PFEIFFER VACUUM

MULTI-STAGE VACUUM PROCESS VACU^{2} REVOLUTIONIZES DIE CASTING

For many years, die casting has been a proven and tested process in the industrial mass or series production of structural parts for various applications. In this process, a liquefied material – the so-called "melt" – is pressed into a mold cavity where it then solidifies.

Many foundries use vacuum for this process. In a joint project with the consulting and development company for foundry, Glimo N.V., Pfeiffer Vacuum developed a groundbreaking multi-stage vacuum process for die casting – the Vacu^{2}.

The goal during the development of this process was set high: The plan was to create a revolutionary vacuum process in die casting, which eliminates the disadvantages of existing processes in terms of the vacuum reached, the process safety and process control. This plan was based on a synthesis of scientific and practical expertise – by carrying out calculations and simulations as well as extensive practical tests and measurements.

Vacuum in die casting

The task of the vacuum system in a die casting system is to evacuate a given volume of air from the mold cavity and the shot sleeve within the shortest possible period of time. This avoids air inclusions in the casting. Vacuum has been used in die casting for several decades now.

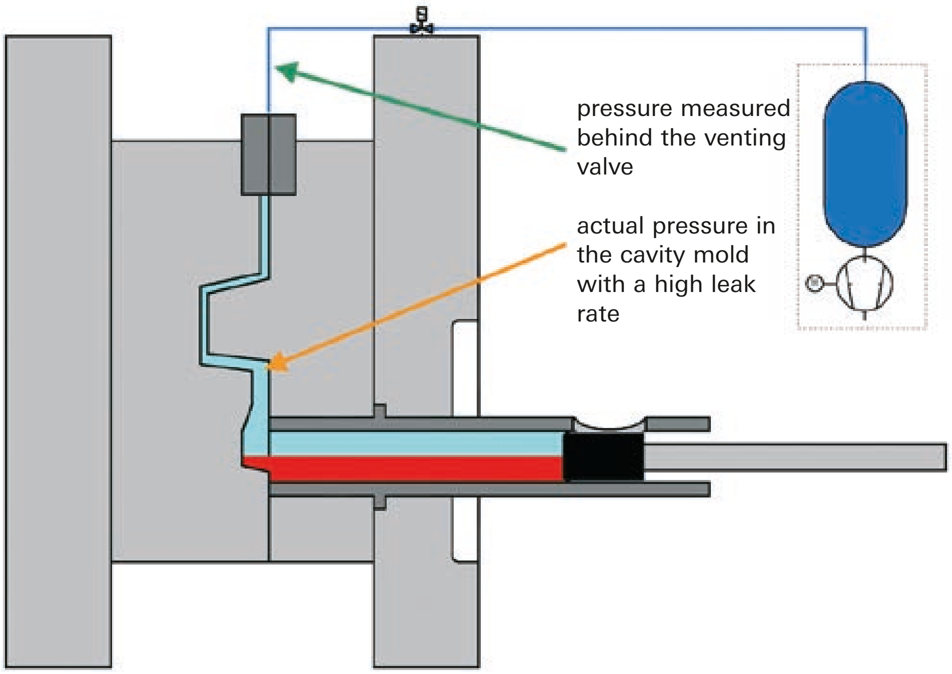

Figure 1a: Standard vacuum process for pressure die-casting

Conventional vacuum processes – disadvantages and difficulties

In the past, mainly two processes have been established:

- With the "standard procedure" (Figure 1a), after the piston has traveled past the shot sleeve inlet, a chamber in which underpressure has been established is connected to the mold cavity.
- With the second process (Figure 1b), evacuation already takes place during the metal dosing process.

In both processes, the connection between the vacuum chamber and the mold cavity is mainly established through a venting valve (vacuum valve) incorporated in the mold. These valves, which are often produced at considerable expense, are designed on the one hand to prevent metal from entering the vacuum system, but on the other hand to still allow as much air as possible to escape from the mold cavity. These conflicting requirements are one reason that some of these valves are relatively susceptible to failure or require intensive maintenance.

There are two types of valves that are widely used on the market:

- Mechanically-closing valves (piston valves)
- Valves that retain the metal in a narrow gap when it solidifies ("washboard valves")

Particularly with aluminum parts which require to be heat treated or welded, vacuum die casting is indispensable. For all other components, there are many weak points regarding the vacuum process application, which previously led many die casters to shy away from using vacuum. These weak points include the blocking effect or the poor process stability that these processes exhibited. The Vacu^2 process is designed to counteract precisely these weak points.

The blocking effect as an interfering factor

The main task of the vacuum system of a die casting machine is to evacuate a given volume of air from the mold cavity and the shot sleeve within a few seconds. Existing systems have to extract this volume of air through the narrow gap of the gate, the geometric constrictions of the mold, the connections of the overflows, the vacuum channels in the mold and not least through the venting valve. Poor conductivities can be expected as a result.

In addition, the laws of physics thwart the process with the blocking effect. The blocking effect occurs under certain pressure conditions at the narrowest point of a pipe. In the best case, i.e., with a correctly designed vacuum system, this would be the venting valve.

In its cross-section, the gases reach supersonic velocity through extreme adiabatic expansion. As long as this condition persists, the amount flowing through cannot be

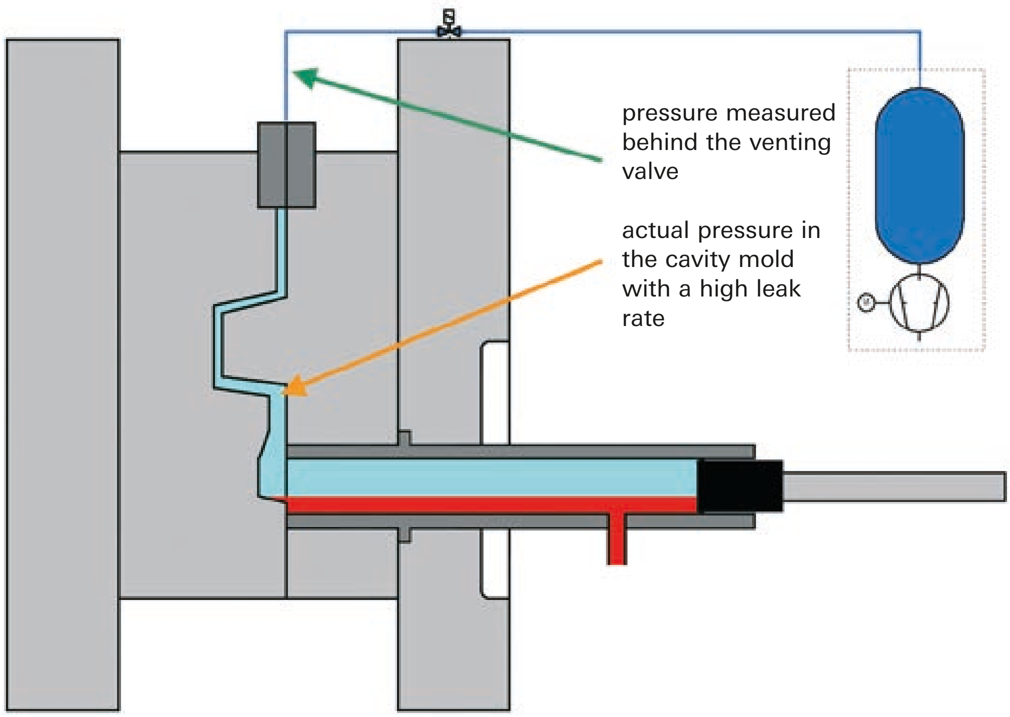

Figure 1b: Vacuum process with metal dosing during the evacuation process

increased either by lowering the pressures in the chamber or by enlarging the vacuum chamber.
Calculations and measurements revealed that in most cases, the available time during die casting is not sufficient to come even close to the desired vacuum levels.

Difficulties with process stability

Figure 2 shows a typical pressure curve, as it usually occurs in vacuum die casting processes. The upper curve represents the actual pressure in the mold cavity and so also the main result of the evacuation process. Unfortunately, this value was rarely able to be measured in the past and so foundry operators usually never got to experience it.

The lower curve represents the measured values behind the venting valve. The actual pressure curve initially shows a steep drop in pressure and then levels out at a certain value.

Among other things, the steepness of the edge and the final pressure level depend on several external factors that determine the process (Figure 6, column 1). The curve varies significantly in its shape when there is a:

- Change in the volume to be suctioned (casting size, chamber volume, connections)
- Change in the leak rate of the entire system (tightness of the mold or the piston)
- Change in the conductivities of the entire system (caused by pollution, congestion).

Figures 2 and 3 show as an example the influence of the leakage rate on the ultimately achievable vacuum level. In addition, in most cases, the time available during the die casting process is not sufficient to achieve the vacuum level mentioned. However, even minor process variations during the still steep portion of the curve will produce very different results. Fluctuations of over 100% of the vacuum achieved within a casting campaign are not uncommon.

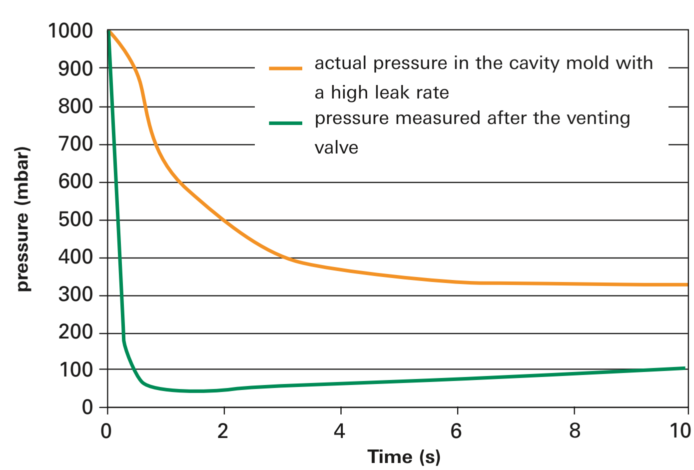

Figure 2: Measured and actual pressure with a relatively leaking mold

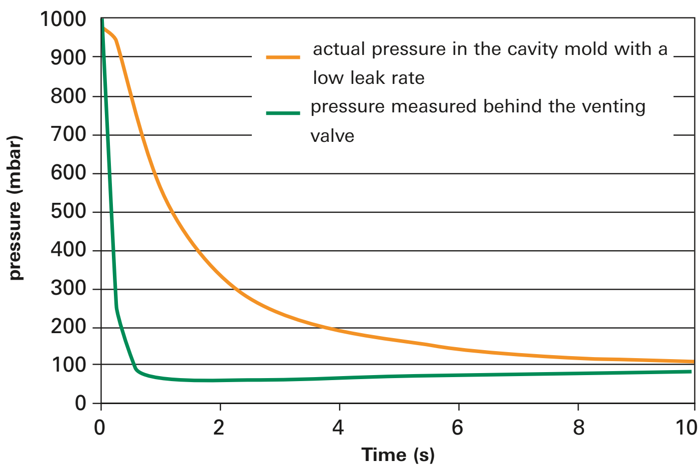

Figure 3: Measured and actual pressure with a relatively leak-tight mold

Process control during the standard procedure with sources of error

For process monitoring, a pressure measurement is carried out behind the venting valve during the standard procedure. The measurement is subject to several sources of error with respect to the measurement of the pressure attained or the maximum trapped volume of air:

- The narrow cross-sections and the occurrence of the blocking effect do not allow a measurement that is relevant for the pressure in the mold cavity in the further course of the line. In fact, this measurement is influenced more by the pressure in the chamber than by the actual pressure in the mold.
- It is a dynamic measurement. It is known that the velocity of gases flowing through a line generates additional negative pressure. This falsifies the measurement result.
- Changes in the conductivities (contamination, congestion) additionally result in a considerable measurement error.

Figures 3 and 4 show that the actual pressure values exhibit major differences, even though the measured (lower) pressure curves hardly differ from each other.

It is not possible to establish a reliable relationship between the main parameter of the process (= vacuum in the mold) and the measured value.

The multi-stage concept as the optimal solution for die casting

The difficulties and interfering factors during the standard procedures provided the impetus to try new approaches and design a process that meets today's requirements of casting technology. The result: The multi-stage vacuum process Vacu^2 and the energy-saving version Vacu^2 eco.

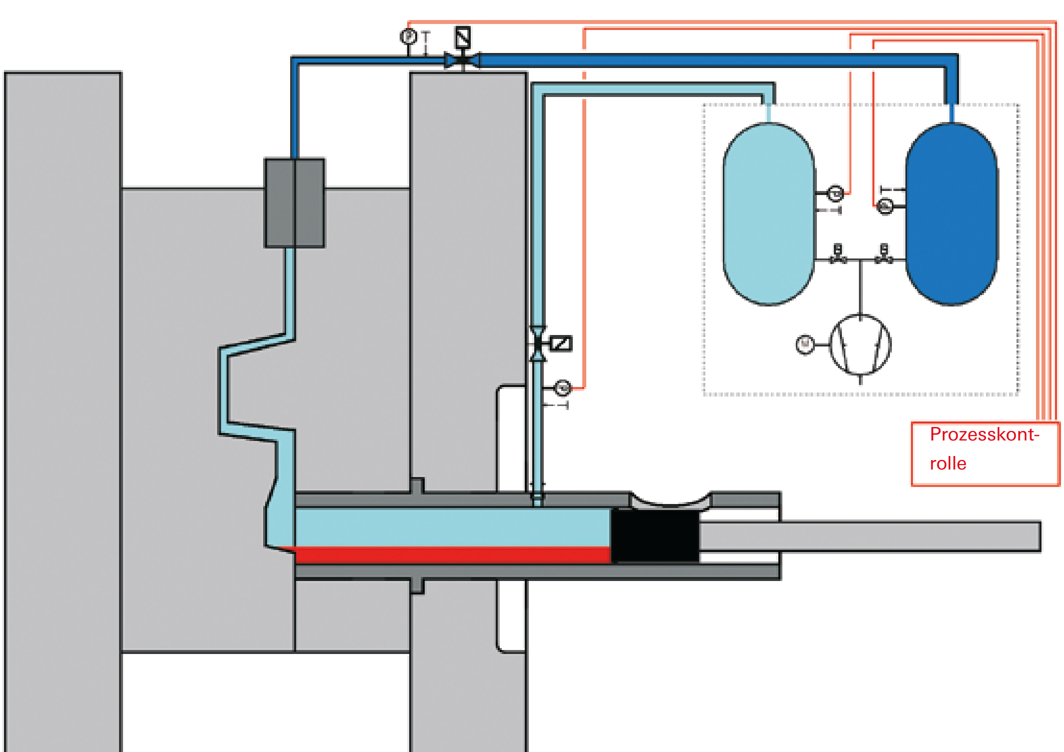

Figure 4: Schematic diagram of a variant of the multi-stage vacuum process

Figure 4 shows the standard version of the new process in schematic form. The solution shown has two vacuum stages and a direct connection to the shot sleeve. Depending on the size of the machine, the filling level and the required tightness of the piston, versions with a shot sleeve cover are also possible.

With this new multi-stage process, two mutually independent but coordinated vacuum stages are created. In the first stage, a chamber under vacuum is connected to the mold cavity via the shot sleeve. After the chamber is disconnected from the shot sleeve again, the second vacuum stage is initiated. For this purpose, another chamber is connected to the mold cavity. The connection can be made via one of the conventional venting valves. Then, through a powerful pump combination, which has been tailored specifically to the vacuum die casting process, the chambers are put back exactly to the adjustable initial vacuum values to ensure the same starting conditions for each shot.

Chamber volumes

In the two-stage process, the volumes and initial pressures for each stage of the process can be adjusted and set separately. With proper layout, the complete independence of the two vacuum circuits leads to a decoupling of the influencing factors (Figure 5, stages 1 and 2), so that only two main variables determine the individual process stages. The decoupling of the two vacuum stages also exponentially increases the theoretically achievable vacuum. Since the second vacuum stage can already begin with a pre-evacuated space, significantly lower pressures can be achieved with only a fraction of the comparable total chamber volume that would be required under a single-stage process.

Process stability and vacuum values attained

The pressure curve in the two-stage process is completely different from that attained in the one-stage process (Figure 6). The chamber volume, initial pressure and connection cross-sections are designed for the first stage in such a way that – in contrast to existing methods – a balance is created between the chamber and the mold cavity. Thus, an absolute pressure of about 50 mbar can be achieved in the mold cavity after only 0.5 to 1.0 seconds. With such fast processes, the leakage rate is hardly noticeable. The pressure curves differ only marginally in the first stage (Figure 6). A significant exchange of heat does not take place either, so that adiabatic changes in the state of the gases can be assumed. The significant temperature changes that occur in adiabatic expansion must be taken into account, of course (Figure 5, stage 1).

The initial value at the start of the second stage already undercuts the classical methods by far. Since almost the entire volume of air has already been removed during the first stage, the second stage is influenced only to a secondary degree by the volume and the available time. A reversal of the stability criteria even takes place. In fact, the greater the volume of the parts in the casting and the lower the remaining available time (Figure 6, stage 2), the less the pressure readings will change. During the second evacuation stage, the pressure level changes more slowly than during the first stage. It may rise or fall, depending on the leak rate and conductivity of the overall system. Ultimate pressures of 20 mbar have already been reached (Figure 7). What is even more important than the absolute value is the stable course of the pressure curve. Variations in process conditions lead to only small changes in the vacuum achieved. An effect analysis demonstrated that changes in a stage are attenuated by the other stage.

Through these modified dependencies, vacuum die casting is opened up in principle to molds with higher leakage rates, slides, less expensive seals, or very large volumes.

Process control at the heart of the Vacu^2

Comprehensive process control is a mandatory requirement for modern production processes. The increasing demands on part quality, process documentation and cost optimization led to modern casting systems having elaborate process monitoring systems for tracking and adjusting most process parameters. Vacuum systems as a component of casting cells must keep up with this development and be integrated into the control system of die casting machines. This requires that not only the main "vacuum" parameters are monitored and documented but also the changes in other process-relevant, potential interference variables such as leakage or conductance.

The process control is therefore the actual heart of the new process. In addition to a PLC control, which purely regulates the processes, the system has a PC-based process monitoring system. This is how the elaborate but necessary algorithms are integrated into the process control. With this help, the vacuum achieved and the deviations in leak and flow rates can be quickly determined with every shot.

However, to achieve a meaningful calculation, it is necessary to obtain adequate measurement data correctly and precisely. To remove the fundamental mathematical indeterminacy of the describing system of equations, the following approach is used:

- Measurements are carried out with highly accurate absolute pressure measuring probes (resolution <0.5 mbar) in four places: Due to the smaller chambers, the pressure measurements are significant – static and dynamic measurements can be performed in the lines at different times
- The relevant laws relating to compressible media are taken into account in the calculations
- The decoupled parameters are mathematically considered as primarily independent of each other.

Before proceeding with the actual casting, different tests are carried out. These are used to determine the characteristic values of the system that consists of the die casting machine, mold and vacuum system. They can be compared with previ-

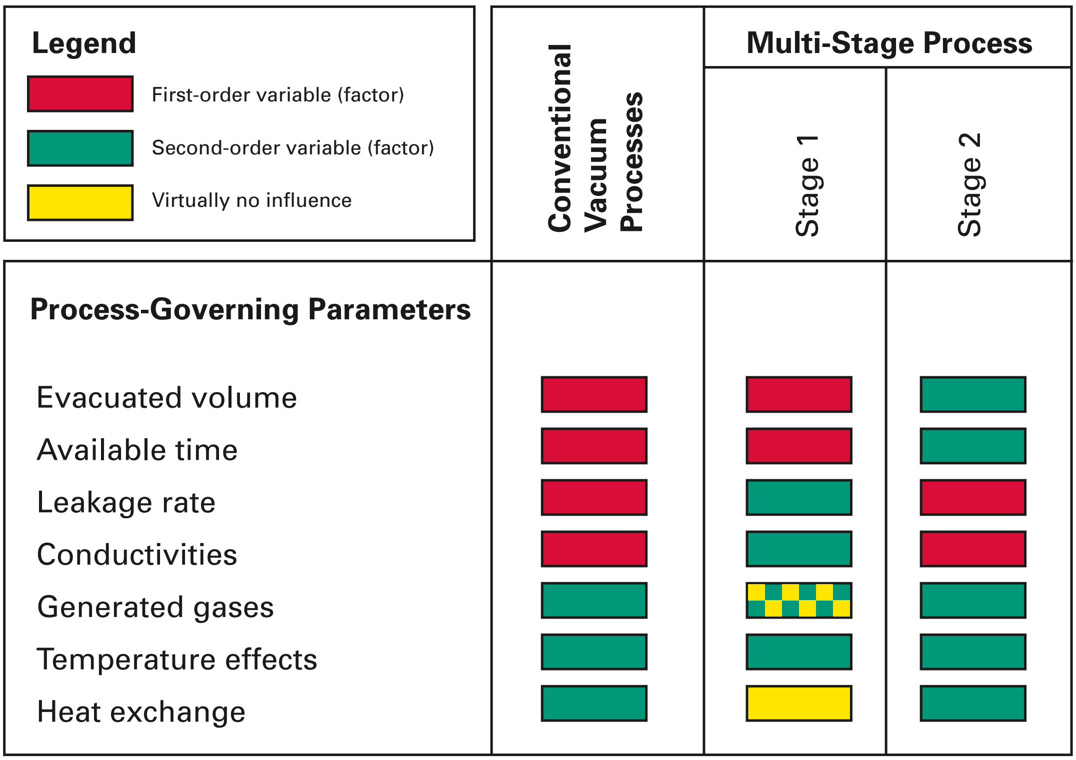

Figure 5: Significance of external influencing factors during the different vacuum processes

ously recorded data. This ensures that reproducible initial conditions prevail and the parameters are within the required limits.

During casting, the process is monitored through five parameters. Two of these are directly determined and three are derived from measurements. The actual final pressure in the mold cavity as well as changes in leakage rate and conductivity are displayed. The monitoring parameters are assigned and documented for every shot. They can be provided with intervention and fault limits. The process parameters at the beginning of casting are proposed to facilitate the setting of the process control system.

Tests and results

The Vacu² system was tested at several foundries with pressure die casting machines in the ranges of 7,000 to 35,000 kN. To determine the application range of the process, tests were conducted on both, sealed and unsealed molds, as well as molds with multiple slides. All application combinations produced excellent results with respect to the vacuum achieved and the quality of the components. Depending upon the application in question, absolute pressures of between 20 and 100 mbar were achieved in the mold. The component quality was determined through

- Mechanical characteristics
- X-rays
- Annealing tests
- Welding tests

Up to an absolute pressure of 40 to 50 mbar, significant differences in the casting quality could be detected. In addition, the characteristics of venting valves and pistons as well as the influences of mold design were investigated. The simulated values showed very good correlation with the values measured under real conditions and confirmed the forecasts relating to the influence of volumes, initial pressures, conductivities, leak rates, and temperature effects.

Outlook: Cost saving potentials and areas of application

The new process provides die casting operators with a range of different cost savings:

- Better vacuum leads to better component quality
- Reliable process monitoring reduces the rejection rate, as process variances can be identified early on and countermeasures can be initiated
- Greater process transparency speeds up optimization of the entire die-casting process, as it eliminates the need for "trial and error" procedures

- Since the process is less susceptible to leakage and conductivity, the time and expense required for mold-building can be reduced and precisely tailored to the relevant requirements.

The process also offers further opportunities to use vacuum profitably, such as for the following:

- Slide-equipped molds or with a large component volume. These now no longer pose any fundamental obstacles with respect to generating high-quality vacuum.
- A broader category of demanding components. Here, the new technique is especially worthwhile.

Vacu² eco efficient solution for small chamber volumes

The energy saving version, Vacu2 eco, for pressure casting machines with a clamping force of up to 750 tons permits the use of the multi-stage vacuum process with high efficiency and low energy consumption. This version is ideal for small chamber and mold volume, and thanks to the low energy consumption it offers potential for saving operating costs.

The multi-stage vacuum process therefore meets all requirements relating to process safety and thus can function as a fully fledged part of the modern die casting process. Vacuum can be used profitably, reproducibly and efficiently in the foundry industry in the future.

Would you like to receive more information on the multi-stage vacuum process Vacu²? Our experts would be pleased to assist you - please contact us!

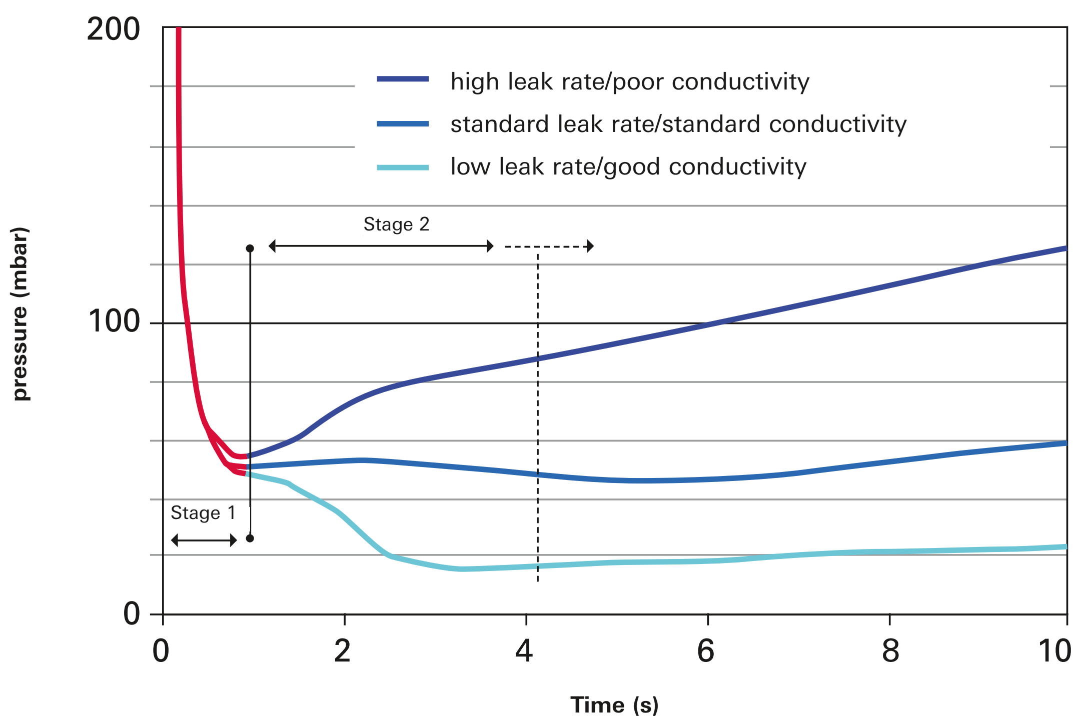

Figure 6: Actual pressure curve in the mold during the two-stage process

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