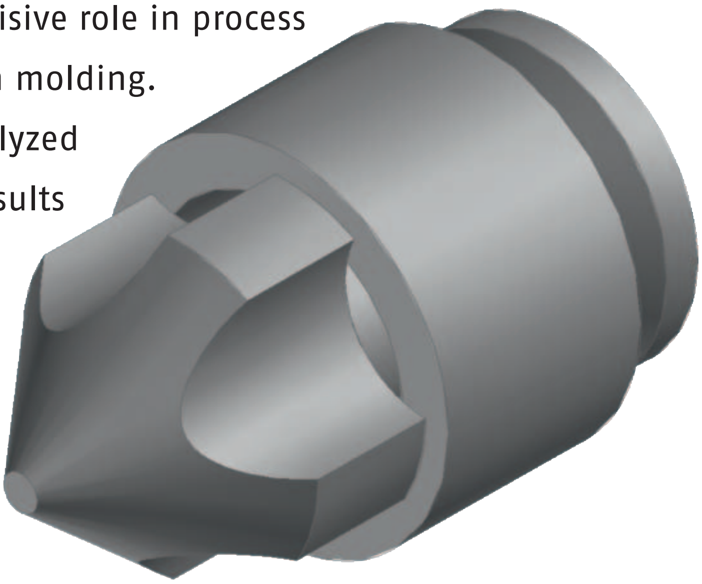
Mathematical Optimization of Annular Non-Return Valves

Simulation. Non-return valves play a decisive role in process constancy and product quality in injection molding. The way in which they work has been analyzed and modeled in a research project. The results make it possible to calculate and hence optimize the closing behavior of annular non-return valves.



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HELMUT POTENTE
HANS-PETER HEIM
THORSTEN THÜMEN

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The simulation of plasticizing units is centered on a number of key points. The possibilities that currently exist for calculating the metering process include a description of the pressure/throughput behavior, the melting behavior, the temperature progression, the calculation of the screw drive power and heating power and an estimate of the mixing behavior. So far, however, no simulation has been available for the movement of the locking ring.

Within an injection molding cycle, the plasticizing unit is required to master not only the metering operation but also the injection process, operating with a high level of precision and a similarly high reproducibility. More than 80 % of injection molding machines are equipped with an annular non-return valve at the screw tip to this end. A moving locking ring within this assembly is designed to prevent plasticized melt from flowing out of the space in front of the screw and back into the screw flight. On the standard design, the movement is governed solely by the flow conditions prevailing around the locking ring. While a high pressure loss over the locking ring promotes the closing movement of the ring, it also reduces the conveying capacity of the screws.

Achieving rapid closing behavior with a high conveying capacity at the same time essentially imposes contradicting design requirements on the non-return valve. In other words, a practicable geometry for the annular return valve can only be worked out by reaching a compromise between low pressure requirements and good closing behavior. Since these properties are also conditioned to a large extent by the process parameters selected and the properties of the plastic being processed, a working group at the KTP Institute of Plastics Engineering at the University of Paderborn, Germany, has now, for the first time, developed a computation method for optimizing the geometry of the locking ring and has implemented this in the PSI (Paderborn Injection Molding Simulation) software.

Modeling the Movements of the Locking Ring

The calculation with the PSI software is based on an axial division of the screw into small intervals, for which simplifying assumptions can be made [1]. This principle is similarly employed for describing the non-return valve. Simplifying assumptions permit a largely analytical description of the melt flow. In view of the similar flow case, it is possible to employ the pressure/throughput relationships that are normally used for mold design [2, 3].

These relationships are not, however, sufficient for describing the flow during

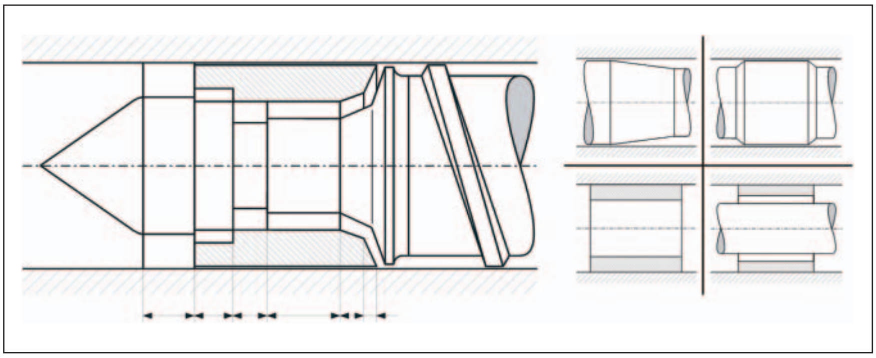

Fig. 1. The geometry of the annular non-return valve is divided up into elements comprising conical and cylindrical shear sections, as well as into pipe and annular gap segments

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the metering process, since the rotational and translational movement of the screw is superimposed on the drag and pressure flow. In this case, the non-Newtonian flow behavior of the plastic melts requires a coupled solution of the conservation laws used to derive the equations for describing the flow. Since the part is geometrically divided up into small sections of constant dimensions (Fig. 1), equations for cylindrical and conical shearing sections can be employed here [4, 5].

After calculating the melt flow, it is possible to draw up an equilibrium of forces and a moment equilibrium for the locking ring on the basis of the pressure differentials prevailing upstream and downstream of the locking ring and the shear stresses acting on the locking ring surface with melt flowing over it (Fig. 2). Solving these balances makes it possible to describe the movements of the locking ring.

The continuously-changing flow cross-section alone shows that it is necessary for the calculation to be implemented in a simulation program. Because of the interaction of the annular non-return valve with the remainder of the screw geometry, its mode of operation is conditioned by the prevailing melt flow. The program additionally tailors the calculation sequence to the geometric situation. It conducts a check, for example, to establish whether the pressure differential between the positions upstream and downstream of the locking ring generates a pressure flow in the gap between the locking ring and the cylinder. If this is not the case, a pure drag flow is taken into account for the calculation; otherwise allowance is made for a superimposed drag and pressure flow.

Phenomenological Investigations

A test stand with an acrylic glass cylinder was constructed for purposes of validating the movements of the locking ring. Working on the basis of optical film evaluation (Fig. 3), it proved possible to derive assumptions for the calculation run, to the effect, among other things, that the locking ring only starts rotating once the maximum opening displacement has been achieved. The time that elapses during the opening and closing of the locking device was established on the basis of the image sequence. An investigation of different locking ring geometries showed the major extent to which the individual geometry parameters influence the closing behavior. The strongest influence is exerted by the outside diameter of the locking ring. When this diameter is reduced (as a result of wear, for instance) this considerably impairs the closing behavior.

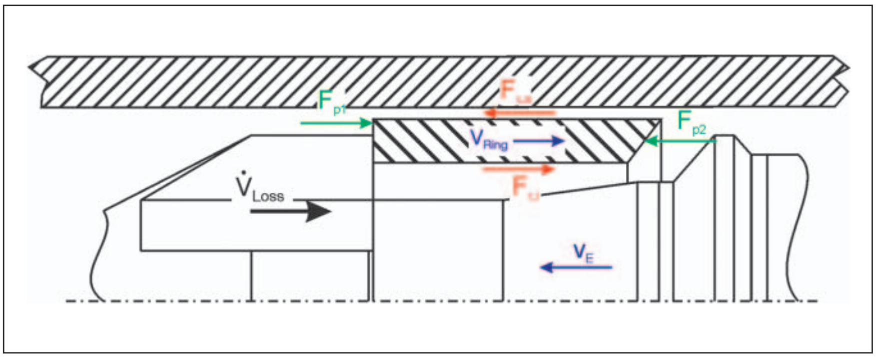


Fig. 2. An equilibrium of forces prevails at the start of the injection phase (compressive forces on ends F_{p1} and F_{p2} / shear stresses on shell surfaces $F_{\tau,a}$ and $F_{\tau,i}$)

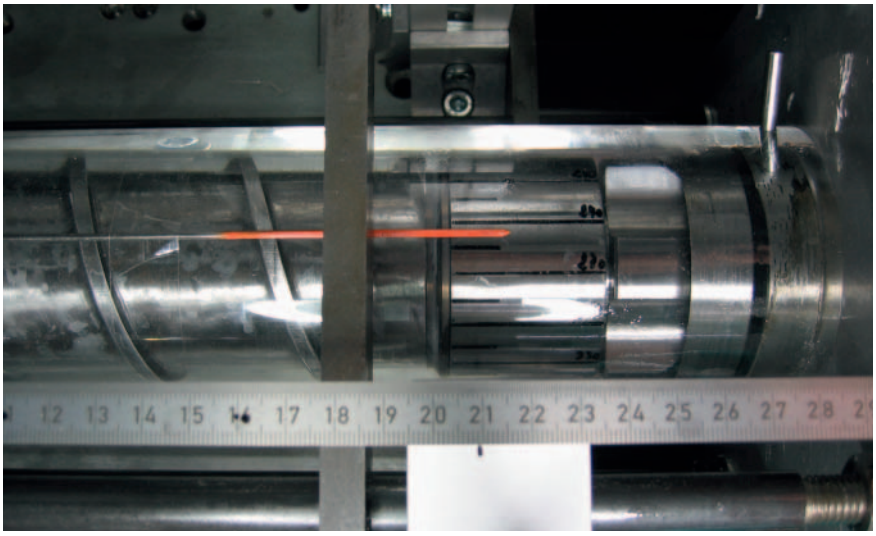


Fig. 3. The test stand with an acrylic glass cylinder is used for the optical analysis of locking ring movements

Software-engineering Implementation

For the simulation of the locking ring movements, it is necessary to know the geometry parameters of the non-return valve (Fig. 4). The geometry input is divided into the four elements of pressure ring, the central parts beneath the locking ring, the tip of the locking device and the locking ring. The system then displays the flow cross-sections that result from this. The user is subsequently in a position to conduct a rapid check on their inputs and to estimate how far the flow cross-section has been reduced by comparison to the preceding screw zone. The value is a key characteristic in the standard approach adopted to the layout of the non-return valve geometry on the basis of empirical knowledge.

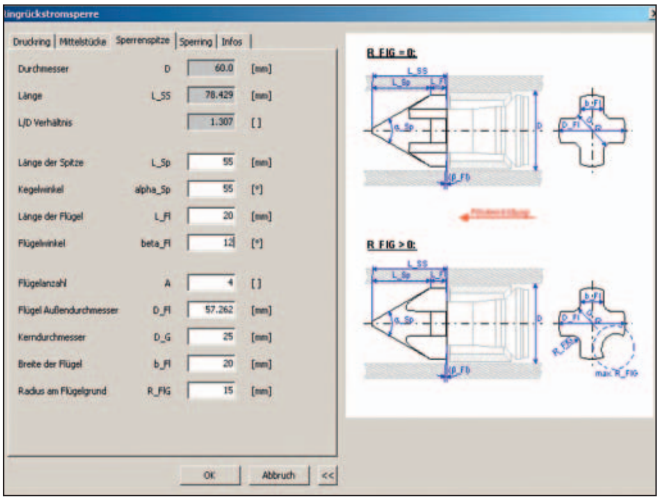
Once the calculation has been completed, the results graph outputs the following (Fig. 5)

- the development in the throughput over the metering path,
- the rotational velocity of the locking ring over the coefficient of friction between the locking ring and the blades of the locking device tip and
- the position of the screw and locking ring over time.

For the metering phase, the outputs also include the numerical values calculated for the

- opening time,
- opening speed,
- contact pressure between the locking ring and the blades of the locking device tip,
- angular speed for the given coefficient of friction.

Since it is difficult to determine the coefficient of friction and this is generally done on an empirical basis by the software user, the correlation between the angular speed and the coefficient of friction is similarly presented in graphic terms. ▶

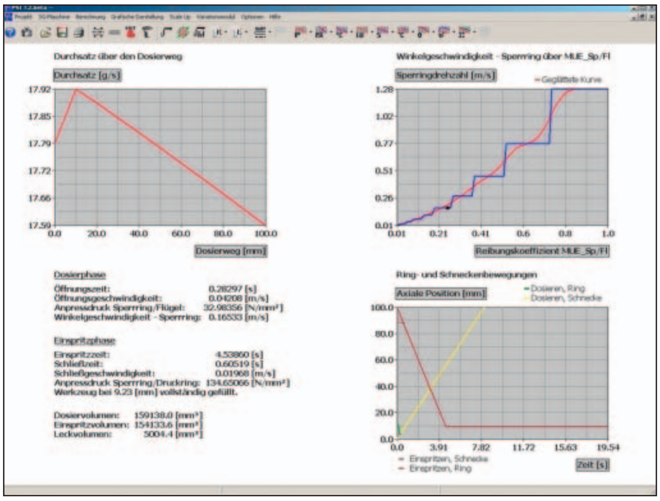


Ringrückstromsperre

Druckring | Mittelstücke | Sperrenspitze | Sperring | Infos

Durchmesser	D	60.0	[mm]
Länge	L_SS	78.429	[mm]
L/D Verhältnis		1.307	[ ]
Länge der Spitze	L_Sp	55	[mm]
Kegelwinkel	alpha_Sp	55	[°]
Länge der Flügel	L_Fl	20	[mm]
Flügelwinkel	beta_Fl	12	[°]
Flügelanzahl	A	4	[ ]
Flügel Außendurchmesser	D_Fl	57.262	[mm]
Kerndurchmesser	D_G	25	[mm]
Breite der Flügel	b_Fl	20	[mm]
Radius am Flügelgrund	R_FlG	15	[mm]

Fig. 4. The input mask for the annular non-return valve geometry is divided into four elements



Dosierphase
Öffnungszeit: 0.28297 [s]
Öffnungsgeschwindigkeit: 0.04208 [m/s]
Anpressdruck Sperrring/Flügel: 32.98356 [N/mm²]
Winkelgeschwindigkeit - Sperrring: 0.16533 [m/s]

Einspritzphase
Einspritzzeit: 4.53860 [s]
Schließzeit: 0.60519 [s]
Schließgeschwindigkeit: 0.01968 [m/s]
Anpressdruck Sperrring/Druckring: 134.65066 [N/mm²]
Werkzeug bei 9.23 [mm] vollständig gefüllt.

Dosiervolumen: 159138.0 [mm³]
Einspritzvolumen: 154133.6 [mm³]
Leckvolumen: 5004.4 [mm³]

Fig. 5. The graph shows the result of the calculation of the locking ring movement

For the injection phase, the following results are set out:

- Injection time,
- Closing time,
- Closing speed,
- Contact pressure between the locking ring and the pressure ring,
- Screw position at the time the die is completely full.

In addition to this, the user is provided with the metering, injection and leakage volume. The latter is the volume of melt that flows back into the screw channel during the injection and holding pressure phase.

These extended calculation options mean that it is now not only possible to allow for the pressure loss in the non-return valve geometry during the metering phase but also to analyze the actual locking function in relation to the process parameters, the properties of the plastic to be processed and the screw geometry. On this point, the wear behavior of the non-return valve is also of great interest, since this has to be regularly replaced, being a part that becomes worn down.

In view of the complex correlations that prevail between different wear mechanisms, it is not yet possible to derive a specific calculation for the wear here [6]. The values for the individual contact pressures and the rotational velocity of the locking ring do, however, permit comparative statements to be made on known geometries and thus allow the user to estimate whether the new geometry will display improved wear behavior. This calculation also offers an additional advantage for the layout of special geometries, if a converter is producing just one specific product, without any change of material, and wishes to employ a specially-tailored geometry for this. ■

Institute

Institut für Kunststofftechnik
Universität Paderborn
Warburger Straße 100
D-33098 Paderborn
Germany
Tel. +49/52 51/60-2451
Fax +49/52 51/60-3821
www.ktpweb.de

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THE AUTHORS

EM. PROF. DR.-ING. HELMUT POTENTE, born in 1939, has been Head of the KTP Institute of Plastics Engineering at the University of Paderborn since 1980.

DR.-ING. HANS-PETER HEIM, born in 1967, has been Managing Partner of 3PI Management & Consulting GmbH, Paderborn, Germany, since 2003, and Managing Director of the plastics engineering sponsors' association, Verein zur Förderung der Kunststofftechnik e.V., since 2004. Since September 2004 he has been acting Head of the KTP, together with Prof. Dr.-Ing. Potente.

DIPL.-ING. THORSTEN THÜMEN, born in 1975, was in charge of single-screw and non-return valve optimization at the KTP. Since April 2007 he has been with injection molding machine manufacturer, Ferromatik Milacron, where he is responsible for the optimization of plasticizing units in process engineering terms.

Contact: ktp@ktp.upb.de