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Variothermal control with various heating processes

High component quality with optimum cycle times

The specialist Swiss temperature control company HB-Therm AG has known for a long time: That mould temperature control has a crucial effect on the quality of components and the economic efficiency of production in high-quality injection moulding. The variothermal process that HB-Therm has been working on for a long time is becoming more and more important.

Philipp Geisser [1]

The variothermal process is what is known as a "forced dynamic temperature pattern" in the mould during an injection cycle. To put it more simply: When does a mould or its shape defining areas need to be hotter and when does it need to be cooler so as to produce and demould the part with the best possible quality? The best mould temperature in each respective cycle phase is the crucial factor here – hence the variothermal control process.

When can a variothermal process be used?

The variothermal process helps injection moulders to prevent unwanted effects. By comparison with "normal" temperature control technology, the variothermal process can help in effectively solving demanding tasks in this field. While component quality increases at higher temperatures, for example, cycle times also become longer. This correlation affects the per-part costs from an economic point of view. When choosing the mould surface temperature, manufacturers thus need to always weigh up component quality and economic considerations. In particular, this applies either when extremely small flow cross-sections entail very high injection pressures, or to avoid sink marks due to extreme wall thickness ratios, or else if perfect surface quality is required in the case of foamed and fibre-reinforced parts. However, variothermal control should also be used for faithful reproduction of finest structures or for achieving a high degree of contour accuracy (e.g. for optical lenses, micro- or nano-structures, piano lacquer, etc.) With certain injection-moulded parts, there is also the requirement to avoid weld lines or other adverse optical effects in the visible area.

[1] *Philipp Geisser, Head of technology HB-Therm*

For variothermal temperature control HB-Therm employs two Thermo-5 temperature control units that are connected to the machine and mould via the Vario-5 switching unit.

How does variothermal control work?

In many applications, the cavity surface in the mould should be "hot" during the injection process and "cold" in the cooling phase. The mould, or just the area close to the cavity, is heated for a certain time and subsequently cooled down again. Using variothermal control, it is possible to change the temperature on the mould cavity surface actively during the injection cycle, which means that there is cyclical heating and cooling by means of a heating system and a cooling system. This demands the temperature control to berun absolutely synchronous with the process cycle. Whereas only cold or low-temperature water is used during cooling (i.e. to dissipate heat), several processes and media are available for heating: for example, liquid heating (using water, oil, CO_2), electrical heating (using resistance or induction means resp. infrared or laser radiation) or steam.

Liquid heating

In the case of liquid heating two temperature control devices and a switching unit are used. The switching unit thus alternates between the "hot" temperature control unit and the "cold" unit according to the cycle dictated by the machine. The unit not connected to the consumer is switched over to bypass operation so that the transmission of heat in the unit is kept up in this phase as well. The fluids typically used in this process include water, oil and, under certain circumstances, CO_2 as well. The effect of this technology depends largely on the design of the consumer and the application process involved. Preconditions for successful operation are:

– suitable mould design (smallest possible mass),
– small distances between cooling channels and cavity surface and long cycle times,
– suitable control of the switching valves in the desired ratio and following the cycle of the machine. the attainable temperatures on the consumer surface (e.g. the mould cavity) depend on the temperature ranges of the temperature control units, the connected consumer and the cycle time.

Electrical heating: Three alternatives

The basic idea behind electrical heating is to keep the mass to be heated as low as possible. In addition, the separate cooling channels need to be accommodated adequately. There are three main options for electrical heating: resistance (ceramic plate, thin layer), induction and radiation (infrared, laser).

Resistance heating
An electrical heating element in the form of a ceramic plate is located close to the mould cavity surface in the variothermal area. The high specific heating capacity facilitates high heating gradients. The cooling channels are placed behind the heating element. Thanks to the relatively high thermal conductivity of the ceramic plate, the cooling effect is still sufficiently strong. This category also includes methods in which the heat is produced by electrical resistance in the cavity coating.

Induction heating
If a magnetic alternating field of a high frequency is applied to a magnetic steel body its surface heats up. This is caused by the induced eddy currents. In theory, induction coils can be introduced from the outside into the open mould. After heating up, which can take only a few seconds, the coil is withdrawn again before the mould closes and the injection process begins. Since the temperature at the surface drops again very quickly after the coil has been switched off, it may be necessary to grossly overheat, eventually resulting in damage to the mould. For this reason, the method of integrating the induction coil into the mould is more widely used even if the costs of incorporating the loops into the mould are much higher.
Alternatively, high-frequency coils can also be placed around the mould for variothermal control.

Heating by radiation
If electromagnetic radiation strikes a surface, it heats up depending on the frequency, intensity and reflection capability. Thus, matt black surfaces heat up much more than polished white ones because the emission factor of the latter is significantly higher. In practice, the radiation source is introduced into the mould. Once the desired temperature has been reached, it is taken out again, the mould is closed and the injection process begins. The absorption capacity of the polished surfaces of steel moulds is not particularly good. Tests with various coatings have shown that the emission factor can be reduced and thus acceptable temperature gradients can be achieved.

Steam temperature control
The very high evaporation heat of water is exploited when heating with steam. If the steam is brought to condensation within the cooling channels, a great amount of heat is released at that point and the surrounding environment is heated up. In the cooling phase, cold water subsequently flows through the channels and cools the mould down again. It is important here as well that the mass to be heated up and cooled down should be kept as small as possible.

Heating process **Evaluation: (0–5)** **0: does not fulfil the requirement** **5: fulfils the requirement completely** **-: not applicable**	**Large areas**	**Complex contours (3D)**	**Existing mould**	**Investment mould**	**Heating rates**	**Temperature distribution**	**Overheating required**	**Investment costs**	**Ergonomics**	**On-road test**
Reference isothermal (continuously)	**5**	**5**	**5**	**5**	**-**	**5**	**-**	**5**	**5**	**5**
Fluid medium (alternating hot/cold)	4	4	4	5	2	4	5	4	5	5
Fluid medium with two circuits (rear constant, front pulsing)	4	4	2	4	2	4	5	4	5	4
CO_2 (alternately hot/cold)	3	4	3	4	1	4	5	2	2	1
Steam	4	4	2	3	2	4	5	3	5	5
Resistance heating elements (ceramic, integrated in mould)	2	2	0	2	4	2	5	3	5	5
Resistance heating elements (movable, integrated into mould)	1	3	1	2	4	2	5	3	5	4
Thick or thin film heater coating on cavity surface	3	2	1	2	4	4	5	3	5	1
Induction heating (inductor via handling in open mould)	3	2	4	5	4	2	1	3	2	4
Induction heating (inductor integrated in open mould)	5	3	0	2	3	4	5	2	3	4
Induction heating (inductor around complete mould)	5	3	2	5	4	4	3	1	2	4
Infrared heat radiator	3	2	3	5	2	2	3	3	2	1
Laser (laser scanner via handling in open mould)	1	4	4	5	4	4	2	2	1	1
Laser (laser beam through light duct in mould)	1	1	0	1	5	4	5	1	3	0
Hot air (with heat recovery)	2	3	5	5	4	2	3	4	2	1

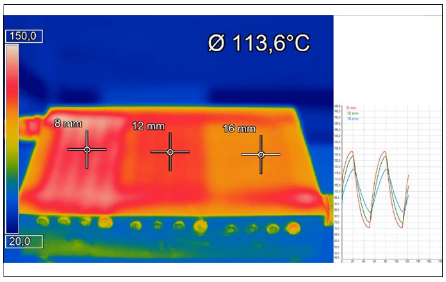
Table: Comparison of heating procedures for variothermal processes. Assessment by HB-Therm, as of 2018

Use of the variothermal process

When should injection moulders use the variothermal process? As in so many cases, it is not possible to offer clear guidelines, since these processes have not been used very widely up to now. However, it can be stated that they generally are more elaborate and require mould designs that are specially adapted for this process, which also makes them more expensive than conventional processes. Regarding the heating system, no one particular process has established itself as the best choice due to the various advantages and disadvantages and their development levels.
The table with the various heating processes and their application properties can be helpful when choosing a system. The details relating to the application must be discussed with the relevant system suppliers.

Variothermal control by HB-Therm

The Vario-5 system from HB-Therm is based on a heating process using liquid media in which hot and cold water are pumped alternately through the circuit requiring variothermal control. Two standard units are used for this with the Vario-5 switching unit connecting either one alternatingly to the corresponding temperature control circuit, thus heating or cooling the mould area. The energy required to achieve the temperature changes is determined by the temperature curve and the arrangement of the temperature control channels. Thepower must be supplied in roughly equal parts by the hot and cold temperature control unit and it corresponds to the variothermal power. The duration of the heating and cooling phases depends on the required mould temperatures and the chosen medium temperatures. The relevant times must be determined in tests with open moulds.
An important parameter that also needs to be taken into consideration is the distance of the temperature control channel from the mould cavity surface. Together with the distance to the valve switching unit, this creates a characteristic delay. When switching from heating to cooling, the temperature on the mould cavity surface initially continues to increase during the delay time, depending on how closely to the contour temperature control can be exerted, until it reaches its maximum and then drops again. This also applies to switching from cooling to heating. The delay time usually is between 4 and 12 seconds.
If you want to reach the maximum temperature at the start of the injection phase, the switchover has to precede it by the amount of the delay time. Depending on the actual arrangement and requirements, switching might need to take place even before the cycle start. The switchover actuation between heating and cooling is based either on time or on temperature. The necessary signals can be generated either by the machine or the variothermal switching unit.
The mould and the process must be optimized appropriately for short cycle times and efficient variothermal control. The following basic principles should be followed:
– The distances between the temperature control channel
– and the cavity must be kept as small as possible (conformal temperature control channels).
– To keep the variothermal area small, it should only be applied to circuits that affect the critical cavity surface area. If possible, inserts that can be easily isolated from the rest of the mould should be preferred.
– In addition, variothermal areas can be separated from the rest of the mould by insulation or air pockets.
– Variothermal inserts should be connected to the temperature control system by direct tubular connections through cut-outs. Supply through the mould plates or frames as well as voluminous water distribution and measuring systems increase the variothermal mass and should thus be avoided.
– In special cases, inserts made of copper alloys or other materials with good thermal conductivity can also be used for the variothermal area.
– Large channel diameters or several channels increase the surface and thereby the transfer of heat.
– The temperature control channels should be designed to achieve the best possible flow rate. This improves the transfer of heat to the mould and leads to shorter response times and faster temperature gradients.
– Ultimately, temperature control circuits using the variothermal process quickly reach the temperature of the hot unit. Seals, couplings and hoses should be selected accordingly. As a result of cyclical temperature changes, moving inserts such as sliders might even jam.



The infrared photograph shows a test mould. It shows the temperature pattern of a test plate with various temperature control channel distances.

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