Simulated Thickness Distribution

Thermally Homogenizing Pre-Distribution in Spiral Mandrel Dies

Thermal effects in the pre-distributor of a spiral mandrel die cause uneven melt flow distribution of the film. Using integrative simulations, the temperature influence on the throughput distribution in pre-distributors is to be analyzed in order to derive measures for homogenizing the pre-distribution.

The most important objective in the design of spiral mandrel dies for blown film extrusion is to ensure a uniform velocity distribution at the die outlet. This is a prerequisite for a homogeneous wall thickness distribution over the circumference of the extruded annular film, which in turn is crucial for the economy of the process and the quality of the film. A non-uniform thickness distribution causes unnecessary material consumption in the form of thick places or production waste when individual layers in the film are outside the tolerances and therefore cannot fulfill their function [1]. Against this background, the design of the spiral mandrel die is of great importance. The design of the flow channel geometry of spiral mandrel dies using numerical methods such as the network theory or the Finite Element Analysis (FEA) is well established [2]. What have not been considered so far, however, are the thermal effects that occur especially in the pre-distributor of spiral mandrel dies [3]. The thermal inhomogeneities in the pre-distributor are due to the external heating of the die, which causes uneven temperature distribution in the pre-distributor. Furthermore there is a different dissipative shear heating of the melt in the channels of the distributor, since, despite their geometric balancing, different shear forces act in the flow channels. The thermal inhomogeneities in the pre-distributor lead, due to the temperature dependence of the melt viscosity, to a non-uniform velocity distribution at the die outlet [4], as can be seen in **Figure 1** with the aid of the leading areas in a color change.

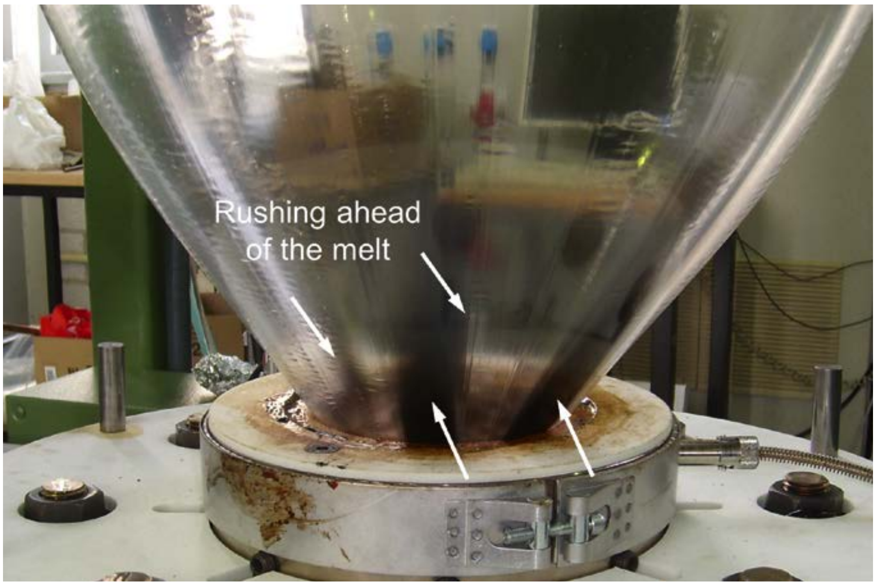

Fig. 1. Flow differences visualized by a color change (figures: IKV)

Therefore, there is a need for the analysis and optimization of the temperature and flow distribution in the pre-distributor. One possibility for this is offered by integrative thermal-rheological simulations in which not only the flow channel, but also the entire pre-distributor is depicted non-isothermally. Such a simulation model is used at the Institute of Plastics Processing (IKV) in Aachen, Germany, to calculate and analyze the influence of the thermal processes in the pre-distributor on the flow behavior under different process conditions. These results form the basis for the derivation of thermal design measures for the homogenization of the melt distribution.

Rheological and Thermal Boundary Conditions

For the investigations, a typical 2^3 pre-distributor was developed (**Fig. 2**). Three distribution levels are used to feed a total of eight spiral mandrel channels. In the design it was considered that certain areas along the flow channel are easily interchangeable in order to enable the use of specific design measures for the homogenization of the temperature in the die, such as the targeted use of highly conductive inserts or heater cartridges. Instead of the spiral mandrel die which would be downstream of the pre-distributor in an actual die, throttles are provided at the end of the flow channels of the pre-distributor. These throttles are designed to simulate the flow resistance of the spiral mandrel die. This exchange of the spiral mandrel plate is necessary »

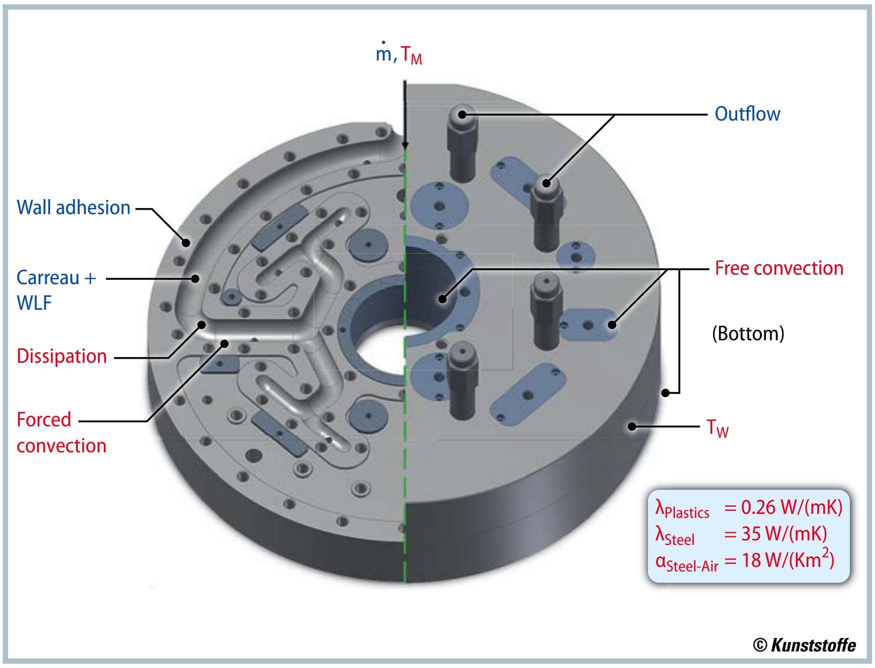

Fig. 2. Boundary conditions in the integrative simulation of the pre-distribution

Test point	Throughput [kg/h]	Mass temperature at the inlet [°C]	Outside wall temperature [°C]
TP1	40	200	200
TP2	150	200	200
TP3	300	200	200
TP4	40	200	220
TP5	150	200	220
TP6	300	200	220
TP7	300	180	190
TP8	300	200	210
TP9	300	220	230

Table 1. Experiment design with three-staged variation of the parameters

to allow a later practical validation of the simulations. Otherwise the flow rates of the individual flow channels of the pre-distribution would flow together again in the spiral mandrel die, making an assignment of the material to a particular flow channel impossible.

The integrative simulation of the constructed pre-distributor is conducted with the Polyflow software from the company Ansys Germany GmbH, Darmstadt, Germany. In the simulations, both the flow channel and the surrounding die steel are modelled three-dimensionally. To keep the calculation times as low as possible, the symmetry of the pre-distributor is used and therefore only one half of the pre-distributor is depicted.

The thermal and rheological boundary conditions in the simulation are shown in **Figure 2**. The flow in the flow channel is assumed to be steady-state, laminar and wall-adherent. The mass flow at the inlet of the pre-distributor is given, whereby a fully developed flow at the flow channel inlet is assumed. At the outlets of the mounted throttles there is ambient pressure. In addition to these rheological boundary conditions thermal boundary conditions for the flow channel must be given. At the flow channel inlet a constant mass temperature is assumed. Within the melt there is thermal conduction and dissipative shear heating. The flow channel outlets are defined so that no thermal conduction occurs. The channel wall is regarded as an interface between the flow channel and the die, at which a convective heat transfer between the melt and the die takes place. The corresponding heat transfer coefficient is automatically calculated by the simulation.

With respect to the thermal boundary conditions of the die, it is assumed that all holes and the plane of symmetry

Practical Benefit

The presented simulation results serve as a basis for the derivation of thermal design measures to compensate the thermal inhomogeneities in pre-distributors and thus ensure uniform melt pre-distribution. Uniform melt pre-distribution contributes directly to the homogeneity of the velocity distribution at the die outlet and thus also to the homogeneity of the film thickness. In this way the efficiency of the extrusion process and the quality of the film can be increased.
In addition, the simulation results can be used for a qualitative prediction of the thickness distribution of the film, so that thick or thin spots can be identified and compensated in advance.

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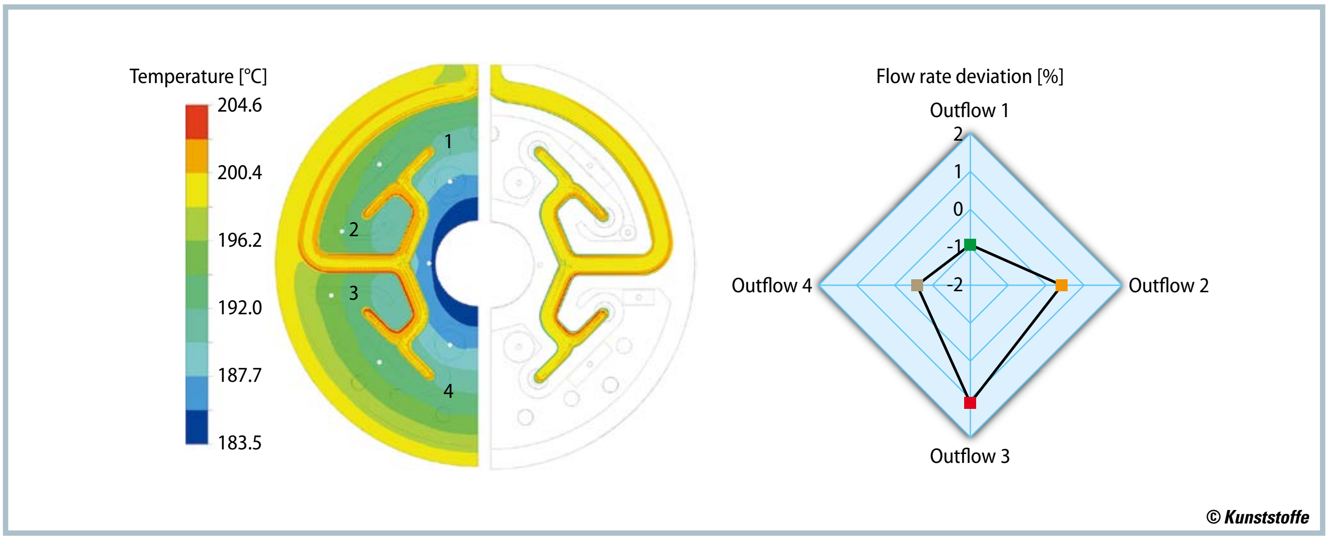

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Fig. 3. Influence of the shear heating on the temperature and flow rate distribution (TP2)

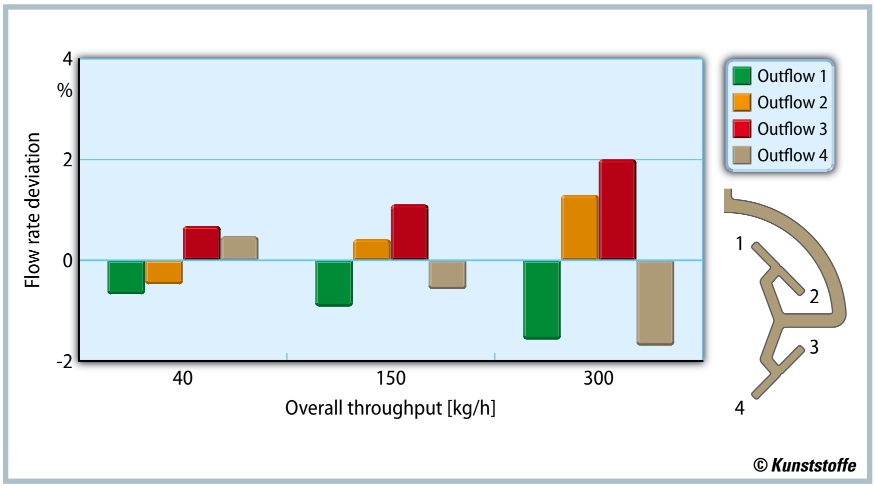

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Fig. 4. Influence of the overall throughput on the effect of the shear heating (TP1–TP3)

are adiabatic. On the outer surface of the pre-distributor, which would be surrounded by a heating tape in reality, a constant temperature is imposed. The remaining free surfaces of the pre-distributor (top, bottom and the interior surface) have a convective heat exchange to the surroundings. The corresponding heat transfer coefficients were determined by comparing the results of the first thermal simulations of the pre-distributor with practical temperature measurements on a comparable pre-distributor geometry. The material used in the simulation is an HDPE, whereby its temperature-dependent, non-Newtonian behavior is described by the Carreau model and the temperature shift according to the Williams-Landel-Ferry equation. In order to evaluate the influence of the temperature at different process conditions, an experimental design was used which is shown in **Table 1**.

Temperature and Throughput Distribution

In **Figure 3**, **left**, the temperature distribution in the pre-distributor for a total throughput of 150 kg/h and an outer die temperature of 200 °C is shown. By selecting a test point with a die temperature corresponding to the inlet temperature of the melt, the influence of the external heating is minimized, so that the focus is on the shear heating. It can be seen that the dissipative shear heating leads to an increase of the melt temperature close to the wall in the first channel section. The subsequent branching of the flow channel, however, causes the increased temperature to remain on only one channel side in each branch. On the other side of the sub-channels, there is now melt from the center of the flow channel before the branching, which was hardly sheared. Although this is partially balanced out further along the channel, the next division of the flow channel quickly follows in order to ensure a low pressure drop. The result is that the melt temperature is higher at outlets 2 and 3 than at outlets 1 and 4. The melt temperature at outlet 3 is somewhat higher than at the second outlet. The reason for this is the manifold before the first branching. The shear heating is stronger on the outside of the manifold due to the longer flow length there.

As shown in **Figure 3**, **right**, the described temperature distribution influences the flow distribution at the outlets of the pre-distribution. It can be seen that the higher the melt temperature at an outlet, the higher the flow rate through it. The highest throughput can be found at outlet 3 as this outlet has the highest melt temperature and therefore the lowest flow resistance. The lowest flow rates on the other hand are at outlets 1 and 4, where the lowest melt temperatures are observed. It should be noted that with increasing total flow rate, the shear heating also increases and, accordingly, the resulting temperature and throughput inhomogeneities are more pronounced (**Fig. 4**).

In addition to the shear heating, the throughput distribution is also influenced by the outer die temperature. As can be seen in **Figure 5**, if the temperature of the outer surface of the pre-distributor deviates from the inlet temperature of the melt, there will be an inhomogeneous temperature distribution in the »

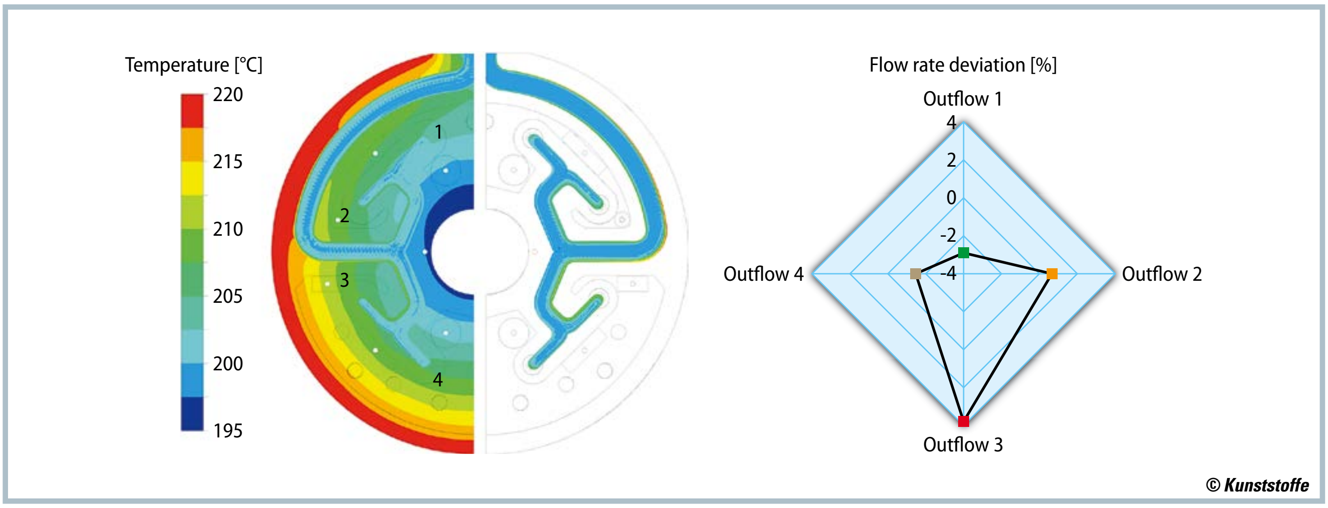

Fig. 5. Influence of the tempering on the temperature and flow rate distribution (TP5)

pre-distributor. It can be observed that the temperature decreases in a radial direction to the middle of the die. At the same time, a temperature gradient can be seen in the circumferential direction. The temperature in the vicinity of the inlet to the pre-distributor is generally lower than on the opposite side (lower half of the pre-distributor in **Figure 5, left**). The explanation for this is that, in the upper part of the pre-distributor, the heating power is absorbed and removed by the melt, so that the die material is heated less here than the lower half of the pre-distributor. The resulting temperature profile in the pre-distributor has a direct effect on the temperature distribution in the melt. In the flow channel region prior to the first branching, the melt is heated more strongly at the flow channel side, which is directed towards the outer edge of the pre-distributor. The reason for this is the higher die temperature on this side. After the branching of the flow channel, the increased melt temperatures only remain on one side of the flow channel, whereas on the other flow channel wall, cold melt flows from the inside of the flow channel before the branching. After the first branching, the heated melt flows in the direction of outlets 2 and 3, whereas the part of the melt that has not heated up so much flows in the direction of the other two outlets. The result is that the highest temperature is at outlet 3 and the lowest temperatures are at outlets 1 and 4.

Correspondingly, the highest throughput can be observed at outlet 3 and the lowest flow rates at outlets 1 and 4. A comparison of **Figures 3 and 5** shows that the outer tempering of the pre-distributor has, in terms of quality, a comparable influence on the throughput distribution as the shear heating. However, the effect of the external heating is generally more pronounced. The difference between the maximum and minimum flow rates in **Figure 3** is 2% of the average flow rate through the sub-channels. The difference in **Figure 5** is 6.8%. Thus, under the simplifying assumption that, in **Figure 5**, the share of the effect of the shear heating is also 2%, the influence of the external temperature can be kept at 4.8%. **Figure 6** shows that the proportion of the external temperature is almost independent of the throughput. With increasing flow rate, an increase in the throughput difference can be observed. However, these differences can be attributed almost exclusively to the increasing influence of the shear heating (light-colored bars in **Figure 6**).

Another process variable that affects the flow behavior of the pre-distributor is the temperature of the melt at the inlet to the pre-distributor. **Figure 7** shows the throughput distribution at different melt inlet temperatures. Here, the temperature of the outer die wall was always chosen 10 K higher than the inlet temperature of the melt. First of all, it can be seen that the throughput distribution always has the same qualitative behavior regardless of the inlet temperature. The highest throughput is always at the third outlet, while outlets 1 and 4 have the lowest flow rates. However, it can also be seen that the inhomogeneities increase with decreasing melt temperature. A decrease of the melt temperature leads to a further decrease of the flow rates at outlets 1 and 4 and a further increase of the throughput at outlets 2 and 3. This observation is due to the fact that, with decreasing melt

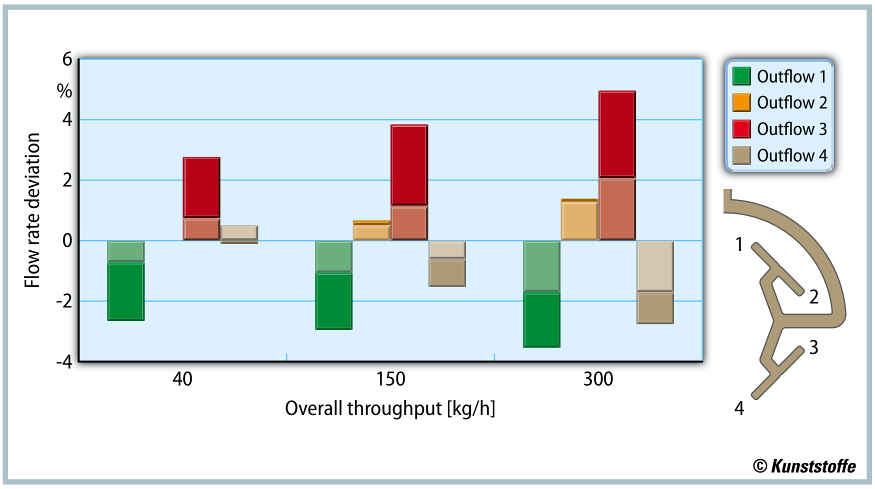

Fig. 6. Influence of the overall throughput on the effect of the tempering (TP4–TP6)

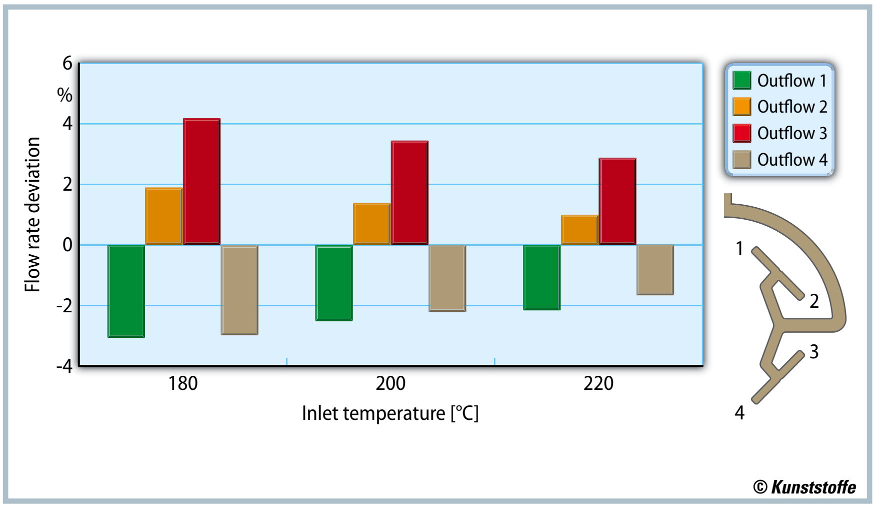

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Fig. 7. Influence of the inlet temperature on the throughput deviation (TP7–TP9)

temperature, the melt viscosity increases. Accordingly, the shear heating increases, resulting in an increase in the throughput differences.

Summary and Outlook

The most important objective in the design of spiral mandrel dies for blown film extrusion is to achieve a uniform velocity distribution at the die outlet. This requires a homogeneous distribution of the melt in the pre-distributor. However, thermal effects occur in the pre-distributor, which lead to different flow rates at the outlets of the pre-distributor. These inhomogeneities can be compensated partially in the subsequent spiral mandrel die. However, due to the very tight tolerances of the film thickness, compensation of the thermal inhomogeneities in the pre-distributor prior to the spiral mandrel die is still desirable. The biggest influence here is exercised by the outer die temperature and the resulting temperature distribution in the pre-distribution. In addition, there is the influence of the dissipative shear heating, which causes a qualitatively comparable throughput distribution as the outer die temperature, and therefore increases the effect of the tempering. The inhomogeneities caused by the shear are the more pronounced the higher the overall flow rate and the lower the inlet temperature of the melt. Polyflow is able to compute these effects.

The results of the presented simulation series form the basis for the next step, in which thermal design measures for the homogenization of the temperature and flow rate distribution in the pre-distribution are to be derived. For this, in a future series of simulations, cartridge heaters and high-conductivity inserts will be placed along the flow channels in order to exert an influence on the temperature distribution in the melt and to homogenize the throughput distribution of the pre-distributor. Finally, the determined design measures will be practically tested and evaluated. ■

Linked Modular Robot Cells

Handling Syringes in a Confined Space

Robotronic AG, Winterthur, Switzerland, together with Mitsubishi Electric Europe B.V., Ratingen, Germany, has developed a handling solution that rapidly and flexibly feeds disposable syringes to an end packaging unit via a rail system. The compact system can be rapidly retooled between different syringe and carrier formats. It consists of two modular robot cells, so-called MRTs (modular robot technology). In one cell, two synchronized Melfa robots of the RV-4FL series (Mitsubishi Electric) perform the handling of tubs and syringe carriers as well as the different syringe formats from 0.5 to 10 ml. For the purpose, they have a corresponding retooling option. The second cell contains a rotatable magazine turret, which transports up to 20 tubs filled with syringe carriers into the unit. The MRT base module, with 1.0 x 1.3 m, has a footprint of just about the size of one Euro-pallet and is 2.2 m high. The concept comprises a complete component kit, which can be put together according to requirements.

The two compact overhead jointed robots can perform both renesting and denesting tasks, and, in a demo application at the trade show, processed 400 syringes per minute. The performance of the cell can be increased to 600 units per minute by integrating an additional axis. The turret is driven by an MR-J4 servomotor (Mitsubishi Electric). The turret allows the MRT to be recharged while the process is running, reducing the downtime.

In addition, Robotronic has realized an overall concept for feeding and packaging injection vials in different sizes, also integrating two robots of the RV-4FL series and a total of twelve servo drives of the type MR-J4. The system consists of two MRT cells, with one six-axis robot each, and can be expanded with almost no restrictions. A conveying line with eight servo-driven positioning screws feeds the vials to the robots, which pick up two rows of five vials each from the conveyor by means of vacuum grippers and place them in the waiting packages.

The syringe handling solution can synchronize 400 syringes per minute into the discharge rail. With an additional axis, this solution allows up to 600 units per minute to be processed (figure: Mitsubishi Electric)

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