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NADCA

A Method for Developing Uniform Cavity Pressure, Extending Die Life by Integrating SoftSHOT Technology Onto Automotive Transfer Case Die

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ABSTRACT

The premature failure of an existing die, which had been built to an original inherited die design, provided an opportunity to develop a new tool design using the latest modeling techniques. Numerous changes to the gating and runner system were evaluated in an effort to improve the filling pattern and to minimize porosity in a critical machined hole location. Using the First Tool Design, a baseline was established for the filling pattern and problem areas.

After a re-designed runner and gate that yielded an improved filling pattern had been developed, the Second Tool Design and proposed die casting process was evaluated using SoftSHOT Technology. The purpose of the SoftSHOT Technology evaluation was to determine an optimized overflow set that would help to fill certain difficult areas of the casting, as well as to limit the ultimate cavity pressure that would be achieved. By limiting the peak cavity pressure to a level that the clamp end of the machine could hold firmly closed, thereby eliminating flash, the problem of a blown slide was eliminated. The result was an extremely robust process with reduced variation, and a substantial improvement to die life.

INTRODUCTION

The subject part is an automotive transfer case, which is high pressure die cast by the Port City Group. The job was inherited by the Port City Group, who built a new die to the same tool design that was employed by the previous supplier of the casting. The previous supplier was in extremis, leaving no time for re-designing the tool. This tool will be referenced throughout as the First Tool Design by PCG.

The PCG had anticipated a certain die life based upon their experience, and had priced the job to their customer accordingly. The First Tool Design by PCG was retired prematurely having run 82% of the anticipated number of castings. The decision to retire the tool was based collectively upon the following conditions:

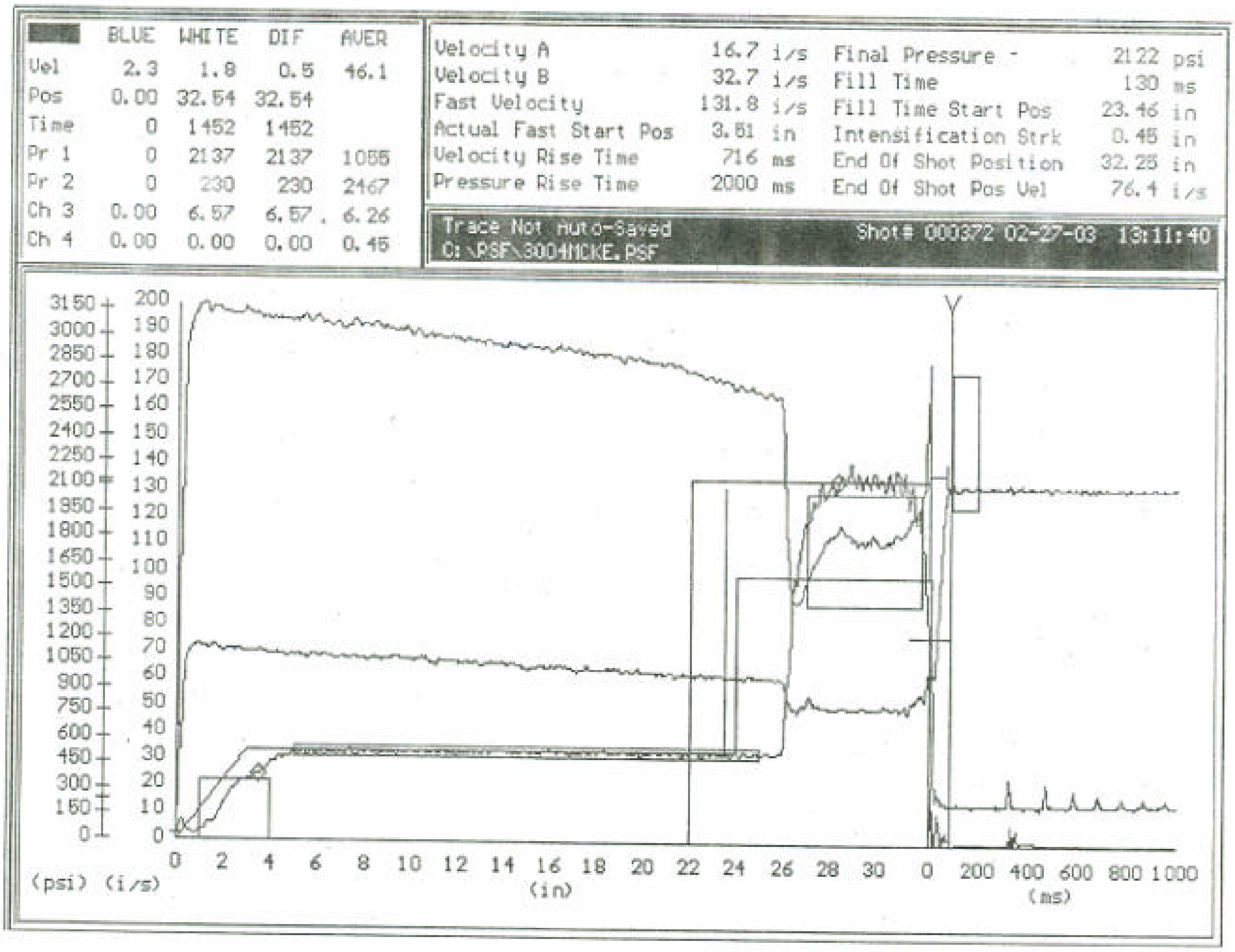
(a) The large slide had been severely blown, confronting PCG with an expensive repair.
(b) Maintenance costs for the slide area were already high
(c) Running the die resulted in excessive downtime and poor machine utilization
(d) (a), (b), and (c) made the job unprofitable

In order to more fully understand the deficiencies of the First Tool Design, the Port City Group embarked upon an evaluation of the existing tool design, including the gate and runner system. This process provided a basis for comparative analysis with an intended new design.

INITIAL GATING DESIGN EVALUATION

The Port City Group's approach to gate sizing is based upon NADCA's standards for gate velocity. A gate cross sectional area of 1.32 sq. in. was established using a gate velocity comfortably between NADCA's 1200 IPS and 1800 IPS gate velocity range. A desired cavity fill time of 81 mS was determined by a simple formula that relates cavity fill time to the minimum wall thickness of the casting (1/3 minimum wall thickness (in inches) = cavity fill time (in (mS). Pour weight is 19.68 lbs. The trimmed casting weighs 12.82 lbs.

Further calculations established that their 1200 Ton die casting machine had sufficient horsepower to displace the required amount of metal through the 1.32 sq. in. gate cross sectional area in the desired cavity fill time of 81 mS using a 4-1/2" diameter tip and a filling velocity for the shot system of 125 IPS.
All of these values remained the same for the First Tool Design and the Second Tool Design. The shot profile in Figure 1 shows the injection process employed with the First Tool Design



	BLUE	WHITE	DIF	AVER
Vel	2.3	1.8	0.5	46.1
Pos	0.00	32.54	32.54	
Time	0	1452	1452	
Pr 1	0	2137	2137	1055
Pr 2	0	230	230	2467
Ch 3	0.00	6.57	6.57 .	6.26
Ch 4	0.00	0.00	0.00	0.45

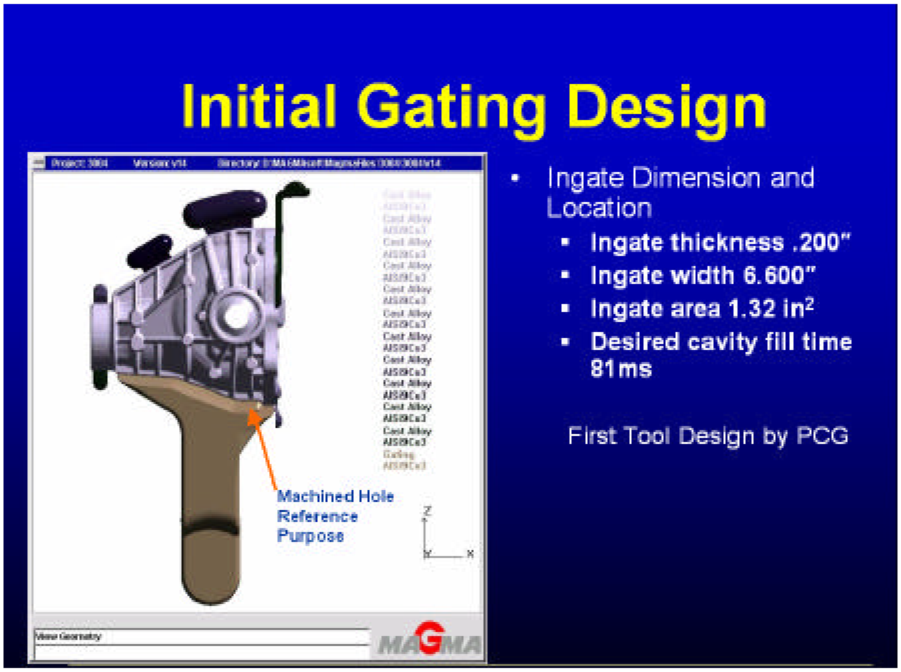
Velocity A	16.7	i/s	Final Pressure -	2122	psi
Velocity B	32.7	i/s	Fill Time	130	ms
Fast Velocity	131.8	i/s	Fill Time Start Pos	23.46	in
Actual Fast Start Pos	3.81	in	Intensification Strk	0.45	in
Velocity Rise Time	716	ms	End Of Shot Position	32.25	in
Pressure Rise Time	2000	ms	End Of Shot Pos Vel	76.4	i/s

Trace Not Auto-Saved Shot# 000372 02-27-03 13:11:40
C:\PSF\3004MCKE.PSF

```
Fast Actual Test Window Start ..........  27.00 in
Fast Actual Test Window End ............  32.00 in

Biscuit Length .........................  0.987 in

Velocity Rise Time 'From Velocity' .....   24.0 i/s
Velocity Rise Time 'To   Velocity' .....  135.0 i/s
Velocity Rise Time 'From Position' .....  3.513 in
Velocity Rise Time 'To   Position' ..... 28.380 in

Pressure Rise Time from Vel. ...........   76.4 i/s
Desired Pressure Rise Time Pressure ....   2200 psi

Final Pressure from (ms after EOS) .....    100 ms
Final Pressure to   (ms after EOS) .....    200 ms

Position to Start looking for EOS Vel. .  30.00 in
Minimum Stroke Velocity ................    0.0 i/s
Time to Wait for Fully Forward .........     30 sec
End Of Shot Velocity to Test For .......   10.0 i/s

Plunger Diameter .......................  4.500 in
Metal Density (pounds per cubic inch) ..  0.098
Part Weight ............................ 13.706 lb
```

Figure 1

The initial gating design is shown in Figure 2 below.



Initial Gating Design

- Ingate Dimension and Location
  - **Ingate thickness .200"**
  - **Ingate width 6.600"**
  - **Ingate area 1.32 in^2**
  - **Desired cavity fill time 81ms**

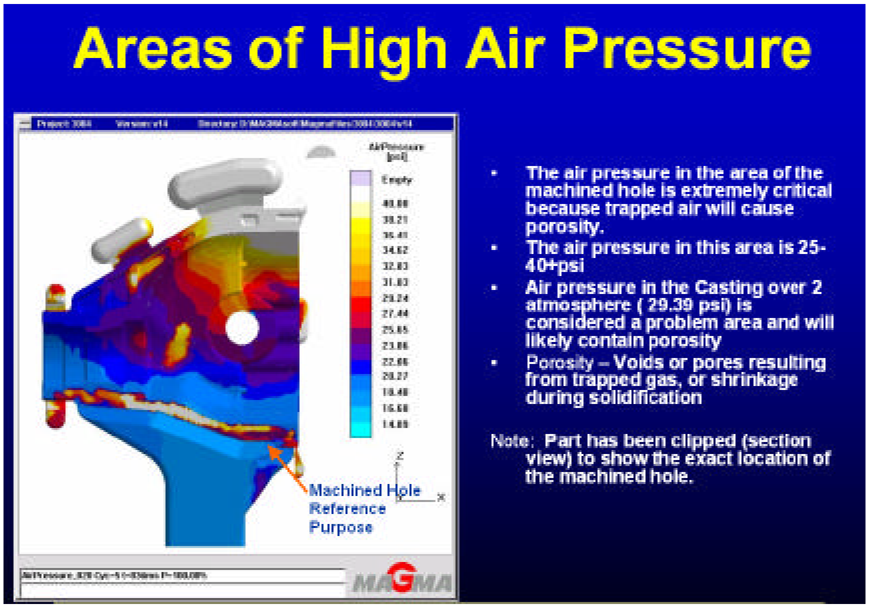
First Tool Design by PCG

Figure 2

All of the gating, filling, air pressure, and solidification modeling was done using the gate areas and fill times defined above.

The final part has a drilled and tapped hole that is a critical area for sealing. The gating area encompasses the machined hole location on the First Tool Design. The filling simulation revealed that this area has high entrapped air, which is the result of a significant variation between the ingate thickness and the casting thickness. Further modeling using a Tracer Particle Evaluation shows the swirling effect caused by this thickness variation. See Figures 3 and 4.

The MagmaSoft modeling software revealed that the air pressure in the critical machined hole area would be between 25 PSI and 40+ PSI using the gate design that was employed on the First Tool Design. From past experience, the Port City Group knew that air pressure in the casting during filling in excess of 2 atmospheres (29.4 PSI) would result in porosity in that area of the casting. It was hoped that effective intensification could reduce the problems associated with porosity in this area of the machined hole.

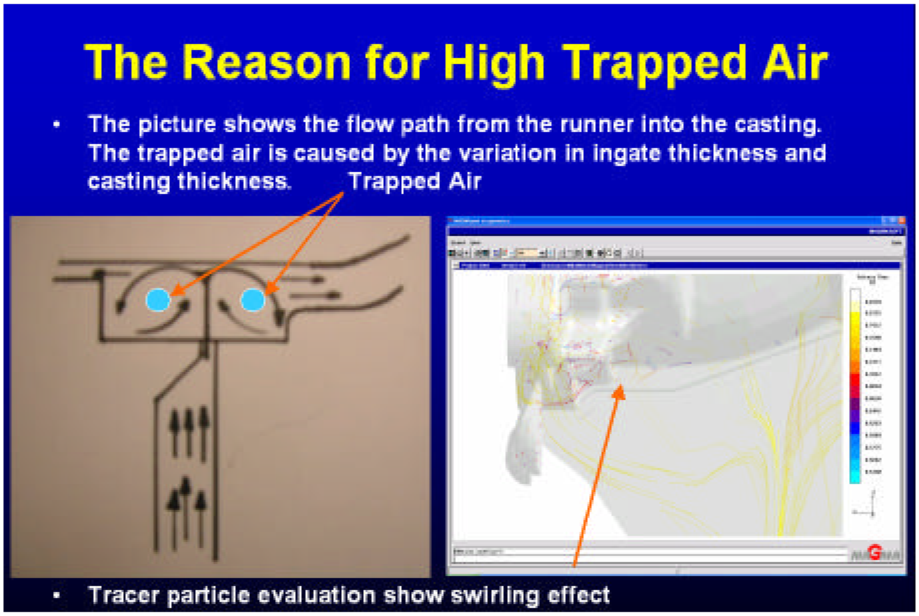


Areas of High Air Pressure

- The air pressure in the area of the machined hole is extremely critical because trapped air will cause porosity.
- The air pressure in this area is 25-40+psi
- Air pressure in the Casting over 2 atmosphere (29.39 psi) is considered a problem area and will likely contain porosity
- Porosity – Voids or pores resulting from trapped gas, or shrinkage during solidification

Note: Part has been clipped (section view) to show the exact location of the machined hole.

Figure 3



The Reason for High Trapped Air

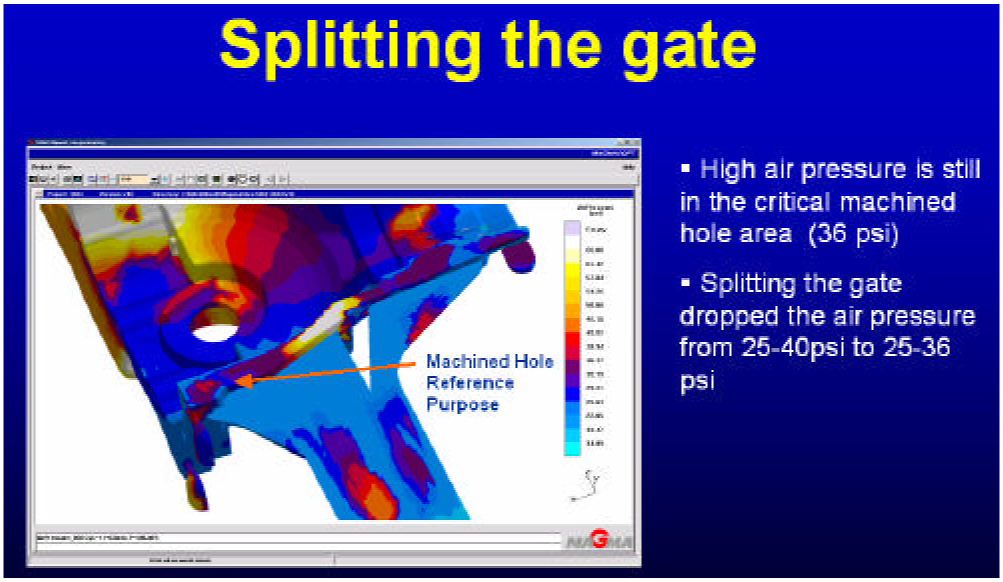
- The picture shows the flow path from the runner into the casting. The trapped air is caused by the variation in ingate thickness and casting thickness.
- Tracer particle evaluation show swirling effect

Figure 4

EVALUATION OF OTHER GATE DESIGNS

Based upon these known problem areas in the casting, evaluation of some different gate and runner systems was deemed to be prudent. The Port City Group proceeded to model three different approaches, including splitting the gate, using a comb gate, and finally, moving the gate to the opposite side of the part.

A filling simulation using a split gate was performed. The result confirmed that there would still be high air pressure in the casting, and specifically the simulation revealed that the air pressure in the area of the critical machined hole would still exceed the 2 atmosphere threshold (25 to 36 PSI was revealed in the simulation). See Figure 5.



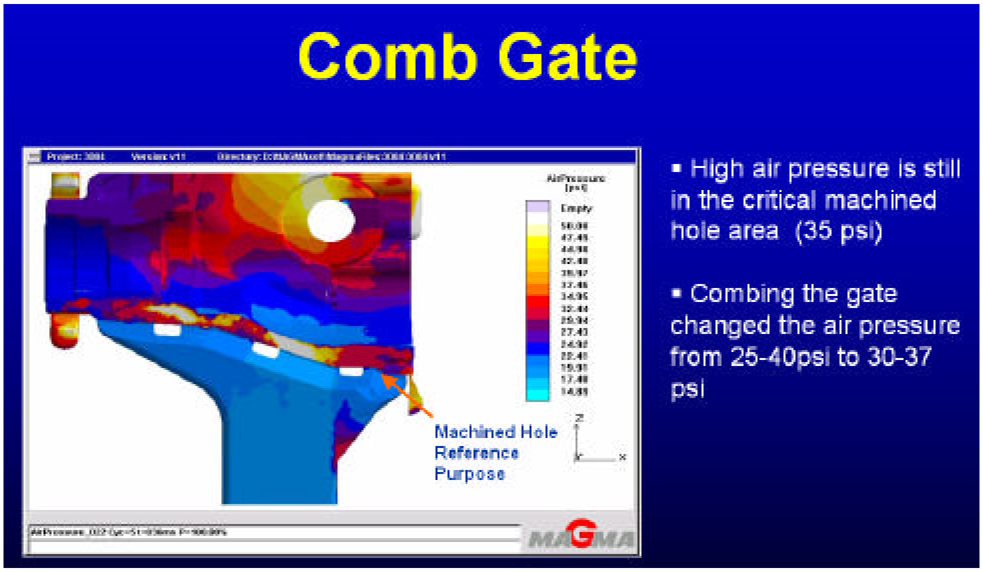
Splitting the gate

Machined Hole Reference Purpose

- High air pressure is still in the critical machined hole area (36 psi)
- Splitting the gate dropped the air pressure from 25-40psi to 25-36 psi

Figure 5

A subsequent simulation employing a comb gate did not resolve this problem, with the air pressure in the critical area between 30 and 37 PSI (Figure 6). So, moving the gate to the opposite side of the casting was simulated. The air pressure in the critical area after moving the gate to the opposite side of the casting still exceeded the 2 atmosphere threshold (32-38 PSI) (See Figure 7). However, in this arrangement, it became possible to place a vent in this critical area which would assist with removal of the entrapped air and help to reduce the air pressure. So, it was decided to move the gate to the opposite side of the casting, and to continue with more simulations to further refine the design.

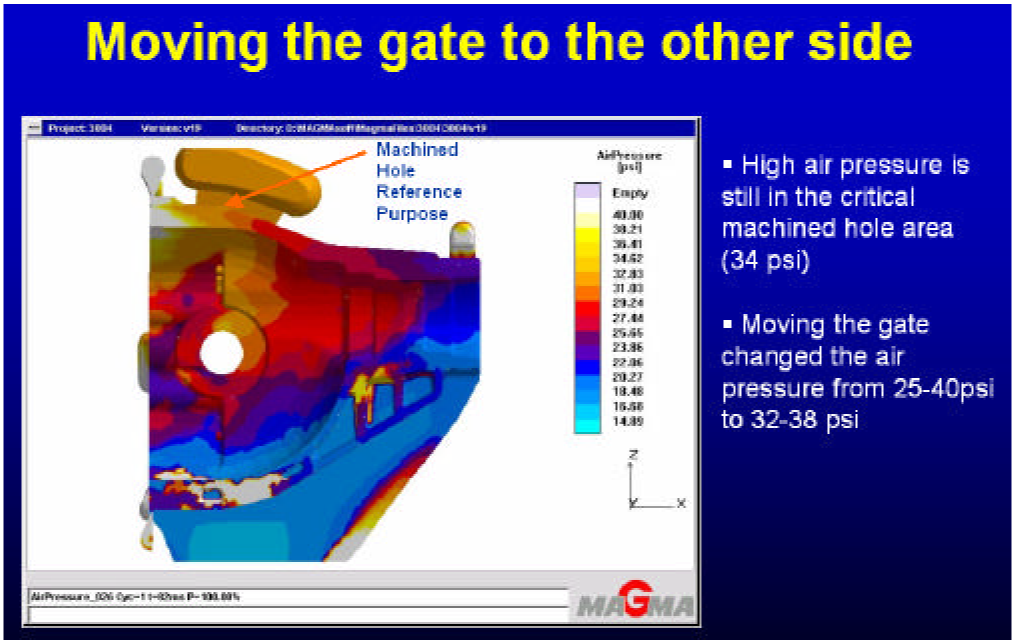


Comb Gate

Machined Hole Reference Purpose

- High air pressure is still in the critical machined hole area (35 psi)
- Combing the gate changed the air pressure from 25-40psi to 30-37 psi

Figure 6



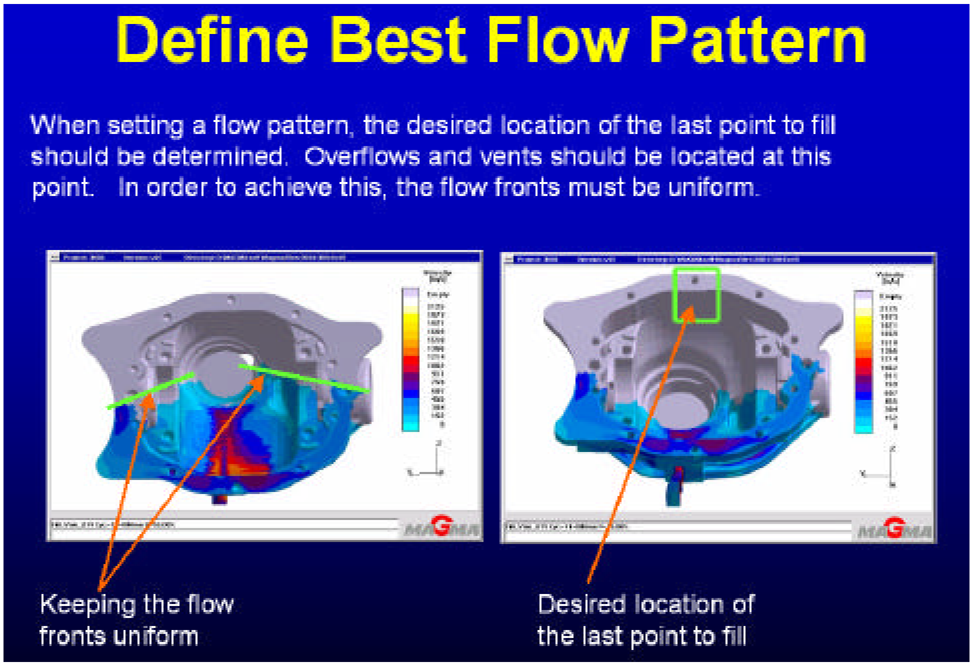
Moving the gate to the other side

- High air pressure is still in the critical machined hole area (34 psi)
- Moving the gate changed the air pressure from 25-40psi to 32-38 psi

Figure 7

GATING OPIMIZATION

Additional filling simulations were performed in order to define the best possible flow pattern that would improve the critical areas of the casting with the ingate moved to the opposite side of the casting. When considering a flow pattern, the desired location(s) of the last point to fill should be determined. (See Figure 8).



Define Best Flow Pattern

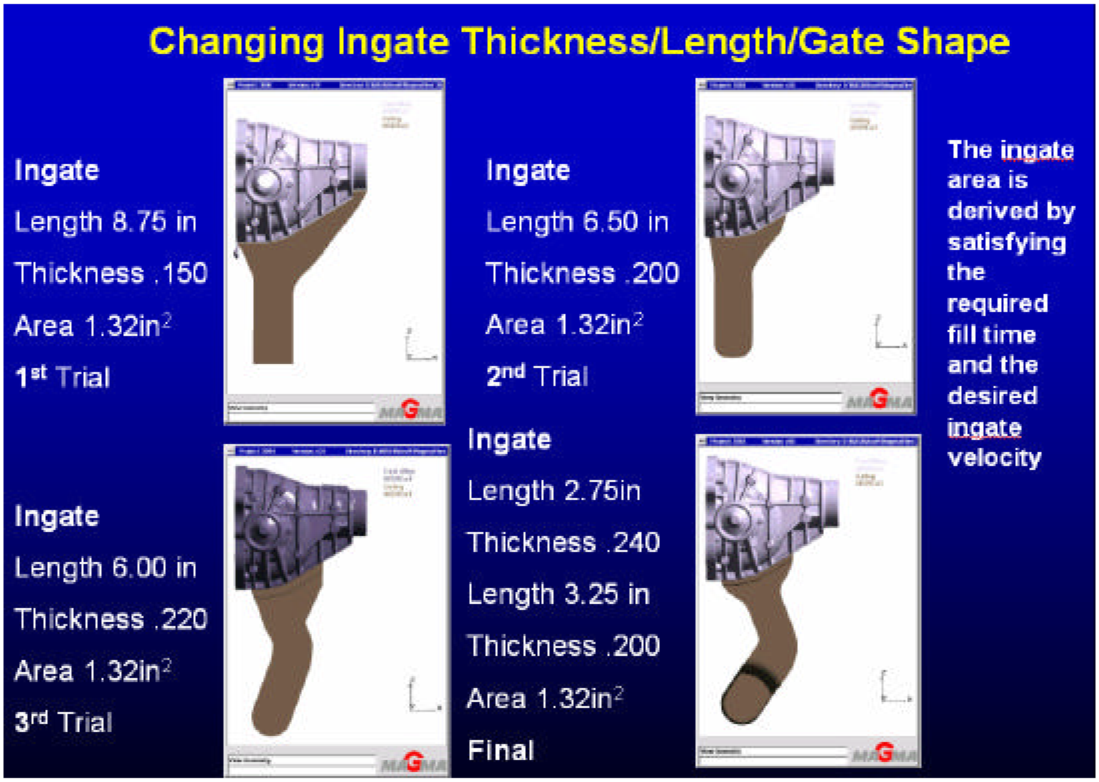
When setting a flow pattern, the desired location of the last point to fill should be determined. Overflows and vents should be located at this point. In order to achieve this, the flow fronts must be uniform.

Keeping the flow fronts uniform

Desired location of the last point to fill

Figure 8

Many different combinations of Ingate Thickness/Length/Gate Shape were simulated (See Figure 9). The best of these, designated as “Final” on Figure 9 was selected.



Changing Ingate Thickness/Length/Gate Shape

Ingate
Length 8.75 in
Thickness .150
Area 1.32in^2
1st Trial

Ingate
Length 6.50 in
Thickness .200
Area 1.32in^2
2nd Trial

The ingate area is derived by satisfying the required fill time and the desired ingate velocity

Ingate
Length 6.00 in
Thickness .220
Area 1.32in^2
3rd Trial

Ingate
Length 2.75in
Thickness .240
Length 3.25 in
Thickness .200
Area 1.32in^2
Final

Figure 9

The following points summarize the progress toward the Second Tool Design:

1. High air pressure was evident in all gating designs considered.
2. Venting was not possible with a split or comb gate
3. Moving the gate to the opposite side of the casting enabled venting
4. Good overflow and vent design should mitigate air entrapment
5. Defining the desired flow pattern and final point to fill is a critical step
6. Many variations were simulated to determine the best combination of ingate width/thickness and angle of approach.
7. All gate simulations utilized the same gate area.

SOFTSHOT TECHNOLOGY

As previously mentioned, flashing in the slide area was the chief culprit in the premature failure of the First Tool Design by PCG. Therefore, elimination of the flashing problem was critical to establishing a robust process with a low scrap rate. The Port City Group decided upon a novel potential solution; using a carefully designed set of overflows, which when properly positioned in the die where the final filling of the casting occurs, have the potential to absorb the kinetic energy of the shot system at impact. This new technology is called SoftSHOT Technology.

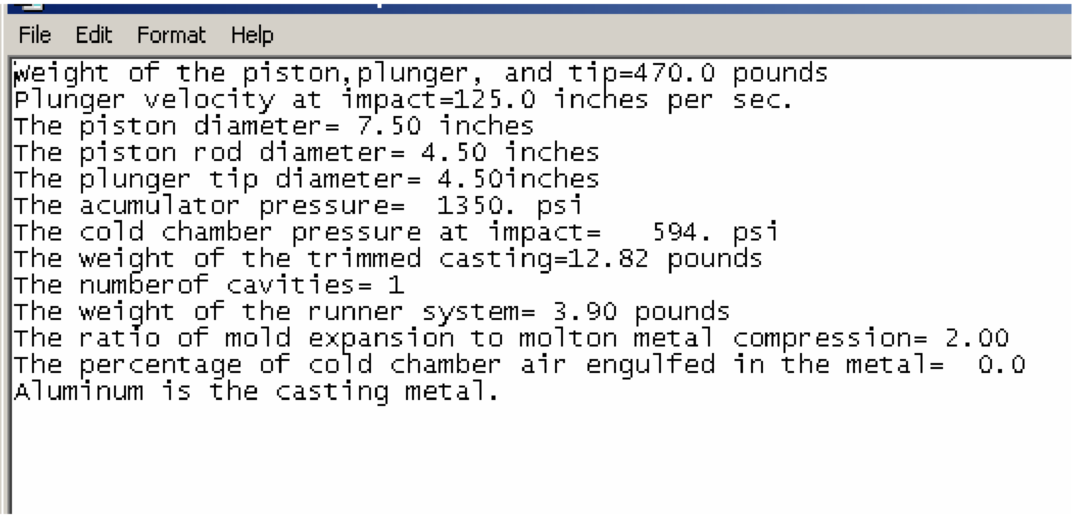
SoftSHOT Technology is a technical innovation that employs carefully designed overflows to (a) limit the cavity pressure at impact, (b) smoothly decelerate the shot system, and (c) because a cavity pressure has been selected that the clamp end can hold firmly closed, eliminate flash from the castings. It is critical to position the deceleration overflows where the final filling of the casting occurs. The filling and flow simulations were invaluable in determining the best location for the deceleration overflows.

SoftSHOT Technology Application Software includes a mathematical model of the dynamics of the shot system and the pressure in the tooling beginning at a hypothetical position on the shot profile where the forced deceleration of the shot system begins. At this hypothetical position, it is assumed that the casting is now made, but the overflows have not yet been filled.

The mathematical model calculates (a) the velocity of the shot system, (b) the pressure in the runner system, (c) the pressure in the cavity area of the die, and (d) the position of the shot system, all displayed versus time on the X-axis and as a percentage of their maximum value on the Y-axis, for the appropriate time window. The model can be employed in various ways to evaluate tooling and overflow designs.

For example, existing overflows on a sample tool can be input, and the model will calculate the likely result for the four factors outlined above. Changes to the overflows can be evaluated in this manner. The model can be used in an optimized format, where the user specifies a desired cavity pressure to be achieved and maintained, and then the model will calculate a set of deceleration overflows that will limit the cavity pressure to the user specified value.

The SoftSHOT Technology model has some required user input fields, known as a Data File. The Data File for the 1200 Ton Prince machine and the process employed by the Port City Group for making this casting is shown in Figure 10.



```
weight of the piston,plunger, and tip=470.0 pounds
Plunger velocity at impact=125.0 inches per sec.
The piston diameter= 7.50 inches
The piston rod diameter= 4.50 inches
The plunger tip diameter= 4.50inches
The acumulator pressure=  1350. psi
The cold chamber pressure at impact=   594. psi
The weight of the trimmed casting=12.82 pounds
The numberof cavities= 1
The weight of the runner system= 3.90 pounds
The ratio of mold expansion to molton metal compression= 2.00
The percentage of cold chamber air engulfed in the metal=  0.0
Aluminum is the casting metal.
```

Figure 10

The Data File establishes the kinetic energy of the shot system at impact, in effect, quantifying the physical blow that the shot system delivers to the tooling and the clamp end of the machine. Other factors, such as the metal being cast, the number of cavities, and some volumes for the runner system are also input.

The SoftSHOT Technology mathematical model can calculate, by means of an iterative process, the size of a series of deceleration overflows that will absorb the kinetic energy of the shot system at impact. “Size” means establishing a specific volume for each deceleration overflow, along with a specific cross sectional gate area for each overflow pocket. The gate leading to the overflow acts as a valve, and the semi-aerated, semi frozen, “milk shake metal” that reaches these overflow gates is the “fluid” crossing the valve. The valve (gate) is sized according to a flow coefficient, and the gates are designed to be inefficient. The pocket volume of each overflow determines how long each of the valves (gates leading to the overflows) are “On.”

Flow curves for hydraulic valves (for example) plot flow across the valve (usually on the X axis) at a given pressure drop (usually on the Y axis). A typical flow curve is pictured below in Figure 11. An efficient valve will exhibit a low pressure drop at a given flow rate. An inefficient valve will exhibit a high pressure drop at a given flow rate. This same concept is behind the overflow sizing calculations.

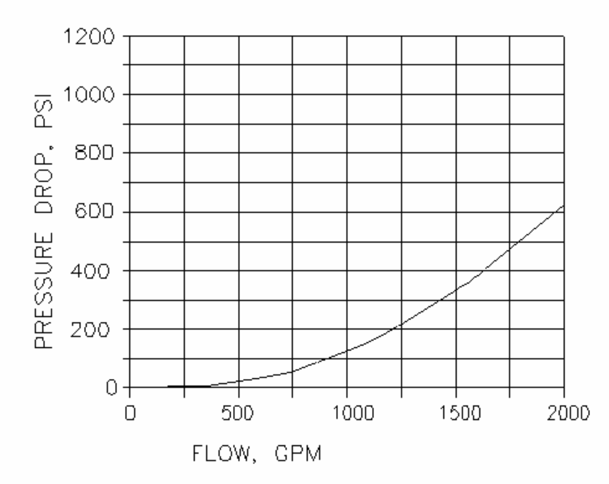
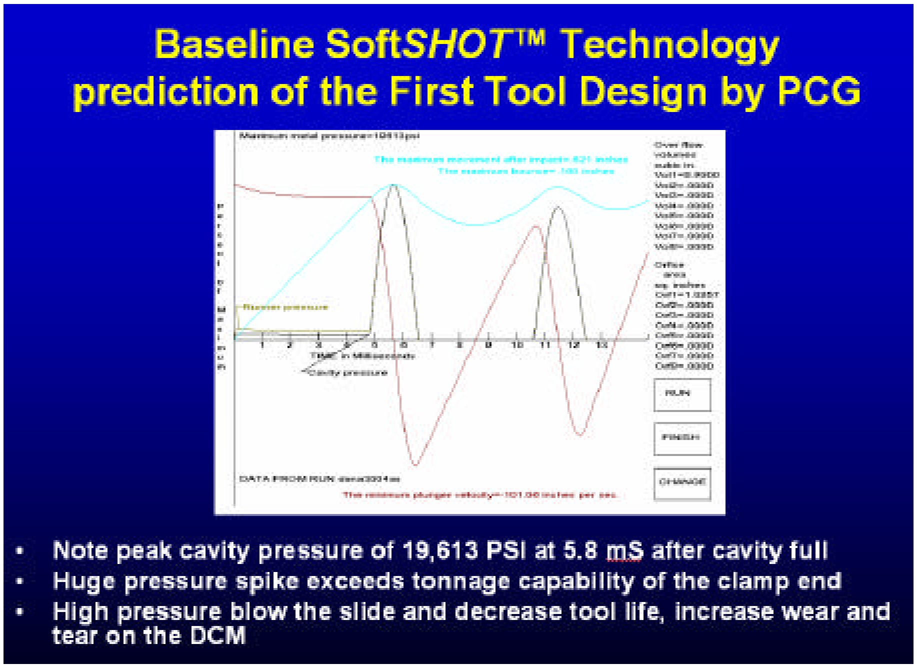


Figure 11

SoftSHOT Technology calculates purposefully inefficient gates which stall out the horsepower of the shotend at the end of the shot, and at precisely the proper moment, i.e., when the die is full, having the added benefit of compensating for the dosing variation, and resulting in a more stable process.

Figure 12 shows the SoftSHOT Technology prediction for the First Tool Design by PCG. The last overflow fills at approximately 4.8 mS after the casting is full. From this point forward, the relationship between plunger displacement and pressure in the tooling is linear. AT 5.7 mS after the casting is full, the plunger has come to a complete stop and the peak cavity pressure of 19,613 psi occurs. This pressure is far beyond what the clamp end of the die casting machine can hold closed. The result is that the die halves are blown apart, and in the case of the First Tool Design, the slide area is badly blown and loaded up with flash. This is the baseline SoftSHOT prediction..

Figure 12 highlights a very unfriendly situation for the tooling and the clamp end of the die casting machine. The huge impact spike delivers a powerful and unnecessary blow to the clamp end of the machine, which results in considerable wear and tear to pins, bushings, platens, linkage, etc. The shotend comes to an abrupt halt, with considerable bouncing, incurring shock and vibration to the mechanical and sensor assemblies.

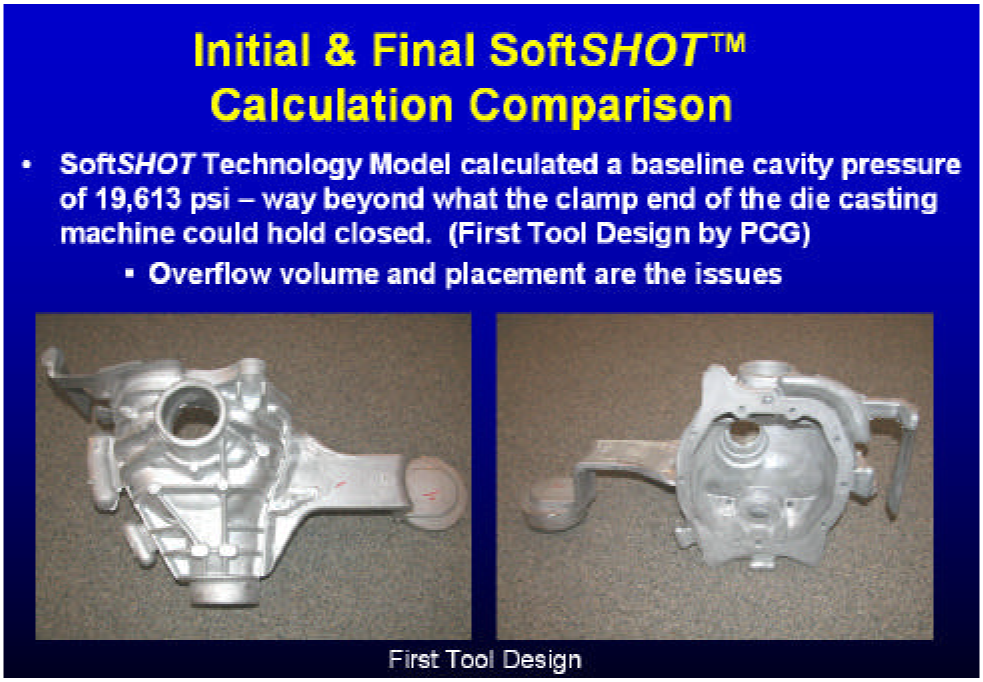


Baseline Soft*SHOT*™ Technology prediction of the First Tool Design by PCG

- Note peak cavity pressure of 19,613 PSI at 5.8 mS after cavity full
- Huge pressure spike exceeds tonnage capability of the clamp end
- High pressure blow the slide and decrease tool life, increase wear and tear on the DCM

Figure 12

Figure 13 shows a casting from the First Tool Design when the tool was new. There is not much evidence of flash, which became much worse as the tool began to wear. The 1200 Ton Prince machine could not hold the die closed without the low impact system enabled.



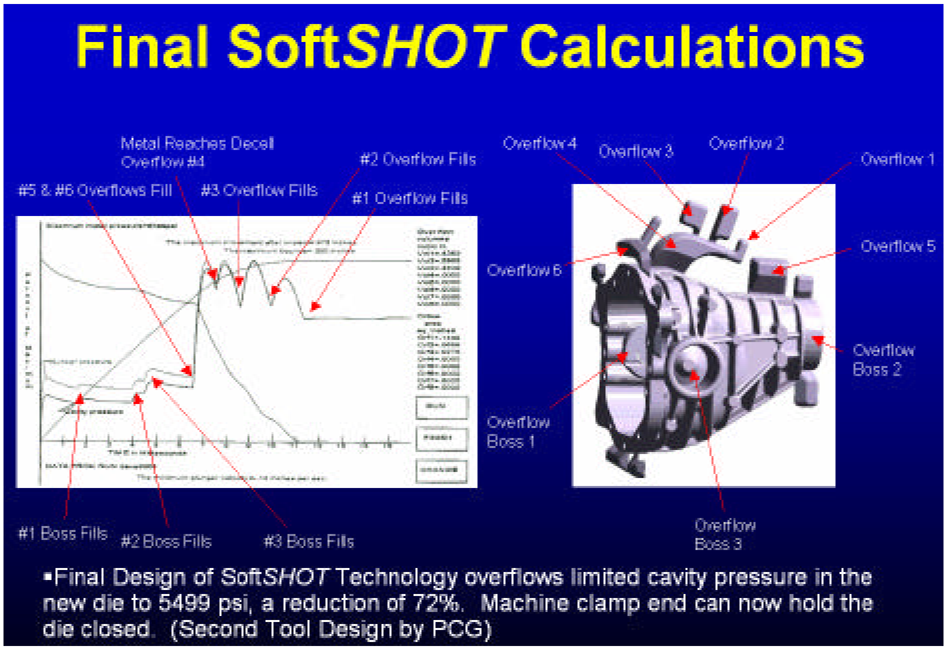
Initial & Final Soft*SHOT*™ Calculation Comparison

- Soft*SHOT* Technology Model calculated a baseline cavity pressure of 19,613 psi – way beyond what the clamp end of the die casting machine could hold closed. (First Tool Design by PCG)
  - Overflow volume and placement are the issues

First Tool Design

Figure 13

Figure 14 shows the SoftSHOT Technology prediction for an optimized set of overflows. The graph has been labeled to show the precise moments and positions where the bosses, overflows, and deceleration overflows are filled. The adjacent detailed image of the casting identifies the bosses, overflows, and deceleration overflows. The deceleration overflows 4, 3, 2, and 1 are responsible for decelerating the shot system smoothly and limiting the cavity pressure. These were positioned in the area of the critical machined hole, which is the final place to fill in the tool.



Final Soft*SHOT* Calculations

- Final Design of Soft*SHOT* Technology overflows limited cavity pressure in the new die to 5499 psi, a reduction of 72%. Machine clamp end can now hold the die closed. (Second Tool Design by PCG)

Figure 14

A cavity pressure of 5500 psi was chosen for the Second Tool Design. Based upon calculations, the clamp end of the die casting machine could easily hold the tool closed at this peak cavity pressure. In comparison to the baseline situation where the calculated peak cavity pressure is 19,613 psi, the SoftSHOT Technology deceleration overflow set reduces the peak cavity pressure by 72%.

The MagmaSoft modeling software was used to evaluate the filling pattern of the new tool design, as previously stated. The best location for all of the overflows was determined from these filling simulations, which showed that the greatest area of air entrapment was directly opposite the ingate. Therefore, most of the overflow volume was placed in this area. See Figure 15 (overflow placement frame).

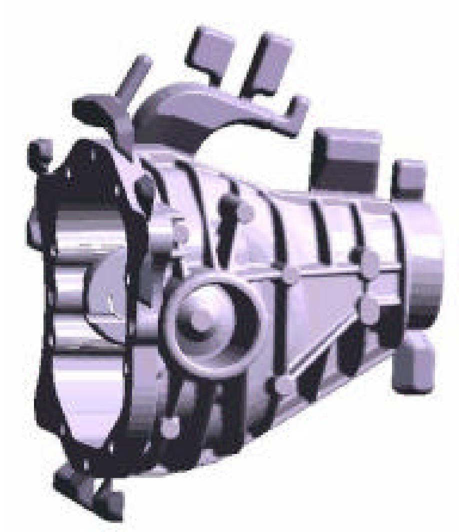
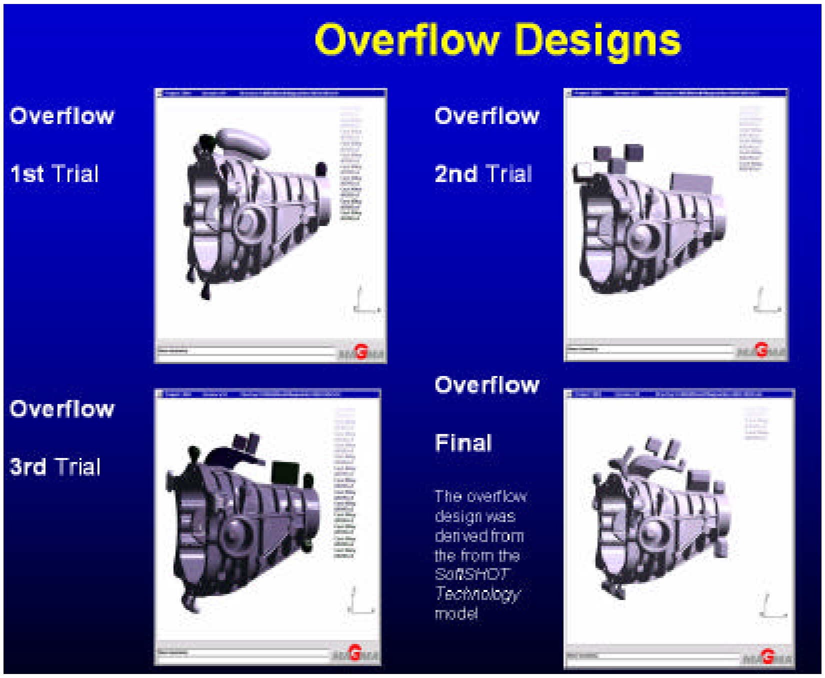


Figure 15

Furthermore, the optimum location for the deceleration overflows was determined. Several deceleration overflow orientations were modeled, as shown in Figure 16 (overflow designs). The "Final" overflow design (lower right hand image on Figure 16) was determined by the SoftSHOT Technology model.



Overflow Designs

Overflow

1st Trial

Overflow

2nd Trial

Overflow

3rd Trial

Overflow

Final

The overflow design was derived from the from the SoftSHOT Technology model

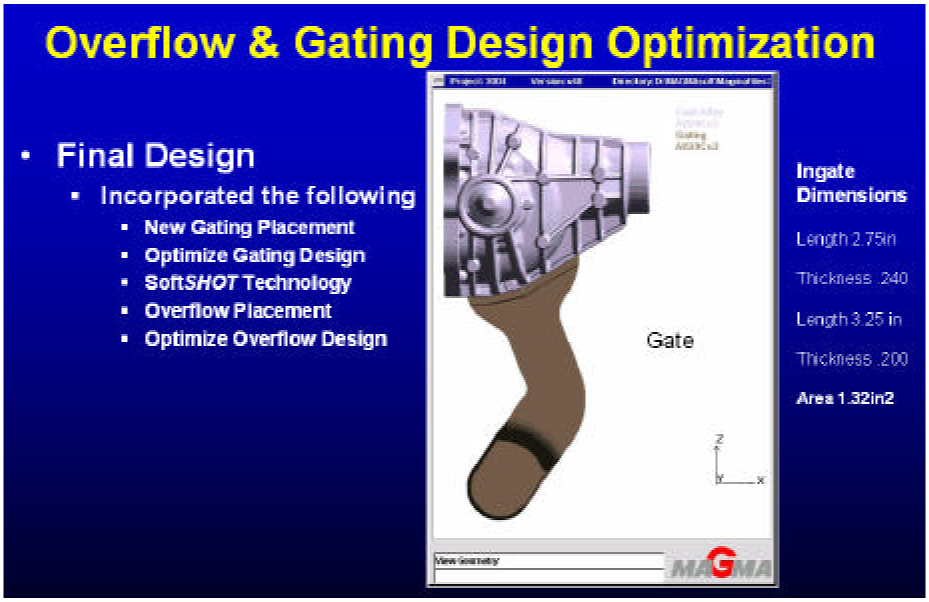
Figure 16

FINAL GATING AND OVERFLOW DESIGN

Figure 17 shows the new gate placement and optimized gate design. Figure 18 also shows the final overflow placement and optimized overflow design. This final design was subjected to MagmaSoft modeling simulations, as follows:

- Filling Temperature
- Air Pressure
- Ingate Velocity
- Cavity Fill Time
- Final Solidification

See Figures 19 through 23.



Overflow & Gating Design Optimization

- Final Design
  - Incorporated the following
    - New Gating Placement
    - Optimize Gating Design
    - Soft*SHOT* Technology
    - Overflow Placement
    - Optimize Overflow Design

Ingate Dimensions

Length 2.75in

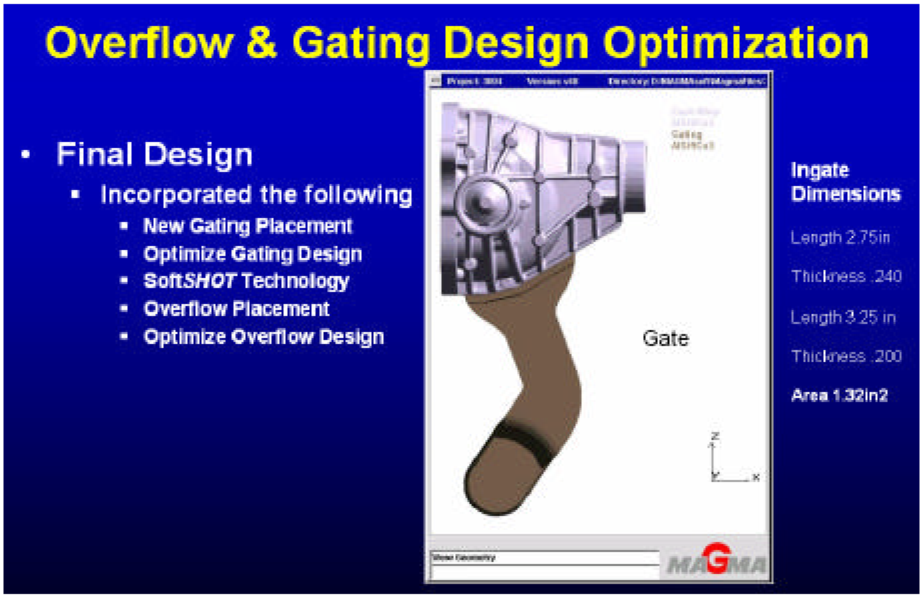
Thickness .240

Length 3.25 in

Thickness .200

Area 1.32in2

Figure 17



Overflow & Gating Design Optimization

- Final Design
  - Incorporated the following
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    - Soft*SHOT* Technology
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Ingate Dimensions

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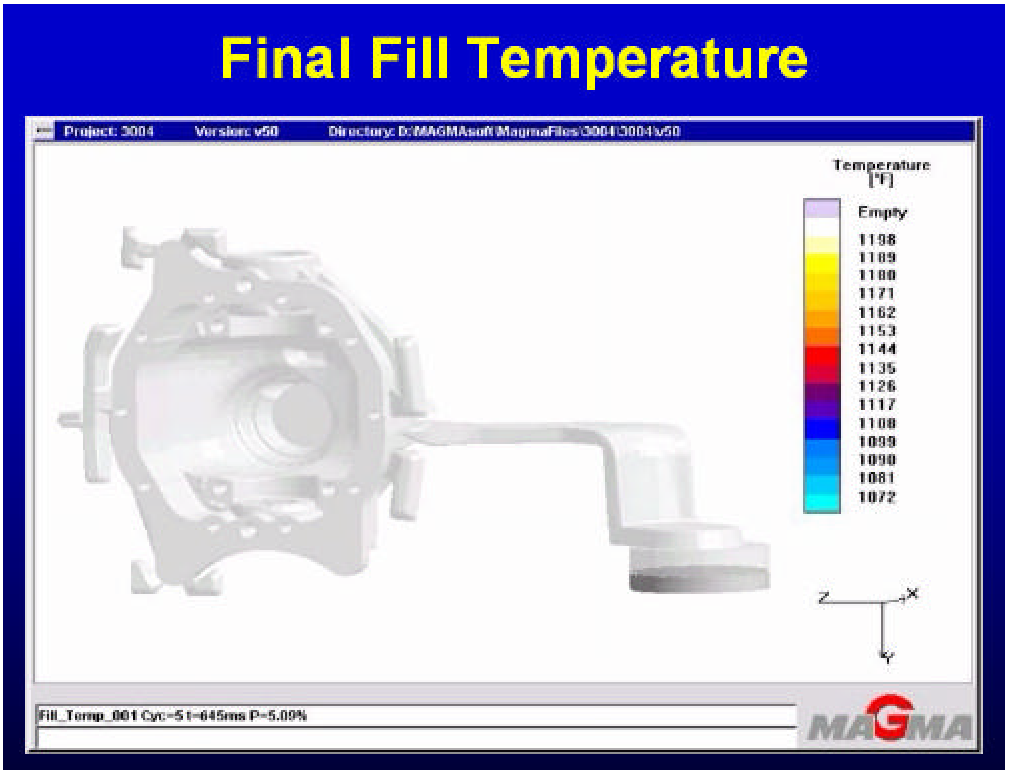
Thickness .200

Area 1.32in2

Figure 18

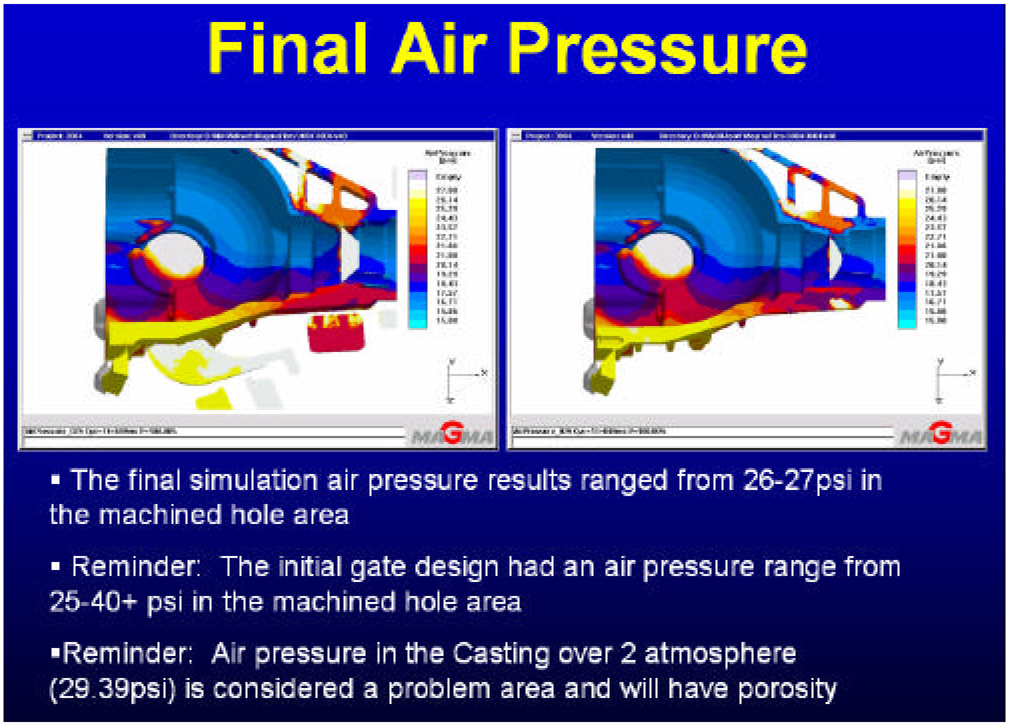


Final Fill Temperature

Project: 3004 Version: v50 Directory: D:\MAGMAsoft\MagmaFiles\3004\3004\v50

Fill_Temp_001 Cyc=5 t=645ms P=5.09%

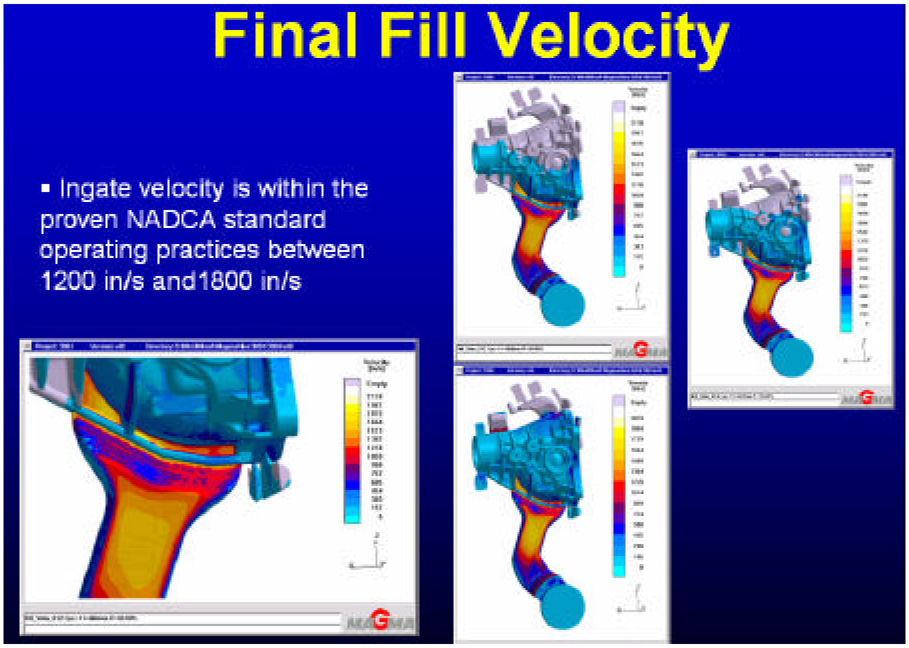
Figure 19



Final Air Pressure

- The final simulation air pressure results ranged from 26-27psi in the machined hole area
- Reminder: The initial gate design had an air pressure range from 25-40+ psi in the machined hole area
- Reminder: Air pressure in the Casting over 2 atmosphere (29.39psi) is considered a problem area and will have porosity

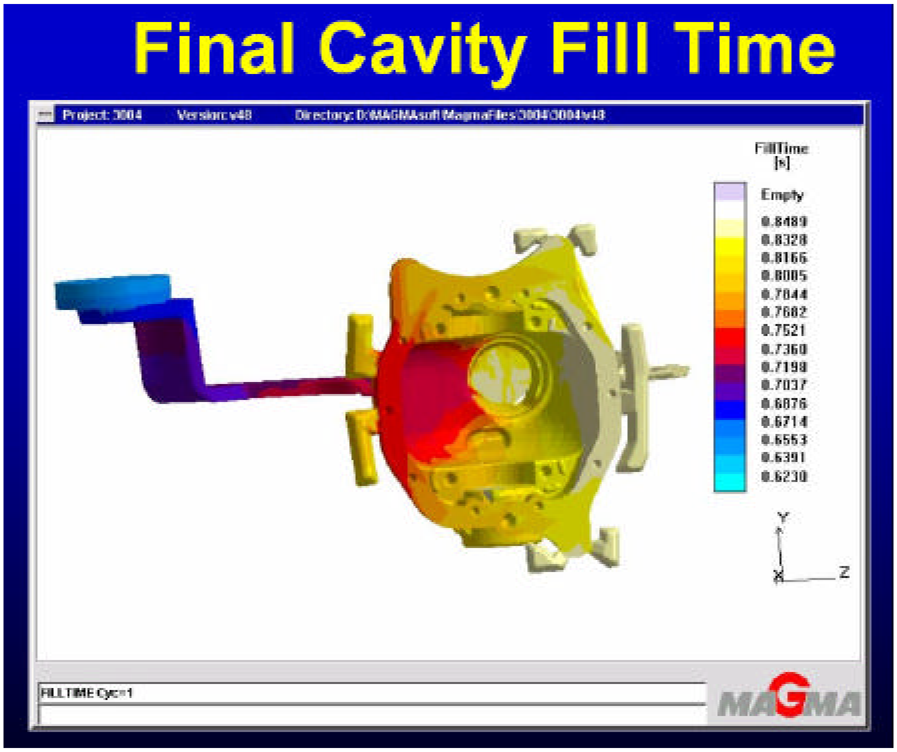
Figure 20



Final Fill Velocity

- Ingate velocity is within the proven NADCA standard operating practices between 1200 in/s and1800 in/s

Figure 21



Final Cavity Fill Time

Project: 3004 Version: v48 Directory: D:\MAGMAsoft\MagmaFiles\3004\3004\v48

FILLTIME Cyc=1

Figure 22

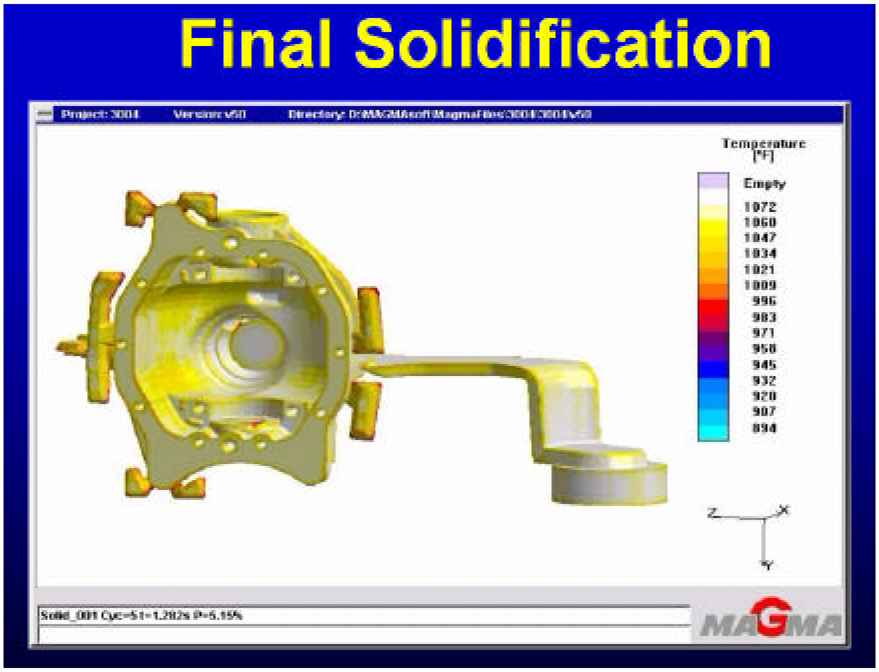


Figure 23

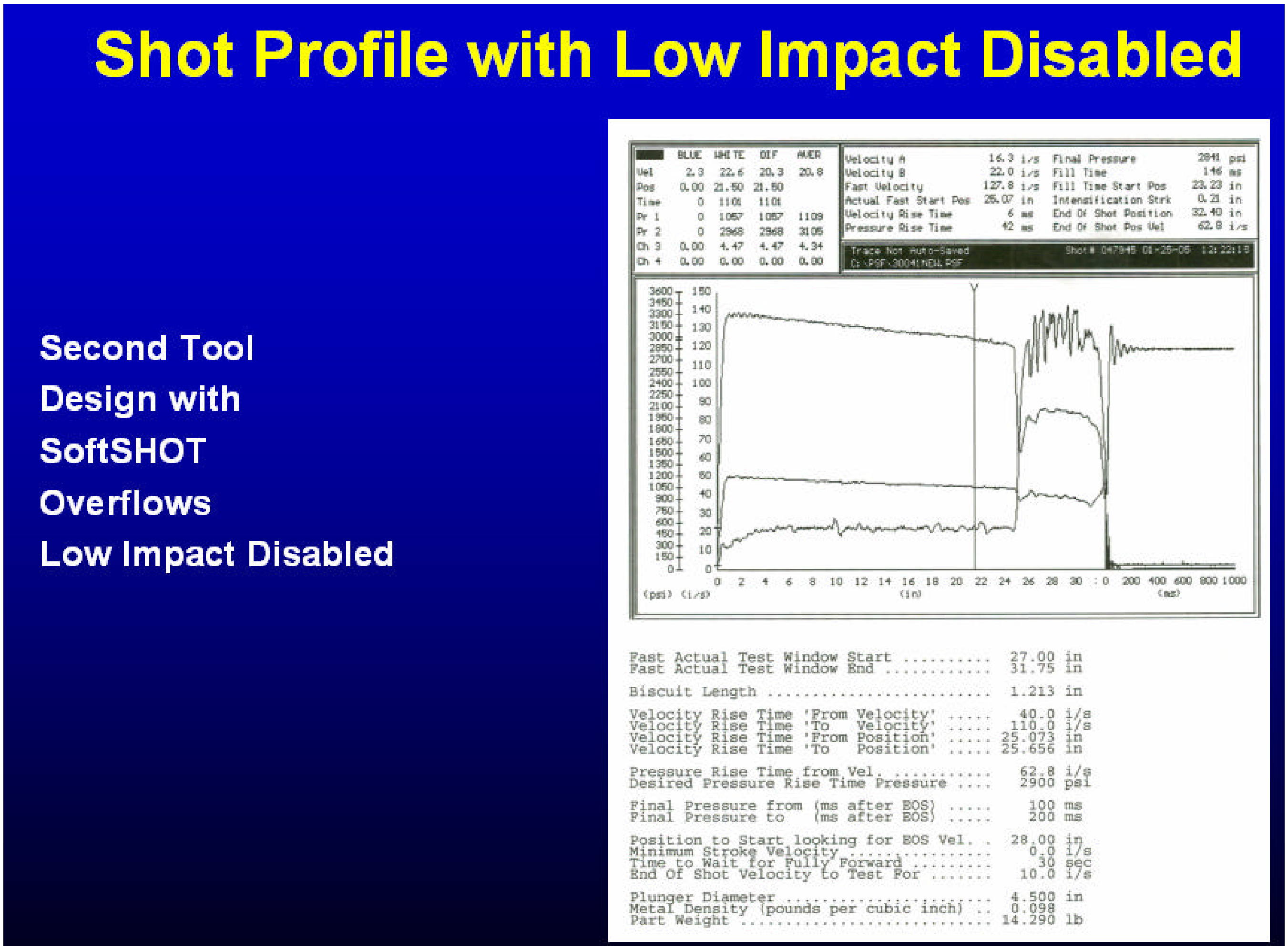
Results from the modeling simulations and the SoftSHOT Technology evaluations were compared to determine whether or not any correlation or corroboration existed between the two methodologies. It was determined that the modeling done by SoftSHOT Technology and MagmaSoft do not overlap. They do, in fact, complement each other. The most applicable of the MagmaSoft simulations vis-à-vis SoftSHOT Technology is the filling simulation, because the filling simulation shows the optimum location for the placement of the deceleration overflows on castings with complicated shapes.

A Fill Pressure simulation was performed for the First Tool Design and the Second Tool Design. The Fill Pressure Result for the Second Tool Design did show a much lower pressure in the area of the deceleration overflows.

VERIFY SOFTSHOT TECHNOLOGY AND THE DIECASTING MACHING

The process at the die casting machine was identical for the two tools. With the First Tool Design, the Port City Group could not hold metal without employing the low impact system on the die casting machine. The calculated peak cavity pressure was 19,613 psi. From the shot profile, the head side pressure at impact was 3100 psi. The tool was scrapped at 82% of projected tool life. (Reference Figure 1)

The Second Tool Design was run successfully with the low impact system turned off. The calculated peak cavity pressure was 5499 psi. The head side pressure at impact showed a value of 2100 psi. (See Figure 26). The tool life at the time of the preparation of this paper was 130% of the original anticipated die life, and the tool is still in very good condition and will run many more castings.



Shot Profile with Low Impact Disabled

Second Tool
Design with
SoftSHOT
Overflows
Low Impact Disabled

```
       BLUE   WHITE   DIF     AVER
Vel     2.3   22.6    20.3    20.8
Pos    0.00   21.50   21.50
Time      0   1101    1101
Pr 1      0   1057    1057    1109
Pr 2      0   2968    2968    3105
Ch 3   0.00   4.47    4.47    4.34
Ch 4   0.00   0.00    0.00    0.00

Velocity A                16.3 i/s   Final Pressure          2841 psi
Velocity B                22.0 i/s   Fill Time                146 ms
Fast Velocity            127.8 i/s   Fill Time Start Pos    23.23 in
Actual Fast Start Pos    25.07 in    Intensification Strk    0.21 in
Velocity Rise Time           6 ms    End Of Shot Position   32.40 in
Pressure Rise Time          42 ms    End Of Shot Pos Vel     62.8 i/s

Trace Not Auto-Saved                 Shot# 047845 01-25-05  12:22:13
C:\PSF\3004\NEW.PSF
```

```
Fast Actual Test Window Start ..........  27.00 in
Fast Actual Test Window End ............  31.75 in

Biscuit Length .........................  1.213 in

Velocity Rise Time 'From Velocity' .....   40.0 i/s
Velocity Rise Time 'To   Velocity' .....  110.0 i/s
Velocity Rise Time 'From Position' ..... 25.073 in
Velocity Rise Time 'To   Position' ..... 25.656 in

Pressure Rise Time from Vel. ...........   62.8 i/s
Desired Pressure Rise Time Pressure ....   2900 psi

Final Pressure from (ms after BOS) .....    100 ms
Final Pressure to   (ms after BOS) .....    200 ms

Position to Start looking for BOS Vel. .  28.00 in
Minimum Stroke Velocity ................    0.0 i/s
Time to Wait for Fully Forward .........     30 sec
End Of Shot Velocity to Test For .......   10.0 i/s

Plunger Diameter .......................  4.500 in
Metal Density (pounds per cubic inch) ..  0.098
Part Weight ............................ 14.290 lb
```

Figure 24

SUMMARY

Moving the gate to the opposite side of the casting and optimizing the gate shape produced a favorable filling pattern that reduced the trapped air in the casting. Overflow and vent placement is critical to reduce the amount of trapped air, and refinement of the overflows and their placement did reduce air entrapment. The air pressure in the area of the machined hole was reduced to a level below the 2 atmosphere threshold.

The low impact system on the die casting machine was turned off for the Second Tool Design, thereby reducing process variation. The impact pressure spike at the end of the filling process was observed to be approximately 30% lower than with the low impact system enabled when running the First Tool Design. Impact Force reduction is much friendlier to the die casting machine and the tooling. And finally, tool life has been substantially extended by reducing the peak cavity pressure by 72% using the specially designed overflow set calculated by the SoftSHOT Technology model.

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The engineering team at Port City Group is able and nimble. They were energetic and intellectually curious, and very committed to seek new solutions to difficult casting problems. They were, and are, a progressive team to work with.