COMPUTERIZED MONITORING AND REAL-TIME INJECTION CONTROL: RETROFITTING - A CASE STUDY

JOHN R. MICKOWSKI
TYMAC CONTROLS CORPORATION
FRANKLIN, NEW JERSEY, USA

From an article published in the Technical Volume of ALUCAST 2001 held at Delhi organized by Arkey Conference Service cell, Pune

Since the world's first introduction of computer graphic profile analysis in 1980, the die casting industry has increasingly gained an understanding of the dynamics of the process, and adopted computerization of the process for the purpose of reducing scrap and cost. Culminating several years of profile analysis of numerous machines and considerable R&D, the first production application of Ty mac's computerized real-time closed-loop injection control occurred in 1984. The result was elimination of unacceptable porosity and dimensional defects in air conditioning compressor parts used by Ford Motor Company. Today, comprehensive process monitoring and graphic profiling are widely used by the industry and became standard equipment with more and more OEM machine builders every year. Since 1984, every major make and type of high-pressure die casting machine has been upgraded with computerized real-time closed-loop injection control by the author's company. The present paper reports the substantial improvements in quality, productivity, and cost reduction which resulted from upgrading a 660D series die casting machine making automotive parts over the 4 years since installation of this technology in Pune, India. Case studies of parts made with this technology and at other installations are provided.

INTRODUCTION

Existing conventional (defined here as without CNC real-time closed-loop injection controls) die casting machines, especially those more than 6 years old, often do not have adequate dry shot speed, flexibility or consistency to meet today's higher quality standards. Without computer monitoring and CNC real-time closed-loop controlled injection velocity with their ability to provide any desired shot profile, including rapid deceleration, on an accurate, consistent basis, quality varies as the shots vary, setups are difficult, and flash is a constant concern. The impact of the shot end’s kinetic energy is absorbed by the metal, forcing the die caster to de-rate the machine's clamping capacity, shortening tool life, and often requiring tools to be frequently reconditioned, which causes downtime and repair costs. Yet the capital cost of replacing these machines often exceeds prudent budgets. Fortunately, technology is available to upgrade the performance of those "workhorses" which are still being used, to state-of-the-art at considerably lower cost. Even if the machines are in bad condition, the combined cost of refurbishing plus upgradation with comprehensive computer process monitoring and CNC real-time closed-loop injection control can be done at substantial savings. Following are a series
of reports on the long-term results achieved by this cost-effective approach.
A conventional 660D series die casting machine was equipped with a comprehensive computer process monitoring and real-time closed-loop injection control system in September 1997. The machine was upgraded with computer control in order to improve casting quality and reduce rejects of a crankcase housing and other parts. Another objective was to improve tool life through elimination of flash and high metal temperatures required by the limitations of the original injection system.

The machine originally had only manually-adjusted valves to set the slow and fast shot speeds. A timer was used to determine the changeover position from slow to fast speeds, and the intensifier was initiated by the buildup of pressure in the injection cylinder resulting from back pressure created at the point of die cavity filling. The monitors used to record process variables, store setups, perform SPC, and program the injection controls are shown in Figure 1.

In addition, the monitor provided graphic profiles of the injection ram velocity and pressures versus position and time. Master profiles were stored for each part, and were superimposed over the “Last Shots” to make setups faster and easier. Actual graphic profiles of the machine’s injection variables are shown in Figures 2 and 3.

Figure 2 shows the complete shot velocity profile, beginning with the initial acceleration ramp to pour hole close velocity (phases 1 and 2), next to the critical slow shot velocity of 41.2 cm/sec (phase 3), then to the cavity filling velocity of 392.9 cm/sec (phase 4), next to impact elimination deceleration (phase 5), next to squeeze velocity (phase 6) and finally intensification (phase 7). The plots are versus position until cavity fill, and thereafter versus time. This method of plotting, called “hybrid plotting” by its inventor, provides the maximum information on one computer screen or paper copy so all the important variables are observed simultaneously. This method also is the easiest to interpret. On the same graph are shown the cylinder piston head pressure, P1, and exhaust pressure, P2. These can be distinguished by noting that at the beginning of the shot, P2 is higher than P1, whereas after cavity fill, P2 drops to essentially zero, while P1 increases with intensification. The left and right vertical cursors provide numeric readouts for all plotted variables and the differences from the left and right positions for each variable. In addition to velocity, position and time, up to eight pressures, vacuums, squeeze pin strokes, or other signals can be plotted for both Master and Last Shot profiles.
The cursors on Figure 2 show the fast response of the real-time control, only 8.5 milliseconds to accelerate from the slow shot to fast shot speeds. This allowed accurate setting of the transition positions, since all velocity phases were programmed in position, rather than time. The short distance and time to accelerate permitted complete filling of the cold chamber without turbulence, thereby minimizing porosity, but accelerated the metal up to the correct gate velocity before reaching the gate, so misfills were also eliminated. The exhaust pressure peak shown at the end of cavity was the result of the real-time control system decelerating the plunger just before cavity fill to eliminate flash.

**Figure 3. Crankcase Impact Shot Profile**

Figure 3 shows the end of cavity fill in detail for the same shot as in Figure 2. In this case, P2 is shown along with pressure at the plunger tip, P4. Here, the cursors are positioned to show the extremely fast deceleration in 3.4 milliseconds, a tiny fraction of the total cavity-fill time. Metal pressure appears to actually dip below zero as the plunger is rapidly decelerated, while the exhaust pressure climbs to 192 bar to absorb the kinetic energy of the entire shot system. Without this deceleration ability, all of the peak pressure would have to be absorbed by the die, which is the cause of flash. It was found that deceleration must take place in a small fraction of the cavity-fill time in order to eliminate flash without extending overall fill time, else surface finish and other quality attributes dependent on a short fill time suffered. Moreover, deceleration to zero velocity prevented intensification, so a tightly-controlled fast deceleration to a controlled velocity (the squeeze velocity, phase 6) was essential to ensure that porosity would be lessened rather than increased.

The intensification system was also modified and enhanced to obtain the means to control it independently of cavity-fill back pressure. The graph shows P4 increasing at the right end of the graph, controlled by any combination of metal pressure buildup, position and/or time which resulted in the best castings.

**Figure 4. Real-Time CNC Closed-Loop Hydraulics Retrofit**

Figure 4 shows the modifications to the original shot end. A manifold rated at 600 bar containing the main servo velocity control valve was installed in series with the existing telescopic exhaust tube. Changes were also made to the hydraulic circuit which supplied oil from the main accumulator to the shot cylinder. The purpose of this was to increase the dry shot speed of the shot end by approximately 34% to take full advantage of the low-impact capability, and permit the casting of larger parts.
CASE STUDY 1: HIGH QUANTITY STRUCTURAL AUTOMOTIVE

Figure 5 shows high quantity production crankshaft housings weighing 3.66 Kg made using the actual shot profiles described above, courtesy of Bajaj Electricals, Matchwel Unit. Scrap rates before upgradation averaged 7%, and required a metal holding furnace temperature of 704 degrees C. After upgradation, cold flow was eliminated and surface finish improved markedly. The die had been used and had suffered flashing for some time, yet flash was substantially reduced on all castings, and completely absent on many. Metal temperature was lowered initially by 45 degrees, and blow holes and porosity in a machined boss which had previously caused many rejects was substantially reduced. The elimination of impact permitted the use of much higher injection speeds, improved surface finish and metal properties, and also allowed the reduction of metal temperature. Prem Singh, Manager of Maintenance, reports the following long-term results:

A. The Tymac SuperShot III was retrofitted on a 660D machine in September 1997. (See Figures 1 and 4). The system has been working satisfactorily since then.

B. There have been no major failures.

C. Special care needs to be taken to filter and prevent dust and contamination of the oil to ensure smooth operation.

D. The advantages achieved since the installation of the Tymac System are:

1. Rejection due to blow holes, pin holes and bearing seat for Bajaj Auto Crankcase reduced to 2% and 1% for continuous runs.

2. Intensifier pressure can be adjusted as high as 700 bars, and fast shot speed is almost double that of other 660D machines.

3. As all injection phases are driven by accumulated pressurized oil, the machine functions consistently even if the metal temperature is as low as 635 to 650 degrees at the holding furnace.

4. Load testing by Bajaj Auto has passed up to 2100 Kg.

5. Flashing was reduced even on old dies due to the low impact and precise computer control of all velocity phases and intensification timing.

6. The monitoring resolution is 800 counts per inch. The monitoring system (see Figure 1) provides many facilities and controls, such as interfacing with auto ladle, auto extractor, hydraulic oil temperature, pressure, and correction of drive and velocity are done automatically during each shot.

8. The monitoring screen displays all parameters on each shot, which can be seen and compared to the performance of each phase of the injection shot for the current shot and stored master shots.

CASE STUDY 2: LOW QUANTITY PLATED CONSUMER CASTING

A vacuum cleaner nozzle previously had presented quality control challenges due to the high standard for surface finish. In order to obtain the required finish, fill time had to be very short. Consequently, fill velocity had to be very high, which caused considerable flashing. In turn the flashing allowed more molten metal into the die, which increased the weight of the castings, and increased the heat input into the die. The increased weight was undesirable, and increased the cost of the parts. The increased heat input forced the chill
time to be extended, which decreased the number of shots per hour, also driving up costs. A complete CNC Real-Time Closed-Loop shot end was installed on a 400 ton machine to solve these problems and similar problems encountered on numerous short run jobs by this custom job shop die caster.

Figure 6. Vacuum Cleaner Nozzles Before and After Low Impact, courtesy Castwell

Figure 6 shows two consecutive shots under the identical operating conditions with the sole exception that the impact elimination deceleration ramp was turned off for the shot exhibiting substantial flash. This short run job shop also reported that a major advantage is the system’s ability to store computerized setups and know that the first shot of each run is accurate, which reduced their previous 25 startup shots to between 1 and 3. Another advantage was that the machine could now produce parts much larger than normal because the rated locking tonnage, without de-rating reduction, can be fully utilized based on metal pressure times projected area. Table I shows the results obtained from the fast fill/impact elimination combination.

### VACUUM CLEANER NOZZLE, PLATED

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Real-Time CNC Shot Controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle Rate per Hour</td>
<td>51</td>
<td>68</td>
</tr>
<tr>
<td>Expected Die Life</td>
<td>100,000</td>
<td>115,000</td>
</tr>
<tr>
<td>Melting/Holding Cost</td>
<td>0.060 US$</td>
<td>0.054 US$</td>
</tr>
<tr>
<td>Metal Cost</td>
<td>0.60 US$</td>
<td>0.60 US$</td>
</tr>
<tr>
<td>Scrap Rate</td>
<td>10.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Total Part Cost</td>
<td>1.74 US$</td>
<td>1.29 US$</td>
</tr>
<tr>
<td>US Parts</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Shipped, Annualized 91,980 173,547

### CASE STUDY 3: HIGH QUANTITY POWDER-COATED AUTOMOTIVE CASTING

A leading Eastern US company specializing in high-quality zinc automotive, computer, and other die cast components manufactured thin-wall side-view automotive mirror brackets requiring buffing, followed by powder coating and baking. See Figure 7.

Figure 7. Automotive Side-View Mirror Bracket, courtesy Sullivan Die Casting

The following statistics were reported by executives of Sullivan Die Casting: A conventional 650-ton hot-chamber machine was originally operated at 106 shots per hour, while scrap levels averaged 18%. The machine was dedicated to the production of these parts on a 2-3 shift basis. Defects were caused primarily by poor surface and porosity which caused blisters during the baking process. It was also necessary to maintain an additional plant to buff the castings. After retrofitting a SuperShot system to the machine, scrap was reduced to 4.5% and approximately 75% of the buffing labor was eliminated. This permitted the consolidation of the scaled-down buffing operation into the die casting plant. In addition, the rapid deceleration provided by the SuperShot within 0.2 inches of the cavity-filling process, resulted in a substantial reduction of fill time by allowing higher fill velocities. Previously, fill velocities had to be reduced due to unacceptable flashing. However, with the SuperShot, flash decreased from 0.012 inches to .002 inches. This generated cost savings, as part weight decreased by 6.6% from 1.52 to 1.42 pounds. The combination of reduced part weight...
and faster fill times resulted in substantially less heat input to the die, and permitted production rates to increase to 142 shots per hour.

**AUTOMOTIVE SIDE-VIEW MIRROR BRACKET**

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Real-Time CNC Shot Controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle Rate per Hour</td>
<td>106</td>
<td>142</td>
</tr>
<tr>
<td>Tooling Maintenance</td>
<td>#38,000-48,000 / year</td>
<td>$5000 / year</td>
</tr>
<tr>
<td>Metal Temperature, C</td>
<td>426</td>
<td>396</td>
</tr>
<tr>
<td>Flash Thickness</td>
<td>0.012 inch</td>
<td>0.002 inch</td>
</tr>
<tr>
<td>Scrap Rate</td>
<td>18.0%</td>
<td>4.5%</td>
</tr>
<tr>
<td>Part Weight, lbs</td>
<td>1.52</td>
<td>1.42</td>
</tr>
<tr>
<td>Metal Savings</td>
<td></td>
<td>40,100#/yr</td>
</tr>
<tr>
<td>Parts Shipped, Annualized</td>
<td>257,040</td>
<td>401,122</td>
</tr>
</tbody>
</table>

Other benefits included die life extended by 50%, and savings on tool repair previously caused by unavoidable flash. Before the SuperShot installation, the die required refitting and bluing every 6-8 weeks at a cost of $5-6,000 each time, averaging $38-48,000 annually. After SuperShot installation, tools required maintenance only once a year at an average annual cost of $5,000. As Table II shows, the combination of improved quality and faster cycle time resulted in an increase in parts shipped from 257,040 to 401,122, for a 56% increase. Material savings resulted from reduced flash amounted to approximately 40,100 pounds annually.

Additional savings that have not been calculated, but are substantial, include reduced downtime due to decreased tool maintenance, energy savings due to a higher percentage of acceptable shots, reduced startup shots, reduced re-melt material losses and energy costs due to less re-melt and lower runner, overflow, and flash weights due to the flash reduction. Substantial energy savings also were realized as furnace holding temperature was reduced from 426 to 396 degrees C. The largest savings came from the dramatic increase in the number of good castings shipped per year, and the consequential reduction of all the fixed costs amortized over shipments. The effective plant capacity was increased substantially without adding machines, operating personnel utilities or floor space.

**CASE STUDY 4: HIGH-PRESSURE HYDRAULIC COMPONENTS**

A prominent Midwestern custom die casting company obtained substantial scrap reductions and quality improvements were by retrofitting Tymac SuperShot CNC real-time closed-loop control systems to several older die casting machines. These included a 600-ton Lester cold chamber die casting machine of late 1970s vintage and a 1978 650-ton B&T. Both machines were also equipped with Tymac Intensimax fast-response intensifier systems. In the first application, the specifications for the barrel for a portable nailgun required close-tolerance machining of the inside diameter, followed by chrome plating and heat treating. Production rates ranged from 3,000 to 4,000 per month. Due to the draft required on the 7 inch long bore, between .100 and .125 inches of material had to be machined off, exposing the interior of the casting, where porosity is most difficult to eliminate. According to executives at Top, prior to installation of the SuperShot system, scrap was 80%.

After, it decreased to less than 2%. Meeting the leak requirements was particularly challenging due to the extreme pressure requirements, and the fact that any surface porosity exposed by the machining was expanded during the plating process. Porosity control was also essential because the parts required heat treating.

In a second application, a hydraulic adapter between the motor and pump of a personnel lifting device (also known as a “cherry picker”, see Figure 8) required 5000PSI leak testing after machining and impregnation.
Figure 8. “Cherry Picker”, courtesy Top Die Casting

The previous supplier had experienced scrap levels as high as 80%, and an average of 35% over a three year period. Top's Tymac MTU-9000 Central Computer was used to analyze filling conditions and determine the optimum gating. The parts were then made on a SuperShot-equipped 1978 650-ton B&T machine. In the first month of operation a scrap level of 8% was achieved. In the second month after gating changes were made in accordance with the MTU-9000 recommendations, scrap decreased to 1%. Further improvements were made in the process settings, resulting in scrap levels consistently below 0.4%. The die casting purchaser's confidence increased as a result of the long term reliability of the process to the extent that today they no longer required leak testing. This resulted in considerable savings, because they were able to rely on the consistent process control provided by the SuperShot real-time closed-loop control system, and the MTU-9000 Central Computer monitoring of 100% of the parts produced. Top also reports that they successfully do 800-ton jobs on their SuperShot-equipped 650-ton machines, due to the effectiveness of the low impact deceleration.

CONCLUSIONS

Comprehensive computer process monitoring combined with upgrading the machines with CNC real-time closed-loop control provides proven substantial quality and cost improvements. In each case, proven results led to additional installations. As was the case with each of the companies with the long-term experiences described in the case studies, based on the positive results achieved on the 660D at Bajaj Electricals Matchwel unit, the decision was taken to install a complete new shot end equipped with a CNC real-time closed-loop shot monitoring and control system similar to the system retrofitted to the 660D on an 1100-ton die casting machine in their Chakan unit. This new shot end was designed from the beginning for shot control. Dry shot speed exceeds 10 meters per second due to the high-efficiency, low-inertia design. Figure 9 shows a similar complete shot end. Its entire injection process will be monitored and computer numeric controlled instead of via valves, timers and limit switches adjusted by hand.

Figure 9. Complete CNC-Controlled Shot End

The additional power, free of impact constraints, will increase the effective capacity of the machine to the range of 1300 to 1500 tons, allowing the production of larger parts than would otherwise be possible at lower cost, while maintaining world-class quality and faster production rates.

The process variables for each shot will be compared to tolerances, and stored, keeping track of the process integrity of every part, and will provide automatic warnings of any out of tolerance process condition. In this way, defects are prevented, substantially increasing the number of good parts actually produced per hour's production, the key to long term success. These examples of
long-term success in modernizing and upgrading older machines show a proven path to realizing world class quality and productivity levels at lower capital investment levels by saving the major portion of previous investments in die casting machines.
BIBLIOGRAPHY