Numerical simulation of the utility glass press-and-blow process

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Introduction

Glass melt press-and-blow process is a typical two–stage technology allowing automatized production of the hollow utility glass. The use of numerical simulation means in the premanufacturing stage is the best way to making new job engineering more effective.

The comprehensive numerical simulation of glass melt forming allows the course of particular phases of the forming cycle to be monitored as well as the effect of individual technological parameters on the forming cycle course and subsequently also on the production quality to be evaluated. Based on a detailed analysis of the forming cycle, it is possible to identify areas where possible technological problems can occur, and to optimize particular phases of the forming cycle prior to a new assortment production is started and so to minimize manufacturing costs.

Description of press and blow process

Feeding of thermally stabilized and chemically homogenized glass gob is a initial step of glass forming cycle. During feeding glass gob having desired shape and weight is transported to a plunger working surface using a delivery chute.

The forming cycle itself starts in the moment when glass gob falls to the plunger working surface – Fig. 2 b). After technological delay, the glass gob is preformed to the required shape (technological blank) using the plunger and blank mould – Fig. 2 c) and d). During pressing a noticeable temperature interaction occurs between the glass melt and forming tools. This temperature interaction substantially influences temperature field distribution in the blank being
formed, and subsequently it has also an influence on the course of a final operation of the forming cycle as well as on the production quality.

When carrying parison to a support plate of a turntable machine bearing table, a blow head is moved to the pressed piece. Then parison, rotating continuously around its vertical axis, is formed due to gravity forces and compressed air impact (Fig. 3).

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**Figure 2.** – a) Fall of glass gob to the plunger; b) glass gob falls to the plunger; c) pressing of parison; d) repressing of parison – final stage

**Figure 3.** – Free forming: a) Fall of parison to the carrier ring; b) parison free forming; c) parison blowing; d) parison cooling by blasting
A final stage of the forming cycle is glass melt forming in a blow mould (Fig. 4 b) using compressed air. In the course of this operation, no immediate contact of glass melt and the mould work area occurs. Working surface of the mould is covered by a special porous layer. The rotating parison and mould work area are separated from each other by a steam interlayer modifying frictional conditions, and providing both uniform heat removal and high quality of product final surfaces.

![Diagram](image)

**Figure 4.** – Glass melt in blow mould: a) Elongating glass melt in the blow mould; b) final blowing in the blow mould; c) product final shape – opened blow mould and removed blow head.

After forming, the parison (Fig. 4 c)) is moved to an annealing lehr where a residual stresses are removed using controlled cooling. A scheme of the 12-section carroussel machine FORMA – KUTZSCHER IBS 12/R44 producing given assortment is shown in Fig. 4 d).

**Numerical simulation of press and blow process**

From the physical point of view, the glass forming cycle is the complex thermomechanical problem with strong interaction between heat transfer and viscous flow of molten glass. Because glass melt viscosity depends considerably on temperature the course of glass forming is primarily governed with distribution and development of temperature fields in glass formed.

An approach to the solution of the numerical simulation problems is based on the strategy of the coupled thermo-mechanical solution (Fig. 5). Balance equations describing the glass melt flow and heat transfer can be expressed by mechanical and thermal equilibrium equations in set of Lagrangian coordinates, which must be completed by appropriate boundary and initial conditions. As for the temperature area within the forming interval, glass melt can be considered to be viscous incompressible liquid (Fig. 6).
Optimalizace vlastností strojů a pracovních procesů
To create a comprehensive numerical model, commercial nonlinear FEM (Finite element method) code MSC MARC was used that allows the all fundamental parameters influencing the press-and-blow process to be integrated. Owing to the solved task complexity, it was necessary to use external subroutines when controlling the virtual forming cycle course. These subroutines were also used when specifying constitutive relations, controlling heat transmission on the interface between glass melt and mould, and defining the surface tension.

To define interactions between glass melt and mould was a substantial problem. When specifying a mechanical contact, the automatic contact algorithm implemented in the code used was applied. Thermal interaction was described using the contact heat transfer coefficient varying in time. In the course of the project solution, many variants of the heat transfer definition were carried out and analysed. The option derived from the equation describing an ideal contact [1] was chosen to be preferable variant

$$\alpha^{MKP} = S \, B \, \frac{\sqrt{t_2} - \sqrt{t_1}}{t_2 - t_1} \, \frac{T_{s0} - T_{f0}}{T_s - T_f}$$

which guarantees that amount of heat removed is invariant to the time step choice. Quality of the thermal contact on the interface glass-mould was controlled by the coefficient $s$. The heat transfer coefficient (or temperature flow respectively) on the interface glass – porous mould is very
complex factor depending on the temperature, contact time, amount of water in the system, etc. The amount of heat removed from the glass melt to porous mould was defined by the relation as follows

\[ Q_s = r(m_0 - m_z) + c m_0 (T_z - T_0) + Q_f. \]

\( T_s \) glass melt temperature, \( T_s0 \) glass melt initial temperature, \( T_f \) mould temperature, \( T_f0 \) mould initial temperature, \( t_2 \) time from contact beginning up to increment beginning, \( t_1 \) time from contact beginning up to increment end, \( B \) is material constant depending on material properties of glass melt and mould, \( m_0 \) and \( m_z \) is initial and residual amount of water absorbed in the porous surface layer, \( T_0 \) is water initial temperature, \( T_z \) is temperature of residual amount of water on the end of contact, \( Q_f \) is heat removed by mould, \( Q_s \) is heat removed from glass melt, \( T_p \) is temperature of body surface, \( T_\infty \) is surrounding temperature, \( Tr \) is temperature value of surrounding body for calculation of radiation, \( \varepsilon \) is emissivity, \( \sigma \) is Stefan-Boltzman constant, \( \alpha_r \) is heat transfer coefficient – the effect of radiation, \( \alpha_c \) is heat transfer coefficient – the effect of convection, \( \lambda \) is conductivity, \( c \) is specific heat, \( u \) is displacement, \( \sigma \) is stress, \( \varepsilon \) is strain, \( f \) is volume force, \( \eta \) is viscosity of glass, \( s \) – coefficient taking quality of the contact glass-mould into account.

Results of numerical simulation

In order to be possible to consider the computational model as an effective tool for the glass forming process optimization, it must give a sufficiency of information about the course of appropriate phases of the forming cycle. Therefore user subroutines were implemented to the model allowing the integral quantities such as amount of heat removed from glass melt to moulds, mean temperature of the glass melt and mean viscosity to be calculated. The press-and-blow process numerical simulation is demonstrated by pressing of large thin-walled vase of soda potash glass.

To verify the model reliability, series of experimental measurements was carried out:

- measurements of surface temperatures for the glass melt and mould,
- temperature measurements in the plunger section,
- calorimetric measurements,
- thermovision measurements (Fig. 7).

Many sensitivity analyses was realized using the FEM model created so that chosen input parameters were evaluated. Besides the sensitivity study of the effect of physical and technological parameters, parameters of the applied model (size of the network elements, time step, setting-up of convergent criteria) were also analysed in details. The numerical model parameters used for final calculations spelt a compromise between time demands of the calculation and the solution accuracy.
Apart from the sensitivity analysis of the influence of thermophysical properties, forming tool temperatures, configuration of the forming cycle or time course of compressed air, the effect of the surface tension on the forming cycle course was also analysed.

Two basic verifying criteria were chosen for an evaluation of the computational model, namely a comparison of measured and calculated geometrical characteristics of the parison during gravity forming (Fig. 8) as well as an analysis of the wall thickness of the vase. When comparing the geometrical characteristics (Fig. 8), it is possible to arrive at a conclusion that calculated values reproduced measured ones relatively well. A certain deviation was found in initial phases of the free forming, which can be caused by viscosity definition inaccuracies in the extrapolation part of the viscosity curve (at low temperature).
Conclusions

The article indicates a general approach to the numerical simulation of the press-and-blow process. Possibilities for the use of numerical simulation means are demonstrated using large vase forming as an example where the free forming figures prominently. The analysis of the simulation results showed that the computational model could be a useful tool for monitoring the press-and-blow course as well as for detecting the effect of appropriate technological parameters on final products. Although computational programs allow the forming process to be simulated, a limiting factor of the effective application of virtual simulations is knowledge of thermal-mechanical properties and boundary conditions, especially on the interface glass-mould.

References:


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