Part 7 of the Series: How the Digital Shadow Enlightens Real Processes in the PIC 4.0

Out of the Shadow into the Light

The digital shadow is the core concept of the Cluster of Excellence “Internet of Production” at RWTH Aachen University. It represents the data trace of an asset to describe its real behavior. In the Plastics Innovation Center 4.0 (PIC 4.0), digital shadows, e.g. the data trace of a sensor, are used to optimize processes taking into account real behavior and to determine simulation quality.

Industry and science are constantly striving to fully capture and model production processes in order to manufacture high-quality products in the shortest possible time and with the least possible use of resources. The possibilities of predicting complex interactions between process settings and control variables and influencing product quality are increasing, although predictions are becoming more computationally intensive and automated matching with reality is still very cost-intensive or fails completely. The digital shadow, on the other hand, aims at capturing the real behavior of a process, for example, through the data trace of a sensor, and taking it into account in model calculations [1].

The construction of the PIC 4.0 proceeds and throws its shadow on the Campus Melaten. © IKV

Testbeds Create Use-Case-Related Digital Shadows

The consistent interconnection of machines and peripherals within the PIC 4.0 makes it possible to capture a wide range of real process data. However, in order to integrate scientific methods and approaches seamless into real production environments, these different data traces must be processed and analyzed in a targeted manner. For this purpose, testbeds are set up in the PIC 4.0, which can be used to test the interaction of software services and real testbeds for a specific research question [2]. The initial testbeds focus, among other things, on the influence of the use of recycled material in injection molding production, including the associated material preparation, and, on the other hand, on the synchronization of quality-relevant data traces in order to improve data-driven quality controls and to determine the simulation quality with regard to the real process behavior.

A modular measuring cell is being integrated into an injection molding process for the focused examination of quality control issues. In addition to determining the weight of the molded part, the extent to which optical 3D measurement is currently being examined. This includes CAD output of the real part and measurement of the surface structure using e.g. white-light interferometry and laser scanning methods suitable for this purpose. The individual data traces of these measuring systems are to be supplemented by the data traces of the injection molding machine as well as a fully comprehensive recording and evaluation of cavity pressure and temperature signals. Finally, the nozzle of the injection molding machine is also to be equipped with sensors so that the processes in the screw antechamber can be taken into account for model optimization. The setup of the testbed allows to determine the full potential of the individual measuring systems in the production environment either individually or in combination.

On the software side, there are challenges in data handling as well as in the automated synchronization and assignment of data traces to a production order or even the individual product. On the other hand, new analysis services for the optimization of the process and the prediction models become possible through the interconnection. To this end, a system is being developed which assigns sensor signals directly to a simulated soft sensor in the filling simulation and calculates the real flow-front-velocity for comparison with the simulated ideal at the operator terminal. This will make it possible to implement further assistance systems, e.g. for optimizing the setting parameters to achieve a constant flow-front-velocity as a quality criterion.

Investigations into flow-front-velocity and geometry-dependent process-control are currently the subject of various research projects at the Institute for Plastics Processing (IKV), Aachen, Germany. The planned testbed as a real demonstrator will make the research results available for rapid technology-transfer to industrial applications.

Simulation, Machine and Mold Provide Different Digital Shadows

Particularly in the case of complex-shaped injection molded parts, flow-front-velocities that are too high or too low can occur due to changes in the flow cross-section [3–5]. One approach to prevent quality defects occurring as a result is to ensure a constant flow front velocity by smart adjustments of the injection speed [6–8]. However, it is hardly possible to track the flow-front-velocity even at constant injection speed or even to correlate it with an injection profile. A solution is offered by the filling-simulation, which, however, only corresponds to the real process to a limited extent.

For the implementation of the envisaged assistance system, it is assumed that the filling simulation maps the basic filling behavior and the flow path sufficiently accurate. The fine tuning of the simulated flow-front-velocity to the real process is achieved by correlating the data traces from the machine, sensors and simulation. An operator interface near the injection molding machine should make it possible to intuitively assign the simulated sensor positions to real sensor signals. In addition, the correlation between sensor signals and a defined filling level is ensured by this interconnection. The simulation software, the mold sensor system and also the injection molding machine itself provide data traces with different information content for this (**Fig. 1**).

The Digital Shadow Brings Clarity

The digital shadow of the machine provides insight into the real acceleration of the screw and the volume flow induced by it. This acceleration behavior and the non-ideal volume flow and pressure transfer from the plasticizing-unit are the main reasons for the deviations between simulation and reality. The closing behavior of the non-return valve and the volume-loss that flows back via the screw flights also play a significant role in the fact that, measured against the screw position, a deviating melt volume must be dosed and injected. Even with knowledge of a simulated filling process and the virtually optimized process point, it is difficult to determine the correct parameter setting on the injection molding machine. »

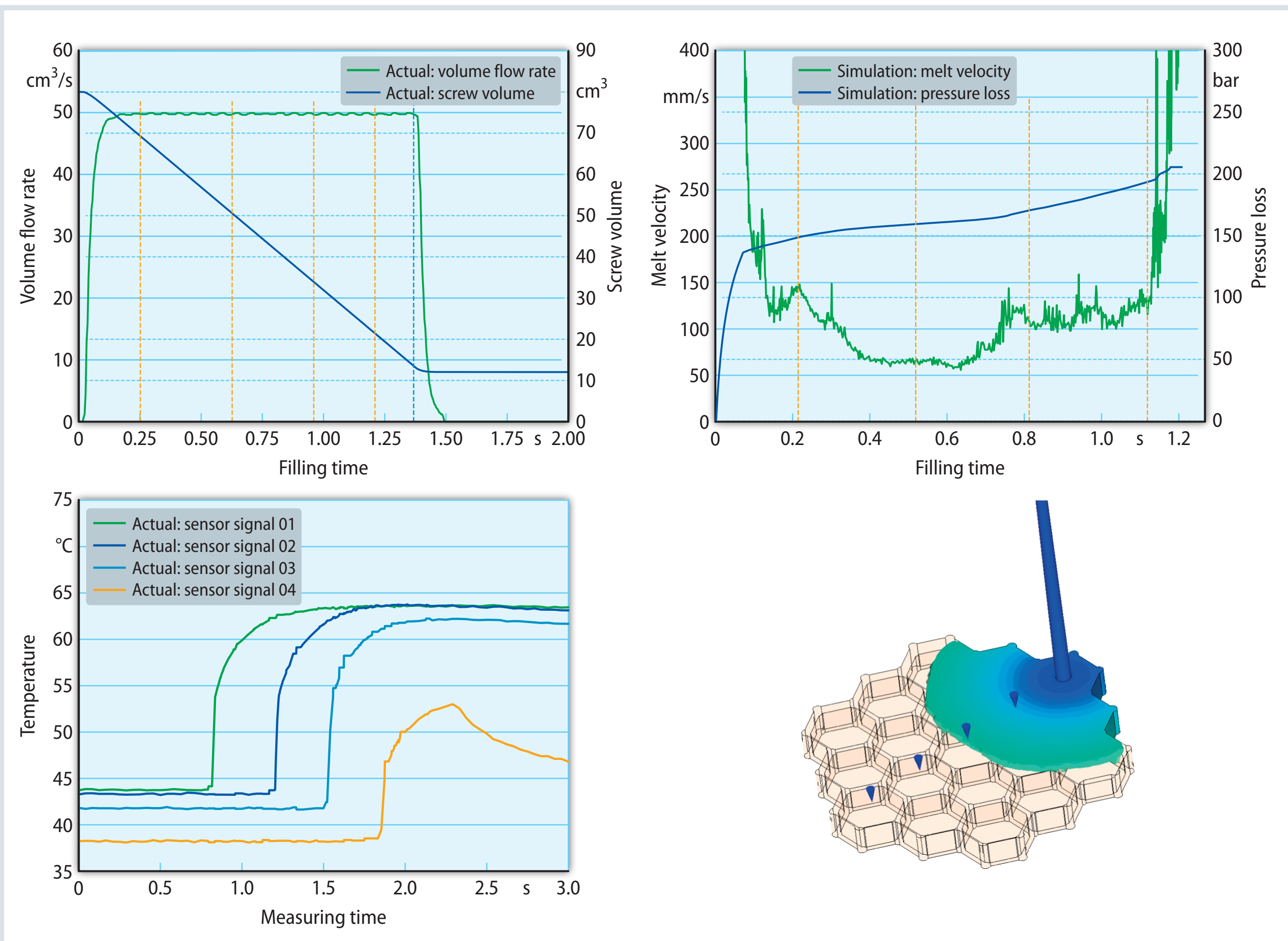

Fig. 1. Data traces of the injection molding machine about the screw acceleration, from simulation about the flow-front-velocity and from sensors about the real filling-behavior exemplary for a honeycomb-structured part. Source: IKV; graphic: © Hanser

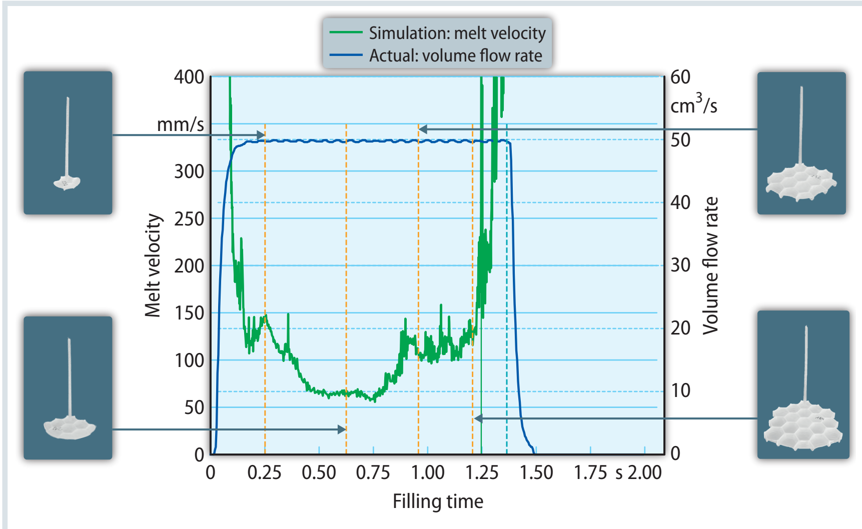

Fig. 2. The interconnection of data traces from simulation and machine enables further extension of optimization strategies with respect to injection profiles at an injection molding machine.

Source: IKV; graphic: © Hanser

In addition to the marked switchover point (**Fig. 1 top left**) at 1.368 s for volumetric filling of the product, four sensor positions are highlighted. Four piezoelectric combined temperature and pressure sensors are installed inside the cavity, providing insight into the real filling behavior of the product. Due to the different acquisition systems, e.g. directly via the injection molding machine or via a separate edge-device, the difficulty of how to synchronize the measurement records stands out. If the flow front reaches a sensor, this is very clearly recognizable by the temperature deflection, as is the abrupt drop in temperature at sensor signal 4 at the time of the switchover point (**Fig. 1 bottom left**). This also allows the other sensor signals to be clearly assigned, so that the relevant measuring time of the sensors in the digital shadow of the injection molding system can be directly correlated with the filling time.

The third figure (**Fig. 1 right**) shows a simulation of the filling process corresponding to the process point. The sensor positions can be positioned analogously to the real mold in order to match simulation and real process. Based on the results of the process simulation, the flow front can be traced and the average flow-front-velocity can be calculated for each filling level. For this purpose, the time of filling, filling level, pressure drop and melt velocity are simulated for each node of the simulation mesh. Due to the idealized system assumptions made when setting up the process simulation and neglecting the machine-related influences, the filling time as well as the times at which the nodes of the sensor positions are reached deviate from reality.

Finally, the correlation of the individual data traces makes it possible to match simulation and reality (**Fig. 2**). For this purpose, both the simulated flow-front-velocity is adjusted to the real filling and the time intervals between the respective simulated and realized sensor signals, at which the melt reaches the sensors.

User-Friendly Process Setup

The assistance system will enable the operator to fine-tune the injection profile directly at the machine, taking into account the product geometry. At the same time, the system will enable researchers within the PIC 4.0 to evaluate this and other optimization approaches for industrial application in a data-based manner by combining digital shadows, for example by adding data traces on the melt pressure in the screw antechamber or by taking into account the automated comparison between realized and simulated product quality through integrated 3D measurement of the product. This makes the PIC 4.0 a demonstration platform for innovative optimization services from research concept to industrial application. ■

Info

Cluster of IoP

The Cluster of Excellence Internet of Production (IoP) is an interdisciplinary research project funded by the German Research Foundation (DFG). More than 25 institutes and further institutions near the university cooperate in the first funding period (01/2019 – 12/2025) on topics of digitized production technology to enable sustainable competitiveness of the German industry. The future technologies of the IoP should result in real demonstrators inside the PIC 4.0.

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The Series Continues

The following contribution describes how flexible structures enable a versatile research environment and thereby a continuous innovation management. It appears in one of the next issues.

References & Digital Version

You can find the list of references and a PDF file of the article at ***www.kunststoffe-international.com/archive***

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