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# Vacuum Die Casting User's Guide

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“A casting is a series of blow holes, shrinkage, porosity and other discontinuities more or less held together by a metal of questionable quality and usually reinforced by welding”. (Elwin Roy). This quasi-quote holds some truth, in particular for die casting. The high speed of filling the cavity with molten metal does not normally allow the air to escape. Gas porosity and shrinkage are therefore often encountered in die casting and can interfere with heat treating and surface treatments. During heating of the parts, trapped air expands forming blisters. Consequently, many die cast components cannot benefit from the improved mechanical properties provided by heat treating.

The main source of gas porosity in die cast components is gas entrapment during the shot and fill steps of the process. These gases originate from ambient air, by-products of sprayed cooling water and die lubricants. Control of the shot profile, good gating practices and venting can minimize but not completely eliminate gas entrapment. When correctly utilized, vacuum die casting can further minimize porosity to very low levels, permitting heat treating and application of surface treatments to die cast components. An added benefit of vacuum assist die casting is enhanced filling of thin sections. Unless effectively removed, gases trapped in the die cavity can slow filling causing misruns. While in heavier sections this delay is acceptable, in thin sections it can not be tolerated.

This guide reviews the most common vacuum assist methods and procedures. It highlights the advantages and limitations of each method. The resources provided will hopefully assist die casters considering vacuum alternatives in making informed decisions on implementation of this technology in their operation.
Die casting shines when large, thin-wall castings have to be made. The molten metal is injected at extreme velocity into the cavity so that before it has a chance to solidify it fills the cavity. However, while being injected in the atomized condition it also mixes with the air and the other gases present in the cavity, leading to porosity in die cast parts. While the high intensification pressure applied after filling minimizes the size of the pores, it can't eliminate them. In contrast to die casting, other metal mold processes such as low pressure and squeeze casting utilize a controlled, slow and quiescent fill that prevents air entrapment. These processes produce high integrity parts, but are limited to heavier wall sections. Eliminating most of the air and other gaseous species from the cavity before injecting the molten metal and during filling is a logical way to minimize the porosity in the casting. This is not necessarily an easy task. The air and the evaporated die-lubricant inside the die-cavity will be compressed up to 1800 mbar at the beginning of the injection-phase (A). As the molten metal flows advances during the filling-phase, the air pressure doubles or triples (C). In some sections (i.e., last filling point inside the casting, dead ends etc.), the applied intensification pressure of 100 bar is lower than the trapped air pressure, resulting in visible gas holes characterized by round appearance with fine and shiny surface. Figures 2.1 and 2.2 illustrate the typical pressures in the cavity with conventional and vacuum die casting. Significantly lower pressures are measured when a vacuum system is used to evacuate air. While air entrapment is not eliminated, it is significantly reduced as shown in Figure 2.3.

Prior to making a shot, air is present in the shot sleeve, metal feed system and die cavity, as illustrated in Figure 2.4. Additional gases are created during the injection of the molten metal due to evaporation of cooling water and die lubricants. During pouring of the molten metal into the shot sleeve, some of the air in the shot sleeve is displaced with metal. However, around 70% of the sleeve space still contains air. As the liquid metal is injected into the cavity the air mixes with the molten metal and is compressed into the casting during metal solidification. This sequence of events occurs to some extent even if the die casting...
machine is fully capable of attaining critical slow shot speed (Fondarex). For porosity to be eliminated or minimized, the air and other gases must therefore be efficiently evacuated in the short time interval between injection of the molten metal from the shot sleeve into the cavity and the solidification. This means that a specific volume of air must pass through a defined venting area in a given amount of time. If the time or vent area are not adequate to allow the entrapped air to escape, porosity will occur in the casting.

In conventional die casting the air is pushed out of the cavity into overflows and venting orifices. These allow a certain amount of air to escape to atmosphere or be displaced to an area outside the casting. Most vents are designed to a thickness of .005" to .006". The force required to "push" air from the tool to the atmosphere is therefore quite high. Vents and overflows have to be maintained clean and in good condition to perform their role. Under normal operating conditions vents are frequently prone to close off due to metal flash and die lubrication build-up. In addition, if vents are not maintained free of flash, the die steel around the edges of the vents can distort and close off or reduce the effective area.

The vent area is often calculated as a percent of the total inlet gate. For example, a casting with a 0.100in² inlet gate area would be vented at 30% of that area, or a vent area of 0.03 in². The underlying principle of this calculation ad-

Using vacuum to eliminate the gas from the die cavity is an attractive alternative, but comes with a price. Maintaining the high levels of vacuum required in complex dies (especially those having numerous slides) is not an easy task; many surfaces and joints must be sealed against leakage and the intrusion of ambient atmosphere. Relatively expensive tooling and equipment, the premium nature of the alloys involved and greater expense during processing combine to make high vacuum die casting significantly more expensive then conventional die casting (still, parts made in the process can be very cost-effective). Thin, rangy parts are notable difficult to eject from a steel tool and cool to ambient temperature without significant warping and requirement for subsequent straightening (Jorstad).
Chapter 3
Methods and Equipment for Applying Vacuum to the Die

The Gibbs Verticast Process

This process is employed in production of aluminum and magnesium castings at Gibbs Die Casting in Henderson, KY and at Gibbs operations overseas. The vacuum is applied to a gasket-sealed, leak-tight cavity. In addition to evacuating gas from the cavity, the vacuum is also used to draw molten metal from the center of a crucible furnace to the cavity via a transfer tube. This ensures a supply of oxide free metal with no exposure to air during transfer. It is well known that molten aluminum forms an oxide film instantaneously upon coming in contact with air. If trapped in the casting, such oxide films are detrimental to the mechanical properties of the castings, especially ductility and fatigue strength. Magnesium is even more susceptible than aluminum to oxidation and requires a protective gas blanket during melting and handling. In conventional die casting practice, magnesium is pumped or hand-ladled into the shot sleeve. During injection, it reacts with the air in the shot sleeve, forming oxides. The Verticast process eliminates by and large the oxide formation during injection. The Gibbs Vertical Vacuum Die Casting process is illustrated in Figure 3.1.1. After evacuating the air from the cavity and the shot sleeve (Step 1), metal is drawn from the center of the crucible and fills the shot sleeve (Step 2). Next, the molten metal is slowly injected into the cavity (Step 3). Finally, the intensification pressure is applied. After solidification the part is ejected (Step 4). The reduced level of porosity and oxide inclusions provides heat treatable aluminum and magnesium castings with superior strength and ductility. A table with typical mechanical properties for a variety of alloys is included in Appendix A. For instance, die cast 380 in the as-cast condition provide a UTS of 45 ksi with 10.5% elongation. Alloy 356 can also be die cast, providing a UTS of 45 ksi with 8.4% elongation. For the 380 alloy, the UTS in the T5 condition is 46ksi and the elongation is 2.57. For the 356 alloy, the UTS in the T5 condition is 49ksi and the elongation is 4.7%.

The patented Vacural process illustrated in Figure 3.2.1, has been used for many years to produce castings with an

The Vacural Method

This patented technology is marketed by Weigarten Muller in Germany. The fluid metal is taken from an electrically heated basin furnace and fed into the fill chamber via the suction pipe by means of a vacuum that is created in the die and fill chamber.

Figure 3.1.1: The Verticast die casting method (Gibbs). 1) A strong vacuum instantaneously evacuates all air from the cavities and feed channels. 2) In two seconds or less, the desired amount of molten alloy is drawn from the center of the melt, through the transfer tube, and into the injection cylinder. The first movement of the plunger shuts off the metal flow from the feed tube to control the amount of metal ladled. 3) The molten alloy is then smoothly injected into the air-free die cavities and high pressure is brought to bear on the freezing metal, while the vacuum remains active. 4) After a dwell time, the die opens and the part is automatically ejected onto a shuttle tray for transfer out of the die area.
extremely low level of gas and oxide inclusions. According to the Weingarten Muller, the process allows the reliable production of

- Highly ductile structural and chassis components
- Thin-walled, weldable chassis components
- Coatable surface parts

The extremely low level of gas in castings produced using VA-CURAL technology enables the mechanical properties of the part to be improved by means of heat treatment after casting. In this way it is possible to ensure high static and dynamic stability as well as high ductility. Figure 3.2.2 illustrates the vacuum level applied to the cavity in the Vacural method. It is higher and applied earlier in the process, during “suction” of the metal from the furnace.

**The Alcan High-Q-Cast Process**

This process was initially developed and patented by Alcan in 1996. It is a cold chamber die casting process that produces premium aluminum and magnesium castings with laser and MIG weldability, excellent mechanical properties and high flow length: wall thickness ratios. A comparison between conventional die casting and the High-Q-Cast process is included in Figure 3.3.1. This process was originally used by Alcan in Europe for a variety of automotive applications and subsequently licensed to die casters in North America such as SPX Contech. The Alcan Bayerische Druckguss Werke (BDW) in Markt Schwaben has been using this method since 2000 on eight cold chamber machines ranging from 280 to 2,500 Ton. BDW operation was previously owned by the Thurner family. The High-Q-Cast process is an improvement of the original Minimum Fill Time (MFT) vacuum technology developed

<table>
<thead>
<tr>
<th>Feature</th>
<th>HPDC (vacuum assist)</th>
<th>High-Q-Cast®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degassed metal</td>
<td>Lesser degree</td>
<td>Higher degree (&lt;97% density index preferred)</td>
</tr>
<tr>
<td>Metal transfer into cold chamber</td>
<td>Ladle</td>
<td>Dosing furnace</td>
</tr>
<tr>
<td>Preferred wall thickness</td>
<td>3 – 8 mm</td>
<td>2 – 5 mm</td>
</tr>
<tr>
<td>Sealed dies</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Vacuum level</td>
<td>24 – 28” Hg</td>
<td>&gt;29” Hg</td>
</tr>
<tr>
<td>Vacuum valve type</td>
<td>eg. Thurner</td>
<td>Optimized vacuum valve</td>
</tr>
<tr>
<td>Vacuum valve close</td>
<td>Before fast shot</td>
<td>During fast shot</td>
</tr>
<tr>
<td>Advanced vacuum monitoring</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Cavity humidity measurement</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Importance of die spray and tip lube selection</td>
<td>Low</td>
<td>Very High</td>
</tr>
<tr>
<td>Solution treatable</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Weldability</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Commonly used alloys</td>
<td>380, 383</td>
<td>Aural – 2 and 3</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Moderate strength and low ductility</td>
<td>High strength and/or high ductility</td>
</tr>
<tr>
<td>Susceptibility to shrink porosity/oxide</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Figure 3.3.1: A comparison between conventional die casting and the High-Q-Cast process.
there. It employs a piezo-electric controlled vacuum valve that can close 12 times faster than a conventional hydraulic valve. The valve opens when the plunger begins to move. It remains open during all the slow shot and most of the fast shot. This allows the vacuum to be applied almost the entire filling cycle, while the metal is flowing into the die. In the previous generation of the Minimum Fill Technology the valve had to be closed at the end of the slow shot to prevent penetration of molten metal into the valve. In other words, the fast reaction of the piezo-electric valve used in the High-Q-Process allows it to stay open longer yet close in time to prevent metal penetration.

Heavier vacuum lines and a tight seal at the parting line along with larger vacuum pumps also allow a higher vacuum level to be obtained. This vacuum is as low as 20-50 milli-bar, or 1/50 atmosphere. With MFT, the vacuum level was an order of magnitude worse, i.e. 200-300 millibar or about 1/5 of atmospheric pressure.

Low-reactivity waterborne lubricants have to be used with the High-Q-Cast process. These produce less gas than conventional die lubricant, thus reducing porosity from this source as shown in Figure 3.3.2. Consequently, a uniform, low porosity level is obtained throughout the part, enhancing weldability and providing consistent mechanical properties. While the MFT provided low porosity on the vacuum valve side, the porosity on the gated side of the casting was usually higher, lowering properties and preventing welding. These features are illustrated in Figure 3.3.3.

Sound parts with a wall thickness of 2mm (0.079") or less can be made with this method. High-Q-Cast parts are usually gated with 20-30 gates, in contrast to 3-4 gates in conventional die casting. The Audi B-pillar part made by the High-Q-Cast method included 46 gates, yet the ratio of shot to part weight was just 2.5:1. This part is illustrated in Figure 3.3.4. It won the 2001 International Die Casting Competition. It is 47.5" long and weighs 4.8 pounds. As an integral element of the all-aluminum structure of the Audi A2, this part forms the vertical post between the A2’s front and rear doors. It provides critical stiffness to the overall vehicle structure along with added strength in a side impact. The single casting replaces up to eight separate sheet stampings typically assembled for this application.

Figure 3.3.2: Various die lubricants and the amount of gas generated (Brown).
The High-Q-Casting dies require tighter seal at the parting line than conventional dies. As a result, they usually cost about 10% more.

**The Minimum Fill Technology (MFT)**

The Minimum Fill Technology (MFT) has been superseded by the High-Q-Cast method. It is however of interest to explain it as part of the evolution of vacuum die casting technology. The principles of MFT were described in detail in a NADCA Die Casting Engineer paper published by H. Thurner and B. Asquith in 1998. The MFT technology was promoted as a comprehensive methodology of die casting, with vacuum as one of the key ingredients. The other ingredients included a proper feeding and gating design, die design, die cooling techniques, control of metal volume, vacuum system control, die lubrication control, automation practices to ensure consistency of production and precise, accurate shot control. Using this technology, Bavarian Die Casting Works (BDW) could produce very thin wall (1.8-2.0mm thickness) aluminum and magnesium castings, primarily for automotive applications. These castings were weldable and heat treatable. The Minimum Fill Technology comprises three main steps:

1. **Very slow speed initial motion of the plunger, controlled by an electro-magnetic switch**
2. **Fast, limit switch triggered transition to fast shot**

The fast transition is critical as to ensure rapid filling of the cavity. The fast shot could not be initiated until the vacuum valve was closed. Interlocking had to be used to prevent inadvertent filling of the vacuum valve with metal during the fast shot.

Once the cavity was filled, piston force was doubled or tripled to reduce shrinkage porosity. Implementation of the MFT required up-to-date shot-end performance. The main problems that had to be overcome included lack of programmability and flexibility to set up shot speed, limited dynamic response capability, no acceleration control and quick deceleration for low impact and limited capability to document process and production capabilities. A Visi-Track Real-Time Shot Control was identified that addresses these problems. This system comprised of:

1. **Digital position and velocity feedback sensor assembly**
2. **Computerized monitoring system with real time shot control option**
3. **Electro-hydraulically actuated velocity control valve closely coupled to the discharge of the shot cylinder.**

This Shot Control system provided accurate information and eliminated the need for inaccurate and difficult to set electro-mechanical limit switches.

The addition of this control system allowed a 20% increase in production from reduced scrap and less down-time. The main source of scrap used to be dimensional issues caused by flashing in the slide area. The low impact capability eliminated die flashing. Down time was also associated with the need to clean the slide area of the die from flash.

Traditionally, thin wall high quality die castings require a very short fill time to prevent premature solidification. This short fill time can be achieved with an oversized shot sleeve inside diameter or very high tip velocity. The disadvantage of oversized shot sleeves is the low sleeve fill percentage (generally 11-15%) that leads to more air entrapment. Thanks to the lower plunger impact speed and lower resultant pressure peaks, the MFT method can utilize smaller shot sleeve diameters in spite of high tip velocity during fill. This feature reduced the potential for gas porosity typical of very low sleeve fill percentages, thus allowing heat treating of die cast components for automotive applications.

Another reported gain of the MFT is a gain of about 20% in die casting machine locking force. This results from the damping capability of the low impact feature. Applications that normally require a 1,000 ton machine can be run on a 800 ton machine. Die wear has also been reduced as a result of the low impact feature. Better repeatability of the process is reported. These advantages added up to a payback of less than 15 months. Continued training and a disciplined approach to maintenance and operations is essential if these advantages are to be accomplished.

**Fondarex Vacuum Die Casting (Fondarex)**

The ultimate purpose of the vacuum system is to reduce the volume of air and gas inside the cavity to a minimum. With an optimal design of the vacuum system and perfect casting conditions, a pressure between 20 to 70 mbar should be attained in the cavity. Even if casting conditions are not perfect (gaps between slide cores, insufficient die tightness) it is possible to reach ~700 mbar (300 mbar absolute pressure) vacuum at the end of the filling phase (C) provided a self-closing Fondarex vacuum valve is used. The volume of air and gas are therefore reduced more than ten fold compared to the conventional die casting. This enables die casting parts with less injection pressure. Because of the lower back-pressure in the cavity, it is easier to attain the required cavity fill time and thin walled sections.

The final vacuum level inside the die cavity mainly depends on:

- Tool tightness (closing)
- Cleanliness (dryness) of the tool

Other factors that influence vacuum level in the die cavity:

- Piston speed used in the casting process
- Dimensional tolerances between plunger and the shoot sleeve
If all these factors are chosen correctly, a superior vacuum level with a final pressure as low as 30 mbar can be generated in the cavity. Practical experience shows that at a pressure equal to half that of one atmosphere a reduction in porosity can be observed.

Naturally, in addition to the vacuum requirements, producing a high quality component requires a robust die casting process that takes into consideration:

- Die design/ lay out/ precision
- Gating and runner system
- Venting (vacuum)
- Die temperature
- Die casting machine performance
- Die casting machine setting
- Plunger and shoot sleeve precision
- Casting alloy quality
- Lubricants (quality and application procedure)

General Description

The Fondarex system comprises the vacuum pump and hoses as well as the valves. A schematic of a Fondarex Vacuum Die Casting system is shown in Figure 3.5.1.1. A number of models are available, depending on the size of the parts.

In the Fondarex Vacuum Die Casting method, one vacuum valve is incorporated into the pressure-casting tool (die). This valve is connected to the die cavity via a vacuum channel. The vacuum valve (1) is connected to the vacuum tank by a vacuum hose, via a second valve (2) on the vacuum tank. The vacuum pump evacuates the air from the tank, creating a “vacuum reservoir.”

By opening vacuum valve (1) the mold cavity is effectively extended as far as the vacuum equipment valve (2). When vacuum valve 2 is opened (vacuum start), the air in the mold cavity escapes into the vacuum tank.

This sequence applies for all the systems on the market. Minor variations in valve technology and in the operation and control of the various types of vacuum system are used to maximize the efficiency of the system.

Figure 3.5.1.2 illustrates the typical components and operation of a Fondarex cold chamber vacuum die casting system. The components are listed below:

| 1. Phase 1 | 14. Runner |
| 2. Phase 2 (Fill phase) | 15. Gate (feeding gate) |
| 4. Biscuit | 17. Vacuum gate |
| 5. Pour hole | 18. Vacuum channel |
| 6. Vacuum start signal-plunger forward | 19. Closing point of vacuum |
| 7. Minimum vacuum delay (t1) valve | 20. Initio piston (Initial piston) |
| 8. Vacuum start signal direct (limit switch) | 21. Evacuation piston |
| 9. Possible vacuum delay | 22. Evacuation connection |
| 10. Vacuum measure (t 2) | 23. Vacuum measure |
| 11. v1, velocity phase 1 connection | 24. Mass of alloy |
| 12. v2, velocity filling phase | 25. Supervac vacuum valve |
| 13. Plunger (diameter) |

Figure 3.5.1: Vacuum extraction of air from the die.

Figure 3.5.1.2: Cold chamber Fondarex vacuum die casting system.
Figure 3.5.1.3 illustrates the typical components and operation of a Fondarex hot chamber vacuum die casting system.

| 1. Mold (die)             | 14. Runner                      |
| 15. Gate (feeding gate)  |
| 2. Bath                  | 16. Cavity, casting part        |
| 3. Phase 1 (slow phase)  | 17. Vacuum gate                 |
| 4. Phase 2 (Fill phase)  | 18. Vacuum channel              |
| 5. Fill hole shot sleeve | 19. Closing point of vacuum     |
| 6. Vacuum start signal   | 20. Initiio piston (Initial piston) |
| plunger forward          | 21. Evacuation piston           |
| 7. Minimum vacuum delay  | 22. Evacuation connection       |
| (t1) valve               | 23. Vacuum measure              |
| direct (or limit switch) | 25. Supervac vacuum valve       |
| 9. Possible vacuum delay |                                |
| 10. Vacuum measure (t 2) |                                |
| 11. v1, velocity phase 1 |                                |
| connection               |                                |
| 12. v2, velocity filling phase |                        |
| 13. Plunger (diameter)   |                                |

Supervac Fondarex Valves

The Fondarex valve design illustrated in Figure 3.5.2.1 comprises of two pistons integrated in a series of vacuum channels. The pistons are placed at a pre-determined distance from one another, to make sure that the initiator or release piston (Initio piston) is operated first. By the time the leading surface of the metal reaches the effective closure piston (Evacuation piston), the latter must be closed. This is accomplished by connecting the two pistons so they move simultaneously when the molten metal strikes the first piston (Initio piston).

To avoid placing the two pistons far apart, a few turns and constrictions are incorporated in the vacuum channel.

Five valve sizes are currently available. This allows the valve to be customized based on the quantity of molten metal injected and size of the overflows (see the summary in Figure 3.5.2.2).

Selection Criteria of the Valve

The valve is selected according to the following criteria.

- Evacuation volume
- Maximum vacuum channel and vacuum gate size for evacuation
- Die casting machine size
- Presence of other inserts in the same die holder
- Space available in the die holder/insert depth available to install the vacuum valve
- Cast alloy (Al, Zn, CuSn, Mg, Pb)
- Type of part being cast (wall thickness, flow paths, etc.)
- Weight (volume) of the parts
- Calculation based on the volume of air to be extracted and the time available for this specific part.
- Casting parameters

The calculated air volume inside the cavity can also influence the selection.

Examples of Fondarex Vacuum System Configuration

In addition to the correct selection of the valve, the configuration of the vacuum system is critical to a successful application.
Specifically, the size of the channels and the position of the valve relative to the parts and the ingates have to be carefully considered as illustrated in the following design schematics in Figure 3.5.4.1 and Figure 3.5.4.2.

The Castool Vacuum System designed by Allper of Switzerland is shown in Figure 3.6.1. Before the shot occurs, a vacuum is drawn in both the shot sleeve and the mold cavity. The suction continues until the injection cycle has been completed. This virtually eliminates any possibility of air or gases being trapped in the casting. The vacuum valve closes immediately when the mold is filled. The Castool Vacuum valves are illustrated in Figure 3.6.2.

Highlighted Benefits to the Die Caster:

- Reduces rate of rejection
- Ensures good surface for plating or powder coating
- Makes thinner sections possible (reduces weight)
- Reduces shot pressure
- Increases mold life
- Increases density of product
- Used for aluminum, magnesium, zinc, or brass
- Easy to add to any cold chamber die casting process
- Maintenance is minimal

**MULTI-VAC 250-2**

- Can control two valves simultaneously.
- Vacuum Pump:
  
  Standard - 900 cu.ft./hr. (25 cu.m./hr.)
  Optional - 1412 cu.ft/hr. (40 cu.m./hr.)

- Tank capacity:
  
  66 US gal. - 55 Imp. gal. (250 L)

- Dimensions:
  
  40" x 24" x 73"
  (100cm x 60cm x 185cm)

- Weight (approx):
  
  620 lbs (280 Kg)

**MULTI-VAC 250-3**

Same as 250-2, but can control up to 3 valves.
**MULTI-VAC C-2**
Same as 250-2, but does not include either pump or tank. This is primarily for die casters who want to implement a central vacuum system throughout their plant. Castool will provide technical assistance and layout drawings, to properly size and install the equipment.

**MULTI-VAC C-3**
Same as C-2, but can control up to 3 valves.

**VALVES**
The V\(_f\) line of valves. These valves are designed to get the highest amount of vacuum until the very end of the injection. They close less than two milliseconds after the flow of metal reaches the piston which closes the vacuum valve. They are recommended for extra high quality castings.

The V\(_p\) line of valves. The V\(_p\) valves are intended for an extremely efficient vacuum for large production runs. They are pneumatically activated, and have fewer wearing parts than the V\(_f\) line. They therefore require less maintenance than flow activated valves.

The Castool Vacuum System is promoted as a profitable upgrade for the die casting process that can eliminate rejected product due to porosity. According to Castool, additional savings can be realized due to the increased mold life and DCM life, that results from reduced shot pressure.

---

**The IdraPrince System (IdraPrince)**
IdraPrince claims the OMC/Prince Vacuum Die Casting Systems is able to remove nearly all air and gasses from the die cavity and shot sleeve. This allows the die caster to produce higher quality, leak tight, or T6 heat treatable parts. IdraPrince provides systems, components, applications engineering, service and parts. Schematic of the system and valve are illustrated in Figure 3.7.1. (a) and (b). Typical hardware is shown in Figure 3.7.2.

**Features**
These units include rotary vane vacuum pump with Allen Bradley PLC and Panelview 300 operator interface, flexible piping and cords. The systems will supply vacuum to one or two die casting dies through one or two vacuum valves.

**Controls**
- Allen Bradley SLC 500 programmable controller.
- The patented control logic is backed up with an on board EEPROM.
- Operator interface is an Allen Bradley DTAM Plus providing on board control of all screen functions and communications.

**Mechanical System**
The process piping module built with schedule 40 galvanized pipe with control solenoids and ASME certified vacuum receiver is built to provide one or two die casting dies with one or two vacuum lines. Filter canisters with commercially available filter elements protects vacuum valves and piping. Vacuum is delivered to the vacuum valve through the one or 1½ inch tank truck hose provided.

**Peripherals**
OMC/Prince vacuum die casting equipment includes patented two piece vacuum valves machined and precision ground using H13 steel hardened and tempered to 44-46 Rockwell C. The internal components are modified from standard automotive parts. These valves can be rebuilt in about 20 minutes with about $50.00 in parts. OMC/Prince’s patented actuator assemblies operate on 108
Volts DC allowing the vacuum valve to close in about 10 milliseconds. The specifications of the system are shown in the table above.

### Valve-less Vacuum Systems (Winkler)

In the late 60s, the American Die Casting Institute (ADCI) became involved with the development of vacuum systems and blocks. These blocks were originally produced from beryllium copper because of its exceptional heat transfer capability. In addition, one major advantage of these blocks was that they had no moving parts. Die casters utilized these vacuum blocks for a number of years with varying degrees of success. However, because beryllium copper is relatively soft and its cost is high compared to other materials, the blocks were easily damaged and required frequent maintenance and replacement. In addition, licensing fees paid for using the block designs and systems were costly. As a result, this style of serrated vacuum block fell out of favor with many die casters.

During this same decade, die casters started using valve style vacuum systems. Various valve style vacuum systems continue to be produced and utilized today. These valve style systems utilize a valve to stop the flow of metal and vacuum. Several methods have been developed for closing metal flow through the vacuum vent system to prevent the molten metal from contacting and plugging the shut off valves. A few of these methods, are described in sections 3.4-3.7.

These methods utilize timers, metal position indicators and the actual metal stream itself to activate the closing of a valve. If the valves are properly maintained, the vacuum blocks will function adequately. There is a “price” to pay for these valve style methods however. First, the initial cost for purchasing and installing the vacuum system on a die casting machine and the die-casting tool. The system includes pumps, tanks, controls, associated utilities and other materials required for installation on a machine. Next, there are the on-going expenses associated with maintaining the systems.

A couple of areas deserve consideration when selecting a valve style block system. This system requires the valves be shut off some specific time during the injection phase of the cycle. If the shut-off does not occur precisely, a vacuum will not be properly executed and the gases will not be completely evacuated from the die cavity. If an error is made in properly setting the vacuum valve timer and position indicator, or the valve sticks due to excessive wear, the valve will be plugged with metal. The resulting effect will be machine down time. The solution to this problem is either to ensure that the timing is properly set, the valve is maintained in proper operating order or there might be a need to install a system containing a larger valve area.

Another method for shutting off the flow of vacuum and metal in a system is to utilize the liquid metal stream traveling through the vacuum block to close the vacuum valve. As with the timed system, this too has a high initial investment cost and requires maintenance to keep it operating properly. This method has an advantage over the timer, and/or position systems in that the vacuum is pulled during the entire injection phase of the cycle. The down side is that the components associated with accomplishing the vacuum and metal shut off are high wear components as they are exposed to hot liquid metal and wear during each shot. One other method that is being widely accepted by more and more die casters is a take off of the original chill block concept. This method uses resistance to metal flow and the solidification of the metal to shut off the vacuum and metal flow. There are no moving parts associated with this system, thus the

<table>
<thead>
<tr>
<th>Capability (Tonnage)</th>
<th>System Size (Horsepower)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td>Single Machine:</td>
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<td>Two Machines:</td>
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<table>
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<th>Air Flow (scfm)</th>
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<td>150</td>
<td>94</td>
</tr>
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<td>10</td>
<td>200</td>
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<table>
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<th>Receiver Size (gallons):</th>
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<th>80</th>
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<td>Motor Voltage (volts):</td>
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<td>460</td>
</tr>
<tr>
<td>Weight (pounds):</td>
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<td>1200</td>
</tr>
<tr>
<td>Size (l x w x h) (feet):</td>
<td>3.2 x 5 x 4.5</td>
<td>2.5 x 5 x 6</td>
</tr>
</tbody>
</table>
degree of maintenance required to keep the system operating properly is minimal. This method has been termed “valve-less vacuum” and is illustrated in Figures 3.8.1 and 3.8.2.

Unlike the original beryllium copper chill blocks these vacuum blocks are produced from tool steel and possess longer life. An added advantage with the “valve-less vacuum” blocks is the application of central vacuum systems. The vacuum activation valve, control and filter are all located at the die-casting machine. The vacuum pump and tank are located in a central area of the die casting plant and piped to each die casting machine. This reduces the cost of the system by utilizing one tank and pump. A back up pump may be added if desired.

The key to the successful application of each style of vacuum system is in the correct sizing of the vacuum block area, design of the vacuum gate/runners systems and proper installation. Blocks are available commercially from Midland Technologies and Progressive Components. Shown in Appendix II are typical dimensions of these blocks.

Determining the area that will provide adequate evacuation is the initial step in designing a vacuum system. This determination may be performed using a computer program configured to utilize the total volume of air to be evacuated, and the cavity fill-time. Once the required vacuum area is determined the vacuum gates and runners must be designed. Next, it is necessary to determine the number and location of the vacuum outlet gates, based upon the total calculated vacuum area. These vacuum outlet gates should be located in the areas of the die that are the last to fill. The outlets should be grouped in pairs and extend far enough from the cavity to prevent back filling of the cavity. A degree of resistance in the vacuum runner system is also needed to assure that the metal does not blow through the blocks during injection into the die cavity. The runners should be designed to reduce metal velocity as they approach the vacuum block main runner.

CASTvac™ - Cast Metals Manufacturing, Australia (Wang et. al.)

The concept behind the CASTvac™ system is to rotate the face of the conventional chill vent by an angle up to 90 degree, so that the main face of the new vent is nearly perpendicular to the die parting face. By doing so, a limited space can have more chill faces. The advantage of this approach is the size of the chill face can be substantially larger without increasing the die projected area. This invention is embodied in the design of a new venting device as illustrated in Fig. 3.9.1. The device consists of two wedge-shaped inserts as shown in Fig. 1a. When the die closes, the two inserts engage, as shown in Fig. 1b, forming a corrugated venting gap. The molten metal is pulled by the applied vacuum towards the port at the bottom of the vent as shown in Fig. 1a. While flowing in the corrugated gap it looses heat, until eventually solidifying as it does in the conventional chill vent.

CASTvac claims the following advantages:

- **Robust.** CASTvac has no moving parts. It will never fail to close off the vacuum path. The mechanical type of valves consists of a complex triggering system and a shut-off piston which can fail due to many uncontrollable reasons. For instance, pre-ingress of metal droplets or flimsy flash metal will jam the piston to be shut off. A fragmented metal flow will result in an insufficient pressure difference for the activation of the triggering system. Industry experience indicates that the unpredictability of the machine stops due to
the valve failure induces more frustration than the production interruption itself.

- **Low cost.** Machine time is very costly to the die casting industry. Any machine stoppage will add more cost to the product. The cost is a very crucial issue to die casters in such a competitive environment. Machine stoppage due to failure of a mechanical valve is unavoidable. Furthermore, the moving parts used in the mechanical valve need to be precisely made and very well maintained, leading to high manufacturing and maintenance costs. CASTvac costs are lower because stoppages are rare and maintenance in the tool room negligible.

- **Efficient.** In principle, the evacuation channel of CASTvac is open until the last instance of cavity fill so that a high level of vacuum can be maintained during cavity fill. The cross-sectional area of the venting path is almost 4 times that of a conventional chill vent. As will be discussed later in this paper, CASTvac has been proven to have the same efficiency as the advanced mechanical shut-off valves and is much more efficient than the conventional chill vent.

- **Simple.** A mechanical valve requires a special runner to control the metal flow to avoid a direct impact to the mechanical triggering system of the valve. Fig. 2 lists two examples of the runner design. The problem is that no common rule exists for the design of this kind of runner for different part shapes. In some cases, the shape of the runner is critical to avoid a malfunction of the valve. For a new part, it takes time to get the runner design right. This could make the die casters frustrated for the commitment of the delivery of a new contract. The use of CASTvac can be as simple as the conventional chill vent. No special runner is required.

- **Easy to adapt.** CASTvac is designed as such to fit the same envelope in the die as for the commercial mechanical shut-off valves. Little extra effort is required to substitute the existing commercial valve with CASTvac.

- **Flexible.** CASTvac is made in a modular structure. When one insert is worn out or damaged, only that piece needs to be replaced.

A PCT application has been lodged for this innovation. The patent is held by CAST.

CASTvac has been trialed in the plant for two types of parts on an 800t machine. In one trial, CASTvac was continuously run for 1800 shots. The trial was stopped when a sufficient number of sample castings had been produced for quality assessment, and not due to any failure of CASTvac. Pressure sensors were installed in the vacuum line to monitor gas pressure in different locations both for the trials of CASTvac and for the normal production using a commercial mechanical valve. Typical pressure changes in the downstream adjacent to the vacuum valves are plotted in Fig. 3.9.2. As can be seen in the figure, both valves could quickly achieve a high level of vacuum (0.3 sec in this case) at the measured spot (in principle a high level of vacuum in the cavity as well) and CASTvac performed as well as the mechanical valve.

During the trial, the casting quality was monitored using an in-house X-ray machine. Also, all the castings from the trial were sent to the customer for the final quality assessment. The results both from the in-house X-ray inspection and from the customer indicated that in general the casting quality from the trial was the same as that from the normal production using the commercial mechanical valve.

A bench test was conducted to compare CASTvac with a conventional chill vent. Since CASTvac was not designed to fit the same die envelope as the conventional chill vent, a direct comparison with the chill vent was not feasible. An experimental apparatus was built up for this test. It consisted of a vacuum tank (110 liters), a vacuum pump and a vacuum vessel (3 liters) which simulated the die cavity. The conventional chill vent used in this test had a gap of 100 mm in width and 0.6 mm in depth. Fig. 5 shows the pressure change in the vacuum vessel after connecting it to the vacuum tank. This experiment indicates that CASTvac is much more efficient in evacuating the air from the vacuum vessel than a conventional chill vent.

It should be emphasized that the objectives for developing CASTvac were not to achieve better casting quality than the commercial mechanical valves, but rather to have a reliable vacuum valve while producing castings of similar quality. It provides the same robustness of the conventional chill vent, yet has a more efficient venting capability and consequently could produce better quality of castings. CAST is currently seeking an appropriate commercialization company to take CASTvac to market.

---

**Figure 3.9.2:** Changes of gas pressure in the downstream adjacent to the vacuum valve.

**Figure 3.9.3:** Comparison of air evacuation efficiency for CASTvac and a conventional chill vent.
Chapter 4
Typical Applications and Case Studies

As pointed out in the previous section, when correctly implemented, vacuum die casting has distinct advantages over conventional die casting. However, it adds cost, complexity and maintenance to the operation. When should a die caster consider implementing vacuum? Following are some guidelines:

- Die is not completely filled in spite good gating practice
- Air and gas porosity inclusions are exposed during subsequent processing
- Insufficient tensile strength due to porosity
- Parts are not pressure tight
- Tensile properties and tightness requirements are not met
- Welding is difficult or not possible
- Blisters show on the surface after Teflon, chrome, powder coating, and other surface treatments.
- Die does not close completely (flashes, pressure loss).
- Cast parts do not meet dimensional requirements
- Die lubricant and piston lubricant inclusions in the casting
- Low quality surface finish

Low yield due to excessive scrap has a negative impact on manufacturing costs and affects competitiveness and profit margins. Correctly used, vacuum assist can reduce scrap rates and often comes with short pay-back of the investment. However, as many die casters will tell, vacuum die casting is not necessary in every application. Good conventional die casting practices can often provide satisfactory results.

Case Studies

**DeimlerCrysler Class C and Class S Engine Cradles**

*Die Caster: Honsel, Germany*

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<thead>
<tr>
<th>Alloy: GD-AlSi9MgMn T2</th>
<th>Alloy: GD-AlSi9MgMn T7</th>
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</thead>
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<tr>
<td>(Special alloy, vacuum)</td>
<td>(Special Alloy, vacuum)</td>
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<table>
<thead>
<tr>
<th>Dimension: 890 x 730 x 170 mm</th>
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</thead>
<tbody>
<tr>
<td>Weight: 10.2 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimension: 930 x 560 x 185 mm</th>
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</thead>
<tbody>
<tr>
<td>Weight: 10.9 kg</td>
</tr>
</tbody>
</table>

Method: HOVAC (valve-less)
(Wappelhorst et al.)
**BMW Automotive Dashboards**

*Method:*
Castool Vacuum
(Robins)

---

**Die Caster: Twin City Die Casting**

*Method:*
Valve-less

*Note:*
w/o vacuum the part has unacceptable porosity
BMW Engine Block

Die Caster: BMW Landshut, Germany

Method: Fondarex vacuum

Material: Magnesium with aluminum insert

6 Cylinder Engine

Gear Box

Receiver Casting

Oil Sump Cover

Turbo

Dash Board

Method: Fondarex
Potential Market: Suspension

Longitudinal Beam

*Method:*
High-Q-Cast

*Alloy:*
Aural-2

*Heat Treatment:*
Auraltherm™

Potential Market: Door Structures

Aural 2
as cast
Rp 0.2 > 130MPa
Rm > 270 Mpa
A5 > 6%
Chapter 5

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### Appendix 1: Typical Mechanical Properties with the Gibbs Verticast Process

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<th>Elongation %</th>
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<td>10.6</td>
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<td>48/331</td>
<td>32/221</td>
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<td>350°F(154°C)/10hours</td>
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<td>17/117</td>
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<td></td>
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<tr>
<td>T6</td>
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<td>T7</td>
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<td>30/207</td>
<td>9.64</td>
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<td>950°F(510°C)/4 hours 400°F(204°C)/3 hours</td>
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<td>T7</td>
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The following typical properties are not guaranteed since in most cases they are averages for various sizes, product forms and method of manufacture and may not be exactly representative of any particular product or size. These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

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Appendix 2: Midland/Progressive Components Blocks

Vacuum Blocks

The Vacuum Blocks are designed with Progressive's alliance with Midland Technologies and are available in two different styles:

- **Valve-less Standard Vacuum**: Common venting is fit for vacuum connection to reduce porosity and improve surface finish in casting containing complex geometry.
- **Valve-less Super Chill Vacuum**: Same features as the Standard Vacuum, but with replaceable, water-cooled chill inserts (two materials available).

Vent Blocks are also available:

- **Ultimate Vent**: Same as the Standard Vacuum, but water chilled without vacuum connections.

### Vacuum Blocks Specifications

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<tr>
<th>Series</th>
<th>Die Half</th>
<th>W ± .001</th>
<th>PW ± .005</th>
<th>X ± .001</th>
<th>L ± .0005</th>
<th>T P ± .010</th>
<th>S 1 ± .005</th>
<th>S 3 ± .005</th>
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<th>S H C S</th>
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<td>2.388</td>
<td>.625</td>
<td>-</td>
<td>3.625</td>
<td>2.875</td>
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<td>Ejector</td>
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</table>

Note: Blocks are to be installed with the same preload used on the cavity inserts or raised .001” above the cavity insert to ensure a proper seal. Blocks can be installed internally or externally. Contact Progressive for technical information or visit www.procomps.com.
Appendix 3 – Resources and Contact Information

Fondarex: http://www.fondarex.com/
Awintech: http://awintech.com/home.html
SPX Contech: http://www.spxcontech.com/
Muller Weingarten: http://www.mwcorp.com/web/welcome/welcome_in.cfm
IdraPrince: http://www.idraprince.com/
Midland Technology/Progressive Components: http://www.procomps.com/
Gibbs Die Casting: http://www.gibbsdc.com/
Blue Ox Software: www.blueoxsw.com
CAST: www.cast.crc.org.au