Photo: Author

Fig.1: On the K-2016 LWB-Steinl presented two vertical 300-ton rubber injection molding machines with different equipment packages competing against each other molding the same parts.

Quicker to top quality

The rubber injection molding machine manufacturer LWB-Steinl took the K 2016 as an opportunity to stage a sporty comparison of two injection molding concepts on his stand. Low-cost "Lean-Tech" countered innovative "high-tech". Two equal-sized vertical machines of the latest design produced qualitatively identical molded parts in different ways (Fig.1). Without pre-empting the details on the outcome at the end of this article, just so much: the "high-tech" system had its nose in front, and that clearly. But despite the proven superiority of the high-tech version, the rugged lean-Tech still has a large fan base. And this, despite the fact that the available methods for increasing the performance of rubber plastification have already been successfully used for more than 10 years, as proven by an experience report from the North German rubber and silicone manufacturer Präzisa in Ratekau near Lübeck.

The K-fair taking part every three years is for the plastic industry, the same as the Olympic Games for the sport. There as here, the focus is on competition of the participants and on top-performance. Accordingly, the elastomer molding machine manufacturer LWB-Steinl organized a competition between two equal-sized injection molding machines with vertical clamping units (each 3000 kN clamping force) on its booth. The difference was in the technical specification of the drive hydraulics and the injection units. Machine #1 competed with proportional hydraulics and an EFD standard injection unit against the servohydraulically driven machine #2, which represents, with the EFE injection unit including ACC (Adaptive Cure Control) system, the ultimate state of the rubber injection molding technology. The aim was to produce qualitatively equivalent parts. To ensure equal quality, both machines were connected to the process control system Jidoka P 101 of the technology developer CAS in Reinbeck near Hamburg. Using the CAS tester Jidoka S 101 for an automated and non-destructive test the quality parameters could be traced back tot he production parameters. That the performance comparison would go in favor of the more expensive and therefore more expensive machine was to be assumed, but could it beat the more cost-effective lean-tech machine with cheaper averall costs?

The EFE system has become a reliable standard

The system platform for improving the productivity of rubber injection molding is the EFE plasticizing system already presented by LWB-Steinl in 2004. It is the patented combination of two sub-units, developed by the company founder Alfred Steinl. The units are a FIFO plasticizing unit and a so-called nozzle head with an integrated injection piston, which combines several functions in itself. First, it serves as a shut-off element for the plasticizing cylinder during the dosing operation, second as a throttle nozzle in the material flow during injection, and third as a piston for pushing the residual material out of the nozzle head at the end of the injection process. (Details and function scheme in the "EFE" fact box)

The innovative aspect of the EFE system is, that at the 90 degree deflection of the melt flow, the piston is positioned in the nozzle head so, that a constriction is created in the flow channel. The flow rate and the shear rate in the plastificated rubber compound raises during the injection movement of the FIFO unit. The expanded rubber molecular chains relax after the throttling point, thereby releasing the previously accumulated mechanical energy in the form of heat. This increases the mass temperature. With the temperature rise and the melt viscosity decreases. Likewise, also the pressure level required for filling the mold-cavity drops. A welcome side effect of the additional energy input right before the filling of the mold is the activation of the vulcanisation reaction, without having to await the heat transfer from cavity surface into the rubber material.

EFE-user with 10 years experience

In 2007, Jörg Nagel, then plant manager of the north German rubber processor Präzisa, who was widly known as an innovative rubber moulder, informed his boss about the advantages of the EFE system, which was rather new and had hardly outgrown the stage of testing. Nevertheless, he was able to achieve, that the next LWB machine had been ordered with the EFE system. It was a vertical VREFE 2700/1000. It supplemented the conventional LWB machines with 100, 320 and 450 tonnes of closing force, which had been in operation since 1995. Knut Ziegenbein, managing director of the second generation, explains the motivation for the decision at the time: "In 2007, the rapid expansion of our injection molding department, which was set up in 1995 for the production of rubber and HTV parts, was calling for an expansion of the production space.

Therefore, a machine, which promised up to 50 per cent more output, was an interesting option, thus postponing an investment need into additional machines and a building extension into the future. Positive experiments at the LWB application center pushed our initial skepticism aside and made us deciding for the still new application technology."

Theory confirmed in practice, additional advantages found

The announced benefits have been confirmed in practice. Knut Ziegenbein added: "The EFE injection system brings us four essential advantages over the conventional FIFO injection units.

Advantage One: The increase in the production output. To cite one example: in the case of ventilation masks made of CR/NR-compounds and with single-cavity molds, the heating times, initially within the range of 180 seconds, could be reduced to 120 seconds. Accordingly, the production rose from 100 to 140 pieces per 8-hour shift, taking into account a relatively complex demolding process. This productivity gain is also effective for all other rubber moldings (Fig.2 and 3). The confirmation of this is the unchanged cycle time after the conversion of the product to an EPDM compound.

Advantage Two: The viscosity reduction, which is associated with the additional internal heating, reduces the demand for pressure and speed for filling the cavities. This opened up new possibilities for shifting moldings with long flow paths, e.g. respiratory masks, to smaller machines. A very important additional benefit is that additional orders for thin-walled, complex moldings with long flow paths can now be manufactured (Figures 4 and 5).

Advantage Three: The production practice has shown, that the time window for the processing of stored rubber compounds is significantly extended by the EFE system. Obviously, due to the additional shearing in the throttling point, the structural consolidation commencing during the storage of rubber compounds is so far recirculated and homogenized that the cross-linking capability is maintained over a long period of time. As a result, the EFE system can be used to process rubber compounds which would only be conditionally or even no longer processable on conventional machines without compromising the product quality.

Advantage Four: A continuously observed secondary effect of the two-stage energy charging of the rubber melt is the lesser tendency to form deposits in the mold cavities. Experience shows that, on machines without EFE injection unit, mold cavities have to be cleaned once per shift, which usually takes one hour. With the EFE-plasticized compounds, the cleaning intervals extend to a multiple - and this across all rubber types. This is essential since the majority of the moldings must be produced according to strict quality specifications without the use of release agents. In response to a possible explanation for this effect, it is evident that the faster formation of the skin on the molding is obviously the result of the faster reaction of the crosslinking reaction.

However, the is by far not the full potential oft he EFE-system to enhance a rubber molding production. At the K-2010, LWB-Steinl presented for the first time a variant of the EFE system with a continuous adjustment of the throttling point in combination with a closed-loop control system along the flow path of the plasticized rubber compound during injection.

ACC raises EFE to the next level of efficiency

The system received the product name "Adaptive Cure Control" (ACC). Its central elements are an a controll hydraulics for the injection piston and the already mentioned sensor system (temperature, pressure, paths) in combination with a fuzzy control technology. It controls the piston position as a function of the measured condition of the plastificated rubber compound and, if necessary, changes it during the injection process. However, the mass temperature is controlled not only during the passage of the throttle point and thereafter, but also throughout the entire injection process. Starting from the plasticizing process in the FIFO unit, the mass temperature thus is increased in a cascade-like manner to a level at which the crosslinking reaction proceeds in an accelerated manner. All three stages of temperature generation are regulated and linked to a process model via the ACC system.
The central functional component is the piston of the E-type injection unit. By servo-hydraulically actuated retraction or advancing, the piston increases or decreases the cross-section of the throttling point. The piston tip is shaped in such a way that it promotes the formation of an adherend flow along the piston tip and has the effect that a large portion of the rubber compound heated in the throat is guided along the tip of the piston into the center of the flow stream in the adjoining nozzle. (Fig.7a + b) The result is a symmetrical temperature distribution over the cross-section of the rubber melt, with a maximum in the center (Fig.8). The control process of the piston is designed in such a way that, at the end of each filling cycle, the constriction is temporarily increased by retracting the piston, whereby the melt temperature at the dosing end is lowered. That excludes that an activated material remains in the throttle.
The combination of the EFE + ACC systems has proved itself in operation with all common elastomer compounds (NR, CR, EPDM, NBR, ACM) in the hardness range between 45 and 78 Shore A. Above all, with thick walled moldings, heating time reductions of 30 to 50 percent could be achieved compared to a standard system without the possibility of energy conversion.

With CAS-Jidoka to optimal quality
An increasing production output should be accompanied with high product quality. To ensure that LWB-Steinl is using the systems of the North German company „CAS - Computerunterstütztete Automatisierungssysteme GmbH & Co. KG“ in Reinbeck near Hamburg. Their process control system Jidoka P 101 III works with physical models and their mathematical description to simulate the complex processes of rubber crosslinking over all process stages within an injection molding machine. The process optimization system automatically calculates the changes of the material from the intake of the rubber strip into the screw through to the cooled rubber molding. The models have been developed and refined since 1987. The starting points for the calculation of a certain degree of crosslinking are the datas from an input test of a rubber compound.
From this, in combination with the required degree of crosslinking, setting data for the injection molding machines are calculated. These can can be used as guidelines for the machine operator or adopted automatically by means of an interface into the machine control. An intervention in the machine settings always refers to the required mechanical properties of the finished part, no matter what fluctuations the process variables have. The quality produced can be documented on-line by the integration of a CAS test device (JIDOKA S 101 III) in the production process. To the test device the moldings are transfered by a handling device for carrying out a non-destructive rapid test. The measured data of the

dynamic and static material characteristics can be used as the basis for potential necessary setting adjustments.

Considerable productivity gains possible

In order to demonstrate the efficiency of the interaction of the technology modules, described above, LWB-Steinl displayed two 300 T vertical machines of the latest "performance“ machine models with different equipment options on their K-2016 booth, competing against each other (Fig.1). In Machine #1, the moldings (thick-walled ashtrays made of 1000 cm3 EPDM with 70 Shore A) were produced with an open cold-runner injection system and a 4-cavity mold.

Machine #2 was equipped with a dual servo motor drive system and the EFE injection system, combined with the ACC system. The four mold cavities were injected via a needle-shut-off cold-runner system. The same quality standards and degree of crosslinking were applied to both machines and supervised by the CAS-Jidoka system. An on-line test in the Jidoka tester documented the same quality.

The result of the technology comparison is impressive: With the same part quality, the "Lean-Tech" production unit produced only 50 parts per hour, while the "high-tech" unit reached 80 parts per hour. This is a productivity difference of 60 percent, reducing the production costs by 15 percent. A not inconsiderable side effect is that the required injection pressure is 20 percent lower resulting in a lower energy consumption. In view of these facts, it is all the more astonishing that the high-performance injection molding systems for the processing of the rubber are not yet been used extensively.

■■■

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Figures:

Photo: Author

Fig.2: Complex and precise rubber moldings, such as respiratory protective masks made from silicone rubber and EPDM blends, as produced for the safety and medical technology manufacturer Dräger in Lübeck, are the core competency of Präzisa GmbH in Ratekau.

Photo: Author

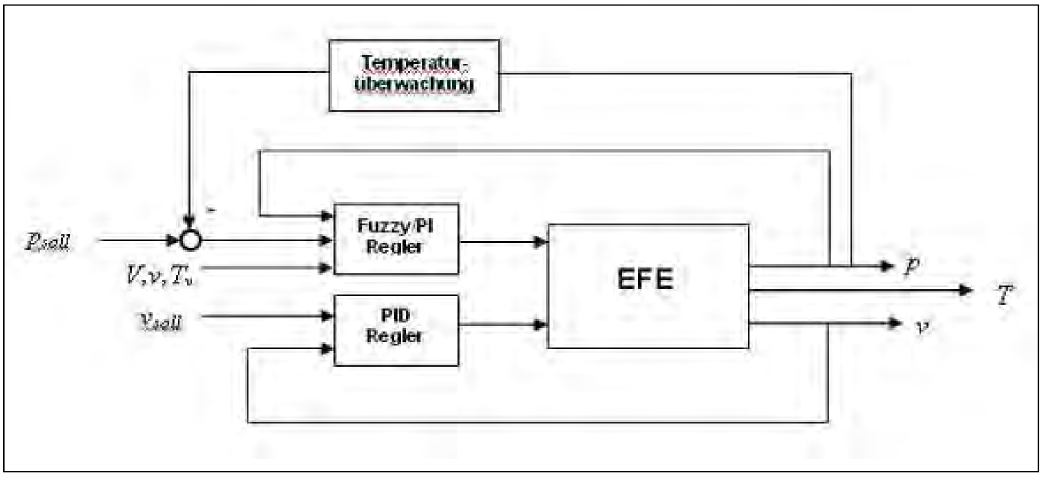
Fig.3: The production of molded parts with long flow paths, here demonstrated with of mask bodies for Dräger respiration masks, is considerably facilitated by the EFE system.

Photo: Author

Fig. 4: Thin-wall-moldings with long flow paths, such as the component for a resiration device made from EPDM rubber depicted here, can be produced with the EFE system with less pressure and a correspondingly lower clamping force, and moreover even faster.

Photo: Author

Fig. 5: Knut Ziegenbein, managing partner of PRÄZISA (left) and LWB sales technician Thomas Vodnansky look back on 10 years of positive experience with the EFE injection system.



Graphic: LWB-Steinl

Fig.6: Block diagram of the MIMO (Multi-Input / Multi-Output) control: The output of the controller is the throttle setting; At the same time the measured temperature T behind the throttle is monitored and, when a limit value is exceeded, is reduced by a controller intervention.

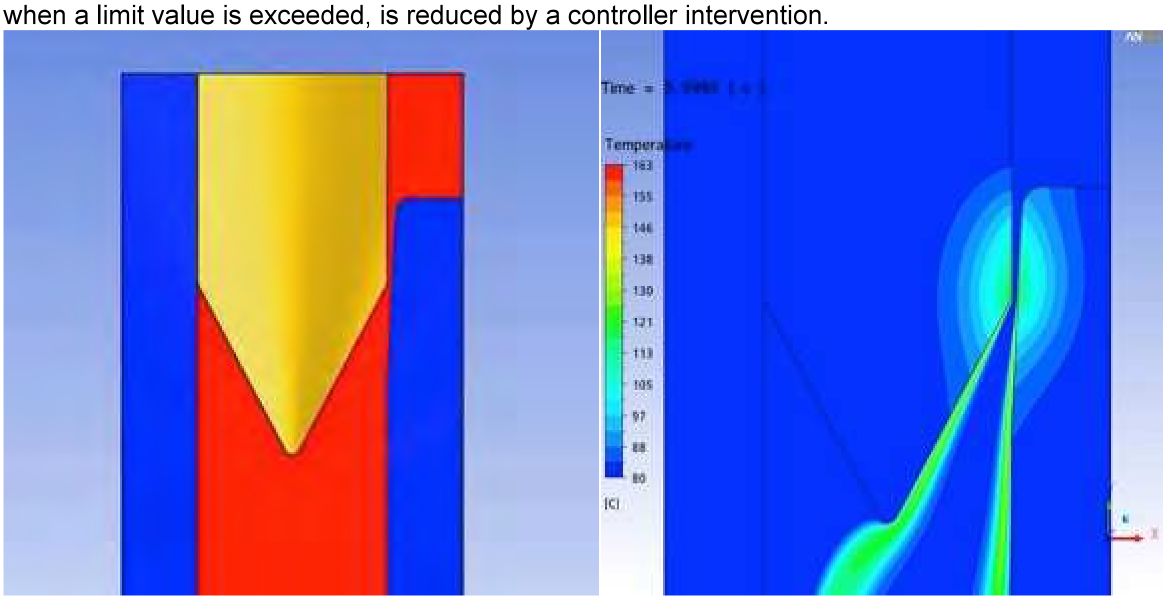


Fig: LWB-Steinl

Fig.7a + b: Detailed view of the specifically created constriction (throttle) in the connection channel between the plasticizing unit and the piston injection unit. Fig. 7b visualizes the heat generation in the squeezing area of the flow channel and the subsequent distribution in the material stream.

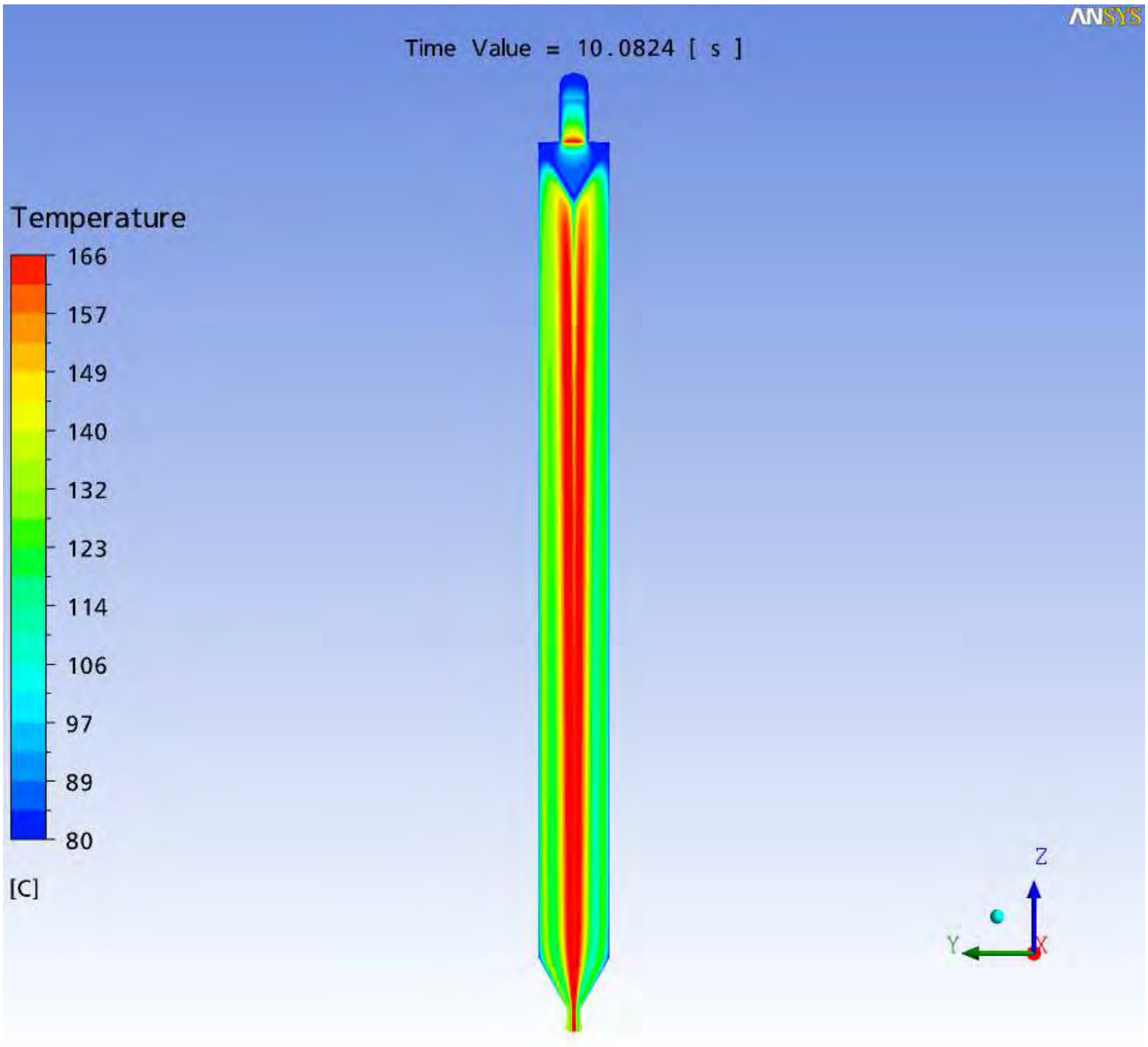


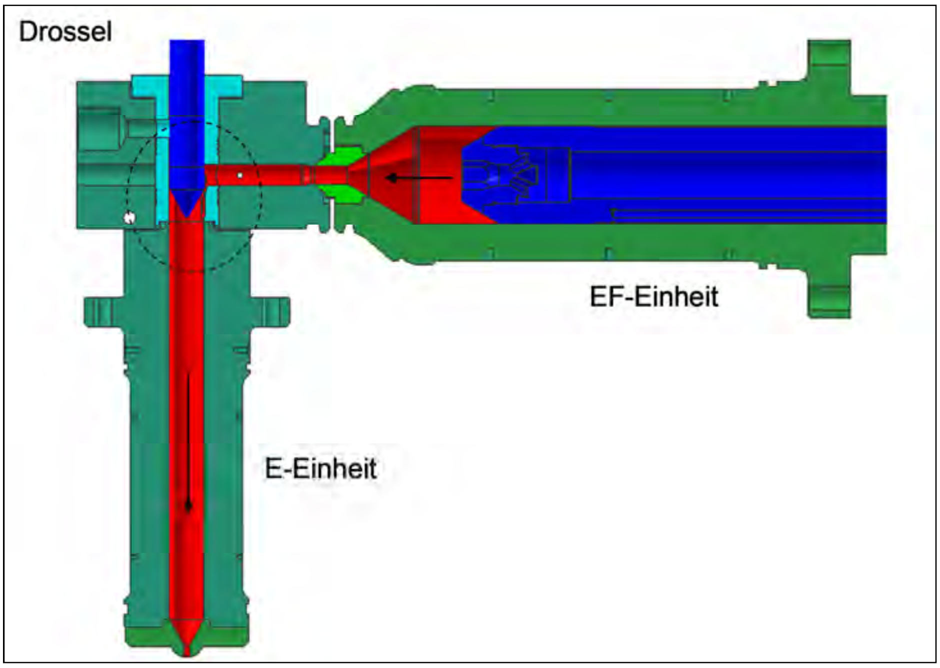
Fig: LWB-Steinl

Fig.8: Temperature distribution from a flow simulation in the injection unit with a throttle position with 80% closure of the flow cross section for the flow rate 40 cm³/s.

Infobox: EFE-System

What is the structure?

The EFE injection system is the combination of a FIFO plasticizing unit (EF unit) and a subsequent nozzle block (E-unit) consisting of a nozzle and a piston. The EF unit is used to plasticize a certain amount of a rubber compound per cycle and then to inject it into the mold with the screw piston through the adjoining nozzle block. In doing so, the piston of the nozzle block is positioned at the deflection point in such a way that a constriction occurs. During injection, the flow velocity and the shear increase. This leads to additional heating of the rubber mixture. After the screw-plunger of the EF unit has reached its end position, the nozzle piston is moved forward and empties the nozzle block. Parallel to this, the screw unit begins to plasticize again with the nozzle channel closed.



Grafik: LWB-Steinl

What are the advantages?

> The temperature increase during the injection process reduces the viscosity of the rubber compound and thus allows to fill a thin wall thickness without increase of pressure

> Additional energy input allows vulcanisation to be started faster, thus shortening the heating time

> Due to the two-stage additional energy input, fluctuations in the mixing quality can be compensated within certain limits.

Which sizes are available?

> Injection volumes from 115 to 8500 cm³, depending on the aggregate size

> Injection pressure up to 2200 bar

Infobox: ACC-System

The ACC Control Concept

The "Adaptive Cure Control (ACC)" is a hardware/software extension of the EFE injection system, with which a predefined mass temperature can be increased and controlled within narrow limits through converting mechanical energy into heat during the injection process. For this purpose, a process model calculates for each working cycle, in combination with a multi-input / multi-output control system, the desired course of the injection pressure and the piston position in the throttle. The process model uses as input variables the starting temperature of the plasticized rubber compound, the metered volume V, the injection speed of the FIFO injection unit and the wall temperatures at different measuring points upstream and downstream of the throttle. The process control also takes into account and compensates fluctuating technical constraints, such as differing dead times, varying ambient temperatures or fluctuations in the mixing quality. In order to "heat the melt", the counterpressure of the melt via the throttling position is controlled in such a way that the desired mass temperature is reached rapidly by a high energy input and is then kept constant by a constant adaptation of the throttle. At the end of the injection process, the nozzle channel is emptied by advancing the piston, analogously to the standard EFE operation.