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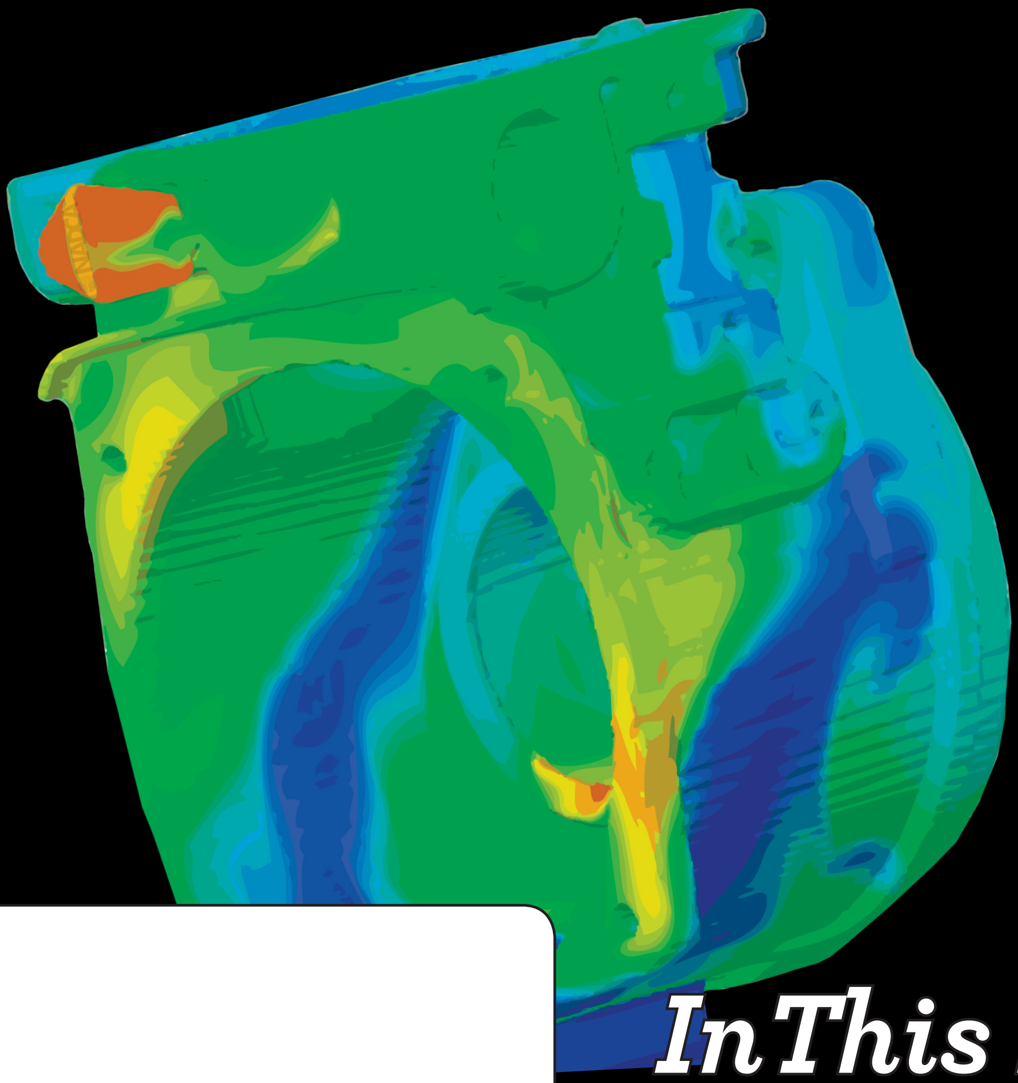
Computer Modeling and Simulation



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From Simulation to Process Automation – "Define It And Do It"

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"The modeling (or simulation) of a complex technical process like high pressure die casting means to DEFINE, to quantify, and to take into consideration the characteristic values and influential mechanisms of the process." (P.N. Hansen et al)

The ability to accurately model and simulate the dynamic and complex interactions of the process has enhanced die caster's ability to understand the causes of problems that have plagued die casting for decades. This enhanced definition of the problems has in turn provided many successful tools for their elimination.

Process Automation provides a bridge between the theoretical insight of the design stage and the practical realities of a 24/7 production environment.

Problem solving begins with:

1. Definition of the problem (Define it)
2. Consideration and test alternatives for solving the problem (Do it)
3. Ensure that the solutions are instituted and adhered by use of an effective information and control network with which to assess and ensure your operational effectiveness

Key Die Casting Problems Observed Through Simulation and Research – Define It

Define the most common and most detrimental production problems facing die casting operations today:

PROBLEM: Excess porosity due to trapped air during the slow phase

RESULT: Decreased quality, increased scrap, and part failure.

CAUSE: Improper speed control leads to excessive entrapped air in die cast parts as the metal advances from just past the pour opening to sleeve full position (P1) and runner full position (P-2).

PROBLEM: Excessive metal turbulence, poor and incomplete cavity fill, heat build-up, and cold flow areas

RESULT: Poor part integrity, blistering, premature heat checking of die surfaces and even cracking of die inserts

CAUSE: Improper runner design, gate placement, and improper placement of cooling.

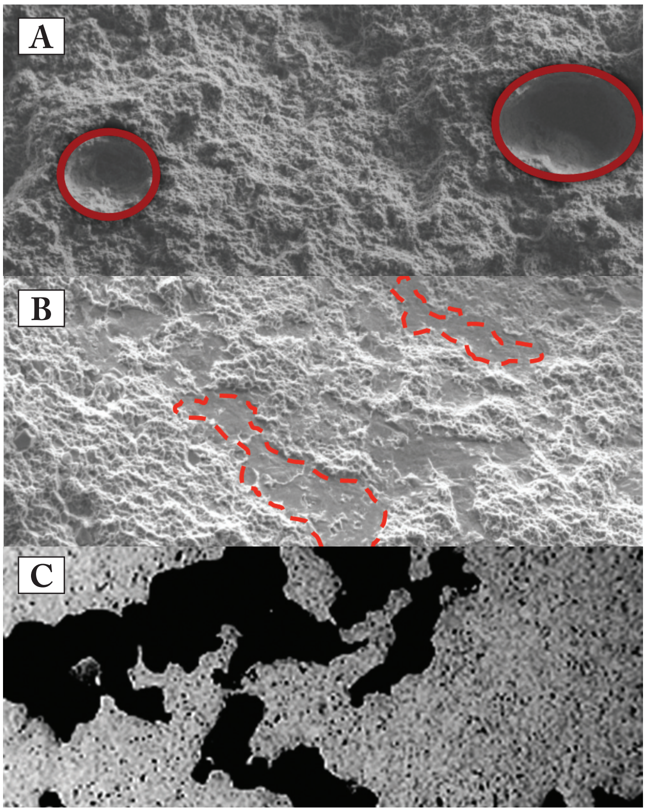


Figure 1 – Scanning electron microscope (SEM) images of casting showing microscopic view of entrapped gases (a) material separation (b) and shrinkage porosity (c).

PROBLEM: Excessive flashing

RESULT: Extensive metal loss and die wear and tear leading to costly premature die failure. Secondarily, flashing causes decreased operating efficiency from downtime to clear die surfaces of build–up, lost time to warm-up dies again, and scrapped parts due to interrupted die thermal balance.

CAUSE: Plunger impacts during cavity fill against molten metal front in sleeve. This powerful impact and the resulting pressure spikes can overcome the locking tonnage of the machine and produce flashing.

PROBLEM: Thermal Imbalance

RESULT: Lower Margins – poor part quality

CAUSE: Interruption of machine cycles by personnel issues, as well as mechanical, electrical and hydraulic problems with the machine. Slow diagnoses of these issues quickly lead to loss of thermal balance in the dies and even more scrap.

Developing and Implementing the Alternatives – "Doing It"

Years of experience, simulation and experimentation have identified the problems outlined above to be among the most expensive, perplexing, and prevalent but they are by no means inclusive in identifying all of the complex interactions that attack part quality, machine efficiency, and the margins and profitability of the die caster. Addressing these problems with affordable and effective solutions is the key to recovering lost profitability.

PROBLEM: Excess porosity due to trapped air during the slow phase

SOLUTION: 30 year-old flow simulation defines solutions for dramatically reducing air entrapment in the slow phase. Vacuum systems and specialty tilt ladles can further reduce porosity.

The 70's can best be defined as the period of "by guess and by golly" in the die casting industry. The typical die cast engineer claimed that he could see it (the filling phase) and feel it (the intensifier was hitting just right). They'd even spit on the die to see if it were up to temperature. Highly complex mathematical modeling to simulate pressure die casting metal flows, solidification, and heat transfer was science-fiction to the die caster.

However, by the early 80's simpler simulations were employed, such as water analog methods with transparent shot sleeves, to study the effect of plunger movement during the slow phase (sleeve fill (P1) and runner fill (P2)) on air entrapment in the casting.

Garber and others used this simulation technology to study and prove a mathematical model based on Bernoulli's equation, which defined a critical slow shot speed where metal filled the sleeve without creating a wave front (forward or backward) avoiding entrapped air being injected along with the metal.

- Figure 2 shows that when the slow shot speed is too slow, the wave will not reach the top of the sleeve and thus trap air behind the wave resulting in internal porosity.
- Figure 3 shows that when the slow shot speed is too high. A forward acting wave is created with similar results.
- Figure 4 shows the "Critical" or desired wave front for reducing air entrapment.

Garber's studies proved that for sleeve fill percentages of greater than 50% the critical slow shot speeds produce wave formations that allowed air to escape ahead of the metal. However, at filling percentages of less than 50% the calculated critical slow shot velocity would still produce a wave that would entrap air. This made his discoveries of limited usefulness since most die casters have to work with sleeve fill percentages often less than 50%. His studies did not take into effect the impact of dynamic changes in speed (acceleration) which can be achieved with modern real time control systems.

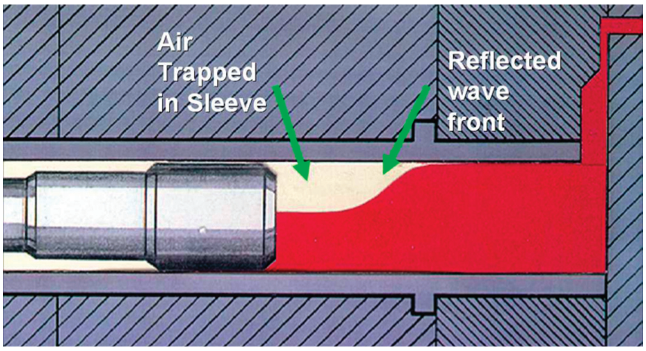


Figure 2 – Performing a slow shot that is too slow creates a reverse wave and trapping air.

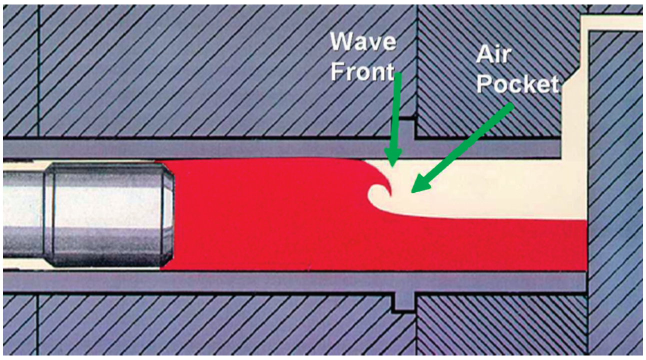


Figure 3 – Performing a slow shot that is too fast creates a forward facing wave and trapping air.

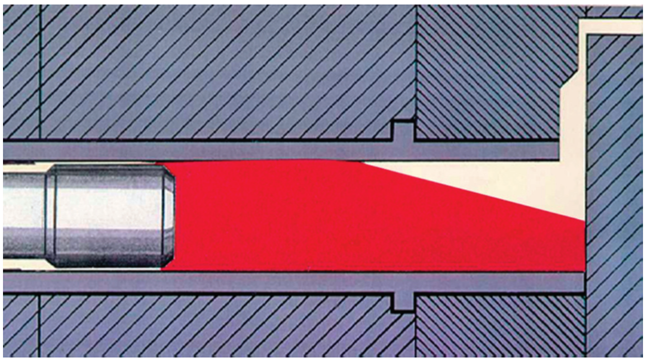


Figure 4 – A slow shot with critical slow shot velocity and constant acceleration reduces air entrapment.

In the early 90's a further study conducted under the supervision of Dr. Jerald Brevick at Ohio State University discovered the importance of acceleration changes on the efficacy of the Critical Slow Shot Speed (Experimental Determination of Slow Shot Velocity-Position Profile to Minimize Air Entrapment. Jerald R. Brevick, Mauricio Duran, Yiftah Karni)

This study used colored water and a transparent shot sleeve to simulate the metal flow during the slow shot phase. The flow was recorded and viewed in slow motion for analysis. This study used a hydraulic test stand provided by Prince Corporation and a real time control provided by Visi-Trak to obtain the desired acceleration control to test results.

A series of profiles were developed using different plunger velocity vs. position profiles with different sleeve fill percentages and measured the resultant overall air entrapment. The study concluded:

- Air entrapment within the shot sleeve in cold chamber die-casting is a major source of casting porosity.
- For all sleeve diameters and initial fill percentages used in the study, air entrapment was found to be minimal when constant acceleration was utilized to achieve the calculated critical slow shot speed.
- Use of the acceleration of 2 in. per second per inch resulted in full height, non breaking wave formations for all initial fill percentages (20%, 30%, 50% and 70%)

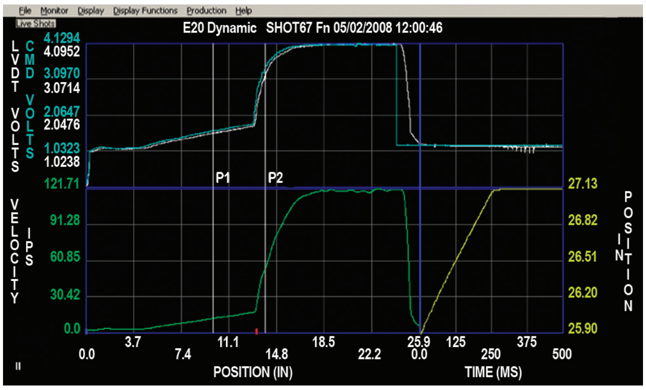


Figure 5 – Modern control systems have the ability to dynamically adjust the acceleration, velocities, and pressures after cavity fill to help reduce the level of gas porosity in die cast parts.

Dynamic Control – Many modern control systems have the ability to dynamically adjust the acceleration, velocities, and pressures after cavity fill to help reduce the level of gas porosity in die cast parts. This type of real time control provides the ability to create almost any type of filling curve and velocity – and avoid metal porosity. [Figure 5]

Vacuum Systems – High Integrity Die Casting Technologies such as High-Q-Cast®have been utilized to produce very thin wall, weldable and heat treatable die castings. This technology adds high vacuum air evacuation ahead of the metal front to the previously mentioned tight controls over all aspects of the high-pressure die casting process. [Figure 6] This technology has achieved gas porosity levels of less than 0.5%.Typical die castings have 2.5% or more as shown. [Figure 7] This low porosity process, custom alloys, and heat treatment can produce high pressure die castings with customized physical properties like unique strength, compression, and ductility for automotive structural, suspension and power train applications.

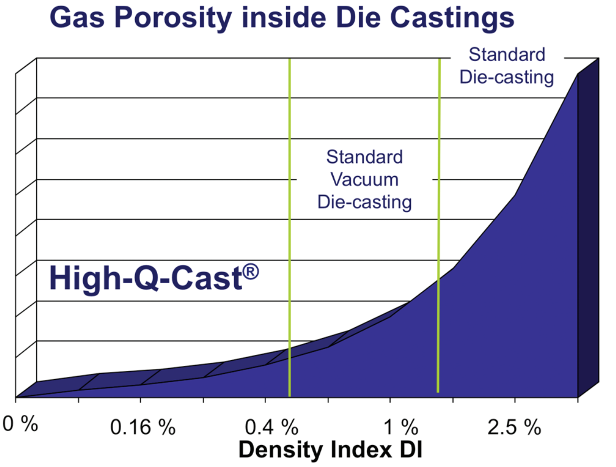


Figure 7 – High integrity casting processes incorporating these tools can reduce gas entrapment from a typical range of 2.5% to less than 0.5%.

Tilt Ladle – High-Q-Cast also offers an optional metal delivery system for further reducing porosity. After recognizing a 10% fallout in a suspension casting for Porsche, due to porosity, engineers at BDW focused on the dosing mechanism and the turbulence created in initial delivery of metal into the sleeve. They devised a smoother method of delivery, where a tilting ladle is lowered into the shot sleeve, and gradually raised along with the sleeve fill, eliminating the oxide inclusions.

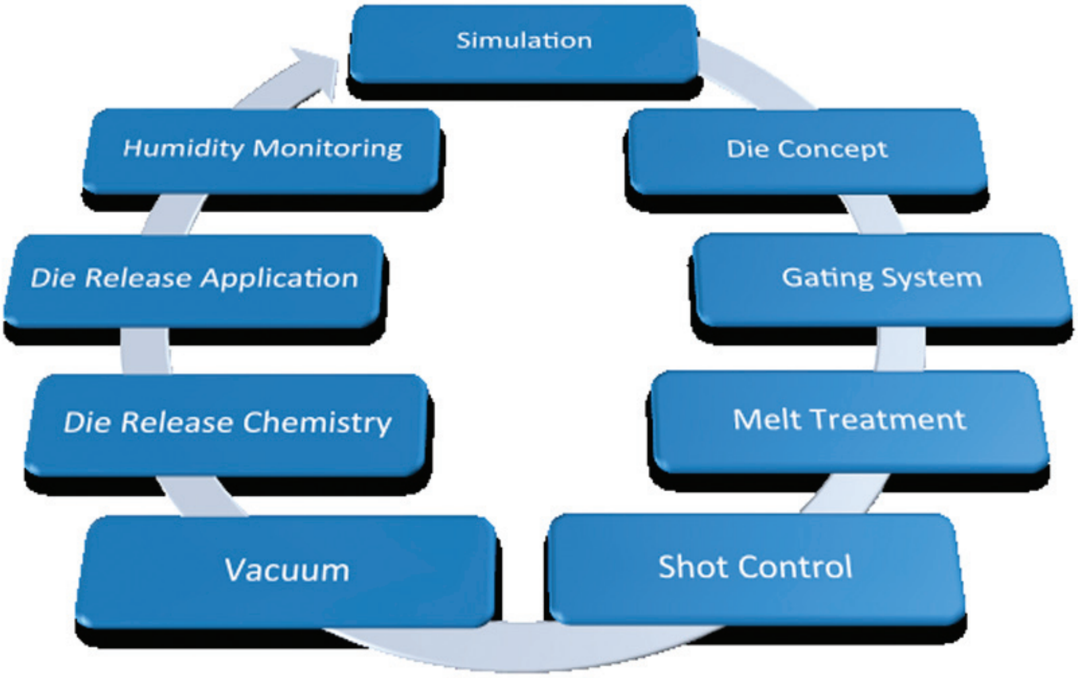


Figure 6 – A host of process automation technologies have been developed to put the insights of simulation into production and solve the common problems that reduce quality and profitability - allowing high integrity castings.

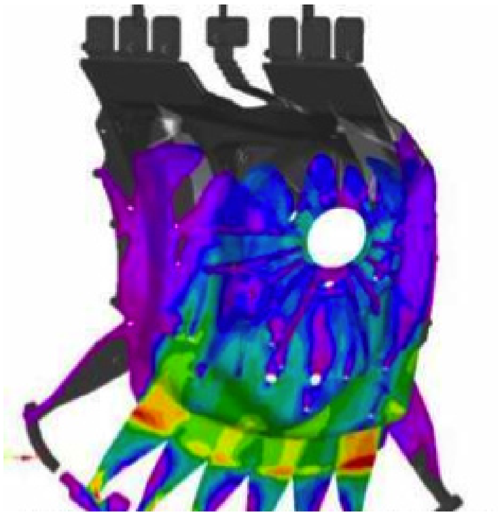


Figure 8 – Modern flow simulation allows clear view of filling pattern during sleeve and runner fill as well as cavity fill phase. These simulations have eliminated the intuitive die designs that were based on guesswork and can often assist in obtaining first shot success on new die designs.

PROBLEM: Excessive metal turbulence, poor and incomplete cavity fill, heat build-up, and cold flow areas.

SOLUTION: Poor runner design and placement as well as improper gate location and configuration lead to a a host of problems:

a. excessive metal turbulence

b. poor and incomplete cavity fill

c. cold flow areas on the part

d. shrink porosity

e. poor part integrity.

Additionally improper placement of cooling lines can lead to excessive heat buildup in certain areas of the die which causes blistering, soldering, premature heat checking of die surfaces and even premature cracking of die inserts.

By the 90's computing power had evolved to the point that complex modeling could be economically developed. This finally provided the elusive ability to visualize metal delivery in the runners and die cavity and observe metal action during the sleeve fill, runner fill and die fill. Die designs could now be perfected before the expensive build out. (Defining it)

No more:

- Welding and rework of runners and gates.
- Changing of location of overflows and vents.
- Excessive hot spots and premature heat checking and cracking of die inserts due to improperly located water lines.
- Internal part defects due to improper filling from high turbulence during cavity fill.

Simulation let die casters consider many alternatives designs to overcome problems inherent in intuitive designs. Die designs could be intelligently developed for "first shot" success leading to greater customer satisfaction, higher margins, and greater profitability. Today, simulation is a staple tool for most die casting firms that continues to enhance their competitive position with rapid payback as a plus.

PROBLEM: Excessive flashing

SOLUTION: Precisely control cavity pressure and deceleration

Excessive Flashing is a decades-long problem that exists in die casting. It results when the mass in motion of the shot piston, piston rod, plunger and tip collide with the molten metal suddenly at the end of the cavity fill phase. This creates pressure spikes that cause the shot injection forces to exceed the locking tonnage capability of the machine. Attempting to control this flashing without regard to metal pour has been an ongoing problem in die casting.

One mathematical modeling technology (SoftShot™) developed by Peter Olmsted in the early 2000's provides an elegantly simple solution to this problem by establishing

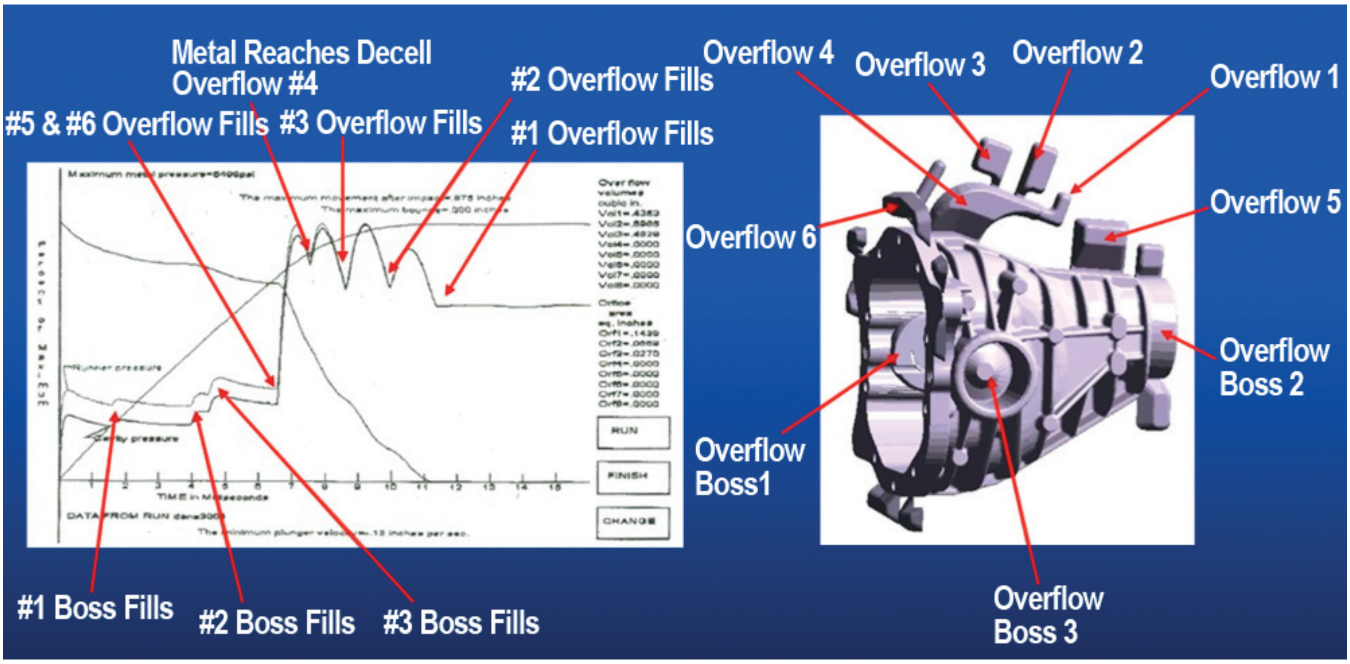


Figure 9 – Final design of SoftShot overflows limited cavity pressure in this new die designed by licensee, Port City Die Casting Group, to 5,499 p.s.i, a reduction of 72% from the original design almost entirely eliminating flashing which greatly extended die life.

Figure 10 – Total Thermal Vision® from Baraldi can read and store the die skin temperature at each cycle of the machine by monitoring the entire die with an IR camera mounted in a protective stainless steel case.

a set of overflows, strategically sized and located that will eliminate flash from die cast parts:

- By limiting final cavity pressure in the die.
- By decelerating the shot system at the point of cavity fill regardless of metal pour variation.
- Greatly extending tool life, by reducing wear and tear on the machine
- Improve operating efficiency by eliminating downtime to clean die and slides of excessive flash build up.

Precise sizing creates cross sectional area for each overflow and sets an exact pocket volume for each SoftShot overflow. The gate leading to each overflow pocket acts like a valve restricting flow and absorbing rapid pressure build up at point of cavity fill. The time each overflow (valve) is on is regulated by overflow cavity volume.

Simulation Software such as Magma or Flow Sciences is used to determine where the final filling occurs - this is where the SoftShot overflows are placed. The size of the gates and volumes are determined by the SoftShot program based on a number of variables such as:

- Weight of the piston, piston rod, plunger, and tip
- Plunger velocity at impact
- The piston diameter
- Piston rod diameter
- Plunger tip diameter
- Cold chamber pressure at impact
- The weight of the casting
- Ratio of mold expansion to molten metal compression
- As well as other factors

Figure 9 shows that the final design of SoftShot technology overflows limited cavity pressure in this new die designed by licensee, Port City Die Casting Group, to 5,499 psi, a reduction of 72% from the original design. The machine clamp end could then hold the die closed with essentially zero flashing as shown. This technology provides the deceleration and reducing of impact pressures regardless of metal pour variations. The result can dramatically extended die life, lessen wear and tear on the machine; improve part dimensional stability and operating efficiency. All of these factors can have a dramatic impact on margins and profitability.

With well designed, real time shot control systems, specified deceleration speeds can be programmed to occur just prior to calculated cavity fill also reducing excessive flashing and wear and tear on machine and dies. These low impact controls can be effective as long as ladle pour volumes remain consistent. With inconsis-

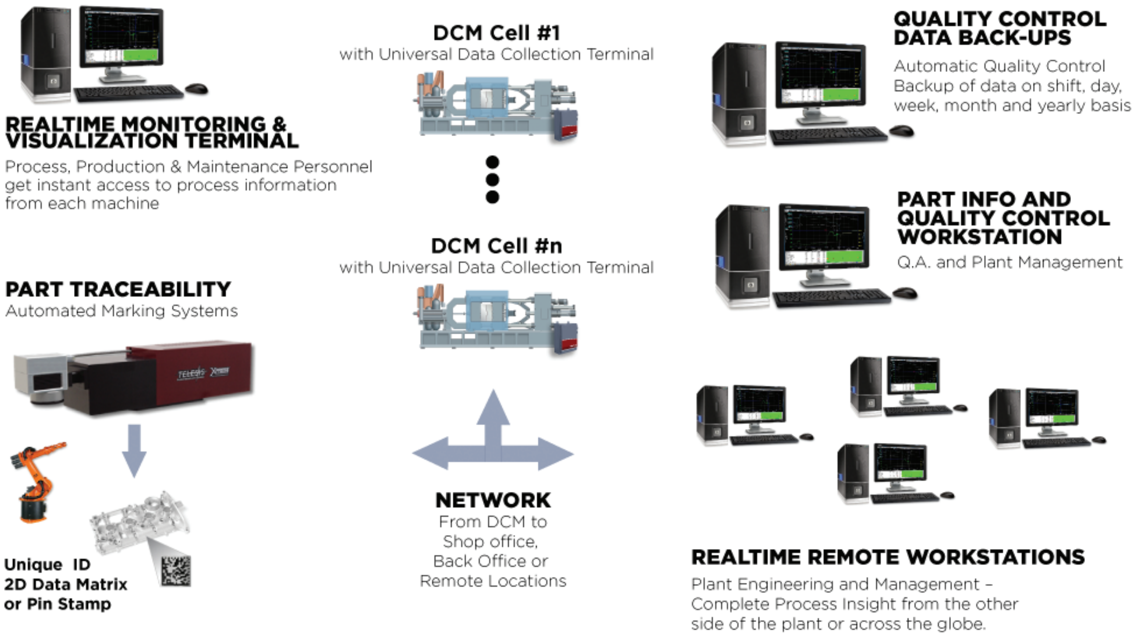


Figure 11 – The promise of true plantwide process control – A full suite of sensors, monitors and controls provide continuous information to process control, production, maintenance, and plant management personnel enabling them to observe and manage real time performance of the machine and process regardless of the location or manufacturer.

tent metal pour these systems can provide this deceleration either too early or too late (long pour). Metal pour consistency is less of a problem with modern dosing and ladle systems, but it remains an issue in many cases.

PROBLEM: Thermal Imbalance

SOLUTION: Better design, mechanical automation, real-time die temperature tracking

Thermal Imbalance can result from poor die design and water line placement, or interruption of machine cycles due to human, machine, mechanical, electrical, or hydraulic failures. These unplanned downtime and delays can wreck havoc with production schedules and the critical thermal balance in the die - destroying your margins and profits.

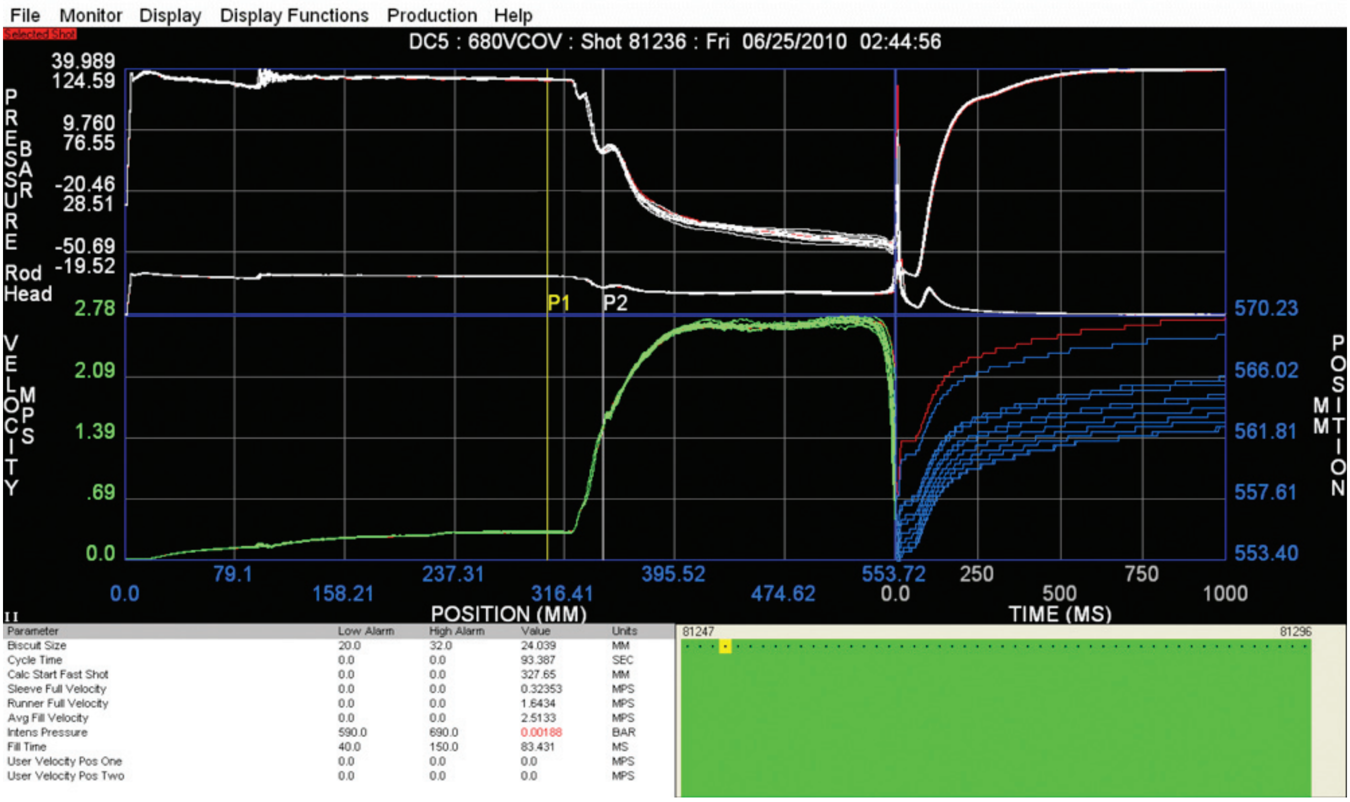
Simulation leads to better die designs, water line placements and identification of potential hot spots. Hot oil systems employed today can also assist in regulating internal die temperatures to get dies up to proper temperatures more quickly while maintaining some ability to adaptively control thermal conditions in the die.

Mechanically automating the manual tasks operators had to carry out in the 60's and 70's provides better cycle consistency, which means more consistent thermal balance. This technology was rapidly accepted as accountants and management could easily define the paybacks in terms of reduced labor costs from reduced set ups and greater operating efficiency (more machine uptime).

Many systems for real time tracking of die temperatures have been tested over the last two decades to limited success. Early attempts to monitor die temperatures by strategic placement of "J" Thermocouples in the die near the surface failed in most cases because of the high cost and difficulty in maintaining these sensors in the die casting production environment. Handheld IR cameras have been employed by some for periodic checks of die surface temperatures. While useful, these were not a practical solution for the automated die casting plant.

In recent years several innovative approaches have been developed and commercialization initiated for cycle-to-cycle die surface temperature monitoring in real time. These systems also promise potential for cycle-to-cycle adaptive control of temperatures by interaction with the die lube reciprocator or robotic spray device. One such system is shown in figure 10 which can read and store the die skin temperature at each cycle of the machine. It can monitor the die (outlined by laser pointers) with an IR camera mounted in a protective stainless steel case. Automatic opening and closing of a front protective shutter when taking a snap shot of the die surface at machine opening and after part ejection. High/low limits can be set to alert the robot or unloading device to segregate a casting with an out of spec reading.

This type of device has the added benefit of minimizing the time required for running warm up shots after cycle interruption by sending signals to the controller to move from warm up shots to production mode as soon as proper die surface temperature is detected. Over extended production, this quick exit from non-productive warm up to production can have a big impact on company's OEE.



Parameter	Low Alarm	High Alarm	Value	Units
Biscuit Size	20.0	32.0	24.039	MM
Cycle Time	0.0	0.0	93.387	SEC
Calc Start Fast Shot	0.0	0.0	327.65	MM
Sleeve Full Velocity	0.0	0.0	0.32353	MPS
Runner Full Velocity	0.0	0.0	1.6434	MPS
Avg Fill Velocity	0.0	0.0	2.5133	MPS
Intens Pressure	590.0	690.0	0.00188	BAR
Fill Time	40.0	150.0	83.431	MS
User Velocity Pos One	0.0	0.0	0.0	MPS
User Velocity Pos Two	0.0	0.0	0.0	MPS

Figure 12 – Monitoring provides the ability to observe shot-to-shot repeatability and continuous overlay illustrates the exacting repeatability provided by real time control.

Universal Plantwide Process Automation Ensures Optimal Parameters Are Maintained 24/7

Simulation and modeling programs are able to calculate and even optimize various process values like:

- Critical slow shot velocity and accelerations
- Gate velocity and optimal in gate areas
- Location and volumes of overflows necessary to reduce cavity pressures to levels that prevent die blow back.
- Necessary locking force
- PQ^2 Diagrams enable calculations of optimally adjusted operating points for machine and die.
- Optimal thermal balance

The extent to which this information can lead to overall improvement in the casting process beyond die design is dependent on providing other tools that can be integrated into the casting process as an adjunct to the simulation tools. These sensors, monitors, and controls provide continuous information to process control, production, maintenance, and plant management personnel. This information enables them to observe, and manage real time performance of the machine and process and at long last offer the promise of eliminating the guesswork that was the norm since the 70's.

This information can be utilized to provide real time feedback and control of critical process parameters such as:

a. Defining the ideal shot profile and automating corrective action on a shot-to-shot basis to ensure exacting repeatability.

b. Providing outputs to adaptive control loops for temperature and other parameters for between cycle adjustments.

c. Alerting process personnel to take or call for corrective action when critical parameters drift out of acceptable limits.

d. Alerting maintenance personnel immediately to a machine downtime situation at any of the machines within the network.

e. Quickly diagnosing hydraulic, mechanical or electrical problems and directing corrective action.

f. Informing production personnel of total production counts, cycle times, and downtime information to manage for improved OEE.

g. Reporting to management timely information on machine uptime/downtime along with causes and statistical analysis of critical parameters for each machine.

h. Storing historical process information indefinitely in a database for recall and matching part Q.A. information by part no., date and time information as demanded by customers.

i. Providing complete part traceability to drive a scripting machine to permanently identify parts as they come off the machine. Something that is increasingly being demanded by customers to insure greater accountability for quality production.

j. Diagnosing probable causes of of standard production by allowing examination of historical process data on a continuous basis. It can even allow editing of the database from the customer's plant when parts are scrapped after pressure test or secondary machining operations.

Process simulation and modeling has provided significant insights into many of the process problems that have challenged the industry for years. To "Define it" (the process) and the "Do it" (the execution) to can lead to die designs that work the first time and help develop initial optimal process guidelines.

The ability to implement, repeat and maintain optimum process parameters on a continuous production basis, and the ability to manage for maximum operating efficiency provides the "do it" that can make a real difference.

The promise of a die casting process that can provide survivable and highly profitable margins as well as ability to produce castings previously considered impossible will be the long-term payback for die casters and their customers.

The challenge is to develop cost systems that clearly recognize the cost of poor machine operating efficiency as well as the cost of scrap and low quality part production. Once those costs are recognized, the adaptation of Simulation Tools and Process Automation technology will be quickly implemented. The success is dependent on management support, training and the appointment of a "champion" for system implementation.

Process Automation technology is the natural partner to Simulation Technology and the critical extension required to insure 24/7 acceptable production. Forming their own closed loop process automation can further assist simulation by providing the analytical tools to identify probable cause of off standard production and further define the questions simulation answers.

About the Author

Jack Vann has been President/CEO of Visi-Trak Wordwide since 2001, and President of its predecessor companies since May of 1981. Prior to this he served as Sales and General Manager of Cuyahoga Industries, a manufacturer of die casting dies, die casting machines and provider of die sampling and prototype production services from the beginning of the 70's. The initial Visi-Trak sensor and first meter out, closed loop control was developed at Cuyahoga during the 70's. Jack attended Duke University and received a B.A. from the University of Virginia in 1962 and an MBA from Darden Graduate Business School at UVA in 1968. He served as an Engineering Officer in the U.S. Navy and Liason Officer to the U.S. Marine Corp from 1963 until 1966 after completion of Officer's Candidate School. From 1968 – 1970 Jack served as an Acquisition Analyst with Heublein, Inc. in Hartford, Conn.

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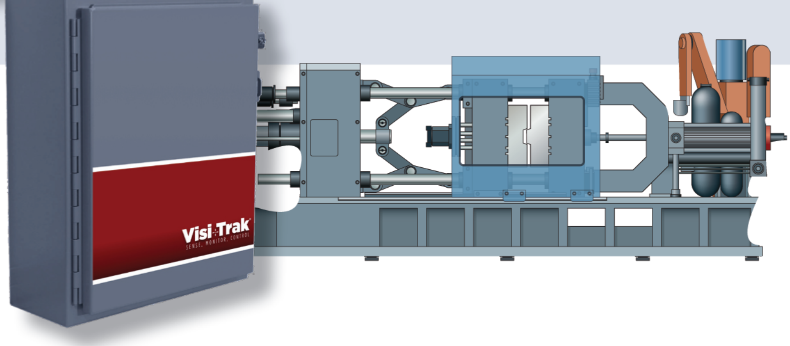

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