■Paper No. G-T89-022

15th International Die Casting Congress & Exposition
October 16-19, 1989
St. Louis, MO

Real-Time Closed-Loop Control System for the Shot End

Jorgen G. Hedenhag
Tymac Controls Corp.
Franklin, New Jersey

Presented By:
North American Die Casting Association

Abstract

There are a great number of variables that affect filling conditions in the die and thereby ultimately affect the casting. It is important to eliminate as many of the variables as possible and minimize the effect of the remaining ones. This paper reviews a number of these factors.

The shot end is the most dynamic factor affecting the die casting process. A shot control system that compensates for the variables during the shot will facilitate consistent, high-quality production. A real-time closed-loop shot control system is reviewed. The importance of short response time is explained and a number of shot profiles for different machines and different tonnages are analyzed.

The importance of low impact based on metal pressure in the die and compensation for variations in biscuit lengths is also explained.

Introduction

There are a great number of variables that affect filling conditions in the die and thereby ultimately affect the casting.

In today's competitive market dimensional accuracy, absence of porosity and surface flaws in the castings are of the greatest importance. The more we can eliminate or minimize these variables, the better we can control the filling conditions and thereby attain better castings and reduce the amount of rejects to a minimum.

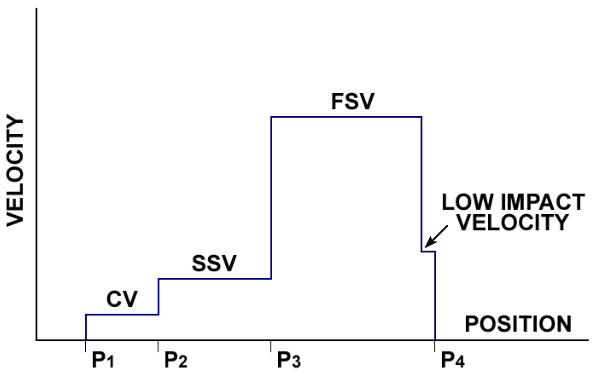
The variable factors can be divided into three categories: static, manual, and dynamic. The static factors are items such as condition of the die cast machine, design and condition of the die, accumulator pressure, and intensifier pressure. Subject to manual setting or influence are valves, timers and limit switches, metal temperature and hydraulic fluid viscosity. More difficult to control are the dynamic factors such as amount of metal in the sleeve or in the gooseneck, plunger drag, die temperature and vacuum pressure profile.

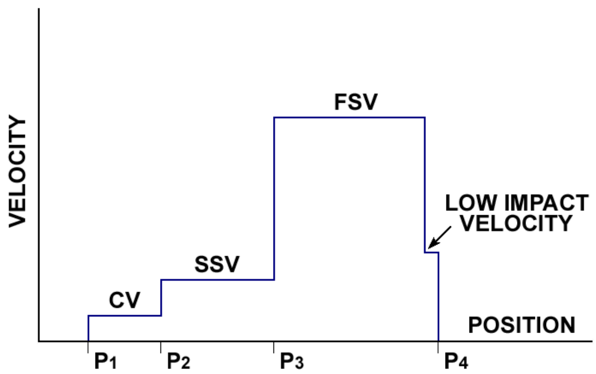
These factors have the greatest influence on the hydraulic pressure and shot velocity profiles, which are the ultimate parameters controlling the filling of the die.

Controlling Variables

The metal temperature will inevitably vary from shot to shot, as will other factors, regardless of how hard we try to keep them constant. The greatest variations are, however, to be found in the dynamic category. Variations can be illustrated most vividly if the die cast machine has a monitoring system with graphics readouts and the capability to overlay shot profiles of a number of consecutive shots. The variations in pressure and shot speed are substantial and very inconsistent from shot to shot.

The ideal plunger velocity profile as a function of position is shown in Fig. 1. It assumes that acceleration





to creep velocity (CV) at position P1, slow shot velocity

Fig. 2. Master profile

(SSV) at position P2, acceleration to fast shot velocity (FSV) at position P3, and deceleration to zero velocity at position P4 are all instantaneous, which of course, is unattainable during actual conditions. It is, however, desirable to come as close as possible to this ideal shot profile. The profile that can be maintained may look as shown in Fig. 2.

With present technology, even the best control system will exhibit minor variations in the profile from shot to shot, while producing acceptable castings. Depending on the casting itself, we can set a range within which the profile may vary, without violating the tolerances set for acceptable castings (Fig. 3). As long as the shot profile stays within the dotted lines, the casting is acceptable. A shot falling outside the tolerance range is not necessarily a reject, but needs to be inspected for quality.

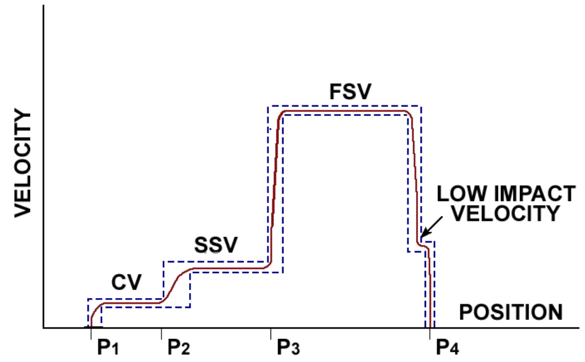


Fig. 3. Master profile with allowable variation limits.

A wider range set by "alarm limits" should also be established (Fig. 3). Shots outside the alarm limits are rejects and should trigger an alarm to alert the operator that the machine is producing rejects.

The static factors mentioned above can not be changed without alterations of the die cast machine or the die. The manual factors, however, can be kept fairly constant without too much difficulty. Control of the die temperature can be made part of the shot end control system.

As said before, the shot profile will vary greatly and inconsistently from shot to shot on a die cast machine without shot control. The dynamic factors and remaining variations in the manual factors must therefore be compensated for by a shot control system that corrects the shot parameters ***during*** the shot.

The average fill time is between 20 and 80 milliseconds. In order to be effective, the shot control system must therefore be able to control the velocity profile with a total response time of about 1/10 of the fill time, or 2 to 8 milliseconds. Total response time is defined here as the time elapsed from the moment the sensor detects a deviation to the instant the plunger starts to react. In other words. the response time for the hydraulic system, including valve and shot cylinder delays, must be included in the total response time. These requirements put extraordinary demands on the electronic circuitry which must respond within a few microseconds.

Meter-Out Control System

The only shot control system that can give these results is a real-time, fast-responding, closed-loop system. An adaptive control system, i.e. a system that corrects the shot parameters based on the previous shot, is consequently of limited value, since it can not adjust for the large and inconsistent variations which take place from shot to shot and within each shot.

In the real-time closed-loop control system, the actual plunger velocity is controlled by the hydraulic pressure in the shot cylinder. The pressure continuously changes to make the plunger follow the master velocity profile.

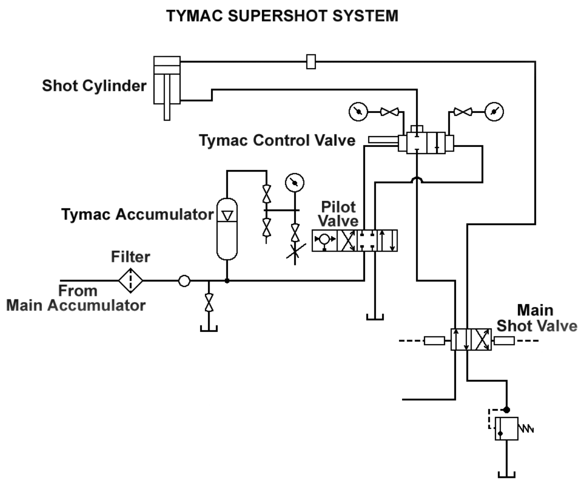


Fig. 4. Hydraulic flow sheet of a meter-out system

The system described is a meter-out system, meaning that the hydraulic pressure is controlled on the rod side of the shot cylinder (see Fig. 4). The cross-sectional area of the cylinder is smaller on the rod side. The cylinder thus acts as a multiplier. Further, less volume of hydraulic fluid has to be moved on the rod side than on the head side for a certain distance of the travel of the piston.

When the shot control valve opens, the plunger moves forward, and when the valve is fully closed, it stops. The hydraulic fluid thus absorbs the impact spike at the end of the shot, rather than the metal, thereby achieving a low impact, flash-free shot.

The main requirement of the hydraulic system is for the valve-driving mechanism to be extremely fast-acting. The valve itself requires a large flow capacity to allow quick response of hydraulic fluid and fast movement of the cylinder piston.

Figs. 5 and 6 show the pressure profile of the head side and the rod side, respectively, for the shot in Fig. 2. Note the hydraulic pressure spike on the rod side at the end of the shot, yielding low-impact metal pressure.

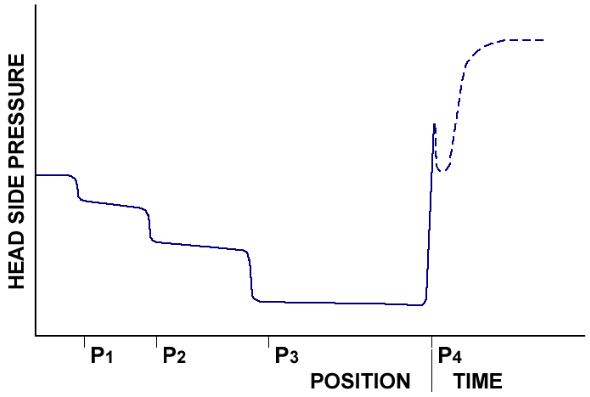
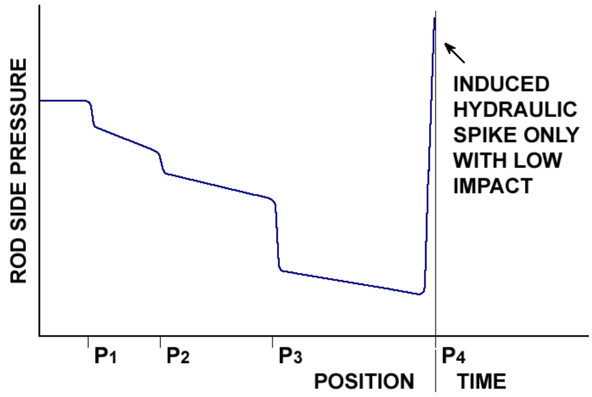


Fig. 5. Hydraulic pressure profile on the head side



Actual shot traces for different sizes of die cast machines are shown in Figs. 7 through 10.

Figs. 7 and 8 show the head side and rod side of the same shot on a 2,500-ton machine. Note the acceleration from a slow shot velocity of 15IPS to fast shot of 90IPS in 7 milliseconds, and deceleration at the end of the shot in 4 milliseconds.

Also note that fast shot velocity is maintained constant despite variations in hydraulic pressure.

Fig. 9 shows a 600-ton machine operating with a fast shot speed of over 300IPS. In this case. acceleration to and deceleration from fast shot speed is approximately 3 milliseconds.

Fig. 10 illustrates that even on a short stroke machine of old vintage, acceleration and deceleration can be achieved in an extremely short time span.

When the shot velocity at the end of the stroke decelerates below 10IPS, the system's computer switches domain from velocity-vs-position to velocity-vs-time. Intensification can thus be activated at the end of the stroke without any time delay, or if the casting process so requires. with an appropriate time delay. The time delay must be adjustable to meet the requirements of a versatile shot end control system in order to make it possible to cast different parts with different demands on intensification.

If the end of a shot is determined by the position of the plunger and there are variations in the amount of metal poured into the shot sleeve, the metal impact pressure will vary with the size of the biscuit. The system described has the ability to sense metal pressure and fast enough response time to trigger the low impact point on a preset metal pressure, thereby compensating for variations in biscuit lengths and preventing flash and the disadvantages associated with it. Metal pressure is calculated in the system's computer based on the difference between head side and rod side pressure, rather than being triggered by an unreliable sensing device in the hot metal. A certain minimum shot length must, however, have been reached before the metal pressure can trigger the low impact. Intensification can also be triggered by the end of the actual shot rather than by a predetermined plunger position.

In hot chamber die cast machines, as well as vertical machines, vacuum often determines the level of metal in the gooseneck or sleeve. By controlling the vacuum pressure, the size of the biscuit can be controlled. This is often required to make the extractor robot operate properly.

In this case, adaptive control is used since the amount of metal can not be changed after the plunger starts to move, and small variations in biscuit length of 1/8 in. to 1/4 in. will not affect the operation of the robot.

A closed-loop control system as described above can be applied to new die casting machines or as a retrofit to old machines. In both cases it will improve the machine's performance drastically. A real-time closed-loop control system will, however, give optimum

Fig. 7. Velocity & head side pressure of a 2500-ton machine

Fig. 6. Hydraulic pressure profile on the rod side

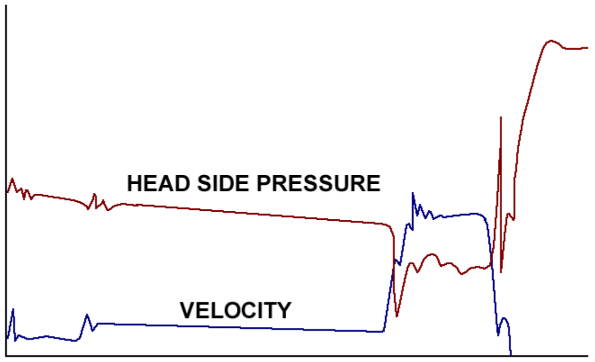
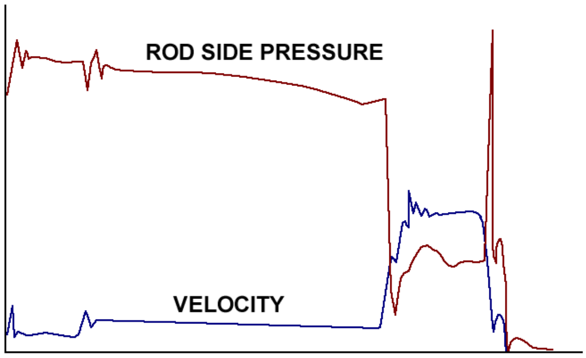


Fig. 8. Same as Fig. 7 but showing rod side pressure



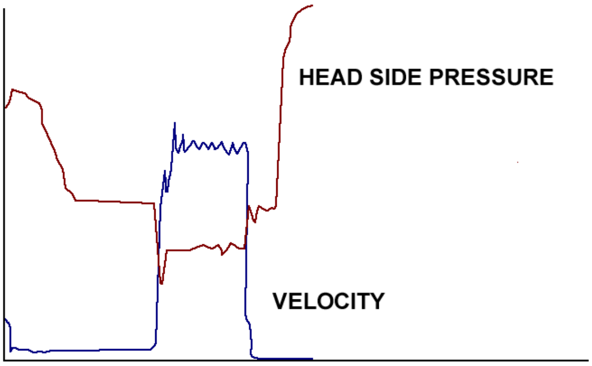


Fig. 9. Shot profile of 600-ton machine with high fast-shot speed

results when the other factors not controlled by the shot end control system, such as metal temperature and die temperature, are kept as constant as possible.

It is, of course, also important to keep the die casting machine in good trim and have an efficient hydraulic fluid filtration system. Although the pilot valve can allow particle sizes up to 25 microns, it is a good investment to install an off-line filtration system connected to the machine reservoir. With a proper filter element, entrained particulates can be removed, as well as tramp oil. This is particularly important for vertical machines, where the die and plunger spray quite often contaminate the hydraulic fluid.

Benefits of Shot Control

Reduced Scrap Rates - Higher Yield: A real-time closed-loop shot end control system will give any die cast operation, new or old, the optimum part quality and dimensional accuracy. It also provides superior uniformity and consistency from shot to shot and from setup to setup. The system further eliminates flash, porosity and short shots, thereby minimizing rejects. Typically, reject rates of 0.2% to 0.3% or better can be achieved.

Higher Productivity: The shot control system optimizes cycle time by attaining fastest possible slow approach and fill time without excessive flash or porosity. This allows reduced cycle time and increases productivity. Further, due to the low impact control, castings normally requiring 125% of rated machine tonnage can be produced on smaller, faster machines.

Variations in die temperature and other process conditions cause rejects during startup. The control system automatically compensates for normal variations in process conditions and virtually eliminates startup time. Most of the time, the first or second shot will produce acceptable parts.

Metal Savings: Tighter process control permits die design with smaller runners, overflow, and biscuits and reduces metal loss and energy costs associated with remelting. Further, flash opens the die and causes overweight castings, which the die caster is not compensated for. By eliminating flash and associated overweights, it is possible to achieve substantial metal savings.

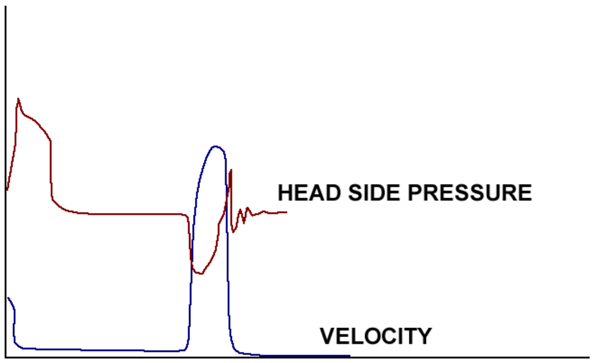


Fig. 10. Old die casting machine wih short stroke and high fast-shot speed

Operator Independence: With the shot control system described, the die casting machine is set up numerically before production begins. Any operator can consequently do the setup and the machine will automatically produce the best possible parts without rejects or flash. It is no longer necessary to rely solely on operator memory or special setup personnel.

Prolonged Die Life: Flash is one of the most damaging conditions of the die. Once flash occurs, it damages the parting line and causes flash to occur more easily on subsequent shots. With the absence of flash, the costs associated with die repair, including the cost of downtime, will be substantially reduced.

Conclusion

Shot-end performance and repeatability are crucial to casting quality and consistency. The shot end is the most dynamic factor affecting the process. The typical fast shot occurs in much less than 0.1 sec, which means that critical die casting parameters must be accurately and continuously controlled.

A shot control system that corrects parameters during the shot, with an extremely rapid response time, will facilitate consistent high-quality production. The claims of different suppliers of real-time closed-loop control systems should be evaluated very carefully. Such systems will only be effective if they fulfill basic criteria as outlined in this paper.

Progressive die casters who take advantage of shot control technology are realizing rapid paybacks from substantially fewer rejects, metal savings, and higher machine utilization rates.