

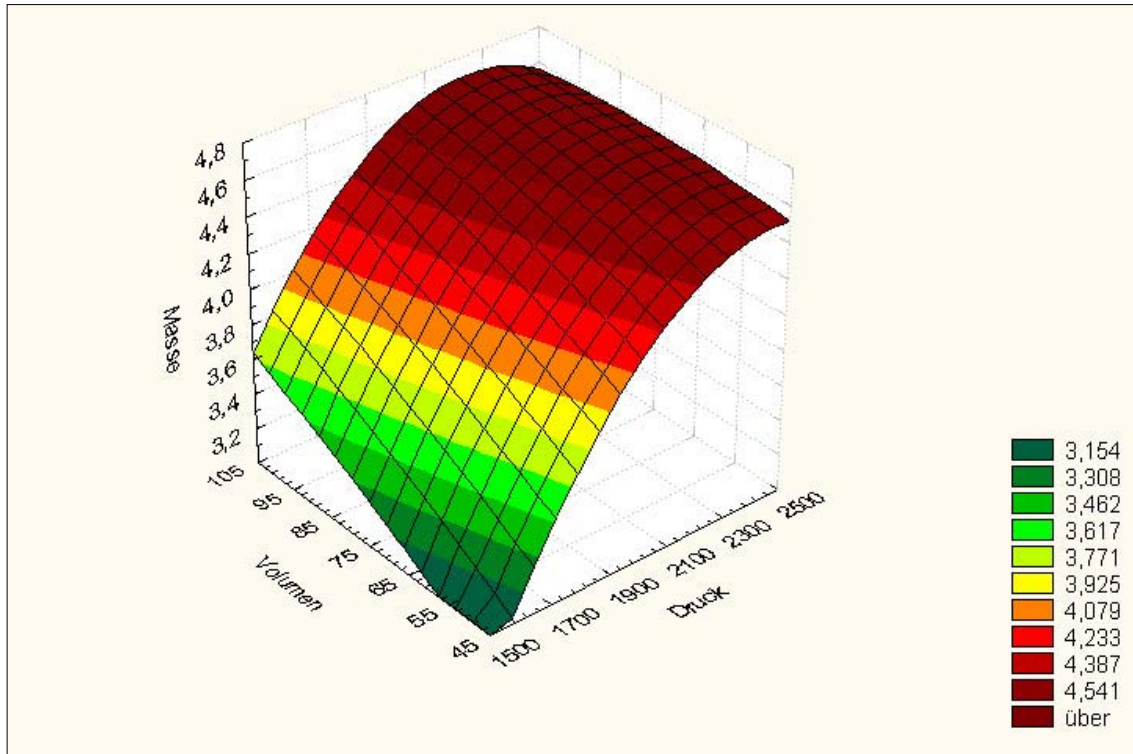
ENGEL

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X-Melt
Expansion Melt
Technology

TECHNICAL INFORMATION

X-Melt



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Introduction:

Today's injection molder faces many challenges including cost-efficient molding production and further pushing the limits of what's currently possible in modern injection molding. Key words used are faster cycles, thinner wall thicknesses (lighter parts) and "more precise" (higher quality) parts. These are the benchmarks against which the cost-efficiency of part manufacture is measured, especially when the focus is on high speed injection molding of thin-walled precision parts.

Faster,...

As machine costs are calculated per time unit (in contrast to those of a mold), the production cost for an injection molded part drops as the number of parts produced during the time unit increases. There are different factors that can influence the cycle time of a part. Machine or mold related times can be influenced to reduce the overall cycle of a part. In some cases automation equipment can also influence the cycle time achieved. As far as injection molding machines are concerned, almost every current machine design from the leading manufacturers presents a virtually identical high standard, which draws the conclusion that influencing the cycle time by the machine used is almost impossible.

The mold's influence on productivity is of much higher value, due to the fact that cooling time is often the cycle determining factor. Cooling time can be influenced by either perfectly designed cooling circuits or by decreasing the wall thickness where possible. Since wall thickness is entered in the calculation for the cooling time in squared form, the conclusion is easy: the thinner, the faster, the cheaper, the more profit!

Figure 1 shows the relationship between wall thickness and cooling time.

.....Lighter....

Reducing the wall thickness of the part not only reduces the cooling time, (thus usually cycle time as well) but also material costs. In modern electronic and communication devices especially, wall thickness has been reduced with each model generation over the last years. Reduced wall thickness enables the design engineer to put in more electronic components without changing the design and overall dimensions of the device.

... More Precise

For electronic products in particular, extremely tight tolerances are now required for the precision and quality of injection molded parts. The prerequisites for achieving these demands are a highly accurate injection molding machine and a perfectly built mould. Apart from a very high level of reproducibility, the machine must also be designed for high speeds and in particular for high injection speeds.

Thin-wall Injection Molding Today

The production of thin-walled parts is not new. More than twenty years ago, flower pots and drinking cups made of PS or PP were injection molded with wall thicknesses of 0.5 to 0.6mm (0.019"-0.023"). Materials with extremely high MVR were used, in combination with injection speeds of approx. 300 mm/s (12"/sec.). To achieve these high injection speeds, the injection-molding machine must be equipped with a separate hydraulic accumulator for the injection unit.

Contrary to the production of these parts, easy-flowing PS and PP are not commonly used in today's applications. Instead, ABS, ABS/PC blends and LCP (liquid crystal polymers) are the main materials

employed. With the exception of LCP, the materials mentioned have a considerably higher viscosity than the grades used for the production of flowerpots or drinking cups. Despite this, it is still possible to achieve wall thicknesses of 0.6 mm and even less, although this does require certain prerequisites to be met. The flow paths must not be too long, and injection speeds of 1000 mm/s (40"/s) or more are necessary. A large number of machine producers have taken care of this problem by coming up with corresponding machine design concepts. This development work provided interesting ideas to reflect on new possibilities in injection molding.

Before designing the injection unit for an injection speed -- or to be more precise, screw moving speed -- of 1000 mm/s (40"/s), a number of boundary conditions must be observed. First of all, an accumulator concept must be designed which will enable the desired injection speed. A correspondingly large amount

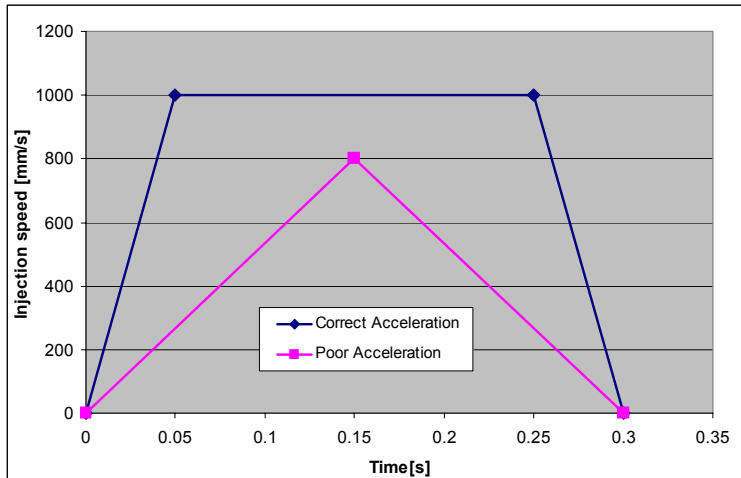


Figure 1: Actual Screw moving speed (Injection speed) dependent on injection time. Inadequate acceleration prevents reaching maximum injection speed.

of oil must be available at sufficient injection pressure to fill the part. Due to these high injection speeds, filling times are very short. Filling times of less than 0.1 s are common. The fast response of the control valve is of supreme importance: the moving parts of the injection unit must be accelerated to their maximum speed and then slowed down again prior to the end of the injection phase (Fig.1). If the final speed is not reached before half the injection time has elapsed, because of too low an acceleration, the maximum injection speed will never be reached. Engel uses a highly-dynamic servo valve with a special piston and accumulator to ensure steep acceleration and brake slopes.

Velocity of 1000mm/s only Theory

A further key aspect is control of the injection speed. For injection speeds of up to 600mm/s (24"/s), standard control equipment can be used. Despite the use of a 64bit RISC card, speeds higher than this can no longer be controlled by standard control equipment. For higher injection speeds, indirect, adaptive control is required, which involves measuring the effective velocity and then calculating and correcting the control parameters in each case, for the next shot. In practice, a stable process prevails by atleast the third injection cycle. These processes can be mastered, and hence a machine with an injection speed of 1000 mm/s (40"/s) is currently common technology. In the testing stage for these machines, moulds with several pressure transducers in the flow path were used. Surprising results were seen; although the screw reached a speed of 1000 mm/s, the flow front of the material did not even come close to this speed. It is commonly known that plastic is compressible (amorphous materials around 10%, semi-crystalline materials about 30%), however, a large part of the energy introduced during the screw moving is used to compress the melt in the barrel in front of the screw. This even led to a situation where the flow front speed remained constant as the screw speed reached 650 to 700mm/s. A further increase of the screw speed did not lead to shorter fill times.

An additional effect was also seen: after the screw stopped, melt continued to flow into the cavity. The highly compressed melt in front of the screw expanded into the mould until pressure equilibrium was attained.

The results of these investigations prompted the idea of using these viscoelastic properties of plastic melts for process engineering purposes. The development of "expansion injection molding", the Engel technology module "X-Melt", had begun.

Expansion Injection Molding

The compressibility of thermoplastics is common knowledge and explicitly documented in the p-v-T diagram (Fig.2). If melt under high pressure suddenly has the pressure relieved, it will expand explosively. This is not an isothermal process but - depending on the velocity - an adiabatic or polytropic process. The abrupt expansion of the melt does not cause any additional thermal stress to the material, and results in a more rapid cooling of the melt. From the p-v-T diagram, it is possible to determine an expansion volume of approximately 10% for the materials investigated, with a precompression pressure of approx. 2000 bar (28,800 psi). This can also be reproduced in practice, given identical thermal conditions.

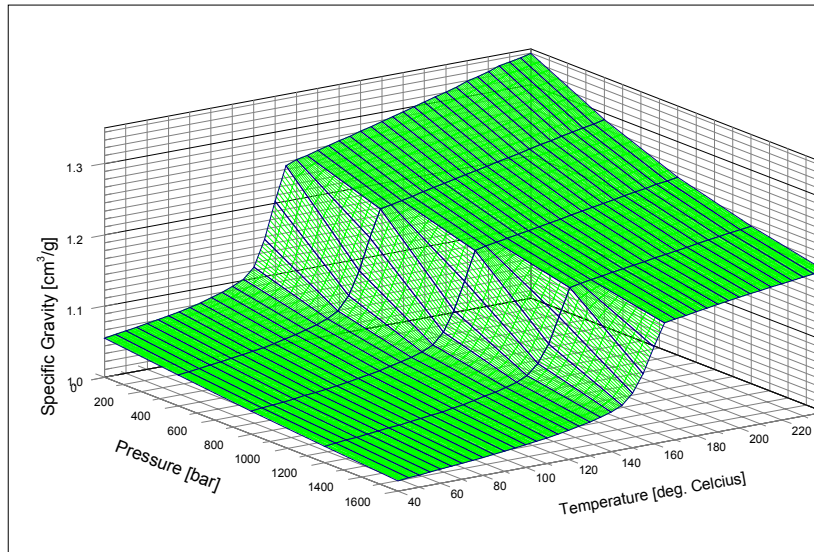


Figure 2: p-v-T diagram for a LD-PE. "Compressed energy" (compressed volume) enables X-melt (expansion molding process).

The constraint for a reproducible process is that the compressed melt volume remains constant. This requires the screw to be held in a locked position after the compression of the melt, until a certain pressure is achieved. Otherwise, the screw would move forward when the nozzle is opened, whereby overloading of the cavity could occur. With conventional hydraulic injection molding machines where the melt,

The screw and hydraulics are in a mutually influencing equilibrium, this is almost impossible to control in engineering terms. Expansion injection molding - and also the tests described here - were conducted on an all-electric machine.

Machine Concept

The new all-electric "e-motion" series from Engel, allows the range of injection molded parts suitable for this technology to be optimally covered. On the e-motion machine, the screw can be placed in any desired axial position and be kept at precisely this position, even with high pressures.

In addition to the ability to lock the screw in position, an appropriate locking system is also required for closing off the barrel. This is best achieved by a hydraulically or pneumatically driven shut-off nozzle. The needle on shut-off nozzles is usually opened by the injection pressure. For expansion injection molding, the needle must remain closed during the entire compression stage and only open when the expansion phase commences. As a second option with expansion molding, this closure can also be integrated in a hot-runner nozzle. The advantage is easy to see: this increases the compression volume while, at the same time, reducing the expansion volume, since the runner increases the complete compression volume in front of the screw. The demands are the same as for the machine shut-off nozzle.

Process Steps

After the mould has been closed and the injection unit pressed against it, the melt is compressed with the shut-off nozzle closed (Fig.3). This compression is done at a moderate screw speed in order to avoid local pressure differences throughout the melt. The subsequent short delay time allows a pressure

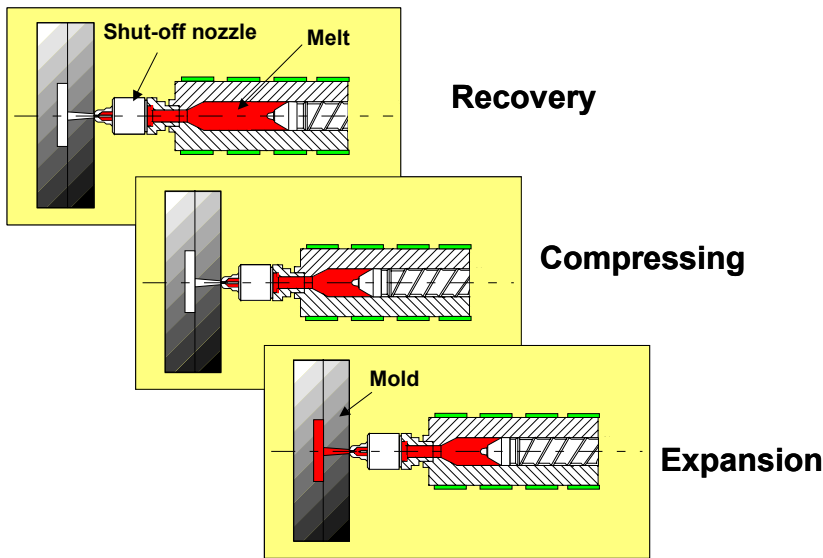


Figure 3: Processing steps for X-melt: Recovery – Compression - Expansion

equilibrium to be established in the melt. The screw moving speed and delay time are determined in accordance with the compression volume and the desired compression pressure in each case. After a uniform pressure level has been attained, the shut-off nozzle opens, enabling the melt to expand into the cavity. Once a previously-defined holding pressure has been reached, the machine switches to the conventional holding - pressure program. The holding pressure time will be very short in practice, and is dependent on the level of the holding pressure. With very thin or small parts which have been

injection molded using this process, the holding pressure is not normally of any major importance. The correct setting parameters are established empirically. If the shot weight is known, then a compression volume of roughly ten times the part weight is selected. To begin with, a value on the small side should be set for the compression pressure. If the mould cavity is not completely filled, then the compression pressure should be increased step-by-step until an optimally-manufactured injection molded part is obtained. The processing point established in this way is only one of several possibilities.

Rapid, Precise and Perfectly Reproducible Without an Accumulator: Examples

Investigations into thin-wall expansion injection molding have so far been conducted with different materials, such as PP, PS, ABS and ABS/PC, as well as with different molds. Typical thin-walled parts would doubtless include keypads, covers for

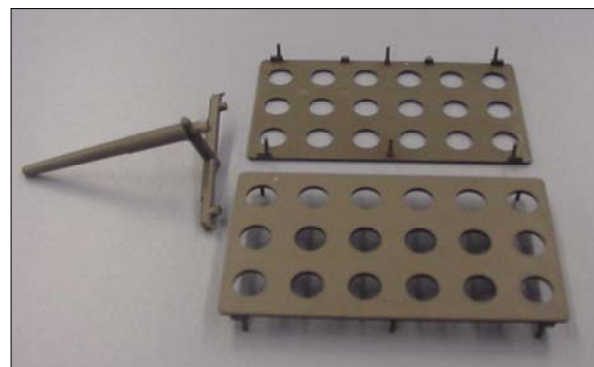


Figure 4: Cover plate made out of PC/ABS. Average wall thickness 0.5 mm (0.019"). Fill time 0.08 sec.

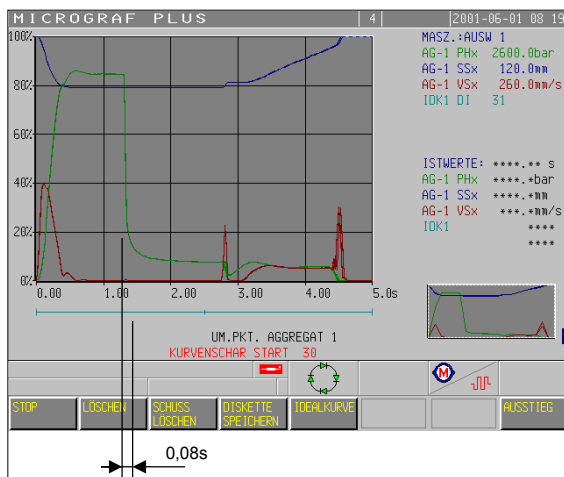


Figure 5: After opening the shut-off nozzle the pressure drops immediately. The plastic fills the cavity within 0.08 sec. The screw stays in exactly in position not to overload the cavity.

mobile phones and other lightweight electronic devices like palm pilots.

Mobile phone covers have already been injection molded with this innovative process, being produced out of an ABS/PC blend with a wall thickness of only 0.5 mm (0.019"). (The customer has not agreed to release details/pictures of the part for this publication.) The keypad shown here (Fig.4), was produced in a two-cavity mold. A flow front speed of 875 mm/s (34.5"/sec.) was achieved, with an injection

1	4.6092
10	4.6087
20	4.6084
30	4.6077
40	4.6047
50	4.6058
60	4.6080
70	4.6058
80	4.6045
90	4.6062
Average	4.6069
Min	4.6045
Max	4.6092
Standard deviation	0.0017
Weight tol. [%]	0.1020

Figure 6: Part weight statistical information

time of 0.08 sec., which was achieved without an accumulator. Figure 5 shows the melt pressure profile in the barrel, in front of the screw, as a function over time; this can be used to establish the effective fill time of the cavity. This explosion like discharge of the stored energy can be visualized by a simple test: when the *jet* of melt expands straight into the air, it will easily shoot through a 3 mm thick wooden plate, leaving a smooth hole in panel.

Expansion injection molding is capable of outstanding weight tolerances: the scatter for one hundred shots was only 0.0047 g with a standard deviation of 0.0017. Part weight is 4.6 g. This results in a 0.1 % variation only. Figure 6 shows the data collected for this trial.

Expansion injection molding guarantees the reproducibility required for high quality thin-walled precision parts.

X-Melt-Technology is just at the Outset of its Development

As tempting as *this* new technology is, it also has its limits. Because of the physical situation outlined above, expansion injection molding is only suitable for small shot weights, since the compressed volume in the volume in front of the screw must be roughly ten times the shotsize. Conventional hot runners cannot be used for this process, since the complete hot runner is under the extremely high compression pressure. As a rule, hot runner systems are designed for 2000 bar, but for expansion injection molding they must withstand a pressure of at least 2500 bar on a permanent basis. In addition to this, it must be possible to open the needle shut-off valve easily and abruptly at the maximum compression pressure. Manufacturers of hot runner systems have already indicated that this problem can be solved satisfactorily.

One possible problem could be faced with thermally sensitive materials in terms of residence times. At the present time, there are not enough results available regarding this. Co-operation with material manufacturers is necessary for detailed information of different materials.

Engel has achieved a further technological advance with X-Melt, by combining it with the all-electric injection-molding machine -- Engel's e-motion -- which also allows independent parallel movements. High-speed injection molding is then feasible with high precision and reproduction accuracy, requiring no elaborate additional units, such as a hydraulic accumulator. Although the applications are currently restricted to thin, lightweight parts, like all innovations, a large number of new applications will result from this technology, as an increasing base of knowledge and experience is gained over time.

If you need any further information please contact us at any time.

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