All about plasticizing screws

Part 1 of the series

The first part of this three-part series of articles discusses the basic design of a plasticizing unit and the correct choice of injection unit. It shows how the required screw diameter can be ascertained on the basis of the shot volume. The formula for the average residence time can be used to estimate the degree of utilization and the thermal load on the material (which should be kept low in the interest of high product quality). Last but not least, the maximum injection pressure and the available screw torque are key variables for successful injection molding production. – Basic principles for the selection of a barrel-and-screw combination, and the starting point for further optimization.

Filipp Pühringer

Various shapes of plasticizing screws.

Designing an injection molding machine is actually a highly complex task. To ensure that no wrong choice is made when selecting the machine, a large number of key parameters must first be identified and included in the calculation.

Particular attention must be paid to the plasticizing unit, since it is a vital success factor in manufacturing high-quality products. The requirements these aggregates have to meet are extremely complex, but by carefully balancing the different aspects already at the stage of designing the equipment, it is possible to eliminate conflicts of objectives. For example, the demand for the highest possible throughput conflicts with the requirements for material homogeneity, melt quality, conveying stability and wear resistance. The wear resistance does not depend exclusively on the type of material processed, but is rather an attribute resulting from the systemic interplay between the geometry and the correct choice of materials.

The discussion presented here focuses on what needs to be considered in planning the basic design of the plasticizing unit and the injection unit. The definition of the basic design of the plasticizing unit and the injection unit provides the prerequisites for the next step, that is, the choice of the screw geometry. In the next issue of innovations, the development of a new screw geometry will be explained in more detail. (The limiting factors in developing new screw geometries are the loads on the material processed and on the machine, such as pressure, temperature, dosing torque, etc.)

Basic design of the plasticizing unit

Shot volume

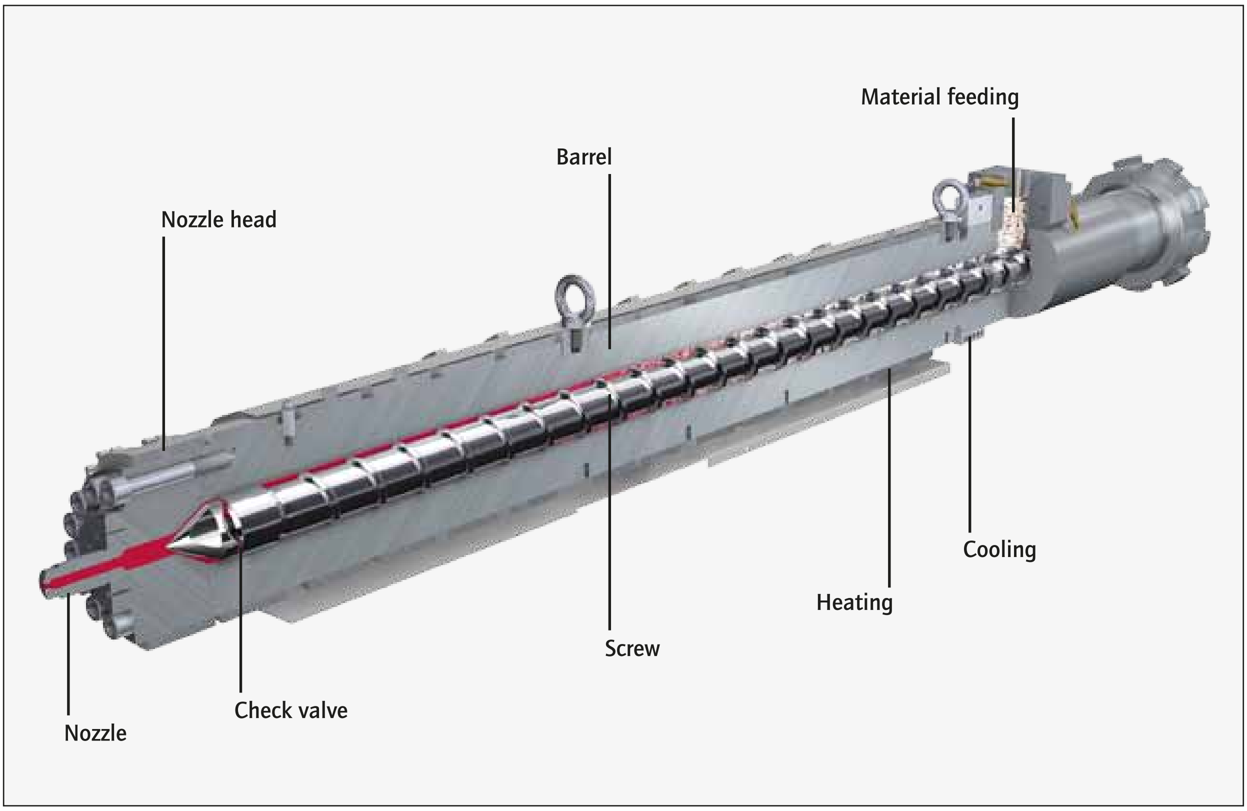
Depending on the material to be processed, the optimal operating range of a plasticizing unit is a screw stroke roughly between 1 and 3 screw diameters (D). If a dosing stroke of more than 4 D is selected for loading the injection unit, maximum process stability can no longer be ensured. The possible consequences would be dosing time fluctuations, air induction and accelerated wear of the unit. The reason is that the ***effective screw length*** is reduced by an increased dosing stroke. Thus, the length of the channel is shortened to compression level, which means that the material has less time to absorb sufficient heat for melting. The result would be rising pressures inside the channel, which would strain both the material and the machine. The shot volume V_{SCH} is calculated as follows:

$$V_{SCH} = \frac{m_T}{\rho_m} + f_{HK} \cdot V_{HK} + V_{MP}$$

Effective screw length: *The length of screw lying between the front edge of the filling hole and the screw tip inside the working area of the barrel. It is decisive for material conveyance and pressure build-up.*

For hot runner tools, the compression of the melt inside the hot runner must be taken into account – depending on whether the hot runner needs to be cyclically unloaded (e.g. in the case of open hot runners with easy-flowing materials). The higher the melt compressibility and the higher the injection pressure, the higher the factor f_{HK} for the hot runner. Typical values for f_{HK} lie between 0.1 and 0.3. Thus, even with relatively small part weights m_T, the required stroke volume may be doubled! For tooling with solidifying sprue, the factor f_{HK} tends towards zero. It is important to note that the weight of the solidifying sprue system is then included in the part weight m_T and taken into account accordingly. The volume of the residual melt cushion V_{MP} should change in relation to the screw diameter D. As a general rule, a screw stroke of 0.1 to 0.3 D should be found inside the barrel at the end of the holding pressure phase. Consequently, the volume of the melt cushion V_{MP} must be calculated as follows:

$$V_{MP} = 0{,}3 \cdot \frac{D^3}{4} \cdot \pi$$



Schematic diagram of the plasticizing system.

The screw diameter can be derived from the calculated shot volume. As already stated, the metering stroke can be defined as a distance equal to the length of 1 to 3 screw diameters. Accordingly, the following limit diameters apply to the screw:

$$D_{min} = \sqrt[3]{\frac{4 \cdot V_{SCH}}{\pi \cdot 3}} \quad \text{and} \quad D_{max} = \sqrt[3]{\frac{4 \cdot V_{SCH}}{\pi \cdot 1}}$$

In the final choice of the screw diameter, the characteristics of all products to be manufactured must be taken into account. Following careful consideration of the calculated diameter ranges, the actual screw diameter is selected.

Residence time

Residence time is the length of time spent by a given plastic particle inside the barrel. Due to the complex flow processes inside the barrel, however, there is no precisely defined time span which applies equally to all melt fractions, but a certain residence time distribution. This depends on factors such as the channel volume, the total cycle time, the material bulk density, the melt density and process parameters such as back pressure and screw speed.

The residence time distribution provides information about the material quality concerning homogeneity and sufficient plasticization. The wider the residence time distribution, the higher the homogenizing effect. Calculating the residence time distribution is a complex mathematical task. In practice, however, a simplified formula for the mean residence time t_V is often sufficient for an assessment. The mean residence time is the amount of

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V_{SCH}	*Shot volume*
m_T	*Part weight*
ρ_m	*Melt density*
f_{HK}	*Hot runner factor*
V_{HK}	*Hot runner volume*
V_{MP}	*Volume of residual melt cushion*
D	*Screw diameter*
D_{min}	*Smallest recommended screw diameter*
D_{max}	*Largest recommended screw diameter*
t_V	*Mean residence time*
t_{zykl}	*Total cycle time*
V_K	*Screw channel volume*
f_{MAT}	*Density correction factor*

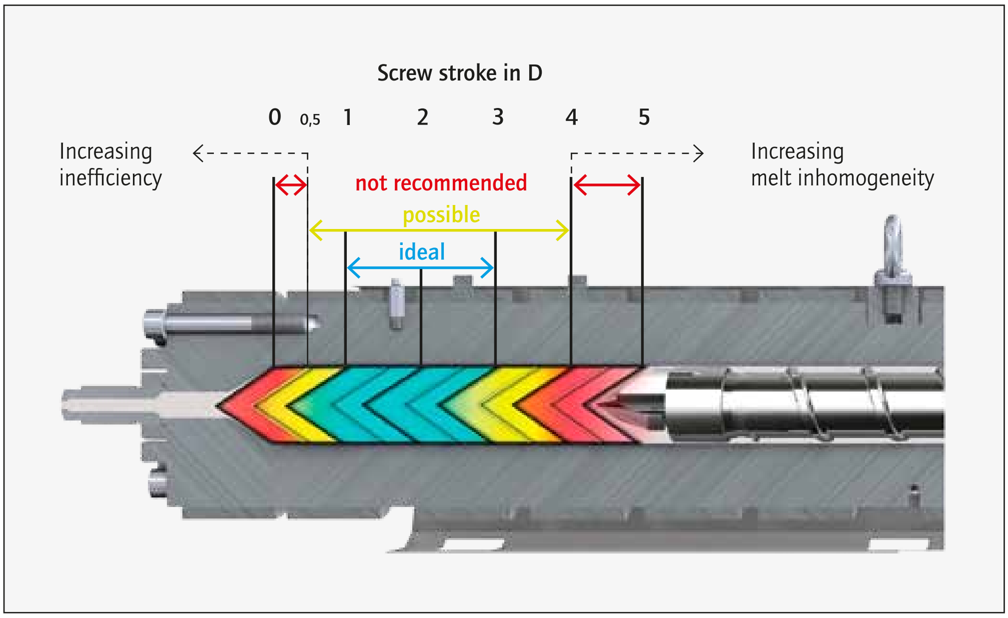
time a plastic particle spends on average inside the barrel. The mean residence time serves as a first indicator of thermal damage to the material.

$$\overline{t_V} = f_{MAT} \cdot \frac{V_K}{V_{SCH}} \cdot t_{zykl}$$

The factor f_{MAT} takes into account the varying material densities. For instance, the density of solid material is higher than that of the melt, which again is higher than the bulk material density to be found in granulated raw material. Experiments have shown that this factor generally lies between 0.8 and 0.9.

Thus, the calculated residence time is reduced by the empty spaces between the granulate grains in the feed zone of the screw.

For common types of plastics, an optimal time window ranging from 2 min to about 8 min is to be expected. The residence time should not fall below at least 1 min. It should also be mentioned that, depending on the types of additives and base polymers, there are large differences in the thermal stability of plastics. So some special types of material – for example for lens production – can easily withstand residence times of more than 30 min, while in plastics with medical ingredients degradation processes may already set in after only 2 min.



Schematic diagram: recommended stroke utilization.

At the stage of developing a specific screw geometry, the exact channel volume is of course not yet known. Here, the volume of the existing standard 3-zone screw can be used for preliminary orientation. In the case of screws operating according to the same principle, the volumes usually deviate only slightly from the standard value.

In principle, calculation of the residence time can provide a first reference value for the total length of the screw. Screws are lengthened for extremely short dwell times and shortened for extremely long dwell times.

Maximum screw torque

Every injection unit has a maximum screw drive torque. It is fixed by the installed drive system. Injection molding machines from WITTMANN BATTENFELD are available with different equipment variants to provide higher drive torques. In this context, the mechanical strength of the driven screw must also be taken into account. Here, the thinnest cross-section is the limiting factor.

Accordingly, the drive torque is adapted to the strength of each type of screw to prevent screw breaks. For determining the required torque, the previously defined variables such as stroke utilization and residence time, as well as the viscosity of the material to be processed, are decisive.

In addition to using precise calculation tools, WITTMANN BATTENFELD can draw on extensive experience from countless systems previously installed to make the correct choice in each particular case.

Maximum injection pressure

The maximum possible injection pressure must be ascertained in every single case. There is a choice of barrels in different dimensions for every size of injection unit. Especially in the case of large barrels, the maximum injection pressure must be observed. Due to the larger cross-sectional area of the screw, a lower specific injection pressure can be set to obtain the same injection force.

Another important point: the smaller the screw diameter, the higher the transmission ratio of the specific injection pressure to injection force will become, which has an effect on control accuracy. This is ultimately the reason why no small barrels can be installed in large aggregates of any size.

In practice, the required injection pressures are derived from empirical values or determined by calculation (e.g. by filling simulations). Nevertheless, the mechanical engineering design should be laid out to provide a sufficient reserve.

Basic parameters for decision-making

Shot volume, residence time, maximum screw torque and maximum injection pressure: the clarification of these central parameters should make it possible to determine the size of the screw and to choose the right injection unit to match it – or at least strongly limit the choice for both decisions. ◆

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