). Different parameters like grid point density or additional smoothing parameters can be applied to influence the resolution of the correction for instance. The method can also be applied directly for a correction of the mould CAD model, see figure 1.

At this point resulting CAD model would have some open spaces between patch boundaries. To create a new sealed 'watertight' CAD model connections to neighboring patches are calculated automatically. Modifications and original continuity conditions of the corrected patch determine the ideal technique to be used for this step. The updated CAD model can be converted via the established CAD / CAM system into the manufacturing process using a CNC machine to incorporate the

changes into the mould to produce a new sample part. It is important to maintain the same process parameters in the second round of moulding to keep complex effects such as shrinkage constant. Through the precise measurement and correction method only one correction loop is expected. However an iterative approach may sometimes be required.

3. Validation concept

In a first step of the validation, correction results were generated and compared to manually calculated correction data which has already been successfully used in practice. Deviations between the two methods were determined. The results match the expected values within a span of not more than 5 μm . In addition, a correction process is to be performed by way of example on the basis of a test workpiece. Explicitly for this application, a test workpiece with process-typical features like sealing surfaces, an imitation of a plug connection and cross-rib design was constructed. Then twelve characteristic correction surfaces were selected on the same (Fig. 5).

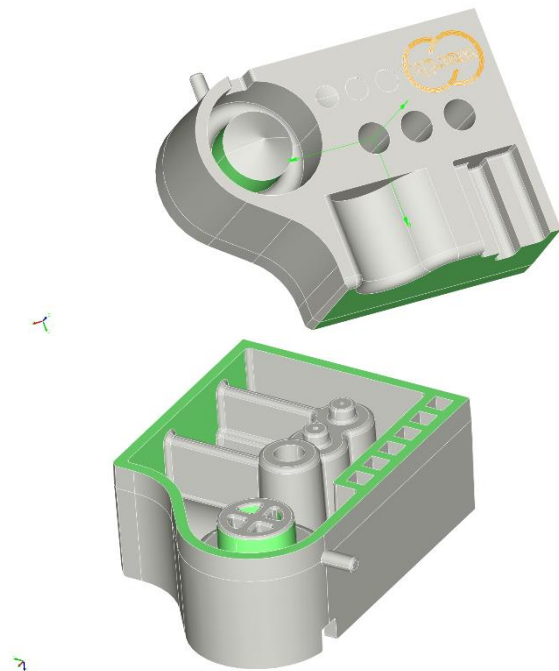


Figure 5. test workpiece: faces to be corrected are coloured green.

In accordance with the standard procedure and with the use of mould flow simulations, the corresponding tool was designed by a plastic injection moulding manufacturer. Using a process parameter control, a defined batch size of sample parts was produced. A sample size of 25 out of 125 workpieces was completely measured with a coordinate measuring machine with a computed tomography sensor. The evaluation of all 25 measured point clouds confirmed a high process stability by a maximum range of approximately 3.5 μm with the evaluation of 13 features used for calibration. Considering all 25 measurements the stability of the correction result can be increased. By calibration of a workpiece on a coordinate measuring machine with a tactile sensor system systematic deviations of the computed tomography measurement could be determined and corrected. Table 1 summarizes for selected features calibration values of the measurement results with computed tomography as well as standard deviation and range of 25 repetition measurements. The magnitude of the range is indicative of the expected uncertainty of the correction result.

Table 1. Extract of calibration values of the CT measurements.

Feature	Calibration value (CT)/mm	Standard deviation/ μm	Range/ μm
M4	24.8784	0.6	2.2
M3	15.0477	0.3	1.3
M6	6.8491	0.3	1.2
M10	14.9778	1.1	4.3

Based on the correction results, the previously measured mould geometry is adjusted and remeasured to determine the uncertainty of the manufacturing process and to estimate its influence on the change of new measurement results after a correction. After renewed production with adapted tools and under the same process parameters, parts are again manufactured, which are measured by the same method. After evaluating the remaining deviations, whether a second correction loop is required has to be checked. In such case the procedure described above should be repeated.

4. Correction results

In the following the correction of one out of twelve selected patches to be corrected is documented. In the first step the distribution and the magnitude of the deviations of the measuring points are examined relative to the desired geometry. For this purpose the analysis of a color-coded deviation representation is used, see figure 6.

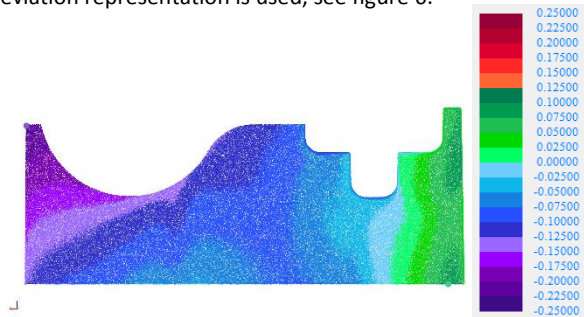


Figure 6. Deviation of measured point clouds to workpiece CAD model in mm.

The course of the deviations is checked for plausibility. Discontinuous deviations indicate an incorrect assignment of the measuring points. In the present case typical for the plastic injection moulding a continuous deformation of the surface can be seen. The mean deviations before the correction amount to approximately 125 μm .

Correction parameters are to be selected for the correction. These influence on the one hand the selection of considered measuring points and on the other the arrangement of the grid points for the new modified BSpline surface. Selecting the measuring points, the noise of the measuring point cloud and the position of the measuring points should be checked, especially in the area close to the boundary curves of the patch. By means of a corresponding edge distance, process-related curvatures in edge regions can be excluded from the correction. In principle the density of the interpolation points corresponds to a sampling rate of detected deviations. A high sampling rate leads to a more accurate correction and thus to a reduction of remaining deviations. However, BSpline surfaces with a high grid point density tend to swing up. Therefore, a compromise should be found of sufficiently mapping the correction according to given tolerances and the risk of surface oscillation.

A preview of the remaining deviations after correction is shown in figure 7. For this purpose, the deviations of the measuring points used compared to the non-mirrored grid points of the new BSpline surface are visualized. The global

colouring of the surface indicates a considerably lower mean residual deviation. The mean deviations are estimated to be $\pm 6 \mu\text{m}$.

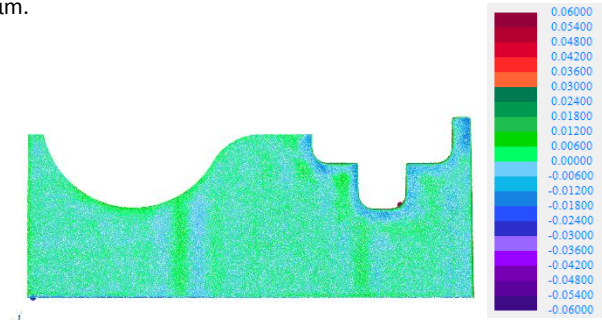


Figure 7. Expected remaining deviations after modification of the mould and manufacturing in mm.

When correcting the other patches, the same procedure has been followed. The remaining deviations averaged 7 μm .

5. Summary and outlook

Using the new method, which is fully integrated into WinWerth® measuring software from Werth Messtechnik GmbH, an improvement of the mould optimizing process for injection moulding is feasible. The interfaces to the design and the manufacturing process are clearly defined and offer easy access and a convenient data exchange. According to the most recent development, the efficient correction of one or more patches at the same time is possible. Presently, correction parameters are chosen manually and determined by manufacturing, shape and position tolerances. Improving the handling of the correction process through an automatic parameter choice seems prudent. If necessary, this can be supplemented by manual interventions. Beyond this practical knowledge will be integrated into the development process. These includes automatic adherence of constant or minimal wall thickness or a correction with consideration of draft clearance.

The immediate next step is the completion of validation. At first the correction results should be transferred to the mould geometry. After these have been measured and the manufacturing tolerance is determined, new sample parts are to be manufactured. With the same measuring method and taking into account the same parameters, the new workpieces are measured and the effectiveness of the correction method is evaluated.

References

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