There Is More beyond the Horizon

Innovative Injection Molding in Times of Pandemic

Over past months, many in-house workflows and development processes have slowed down and also changed. Nevertheless, time has not stood still, also not in injection molding technology. The debate and development have been shaped by two themes: digitalization and the circular economy. Below are some examples of developments and projects that underpin this trend.

Two displays are seamlessly integrated into the continuously 3D-formed instrument panel © Continental

Anyone trying to report on developments and innovations in times of the corona pandemic feels as though they are commenting on a soccer game that is not taking place. Trade shows, congresses, customer events and visits were being canceled for a long time or took place online, if at all. The following overview – written on a home computer, in order to illustrate some of the trends in injection molding – can therefore only be selective.

3D-Formed Plastic Panels with Integrated Displays

Continental uses a combination of film insert molding (FIM), in-mold decoration (IMD) and injection-compression molding to produce large, three-dimensionally formed instrument panels with integrated displays (**Title figure**). The challenge here is to synchronize the technical properties of displays arranged side by side regarding white point, color temperature, color coordinates and black homogeneity, and to harmoniously integrate the display surfaces into the lines of a cockpit [1].

To implement the project, Continental has combined several special injection molding processes. A two-dimensional printed film is first formed in the HPF (high pressure forming) process to the three-dimensional contour of the final part. This preform is subsequently inserted into a mold and back-molded by the FIM method. In the IMD process, the hard coating is finally applied to the part in a roll-to-roll process, which, in combination with injection-compression molding, ensures a very low stress distribution in the part. With the combination of all steps, according to Continental, this was a new process at the time of commissioning, in which the machines used are unique in the world.

The injection mold, into which the printed 3D film is inserted before back-molding, weighs a total of 16 t. Because of its complexity, it has a certain intelligence in the form of a programmable logic controller (PLC), which supports, e.g., operation by smartphone and WLAN. The PLC is responsible for monitoring and coordinating the over 60 actuators and sensors that are located in the mold, and independently handles the interplay between the injection molding machine and two further secondary ancillary units. Continental's project is thus a flagship for innovation – strictly speaking the implementation of an idea as new products, services or processes – and for the interplay of technology and digitalization in injection molding.

New Approaches to Thermoplastic Foam Injection Molding

Foamed parts have a three-layer structure, in which a porous core is surrounded by two non-foamed cover layers. Classical density reductions in the TFIM (thermoplastic foam injection molding) process are around 10 %, as new developments in the tool and process technology permit (local) density reductions of up to 50 % – which greatly reduces the lightweight construction potential of this technology. Another ad- »

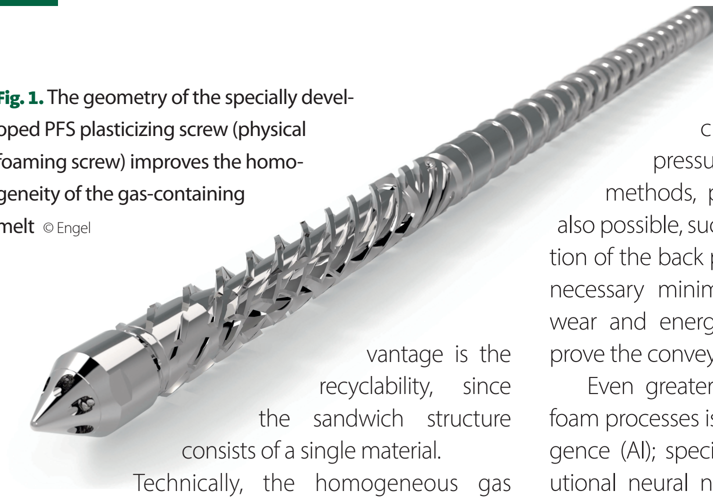

Fig. 1. The geometry of the specially developed PFS plasticizing screw (physical foaming screw) improves the homogeneity of the gas-containing melt © Engel

vantage is the recyclability, since the sandwich structure consists of a single material.

Technically, the homogeneous gas pressure minimizes the warpage and improves the fidelity of reproduction, with the gases acting as "plasticizers" during processing: depending on the gas and concentration, the viscosity is reduced by up to 50 %, which under certain circumstances permits smaller machines to be used. The Institute of Polymer Injection Molding and Process Automation (IPIM) at Johannes Kepler University in Linz, Austria, together with the Competence Center Chase and Engel, is developing a new process technology which uses optimized plasticizing screws (**Fig. 1**), as well as new methods for inline determination of the gas solubility under dynamic conditions [2].

The key factor here is the compression modulus of the mixture, which characterizes the volume changes as a result of the pressure rise. Based on these methods, process optimizations are also possible, such as the automatic reduction of the back pressure to the technically necessary minimum in order to reduce wear and energy consumption and improve the conveying behavior.

Even greater potential for optimizing foam processes is offered by artificial intelligence (AI); specifically the use of convolutional neural network (CNN) developed and trained at IPIM for optimizing the part surfaces by the TFIM process. The goal is to find suitable process settings for unknown processes without having to perform complicated tests. In future, the system should be capable of automatically counteracting deviations from the set process in correlation with the setting parameters.

Mold-Integrated Assistance System for Process Control in Injection Molding

Based on algorithms from machine learning, the project partners Schneider Form GmbH and the University of Schmalkalden, Germany, are developing a "mold-integrated assistance system for production control in the injection molding of highly complex and challenging part specifications," abbreviated to Wasabi [3]. The digital assistant conducts an indirect permanent quality control during a production cycle, taking into account the mold breathing that occurs in every injection molding process.

The output of the system is intended to ensure an understandably prepared assessment of the current process cycle, with which even inexperienced personnel can assess the process stability and part quality. The system shortens the start-up procedure for re-setting up molds, ensures permanent monitoring in the cycle, registers unnecessary mechanical stresses and support the setter and QM employee. According to the project partners, knowledge about the process should stay permanently where it is required, namely on the mold.

For development of the system, a car bumper was chosen as research object because of its complex and challenging part specifications. To determine the measurement data, a total of 26 sensors (cavity pressure, melt front, mold temperature, displacement measurement and mold breathing) were distributed through the two mold halves (**Fig. 2**). Over several series of tests, the database for the design of experiments (DoE) was created in order to determine the relevant influencing parameters for the »

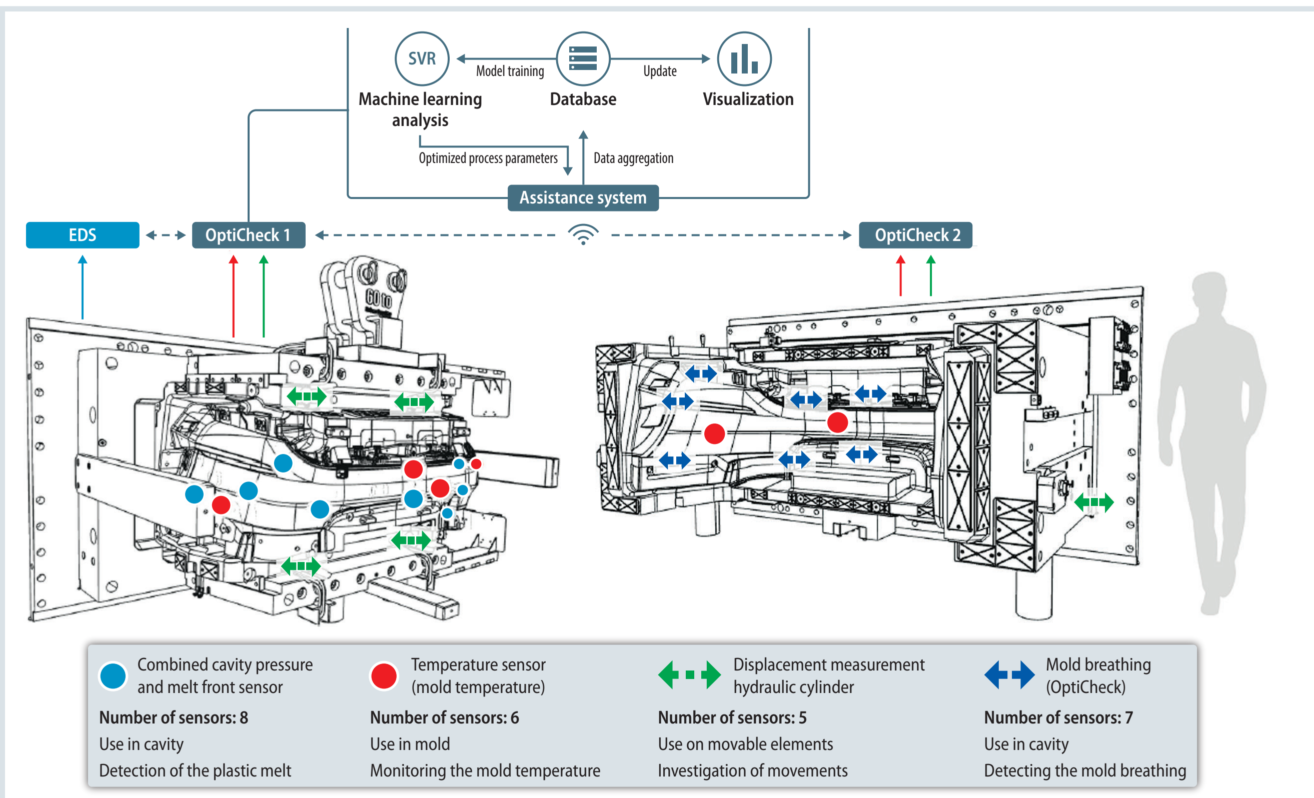

Fig. 2. Wasabi system concept: 16 sensors are installed on the moving mold half, and ten on the fixed side Source: Schneider Form; graphic © Hanser

Fig. 3. The panels are installed in automotive sports seats and light up as a welcome © Arburg

quality of the target criteria. Local deformations of the mold could be demonstrated, which have a negative effect on the part quality (flash) and the mold lifetime. For the linear relationships between parameters and quality criteria, as well as interactions between the parameters, feature combinations for a targeted approach to machine learning were worked out with the aid of specially modified programs. A suitable machine learning method is support vector regression (SVR) from the family of Support Vector Machines.

Injection-Compression Molding in Utmost Perfection

The injection-compression process itself is not a world innovation. In combination with smart applications, such as backlit panels for automotive sports seats it is at least a challenge. The lighting technology specialist Lumitec, together with Arburg, has optimized the injection-compression molding of electroluminescent films. This multilayer film less than 1 mm thick is characterized in that it emits light when an electrical field is applied. Between two electrodes, there is the so-called dielectric; one electrode usually consists of a light-permeable plastic film printed with indium-tin oxide structures and the other reflects the light [4]. They are installed in the backrests of the seats for example as identification carriers and "welcome indicator" with colored backlighting as soon as the vehicles are opened (**Fig. 3**).

In the process, the film is thermally preformed in the mold, so that the end forming is only achieved with the injection-compression process. Injection-compression is a low-pressure process in which the holding pressure phase is replaced by the compression process, so that, for example, inserts such as films or decorative layers are preserved.

Assistance Systems of the Machine Manufacturer

The large injection-molding machine manufacturers, with products such as iQ weight control (Engel), aXw Control PressurePilot (Arburg), APC plus (KraussMaffei) or HiQ Flow (Wittmann Battenfeld), now offer adaptive process controllers in order to counter process fluctuations in a targeted way. Here, the setpoint profiles are adjusted during the injection phase (and partially during the holding pressure phase) so as to achieve a constant viscosity of the melt within the machine. The basis for this is formed, for example, by the control of injection work, holding pressure profile or dynamic adjustment of the changeover point from the injection to holding pressure phase.

The HiQ Flow assistance system from Wittmann-Battenfeld, for example, performs monitoring, documentation and control of viscosity deviations during the injection and holding pressure process in order to obtain a uniformly high part quality independently of the material viscosity [5]. Viscosity changes detected during the injection phase are actively corrected in the

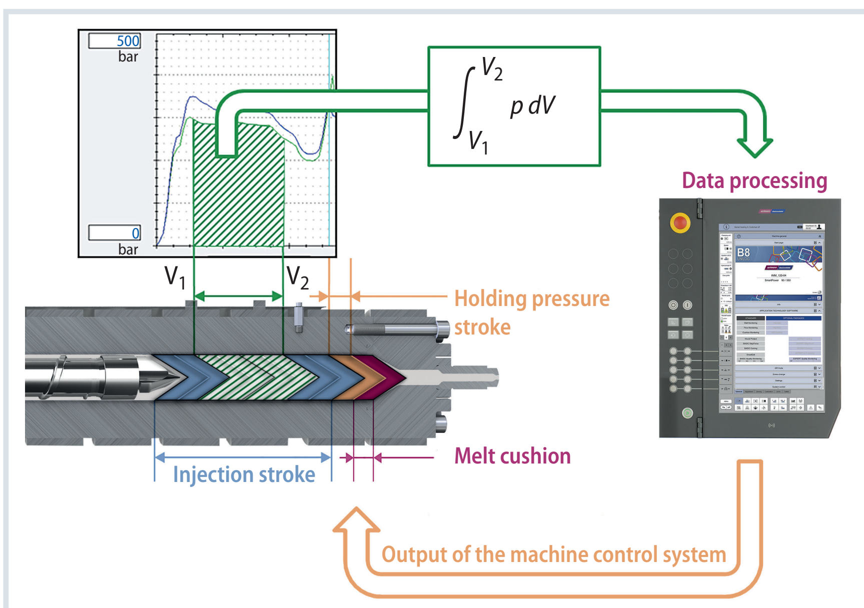

Fig. 4. The HiQ Flow assistance system corrects viscosity deviations during the injection and holding pressure phases in the same shot Source: Wittmann Battenfeld; graphic © Hanser

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Service

References & Digital Version

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Fig. 5. The "aXw Control FillAssist" shows the operator what is currently taking place in the mold © Arburg

Fig. 6. The ALS host computer system ensures end-to-end IT networking © Arburg

same shot (**Fig. 4**), in that the integral of the injection pressure, the cylinder surface area and the position of the injection piston is determined. Based on a reference shot, the changeover point and holding pressure level are determined in dependence on the injection work of the current shot.

Some of these functions are not new in principle, but were already registered for a patent in the 1980s [6]. The implementation alone took some years. In view of the growing processing of bioplastics and recycled materials, which is inevitably associated with relatively large process fluctuations, the principle of adaptive process control is certainly a step in the right direction. For the sake of completeness, it is also worth mentioning here that, for the melt, there is also a "life after the machine," namely in the hot runner and in the cavities. To what extent these purely machine-based solutions are delimited for example in multi-cavity and family molds remains to be seen.

However, assistance systems are not only limited to adaptive process control; their application spectrum is continually being extended with many areas – process optimization, production, predictive maintenance and service, to name but a few. In conversation with Johannes Kilian, Head of the department of process technologies at Engel, is becomes clear »

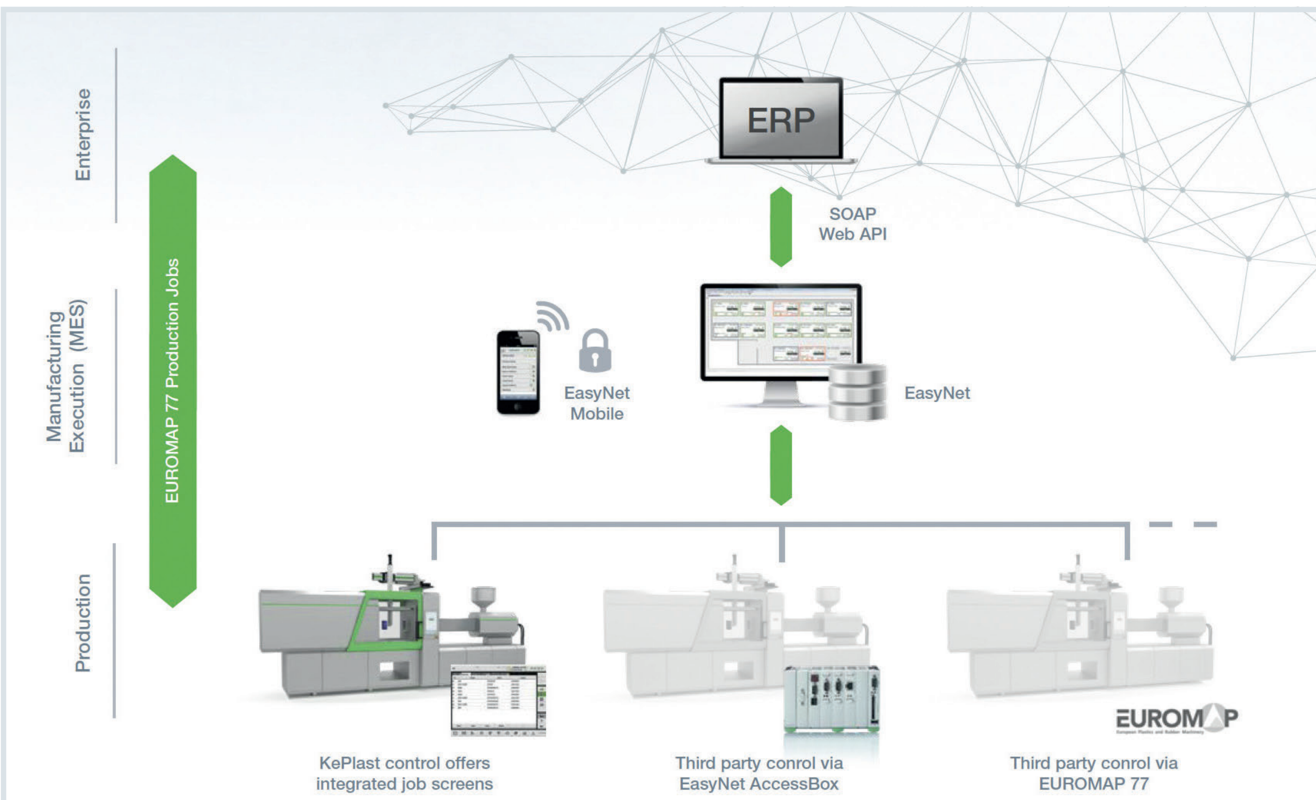

Fig. 7. KePlast EasyNet MES is a user-friendly program for the inexpensive networking and monitoring of injection-molding machines, which is ideal for centralized data acquisition and backup on stationary and mobile devices. The new production management feature allows deep vertical integration of production orders from the ERP system directly to the machine operator – these orders are dispatched to the HMI in real time and all collected data are returned again to the production status © Keba

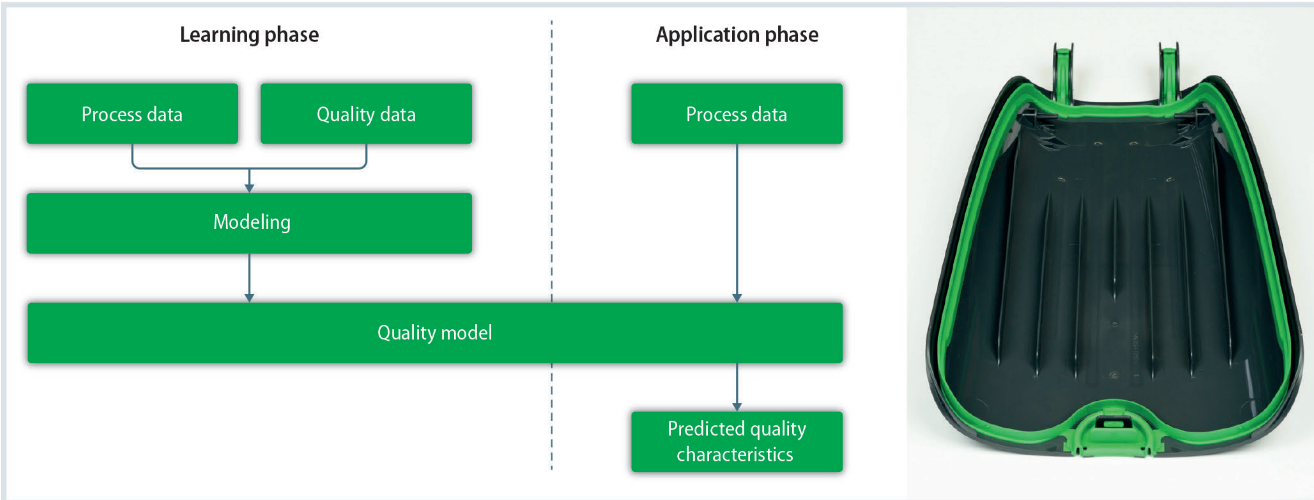

Fig. 8. Concept for modeling for quality prediction. The studies for introducing Industry 4.0 measures centered around complete molding of the vacuum-cleaner cover and the correct, surrounding position of the TPE contour Photo: © Vorwerk; graphic: source IPE, © Hanser

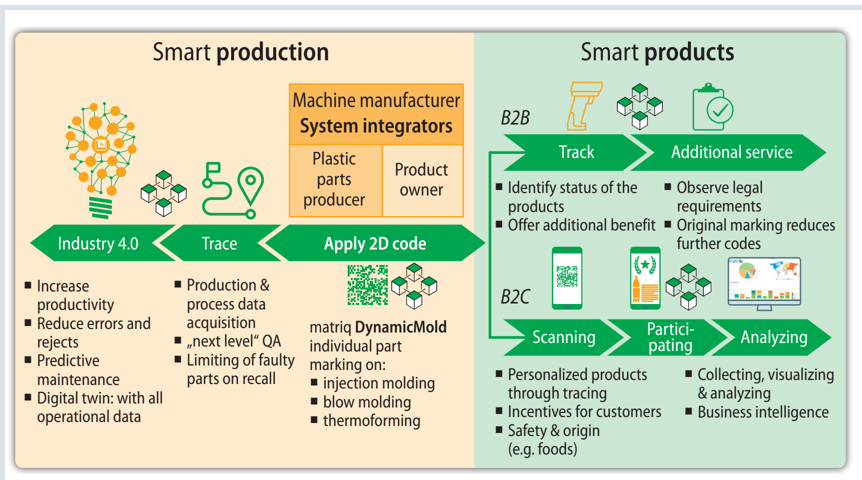

Fig. 9. The new product marking system Dynamic Mold generates a cyclical code for clear traceability of the plastic parts © matriq

where the journey is headed: it is a matter of optimally adjusting the process so as to make as few errors as possible and largely simplify the route there. As an example, he quotes the iQ process observer, which has been in use with selected customers since May 2021. The system, which is not a process controller, checks, based on statistical indicators and other stochastic methods, where the process is heading and calculates proposals for changes. The system, which is also planned as a web application, should also make the process more transparent, and thereby simplify the application as much as possible.

The Machine Knows the Part – Machine-Integrated Simulation

The Engel approach to using simulation data tends in the same direction. Sim link is an intelligent interface to Autodesk Moldflow, which transforms the dataset from the injection molding simulation and checks its accuracy. In principle, this product is regarded as an 80 % solution, and thus as a support for the user. Finally, the customer must optimize his process, which then should be kept constant with intelligent assistance systems such as iQ weight control. In general, Johannes Kilian confirms that the iQ products at Engel have grown rapidly and were not developed as an end in themselves but also have to pay off economically.

At Arburg, too, the link between simulation and machine control is already reality, with the machine manufacturer here working with the software supplier Simcon. In an interview, Eberhard Duffner (Arburg) and Paul F. Filz (Simcon) have explained the concept [7], which is to be realized in two stages. In the first step, a filling assistant is implemented from the simulation, which visualizes the filling process in 3D (**Fig. 5**). Here, too, the aim is make the work easier for the setter so that he no longer has to interpret complex diagrams, such as the screw motion or the pressure profile over time.

In a second step, it is a matter of eliminating quality problems and illustrating process fluctuations in an easily understandable presentation. The limits for this approach currently lie both in the application and at the material side. Molds with a lot of cavities and high hot-runner volumes are currently excluded because of the compressibility and the fact that the hot runner has a control-life of its own, which cannot be considered at all in the simulation.

Digitalization Is another Term

The term "digitalization" is used in a very generalized way where data of any kind have to be communicated. For some SMEs, this already begins with the use of project management tools, such as Microsoft Teams. For other companies, the term is a synonym for interfaces and protocols of measurement data and other digital information, while premium class users understand it to mean completely networked MES systems for production planning, and the like (**Fig. 6**).

Digitalization solutions are for the large part already available at all stages – either machine-integrated or from external suppliers, as shown by the product and trade names Arburg host computer system ALS,

Fig. 10. A-pillars from buckets: KraussMaffei shows a closed material and manufacturing loop from extrusion and injection molding technology in combination with digital solutions © KraussMaffei

KraussMaffei Plastics 4.0, Engel inject 4.0, Wittmann 4.0, Sumitomo (SHI) Demag myConnect and KePlast EasyNet (an extract from the Keba Smart Factory portfolio; **Fig. 7**). They form the basis for future developments, for example for increasing production efficiency or simplifying the process and making it more transparent.

Automation and Artificial Intelligence

To remain competitive in the long term, Vorwerk, together with the Institute of Product Engineering (IPE) of the University of Duisburg-Essen, Germany, decided to examine the added value of 100%-inline quality-related data recording, as well as direct prediction of part quality based on the process data [8]. With a filter cover for a vacuum cleaner (**Fig. 8**), the complete forming of the sealing lip of TPE and the correct, surrounding position of the TPE contour were examined in more detail. To record the variation of the width dimension, a camera system with black-white sensor and a resolution of 21 megapixels was used, with which the parts are scanned immediately after removal.

The molding dimensions were first defined, then automatically recorded and provided with a time stamp. For this reason, the times of the injection-molding machine and camera system must be synchronized via a time server of the company network. In addition to optical inline quality-related recording, it was investigated whether the quality characteristics considered can also be indirectly predicted, with modeling playing a key role. Seven state-of-the-art learning processes (including neural networks, support vector methods, Gaussian process regression) are trained in parallel and compete against one another, so that in the end only the model with the best validation data is used for the prediction (**Fig. 8**).

Here, too, this is a very interesting approach, but, as so often, has to struggle for universal application. For example, it must be considered that the shrinkage of the parts is not yet complete at the point of recording with the camera system. Vorwerk also points out that a prediction is only possible if a high standard of the quality data used in the learning phase can be presupposed.

The Country Needs New Ideas

A good example from the field of digital transformation is a new product marking system from matriq for injection molded, blow molded and thermoformed plastic articles (**Fig. 9**). Herein, the individual products are individually provided with an inseparable product marking by "branding" each part manufactured with a unique code. Each code is cyclically generated each time, so that the parts themselves are clearly traceable. In contrast to downstream systems, such as laser, printing or bonded marks, this is performed directly during manufacture of the parts. The benefit of a complex and expensive network solution is thereby significantly increased.

Sustainability – the Mega-Hype

Sustainability is the great theme of our age and will probably also determine the coming trade shows. It is not yet decided where the focuses will lie. Certainly, recycling will play a major role, as KraussMaffei has already enriched the topic of the circular economy with an example of upcycling. Here, injection-molded buckets are externally shredded and fed back into the material loop as regrind.

With the aid of a twin-screw extruder, the secondary raw material is turned into a new upcycled pellet stock with the addition of a pigment and 20% talc. From this "postindustrial material," the covering of an A-pillar with textile surface – a high-tech part from the automotive industry – is ultimately manufactured by injection molding (**Fig. 10**). KraussMaffei sees itself as the only manufacturer on the market offering the turnkey systems necessary for this cycle from a single supplier, and thereby as a solution supplier for the circular economy [10].

Summary

If you consider the last K show in Düsseldorf, Germany, there are two themes that stick in your mind: digitalization with Industry 4.0 and the circular economy. While the first hype was at its peak, the second was just at the beginning of an incredible development. The aids to digitalization in the form of hardware and software platforms, interfaces and ancillaries are now extremely widely and universally present. The homework has been done, but often, unfortunately, not standardized and rarely compatible. Now comes the more interesting and considerably more innovative part in terms of simplification and process automation. This requires ideas, algorithms as well as a portion of artificial intelligence. The field of process control will separate the wheat from the chaff. As regards sustainability, on the other hand, the zenith has by no means been reached. We can wait eagerly to see how the industry gets to grips technically and commercially with the political requirements of a green deal. ■