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The Control of Impact Pressure in the High Pressure Die Casting Process

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Abstract

Results of an investigation of methods of controlling flash and the applications of a real-time closed-loop shot control system to control impact pressure are presented. The process of making various parts using the high-pressure die casting process was examined using a comprehensive process monitoring system and controlled by a seven-phase real-time closed-loop shot control system. The requirements and benefits of the low-impact control system are described.

Introduction

"During the fast shot velocity, the moving parts of the system contain considerable kinetic enrgy. The hydraulic fluid, hydraulic cylinder piston, plunger, plunger rod and molten metal all have mass and are moving at high speeds. When the cavity fills, these masses must stop moving. The energy is dissipated by creating a very high pressure spike (Impact Pressure) and elastically deforming machine and die members." (1)

The impact pressure peak is the cause of many problems in the high-pressure die casting process. The impact pressure peak causes excessive stresses on both the machine and die, shortening the life of each. The high cavity pressure at impact is the primary cause of flash. An example of an impact pressure spike is shown in Fig. 1. The magnitude of the impact pressure spike is affected by several factors, including machine design, plunger size, plunger velocity, mass of the moving parts, and the time required to stop the movement.

Plunger velocity is the most significant factor in determining impact pressure. According to E. A. Herman, "The amount of energy, and hence the magnitude of the pressure spike is proportional to the square of the velocity." (2) Therefore, if one reduces the fast shot velocity by 50%, then the impact peak pressure should decrease to only 25% of its former value. One of the simplifying assumptions underlying the relationship stated is that the distance over which the energy is absorbed is constant, regardless of velocity.

However, measurements taken of actual production die casting process parameters showed that, in the absence of gross flashing, this distance actually increased as plunger velocity is decreased, as shown in Fig. 5. The peak pressure reduction appeared to be greater than that proposed by Mr. Herman. The increase in peak pressure, and consequently the required clamping capacity of the machine, increased even more than the ratio of velocities squared in observations, as seen in Fig. 5. Therefore, impact pressure was found to be very sensitive to plunger velocity at the instant of cavity and overflow filling.

Other factors which determine impact pressure, including machine design, the mass of moving machine injection components, and the amount of metal in the shot are important factors to consider. However, there is very little that can be done to effect significant change in reducing impact pressure using these methods. Consideration of major alterations in machine design are not within the scope of this paper. Only minor reductions in the mass of the moving injection components are

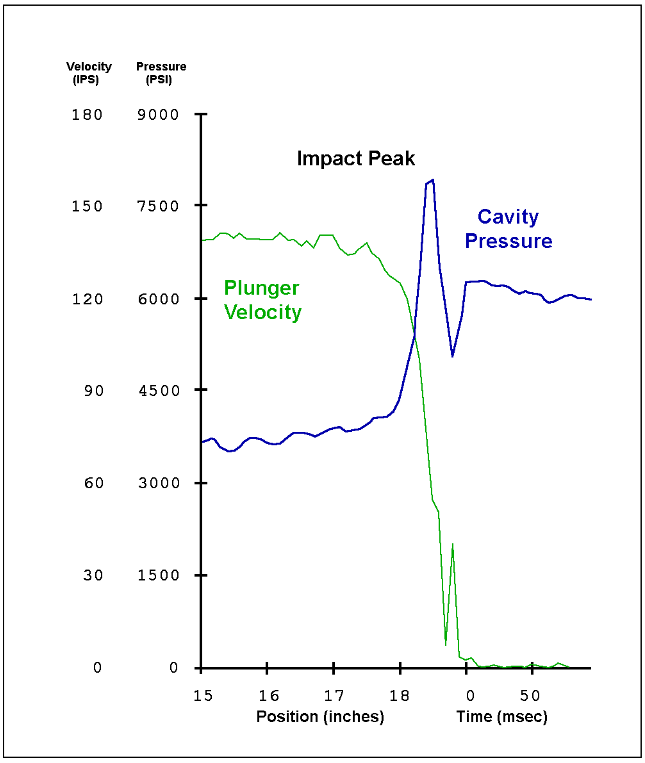

Fig. 1. Example of impact pressure peak profiles.

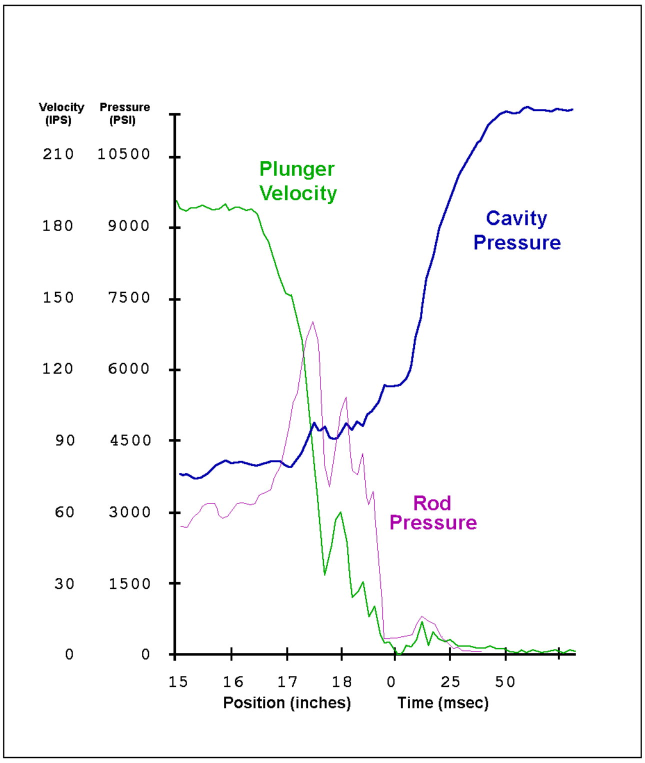

Fig. 2. Example of impact pressure control profiles.

practical. The amount of metal being cast for a given part can only be slightly reduced, if at all.

Methods of Eliminating Excess Impact Pressure

Another method of reducing impact pressure is increasing plunger diameter. Increasing plunger diameter permits the use of a lower velocity while maintaining the same cavity filling time. For example, increasing the plunger diameter by 10% decreases the required plunger velocity by 21%. This can be a useful approach to reduce the impact pressure. However, with the larger plunger, the machine may not be able to develop enough pressure in the metal to force it through the in-gate at sufficient flow rates to achieve the optimum fill time. Increasing the plunger diameter also reduces the maximum metal pressure the machine is able to supply, possibly resulting in casting defects such as increased porosity.

In the case of cold-chamber machines, larger plunger and sleeve diameters usually increase metal heat loss to the machine. The larger plunger usually lowers the percentage of the cold chamber filled by the metal, thereby increasing the potential for gas entrapment, unless the injection system in capable of varying velocity during the cold-chamber filling phase. Increasing plunger diameter is frequenty not a feasible approach to impact pressure reduction, and, in any event, cannot completely eliminate the excess impact pressure.

Simply reducing the filling velocity will increase fill time and may not achieve atomized flow at the in-gate, resulting in lower-quality castings. Impact pressure also limits the size of the casting that can be produced on a given machine. “Since the impact pressure occurs at the instant of cavity filling, it will be the force to be considered when computing machine clamping force if it is large.”(3) Impact pressure not only affects the amount of clamping force required to prevent flash, but also determines if the core slides will remain closed.

A practical and reliable method of reducing or eliminating the excess pressure at impact is desirable. Investigation began by monitoring the pressure die casting process of a variety of hot- and cold-chamber machines and applications. Suitable die casting process monitors were used to measure the process variables and record the data. A closed-loop control system provided a flexible method of experimentally testing the effects of various techniques for controlling impact pressure. The seven-phase closed-loop control system allowed control of the following phases: Lift-Off, Close Pour Hole, Slow Approach, Fast Shot, Low Impact, Final Fill, and Final Squeeze (Intensification). Fig. 3 shows a simplified hydraulic schematic of a typical real-time velocity control system.

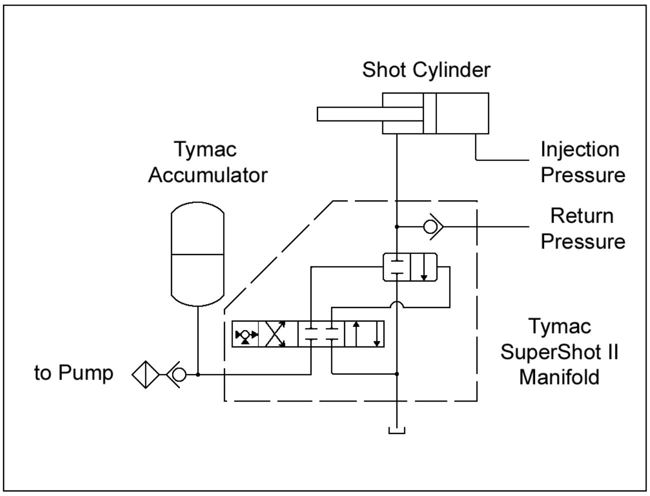

Fig. 3. Tymac SuperShot III hydraulic schematic.

The results of experiments on parts representative of the hot-chamber and cold-chamber pressure die casting process are presented in Table 1.

The representative hot-chamber part studied was a thin-wall zinc automotive side mirror bracket. This part required an excellent surface finish in preparation for powder-coating and baking. It was produced on a 650-ton hot-chamber die casting machine of recent maufacture, and utilized complex movable cores. Calculations indicated that a minimum plunger velocity of 32ips was required in order to achieve the shot fill time necessary to obtain acceptable quality. However, at this velocity, the core slides could not withstand the impact pressure, averaging 4757psi, and caused excessive flashing. Lowering the velocity to the degree required to eliminate the flash resulted in unacceptable surface finish.

A compromise was reached at a velocity of 19ips, which resulted in flashing ranging from 0.011 to 0.013 in thickness. Scrap rates averaged about 14%, and a substantial amount of buffing was required to obtain an aceptable surface finish. In addition, metal and die surface temperatures were elevated to help compensate for the slow fill time, and limited the cycle rate to 109 per hour.

Table 1. Comparison of un-controlled vs. controlled impact pressures.

Impact Pressure		
Variable	Uncontrolled	Controlled
System Pressure	1471 PSI	1472 PSI
Plunger Velocity	32.0 IPS	32.2 IPS
Cavity Pressure at Impact	4757 PSI	3400 PSI
Rod Pressure at Impact	1006 PSI	2663 PSI

Initially, a series of tests were performed at various plunger velocities, without modification in the machine's conventional injection process. Plunger velocity was reduced in small increments, while part quality was monitored. The velocity had to be reduced by 10% before a significant amount of flash was eliminated. However, part quality suffered. Defects included poor fills and surface finish. The other method of reducing impact pressure - increasing plunger size - was rejected because it would have resulted in insufficient pressure. The analysis of these alternatives showed that both of the traditional solutions to reducing impact pressure were ineffective in this application.

It was essential to maintain the plunger velocity and final cavity pressure while reducing the impact pressure. The closed-loop velocity control system was used to achieve this objective. It was programmed to maintain the optimum velocity while filling the cavity, but also to rapidly decelerate the plunger an instant before impact. This deceleration was achieved by suddenly restricting the flow from the exhaust (rod) side of the shot cylinder. The build-up of pressure in the rod side of the cylinder dissipated the energy of the moving mass of the machine, cushioning the impact.

The reduced cavity pressure at impact was measured as 3400psi, which preventer the flash from forming around the cores. The velocity while filling the cavity remained at 32ips and final cavity pressure remained high to prevent blisters and porosity. Since introducing control of the impact pressure, the process - which was producing 109 castings per hour with a scrap rate of 14% - has consistently produced 150 parts per hour with a 2.3% scrap rate including start-up shots. The amunt of buffing

Table 2. Productivity gained by controlling impact pressure.

Productivity			
	Uncontrolled	Controlled	Gain
Production (rate/hour)	109	150	38%
Scrap Rate	14%	2.3%	11%
Acceptable Parts/hour	93	146	56%

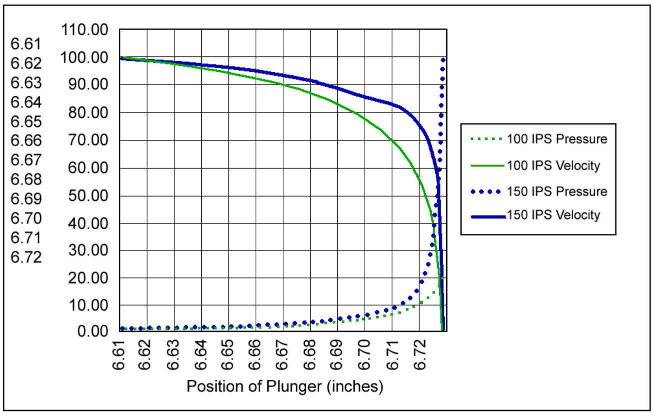

Fig. 4. Excessive back pressure causing ineffective intensification.

required to clean up the parts was also significantly reduced. Control of impact pressure succeeded without the adverse side effects of the traditional methods of controlling impact pressure. The productivity improvements associated with control of impact pressure are shown in table 2.

Additional testing was performed on a 750-ton (metric) cold-chamber pressure die casting machine operating with an intensifier (multiplier). Velocities were much higher than in the case of the 650-ton hot-chamber machine. As in the case of the hot-chamber machine, decreasing plunger velocity, while it reduced flash, resulted in poor surface finish, and incomplete parts. As before, maintaining high fill velocity throughout approximately 95% of the cavity-filling stroke, followed by rapid deceleration just before impact, resulted in acceptable surface quality and complete fills without the flash experienced with the un-controlled conventional process. However, although the parts appeared visually superior, internal porosity actually increased.

Careful analysis of injection metal pressure profiles disclosed that as a result of the programmed deceleration, the nearly-closed valve continued to restrict flow from the rod side of the cylinder long after cavity fill. Consequently, while the intensifier was increasing the pressure on the head side of the injection cylinder in a very short time (approximately 12msec), the pressure increase on the metal itself was delayed by the back pressure on the rod side caused by the restriction. A sample profile showing the effects of excessive back pressure is provided (see Fig. 4).

This analysis also demonstrates the importance of monitoring the dynamic pressure on both sides of the injection cylinder piston when the machine is designed for regulating the velocity by restricting the rod-side flow ("Meter Out Control"). Since the head-side pressure is increased by the intensifier without delay, one could not detect a delay in the increase in metal pressure merely by looking at the head pressure profile. In addition to the head- and rod-side pressure profiles, a profile of the equivalent dynamic metal pressure was obtained by using a combination of electronic circuitry and software. This automated and simplified the process of monitoring the actual dynamic pressure of the metal during all phases of the shot.

Table 3. Summary of real-time closed-loop control phases.

Real-Time Control Phases

1. "Lift-Off" - absorbs initial oil surge from the accumulator to prevent a shock wave in the metal.
2. "Close Pour Hole" - advances plunger past pour hole.
3. Slow Approach - "Critical Slow Shot Speed" is maintained to reduce gas entrapment.
4. "Fast Shot" - fast velocities while the cavity is being filled.
5. "Low Impact" - extremely rapid deceleration in a small final fraction of the cavity plunger stroke so as to maintain an overall cavity fill time at least as short as in the uncontrolled, conventional process.
6. "Final Fill" - extremely rapid re-opening of the control valve to permit unrestricted rapid intensification.
7. "Final Squeeze" - application of intensifier.

A New Method of Controlling Impact

Once the cause of the ineffective intensification was identified, the solution was apparent. The closed-loop control system was simply re-programmed to cause the valve to almost completely close in order to achieve the desired deceleration. It was then commanded to very quickly re-open just in time to permit unrestricted intensification. Of course, this requires very fast response in order to be effective. Actual measured injection parameter profiles are shown in Fig. 2.

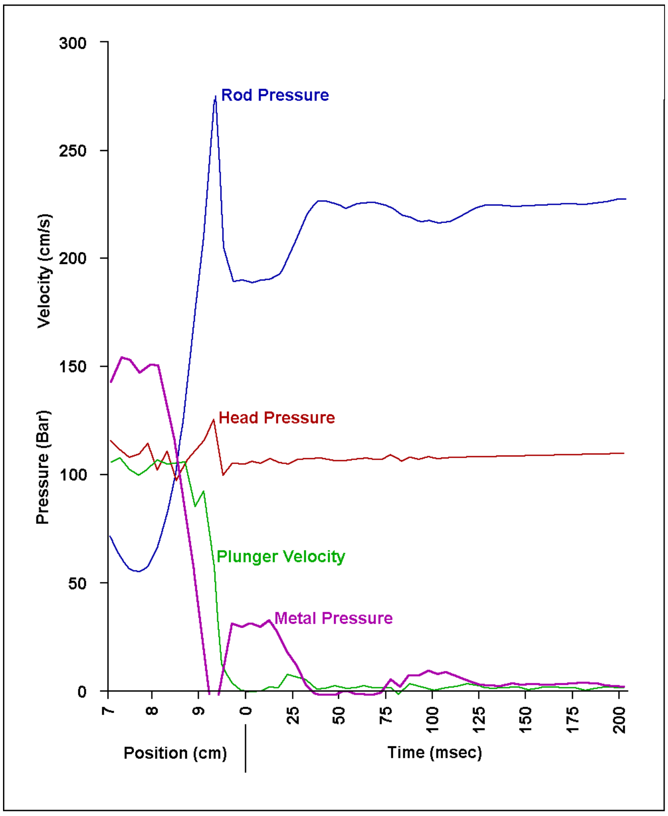

Fig. 5. The effect of plunger velocity on impact parameters

Table 3 summarizes the 7 phases of a real-time closed-loop control system including the three low-impact control phases numbered 4, 5 and 6.

This method permitted the maintenance of short fill times, which promoted good surface finish and complete fills, eliminated the major cause of flash, and responded fast enough to avoid interfering with rapid intensification in order to reduce porosity and increase casting density.

However, it must be understood that successful application of this method is dependent on achieving extremely fast injection velocity response times while using very large flow capacity control hydraulics. Although the response time of the velocity control valve is obviously a critical factor, it is not sufficient to merely be able to open and close the velocity control valve in a few msec.

The control valve must also have sufficient flow capacity to permit the fast speeds desired in the cavity-filling phase. The control hydraulics, electronics, and software must be designed to match the injection cylinder characteristics in order to achieve the required injection cylinder velocities, accelerations, and decelerations which are necessary for a successful application of the method. Prior attempts to utilize real-time closed-loop control in the pressure die casting process were often unsuccessful because of slow overall response time, insufficient flow capacity, or both.

The Effects of Dosage Variation

Studies of the effect of variation in metal dosage showed that when the metal dosage (amount ladled), or in the case of the hot-chamber process, the level of metal in the holding pot, was subject to wide variation, difficulties were sometimes experienced when attempting to eliminate the excess impact pressure. For example, in injection systems which depended only on mechanical means to reduce velocity at a fixed stroke position, the plunger always decelerated at the same position, even though the position at which the cavity is filled varied.

Under this method, the plunger continued to decelerate further as the stroke continued. Therefore, the velocity at the instant of cavity fill was even more sensitive to variation in metal dosage (or metal level) than a conventional injection system. Consequently, high metal dosage resulted in filling of the cavity before deceleration took place, and the tendency to flash was increased. Low metal dosage resulted in deceleration to an excessively low velocity, and the tendency toward misfills, poor surface finish, and porosity was increased.

In contrast, the real-time closed-loop velocity control system studied was programmed to decelerate to a fixed velocity which was a fraction of the fill velocity, rather than zero. This provided the advantage of making the final velocity at impact independent of dosage variation.

Although improvements have been made over the years, in practical pressure die casting, metal dosage and levels continue to vary from shot to shot. An approach which automatically compensates for this variation is desirable, and would reduce the complexity of setting up the machine process. However, to be successful, the solution would have be capable of compensating completely within the injection process itself, since the exact amount dosed is not known until after it is ladled.

An approach which was tried experimentally by the Die Casting Research Foundation of the American Die Casting Institute in the early 1980s, used a sensor mounted in the runner to detect the presence of metal. Today, such a sensor could be used by a computerized control system to calculate the optimum deceleration position to control impact pressure. The computer would command a real-time closed-loop velocity control system to decelerate at that stroke position, automatically compensating for dosage variation. However, the cost of providing a sensor in every die - and difficulties in maintaining it - have been significant obstacles.

As a result of observing metal pressure profiles for a wide variety of parts, another solution which compensates for dosage variation automatically and within the injection was conceived. Each die has a characteristic metal fill pressure profile, beginning when the metal reaches the in-gate. A brief study of injection velocity, position, and metal pressure profiles of various parts permitted the experimenter to identify a place on each part's metal pressure curve which consistently exhibited a sharp increase in metal pressure.

In some cases the best location was at the point when the metal reached the in-gate, particularly for parts cast with relatively small gate areas and short fill times, such as is commonly found in thin-wall die designs. In the other instances, a sharp rise in pressure was found consistently near the end of cavity fill. Once the desired pressure rise was located, the low-impact deceleration was programmed to automatically occur a fixed stroke length after the pressure rise was detected. The injection control system was required to react very quickly. This method compensated automatically for variation in metal dosage within the shot itself, and has been successful in achieving consistent flash elimination, while preventing premature deceleration when dosage is less.

The control system must meet several requirements to successfully control impact. It must respond very quickly, within 5 to 10 msec, or in some applications even less, to cushion impact and prevent interference with the intensifier. The system must also operate in real time to detect the metal pressure build-up so that impact control is applied at the correct time.

Conclusions

Various methods of controlling and reducing or eliminating the excess impact pressure which occurs at the end of cavity filling in the high-pressure die casting process were investigated and evaluated. A new method based on a real-time closed-loop controlled injection velocity and pressure profile system eliminated the excess pressure in a variety of hot and cold chamber applications, without interference with desirable rapid increases in final cavity pressure or intensification.

A novel approach to initiating low-impact deceleration based on metal pressure increase compensated automatically for dosage variation.

Elimination of the excess impact pressure increased the effective clamping capacity of the machines, permitting the casting of larger parts for a given size machine. Substantial reduction or elimination of flash was achieved without deterioration in surface finish or increasing porosity defects. As a result, substantial reductions in scrap rates and higher production rates were achieved in a wide variety of applications.

In some applications, large reductions in holding furnace temperature were possible, while actually improving surface finish. For example, for a zinc automotive side mirror bracket, the elimination of the excess impact permitted an increase in fill velocity of 68%, and allowed the lowering of pot temperature from 800 to 745 F, while increasing cycle rate by 37%. The elimination of flash, combined with colder metal reaching the in-gate, has reduced die-related downtime by approximately 24%. These combined process improvements should theoretically result in improved die life. An investigation of the long-term effects on die life would be of interest.

Today, impact pressure and its detrimental effects on casting quality and die life need no longer uncontrollably affect the process. Rather, it is now a measurable and programmable variable which can be controlled consistently as another means to achieve maximum quality and eliminate one of the major causes of die maintenance problems and defects.

References and Bibliography

1. Herman, E.A. Die Casting Process Engineering and Control. River Grove Illinois, Society of Die Casting Engineers, Inc., 1988 P. 33.
2. ibid
3. ibid
4. Buithaupt, T. & Teufert, C.E. "Process Monitoring in the 1990's" Die Casting Management, February 1991, Vol. 9 No. 1, p. 29-22.
5. Cocks, D.L. "Increasing Die Life" International Pressure Diecasting Conference 1993, paper No. 17, May 1993.
6. Hedenhag, Jorgen G. "Real Time Closed-Loop Control System for the Shot End", NADCA Transactions, vol 15, paper No. G-T89-022, October 1989.
7. ILZRO, Designing For Thin Wall Zinc Die Castings, International Lead Zinc Research Organization Inc., April 1986.
8. Zhao Wei Ruo "Relationship Between the Operating Parameters During 3-Phase Injection and the PQ2 Diagram", NADCA Transactions, vol. 15, paper No. G-T89-063, October 1989.