

Measurement of deformation on an experimental injection mold tool

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With injection molding the quality of the molded part depends to a large extent on the deformation characteristics of the mold tool. The tools are subjected to extreme loads due to the very high pressure levels that can occur inside the mold. This means that their deformation characteristics have to be considered during the design of the mold tool. The authors describe a way of checking the model upon which the computeraided tool design is based. A specially developed measurement system based on inductive displacement transducers is described which provides information on the deformation effects on injection mold tools under load.

Introduction

The technical requirements with regard to dimensional tolerances for injection molded parts are continually increasing. Most of the part's quality features are determined by the injection mold tool and by the process parameters. For this reason it is important that the deformation behavior of a tool is investigated right at the design stage. During the specification of the permissible deformations, special significance is given to freedom from burrs, proper opening of the tool, removal of the part from the mold and to producing a distortion-free surface on the molded part.

The investigation described here involves deformation measurements at the critical points of an injection mold tool. The experiments should also provide information about loads on various machine and tool components caused by the closing force and internal mold pressure. The variation of the forces during the tool filling process was also to be determined.

Measurement equipment

In order to measure the small deformations on the tool, a measurement system was developed which had small dimensions, enabling it to be accommodated in the ejector space within a specially modified experimental tool.

The principle of the measurement system, which is shown in **Fig. 1**, is based on the transfer of the deformation on the closing side of the tool plate using a bar on a bending spring. A double strain gage, type DY 116/ 350, is applied to the top and bottom sides of the bend-

ing spring and the four measuring grids of these gages are wired to form a full bridge. The output signal of this full bridge represents the bending of the spring resulting from the tool deformation. The closing side of the tool normally experiences the largest deforma-

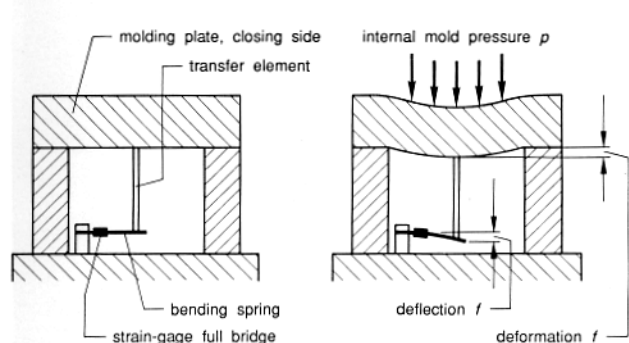


Fig. 1: Measurement principle: Transfer of the deformation on the closing side of the molding plate to a bending spring fitted with strain gages

tions, since it is bent by the internal tool pressure via the machine columns. Therefore, most of the measuring points were fitted to this tool plate.

The positions of the measuring points can be seen from **Fig. 2** which illustrates a diagram of positions in a) and a corresponding photograph in b). The arrangement of the measuring points takes into account the cavity's symmetry and it was chosen such that the middle and edge of the cavity were measured as well as the edge of the plate. In addition, the deformations on the inside of the plate on the gating side and on the inside and outside of the plate on the closing side were measured.

In order to be able to measure the deformations at the same x-y coordinates on the top and bottom of the mold tool on the closing side as well as on the gating side, three deformation elements were positioned at each measurement position, with each of the elements above the other in the z direction. A transfer system was designed that transferred the deformation to the corresponding bending spring.

The telescopic transfer system consists, as shown in Fig. 3, of two concentric metal tubes through which a rod is passed. Suitable holes were drilled in the molding plate to accommodate the transfer system. The external tube, transfer tube 2, makes contact with the

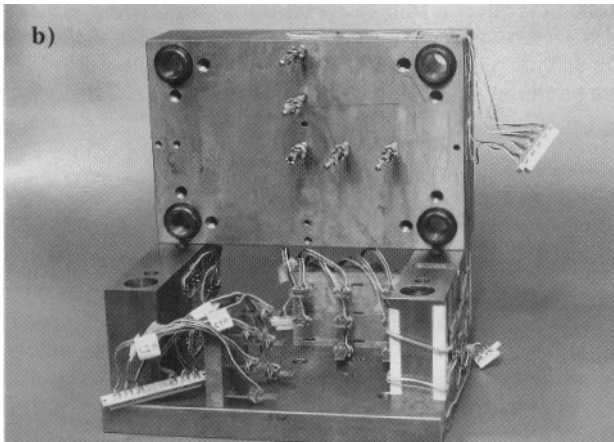
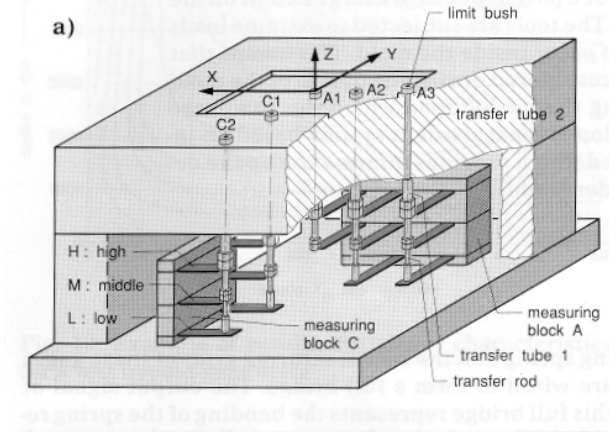


Fig. 2: Measuring point arrangement
a) diagram showing labeling of the measuring points
b) photograph of the measuring point arrangement

bottom of the plate due to spring pressure and the internal tube, transfer tube 1, is referenced to the top of the plate. The rod makes contact with the gating side of the tool. Contact is maintained by the initial tension in the bending springs and the transfer elements can move freely with respect to one another so that they do not impair measurements.

The three transfer elements are fitted with threads and lock nuts at their ends. It is then possible to exactly adjust the initial tension on the bending springs. The transfer system is illustrated in a photograph in Fig. 4.

Due to the large number of measuring points, many bending springs are positioned above or next to one another. Two measuring blocks are used to hold the elements which are clamped in the blocks at one end. The blocks themselves are attached with screws to the tool mounting plate.

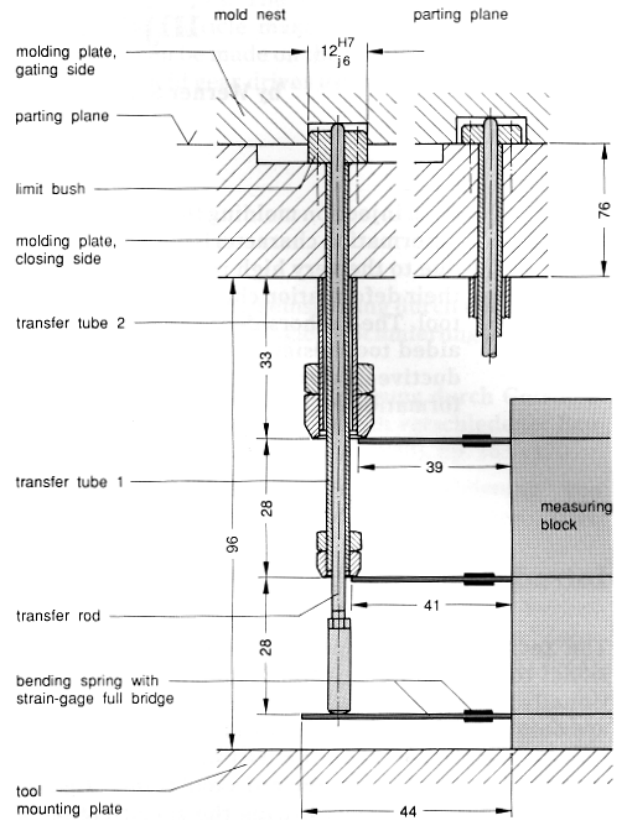


Fig. 3: Telescopic transfer system used for the deformation measurements

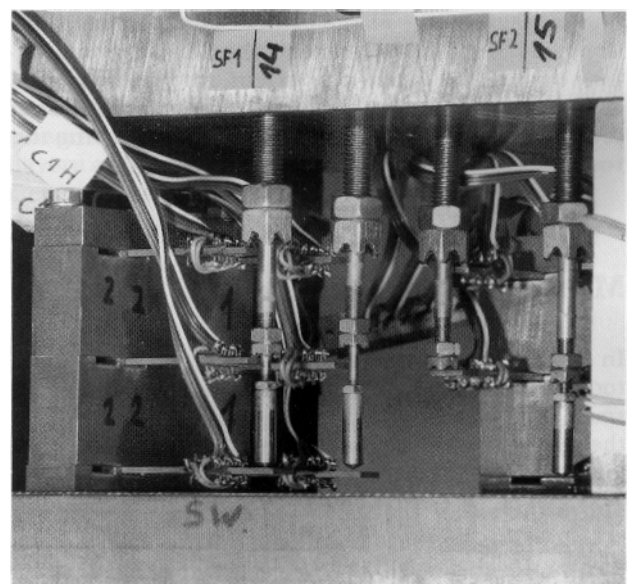


Fig. 4: Photograph of the transfer system

The limit bushes, which can be seen in **Fig. 3**, provide contact for the internal transfer tube with the floor of the mold cavity. This ensures that the deformation is transferred which occurs in this plane of the molding plate. Apart from the one under the gating inlet, all the limit bushes have a centrally located hole. The rod, which is pressed against the inside of the gating side of the mold, is passed through this hole. The limit bushes in the mold nest are recessed in the molding plate on the gating side, so that the measuring point is isolated from penetrating plastic.

The labeling of the measuring points is based on the following system. The measuring points in the x direction are named A_i , in the y direction C_j . Another suffix labels the corresponding level in the z direction, i.e. H for high, M for middle and L for low. This means for example that A2H measures the deformation on the bottom of the plate, A2M the deformation on the top side of the plate and A2L the deformation on the gating side. A pressure transducer is mounted in the cavity near to the gating inlet to pass the internal mold pressure to the control unit on the injection molding machine.

Calibration of the individual bending springs

Each individual bending spring was calibrated before the deformation measurements. For the calibration, the measuring signal supplied by the mounted full bridge of strain gages was found for each bending spring in dependence of the displacement of the transfer element and a line of regression drawn through the measuring points. The displacement of the transfer elements was measured inductively and a DMD 20A Digital Strain Meter was used for the amplification and display of the measuring signal from the strain-gage full bridge on the bending spring. The compression of the transfer elements due to the spring forces proved to be negligible.

Measuring points on the injection molding machine

The overall stiffness values for the injection molding machine and tool constitute an important criterion for the quality of the molded part. Therefore, the strains on the columns, which in turn give the column forces, were also measured as part of the experiments described here. The forces acting in the columns are transferred from the columns to the tool and they represent a measure of the load on the tool.

A strain-gage full bridge each with two strain gages of the type XY 916/120 was applied to each of the four columns. These strain gages each have two measuring grids with the measurement directions perpendicular to one another. A strain transducer for machine control was also fitted in a column producing a measurement

display on the monitor of the injection molding machine. Therefore a total of five measuring signals could be used for comparison purposes.

Carrying out the measurements

The UPM 60 Multipoint Measuring Unit, which was the instrument used to scan and amplify the measurements, is illustrated in **Fig. 5**. It can accept signals from up to 60 measuring points. The instrument, which is controlled by a microprocessor, can be programmed to specify the measuring points that should be monitored and the complete measurement sequence. In this application the instrument scanned 38 strain-gage measuring points in a specified sequence. The 225 Hz carrier frequency amplifier channel of the unit was selected for amplification of the signals from the strain-gage measuring points. The UPM 60 provides a freely selectable scanning rate. Depending on the requirements of the measurement application, an integration time of between 4 ms and 100 ms can be selected.

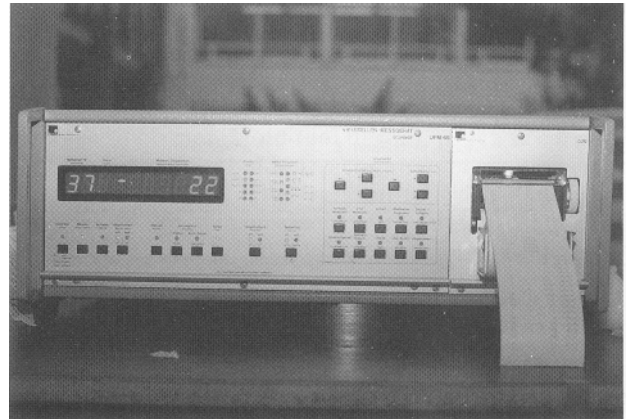


Fig. 5: The UPM 60 Multipoint Measuring Unit used for the cyclical scanning of the measuring points

An integration time of 20 ms was selected for the measurements described here. This gave a duration of just under two seconds for a measurement cycle with 38 measuring points using the 225 Hz CF amplifier channel. This meant that the internal mold pressure had to be held constant over a period from two to three seconds so that the pressure conditions were the same for all measuring points during the measurement cycle.

The measurements are shown on the display and can be printed out as a measurement log on the integral thermal printer.

Column forces

First of all the load on the machine columns caused by the closing force and the internal mold pressure was taken into account. The closing force is transferred by

the columns to the tool and the force transferred by each column was measured, as described, with strain gages. **Figure 6** shows an example of the measured column forces in relationship to the internal mold pressure. In the example, the column forces of the four individual columns are recorded cumulatively above the internal mold pressure for a closing force of 41 t (40.4 tons).

For an explanation of the curves shown in **Fig. 6** an "ideally stiff" mold tool, which exhibits no deformation under load and which opens under "over-injection" conditions, can be considered in contrast to the real tool. With this "ideally stiff" mold tool the column load due to the closing force remains constant for increasing mold pressure while ever the pressing force between the plate levels is greater than zero. At the moment of over-injection the force produced by the internal mold pressure exceeds the closing force and the tool opens. The column load noticeably increases as a consequence and increases further for rising internal mold pressure.

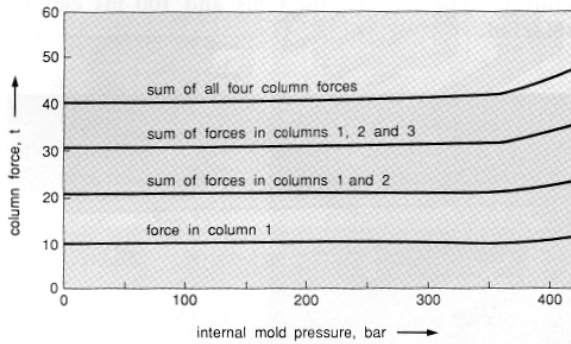


Fig. 6: Column forces in dependence of the internal mold pressure

The real tool is subject to an elastic compression under the action of the closing force. Due to the increasing internal mold pressure, the elastic compression causes a reaction effect. This produces a corresponding increase in the load on the columns. As with the ideally stiff mold tool, over-injection of the tool leads to a noticeable increase in the column load.

The experimental tool, which can be regarded as being "relatively stiff", enables the additional column load caused by reaction to be clearly recognized when the internal mold pressure increases. The bend in the curve at about 360 bar (5221 psi) and the increase in the slope of the curve clearly indicate the over-injection of the mold tool.

With regard to the load on the machine, the tool should be made as stiff as possible and, following the above argument, over-injection should be avoided.

Tool deformation

The deformation characteristic of a tool depends on its design. Here, the manner in which the molding plates are supported is very important. Basically, two

methods of supporting the plates, as shown diagrammatically in **Fig. 7**, can be considered. Where the molding plate is just supported, there are no moments acting on the supports, whereas the supports of a plate clamped on two sides are subject to moments. Therefore, the clamped plate is stiffer, i.e. its deformation is smaller under defined loads, than the plate which is just supported. In the following, purely analytically calculated deformations are compared with deformation measurements.

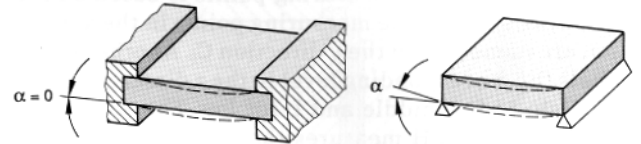


Fig. 7: Two-sided clamping and freely supporting methods of holding the molding plate represent the limiting cases of molding plate fixture

The molding plate on the closing side is deformed by the internal mold pressure via the guides. In this respect the maximum deformation in the middle of the plate and at the edge of the cavity is important for the quality of the molded part. The measurements shown in **Fig. 8** were taken at a closing force of 57 t (56.1 tons). The computed deformation values for the supported and the clamped plates are drawn for comparison.

In the lower region up to about 115 bar (1668 psi) the measurement curves exhibit a linear shape, but then they have a clearly defined bend with a superproportional slope. The curve finishes at pressure values which lead to substantial over-injection of the molded part. The series of measurements had to be interrupted here. The lower straight line indicates the computed deformation for the plate which was clamped on

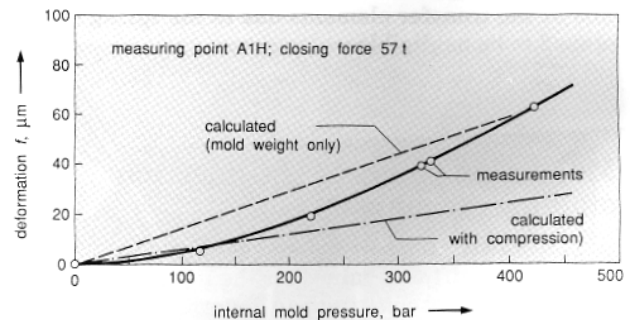


Fig. 8: Deformation of the molding plate measured in the center of the plate in relationship to the internal mold pressure

two sides and the upper straight line shows the deformation for a freely supported plate. The space between the two straight lines can be regarded as the area of spread in which the plate is not completely clamped firm nor completely freely supported. For low pressures the methods of supporting the plates, i.e. clamped or freely supported, give roughly the

same results. The measurement curve shows that a sudden change does not occur between the "clamped" or the "supported" states at a certain pressure or at a certain lifting force. The larger the projected area and the internal pressure of the mold nest, then the earlier the parting plane will be loaded. The deciding factor is therefore the ratio of the closing force to the lifting force.

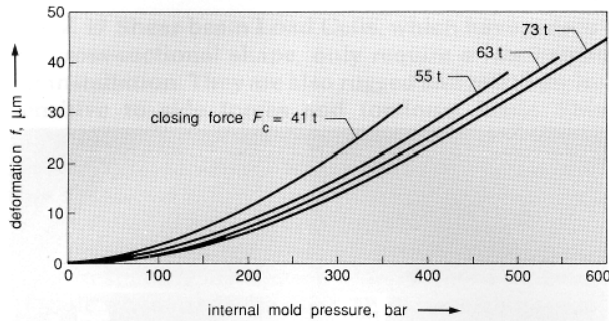


Fig. 9: Effect of the closing force on the molding plate deformation

The superproportional slope of the molding plate deformation, which occurs with increasing internal mold pressure, can be explained by stating that the closing force of the machine is no longer great enough to guarantee contact between the two molding plates. Relative movement between the molding plates can therefore occur. In addition the transition from the clamped to the freely supported case can be explained by the tilting of the molding plate with respect to the guides, combined with a deformation of the guides. A direct relationship between the closing force and the deformation of the molding plate on the closing side can therefore be made. The deformations for various closing forces shown in **Fig. 9** were determined for checking the above relationships. A transition from the clamped to the supported case can be clearly re

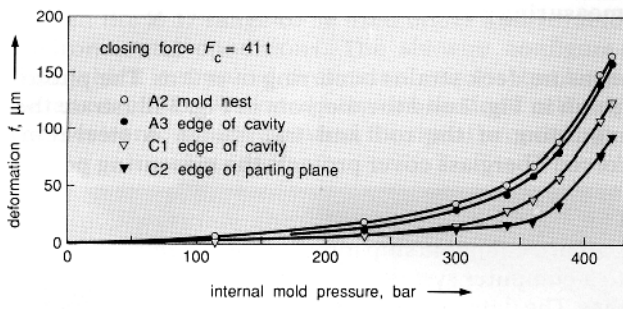


Fig. 10: Deformations on the molding plate occurring at different measuring points for the same operating conditions

cognised for increasing closing force, i.e. the superproportional slope of the curve is displaced toward the higher pressure values. It therefore follows that the closing force has a significant effect on the deformation.

Figure 10 shows the deformations measured at constant closing force on four different measuring points on the mold tool in dependence of the internal mold pressure. From the rise in the curves it can be clearly seen that the cavity distends like a balloon. At a pressure of about 350 bar (5076 psi) a bend in the graph appears and from this point onward the curves extend with an increased slope almost parallel to one another. The bend in the curve signals the opening of the tool as a result of over-injection. Thereafter, a significant additional load occurs on the columns. The expansion of the cavity is not then just a problem involving the tool, but instead it must be considered in conjunction with the machine stiffness and the set value of closing force.

Conclusion

Injection mold tools are subject to extreme loads. Internal mold tool pressures of over 1,000 bar (14,504 psi) are not uncommon. As a consequence adequate dimensioning of the tool is particularly important at the design stage if the quality requirements of the molded part are to be met. Mold-tool design, which is carried out using computer-aided techniques, is based on a theoretical model, the reliability of which was checked by the measurement of the deformations on an experimental mold tool. A specially developed measuring system provides information on some fundamental deformation effects when an injection molding tool comes under load.

During all the experiments it has been shown that the closing force has a significant effect on the deformation of the tool elements. Any effect that the closing force has on the deformation has previously not been taken into account in most computational methods. It has been found that an increase in the closing force reduces the deformation of the molding plates. This is caused by a change in the supporting conditions in the region of the molding plates.

Prof. Dipl.-Ing. Werner Schneider lectures in engineering mechanics and designing with plastics at the Märkischen Fachhochschule Iserlohn, FRG. **Dipl.-Ing. Frank Bayerl** and **Dipl.-Ing. Bernd Goltz** have together completed their diploma project upon which this article is based.