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New plasticising process for increased precision and reduced residence times in injection moulding of micro parts

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A B S T R A C T

Plastic components for current applications in microsystems technology are becoming increasingly complex. At the same time the dimensions of these components decrease. A precise process control is essential for a constant high quality in injection moulding of these components.

Since especially small shot weights can be difficult to realise with standard injection moulding, a series of special machines have been developed in the course of recent decades, which allow the processing of even the smallest amounts of melt in the milligram range.

This paper describes the design, development and commissioning of an alternative plasticising unit for micro injection moulding. In the first step, the geometry of the so-called *Inverse screw* is designed and a test rig for plasticising trials is developed. After optimising the geometry based on experimental tests different concepts for non-return valves are designed and tested for their closing performance. Finally, the concept is transferred to a micro injection moulding machine and the applicability in practical investigations is demonstrated.

Introduction

Microsystems technology is one of the key technologies of the 21st century which deals with the integration of different procedures into the smallest possible space. Many of today's consumer products can only be realised by the appropriate combination of different complex microsystems. The consistent further development of these systems, which are characterised by an increasing functional integration, is only possible through innovative combinations of materials as well as by new manufacturing processes. Therefore thermoplastics play an increasingly important role, particularly in the field of micro-fluidics, micro-optics and as components for medical devices [1,2].

But also the increasing demand for components for micro-systems and the general trend towards shorter life cycles leads to an increased use of plastics and their economic manufacturing processes suitable for series production, such as hot embossing, pressing, stereolithography or injection moulding [3,4].

Against this background micro injection moulding is one of the most important methods for the production of thermoplastic micro parts. Once an injection mould has been build, fabrication costs of moulded micro parts are hardly affected by the complexity of the design and due to the low costs of the raw material and the small required material quantities. The manufacturing process enables fully automated mass production of large numbers while the produced components require almost no secondary finishing or assembly processing and show sufficiently good dimensional fidelity [5].

Classification of micro parts

Until today there is no defined differentiation between standard and micro injection moulding. However, it is important to differentiate the various micro components in order to adapt the production process and mould technology on the specific requirements of the particular micro component. Therefore the classification results based on the components to be produced [3,6,7]:

- Components with macroscopically large dimensions and masses >10 g with microstructures of low aspect ratios (AR, ratio of structural depth to width), e.g. DVD, BD.
- Microstructured parts with masses between 0.1 and 10 g and surface structures with high AR, e.g. micro-spectrometers or lab-on-a-chip.
- Micro precision components with arbitrary geometry and masses >5 g with local details of small dimensional tolerances <2 μm, e.g. connectors for fibre optics.

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- Singular micro parts with minimum component dimensions and masses below 0.1 g and high AR, e.g. micro gears or micro ball bearings.

Depending on the type of micro component in regard to their various moulding masses, aspect ratios and overall tolerances different requirements needs to be taken into account for their production. While components of the first three groups can be manufactured with common injection moulding machines in combination with adaptions of the mould technology (e.g. variothermal processing), the manufacture of micro parts according to the fourth group often reaches the limits of standard injection moulding machines with regard to the material specific processing of small quantities of melt.

Injection moulding of micro parts

In order to achieve high manufacturing reproducibility at the injection moulding of micro parts an excellent process control is needed. Furthermore, for an economic production the amount of melt has to be minimised to reduce the residence time and therefore the risk of thermal degradation of the material. Both aspects directly result from the design of the plasticising unit and are insufficiently taken into account when conventional injection moulding machines are used for the production of micro components.

To realise a reproducible acceleration of the commonly used three-section-screw and the melt, the injection stroke should be within 1–3 D (D = screw diameter) [8]. At the same time the flight depth's geometry of the screw needs to allow the processing of standard granules which results in a smallest possible screw diameter of 14 mm. Even with short injection strokes of 1 D dosing volumes of over 2000 mm^3 are generated. Further reductions of the shot volume without reducing the process reproducibility cannot be achieved [5,9]. As a consequence more and more different production strategies for the manufacturing of polymer micro parts have to be developed and explored [10].

Micro injection moulding machines

Today, special micro injection moulding machinery which is adapted to the boundary conditions of the production of thermoplastic micro parts is state of the art. The most important feature of these systems is to reduce the minimal reproducible dosing and injection volume. By a more precise positioning and better process control, the overall melt volume can be significantly reduced. Thus, the cycle times are shortened and a potential material degradation counteracted. In summary, the following requirements on the machine technology for the production of thermoplastic micro parts can be defined [11]:

- Small-sized injection units to minimise residence times of the melt and to achieve accurate injection.
- Robust construction with high mounting platen parallelism.
- High and accurate resolution of the position measurement systems.
- Exact high-resolution and high dynamic drive technology.
- Interfaces and space for handling and monitoring.

These so-called micro injection moulding machines no longer use three-section-screws for the plasticising. The reduction of the melt volume is achieved by the separation of the two functions plasticising/homogenising and injection. Currently on the market are variations of two basic machine concepts with altered plasticising mechanism: the combined screw plunger injection moulding machine and the two-stage plunger injection moulding machine (Fig. 1).

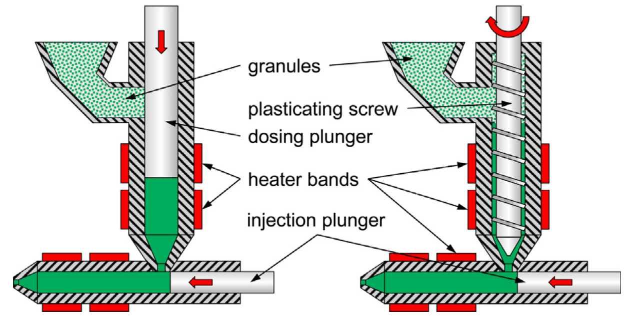

Fig. 1. Basic concepts of micro injection moulding machines: two-stage plunger (left) and combined screw plunger (right).

Both feature in addition to the significant reduction of the shot volume high precision injection through an injection plunger with a significantly reduced diameter and the principle of 'first in, first out'. The screw plunger injection moulding machines also provide good thermal and material homogenisation which is beneficial for the plasticising, whereas two-stage plunger systems provide even smaller possible shot weights. Disadvantageous however is the already from the beginning of injection moulding known leakage of plunger injection systems, lack of thermal uniformity and poor mixing of the material [12,13].

Further approaches for the production of micro injection moulded parts are currently in developmental stage. An example for the deployment of very small shot volumes is the plasticising using ultrasound in combination with a plunger injection. In this method, the physical properties of thermoplastic polymers – the conversion of mechanical vibration stresses into heat due to internal damping and external friction – is used. Thereby only the smallest amount of material is melted which is required for one production cycle. This makes it ideal for expensive, thermally sensitive materials such as absorbable resins which are used in medical technology [14,15].

The *expansion injection moulding* (EIM) by cavity near melt compression, which realises the filling of the cavity by the expansion of the previously compressed melt, promises extremely high volume flows and an accurate impression of complex geometries and details with high flow path/wall thickness ratios. The cavity near compression is achieved by a mould equipped with a hot runner shut-off nozzle. The design of the hot runner allows compressing the polymer melt with a screw stroke while the needle is closed. During melt expansion the valve allows the expansion of the melt into the cavity and ensures a closure of the mould in the direction of the screw at the same time [16,17].

Plasticising using the *Inverse screw*

Concept

An entirely new approach for the processing of small melt amounts is explored at the Institute of Plastics Processing (IKV) at RWTH Aachen University in cooperation with Arburg GmbH + Co. KG, Loßburg, Germany.

The so-called *Inverse screw* is characterised by its internal structure. The screw flights for the melt conveyance are part of the cylinder's geometry. This allows on the one hand achieving a sufficient depth in the feed zone for the processing of standard granules, but on the other hand reducing the diameter of the injection plunger, which is located coaxially within the cylinder, at the same time.

Through this approach the good melting and homogenising of a screw plasticising can be combined with the high precision of an