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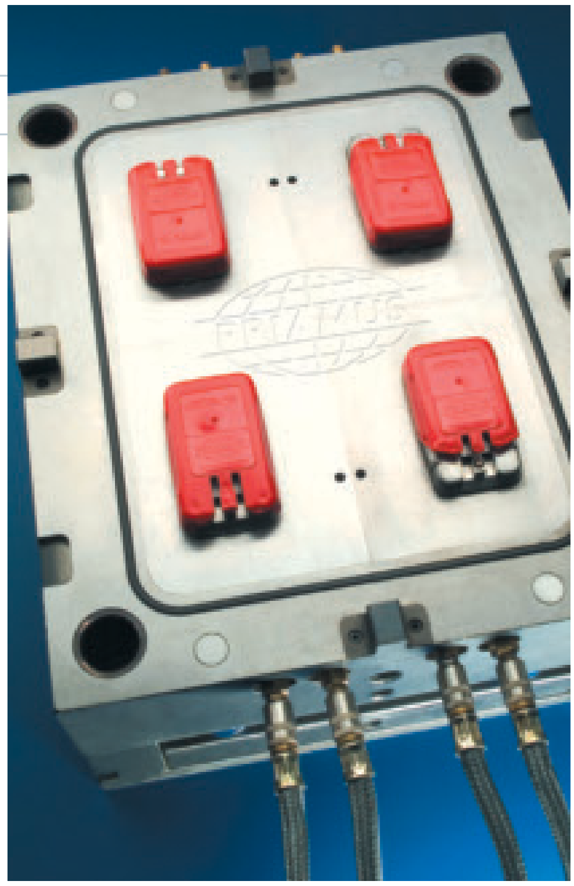
Controlled Conditions

Special reprint



Controlled Conditions

Hot-runner Systems. For precise balancing of a multicavity hot-runner mould, neither cavity pressure sensors nor filling studies suitable cavity temperature sensors compensate for viscosity changes in the melt by changing the hot-runner nozzle settings until every cavity has been filled at the same time.

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Recent years have seen a proliferation in the number of multicavity moulds used in injection moulding production. The greater the number of cavities, the more complicated the process is to handle. If the product requires, for example, high dimensional stability with narrow tolerances, it becomes increasingly difficult – despite sophisticated hot-runner and mould technology – to optimise the process technology to each part. The main causes of this are problems with balancing, which result in different degrees of filling. In the injection phase, the flow fronts in the individual parts spread non-uniformly because of viscosity differences. At the switchover point, both filled and partly filled cavities are then present. This leads to overfeeding and flash in the cavities that have already been filled. The partly-filled cavities are filled under holding pressure – resulting in side effects such as sink marks and fluctuations in dimensions and weight.

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Balancing by Controlling the Cavity Temperature

Traditional process optimisation and monitoring methods consist in measuring the cavity pressure. These techniques are primarily suitable for use in single cavity moulds. It is rare that they can be transferred to multicavity moulds. Multicavity moulds imply particular difficulties ▶

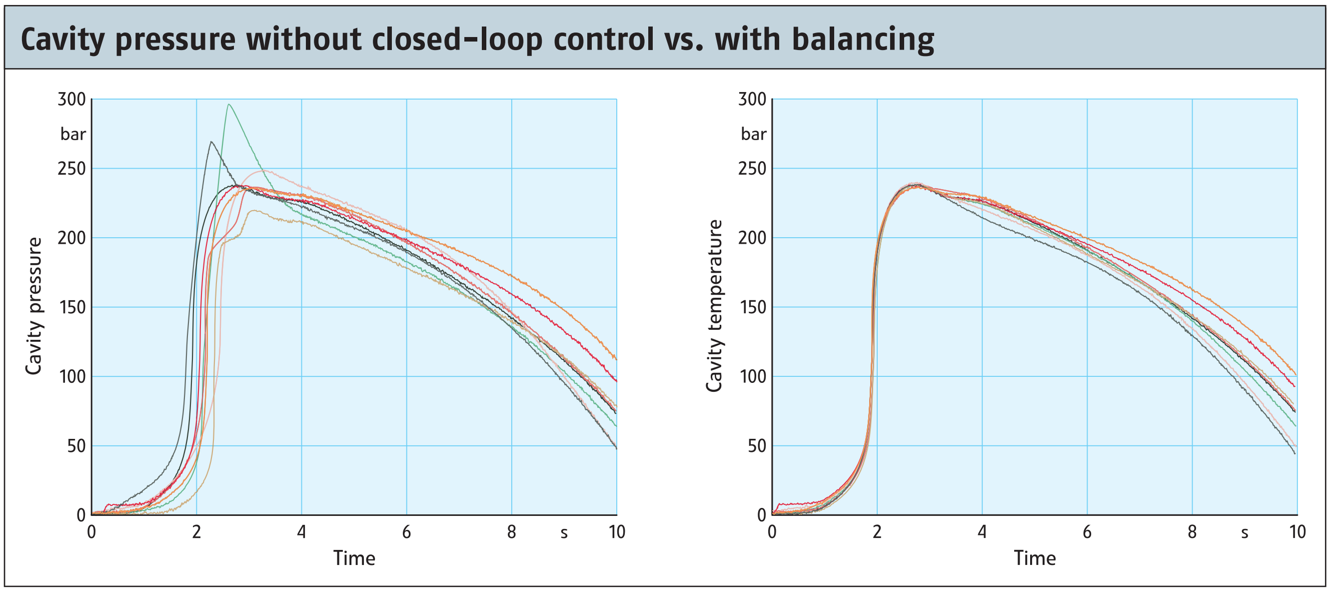

Fig. 1. Cavity pressure measured in eight cavities. Left: the hot-runner system is not closed-loop controlled; right: after balancing of the hot-runner system, different temperature distributions that lead to different degrees of shrinkage are not identifiable

for quality assurance because the individual cavities have different process behaviours, which in some cases are operating-point-dependent [1]. Therefore, when the cavities are in an unbalanced state, just one cavity pressure sensor in one cavity does not provide information about the cavity pressure profile in the other cavities. On the other hand, when the mould has 64 cavities or more, measurement of the pressure in each cavity is not particularly practical regarding economic considerations.

However, measurement of the temperature in each cavity is comparatively inexpensive, permits fully automatic control and balancing of the hot-runner systems and provides valuable information for process optimisation [2]. The use of cavity temperature sensors is also technically useful. While in an optimised multicavity mould, the cavity pressure curves in each cavity are practically identical (Fig. 1), the cavity temperature curves, even in a balanced state differ quite considerably from cavity to cavity (Fig. 2). Although the rise of the temperature curves with time achieves a balancing of the cavities, the absolute temperature differences show that large-area parts vary particularly strongly from cavity to cavity because of the different shrinkage behaviours. A constant cavity pressure alone is therefore not proof of identical part properties.

The temperature measurement method also has advantages regarding the more robust handling of the sensors installed in the cavities. Very small cavity pressure sensors, in particular, run the risk that the sensitive sensor front may come into contact with the installation bore and lose part of its sensitivity. When these sensors in a multicavity mould are compared with one another, there is the risk that control of the pressure signals does not provide the desired result because of the different sensitivity values. Cavity temperature sensors, on the other hand, do not change their properties when installed and are comparable with one another, even when installed in multiple cavities.

Hot-runner moulds, with or without cluster moulds are generally rheologically optimised and "naturally" balanced by the manufacturers. Filling simulations performed in advance also show the simultaneous filling of all cavities (as also expected for individual gating). However, anyone investigating filling of the individual cavities with an actual filling series during production will ascertain that the mould cavities are in reality filled differently, and the degree of filling of the individual cavities continually changes.

The cause of this behaviour lies in the fact that a hot-runner system always operates with open-loop control. That means that only the setpoint temperatures entered for the hot-runner nozzles and manifold are controlled without any knowledge of what effect the change of these temperatures actually has on the process. However, optimum part quality is not only obtained by comparing the setpoint values of a hot-runner system but ultimately only by controlling the viscosity, and therefore the melt flow behaviour.

Cutaway drawing

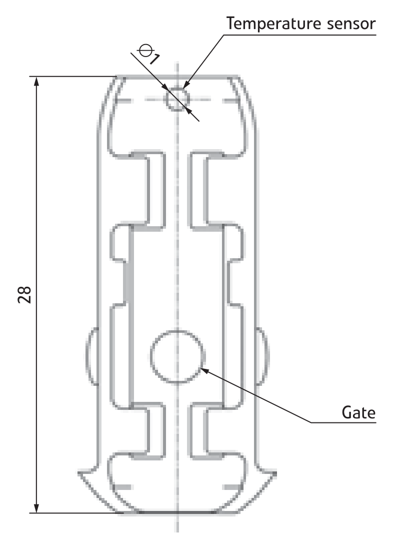

Fig. 3. Joint for automotive application. Position of temperature sensor at end of flow path

Practical Confirmation

To verify the quality of the final product to customers, FPS Kunststofftechnik GmbH, Halver/Germany, decided to employ the Priamus Fill balancing system from Priamus GmbH, Salach/Germany, in production. In the total of four moulds with 24 cavities each, not only the rejects had to be recognised and ejected, but more importantly the cause had to be eliminated.

The part is a POM joint for an automotive application in two different sizes

Cavity temperature without closed-loop control vs. with balancing

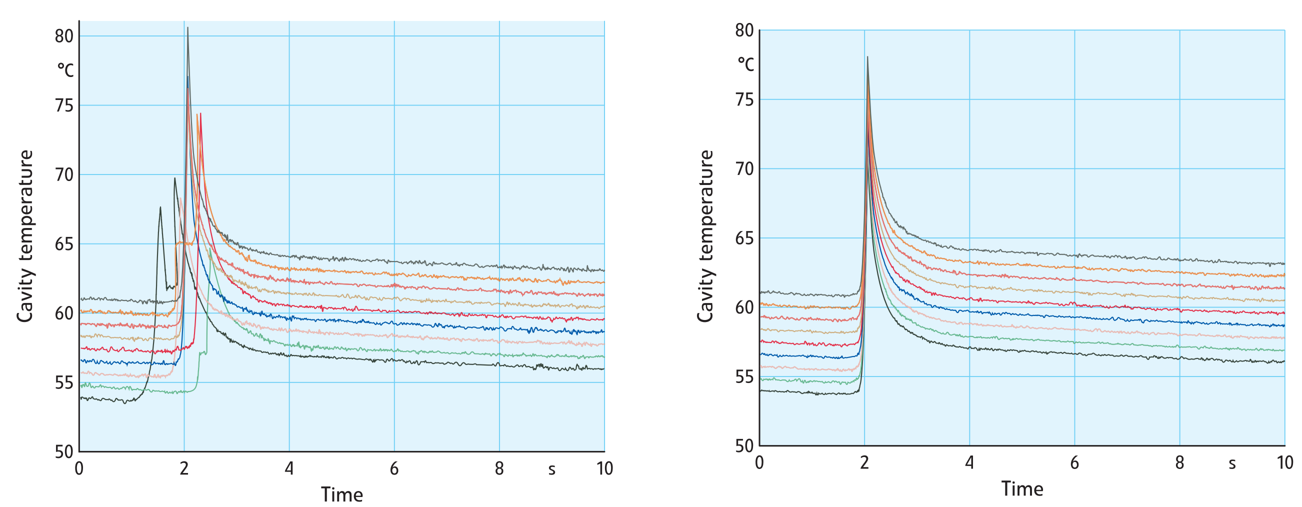

Fig. 2. Cavity temperature measured in the same eight cavities. Left: the hot-runner system is not closed-loop controlled; right: after balancing of the hot-runner system, the rise with respect to time takes place simultaneously (⇒ balanced), the different absolute temperatures indicate different shrinking behaviours

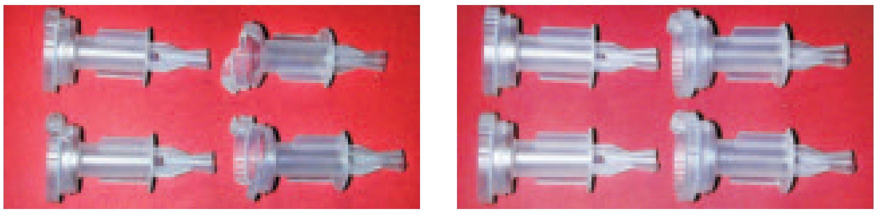

Fig. 4. Filling study of LC aerosol part (4-cavity): without hot-runner balancing (left) and with hot-runner balancing (right)

(Fig. 3). Because of the material's good mechanical properties, the requirements on the parts are correspondingly high. It was important that no incompletely formed parts should reach the final customer, since the part is automatically assembled. In addition to other dimensional specifications, the weld line strength at the end of the flow path is also a crucial quality criterion.

The special design of the temperature sensors [3] allows it to be installed flush with the cavity wall. This installation situation allows the arriving flow front, and therefore the filling time of each individual cavity, to be precisely detected. The Priamus Fill automatic hot-runner balancing detects which cavities are filled first and last by virtue of the measured temperature profiles, and, from this, determines the filling time difference in the last cycle. The system uses special algorithms to continuously compute the desired nozzle temperature for each cycle. The nozzle temperatures of the first-filled cavities are reduced within limits set by the user, and those of the last-filled cavities are increased. In this manner, a uniform flow-front profile is set across all cavities, based on equal viscosity levels.

In the practical case described above, the difference in filling time could be reduced from its initial 0.5 s to less than 0.08 s. This corresponds to an improvement of 84 %. The average standard deviation of the part weight was reduced from 0.016 g to 0.006 g, an improvement of 62.5 %.

An example from medical technology is the "LC Aerosol" part from Paritec GmbH, Weilheim/Germany (Fig. 4). The specific requirement for this 4-cavity mould was to reproduce the part geometries extremely precisely with very close manufacturing tolerances, while always filling the parts completely without any overfeeding.

Weight fluctuations

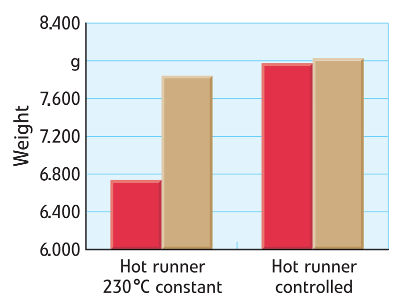

Fig. 5. Fluctuation of average part weight (minimum and maximum values) of all four cavities measured over multiple cycles during production

Experience with a two-cavity mould of the same part showed that permanent process fluctuations can only be compensated by an operator correcting and adjusting the process parameters at the injection moulding machine. Since Paritec has used the Priamus Fill system, thanks to uniform filling in a 4-cavity mould, it has produced uniform parts in a stable process.

The comparison shows that, with identical constant nozzle temperatures in the hot-runner system, the average part weight of all four cavities fluctuates considerably. In the controlled state, on the other hand, the average part weight of all cavities is practically identical (Fig. 5). This result can be attributed to the fact that the automatic balancing considerably reduces the filling-time differences between the individual cavities, from 0.55 s to 0.01 s (Fig. 6).

Summary

The production of injection moulded parts in hot-runner moulds reduces production costs and is gaining in importance. However, the complexity of these systems is increased, and they are difficult to control because of uncontrollable fluctuations during the process. However, temperature sensors in each cavity, with closed-loop control, can achieve uniform filling and prevent overfeeding of the parts.

In contrast to cavity pressure measurement alone, which should still be carried out in at least one cavity for the purposes of monitoring and optimisation, tempe-

Change of filling time difference as a result of balancing

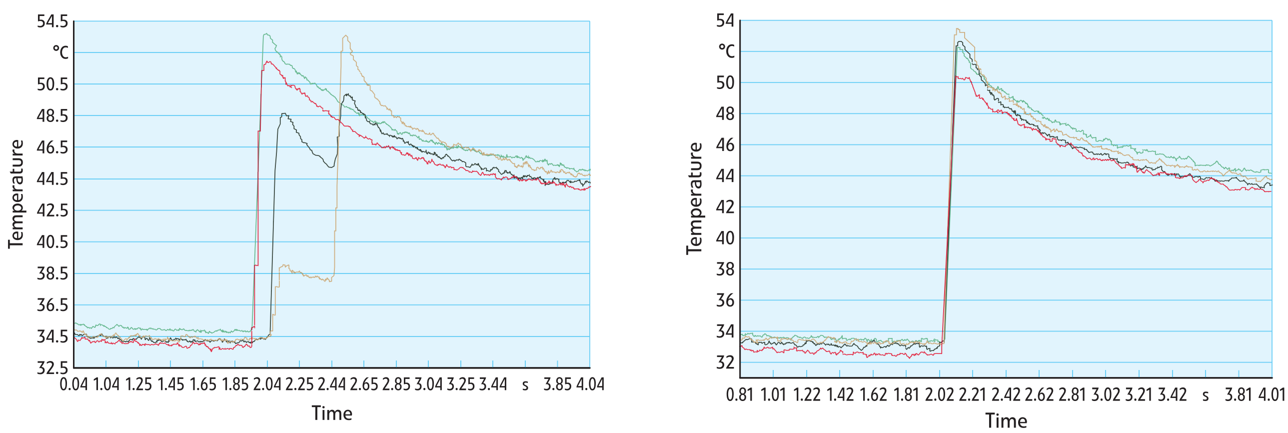

Fig. 6. The filling-time difference for the four cavity temperatures is approx. 0.55 s without hot-runner balancing (left) and approx. 0.01 s with hot-runner balancing (right)

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rature measurement offers additional process information about shrinkage and composition of the parts. The principle of automatic hot-runner balancing is not limited to simple multicavity moulds, but can also be used for multicomponent processes, for families of moulds and for regulating constant weld lines. ■

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Paritec GmbH: The company is a system supplier in medical technology and employs 140 persons at the Weilheim site. The studies were supported by Erich Steiner, Industriemeister Metall and Vera Kreutzmann, Dipl.-Ing. (FH) plastics technology.

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