

Maintaining Stable Pressure Limits

Maximum Protection with no Loss of Dynamics – a Pressure Limit Closed Loop Controller by Engel Austria Does that during Injection

Injection pressure increases constantly while plastic melt is being injected into a mold. In order to maintain a specified injection pressure limit, melt flow has to be slowed down before reaching its limit value. A pressure limit closed loop controller determines the latest possible point for intervening in the injection process, in order to obtain the shortest injection time that is still compatible with maximum mold protection.

The power of electric injection molding machines has increased steadily in recent years. Engel's e-motion and e-cap series (manufacturer: Engel Austria GmbH of Schwertberg, Austria) meanwhile achieve injection speeds of up to 800 mm/s and cycle times considerably lower than 3 s together with injection times sometimes as low as 0.1 s. The impetus for this development comes from the packaging industry. Short cycle times there mean low piece costs. Moreover, trendy thin-wall packaging requires especially high injection pressures.

Specified limit values set either by the operator or dictated by the machine should ensure that pressure does not increase too far after the mold has been filled and that no damage is done to the mold or the cylinder of the injection molding machine. However, from the point of view of closed loop control technology, electric machines require more sophisticated pressure control than hydraulic ones do.

Thin-Wall Production without Process Stability

The masses moved by electric injection molding systems are clearly greater than the amounts moved by hydraulic systems. This is due to the additional mass moment of inertia in the motor, the ball screw and, in part, the belt drive. During the injection sequence, the kinetic energy present in the system is correspondingly higher. This encourages high load stiffness during speed control and there-



The increasing power of injection molding machines, e.g., for producing thin-walled packaging, presents new challenges to pressure limit control. The system developed by Engel for electric injection units has a short response time and thereby reliably protect the machine and the mold while maintaining full dynamics

by complicates pressure limitation. Moreover, the setpoint that limits dynamics is defined by resulting mass moment of inertia and the available driving torque.

A further difference between electric and hydraulic injection units results from the stiffness of the drive train. The high axial stiffness of the drive train with its ball screw enables more precise positioning and repetition. However, this leads at the same time to more rapid pressure increases, thereby increasing demands on closed loop control response time. Compression of the material in the cavity and in front of the screw causes pressure to rise further, at first even during braking (Fig. 1).

The higher the injection rate, the longer the braking phase. That means that melt flow has to be slowed down before reaching the set limit value. This makes it a challenge to select the best possible point in time. If slowed down too late, pressure exceeds the specified limit; if it is slowed down too soon, cycle time is longer, and/or the cavity is not completely filled.

Many of the injection molding machines on the market still use methods of pressure limitation that are incapable of limiting injection pressure reliably. They often do not intervene until the limit has been exceeded – which can result in high pressure peaks and cost-intensive »

damage to the mold and the machine. Particularly when thin-walled parts are being produced and the required injection pressure approaches the limits of the mold and the machine, such machines cannot ensure stable processing.

Not Early, but Timely Intervention

This is unacceptable for the operator who use them. Injection molding machines configured for high-performance applications instead require protective functions to ensure that the set limits are maintained. Engel's product development went one step further: it was their goal to develop a pressure limit controller that would enable not just early, but timely intervention.

Engel's pressure limit controller does not wait to start working until the melt flow has to be slowed down, but works during the entire injection molding process. It has three distinct operating modes:

- **Monitoring:** The pressure sensor records the pressure curve and determines the optimum point for intervening.
- **Intervention:** The controller specifies the injection rate until the pressure stops rising completely.

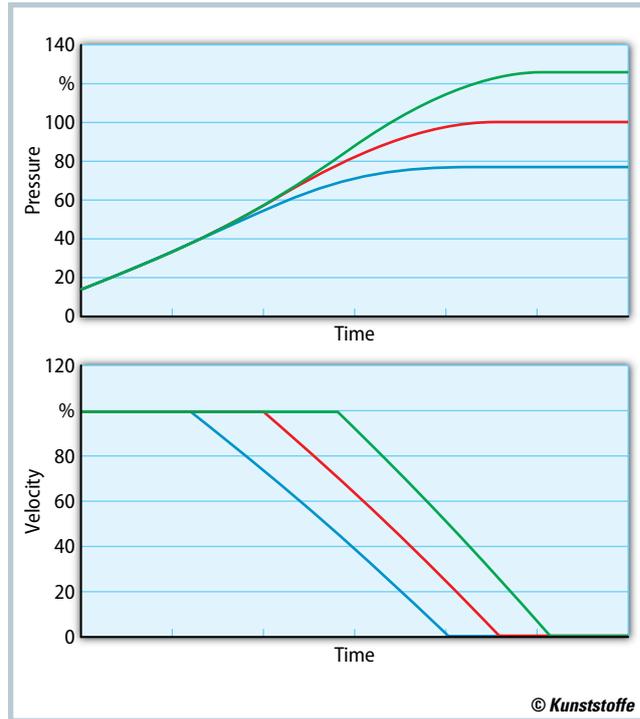


Fig. 1. The operating mode of pressure limit controllers when compressing a melt cushion: the red curve marks the ideal course of the process. The green curve shows a curve without pressure limit control, and the blue one shows a curve with too early intervention

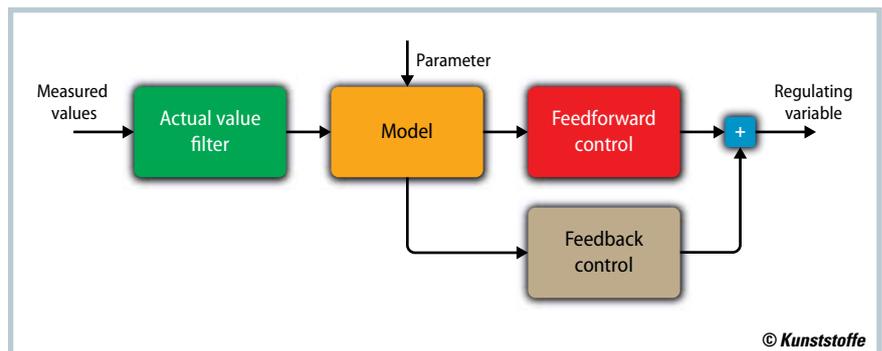


Fig. 2. The concept of the pressure limit controller. The filter suppresses interfering frequencies and high frequency components

■ **Pressure control:** Injection pressure is controlled to the setpoint. The curve of actual pressure increase is insufficient for predicting the expectable pressure increase. The system uses various mathematical models that enable it to weigh the characteristics of the injection unit with those of the material being processed.

As long as the expectable pressure increase remains below the limit value, the injection unit works freely according to the preset speed curve. The pressure limit controller does not interfere with the process until the pre-calculated pressure increase reaches the limit value. Using a model-based feedforward control, it then controls the melt flow downward.

State simply, feedforward control makes it possible to specify the input into

the controlled system in such a way that its output follows a desired course. Thus, the behavior of the system is known in advance and the dynamics of the injection process can be fully utilized. A feedback controller compensates for any remaining deviations.

Feedback Controller Keeps Pressure Reliably under Control

The feedback controller is responsible for correcting the feedforward control based on actual measurements. This is what distinguishes the pressure limit controller from a PID controller (Fig. 2). The feedback controller uses its pre-calculated pressure curve as a setpoint. If pressure rises faster than expected during intervention, pressure reduction

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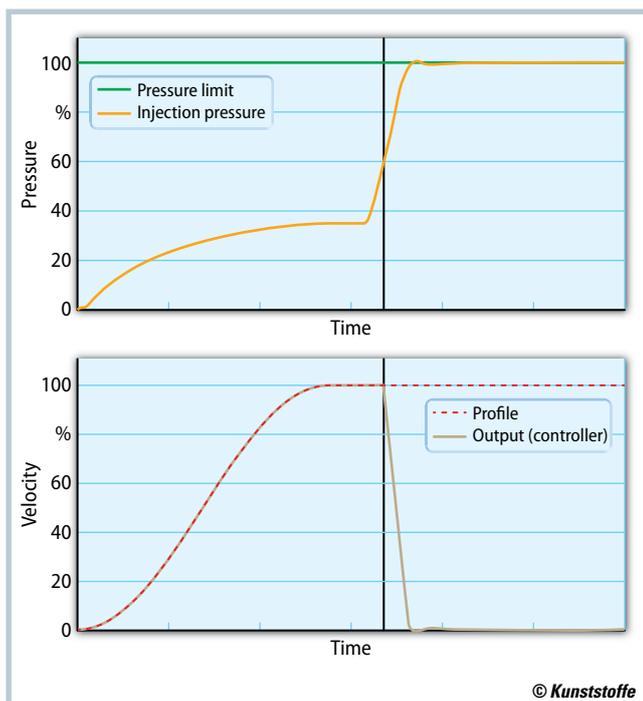
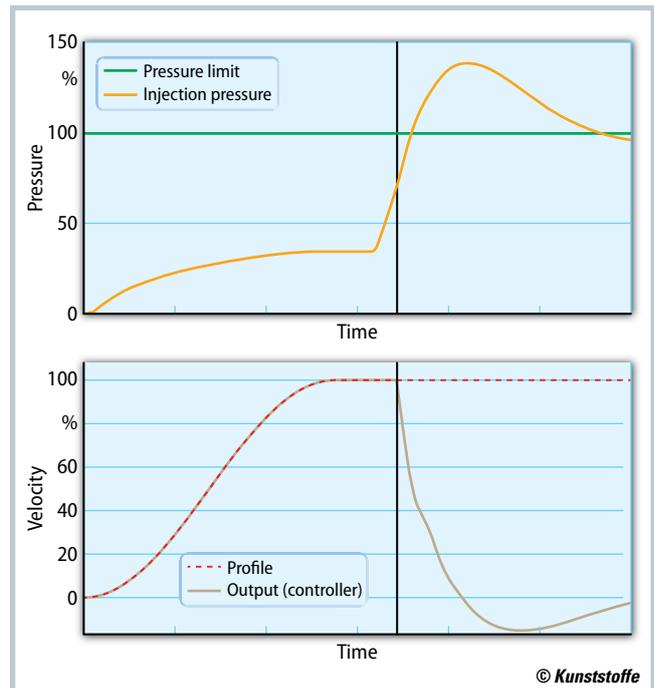
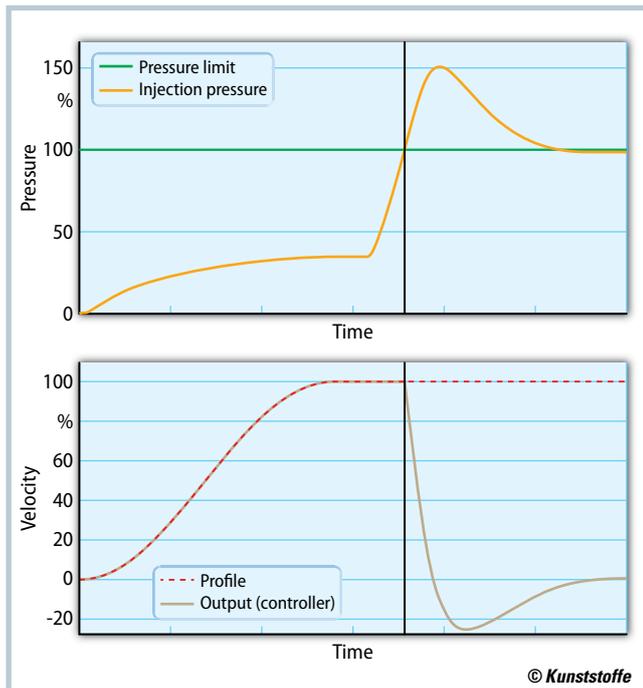


Fig. 3. Simulation results of an injection experiment with a PI controller (top left), a PID controller (right) and an Engel pressure limit control (bottom left): Only advance pressure limit control can prevent pressure overshoots entirely (figures: Engel)

Thanks to its additional differentiating segment, the PID controller does succeed in reducing the speed, even before the pressure limit has been reached, but it, too, cannot entirely prevent overshooting. A PID controller also has the disadvantage that its optimum setting is too strongly dependent on a favorable working point.

Finally, the third figure shows an ideal pressure curve based on the solutions developed by Engel. Injection speed is not reduced until relatively late, but the pressure remains below its limit value.

Conclusion

Intelligent control concepts are required to protect machines and molds from excessive injection pressures at shorter and shorter cycle times. This challenge to the manufacturers of injection molding machines continues to grow. Yet equipment continues to be put on the market whose pressure overshoots commonly exceed 15%.

As in the past, Engel continues to place great value on process stability and on maintaining pressure limits. By continuing the further development of pressure limit control, the company will cope with increasing demands on dynamics in the future – without compromising stability – since it also continues to optimize injection time. ■

is slowed down in order to deviate not any more than necessary from the specified profile. If pressure remains constant even before reaching the pressure limit, the speed is increased again far enough to achieve the set speed profile. Only then does the pressure limit controller cease intervening and returns to the operating mode "monitoring".

A simulation documents the difference between the modes of operation by Engel control and those frequently used

by conventional PI and PID standard controllers. The graphics (Fig. 3) show an injection sequence for a part that requires high injection speed to be completely filled. Due to the strong compression, there is a sharp increase in pressure.

The worst protection for the system is provided by the PI controller. The controller fails to slow down the melt flow until the pressure limit has been exceeded. At this point, a high pressure overshoot can no longer be prevented.