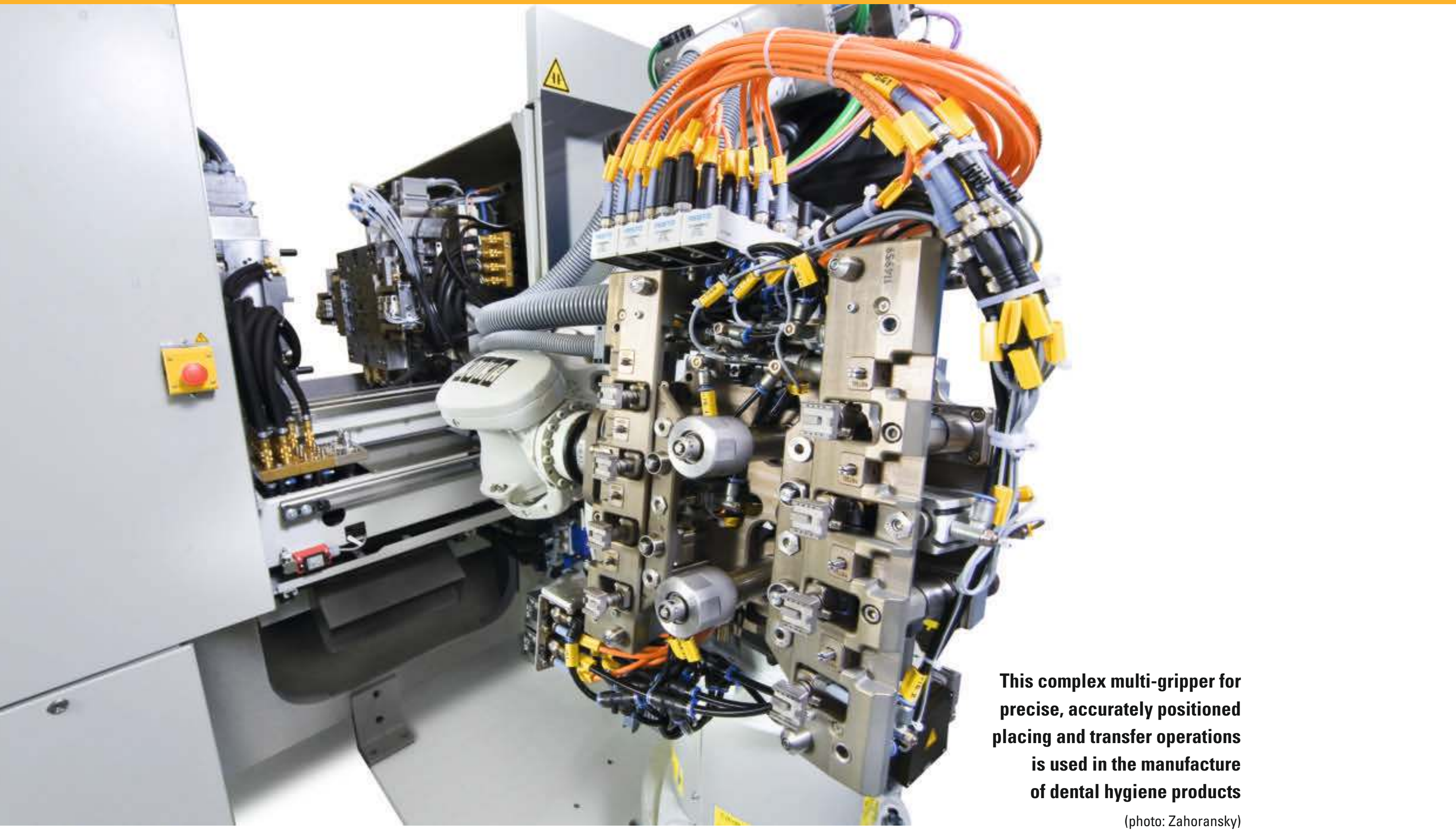

This complex multi-gripper for precise, accurately positioned placing and transfer operations is used in the manufacture of dental hygiene products (photo: Zahoransky)

Things are Moving!

Automation in the Plastics Industry in recent years has shown trends indicating greater integration of robots into injection molding processes and upstream and downstream steps. In addition, operation of the systems and human-machine cooperation is set to become simpler and more reliable. Another focus of the developers is on energy-efficient modes of operation and new applications, including in conjunction with overarching processes.

JÜRGEN WARMBOLD

The integration of robots into injection molding processes is well advanced. Products from various manufacturers can be relatively easily connected up electrically and mechanically via Euromap interfaces 12/67 and 18, and rapidly put into operation. Apart from this, manufacturers of injection molding machines and system integrators now offer robot cells for loading and unloading and other applications as a standard solution. This gives the plant operators tried-and-tested technology, which is moreover available faster and more economically.

However, there are still "contact anxieties" between the control systems of the machines and robots, which must usually be separately programmed by technical experts at great time consumption. Eliminating this disadvantage is a focus of the work of the development departments of both injection molding machine and automation solution manufacturers. The aim is not only to further simplify the plant controls and integrate functions in the robot controls, it allows the systems to be operated more easily and to run more economically even with relatively small batch sizes. From the point of view of the operator, the various control systems should merge into one functional unit.

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Integration of Robots into the Production Machine World

Considering the state of machine-robot cooperation, it is important to distinguish between control cooperation and control integration. Control systems have already been cooperating for years, and as a result offer shorter cycle times – for example, when the positions or movements of the mold and ejectors are transmitted in real time, so that the robots can operate synchronously with the mold opening. The disadvantage lies in a flexibility loss, since it is no longer possible to separate the robot and machine, at least without expensive retrofitting work. In so far, the robot equipment can limit the applications that can run on the machine.

In the case of integration, the robot can be operated via the machine control. KraussMaffei Automation AG, Oberding-Schwaig, Germany, considers this full integration as the state of the art in plastics processing **(Fig. 1)**. Besides, the control, the manufacturer also includes the safety concept and manufacturing cell with common protective housing, and quotes the footprint, functionality, operating reliability and efficiency of the system as advantages. The company sees it as standard to integrate linear systems that originated in simple removal and feed tasks, with the integration of industrial robots with multiple kinematics advancing rapidly.

Arburg GmbH + Co. KG, Lossburg, Germany, has developed a machine control system for all robot systems, and thus created a uniform operating philosophy for injection molding machine and automation **(Fig. 2)**.

This control allows the machine setter to program the robot systems easily in a familiar operating environment and to significantly reduce set-up times. This gives plastics processing companies the ability, independently of external experts, to realize new applications, integrate further work steps into the injection molding process and completely exploit efficiency potential.

In addition, the integration of robots into the machine control facilitates the storage of production data records and the traceability of production. Quality assurance processes are improved, since the records from the production machine and the removal device are stored together. In coming years, Sumitomo (SHI) Demag Plastics Machinery GmbH, Schwaig, Germany, expects the integration of further ancillary equipment, but points out in this context that developers will have the difficult job of treading the narrow line between a highly specialized single-purpose solution and a versatile all-round application.

An End to Terminological Confusion

Against the background that injection molding processes will become ever more complicated because of growing productivity and flexibility requirements, but there will be a lack of qualified personnel and the users will increasingly rely on industrial robots. Kuka Roboter GmbH, Augsburg, Germany, has taken a further step this year. The company offers a fully integrated NC control, which will add a machine tool operating mode to the robot and permit it to understand the CNC language G-Code according to DIN 66025. As a result, it is no longer necessary to translate the CNC programs with the aid of a modified post-processor. The entire product is rounded off with a well-designed CNC interface on the robot control.

If, in a standardized environment, the robot encounters tried-and-tested control worlds, such as those of Siemens or Rockwell, an interface tool ensures seamless integration. As a result, from the point of view of an SPS programmer, the robot, like any other machine component, is represented via its functional modules after its installation. To this extent, the programmer, without any prior knowledge, is capable of teaching the robot how to load and unload a production machine.

On this basis, the programmer can extend the machine operation to the robot. In addition, only one operating unit is required for both. Since, due to this solution, six-axis robots are more strongly integrated into the machine world, the respective degree of operation can be performed faster and more flexibly. That means the cycle and response times, and the space requirement, are reduced; conversion to other products is made easier and the availability and productivity are increased.

Mobile Robots

Integration of robots into the world of production machines also includes the already started development of mobile robots, which – equipped with corresponding sensory capabilities – start up various machines autonomously. Kuka has, for example, a solution in the drawer in which an enclosed six-axis robots runs autonomously along a rotor →

Fig. 1. The robot and machine can be programmed and operated using the machine control and robot-handheld (photo: KraussMaffei)

Fig. 2. Thanks to a standardized operating philosophy, the machine setter can program the robot systems easily in a familiar operating environment and to significantly reduce set-up times (photo: Arburg)

blade for a wind turbine to grind its surface. Arburg, on the other hand, offers a manually displaceable six-axis robot, which is also enclosed and provided with rollers. This robot module can be moved from system to system and thereby increases the flexibility in utilization of the machine park

The robot module is standardized and has the suitable interfaces for communication with the machines. In addition, the grippers can also be easily changed. Users working with these mobile six-axis robots can rapidly move the automation unit to a different machine in the event of a production disturbance.

Linking with Different Production Steps and Processes

Many production steps can be automatically linked to the injection molding process. The upstream works sages include:

- Pretreatment to increase the process stability, e.g. the cleaning of insert parts or static charging of labels,
- isolating insert parts in the event of safety-critical parts,
- the punching of sheet metal and preparation of films to allow them to be inserted into the mold at a later stage, and
- checking insert parts for quality assurance and reject reduction.

In the interests of process integration, various operations can take place downstream of the removal of the injection moldings from the mold:

- Machining, e.g. deflashing,
- testing, e.g. camera inspection and weighing, including for 100 % documentation in the case of safety-relevant parts,
- assembly work,
- printing, bonding, identification, and
- packaging in the transport container.

Linking up injection molding with other processors allows processors to produce more economically. An example of this is an application in which Arburg and Sonderhoff Chemicals GmbH, Cologne, Germany, system supplier for gasket systems, combine injection molding and polyurethane foaming. The PU sealing foam is applied to the still-hot plastic parts directly after injection molding **(Fig. 3)**. Complete handling is performed by a six-axis robot. Compared with traditional downstream gasket foams, the curing time is reduced from 10 to below 3 min.

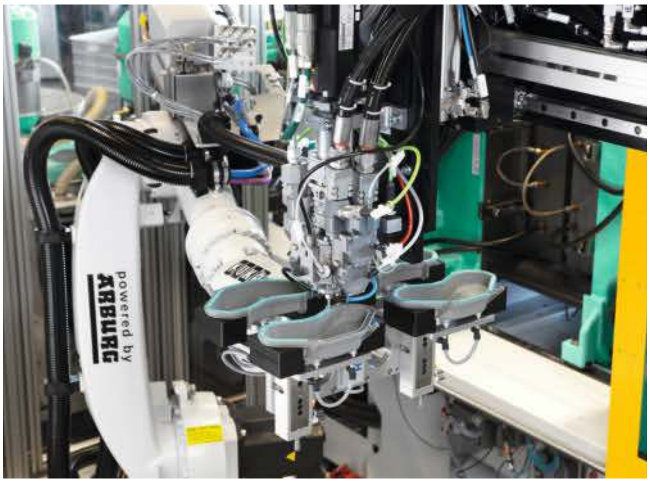

Fig. 3. The PU gasket foam is applied directly to the still-hot plastic parts after injection molding (photo: Arburg)

Fig. 4. The two-arm draft robot with flexible grippers and camera-based parts recognition is being developed for assembly environments that require cooperation with humans (photo: ABB)

By producing a complete product in only one process, the user can increase the part quality, increase value creation in-house, and reduce the process times and the quota of manual operations. Moreover, he profits from the fact that the conveyors and intermediate stores are no longer necessary. However, for each application, it should be checked what is economically appropriate. The limits of automation lie predominantly in the required flexibility in the event of production changes, in the costs for an individual solution and in the return on investment for an automatic production cell.

No Need to Fear a Robot Co-Worker

Orders with small batch sizes and frequent order exchanges, in particular, require human-machine interchange **(Fig. 4)**. In addition, this form of cooperation is an outstanding platform for the pre-series phase or if tasks have to be implemented that are not know when the concept is being drawn up. Fanuc Robotics Deutschland GmbH, Neuhausen a.d.F., Germany, assumes that, in the foreseeable future, human-robot combinations will play a role in complex, multi-step assembly tasks. The company has therefore developed software with the aid of which a robot can be programmed to monitor itself to avert any possible risks to operators.

Current development work is aimed at replacing safety hardware solutions in future with inexpensive software solutions, and thereby reduce spare parts stocks and create a modular, readily extensible safety concept. In addition, it can be assumed that the track points will no longer have to be taught. Instead, the operator guides the robot in resistance-free mode to the teach-in

! Research

The author and editorial team would like to thank the following companies, who cooperated in this survey:

- Arburg GmbH + Co KG, Lossburg, Germany
- Fanuc Robotics Deutschland GmbH, Neuhausen a.d.F., Germany
- FPT Project GmbH, Amtzell, Germany
- Krauss-Maffei Automation AG, Oberding-Schwaig, Germany
- Kuka Roboter GmbH, Augsburg, Germany
- Sepro Robotique GmbH, Rödermark, Germany
- Stäubli Tec-Systems GmbH Robotics, Bayreuth, Germany
- Sumitomo (SHI) Demag Plastics Machinery GmbH, Schwaig, Germany
- Wittmann Kunststoffgeräte Ges.m.b.H., Vienna, Austria
- Yaskawa Europe GmbH, Allershausen, Germany

Fig. 5. A process filed for a patent in 2011 simplifies bonding and sealing applications. Parts no longer have to be produced with accurate joints and an accurate fit, because a new system comprising six-axis robots, metering technology and 2-D laser sensor reliably seals different gap sizes from 2 to 7 mm (photo: Yaskawa)

points and thereby teaches it the movement sequence.

Also settled in this range is the "Safe Robot" (Kuka), with which the operator can cooperate or which he can guide. This six-axis robot comes into consideration as an economical alternative in that, for applications with small batch sizes, the operator lays parts in the grippers and thus makes separation technology unnecessary. Further fields of application could be assembly work on or next to the injection molding machine.

While Sumitomo (SHI) Demag wants to improve safety with optical monitoring of the safety areas without dowelled protection fences, in order to simplify teach-in through a better view, Yaskawa Europe GmbH, Allershausen, Germany, wants to achieve advances in safety without light barriers so as to meet a considerable prerequisite for the use of mobile robots. For this purpose, the company refers to its "Safety Controller," which permits the robot's working range to be restricted, and thereby the use of safety technology to be reduced.

Wittmann Kunststoffgeräte Ges.m.b.H., Vienna, Austria, has other priorities. The company argues that, with the automatic operation of injection molding machines, the takt time is determined not by the people but the cycle time. →

Fig. 6. Six-axis robots in cleanroom design is suitable for sensitive applications, such as here in medical technology (photo: Stäubli)

An obvious way of maximizing the productivity of the systems is to continue work on reducing the cycle times in future. However, the performance data of the systems are already reaching their physical limits. Independently of this, Wittmann uses fixed safety equipment anyway. According to the company, this has the advantage of preventing unintentional and undesirable entry of operators into the workspace and therefore unnecessary downtime of the overall system

Robot Types on Test

In some applications, the system planner is spoilt for choice between different robot types. For the vast majority of automation tasks, linear robots are functionally precisely correct, since they can take on many tasks upstream or downstream of the injection molding operation. Traditionally, they are used in large cubical workspaces and rapid traverse movements for part removal, often combined with insertion tasks. The degree of standardization achieved is expressed in an attractive price-performance ratio in this case. If the task has been formulated over the production years and the investment costs are paramount, a solution with linear robots is advisable, which can be additionally fitted with up to six servo axes.

However, it is often worthwhile investing in a six-axis robot. If offers maximum flexibility, including for future applications **(Fig. 5)**, can execute difficult 3-D movements, can be more precisely positioned thanks to its low static and dynamic compliance (stiffness) and utilizes the idle times of the injection molding process. Six-axis robots are therefore preferably used for conformal secondary finishing, such as deflashing, brushing, milling, assembly and gasket foaming. Stäubli Tec-Systems GmbH Robotics, Bayreuth, Germany, sees a particular demand in cleanroom applications, for example in the pharmaceutical and medical industries **(Fig. 6)**. In addition, there are insertion and demolding processes, along with joining and assembly processes, in which six-axis robots can replace expensive grippers. In questions of preparing insert parts or special packaging tasks, they complement linear units. The users often employ six-axis robots in combination with large machines **(Fig. 7)**.

A special small six-axis robot – the Kuka Agilus, which features high flexibility, agility and range, even in confined spaces – has been integrated into a compact metering cell by Rampf Dosiertechnik GmbH & Co. KG, Zimmern, Germany, **(Fig. 8)**. The cell is suitably used where a low degree of automation and high variation in production are required. The metering cell is suitable for the application of 1-component and 2-component systems on two and three-dimensional parts. The robot can be equipped with various mixing systems and used for foaming, casting and bonding, as well as for processing highly abrasive materials, such as heat sink pastes.

Fig. 7. The larger the machine, the higher the degree of automation with industrial robots. Here, a Kuka robot on the seventh drive axis serves a 55,000 kN injection molding machine producing the trash containers (photo: Engel Austria)

Fig. 8. With the Kuka Agilus, this compact metering cell, shown open here, uses a special six-axis robot (photo: Rampf Dosiertechnik)

Side-entry removal robots are preferred for high-speed production of mass articles and in efficient IML applications with cycle times between 3 and 7 s **(Fig. 9)**. Particularly in packaging, they can minimize the mold open time. In this case, one uses the term fast side-entry units with intervention times of well under 1 s. These systems presuppose a lightweight design and require high-acceleration drives. A solution with two mutually communicating servo axes has recently become available from Hekuma GmbH, Eching, Germany. With an ultra-lightweight gripper arm and, according to the company, probably the fastest robot axis in plastics processing, which achieves a removal time of about 0.18 s, the company is targeting the removal of small, lightweight fast-cycle parts in high volumes.

Linear robots (for fast removal) are often combined with industrial robots (for secondary processing of the molded parts), so that the advantages of both robot types are exploited. As a result, the linear robot can continue to operate and still remove parts despite, e.g., a disruption in assembly that leads to delays in the workflow. With such a combination, there is the added advantage that a control system for linear robots developed by Sepro Robotique, La Roche-sur-Yon, France, can be used, with which the user can also operate and program a swan-neck robot.

Energy Efficiency of Automation Solutions

A still relatively new topic for injection molding and robot manufacturers is the energy efficiency of the systems. Most of them have long regarded "green automation" as making an important contribution to the efficiency of the automation solution. The energy efficiency can be increased, for example, by recovering the brak-

Fig. 9. Production of yogurt cups by the in-mold labeling process with simultaneous removal of parts and insertion of labels by a double gripper (photo: Sumitomo (SHI) Demag)

ing energy or the developer uses vacuum technology with economy setting and reduces the moving masses. Performance peaks during production can be smoothed out by a well-conceived energy management so that the consumption is reduced sustainably. Apart from this, it is advisable to ensure an efficient interplay between the machine, robot and ancillary equipment to throttle energy consumption. This also includes reducing the velocities and dynamics in the traverse movements outside the injection molding machine.

Robot manufacturers are also working towards high energy efficiency by installing high-efficiency servo drives. Further savings can be achieved with standard extra functions such as an eco-mode. In addition, the plant designer in some applications can minimize the compressed air consumption for vacuum and gripper circuits or cylinder functions by using gripping instead of suction. Indirect energy efficiency by the use of application-specific tailored robots is also important, since it can minimize unproductive operation times of the injection molding machine, e. g. the mold open time. Another idea comes from Hahn Automation GmbH, Rheinböllen, Germany. The company reduces the energy consumption of linear robots by means of a holding current on the stroke axis, which it achieves with the aid of a compressed air accumulator **(Fig. 10)**.

Savings potentials can also be obtained by targeted switching of the robots into standby operation or controlled disconnection during production pauses. For example, Kuka has reduced the energy consumption of its robots during movements by up to 30 % and by up to 95 % during standby modes. If the user mounts the robots directly on the machine, he saves space that would otherwise have to be bridged, and so reduces the energy consumption.

Those who can afford it choose lightweight construction solutions for automation, which because of the reduced mass forces, ensure shorter traverse times besides energy savings. Because, if properly designed, they also show less wear, they also provided better availability. Another concept is pursued by FPT Project GmbH, Amtzell, Germany. Since, in the view of the company, the energy efficiency is only marginally involved in the overall potential, FPT places the focus on productivity and therefore primarily on cycle optimization in all controllable processes – such as mold optimization, machine equipment and automation during the machine cycle – which auto- →

matically leads to a high efficiency level.

New Applications from Injection Molding and Robotics

Robotics are so flexible because they offer the possibility of combining injection molding with other manufacturing steps, reliably and efficiently. A relatively new development is, for example, the Inkbot process from FPT Project, which combines digital printing and robotics **(Fig. 11)**. Due to high-precision robot kinematics and improved inkjet industry print heads, it is possible for the first time, using an inline printing system, to use the advantages of digital printing in the high-speed range of industrial production processes even with free geometries.

Fig. 11. The Inkbot process combines digital printing and robotics and thereby permits the exchange of the printing motif in the operating cycle of the injection molding machine (photo: FPT Project)

Compared to traditional processes, such as screen and pad printing, it can also print convex plastic parts up to a height difference of 6 mm by digital printing individually and borderless.

Another system in this context is an inline painting process in the closed mold ("ColorForm," KraussMaffei), which replaces the traditional process, including all the operations upstream and downstream of painting **(Fig. 12)**. The solution assumes that an industrial robot is used that is floor-mounted next to the injection molding machine to ensure a reliable single-stage process.

Automation solutions suitable for series production are also necessary if lightweight structural parts have to be manufactured economically by injection molding. As an example, KraussMaffei quotes the insertion of preforms into the mold, which consist of an endless fiber-reinforced scrim impregnated with a polymer matrix. The handling of this semifinished, heated organic sheet is a serious challenge **(Fig. 13)**.

Seeing and Feeling Robots

In the view of FPT Project seeing and feeling robots still do not play an important role in the plastics industry, because they do not meet the requirements for process reliability and are vulnerable to complications such as e.g. difficult light conditions and part geometries. But since the beginning of automation, manufacturers have already operated with image processing systems for quality assurance **(Fig. 14)**.

Fields of application of seeing robots also lie in the preparation of insert parts, which are fed as bulk materials. While insert parts used to have to be supplied in a defined way, optical systems now recognize their position and can feed them correctly to the system. Such a system also ought to offer clear price advantages in case of part variants by replacing multiple separation and feeding systems. For KraussMaffei, reaching into the box is also possible, but without additional separation. For logistics reasons and in order to save costs, 3-D laser scanners are increasingly being used in combination with industrial robots.

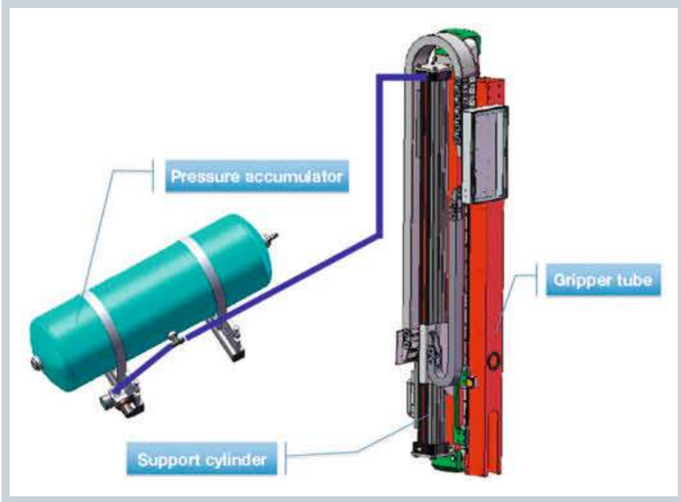

Fig. 10. The energy store in the form of increased air pressure during the downward movement is used to assist the servo drive during the upward movement (figure: Hahn Automation)

Feeling robots equipped with tactile sensors are already standard for the gentle removal of delicate parts. Moreover, they can replace expensive sensors by checking whether a part is present or how high the pressure on the part is. For example, it is possible by means of a Wittmann control system to change over the drives from position control to torque control in order to counteract forces such as ejector movements.

Standard or Quasi-individual Solution?

Before new investments, many users ask themselves whether they are better advised with standard or application-specific solutions, which show a growing trend on the market. Users tend more towards the standard when it is a question of low costs, small batch sizes and growth markets. If a user wants to technically exploit the performance of a system, he

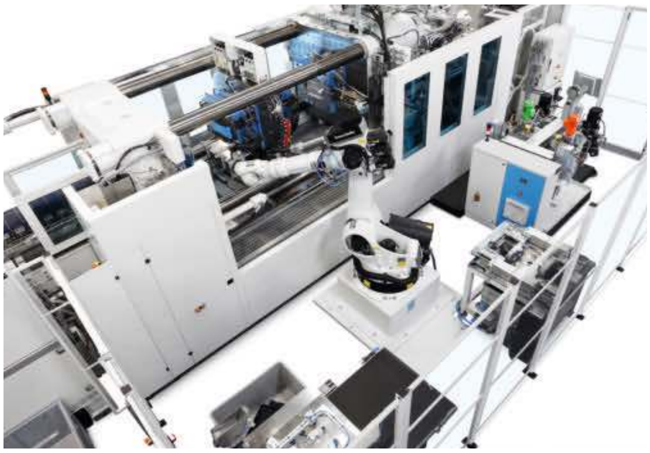

Fig. 12. The inline painting process in the closed mold replaces traditional painting with multiple operations. The system is served by a six-axis robot (photo: KraussMaffei)

first looks for a solution from a standard program. Up to a certain limit, the users and suppliers can put this together from their modular toolbox as a quasi-individual solution.

Operators opt for an application-specific system involving more investment when they want to increase the value creation and to automate uneconomic and complex processes. Kuka Roboter sees a trend towards the "automated general-contractor system" with six-axis robots and easy operation, because, due to the use of industrial robots, both the handling and ancillary systems remain open and future-proof. This is an important point in view of the machine lives of 15 years and longer.

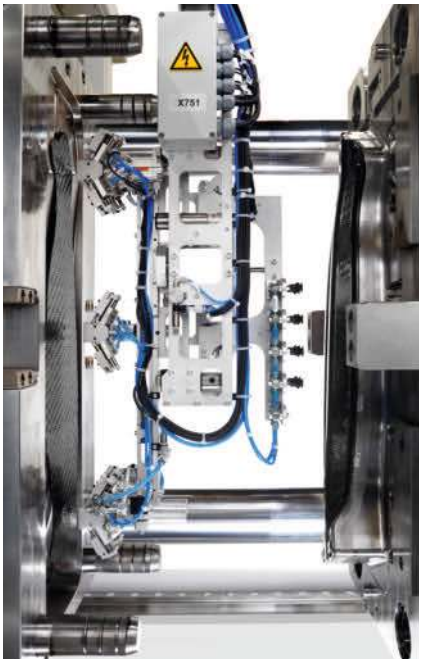

Fig. 13. The challenge during insertion of semi-finished products comprising an endless fiber-reinforced textile impregnated with a polymer matrix into the mold is to handle the prepared, heated organic sheet with a needle gripper (photo: KraussMaffei)

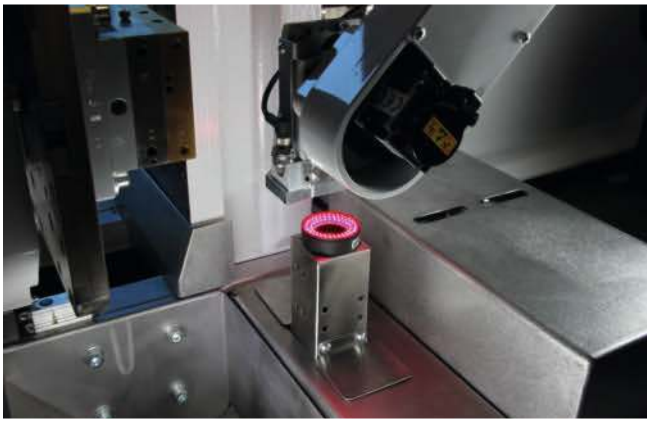

Fig. 14. The optical checking of the part quality – here with an integrated camera with LED illumination – is already a widespread standard (photo: Wittmann)

Handling of Fiber Composites

Overarching methods are also arriving in the plastics industry. For example, for the production of vehicle and aircraft components, the industry is increasingly using fiber composites such as carbon fiber (CRP) and glass fiber reinforced plastics (GRP). Six-axis robots lay the dry scrim on the cutting table and place it in downstroke presses, in which it is three-dimensionally formed, pressed and stiffened. Then the robots demold the ready preforms and lay them in RTM (resin transfer molding) molds for injection-compression molding with reactive resins. The polymer components in the fabric provide the material or part with its ultimate strength and stiffness. For the production of large-volume components, e.g. in aircraft engineering, the industry uses cooperating robots, which lay the fibers in positive or negative molds.

In addition, during the production of CRP parts, six-axis robots are also suitable for tasks such as sewing, weaving and braiding, and for knotting fibers of all kinds. They also saw, edge, mill, drill and rivet the fiber composites and lay CRP stringers precisely in the aircraft fuselage shells. They also check the quality of components with non-destructive surface or penetrating tests using sensors. The handling of the dry scrim, which consists of feeding products that are not inherently stable reliably to the individual processing steps places high requirements on the gripper technology. For handling the limp fiber composite material, needle grippers or vacuum gripper systems have emerged as solutions (**Fig. 15**).

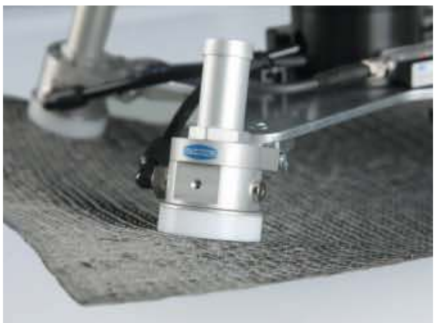

Fig. 15. The large contact area with the defined suction openings lying side by side prevents damage to the CF blank (photo: J. Schmalz)

Summary

In view of the wide range of topics regarding automation in the plastics industry, it is clear that there is a lot of movement, but all the questions have by no means been finally answered. The "contact anxieties" between the machine and robot control systems have not disappeared, nor have all the obstacles to greater ease of operation and higher reliability in human/machine cooperation been removed.

The same applies to the energy efficiency of automation solutions and seeing and feeling robots. Readers and authors are also excitedly looking forward to more detailed responses to the other topics, including new applications and overarching processes, not least because new developments continually raise new questions. ■

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