Requirements for Injection molding machines
Introduction

1. Features of thin-walled packaging containers
   - Markets and applications
   - Classification
   - Typical materials
   - Quality requirements
   - Mould-related requirements
   - Requirements for automation
   - Enhanced function integration for packaging containers

2. Sequence of operations and process control
   - Times and speeds
   - Calculation of cooling time
   - Pressure profile
   - Temperatures

3. Machine-related requirements
   - Clamping unit
     - Main functions of clamping unit
     - Ancillary functions of clamping unit
     - Dimensioning the clamping platens to suit requirements
     - Reinforced machine frame
     - Kinematics of toggle clamp
     - Sensitive and effective mould protection system
   - Injection unit
     - Mechanical design
     - Injection accumulator and servo-valve
     - Melt preparation and homogenization
     - Barrier screw
     - Melt residence time
   - Drive concept and function sequences
     - The “Elexis S” drive concept
     - Parallel function sequences in main and auxiliary axes
     - Machine hour rates due to reduced energy consumption
4. Economics

Assessment of prorated costs of production
Comparison of economics

Conclusions
**Introduction**

In order to produce injection-molded, thin-walled packaging containers economically in an increasingly competitive market, molders are compelled to proceed in strict observation of the cost factors in designing the products to be molded. In order to save raw material, the trend is towards ever thinner wall thicknesses which in the production phase create special requirements to be fulfilled by the injection-molding machine and the production environment. Injection-molding systems that are custom-designed for a specific application form the basis of economical production. The objective of the present article is to review how far modern injection-molding machines and their drive concepts are capable of meeting the process requirements associated with the production of packaging containers.

1. **Features of thin-walled packaging containers**

1.1. **Markets and applications**

Thin-walled, injection-molded packaging containers have application as:

- Food containers (Cups, boxes, pails, etc. for dairy products,
margarine, ice-cream…)

- Catering products (drinking cups, plastic tableware…)
- Hygienic articles (boxes for moist wipes…)
- Containers for paints and oil (buckets…)
- Gardening articles (planting pots…)

1.2. Classification

Thin-walled, injection-molded packaging usually takes the form of hollow bodies which, open at one end of a wide variety of shapes, are suitable for either disposable or reusable containers. Typically, such moldings have wall thicknesses ranging between 0.3 and 1.5 mm in conjunction with very high flow-distance/wall-thickness ratios of up to 400:1.

Economical injection molding of thin-walled packaging containers depends on short cycle times and minimum material usage. The designer’s primary concern in developing thin-walled containers therefore is to reduce their wall thicknesses while meeting all durability specifications.

1.3. Typical material

Injection-molded packaging containers are mostly molded in polyethylene (PE), polypropylene (PP) and polystyrene (PS). Whereas modified or specially compounded standard plastics (HIPS, m-PP…) are also frequently used, engineering plastics will be encountered only in exceptional cases.

Generally, the injection molding of thin-wall containers calls for high flow ability coupled with a high toughness and stiffness as well as close molecular weight distribution. Materials that can be used for high performance injection molding include types with melt flow indices (MFI) from 40 -50g/10min (230°C/2.16kg), and, in special cases, of up to 150g/10min. The formulation should be optimized for high-performance injection molding. Frequently, the materials used are stabilized, mixed with nucleating agents and lubricants as well as antistatic. The melt indices of these materials come within a very
narrow tolerance range. Were in contact with food, additional considerations include protective properties and non-toxicity.

1.4. Quality requirements

While thin-walled packaging containers more often than not are short-lived and generally little valued products, there are a great number of quality requirements to be met, including some rather complex ones:

- Uniform wall thickness distribution,
- Minimal warpage
- High stiffness at elevated temperatures (due to fast demolding during production or stressing when filling hot food or during sterilization),
- Good stacking and lateral pressure strength,
- High surface finish,
- Homogeneous color distribution or, conversely, uniformly high transparency,
- High weight consistency (Delta g: 0.5 to 1%).

1.5. Mould-related requirements

The high quality requirements for thin-walled injection moldings can be fulfilled only by optimum combination of material, machine, mould, and process control. Therefore, it is important that deficiencies in part design and mould imperfections should be avoided from the start. The mould should provide:

- High stability and minimum deflection,
- Surfaces, partially coated if necessary, that facilitate demolding,
- Hydraulically operated compressed-air-assisted demolding,
- Effective mould cooling, i.e. temperature control with high flow rates and low pressure loss,
- Minimum-maintenance guiding and centering elements,
- Minimum differences in degrees of filling.

In the case of some moldings, the use of stack moulds should be
considered for economic reasons. Injection via hot runner system is state of the art.

1.6. Requirements for automation

Orderly removal of thin-walled packaging containers from the injection-molding machine is an important consideration in designing the production system. A factor to be considered is that thin-walled parts are liable to be damaged by unsuitable removal equipment or drop-in-the-box type unloading, and that costly provisions may be necessary for alignment, orientation, stacking, and collective packing.

Medium-sized and larger-size moldings (Cups, trays, pails) are usually removed from the mould by means of fast unloading systems. Modern parts handing equipment and robots are capable of unloading cycles as short as 0.4s.

1.7. Enhanced function integration on packaging containers

The function of modern packing is not only one of protecting the product but it also forms an element in the logistics chain and serves as a marketing instrument in its own right. This goes together with enhanced integration of functions into the packaging. The techniques adopted range from decoration, e.g. by means of in mould labeling (IML), through subsequent finishing (by hot embossing or similar techniques) to the application of handles, etc.
2. Sequence of operations and process control

Planting pot (Ø193mm)

<table>
<thead>
<tr>
<th>Machine:</th>
<th>Ergotech 200/630-840 EL-EXIS S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw:</td>
<td>Ø 45 mm (A) L/D - Verh.: 25 : 1</td>
</tr>
<tr>
<td>Mould:</td>
<td>- fach</td>
</tr>
<tr>
<td>Application:</td>
<td>Pflanztopf</td>
</tr>
<tr>
<td>Diameter:</td>
<td>1 - fach</td>
</tr>
<tr>
<td>Height:</td>
<td>Mauerhöhe: 193 mm</td>
</tr>
<tr>
<td>Wall thickness:</td>
<td>136 mm</td>
</tr>
<tr>
<td>Flow path:</td>
<td>144 mm</td>
</tr>
<tr>
<td>Flow path/ Wall thickness ratio:</td>
<td>320:1</td>
</tr>
<tr>
<td>Proj. area:</td>
<td>293 cm²</td>
</tr>
<tr>
<td>Material:</td>
<td>PP, MFI 35 g/10min (190°/2,16kg)</td>
</tr>
<tr>
<td>Shot weight:</td>
<td>33.5 g</td>
</tr>
<tr>
<td>Cycle time:</td>
<td>0.12 s Injection time</td>
</tr>
<tr>
<td></td>
<td>0.25 s Holding time</td>
</tr>
<tr>
<td></td>
<td>0.80 s Cooling time</td>
</tr>
<tr>
<td></td>
<td>0.10 s Pause time (Handling time)</td>
</tr>
<tr>
<td></td>
<td>1.42 s Machine time (330 mm)</td>
</tr>
<tr>
<td></td>
<td>2.69 s Cycle time</td>
</tr>
</tbody>
</table>

Fig.2: “Planting pot” application

The following application example will be used to analyse the process sequences in the injection molding of thin-walled packaging containers in greater detail. The application involves a planting pot made from polypropylene with a flow distance/wall thickness ratio of 320:1. Unusual for the fabrication of packaging containers, the single-cavity mold was fitted with two pressure sensors in order to permit the pressure level in the cavity to be determined.

Before proceeding to description of the pressure situation, let us have a look at the cycle sequence for this application.
Fig. 3: Cycle sequence for application “Planting pot”

2.1. Times and speeds

The cycle time in injection molding is made up of the following main times:

- Process times (injection, hold pressure, cooling),
- Machine times (mould movement, ejection, nozzle movement),
- Pause time or removal time.

Generally, the process times and, in particular the cooling times, account for the major part of the total cycle time. Apart from specific material properties, the cooling time depends primarily on the wall thickness of the molding, mold wall temperature, and the melt temperature, the cooling time varying as the square of the wall thickness.

<table>
<thead>
<tr>
<th>Step</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle time</td>
<td>2.69</td>
</tr>
<tr>
<td>Ejector</td>
<td>0.33</td>
</tr>
<tr>
<td>Mould open</td>
<td>0.69</td>
</tr>
<tr>
<td>Dosage</td>
<td>1.20</td>
</tr>
<tr>
<td>Cooling time</td>
<td>0.80</td>
</tr>
<tr>
<td>Holding pressure</td>
<td>0.25</td>
</tr>
<tr>
<td>Injection</td>
<td>0.12</td>
</tr>
<tr>
<td>Nozzle protection</td>
<td>0.10</td>
</tr>
<tr>
<td>Mould shut</td>
<td>0.73</td>
</tr>
</tbody>
</table>
Cooling time as a function of wall thickness

Fig. 4: Cooling time as a function of wall thickness

2.2. Calculation of cooling time

For a given material (e.g. PP) and a constant mean mould wall temperature, the relationship between the wall thickness and the cooling time is illustrated by the plot in Fig. 4. Wall thicknesses of thin-walled containers are generally less than 1.5mm and sometimes, depending on the particular application, may be as thin as 0.3mm. This means that in the case of polyolefin cooling times may well be less than 1 second. Total cycle time obtained in molding cups and small containers may be between 3 and 4 s. If, apart from the cooling time within the cycle time, there will remain only a few tenths of a second for the process phases injection and hold pressure.

Under conditions of thin wall thicknesses, long flow lengths, and extremely low mould wall temperatures, the plastic will not remain flowable and molten indefinitely to control the packing of the cavities and shrinkage in the holding pressure phase. Therefore, it is necessary when molding thin-walled containers to use very high injection speeds of up to 1,000mm/s (set value). Moreover, on account of the freezing behavior of the melt, it is absolutely necessary to provide for appropriate acceleration of the screw at the beginning of the injection process.

Demag Plastics Machinery (Ningbo) Co., Ltd.
德马格塑料机械（宁波）有限公司

Add.: No.669, Kunlunshan Road, Beilun District, Ningbo, 315800, Zhejiang Province, P.R.China
地址：浙江省宁波市北仑区昆仑山路669号
邮编：315800
Tel: +86-574-8618 1500
Fax: +86-574-8618 1518
E-mail: stephan.greif@dpg.com

Demag Plastics Machinery (Ningbo) Co., Ltd.
Shanghai Branch
德马格塑料机械（宁波）有限公司上海分公司

Add: 6/F Gienkee Plas Center, No.1221 Hami Road, Shanghai 200335, P.R.China
地址：上海市哈密路1221号锦珂塑胶中心6楼
邮编：200335
Tel: +86-21-5219 5000
Fax: +86-21-5219 6250
E-mail: shanghai@demag-ergotech.com.cn
Due to the high injection speeds for molding thin-walled containers with a high flow-distance/ wall-thickness ratio, correspondingly high injection and cavity pressures have to be reckoned with.

2.3. Pressure profile

The pressure profile obtained in molding the planting pot with a wall thickness of 0.45mm bears out the high injection pressure required of approx.1,500 bar. The interpretation of the pressure plot also shows that the maximum cavity pressure in the injection phase occurs after 0.18s. The holding pressure phase of 0.25s has only little influence on the molding of the part because the melt is already solidified. The melt is compacted only near the gate in the bottom area of the molding as the cavity pressure continues to drop until the gate has been sealed.

Studies undertaken with the single-cavity mould for making planting pot provided information on the pressure propagation during the molding process. The pressure, measured at a point close to the gate and at another point away from the gate permits conclusions to be drawn regarding the pressure drop over the flow path.

If the pressure drop is plotted over the melt path, it will be noticed that considerable pressure losses occur during the injection phase already in the machine nozzle and in the hot runner system. This means that, depending on the specific application, it is necessary to provide injection barrels with injection pressures of up to 2,400 bar, in individual cases even as high as 3,000 bar, in order to obtain a sufficiently high pressure in the mould.

Injection pressure as a function of injection time

[Diagram of injection pressure as a function of injection time]

Optimum Area
Fig. 7: Injection pressure as a function of injection time

Studies made to determine the injection pressure required as a function of the injection time have shown that, in the particular example, the required pressure passes through a minimum at 0.14s. A minimal injection pressure makes for a low pressure level in the mould and, consequently, reduced likelihood of over-pack even where the machine is operated at the hold pressure limit. Moreover, less shear is liable to occur in the melt during mould fill and, consequently, a better part quality is obtainable.

The requirements in respect of injection pressure and injection speed when molding thin-walled containers bear out the need to provide a machine with a suitable high injection capacity.

In order to optimize the process parameter injection speed, it is indispensable to use a servo-valve that is capable of precise switching and, consequently, repaid response as well as a non-return valve designed to provide highly accurate closing. Aside from the wellknown three-part non-return valves consisting of screw tip, check ring and seat, ball-type non-return valves are finding application to improve the closing behavior.

Pressure profile at high injection speed with and without stepping

Fig. 8: Pressure profile at high injection speed with and without stepping.
Repaid-action servo-valves are the basis for controlled injection speed and permit stepping even where injection times are very short. By braking the screw before the transfer point is reached, it is possible to prevent pressure peaks in the mould and, consequently, over-pack. In addition, improved injection time consistency is obtained as an essential parameter for the level of molded part quality to be attained.

2.4. Temperature

**Barrel wall temperatures when processing PP**

The graph shows the bandwidth of the mould wall temperature and the barrel temperature plotted for the material PP. In order to shorten cooling times as much as possible, it is common practice to use water inlet temperatures for mould cooling of 8 to 10 °C at a pressure of 6 to 8 bar.

An L/D ratio of 25:1 allows the temperature level for PP at the heating jacket zones of a screw barrel to be set distinctly lower at 240 to 245 °C than an L/D ratio of 20:1. Also it is possible – with melt quality unchanged – to select a melt temperature in the space ahead of the screw much lower at 255 to 260 °C than an L/D ratio of 20:1 (265 to 280 °C) would
permit. Lower melt temperatures result in shorter hold pressure and cooling times. The temperature variations found for screw barrels with an L/D ratio of 25:1 were in a range of about 5 ºC, whereas the range determined for screw barrels with an L/D ratio of 20:1 was about 15 ºC. Small temperature differences in the melt make for smaller shrinkage differences during the molding process and, consequently, minimize warpage in the molded product.

3. Machine-related requirements

The essential elements of the injection-molding machine are the clamping unit and the injection unit. These will be discussed in the following both regarding the special design features necessary for thin-wall molding and regarding such aspects as drive technology, function and process sequences.

3.1. Clamping unit

Clamping unit with stack-mould

3.1.1. Main functions of clamping unit

The clamping unit of an injection-molding machine provides the following main functions:
3.1.2. Ancillary functions of clamping unit

- Eject the molded parts,
- Protect the mould.

The clear distance between tie bars, mould installation height, maximum opening stroke, and rated clamping force are the key features of a clamping unit. Conventionally, injection-molding machines are classified according to their rated clamping force.

![Diagram of clamping force and locking force](image)

**Fig. 11: Clamping force / locking force**

In closing and locking a toggle-type “form-locking” system, the entire mechanism, including the clamping unit (tie bars, toggle links, platens), and the mould are subject to deformation in the elastic range which can...
be described by means of various spring constants. While the tie bars are subject to extension, the toggle links, platens, and the mould are subject to compression. The clamping force applied describes the state of the rest of the clamping unit with the mould closed.

During injection of the plastic melt, a pressure profile builds up over the injection and holding pressure times due to the flow resistances in the mould. Short-time pressure peaks may attain values of up to 2000 bar near gate. The mould is required to withstand this pressure without the elements of the mould that impart the shape of the molded piece changing their position and alignment.

Mould base plates, intermediate plates and parts that do not impart shape continue to be compressed whereas the mould plates with the shape-imparting parts are relieved. Relief of these mould parts is tantamount to an elongation of the mould which is compensated by continued tie bar extension. Only under conditions of full relief of the mould halves will overpacking tend to occur.

Depending on mould stiffness, a toggle-type machine provides the benefit of a reserve locking force is an asset in particular with thin-walled containers where operation is frequently near the locking force limit.

3.1.3. Dimensioning the clamping platens to suit requirements

Bending stiffness of clamping platens

Fig.12: Bending stiffness of clamping platens
The sum of all forces acting in the opening direction (including proportionate force components due to slide locks) multiplied by the projected area of the molded part result in a buoyancy force of the platens which needs to be kept at a minimum.

Since – as already mentioned – very high cavity pressures are liable to occur in the molding of thin-walled containers, it is necessary to upgrade the dimensioning of the platens accordingly. Platens according to Euromap recommendations have a relatively large centering diameter which allows a degree of deflection that is not acceptable in this area. This can be observed on molded parts that appear to be partially overpacked although no mould breathing was noticeable between the platens. Here the cavity frequently coincides with the centering area where conventional platens are weakened by the centering hole.

With a view to minimizing deflection in centring area, fast-cycling machines for thin-walled containers are provided with smaller centring diameters. In addition, the cutouts for ejector penetrations and/or injection cylinders are kept small.

According to Euromap 62, platen deflections are measured between 10 and 100% of clamping force. Defined test blocks are prescribed for this purpose depending on the clearance between tie bars. The permissible deflection in a conventional injection-molding machine with a clamping force of 2500 KN and a distance between tie bars of 630 mm is 0.15mm for a test block diameter of 400mm. If suitably dimensioned, cast-steel platens permit values of platen deflection due to the clamping force of less than 0.03mm. This is a prime requirement for mould fill in the case of thin-wall containers without core displacement occurring.

Another aspect that is critical to the efficiency of moulding is to maintain parallelism of the two platens. Careful selection of the points where the onnecting rods are hinged to the moving platen and the resulting force application is necessary to ards maintain plane-parallel distances between the mould halves under all operating conditions and ensure minimum wear of the guiding and centering systems in the mould.
3.1.4. Reinforced machine frame

Some multi-cavity moulds for thin-walled containers are extremely heavy. This applies in particular to stack moulds.

Where heavy moulds are frequently used in fast-cycling applications, the machine is designed with a suitably reinforced frame. In modern fast-cycling machines (Such as the Ergotech Elexis S), the weight of the moving platen plus the proportionate weight of the ejector-side half of the mould are absorbed by I-beams integrated in machine frame. To transmit the load, the moving platen is fitted with a roller bearing that is adjustable for height and guided on rails connected to the I-beams.

In order to avoid additional loading of the tiebars where stack moulds are used, it is possible to support the moving centre plate of such a mould on the same guide rails.

3.1.5. Kinematics of toggle clamp

Fig.13: Speed vs. mould position

A clamping unit required to provide a speed profile that meets mould requirements. If correctly designed, the toggle provides a curve-shaped speed profile in conformance with process requirements and controlled by the kinematics of the toggle: It provides for gradual and jerk-free starting, fast speed over the travel distance, and slowdown on entering the mould opening stroke is reached, the speed has reduced to almost zero. The inertia profile is inversely proportional: In the locking range, it
permits optimal conversion of speed into force. In the locked condition, the clamping system is self-jamming and requires no supply of energy.

The attainable mean speeds of the moving platens allow short machine times to be obtained, depending on the size of the clamping unit. A machine with a clamping force of 2500KN will attain a mean travel speed of 0.8m/s. This, in turn, is an important precondition for short cycle times when producing thin-wall containers.

![Diagram of clamping force and speed vs. mould movements](image)

Fig.14: Variations in force VS. Mould movements

The force profile permitted by the mechanical advantage of the toggle linkage, which can be achieved by means of relatively small closing cylinder, illustrates the potential afford by a hydro-mechanical clamp to reduce the energy consumption.

3.1.6. Sensitive and effective mould protection system
Sensitive and effective mould protection system

![Diagram of mould protection system]

Fig.15: Automatic mould protection

It is common practice today to incorporate automatic systems to protect the mould. Their purpose is to reliably prevent damage to the mould if molded parts should hang up while exiting or incorrectly operated mould slides should block the closing motion. Any such obstacles should be promptly detected and the closing motion stopped before mould damage and, consequently, production interruptions occur.

The Ergotech EL-EXIS family of injection molding machines features a particularly effective mould protection system: A piezo-resistive sensor, fitted directly on the connecting rod of the toggle at the rear of the moving platen and a high-resolution measuring system detect even minimal extensions or compressions that occur during mould movement. Minimal variations in the force profile caused by a hang-up part or loss of lubrication of the mould-guiding systems are converted into an electrical signal and thereby supervised.

The machine records the force necessary to move the clamping through a normal cycle by means of a force sensor and stores it as a master curve in the machine controller. During every production cycle, the controller compares the actual force variation against this master curve. If there is any significant deviation of the actual values from the master curve, the closing motion will be actively stopped.
The protective function is not limited to the mould approach range (just before the mould halves contact). The system will detect obstacles over the full opening stroke and during the whole movement of the clamping unit. Since the use of the protective function with active braking of mould movements does not increase the cycle time, here is a technology that is a main benefit for fast-cycling applications.

3.2. Injection unit

3.2.1 Mechanical design

The production of packaging containers includes applications involving markedly different requirement profiles. Therefore, a certain degree of flexibility is needed with respect to the injection unit.

It should be possible to combine different injection units with a clamping unit. The machine design should be amenable to optimization for specific applications.

The top of the injection should be guided and supported on linear guide systems in order to ensure minimum friction and, thereby, easy movement in an axial direction.

Positioning cylinder for the axial movement of the injection unit and nozzle contact should be in line with the screw barrel in order to ensure non-skewing nozzle contact as well as minimum wear when using extended nozzles and screw bushes.

The mounting arrangement for the screw barrel should be flexible so as to accommodate screws with L/D ratios of 25:1 in two different diameters and with different injection pressures.

A high-resolution stroke-measuring system can be provided for accurate detection of screw positions which, linked up with the machine controller, is another contribution towards optimum process and pressure control.

An electric-motor-operated screw drive is recommendable which, in comparison to the hydraulic operated variant, saves energy and is...
capable of plasticizing in parallel (simultaneously) with the mould movements.

3.2.2. Injection accumulator and servo-valve

![Fig.17: Injection unit with accumulator and servo-valve](image)

As already mentioned, the moulding of thin-walled packaging containers generally calls for high injection rates. In order to permit these necessary injection rates to be achieved, it is necessary to use hydraulic accumulators. It is important that charging of the accumulator is energy-efficient via a variable delivery pump.

Fast-action servo-valves with adjustable control parameters are indispensable as a control element for the injection process in order to maintain a specified injection profile even with short injection times where needed for specific applications.
Important of injection Dynamic

![Diagram showing injection speed versus time for conventional and high dynamic injection]

Conventional injection dynamic  
(a=5 m/s²)  
Set injection speed: 800mm/s  
Realized injection speed: 488mm/s  
Injection time: 205ms

High dynamic injection  
(a=12 m/s²)  
Set injection speed: 800mm/s  
Realized injection speed: 633mm/s  
Injection time: 157ms

Fig.18: Injection response and injection capacity

An important consideration in selecting the injection process for thin-wall containers is the necessary rapid response. Short injection times of 0.1 to 0.2s, depending on the particular application, call for appropriate injection dynamics. Provision must be made to permit the desired injection speed, say 800mm/s, to be started at a suitable rate of acceleration. This means that, as shown in the example, an acceleration of 12m²/s is required in the case of short screw strokes to achieve an actual injection speed of 633 mm/s.

3.2.3. Melt preparation and homogenization

The design of an injection molding machine for the production of thin-wall containers is required to take into account the following process criteria:

- Screw displacement,
- Plasticizing capacity,
- Thermal and optical homogeneity of the melt,
- Residence time of melt in screw barrel,
- Melting efficiency,
- Melt degradation due to shear
Thin-wall packaging containers are mainly made from polyolefin, which are partially crystalline materials. In contrast to amorphous materials, these require a significant higher melting efficiency. The reason is in the large enthalpy difference between, say, PS and PP. In the fast-cycling domain, as higher throughput rates and shorter cycle times are adopted, the residence time of the material in total amount of energy supplied decreases and thermal balancing phenomena for a homogeneous melt quality are restricted. Attempts to increase the screw speed to augment the proportion generated by friction are limited by the maximum permissible peripheral velocity which when exceeded would be liable to cause material degradation.

Options to achieve a sufficiently long residence time with a moderate screw speed include:

- The use of longer screws to increase melt residence time, for instance, three section screw s with an L/D ratio of 25:1 formed with shearing and mixing section s and geometry designed for a high throughput rate,
- Changing the screw geometry to improve the melting process, for instance, by the use of barrel screws,
3.2.4. Barrier screw

In a barrier screw, the compression zone of the 3 – section screw is replaced by a “barrier section”. A second flight is started at the beginning of the barrier section which is undercut below the primary flight to form a gap relative to the cylinder barrel. This design feature separates solids and melts because only fully molten material can pass through the narrow gap into the melt channel. Correct process control provided, a thin melt film forms, and the introduction of heat energy by conduction and friction into the solids is improved. Due to the steeper pitch of the barrier flight, melt will collect in the widening melt channel whereas flight depth and width of the solids channel decrease. The melt efficiency of barrier screws compared to standard 3 – section screws is considerably higher, depending on the type of material. The use of barrier screws enables uniform, intensive and controlled melting to be effected. Special mixing and shearing devices do additional homogenizing jobs, including the addition of colorants.
The influence of the residence time on the plasticizing capacity SC-diameter 60mm, PP

![Diagram showing the influence of melt residence time on plasticizing capacity with PP.](image)

Fig.21: Influence of melt residence time on plasticizing capacity with PP

### 3.2.5 Melt residence time

Where barrier screws are used, it is necessary to consider the influence of the melt residence time on the plasticizing capacity. In the case of PP it has been found that with the cycle and residence times generally applied for thin-wall containers, barrier screws will not result in any noticeable improvement in performance over the three-section screw.

The influence of the residence time on the plasticizing capacity SC-diameter 60mm, PE

![Diagram showing the influence of melt residence time on plasticizing capacity with PE.](image)

Fig.22: Influence of melt residence time on plasticizing capacity with PE
If the material processed is PE, however, there is also a decrease in plasticizing capacity, albeit about 30% above the values obtainable from a three-section screw.

In any case, the barrier screw will produce a better homogenizing effect, especially in applications involving greater shot weights and high material throughput, the upper limit of screw stroke utilization being 50-60%.

In the case of a project study it is necessary at an early stage to have information on process parameters for the design of a plasticizing unit. For this purpose, there are simulation programs available, such as PSI of the Paderborn University. The program is designed to permit the calculation of characteristic variables including:

- Material throughput,
- Metering time,
- Temperature profile,
- Pressure profile,
- Melting profile,
- Residence time behavior, as well as
- Power rating and torque requirements.

A comparison of theoretically calculated values against practical test results revealed deviations of fewer than 15%.

Thus, the engineer is in a position to draw on reasonably correct information in developing the design of injection-molding machines.

### 3.3. Drive concept and function sequences

#### 3.3.1. The EL-Exis S drive concept

Modern mould technology with effective cooling arrangements and thin-wall packaging containers with reduced wall thickness permits ever shorter process times and, consequently, ever shorter cycle times. Depending on the shot weight in the specific application, the cooling time available for plasticizing in sequential operation tends to be insufficient.
In order to avoid having the cycle time extended by the necessary plasticizing time, users are recommended to consider the use of independent drives for the main axes, clamping unit and injection unit.

The new drive concept: Ergotech EL-EXIS S

The combination of electrical and hydraulic drives in injection-molding machines offers an advantage in that key movements, which can be performed independent of each other and, consequently, allow an optimum, or shortest cycle time. In the Ergotech EL-EXIS S high-performance injection-molding machine, both electrical and hydraulic drives are provided, depending on where they are most beneficial to power its movements.

The obvious choice for the rotary movement of the plasticizing unit is a frequency-controlled AC-servo drive. It has a distinctly higher efficiency than a hydraulic motor and, compared with the latter, cuts energy usage by 40%. The rotary movement is characterized by extremely rapid response combined with a high degree of accuracy and very good efficiency.
In the case of injection, what is needed is a large amount of power available on call for a short period of time and independent of other movements. The requirement is for highly dynamic acceleration of the screw to provide a rate of advance of up to 1000mm/s. Since electrical drives are limited to a fraction of this speed, injection is effected by means of a hydraulic accumulator.

Opening and closing the mould involves linear movements so that, in principle, a hydraulic drive would be preferable. But, for high performance duties, a rapid response is called for during acceleration and deceleration as well as a high degree of positioning accuracy, for instance, for fast unloading. This is the reason why the Ergotech EL-EXIS S incorporates a patented electro-hydraulic power pack to operate the toggle: A combination of a frequency-controlled electric motor and a hydrostatic transmission to provide the translation into the hydraulic linear movement.

The three auxiliary movements – core puller movement, ejector and nozzle contact – are linear movements that need not be operated in parallel (simultaneously) and which have no significant influence on energy consumption and cycle times. Therefore, they lend themselves to the use of simple and inexpensive hydraulic drives that are powered from the hydraulic accumulator.

Since, in this drive concept, all that is needed is to charge the accumulator, it is possible, for instance in the case of the Ergotech 200 Elexis S, to reduce the installed hydraulic load to 15KW. This is equivalent to only about 30% of the installed load of equal-size hydraulic machines.
3.3.3. Parallel function sequences in main and auxiliary axes

Fig.25: Application “Cup”

The following application example will serve to analyse the potential of cycle time reduction provided by parallel (Simultaneous) cycle sequences in injection molding thin-wall containers in some greater detail. The application involved here is a cup molded in polypropylene with a flow-distance / wall-thickness ratio of 390:1.

The 4-cavity mould was operated in an Ergotech 200/560-840 Eleixs S machine and systematically optimized to achieve the shortest possible cycle.

There is potential for another reduction in cycle time not only in the parallel movement of mould opening and plasticizing, but also in the parallel movement of ejector and mould movements. Mutual interference of the drive is not possible as can be seen from the schematics of the hybrid drive and the ejector supply which is by means of a separate pump set.

Other parallel functions that are apt to save cycle time compared to sequential arrangements include:
Pressure build-up for nozzle contact in parallel with mould locking, Start of injection process in parallel with the locking of the mould.

At first glance, the reduction achieved in the example of 0.56s appears to be of little importance. But judged in relation to the total cycle time of 4.34s, it will be quite obvious what saving potential there is in supposedly minor improvements.

3.3.3. Machine hour rates due to reduced energy consumption

**Fig.27: Application “Drinking Cup”**

A discussion of the example of the “drinking cup” production will highlight the potential offered by modern drive systems in injection-molding machines for increasing productivity and reducing energy consumption.

The drinking cup in the application referred to is made of polystyrene and of the type used by airline companies in their flight catering services.

Based on the use of a 6-cavity mould, a comparison was made between two injection-molding machines, one equipped with a hydraulic drive and the other with an electrical drive, with respect to energy consumption and productivity.
Both injection-molding machines were operated with the 6-cavity cup mould and the same process times were taken as a basis. The Ergotech “rapid” attained a cycle time of 3.6s, to be out performed by the Ergotech Elexis S by another 0.3s. Advantageous factors were the shorter movement times and the additional parallel functions for nozzle contact and injection while mould locking is in process.

Measurements of energy consumption for the illustrated example of the “drinking cup”, showed that energy usage of the Ergotech Elexis S with its modern drive concept, while affording a shorter cycle time and, consequently, higher output, was cut by some 46%.

The reduced energy consumption and the high efficiency of the machine combined to reduce the machine hour rate, which is positively reflected in the assessment of its economics.
4. Economics

4.1. Assessment of prorated costs of production

An analysis of the costs of production in injection molding thin-wall containers shows that materials account for the major part of product cost.

This fact is borne out by the example of the thin-wall drinking cup, which, using a 6-cavity mould in an Ergotech Elexis S IM machine with a clamping force of 2000KN, is produced within 3.3s. The cost of the material in the example given amounts to about 65% and thus represents the major cost item.

Labor and setup costs, on the other hand, account for only about 2%. The reason is that, in the packaging industry, production is usually in very great
numbers. The mould remains in the machine for a long period of time and automatic switch-on and start-up programs permit relatively simple starting of the machines (for instance at the beginning of each week) and take little time. Apart from that, it is common practice for one operator to supervise several machines. This explains the small percentage of labor and setup costs in the costs of production to be reckoned with.

The remaining elements of the costs of production are the investment costs for the machine and auxiliaries (28%) and for the mould (4%). Compared to the production of technical parts which generally are produced in small numbers, the prorated investment costs in the case of packaging containers referred to the total product cost are rather low. The explanation is that investment costs can be spread over a larger number of pieces: And the prorated costs per part are reduced.

In the light of the cost situation described, it can be concluded that it definitely pays off to invest in efficient and reliable injection-molding machines and moulds in order to improve productivity.

4.2. Comparison of economics

In the study recited below, 3 different variants were reviewed for the production of the drinking cups with respect to production costs and contrasted with the least efficient variant.

Variant 1: Injection-molding machine Ergotech “rapid” with hydraulic drive concept and 6- cavity mould.
Variant 2: Injection-molding machine Ergotech Elexis S with electrical drive concept and 6-cavity stack mould.
Variant 3: Injection-molding machine Ergotech Elexis S with electrical drive concept and 6+6 cavity.

The estimated cost of production for variant 1 amount to Euro 13.39 /1000 pieces.

Considering the lower energy costs coupled with the cycle time reduction of 0.3s, this amounts to a saving in production costs relative to variant 1 of about Euro 0.74/1000 pieces for the Elexis S machine despite the
lower investment cost for the Ergotech “rapid” machine calculated on the basis of prices in 1997.

Another possibility of lowering production costs is the use of stack moulds with two parting lines behind each other. Theoretically, such a mould can, on the same clamping area, almost double the part output because, on account of the coinciding buoyancy areas in both daylights, no higher locking force is required.

The reference machine in the comparison is an Ergotech Elexis S with 2500KN and 6+6 – cavity stack mould. In view of the heavier mould weight and the longer opening stroke required, the model with 2500KN instead of 2000KN was selected. In addition, a larger-size injection unit was chosen in order to cover the higher plasticizing and injection capacity.

In production, the system with the 6+6 –cavity stack mould attains a cycle time of 3.9s which is equivalent to an out put of 6545 pieces/h, this means that productivity has been almost doubled.

The saving compared to variant 1 has been estimated at Euro 1.46/1000 pieces which makes it the most economical variant.

It should be mentioned at this junction that a valid economical assessment with respect to the use of stack moulds is extremely difficult. Stack moulds pose most exacting demands in terms of machine performance, mould technology and operator skills. The availability obtainable and assurance of proper support for such equipment are aspects that users should carefully review in the light of their production environment.

**Conclusions**

Investment in state-of-art technology, whether in respect of the injection-molding machines, the moulds of parts-removal technology, as the case may be, generally mean a higher financial outlay. However, the extra expense will pay off in the medium term because the consistent use of modern injection-molding systems allows the molder of thin-wall
packaging containers to exploit to potential for significant reductions in his or her production costs.

The high standards required in terms of molded part quality and output dictate the use of complex equipment and, preliminary to volume production, call for concerted planning between the purchaser and the suppliers involved. Consistent project support right through to commissioning, including verification of the guaranteed performance, are crucial for the molder to achieve his or her targeted objectives.

Thank you for your time. If you have any questions, please don’t hesitate to contact our application engineer Mr. Jack Liu with email jackliu@demag-ergotech.com.cn for more information.

With best regards,

Stephan Greif
CEO Demag Ningbo
Vice President China