Simple inductor for heating small split mold cavities. Through oriented temperature management and influencing the induced eddy currents, inductor design can be simplified (© IKFF)

Less Is More

Induction Heating of Injection Molds Can Be Optimized by Targeted Heating of Specific Mold Areas

In variothermal injection molding, induction heating is one of the fastest and most efficient methods of heating. But even this method has great potential for increased efficiency. Through targeted temperature management and heating of clearly defined mold areas, valuable cycle time can be saved.

To produce challenging thermoplastic injection molded parts, an isothermal injection molding process is often not sufficient. In such cases, variothermal injection molding processes are used. There are various possible methods for cyclic heating of molds. At the Institute of Design and Production in Precision Engineering (IKFF) at the University of Stuttgart, Germany, management of inductive variothermal processes has been a central focus of research since the mid-1990s. There are different design variants but the aim is always to achieve targeted and hence rapid and energy-efficient heating of the required mold areas. The inductors can be arranged externally, i.e. in front of the surface to be heated, or internally, i.e. directly under the mold surface (**Fig. 1**).

An external arrangement also requires a device for moving the inductor into and out of the center of the mold. Such a handling system can place the inductors precisely in front of the surface to be heated but the heating energy can only be applied with the mold open. Since the heat is already dispersing on mold closure and the cavity cools down again before the start of injection, the energy demand is higher than the process actually needs.

In contrast to this, with an internal arrangement, the inductors are integrated into the mold plate as close as possible to the cavity. Consequently, the cavity can be heated independently of machine opening and the cycle phase. In this case, a short heat conduction path to the cavity surface must be crossed. During » this time, heat is dispersed not only in the direction of the cavity but in all directions. As a result, with this variant, valuable cycle time and energy is wasted until the required mold surface temperature is reached, because parts of the mold are heated unnecessarily.

Temperature Management by Air Gaps

To conduct heat more specifically in the required direction with the internal arrangement, it is possible to incorporate gaps, preferably thin air gaps, into the mold plates. These air gaps "frame" the area around the inductor so that heat can only flow in the prescribed direction (**Fig. 2**). A series of simulations has confirmed that, as a result of the air gaps, the heat which is produced around the inductor is forced initially to flow only in the direction of the cavity. Only after passing the air gaps is the heat distributed near to the surface in all directions.

In actual measurements on a design with air gaps, this advantage is shown very clearly through a heating time reduction of more than 60 % as compared with the same geometry without air gaps. Cooling time is also cut by over 60 % thanks to the smaller amount of induced heat with such an arrangement.

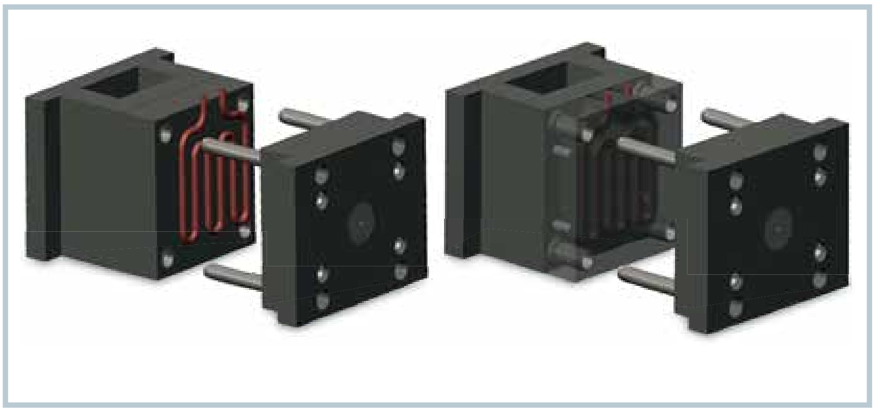

Fig. 1. Depending on requirements, external (left) or internal (right) arrangement of the inductor is recommended (© IKFF)

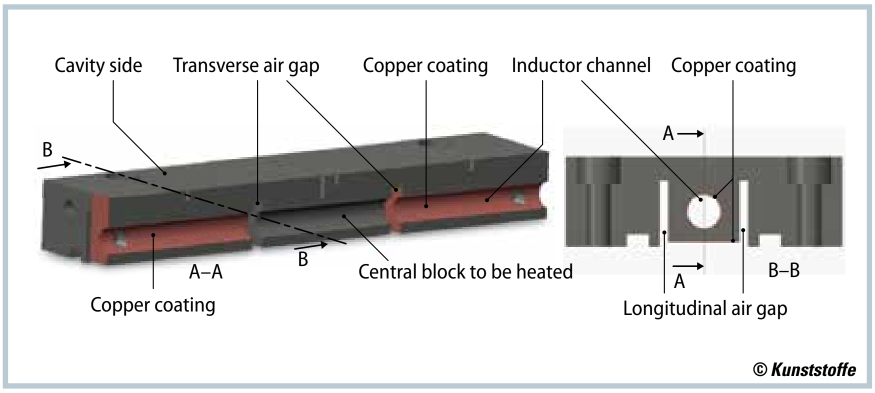

Fig. 2. CAD model of part of the coated test geometry. Left: longitudinal section, right: cross section. The inductor in the inductor channel is not shown (source: IKFF)

A Copper Layer Directs the Induced Eddy Currents

Although air gaps can guide the heat in the direction of the cavity, nevertheless over the entire length of the inductor eddy currents are induced into the plate that lead to heating. If mold areas near the inductor need to be excluded from heating, this can be achieved, for example, by providing greater spacing between the inductors and corresponding ferromagnetic parts. Within the inductor bores, this is only possible by enlarging the bore diameter. This inevitably means increased space requirement and additional component weakening in the vicinity of the cavity.

To overcome this problem, a surface coating with good electrical conductivity can be used to conduct the induced eddy currents into areas where heating is desired with lower heat loss. With the trial geometry employed here, copper is used for this purpose. All the conductive parts surrounding the inductor that are not to be heated are coated with the metal.

The induced eddy currents flow with low loss in the edge layers of the copper coating because of the skin effect. They are short-circuited in themselves and opposed in the axial direction to their origin, the inductor current. For the model shown (**Fig. 2**), this means that, starting from the copper layer, they short-circuit themselves via the central block to be heated and the surface (parting line). In these two areas, heating is required and therefore the copper layer is interrupted so that the eddy currents now flow over a

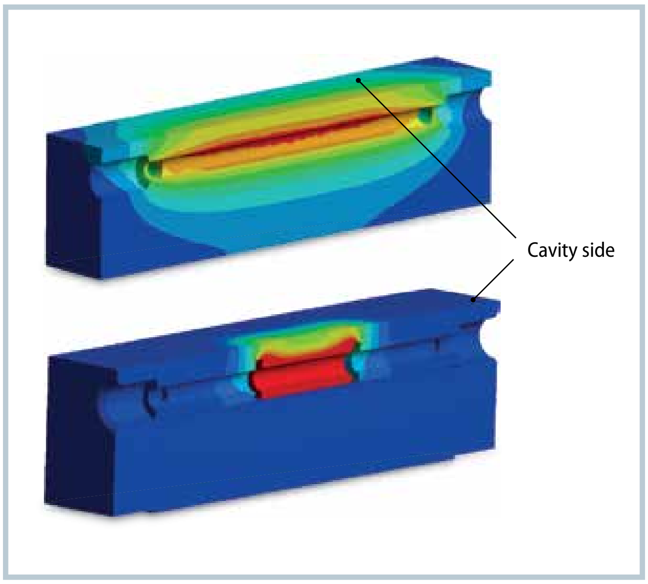

Fig. 3. Qualitative comparison between thermal simulations of a solid material strip (top) and a copper-coated air gap strip (bottom). The latter is only heated in the central uncoated block (© IKFF)

material with higher ohmic resistance. As a result the ohmic losses increase, intensifying heating in these areas.

Since the eddy currents are displaced to a certain skin depth, depending on frequency, the copper layer in the "cool" areas must be at least the thickness of this skin depth. If the copper layer is too thin, the eddy currents cannot be completely displaced into the coating, so that some of the eddy currents flow with high current density in the ferromagnetic material. In this case, the coated area also heats up [1].

Combination of the Two Variants

The part of the trial geometry illustrated in cross and longitudinal section shows the combination of the two variants discussed (**Fig. 2**). On the one hand, the induced eddy currents are conducted through the copper coating so that they short-circuit via the steel in the center of the plate. Here the eddy currents conducted into this area heat up the central uncoated block. On the other hand, in this way, the areas of the plate in which no heating is required are "insulated" from the eddy current losses. Similarly, eddy currents and therefore thermal energy are induced directly in the uncoated area. To guide the spread of the heat so produced to the central area, air gaps were arranged alongside the inductor channel.

A qualitative comparison between two simulations – one with a strip without an air gap and without a coating, from here on referred to simply as solid material, and one with the coated air gap strip – makes clear that the latter records high ohmic losses in the central uncoated block as a consequence of the induced eddy currents and so this area heats up. In the copper-coated areas, no heating takes place in the simulation. Thermal conduction into the surrounding areas is greatly reduced with the lower geometry compared with the upper solid material geometry as a result of the air gaps introduced (**Fig. 3**).

Measurements on the Actual Construction

In the actual test geometry construction, several holes were provided on the surface to allow measurement of temperature distribution at the relevant points (**Fig. 4**). The test results (**Figs. 5 and 6**) confirm the findings already explained. The readings on sensors 4 and 5 show that the central uncoated area is significantly hotter than the surrounding areas (**Fig. 6**). Sensor 4 is located near the inductor and sensor 5 near the surface. As a result of the air gaps arranged around the inductor, heat spread into the edge areas (sensor 3) transverse to the current direction is initially prevented. Only when the air gaps are passed is the heat also spread outwards.

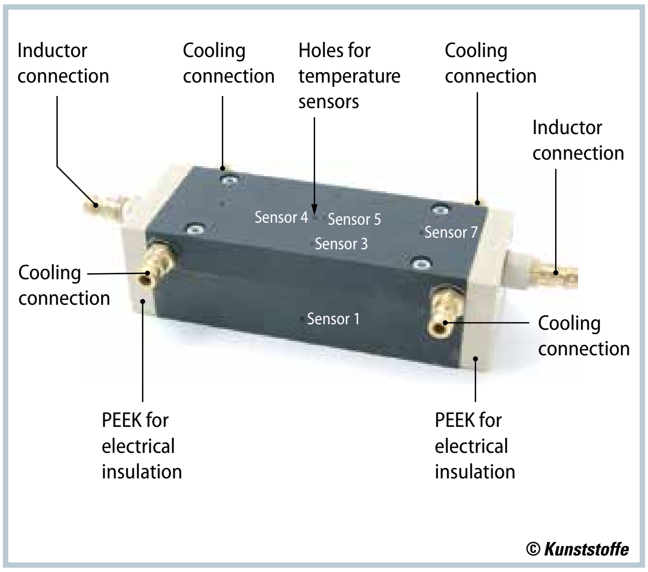

Fig. 4. Actual test construction made from tool steel 1.2312 (black, lacquered). The holes allow the temperature curve to be measured (source: IKFF)

Sensor 7 shows the temperature on the outside in the axial direction. There, too, in comparison with the center, far less heat accumulates, because the eddy currents in these areas are conducted through the copper coating with low loss. Heating of the copper coating cannot be completely prevented, since losses also occur there, but with adequate coating thickness they are very small. With this test geometry, it was not possible for technical reasons to apply the copper coating within the inductor bores in sufficient thickness and therefore somewhat higher losses also occur in this area.

In the graph (**Fig. 6**), the temperature curve for test geometry of the same dimensions without air gaps and copper coating is shown for the sake of comparison. For the same energy input, sensors 4 and 5 record significantly lower heating on the surface after the same time period, whereas when the same target temperature is reached, the sensors in the outer areas (1, 3, and 7) show a higher temperature, because no temperature management is provided. »

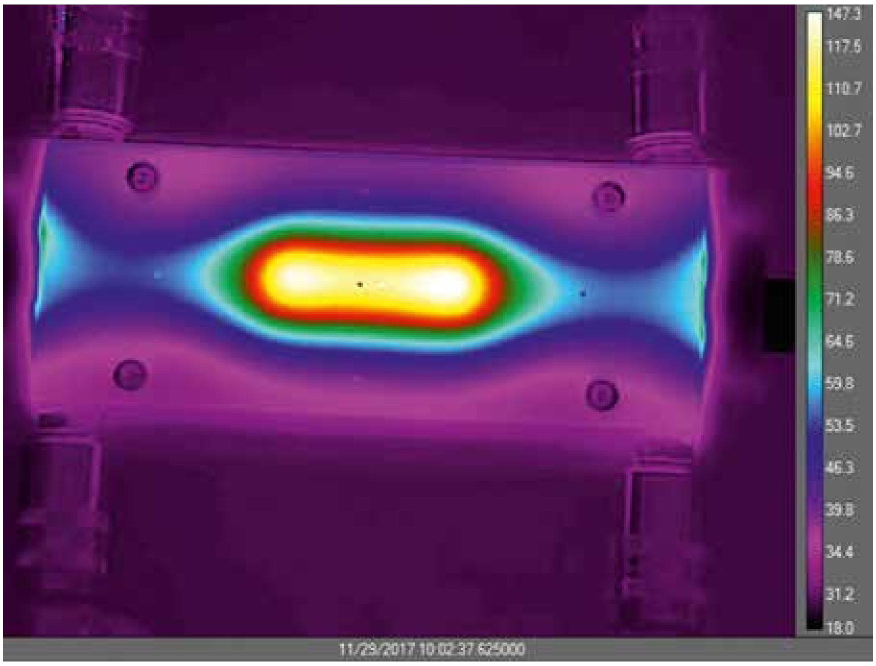

Fig. 5. Thermographic image of the coated test geometry. The image shows inductive heating of the central area of a coated air gap strip (© IKFF)

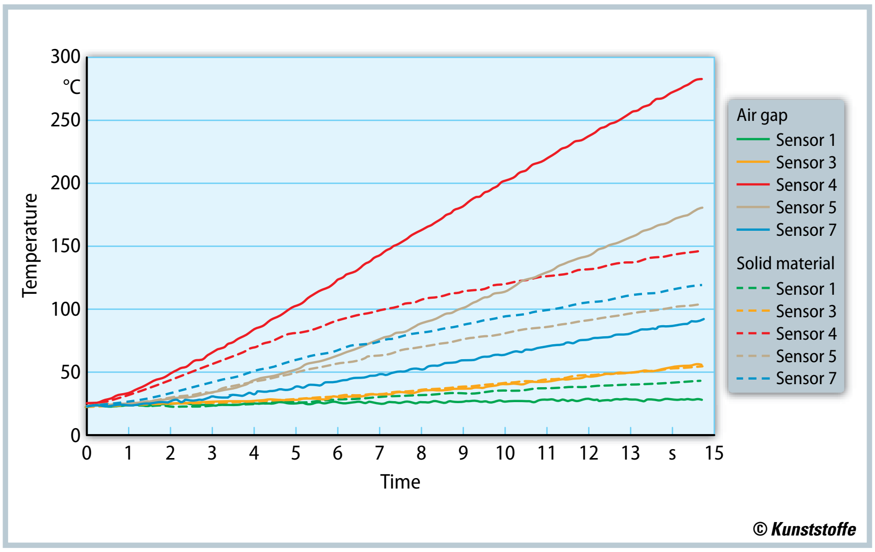

Fig. 6. Various points to measure inductive heating of the copper-coated air gap strip as compared with the so-called solid material strip. The temperature curve for sensor 3 is identical for both variants (source: IKFF)

Faster Heating with Less Energy

With the aid of insulating air gaps around the area of the inductor channel, the heat emanating from the channel wall can be guided in the direction of the cavity. All other directions are initially blocked by the air gaps. In this way, the time required to heat up the desired areas can be substantially reduced for the same energy input.

If, at the same time, other areas not requiring heating (e.g. inductor lines or non-process-relevant mold areas) are coated with good conductive surfaces of suitable thickness, the applied heat energy can be additionally focused and so reduced. In the end, the combination of the two measures not only achieves an improved energy balance but also has a significant influence on the necessary cooling time because less thermal energy is required in total. This makes the induction process more energy-efficient and leads to faster cycles overall. ■

Advantages of the Process

For components with particular requirements such as high aspect ratios or special surfaces, variothermal injection molding processes are necessary. Electromagnetic induction can be used as a rapid, efficient method for heating the cavity. With this method, valuable cycle time can be saved through targeted management of heat generation and distribution using electrically conductive surface coatings on the one hand and thin air gaps on the other. While less energy is introduced into the process overall, not only heating time but also the required cooling time is reduced.

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