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## **Plunger Design - A Key to the Successful Die Casting System**

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### **Abstract**

No single component of the die casting production process should be examined or evaluated individually. Each interacts closely with at least one other complementary element of the process. If the interacting elements are equally efficient, they will reinforce and enhance the function of each other. Only if the entire process is considered as an integrated system, with all parts working together in a common cause, can maximum efficiency be approached.

Properly employed, this technique can be guaranteed to improve productivity.

The Systems Approach will be discussed in the context of production efficiency in light metal die casting.

### **Introduction**

If one part of a process performs a function that is unaffected by any other parts, its operation can be usefully studied, and its efficiency effectively measured. If, however, two components work together to perform a single function, neither can be credibly evaluated alone. Both should be considered together, as their individual functions are inseparably combined in joint interaction. This is the essence of the Systems Approach to aluminum die casting.

The Systems Approach of always considering both action and interaction is based on the fact that die casting is really a holistic process. No single part of the process operates in isolation. For the die caster, the real and immediate value of this technique is that it directly addresses the problem that no matter how well designed and

how precisely produced any component of his production process may be, its actual potential can never be achieved if it is interacting with another part that is less efficient.

### **To Evaluate Components**

To measure the worth of any part of the die casting process, there are really only three questions to ask:

1. How does it affect the casting process? I.e. product quality, scrap, downtime, productivity, etc.
2. How long will it last? The operating life of an expensive component is significant.
3. How well does it interact with other parts of the process?

The third criterion is as important to the die caster as the first two.

### **Interaction of Plunger Tip and Shot Sleeve**

Consider the action and interaction of some of the components of an aluminum die casting system. Perhaps the most critical is the interaction of the plunger tip and the shot sleeve. Unless each is operating at close to optimum efficiency, the operating life of both will be substantially reduced.

Four thousandths of an inch is the maximum gap between the plunger tip and the shot sleeve during the casting process. If at any time during the shot, the gap exceeds 0.004", the alloy is likely to penetrate the space, and flash or blowby will occur. This will inevitably cause excessive wear on both the shot sleeve and the plunger tip.

If the gap becomes much less than 0.004", there is a danger of interference that will cause inconsistent shot velocity. Scrap will result. It is essential, therefore, that a gap that is never more than four thousandth of an inch be maintained at all times during the casting cycle.

### **Thermal Expansion**

When metal is heated, it expands.

The clearance between the plunger and the shot sleeve never remains constant. At the pour end, at the start of the casting cycle, the sleeve is very hot, and the plunger

tip is comparatively cool. As the plunger moves forward toward the die end, the tip becomes hotter. At the end of the injection stroke, the sleeve dissipates heat to the platen and the die, and cools. The tip therefore expands while the shot sleeve contracts. If the initial clearance at the pour end is small enough to prevent penetration of the alloy past the tip of the plunger, the plunger may seize in the sleeve before reaching the end of the stroke. The chance of this happening increases with the length of the shot sleeve.

Typically, a shot sleeve may become 200-300F° hotter at the bottom under the pour hole, than at the top in front of the hole. If the temperature of the sleeve is much higher at the bottom than at the top, unequal expansion will cause it to become oval instead of round. This will also cause the sleeve to become slightly bowed rather than straight. Either of these conditions will cause premature wear of both tip and sleeve. The extent of ovality and distortion is directly related to both the diameter and length of the shot sleeve. To avoid too much variance in thermal expansion, the bottom of the shot sleeve should be cooled so that the difference in temperature, bottom to top, does not exceed 100F°.

If the ID of the shot sleeve is no greater than about three inches, the potential problem is minimal, and can likely be ignored. The coefficient of thermal expansion, however, is a constant. The same increase in temperature of a six-inch shot sleeve, for example, will cause it to expand twice as much as a three-inch sleeve.

The market for larger light metal castings is increasing. Shot sleeves are getting bigger, but whatever the size of the sleeve, that maximum allowable gap of four thousandths of an inch unfortunately remains unchanged.

The importance of precise temperature control of both shot sleeve and plunger tip is emphasized by the fact that if the temperature of a 6 in. copper plunger tip is increased by 200°F, the diameter will increase by more than 0.011 in.

### **Cooling the Plunger Tip**

Plunger tips were originally made of steel. Many steel tips are still used, primarily for their durability and economy. A steel tip, of course, has the same coefficient of thermal expansion as the shot sleeve in which it slides. Since the plunger tip is exposed to

more heat than the sleeve, the expansion of a steel tip is difficult to control very precisely. The next step in the development of the conventional plunger tip was to make it of beryllium copper which has a coefficient of thermal expansion more than 50% greater than that of steel. This made the expansion of the tip much easier to control. It was then possible to maintain the dimensional stability of the tip throughout the length of the stroke. In a large machine, if the plunger tip is not adequately cooled, the gap between plunger and shot sleeve can easily disappear.

Die casters usually reduce the temperature of their plunger tips with water. The most common cause of excessive plunger tip expansion and wear is insufficient coolant. Even experienced die casters sometimes neglect this.

Rate of flow is easily determined, and should be monitored constantly. Maintaining an adequate flow of water is vital to controlling plunger tip expansion,

### **The Evolution of the Allper Plunger Tip**

The series of plunger tips developed by Allper SA in Switzerland is a good example of a designer making best use of the increasing fund of knowledge regarding the interaction of the plunger tip and the shot sleeve, and also responding to changing demands of a growing market.

A conventional plunger tip screws directly onto the hollow plunger rod. With the ARP tip, a stainless steel reusable tip holder is screwed onto the rod, and the copper tip is easily and securely connected with a quick-release bayonet-type connector. The front of the holder lies in full contact with the inside face of the plunger tip, and absorbs the total pressure of the shot. The face can then be uncommonly thin. This enhances the heat exchange. The holder allowed the water to be used more effectively

The water flow is from the center of the shot rod, through the holder, and directly to the inside face of the plunger tip where a turbulent flow is generated to maximize the heat transfer. It is then distributed through several channels to the circular external coolant return channel.

Beryllium copper is an ideal medium to dissipate heat away from the plunger to the cooling water. A major drawback, however, is that it is not nearly as hard or wear-resistant as the steel of the shot sleeve. The copper tip, therefore, would wear out fairly

quickly. Since the tip was then dimensionally stable, and the gap controllable, this problem was then solved with a wear ring of nitrided H-13 steel. This tempered steel ring is split, and expands against the inside wall of the shot sleeve. Only the ring wears, not the comparatively soft tip.

The wear ring floats freely in a groove machined in the plunger tip. It is easily removed or installed with a special hand tool in about five minutes.

The die end of the shot sleeve is chamfered to compress the ring and guide it back into the sleeve. Because the ring is flexible, it makes continuous contact with the inside of the shot sleeve. Flash, which is a major cause of wear, is essentially eliminated. Shot speeds are consistent. Since the expanding wear ring ensures a secure seal between the plunger and the shot sleeve, a better vacuum can be drawn.

The ARP wear ring type plunger tip reduces both scrap and downtime. It eliminates flash, ensures consistent shot velocities, extends shot sleeve operating life, and enables improved vacuum.

The ARP plunger tip has been successfully and profitably used for a number of years, but the market for aluminum castings is changing. Castings are now being required, especially in the automotive sector, that are larger, thinner, more complex, with closer tolerances than ever before, and at a faster rate of production than previously thought possible. Plunger tips used to be seldom larger than 6". Now, 8" tips are not uncommon.

The demands on the plunger tip, particularly in strength and stability, outgrew the replaceable wear ring plunger. This led to the development of the Allper high strength AMP plunger tip.

This high-strength modular plunger tip has been designed specifically for the production of large castings. The beryllium copper body is longer, and it has a replaceable steel head.

As with the standard ARP tip, the copper alloy body of the heavy duty AMP plunger tip is fastened to the stainless steel holder by a bayonet-type quick release coupling.

It incorporates several parts. Optional steel or copper alloy expandable wear rings are available for high vacuum applications,

The extra strength of the steel head on this plunger also helps it to withstand the extreme impact of the inevitable short shots, when the plunger contacts the die.

This durable and efficient plunger tip is now becoming widely used in the high volume production of aluminum automotive engine blocks..

It is very important that plunger tip replacement is always predicted and scheduled. Unscheduled downtime that results in “Knock-offs”, or interrupted production runs, is no longer necessary, and unacceptable.

### **Controlling Shot Sleeve Temperature**

For maximum operating life, the plunger must move smoothly through a round, straight shot sleeve. It must travel the length of the sleeve without binding, and with the gap never exceeding 0.004 in.. This depends on very close control of the shot sleeve temperature.

Experience has proven that there are ideal dimensional ratios for shot sleeves that will allow maximum performance and operating life. For example, the ideal wall thickness is 1/3 of the ID of the shot sleeve. If the wall is too thin, hot spots will develop, and unequal expansion will cause ovality of the sleeve. This will result in excessive wear by both the shot sleeve and the plunger tip. If the wall of the sleeve is too thick, however, the sleeve will retain too much heat and the entire sleeve will overheat. Excessive thermal expansion then may cause the gap between sleeve and plunger tip to increase too much. Blowby may then result.

The diameter of the pour hole should be no more than 70% of the ID of the sleeve. If the pour hole is too large, the shot sleeve will become deformed. Ovality will again be the result.

The clearances between both the shot sleeve and the platen, and the shot sleeve and the die should remain between .005 in. and .015 in., depending on diameter and temperature.

The pour end of the shot sleeve is where the temperature is highest. This is obviously where cooling is most necessary. The usual method of temperature control is the pour end cooling jacket. This effective and economical device puts shot sleeve

cooling where it is needed most, directly below the pour spout. The cooling jacket can also be re-used when the sleeve is replaced.

As well, the alloy being poured into the sleeve is at about 1300°F., while the annealing temperature of H-13, the usual shot sleeve material, is only 1085°F. If the shot sleeve is not adequately cooled, it will likely lose some of its hardness. Wear will then more quickly result from the abrasive action of any alloy that penetrates the gap

If the space between the shot sleeve and the platen is too great, heat will be retained. When this happens, hot spots will occur, and the sleeve will expand at these locations. If the clearance between the shot sleeve and the platen is too small, the platen will draw heat from the sleeve. Cold spots will develop in the sleeve, and it will contract. It may then interfere with the plunger tip and cause inconsistent shot velocity.

If the clearance between the shot sleeve and the die is too small, the expansion at the end of the sleeve will be constrained at the point where the expansion of the plunger tip is greatest. Interference is almost inevitable.

The amount of thermal expansion and contraction of shot end components is much greater than most die casters realize.

Effective shot sleeve temperature control is imperative for good die casting.

### **Using Oil for Shot Sleeve Temperature Control.**

A common misconception is that the amount of thermal expansion of a shot sleeve is simply a factor of its diameter and its maximum temperature. If this were the case, temperature control would simply depend on cooling.

This is incorrect.

The amount of thermal expansion or contraction depends on the ID of the sleeve, and the amount of temperature change, up or down, not on the maximum temperature. This temperature differential, usually known as  $\Delta T$ , will cause exactly the same amount of expansion at any point on the temperature scale.

The maximum temperature change in a shot sleeve occurs at the bottom under the pour hole. If the shot sleeve has been preheated by circulating hot oil at 400°F, for example,  $\Delta T$  will be reduced and consequently so will the amount of expansion. In

addition, as the pour continues all temperatures greater than 400°F will be reduced, as the oil then acts as a coolant.

A major advantage to preheating the shot sleeve is that start-up scrap is eliminated. When using more expensive alloys, this saving can be significant, as well as additional savings in costly production time.

When oil is used for thermal control, shot sleeve temperature variation, both top to bottom and back to front, can be very closely controlled, and expansion minimized. The four thousandths of an inch maximum gap can more easily be maintained.

If the temperatures of both shot sleeve and plunger tip are both not closely controlled, neither can approach maximum efficiency.

### **Porosity and Vacuum Assisted Casting**

Porosity causes more rejected castings than any other reason.

In cold chamber die casting of light metals, because of the turbulence of the alloy as it is forced at a high pressure into the die cavity, and the complex shape of many casting molds, air and other gases are often trapped in the metal. This, of course, results in porosity in some parts of the casting.

If the casting is to be chromed, painted, or powder coated, or if any part of the casting is very thin, any air or gas inclusions usually result in rejection. Porosity also affects the mechanical properties of the product. In structural applications, porosity can act as a stress concentrator and therefore create a site where cracks may occur.

An additional problem is the fact that porosity in a casting may not always be immediately apparent. If discovered after subsequent processing, customer dissatisfaction can be extreme.

Porosity in the casting can be almost completely eliminated by an efficient vacuum system.

Before the injection shot occurs, a vacuum is drawn in both the shot sleeve and the mold cavity. The vacuum is maintained until the injection cycle is completed. Almost all of the air is positively evacuated from the mold.



A good vacuum in the mold cavity enables the alloy to flow into blind recesses in complex shapes. It also allows the fronts of the molten metal to merge freely without forming shuts.

Whatever vacuum method is employed, if it works well, improved quality and reduced scrap can be guaranteed.

Product that is rejected is unusually costly to the die caster. For example, the value of the machine time that is lost while producing the rejected product can never be recovered.

Adding a vacuum system to the operating process benefits a die caster in several ways. First, it reduces his rate of rejection. Second, by lessening the force required on the plunger, it increases the life of almost all components of the DCM. But most importantly today, by allowing the die caster to produce thinner, stronger, and more complex castings, it makes it possible for him participate in a fast growing market sector to which he would otherwise be denied.

### **Vacuum Depends on Good Shot Sleeve - Plunger Tip Interaction**

It is an obvious fact that a vacuum can only be created in a completely enclosed space. This makes the seal between the plunger tip and the shot sleeve critical to vacuum-assisted die casting. The gap between the plunger tip and the wall of the shot sleeve is necessarily very small. If at any time during the return stroke of the plunger it becomes too great, air is likely to be sucked through the gap. Also, during the injection the metal may penetrate the gap. If alloy then collects on the plunger tip, rapid deterioration of the vacuum seal will result as the tip becomes galled and the sleeve becomes soldered.

If close control of this tip-sleeve gap is lost, a good vacuum can be easily destroyed in less than 1,000 shots.

### **Lubricating the Sleeve-Tip Interaction**

The primary purpose of a shot sleeve lubricant is simply to reduce the friction between the sleeve and the plunger tip, and to thus ensure the smooth passage of the tip through the sleeve. This is essential for consistent shot velocities, and also to extend the operating life of both the shot sleeve and the plunger tip.

The amount of lubricant used must be adequate, but care should be taken to avoid any excess. Lubrication should therefore be kept to an absolute minimum. It should be benign, and produce no toxic fumes.

Every effort must be made to eliminate the possibility of any non-metallic substance getting into the mold. Graphite-based lubricants, for example, can cause porosity in the casting.

Lubricant should be applied where it is needed. . And only where it is needed.

Any excess lubricant not actually used, is an unnecessary cost and a workplace pollutant.

A lube-drop system is usually adequate. This incorporates an internal lubricant groove machined into the sleeve, combined with a metered dropper.

The shot sleeve lubrication system is an essential part of the overall die casting production process. Neither the shot sleeve nor the plunger can operate effectively unless the shot sleeve is adequately lubricated

### **An Added Benefit.**

Die release lubrication seems an unlikely function for advantageous interaction, but consider the following. .

The die is sprayed with lubricant before every shot for the following reasons:

1. To form a thin film on the surface of the die that will provide a barrier between the molten casting metal and the die, and thus prevent soldering.
2. To provide a release agent that will facilitate the easy ejection of the casting from the die.
3. To cool the die.

The clearance between the die end of the shot sleeve and the die itself is critical. If there is too much clearance where the sleeve goes through the platen, excessive heat will occur. This will result in a hot spot at the end of the shot sleeve, causing unwelcome expansion.

The die caster who practices the Systems Approach, and constantly thinks in terms of action and interaction, will be attracted to the third function of the die lubricant, "To cool the die."

If the lubricant cools the die between shots, why not also the end of the shot sleeve?

By carefully positioning one or two of the die lubrication nozzles, and spraying the exit of the shot sleeve for about three seconds, the temperature of this critical hot spot can be reduced by as much as 200°F.

This is certainly a worthwhile interaction, and one overlooked by most die casters.

### **The Systems Approach**

The Systems Approach is the best technique yet devised to examine the aluminum die casting process. All components operate as part of the overall system. None should ever be considered in isolation.

No system can ever approach maximum productivity unless all the elements, without exception, are operating at close to their maximum efficiency and also interacting effectively together.

There are only three valid measures to assess the value of any component of the die casting process:

1. How does it affect the process?
2. How long will it last?
3. How well does it interact with other components?

The Systems Approach is just now used by most industry-leading die casters. It also underlines the advantages of single-sourcing several components whenever possible, to gain the benefits of undivided responsibility.

Used properly and consistently, the Systems Approach to appraising the performance of all or any part of the die casting process virtually assures improved productivity.

### **A Profitable System**

In a well-run die casting plant, everything that can be possibly be measured is being monitored, measured, and recorded . . . quantities, speeds, temperatures, dimensions,

etc. The old adage that anything that can be measured can be improved, is as true for light metal die casting as it is for any other process.

All components in the system are operating effectively, and safely within their theoretical maximum capacity. All temperatures are being closely controlled. The objective is not simply maximum speed, but consistent stability, both thermal and dimensional.

The die maker is well aware of the impact that each component has on complementary components with which it interacts.

A good vacuum is being drawn in the die mould and the shot sleeve, and the plunger is running smoothly with a minimum of lubrication.

Scrap is minimal, unscheduled downtime has been virtually eliminated. There are few surprises.

Productivity is gradually but steadily increasing. Profit is on budget as the increased productivity has been accurately forecasted. The entire production process is operating smoothly and predictably, not as a sequence of disparate components, but as a holistic system.