BASIC OPERATOR TRAINING PROGRAM

NADCA

NORTH AMERICAN DIE CASTING ASSOCIATION

Item: 685

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PREFACE

The training program that you are now beginning is designed to give you formal training in the die casting process. This knowledge of the process will help you determine when the process is operating correctly and when it is in trouble and may require corrective action. Along the way, you will learn about the die cast die, the die cast machines, the various materials and alloys that are used on a daily basis and how they must all work together to produce an acceptable casting.

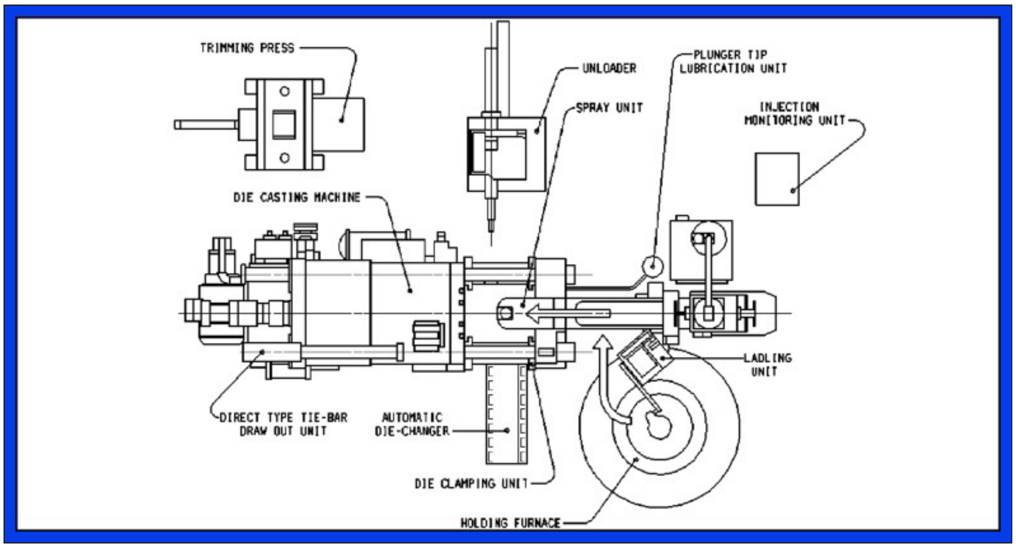
This training program will consist of eleven lessons of varying length. They are:

1. Introduction to Die Casting and Safety on the Shop Floor
2. Understanding Metal Melting/Handling for Operators
3. Die Casting Machine Components and the Die Casting Cycle
4. How It Works – The Shot End
5. Why Shot Monitors Are Important
6. Die Components and Their Functions
7. Everybody Is Involved In Die Setup
8. Proper Care and Treatment of Dies During Production
9. Recognizing and Controlling Flow Defects
10. Recognizing and Controlling Porosity
11. Eliminating Solder and Flash Defects

Each chapter of this book is designed to support the information presented during the corresponding lesson of the training program. The first lesson will set the stage for the entire program. It is designed to tell you about the program, your role in the die casting plant and industry, and will concentrate on safety in the industrial die casting environment.

The second lesson on metal melting and handling will discuss the alloys that are used for the production of die castings. The various alloy compositions will be presented and your responsibilities as an operator will be stressed.

The third lesson on the die casting machine will familiarize you with all of the components of the die casting machine and their function. In the future, this will help you to identify and locate components on the machine that may be a source of trouble, and let you readily communicate about them to your supervisor and a maintenance mechanic.



Lesson four will focus on the shot end of the die casting machine. This part of the machine injects the molten metal into the die at a very high rate of speed. However, this speed is controlled in such a way as to produce acceptable castings. There is some math involved in this section and it will be explained in detail.

Lesson five presents an important control system of modern die casting equipment, the shot monitor. This equipment measures and controls the die casting cycle to insure quality parts and is a critical piece of equipment for each machine operator to understand.

Lesson six will discuss the die components that are used to produce die castings. All of the features of this important piece of equipment will be presented so that you will be able to identify components that may need attention during production.

Lesson seven discusses die setups. There are often frequent die changes in die casting plants and they represent lost production time. It is important to understand the need for preparation and for proper procedures to minimize the time lost during die setups.

Lesson eight presents the care of die casting dies during production. The many details involved in producing good parts time after time are discussed. This will be a critical part of your job as an operator.

The last three lessons present the most common die casting defects and how they can best be controlled. Lesson nine discusses flow defects, lesson ten presents controlling porosity in die castings, and lesson eleven discusses how to eliminate solder and flash defects. It is important that you be able to quickly identify casting defects and take corrective action or notify your supervisor.

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1 INTRODUCTION TO DIE CASTING & SAFETY ON THE SHOP FLOOR

OBJECTIVES

1. To learn about the die casting industry
    - To learn the history of die casting
    - To learn where die castings are used
    - To learn the advantages of die castings
    - To learn about the jobs in the die casting industry
    - To learn about the operator training program
    - To learn what each lesson will cover

2. To learn about safety in the die cast environment
    - To learn about the types of safety hazards
    - To learn about personal protection
    - To learn about general machine safety
    - To learn about general die safety
    - To learn about work place safety
    - To learn about plant air safety

PERSPECTIVE

Metalcasting is an ancient industry. Its modern roots include sand casting, investment casting, lost foam casting, permanent mold casting, centrifugal casting, and die casting. The word "metalcasting" refers to the entire industry of pouring liquid metal into a mold for the purpose of achieving a desired shape. Die casting is a particular variation of metalcasting where liquid metal is forced into a reusable steel mold, or die, very quickly with high pressures.

Sand casting, investment casting, and lost foam casting processes all use gravity to fill the mold. After the mold is filled, it is destroyed to remove the casting. Mold making is as important part of these processes as is making the casting. In all these processes, gravity must fill all the casting, consequently metal flow is slow and walls are much thicker than compared to die casting. The cycle time is also longer because of the inability of the mold material to remove heat.

Permanent mold casting could be considered a cousin to die casting. In this process the mold is reused, not destroyed. The process uses gravity to fill the casting, so flow control is similar to sand casting. Metal flow is slow. Since the mold is steel, and has comparatively good thermal conductivity, the release agents used in this process are also insulators. This is necessary, to keep the casting from freezing periodically, and preventing filling. Machines for this process are relatively small compared to die cast for similar sized castings.

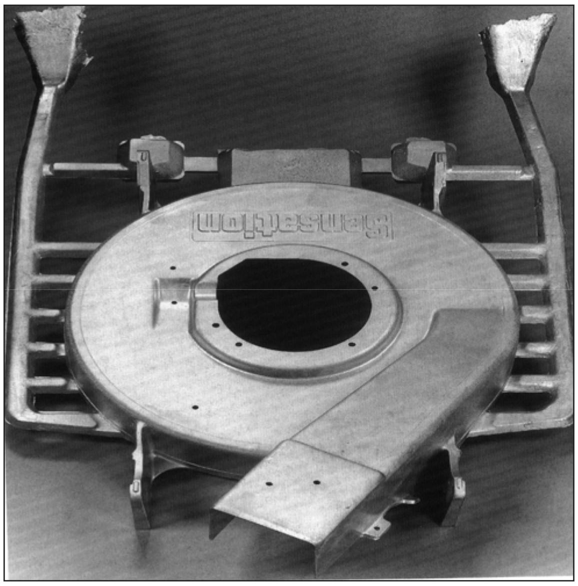


Figure 1-1 - Permanent mold casting

Centrifugal castings are frequently made by jewelers. This is the choice for low volume castings with a small amount of pressure. The molds are placed around the circumference of a centrifuge. As the centrifuge spins, metal is poured in at the center and centrifugal force distributes the metal to the molds.

Die castings are among the highest volume, mass-produced items manufactured by the metalworking industry. Die castings are important components in thousands of consumer, commercial and industrial products, such as automobile equipment, electrical equipment and ordnance, general hardware, power tools, computers, and other business equipment, instruments, toys, novelties, and a great many others to numerous to mention. In fact, die castings have greater utility and are used in more applications than components produced by almost any other metal forming process.

Die casting is a process involving the injection of molten metal at high pressures (as opposed to casting by gravity pressure). It is believed to have begun sometime during the middle of the 19th century. According to records, in 1849, Sturges patented the first manually operated machine for casting printing type.

Another 20 years passed before the process was extended to casting other shapes. The casting of printer's type led to patents, which eventually resulted in development of the linotype machine by Ottmar Mergenthaller.

The earliest commercial applications for die castings occurred in 1892 when parts were produced for phonographs and cash registers. Mass production was further encouraged when the H.H. Franklin Company began die casting babitt alloy bearings for automobile connecting rods shortly after the turn of the century.

Various compositions of tin and lead were the first die casting alloys. Their importance and use declined, however, with the development of zinc alloys just prior to World War I. Magnesium and copper followed shortly thereafter. During the 1930s, many of the alloys we know today had become available. Today alloys of aluminum are most widely used followed by alloys of zinc. Modern science and technology, metallurgical controls and research are making possible still further refinements resulting in new alloys with increased strength and stability.

Through the years, many significant technological improvements have been made to the basic die casting process, to die steels and to die construction, as well as in casting capability and production capacity of the process. The new technology has been tremendously effective in expanding die casting applications into almost every known market.

The major advantages of die casting are:

- Cast parts are net shape or near-net, that is, they are cast to their finished size, requiring no or minimal machining operations.

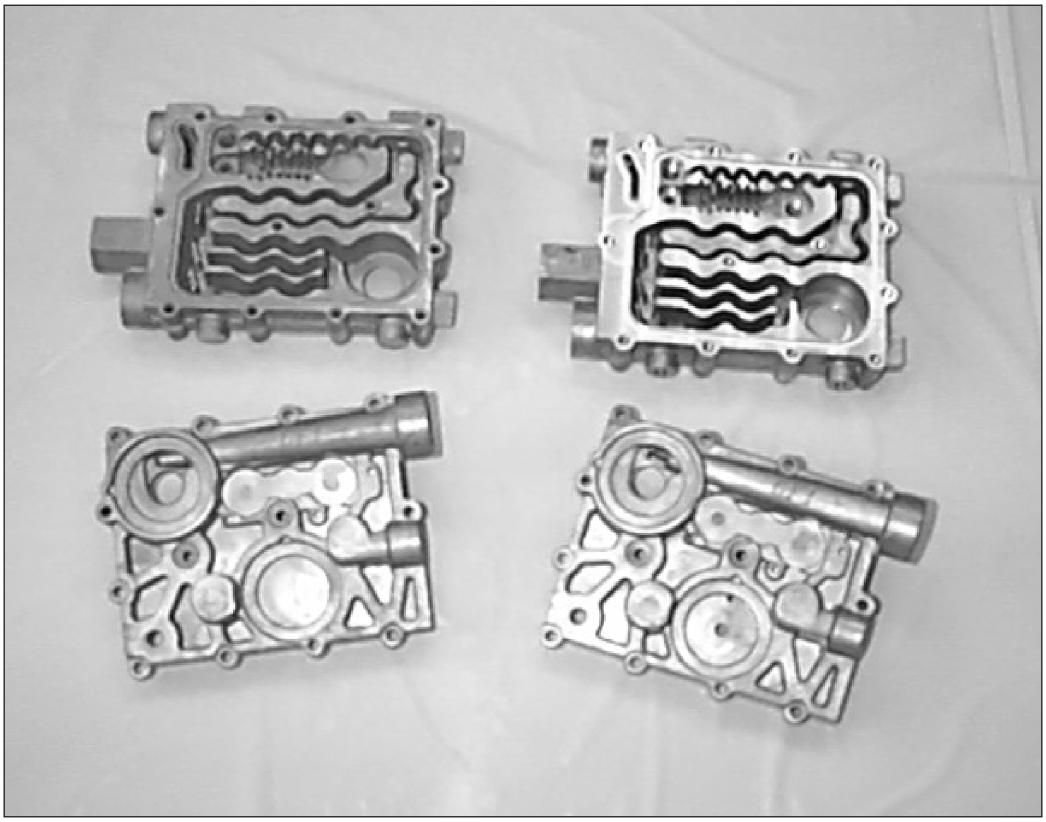


Figure 1-2 - Photo of complex near net shape casting

- A variety of metal and metal alloys can be cast, from aluminum to zinc.

Figure 1-3 - Photos of Al, Mg, Cu base, and Zn alloy castings

- Very large and very small castings can be made from automotive engine blocks and transmissions to miniature gears and pinions.

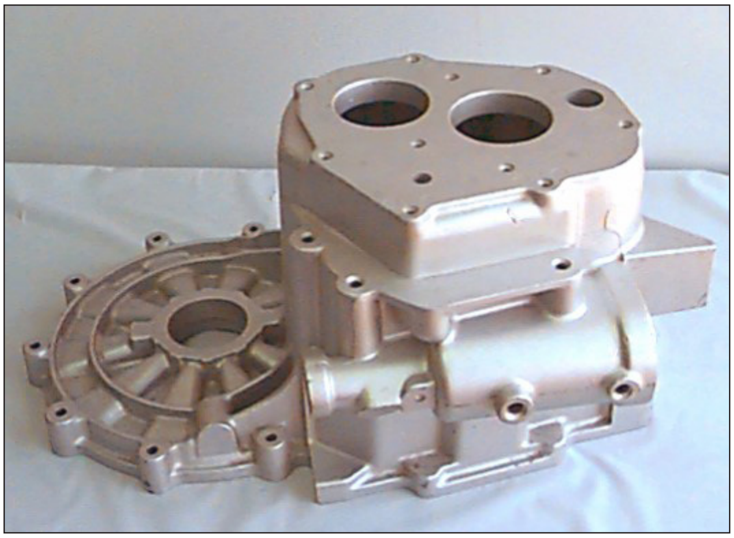


Figure 1-4(a) - Photo of transmission housing

Figure 1-4(b) - Shielded cable header

- Intricate shapes can be produced both on the inside and outside of the casting, automotive transmission valve are an example.

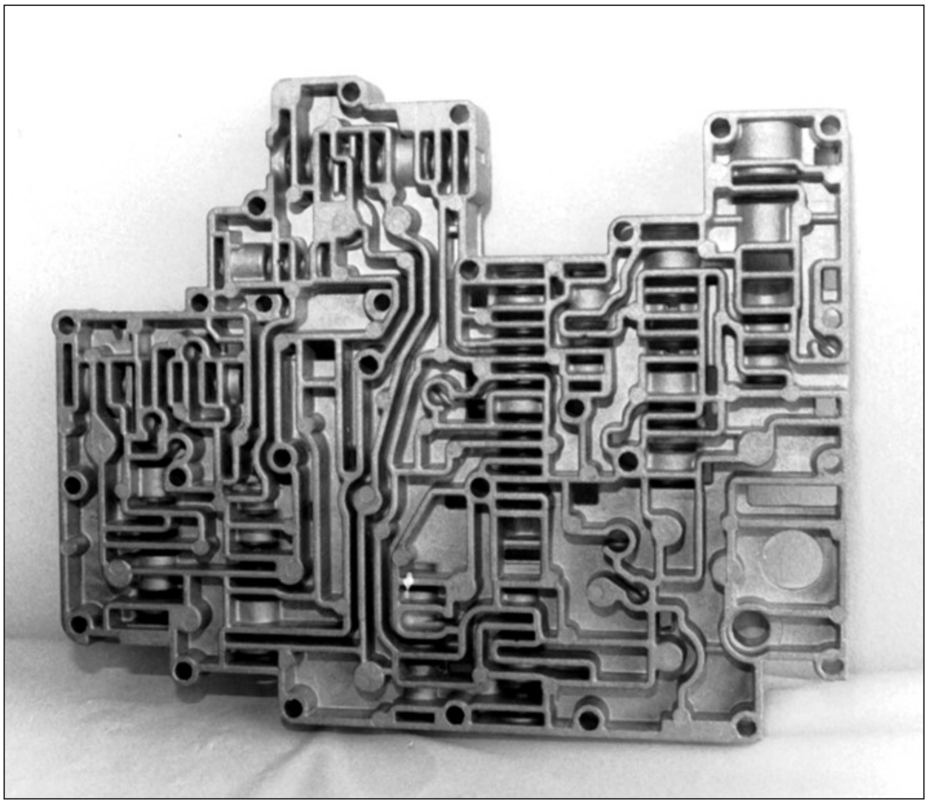


Figure 1-5 - Transmission valve casting

All of the industries products are fully recyclable. In fact most of our alloys are made from recycled materials.

Figure 1-6 - Photo of recycling bins at a secondary smelter

In 2015 there were approximately 450 die casters in North America, with sales of $8 billion. Die castings were produced from aluminum, copper, lead, magnesium and zinc alloys as well as various composite materials. These castings found their end use in cars, machinery, space, appliances, sporting goods, toys, and many other applications.

In a die casting plant there are many different jobs that must be done. These include the president or owner, controller, salesman, maintenance mechanic, smelter, material handler just to name a few. Your job as a die casting machine operator is one of the most important. Just look around as you work. The metal handler, the trimmer, the inspector, the material handler are all doing jobs that service and support your activity as a machine operator. It is most important that the machines run and produce acceptable castings for your customer. If no castings are produced, many of the other jobs in the plant are irrelevant.

SELF TEST 1

Multiple choice; Identify all correct answers.

1. Metal casting processes include:
   a. die casting
   b. forging
   c. permanent molding
   d. lost foam casting

2. The alloys of which element are most widely used in die casting:
   a. aluminum
   b. magnesium
   c. zinc
   d. none of the above

3. Alloys of this element are second most widely used:
   a. aluminum
   b. magnesium
   c. zinc
   d. none of the above

4. The die casting process utilizes:
   a. gravity to fill the die
   b. a re-useable steel die
   c. a wooden pattern
   d. none of the above

5. Advantages of die castings are:
   a. many can be used with little or no machining
   b. the materials are fully recyclable
   c. copper alloys can be used
   d. all of the above

SAFETY

Any industrial environment will have hazards in it. The die casting plant has some particular hazards that you must be aware of to work safely. The die casting plant uses molten metal at very high pressures. This requires that you should be thinking about safety, whatever you are doing. Safety is an attitude; you have to take a defensive attitude. This is similar to driving a car. You have to anticipate what will happen when you take an action, in fact, you should be certain of the outcome before any action is taken. You also have to anticipate the actions of others.

The pursuit of safety requires that top management must be fully committed to safety. The company must provide well maintained properly guarded equipment in a clean working environment. Supervisors and production personnel must work together to teach and motivate safe work attitudes and habits. If an accident occurs, an objective analysis must be made to determine its cause and avoid its repetition.

The types of hazards that occur in the die casting plant can be characterized as pinch, snag, strike, burn, electric shock, pierce, slip-fall, trip-fall and fire. These hazards are not unique to the die casting plant, and as with any activity that has special safety requirements, such as driving a car, you must become familiar with the potential safety hazards, in order to avoid injury to yourself or associates. For example, reaching into the die space to remove a casting exposes the operator to pinch, burn and snag hazards.

Personal Protection

For your personal protection it is important to wear the proper protective clothing. Because of the hazards associated with liquid metals, high pressures, and high temperatures, it is important to “cover up”. Cotton or woolen clothing is appropriate as opposed to polyester or plastic like materials that will melt under conditions of high temperature. Proper clothing for the die casting machine operator includes shirts with long sleeves buttoned at the wrist, long pants, molder’s boots, gloves, and safety glasses. Some plants will require helmets in order to prevent head injuries. Molder’s boots have an elastic closure around the ankle that prevents metal from getting into the shoe. The elastic top also makes them easy to put on and remove. These boots should also have steel toes and arch supports. The safety glasses should have side shields to offer protection from the sides.

Figure 1-7 - Properly attired die caster

Other jobs in the die cast foundry will require special protective clothing. For example, the furnace cleaners will require special clothing to protect them from radiant heat given off by the furnace. This will burn faster than the sun burning a sunbather. The metal handler will have to wear special protective clothing to protect against metal splashing.

Machine

The die casting machine has moving parts, pinch and shear points, lubricants, hydraulic fluid, and electrical controls. Particular areas of the machine may be hot; the hydraulic fluid is usually hot. Areas that are recognized as potential safety hazards along with appropriate preventative measures are discussed in the Die Casting Machine lesson. Typical machine features are described along with the particular type of hazard that could be present.

Die Casting Dies

The die casting die is hot at operating temperatures and can have pinch and shear points. Each die feature that is a recognized potential hazard is discussed in the Die Casting Die lesson along with appropriate preventative measures.

Auxiliary Equipment

Auxiliary equipment such as furnaces, conveyors, reciprocators, robots and the like have safety considerations. These are discussed in detail in the various lessons that are appropriate to them.

Work Environment

The work area also requires special safety considerations. Keeping your work area neat and clean is the first step to a safe environment and maintaining your personal safety. Tripping obstacles can cause injury. Machines will have components that project from them. These are trip-fall hazards. These items should be painted with standard OSHA color coding in order to make them more visible.

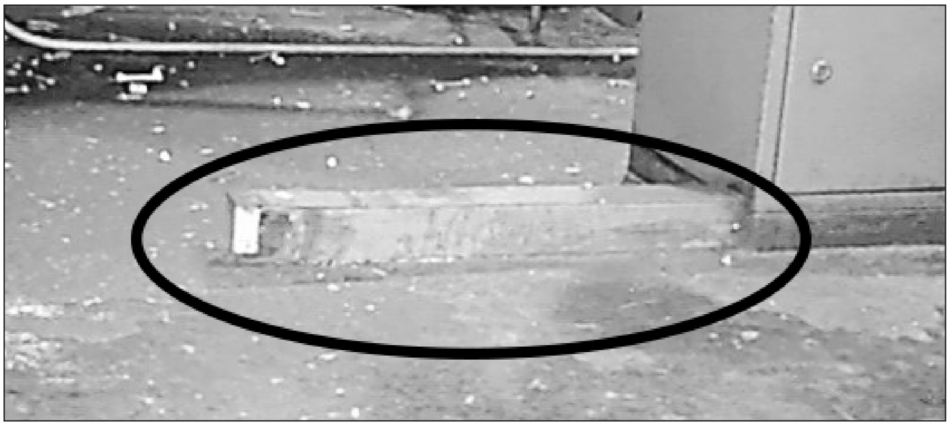


Figure 1-8 - Trip obstacle at machine

Excessive noise can be a hazard that can result in hearing loss in the die casting plant. OSHA has published regulations regarding noise levels in the industrial environment. Modern machines and equipment are built to meet these regulations. However, the combination of noises in the industrial workplace makes it prudent to use hearing protection. At minimum, ear plugs are recommended and are usually readily available. Hearing protection is required in some plants.

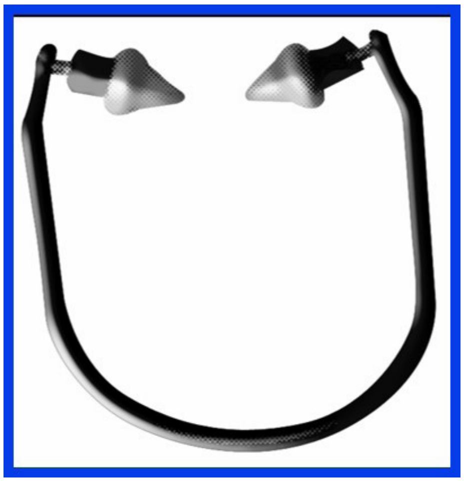


Figure 1-9 - Graphic of ear protection

The die casting process consumes a large amount of lubricants, release and cooling agents. It is not unusual for these to get on the floor and cause a slip-fall hazard. Good housekeeping practices must be maintained to keep floors clean. When liquid spills occur, surface drying compounds should be used immediately. Rigid equipment maintenance and preventative programs should be used to minimize the leakage of fluids from machines and dies.

Figure 1-10 - Hazardous floor conditions

Floor clutter will cause slip-fall hazards. This includes electric cords, cables, and hoses running across the floor. If hoses, pipes and cables must be at approximately floor level, they should be in a trench that is properly covered or be covered above the floor level. Floor clutter could also include process debris such as scrap, biscuits, runners, overflows, and sprues.

Figure 1-11 - Floor clutter

Operator platforms are used to establish the proper working height and prevent fatigue. The platforms should be of uniform height for similar machines. The platforms need to provide a non-skid surface to minimize any slip-fall hazard. Proper working heights are necessary to minimize aches and pains resulting when a person works in an awkward position.

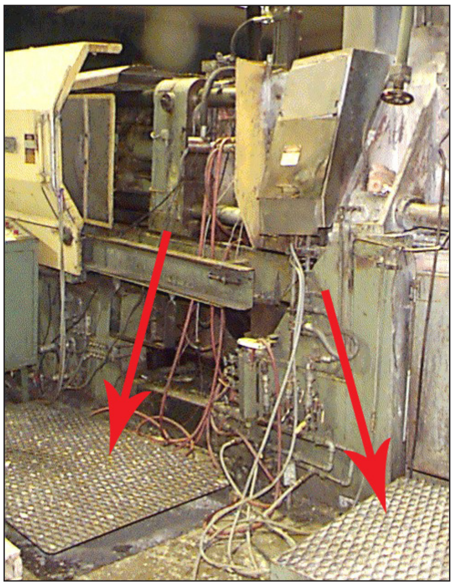


Figure 1-12 - Operator Platform

Machine controls must also be at the proper height to avoid fatigue. A maximum height of 70 inches to the top of the operator control panel has been found to be satisfactory.

Figure 1-13 - Operator at proper height platform

Plant air or high pressure air is used in a variety of ways in the die casting operation, if improperly used it can be hazardous. Escaping air can be noisy and an air blast can carry small particles of dirt or metal. This could be hazardous to your hearing or eyesight. To prevent leakage or sudden air blasts, air connections should be secured by strong couplings and connectors. Air hoses should be arranged to prevent tripping hazards.

There are a number actions that you can take in order to prevent an accident from occurring when working with high pressure air. They are:

- Check all air hose connections before turning on the air or pressurizing the lines.
- When turning air on or off, hold the nozzle end of the hose to prevent whipping of the air line.
- Shut off the air before adjusting air tools.
- Never point an air nozzle at anyone.
- Do not use air to dust off hair or clothing, or to sweep the floor.
- Wear safety glasses when using high pressure air.
- Inspect air hoses regularly and request prompt repair of defective lines.

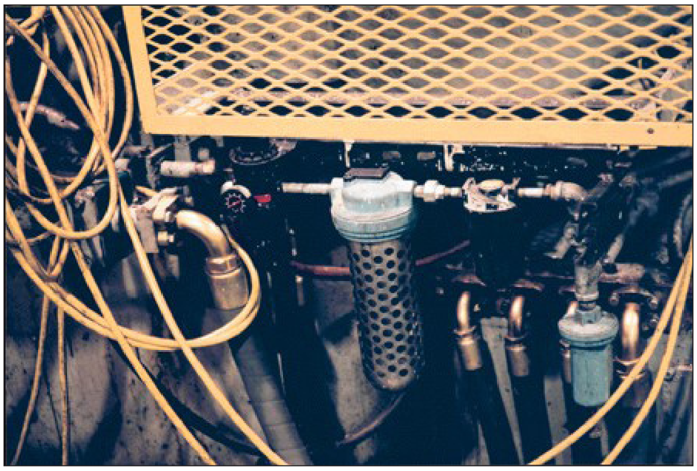


Figure 1-14 - Photo of air hose and/or manifold

Handling materials can also be injurious. Correct handling of objects in the die casting plant is important. The following pointers to the correct procedure for handing various materials should be observed. This is not a comprehensive list, but a starting point.

- Inspect materials for slivers, jagged edges, burrs, and rough or slippery edges.
- Get a firm grip on the object.
- Keep fingers away from pinch points, especially when setting materials down.
- When handling long objects such as pipes and panels, keep hands away from the ends to prevent them from being pinched.
- Wipe off greasy, wet, slippery or dirty objects before trying to handle them.
- Keep hands free of oil and grease.

SELF TEST 2

Multiple choice; Identify all correct answers.

1. Your attitude toward safety should be:
    a. it's not my problem
    b. defensive, anticipate problems
    c. it's a management problem
    d. none of the above

2. There are many hazards in the die casting workplace, they include:
    a. burns
    b. pinches
    c. slipping
    d. all of the above

3. Protective clothing includes:
    a. long sleeve shirts
    b. gloves
    c. safety glasses
    d. all of the above

4. Reaching into the die to remove a casting exposes you to the following hazards:
    a. burn
    b. snag
    c. pinch
    d. all of the above

5. The work environment should be:
    a. free of floor clutter on the traffic pattern
    b. never be hotter than 90ºF
    c. reasonably free of soda cans and other recyclables
    d. all of the above

SAFETY

Let us review a number of items that are crucial to safe operation of the die casting machine. The types of hazards that exist at the die cast machine are pinch, snag, strike, burn, electric shock, pierce, slip-fall and fire.

Pinch hazards exist at the:

Linkage - as the linkage operates, the links and/or accessories attached to them can create pinch areas.

Figure 1-15 - Linkage and die space guards

Safety ratchet pawl -the safety ratchet is a notched bar that moves with the moving platen or toggle cross head. A pawl drops into the notches to prevent accidental closing of the machine. The pawl drops by gravity into a notch in the safety bar. If it should drop when someone's hand is under it, it would create a pinch hazard and cause injury.

Figure 1-16 - Safety ratchet

Power doors -doors are used frequently to deter entry to the parting line area during the machine close and dwell portions of the machine cycle. These gates may be closed manually. However, bigger gates on larger machines require a considerable effort to close. Such gates are closed by pneumatic or hydraulic power. The pressure used to close these gates should be as low as practical. The closing speed should be such that the gate does not pose a serious pinch or strike hazard. The leading edge of these gates should be covered with a resilient padding.

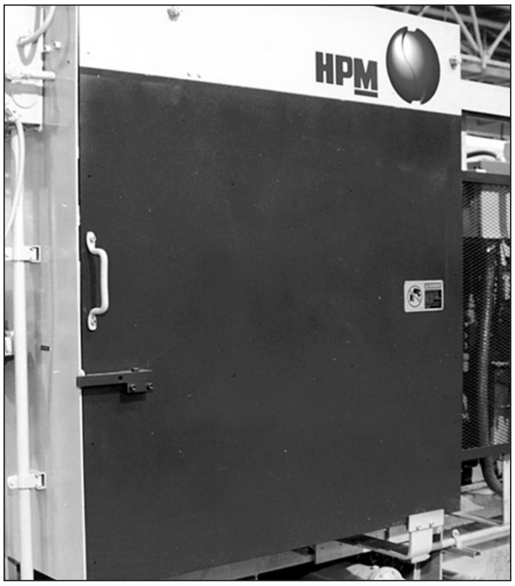


Figure 1-17 - Power driven gate

Chain/Gear drives -normally on die casting machines, chain or gear drives are limited to the powered shut height mechanism. The movement of the chain or gears can create pinch or snag hazards. Machine suppliers provide guards for these areas.

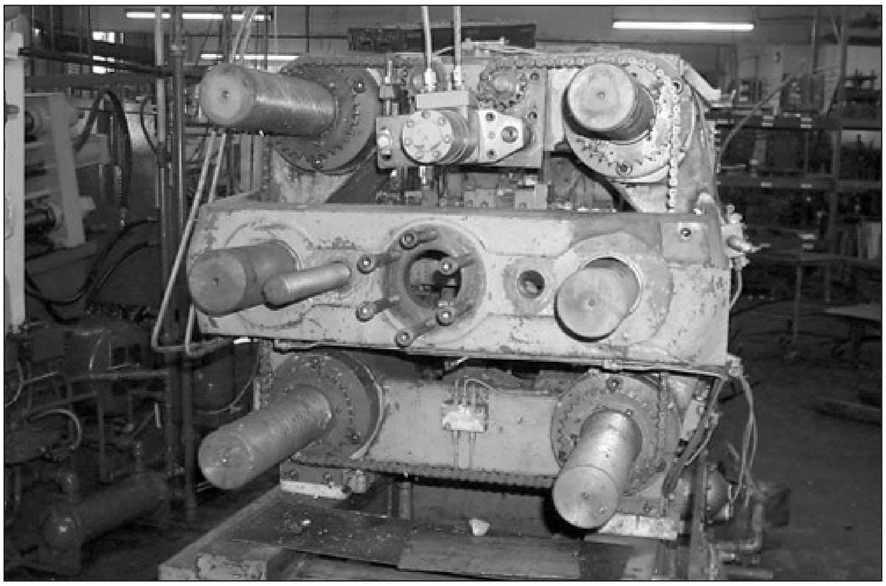


Figure 1-18 - Gear-, worm-, and chain-driven shut heights

Mechanical/ hydraulic bumper plates -the space between the moveable platen and the bumper plate presents a pinch hazard as the platen retracts during machine opening or the bumper plate moves forward during ejection. This area is usually protected by the linkage guards. If the installation of knock out rods requires entry into the pinch area, the machine must be shut down and locked out to a ZES condition.

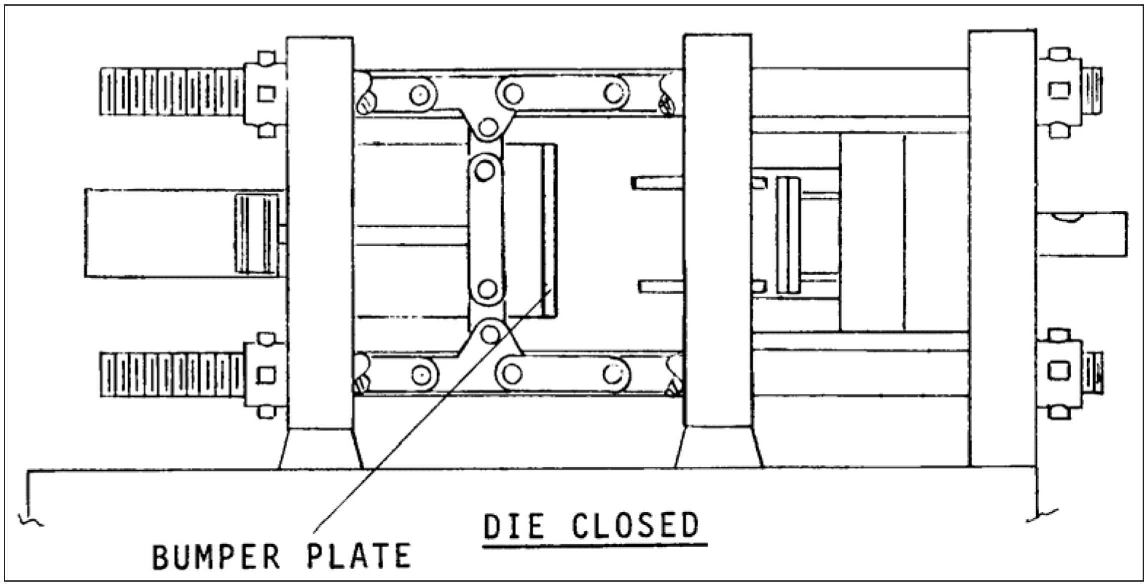


Figure 1-19 - Bumper plate highlighted

Limit trip switch rods -limit switches are actuated by rods or cams that push against the switch arm as the machine moves. As the actuator contacts and actuates the limit switch, it could cause a pinch point. If someone should bump against, grab or otherwise actuate the limit switch, it could cause machine movements, which would be unexpected and therefore hazardous.

Figure 1-20 - Limit switch trip rod

Pour hole -on horizontal cold chamber machines, metal is poured into the hole at the top of the cold chamber. The plunger then moves through the cold chamber to force the molten metal into the die. As the plunger moves forward it creates a shearing action as it passes the edge of the pour hole. This is a serious pinch hazard. A finger is easily amputated if caught in the pour hole as the plunger passes. Drippings of metal solidify around the edges of the pour hole and it is necessary to keep this area free of metal to assure that all metal is poured into the chamber. This metal should never be removed without the use of a tool, screwdriver, pliers or ladle to knock the solidified metal out of the way.

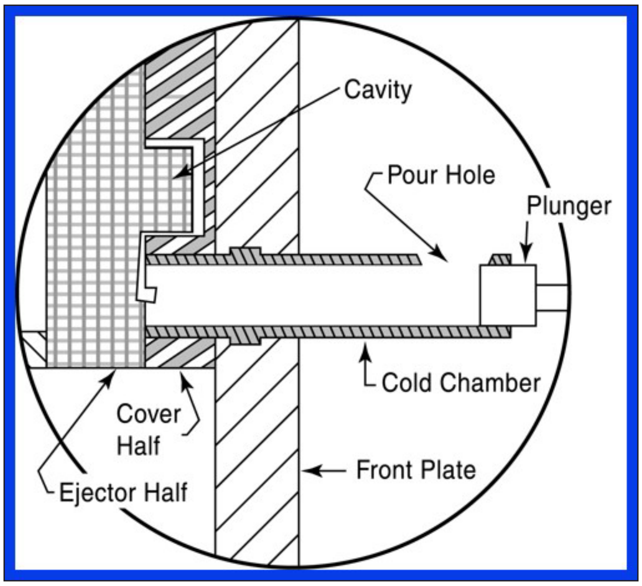


Figure 1-21 - Plunger, pour hole pinch point

Plunger coupling -at the end of the injection stroke a pinch hazard can exist between the coupling, waterlines at the plunger rod and edge of the cold chamber. Care must be taken when moving the plunger forward and rearward if the rod is being rotated to check the fit in the sleeve.

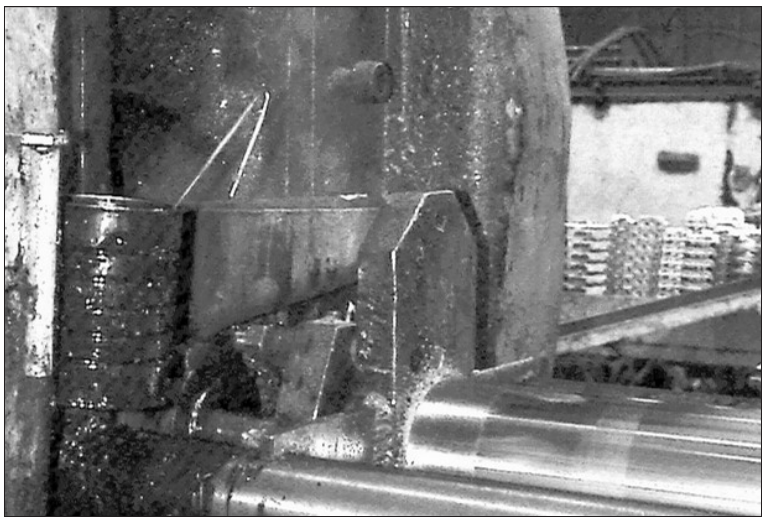


Figure 1-22 - Plunger coupling, fully forward position of stroke

Die carriers -many heavy dies will have supports or carriers that are mounted under the moving die half, to carry its weight and relieve the moving platen of the die weight. Depending on where these carriers are located, as they move back and forth with the die and moving platen a pinch hazard could exist between the carrier and a fixed machine component.

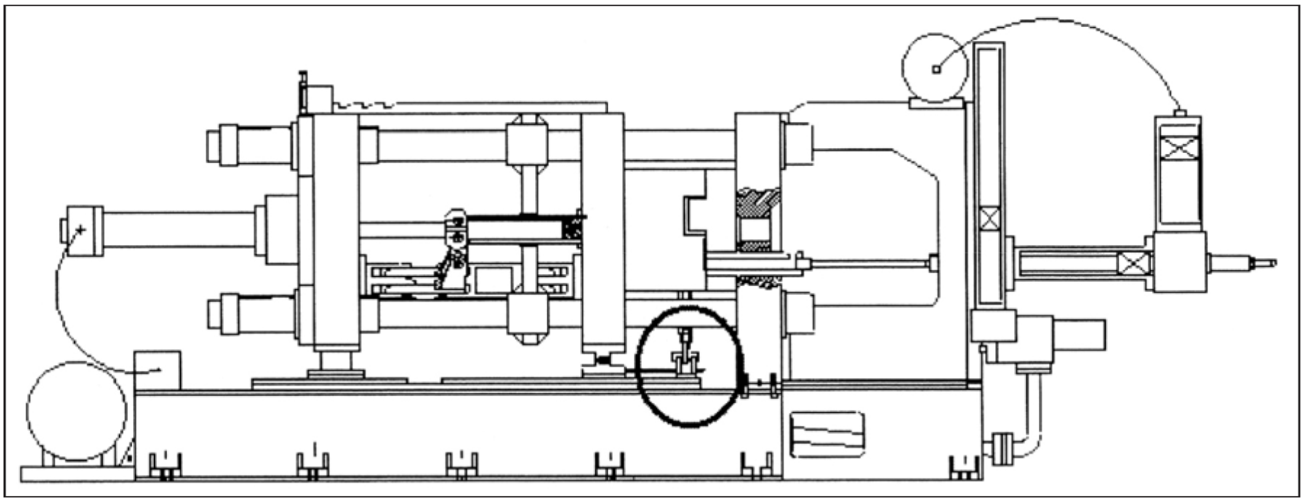


Figure 1-23 - Die carrier

Tie bar pulling mechanism -as the automated tie bar pulling mechanism works, the movement of the various components relative to fixed machine components can cause pinch hazards.

Snag hazards exist at:

Chain or gear drives -see previous entry.

Rotating couplings -the coupling between the motor and the pumps may snag clothing or fingers. The coupling rotates at the motor speed and may have projections. These areas are usually covered with simple sheet metal guards. It is extremely important that these guards be maintained and replaced when they are removed for maintenance.

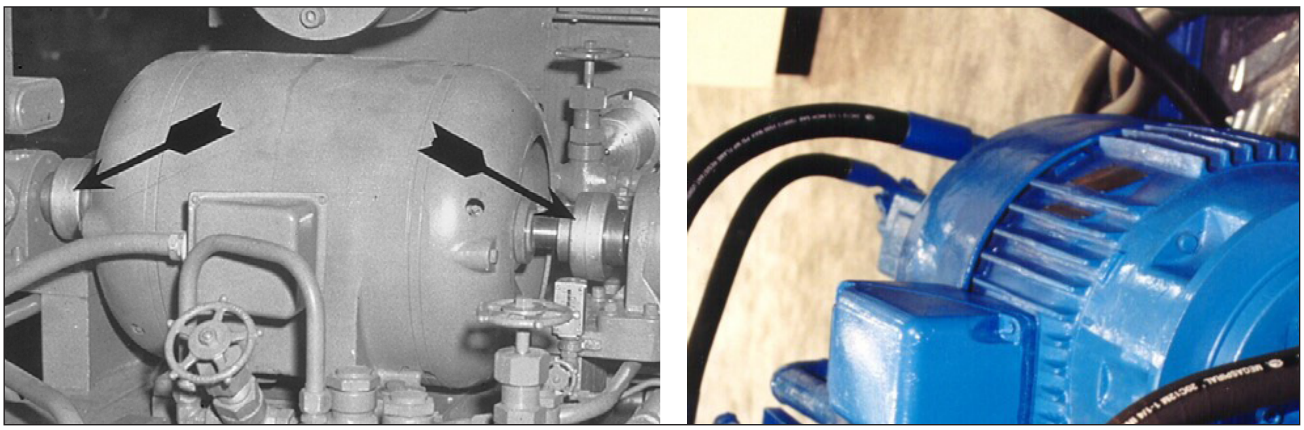


Figure 1-24 - Couplings and Covers

Burn hazards exist at:

Die parting line -occasionally, molten metal may escape the die at its parting plane. The metal will “spit” out of the die at high velocity, and if it is not contained within the machine envelope at can burn anyone who is in the vicinity. Operators and all others in the die casting workshop should be instructed never to stand in line with the parting plane when metal is injected or the die is opening. Some dies will have guards mounted on them to contain any spitting metal. The most effective protection from parting line spitting is safety gates that cover the parting line. A three piece guard for the top, operator and helper sides of the machine is most effective. During normal production the top and helper side gates remain in place. Limit switches are used to check and confirm the position of the safety gates.

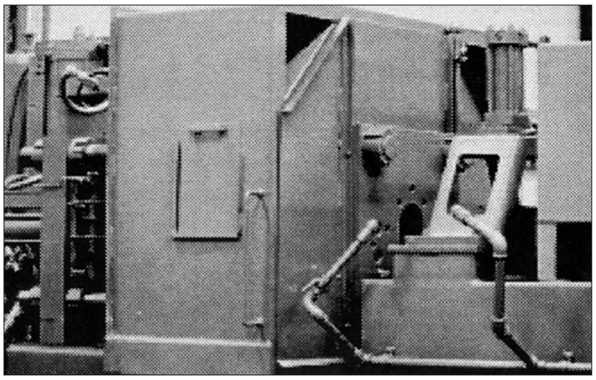


Figure 1-25 - Safety gates

Bursting biscuit -if the biscuit or plug at the end of the cold chamber in front of the plunger tip has not solidified completely when the machine opens it could burst due to the high internal pressure. This explosion can cause metal to be sprayed everywhere and cause a burn hazard. The operator must be aware of this hazard and not be positioned at the parting line when the machine opens the die. The operator should watch and note the position of the plunger at the end of the injection stroke. The ending position of the plunger does not typically vary more than 1/4 inch. If, for example the plunger does not travel as far as is normally expected the operator should be aware that an exceptionally large biscuit may have been formed, and may not be completely solidified when the machine opens the die.

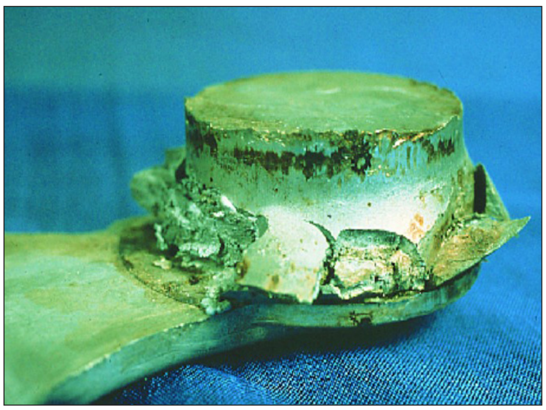


Figure 1-26 - A non-solidified biscuit will burst

Plunger tip spitting -if the fit between the cold chamber and tip is poor; metal could bypass the tip and spit out of the cold chamber. This is a serious burn hazard inasmuch as the metal will be deflected after hitting various machine components and fly in unpredictable directions. The same situation can exist in a hot chamber machine if the rings around the plunger tip fail or are broken. These are hazards that the operator should be watching for, and should correct before they become dangerous.

Figure 1-27 - Hot chamber picture of metal passing plunger

Leaky nozzle/gooseneck bushing -in the hot chamber system an adapter bushing is fitted into the delivery end of the gooseneck. A nozzle is then fitted between the die and the adapter bushing. These are usually metal to metal seals, although some shops will use composite seals in these areas. These sealing areas can be prone to spitting if the components are not kept under an adequate compression. Leakage in this area can be a serious burn hazard.

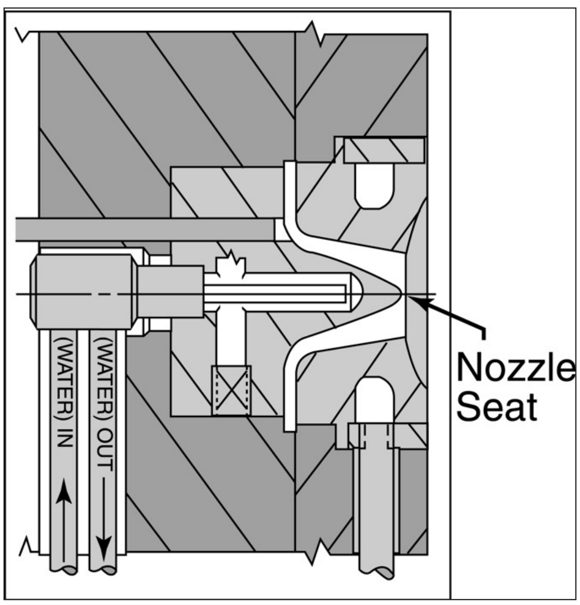


Figure 1-28 - Nozzle seat sprue bushing and post Nozzle Seat

Machine platens -many times the stationary platen will become hot, particularly in the hot chamber process. This could become a burn hazard.

Hydraulic fluid -sometimes the hydraulic fluid gets excessively hot, and leaks could become a burn hazard. In some cases the hoses and piping for the hydraulic lines can become hot and also become a hazard.

Pumps and motors -the hydraulic pumps and electric motors can get hot and become burn hazards. During normal operation these components should not be touched, except possibly to determine if something is going wrong.

Fire hazard exist:

Lubricants, Die and Plunger Tip -certain lubricant compounds are flammable and constitute a fire hazard. Flame and/or minor explosions may occur with them. Every attempt should be made to use non-flammable materials. If flammable materials cannot be avoided, they must be used according to the manufacturer's recommendations. Adequate ventilation should be provided where fumes are created.

Hydraulic Fluids -most die casting machines have large volumes of hydraulic fluid, high pumping capacity, and stored fluid under high pressure in the accumulators. Petroleum hydraulic fluid is highly flammable, a fire hazard, and should not be used. A fire resistant hydraulic fluid is required as part of the ANSI standard for safety requirements related to the construction, care and use of die casting machines. However, the fire resistance of various hydraulic fluids varies widely depending on the fluid type, manufacturer, and exposure to ignition sources.

Many fire-resistant fluids must be checked periodically to assure that their structure and chemistry has not deteriorated. Some fluids can lose their fire-resistance or other operating capabilities with use. A program of periodic fluid sampling may be required to maintain the hydraulic fluid capabilities.

Electrical wiring -improperly maintained electrical wiring could result in a fire hazard. Wires that are not securely connected can work loose with frequent machine vibrations during production. This can cause the connection to fail and cause a machine malfunction, or, the spark/arc from a loose connection could cause excessive heat in the junction and a possibility of igniting flammable materials. Connections must be tight and the wiring must be secured. Electrical conduit must be firmly anchored to the machine, and all junction boxes must be covered. Exposed wiring is not acceptable. The operator must be aware that electrical conduit and flexible cable is not a step or standing place.

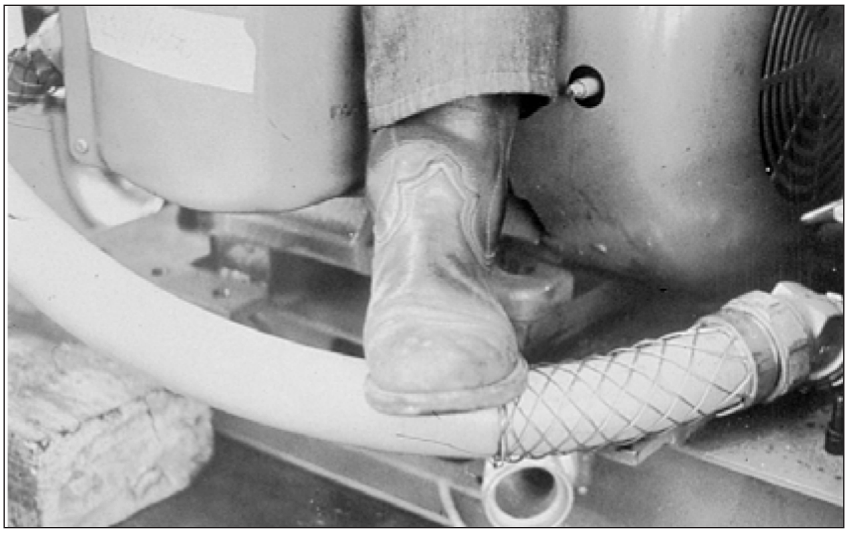


Figure 1-29 - Hazards with electrical wiring

Figure 1-30 - Hazards with electrical wiring

In the event of an electrical fire, only non-conducting materials should be used to extinguish it, not water. CO2 or dry chemical extinguishers should be readily available in the workshop and used on electrical fires.

Electrical Shock Hazards

Grounding -machines with moving parts and most fixed electrical installations must be permanently grounded. This is to reduce the accumulation of static electricity that could result in an electrical shock hazard.

Exposed wiring -when wiring is exposed or wiring conduit is loose, wiring can become broken and insulation frayed. This can result in an electrical hazard if you come in contact with the wire or it can cause a short circuit resulting in a machine malfunction. Electrical conduit and fittings must be firmly connected, and all electrical covers must be in place.

Strike Hazards

Falling machine components -a regular preventive maintenance program to check fasteners is necessary to assure that no machine components come loose during production and strike someone.

Tie bar nuts -if a tie bar were to break, the most likely locations are at the threaded ends. A complete failure could cause the tie bar nut and broken section of the bar to fall. This would be a strike hazard if someone was near by or working on the nut. The tie bar nuts on large machines can be several feet from the floor and weigh hundreds of pounds.

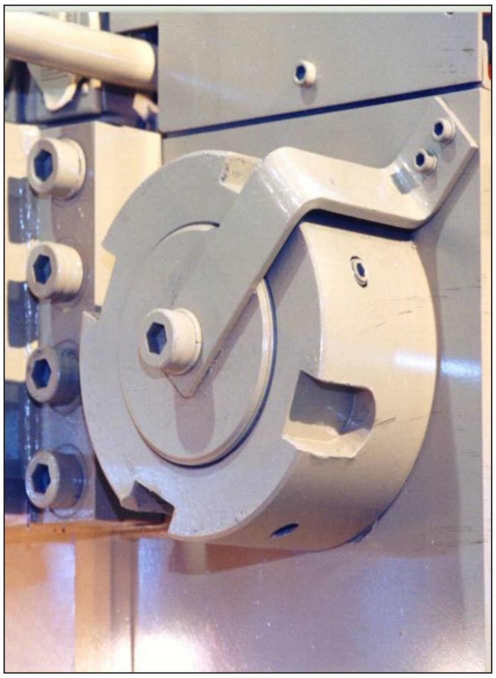


Figure 1-31 - Tie bar nut with safety strap

Machine projectile - if broken during service, certain machine components can become flying projectiles at the time of failure. Such an item could strike someone. Examples would be the cylinder and intensifier tailrods and various caps covers and plates that may be subjected to high pressures during operation.

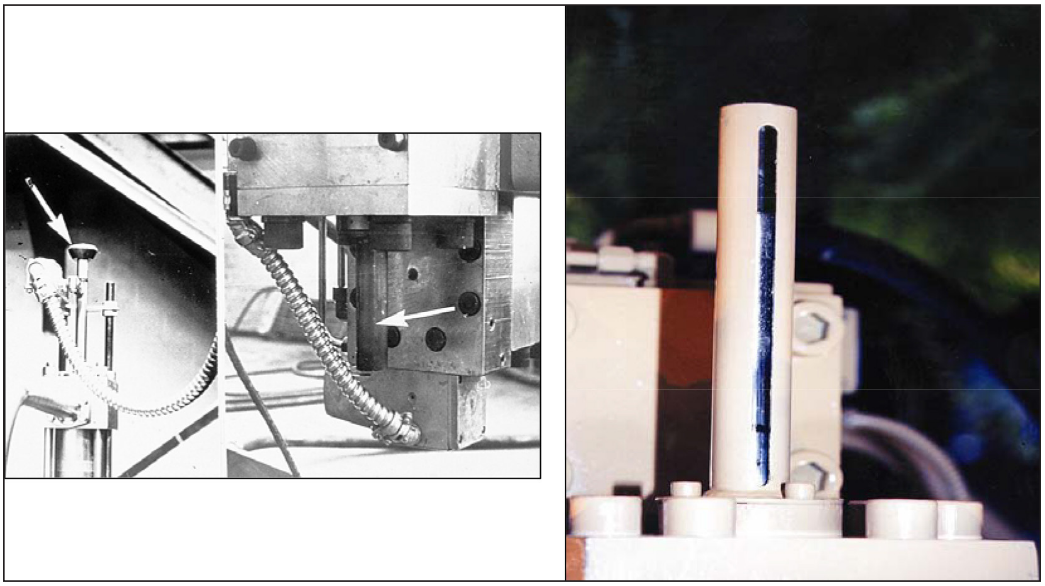


Figure 1-32 - Tailrods

Telescoping tubes -some machines use telescoping fittings and tubes to carry hydraulic fluid to the cylinders. Since these components are moving during certain segments of the cycle, their motion could be a strike hazard. Telescoping fittings can also create pinch hazards and should be guarded to prevent access to the pinch areas.

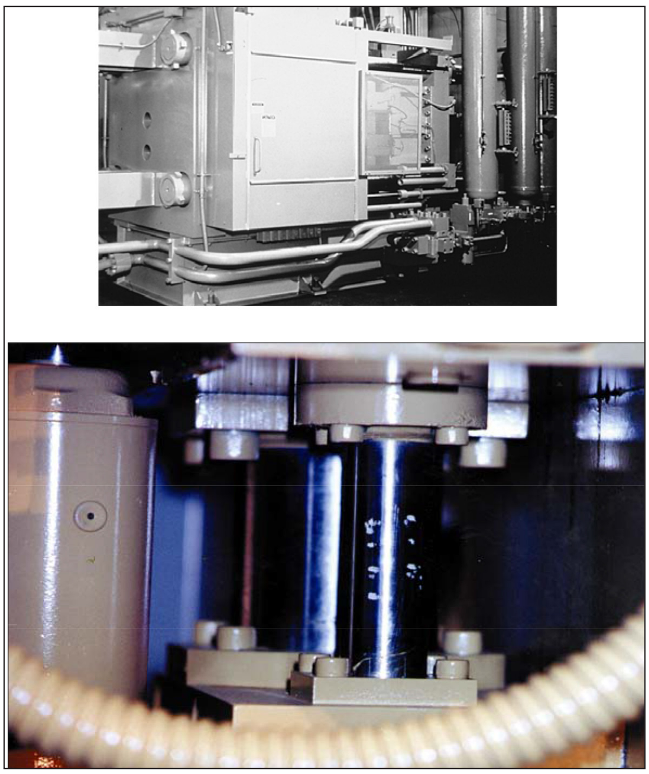


Figure 1-33 - Telescoping fittings, gates and guards

Safety gates, tracks and rollers -automatically operated safety gates can be a strike hazard if someone gets in their way during closing and opening. It is recommended that the leading edges of the gate be padded. A gate coming off the track could also strike someone. The track and rollers should be constructed such that the gate does not merely hang on the track but is interlocked to it. The track height is also important. It should be high enough that the operator need not stoop under it to unload parts; the operator would run the risk of striking the track.

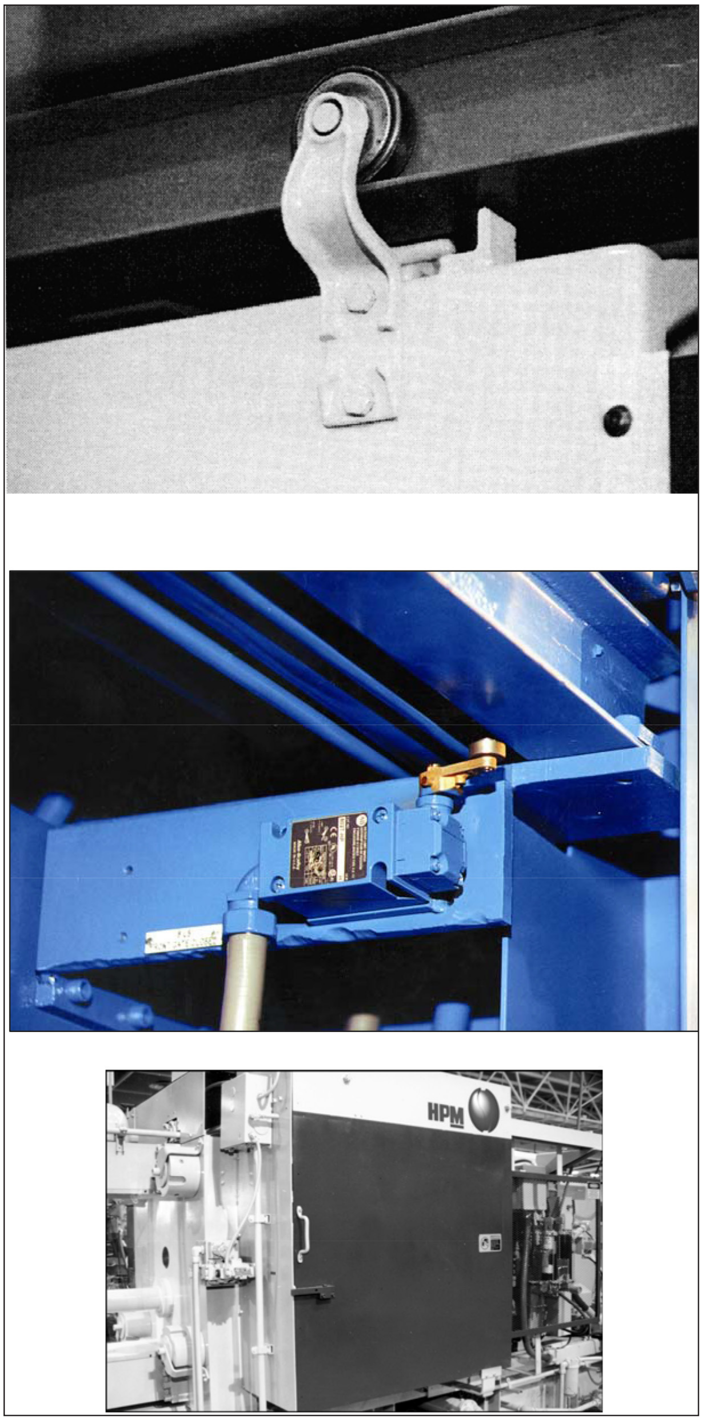


Figure 1-34 - Rollers, doors, and tracks

SELF TEST 3

True or False

1. Pinch points on the die casting machines have caused severe injury and death.

   True False

2. Once the power has been turned off, it is safe to work on the machine.

   True False

3. The parting line of the die is not a pinch point.

   True False

4. Exposed electrical wires on the die casting machine are dangerous.

   True False

5. The pump is an example of a "stored" energy device.

   True False

Multiple choice - Identify all correct answers:

6. Which of the following fabrics should be avoided in the die cast foundry?

   a. cotton
   b. nylon
   c. polyester
   d. wool

7. Personal safety equipment should include the following:

   a. glasses
   b. shoes
   c. long sleeves
   d. gloves

8. Safety feature on the die casting machine can include:

   a. safety bars
   b. screens over the toggle mechanism
   c. double palm buttons
   d. two hydraulic pumps

2 UNDERSTANDING METAL MELTING/ HANDLING FOR OPERATORS

OBJECTIVES

To learn the different alloy systems for die casting alloys.

- To learn about the various elements that makes up the alloy.
- To learn the effects of the various elements on castability and properties.

PERSPECTIVE

There are many different alloys used in die casting today. Aluminum and zinc will be discussed extensively in this lesson.

DIE CASTING ALLOYS

The materials that die castings are made from are alloys of various metals. Alloys are combinations of two or more elements that are mixed together to achieve the mechanical and metallurgical properties required by the casting.

For example, 380 aluminum alloy is part of what is called the aluminum-silicon-copper alloy system. #3 zinc alloy is part of the zinc-aluminum system. The chemistry of the alloys will be discussed later in this lesson. What is of interest to you, the die casting machine operator, is how these alloys freeze and what control you will have on this freezing process. First, let’s discuss how the die casting alloys freeze.

Freezing Behavior

The freezing process with which you are most familiar with is the compound known as water. When water freezes, it freezes at one temperature; 32°F. Pure metals freeze the same way. If water is at room temperature, in order to get it to freeze, you must lower its temperature to 32°F, and then continue to cool it, until it freezes. The temperature verses time graph, shows the freezing behavior of several pure metals that are present in die casting alloys, zinc, aluminum, copper, and silicon. In all cases the various metals freeze at a particular temperature for that metal.

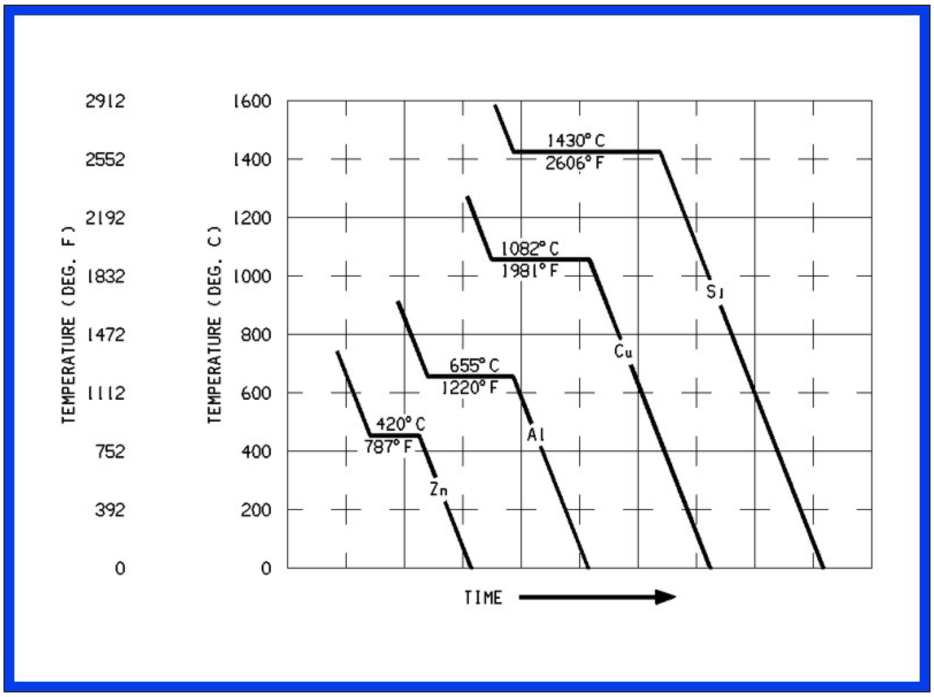


Figure 2-1 - Time vs. temperature graph

Let's expand the example of water freezing, and get more "specific" about what is actually happening. As the water cools, it gives up heat. Heat is a form of pure energy, and as such it has quantity and can be measured. However, heat is not measured directly. A quantity of heat would be measured in BTU or calories. But no one has developed a BTU or calorie meter for measuring heat. Instead, heat is measured indirectly, using temperature.

We have a container with a pound of water in it at room temperature, 70˚F, to which we add 10 BTU of heat energy. What happens to the water? The water warms to 80˚F. In fact, the pound of water warms 1˚F for every BTU that was added. The relationship between the mass or volume of a material and the temperature change due to heat energy is called the "specific heat" of the material. A pound of water has a specific heat of 1 BTU per F˚. In other words, it takes 1 BTU to increase the temperature of a pound of water by 1˚F. This would be written as; the specific heat of water is 1 BTU/lb-˚F. Specific heat may also be related to the volume of a material. (A pound of water is equal to 27.73 cubic inches.) On a volume basis, the specific heat of water is 0.036 BTU/ in^3-˚F.

$$\frac{1 \text{ BTU/lb-°F}}{27.73 \text{ in}^3\text{/lb}} = 0.036 \text{ BTU/in}^3\text{-°F}$$

In die casting we usually make calculations based on the volume of the casting.

This concept of heat flowing into a material, and thereby raising its temperature, and then flowing out and again lowering its temperature is very important to the understanding of die casting materials and the process. *This heat energy related to increasing and decreasing the material's temperature, is known as sensible heat.*

c Alloy	Specific Heat C_p	
	J/cm³-°C	BTU/in³-°F
Mg (AZ91D)	1.850	0.016
Al 360, 380, 384	2.900	0.025
Al 390	2.900	0.025
Zn 12, 27	2.780	0.024
Zn 3,5,7	2.780	0.024
Fe	3.130	0.027
Cu 60/40	3.130	0.027
Cu 85-5-5-5	3.130	0.027
Pb 85-5-5-5	1.450	0.013

Figure 2-2 - Table of specific heats of die casting alloys

Look at the time verses temperature chart. Again, notice that at the freezing temperature for each of the metals, it shows a horizontal line. This means that during the conversion from liquid to solid, heat is given up without any temperature change. This heat energy is known as the latent heat of fusion. For water the heat of fusion is 144 BTU per pound, or 5.19 BTU per cubic inch.

Latent Heat of Fusion Alloy	H1	
	J/cm3	BTU/in3
Mg (AZ91D)	657.0	10.6
Al 360, 380, 384	1447.0	22.5
Al 390	1705.0	26.5
Zn 12, 27	908.0	14.1
Zn 3,5,7	682.0	10.6
Fe	773.0	12.0
Cu 60/40	1391.0	21.6
Cu 85-5-5-5	1391.0	21.6
Pb 85-5-5-5	258.0	4.0

Figure 2-3 - Table of heats of fusion

When most alloys freeze, the time verses temperature chart, is slightly different than that for pure metals and compounds.

There is one combination of an alloy mixture that behaves like a pure metal, this is known is the **eutectic** alloy mixture. The solidification curves for various aluminum alloys are shown in the alloy time verses temperature chart. For most alloys the time verses temperature chart shows a freezing range. The amount of this freezing range varies depending on the alloy.

Alloy	°F	°C
A360, 360	1035-1105	557-596
A380, 380	1000-1100	540-595
383, 384	960-1080	516-582
390	950-1200	510-650
AZ91D	875-1105	470-595
Zn 3,7	718-728	381-387
ZN 5	717-727	380-386
ZA-12	710-810	377-432
ZA-27	708-903	375-484

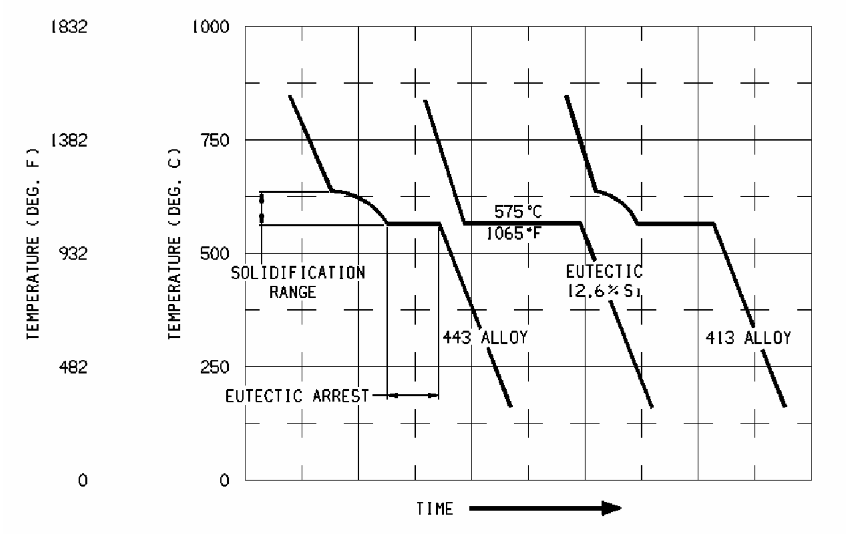


Figure 2-4 - Chart of freezing ranges for various die casting alloys

Heat in the alloy

It is important for you as a diecaster to know how much heat is in the alloy so you will know how much heat has to be processed by the die. Let's determine the amount of heat in a cubic inch of zinc at the casting temperature and the amount of heat that must be processed in the die casting die. The steps needed to calculate the heat input into the alloy to melt it and the heat given up by the die are as follows:

1. Heat input to alloy. ($Q_{TOT} = Q_1 + Q_2 + Q_3$)
   - Q_{TOT} Heat to increase alloy from room temperature to holding furnace temperature.
   - Q_1 Heat to increase alloy to beginning melting temperature (solidus).
   - Q_2 Heat to convert solid alloy to liquid alloy.
   - Q_3 Heat to increase alloy from complete liquid temperature to holding furnace temperature (liquidus).

2. Heat lost in transfer to die.

3. Heat input to the die. ($Q_{DIE} = Q_1 + Q_2 + Q_3$)
   - Q_1 Superheat lost to die.
   - Q_2 Heat lost converting from liquid to solid.
   - Q_3 Heat given up to the die until ejection.

4. Heat given up to quench or atmosphere (Q_Q).

For example, calculate the various amounts of heat inputs and losses given the following information.

For #3 zinc alloy:

Specific heat = 0.024 BTU/in^3-°F

Latent heat of fusion = 10.6 BTU/in3

Room temperature = 70°F

Holding furnace temperature = 800°F

Alloy injection temperature = 780°F

Casting ejection temperature = 550°F

Beginning melting temperature = 718°F (liquidus)

Ending melting temperature = 728°F (solidus)

Quantity of alloy = 1 in^3

1. (a). Heat to increase alloy to beginning melting temperature.

   Q_1 = Sensible heat

   Sensible heat is the product of the amount of alloy specific heat and temperature change.

   Q_1 = (volume of alloy) (specific heat) (temperature change)

   = (1 in^3) (0.024 BTU/in^3-°F) (718 - 70°F)

   = 15.55 BTU

1. (b). Heat to convert solid alloy to liquid alloy plus heat to change temperature from the beginning melting temperature to the ending melting temperature.

   Q_2 = Sensible heat + Latent heat

   = (1 in^3) (0.024 BTU/in^3-°F) (728 - 718°F) + 10.6 BTU

   = 0.24 + 10.6

   = 10.84 BTU

1. (c). Heat to increase liquid alloy to holding furnace temperature.

   Q_3 = Sensible heat

   = (1 in^3) (0.024 BTU/in^3-°F) (800 - 728°F)

   = 1.73 BTU

The total heat to increase a cubic inch of zinc from room temperature to the holding furnace temperature is the sum of 1a to 1c, or 28.12 BTU.

$Q_{TOT} = Q_1 + Q_2 + Q_3$

$Q_{TOT} = 15.55 + 10.84 + 1.73 = 28.12$ BTU

2. Heat lost in transfer of alloy from furnace to die.

Q (amount of heat) = (volume of alloy) (specific heat) (temperature change)

= (1 in^3) (0.024 BTU/in^3-°F) (780 - 800°F)

= -0.48 BTU

3. (a). Superheat lost to die.

Q_1 = (volume of alloy) (specific heat) (temperature change)

= (1 in^3) (0.024 BTU/in^3-°F) (728 - 780°F)

= -1.25 BTU

3. (b). Heat lost converting from liquid to solid.

Q_2 = Sensible heat + Latent heat

= (1 in^3) (0.024 BTU/in^3-°F) (718 - 728°F) + (-10.6 BTU)

= -0.24 + (-10.6)

= -10.84 BTU

3 (c). Heat given up to the die until ejection.

Q_3 = Sensible heat

= (1 in^3) (0.024 BTU/in^3-°F) (550-728°F)

= 4.27 BTU

The total heat, Q_{DIE} , given up to the die is the sum of items Q_1, Q_2 and Q_3, or 16.36 BTU.

$Q_{DIE} = 1.25 + 10.84 + 4.27 = 16.36$ BTU Heat input to the die.

4. Finally, the heat lost to the quench is: Q_Q

Q_Q = Sensible heat

= (1 in^3) (0.024 BTU/in^3-°F) (70 - 550°F)

= -11.52 BTU

With the assumptions of this example, 16.36 BTU are input to the die for every cubic inch of zinc, every cycle.

ALUMINUM 360 EXERCISE

Calculate the various amounts of heat inputs and losses for a cubic inch of 360 aluminum alloy. Follow the steps shown in the previous zinc example.

For 360 aluminum alloy:

Specific heat = 0.025 BTU/in^3-°F

Latent heat of fusion = 22.5 BTU/in^3

Room temperature = 70°F

Holding furnace temperature = 1200°F

Alloy injection temperature = 1175°F

Casting ejection temperature = 700°F

Beginning melting temperature = 1035°F

Ending melting temperature = 1105°F

Quantity of alloy = 1 in^3

ANSWER TO ALUMINUM 360 EXERCISE

1. (a). Heat to increase alloy to beginning melting temperature.

Q_1 = Sensible heat

Q_1 = (volume of alloy) (specific heat) (temperature change)

= (1 in^3) (0.025 BTU/in^3-°F) (1035 - 70°F)

= 24.12 BTU

1. (b). Heat to convert solid alloy to liquid alloy plus heat to change temperature from the beginning melting temperature to the ending melting temperature.

Q_2 = Sensible heat + Latent heat

= (1 in^3) (0.025 BTU/in^3-°F) (1105 - 1035°F) + 22.5 BTU

= 1.75 + 22.5

= 24.25 BTU

1. (c). Heat to increase liquid alloy to holding furnace temperature.

Q_3 = Sensible heat

= (1 in^3) (0.025 BTU/in^3-°F) (1200 - 1105°F)

= 2.38 BTU

The total heat to increase a cubic inch of aluminum from room temperature to the holding furnace temperature is the sum of Q_1 to Q_3, or 45.25 BTU.

24.12 + 24.25 + 2.38 = 50.75 BTU

2. Heat lost in transfer of alloy from furnace to die.

   Q(amount of heat)

   = (volume of alloy) (specific heat) (temperature change)

   = (1 in^3) (0.025 BTU/in^3-°F) (1175 - 1200°F)

   = -0.62 BTU

3. (a). Superheat lost to die.

   Q_1 = (volume of alloy) (specific heat) (temperature change)

   = (1 in^3) (0.025 BTU/in^3-°F) (1105 - 1175°F)

   = -1.75 BTU

3. (b). Heat lost converting from liquid to solid.

   Q_2 = Sensible heat + Latent heat

   = (1 in^3) (0.025 BTU/in^3-°F) (1035 - 1105°F) + 22.5 BTU

   = -1.75 + (-22.5)

   = -24.25 BTU

3. (c). Heat given up to the die until ejection.

   Q_3 = Sensible heat

   = (1 in^3) (0.025 BTU/in^3-°F) (700-1035°F)

   = -8.38 BTU

The total heat, QTOT, given up to the die is the sum of items Q_1, Q_2 and Q_3, or 34.38 BTU.

   Q_{TOT} = 1.75 + 24.25 + 8.38= 34.38 BTU, Heat input to the die.

4. Finally, the heat lost to the quench is:

   Q_Q = Sensible heat

   = (1 in^3) (0.025 BTU/in^3-°F) (70 - 700°F)

   = -15.75 BTU

With the assumptions of this example, 34.38 BTU are input to the die for every cubic inch of aluminum, every cycle.

ALTERNATE EXERCISE

Calculate the various amounts of heat inputs and losses for a cubic inch of AZ91D magnesium alloy. Follow the steps shown in the previous zinc example.

For AZ91D magnesium alloy:

Specific heat = 0.016 BTU/ in^3-°F

Latent heat of fusion = 10.6 BTU/in^3

Room temperature = 70°F

Holding furnace temperature = 1250°F

Alloy injection temperature = 1200°F

Casting ejection temperature = 600°F

Beginning melting temperature = 875°F

Ending melting temperature = 1105°F

Quantity of alloy = 1 in^3

ANSWER TO AZ91D MAGNESIUM EXERCISE

1. (a). Heat to increase alloy to beginning melting temperature.

Q_1 = Sensible heat

Q_1 = (volume of alloy) (specific heat) (temperature change)

= (1 in^3) (0.016 BTU/in^3-°F) (875 - 70°F)

= 12.88 BTU

1. (b). Heat to convert solid alloy to liquid alloy plus heat to change temperature from the beginning melting temperature to the ending melting temperature.

Q_2 = Specific heat + Latent heat

= (1 in3) (0.016 BTU/in3-°F) (1105 - 875°F) + 10.6 BTU

= 3.68 + 10.6

= 14.28 BTU

1. (c). Heat to increase liquid alloy to holding furnace temperature.

Q_3 = Sensible heat

= (1 in^3) (0.016 BTU/in^3-°F) (1250 - 1105°F)

= 2.32 BTU

The total heat to increase a cubic inch of aluminum from room temperature to the holding furnace temperature is the sum of Q_1 to Q_3, or 29.48 BTU.

12.88 + 14.28 + 2.32 = 29.48 BTU

2. Heat lost in transfer of alloy from furnace to die.

Q(amount of heat)

= (volume of alloy) (specific heat) (temperature change)

= (1 in^3) (0.016 BTU/in^3-°F) (1200 - 1250°F)

= -0.80 BTU

3. (a). Superheat lost to die.

Q_1 = (volume of alloy) (specific heat) (temperature change)

= (1 in^3) (0.016 BTU/in^3-°F) (1105 - 1200°F)

= -1.52 BTU

3. (b). Heat lost converting from liquid to solid.

Q_2 = Sensible heat + Latent heat

= (1 in^3) (0.016 BTU/in^3-°F) (875 - 1105°F) + 10.6 BTU

= -3.68 + (-10.6)

= -14.28 BTU

3. (c). Heat given up to the die until ejection.

Q_3 = Sensible heat

= (1 in^3) (0.016 BTU/in^3-°F) (600-875°F)

= -4.40 BTU

The total heat given up to the die is the sum of items Q_1, Q_2 and Q_3, or 20.20 BTU.

Q_{TOT} = 1.52 + 14.28 + 4.40 = 20.20 BTU, Heat input to the die.

4. Finally, the heat lost to the quench is:

Q = Sensible heat

= (1 in^3) (0.016 BTU/in^3-°F) (70 - 600°F)

= -8.48 BTU

With the assumptions of this example, 20.20 BTU are input to the die for every cubic inch of aluminum, every cycle.

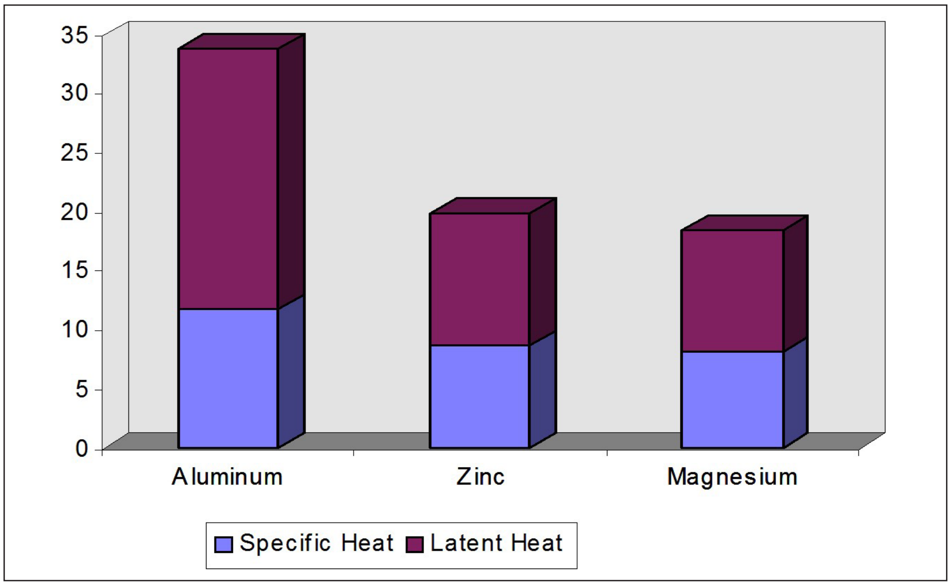


Figure 2-5 - Chart of typical die cast alloy heat load bar graphs

The example and exercises illustrate the differences in heat load of the various alloys. This will be significant to the operator if you are in a plant that runs different alloys because they behave quite differently. The first big difference is the varying amount of heat that they input into the casting die.

Shrinkage

The next big difference is how they freeze. Remember the freezing range for the zinc was 718-728°F, for the aluminum it was 1035-1105°F, and for the magnesium it was 875-1105°F. Once the die is full of metal and the metal begins to freeze, it also shrinks. Shrinkage means that as the casting solidifies, the solid material occupies less space than the liquid material.

The next time you pass the furnace, take a look at the ingots stacked there. Turn the ingot over and look at the top; this is the wide side where the alloy was poured into the ingot mold. The top of the ingot will have a sink or a crack in the middle of it. The metal tender poured the mold full of metal. This cracking and sinking occurred as the alloy was freezing and shrinking.

Figure 2-6 - Top of ingot and cross section showing cracks

This cracking and voids can also occur in a die casting. As the casting freezes, it shrinks, and cracks and voids form, unless high pressure is applied to force more alloy into the die. This shrinkage is one of the reasons the machines apply the high pressure, intensification or prefill, at the end of the shot stroke. If the shrinkage is not controlled, the casting will have internal porosity due to shrinkage or a void or crack at the casting surface if the shrinkage breaks through to the surface. This defect will occur at the last place to freeze, or at a hot spot in the die.

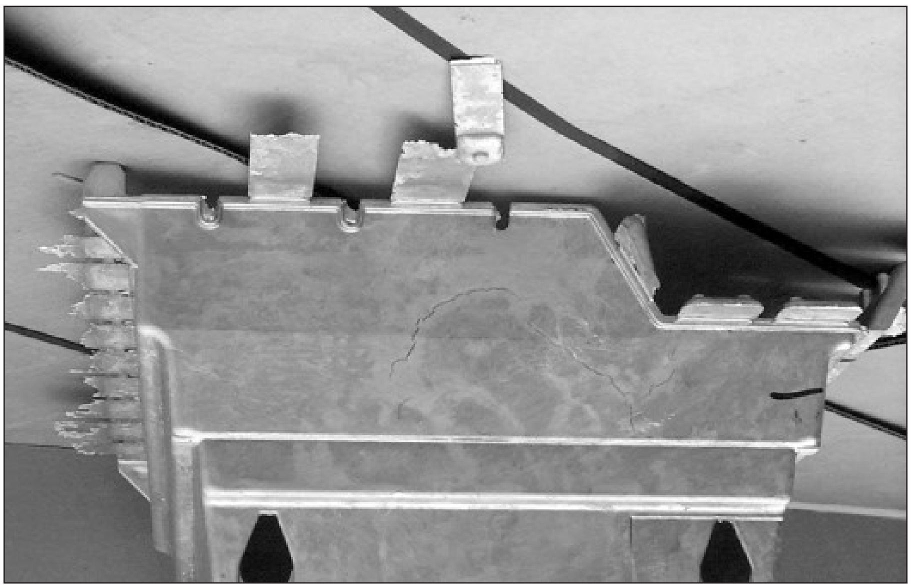


Figure 2-7 - Shrink crack and/or shrink porosity

If you can control the freezing of the casting, you can control shrinkage defects. Ideally, the casting would freeze from the overflows and vents, across the casting, to the gate, runner, and biscuit. In practice this is rarely achieved, but the operator can influence quite a bit by controlling cooling lines and by how die release is applied.

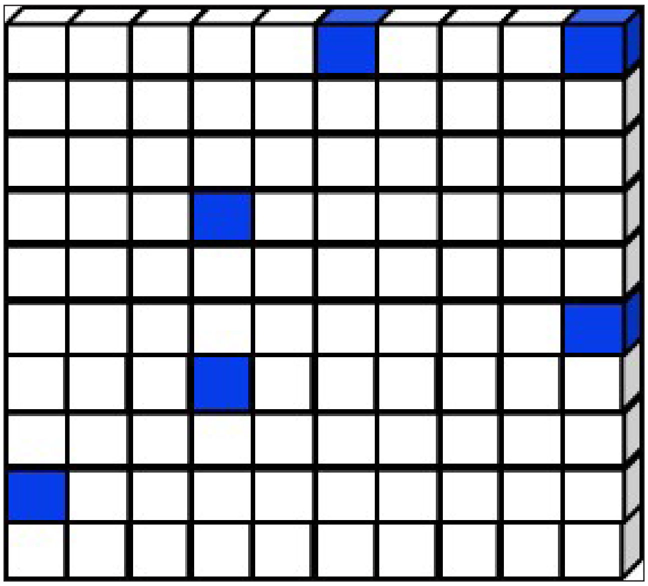


Figure 2-8 - Pictorial, showing 6% voids

The chemistry of the alloy is also a significant factor in the amount of shrinkage that can occur. Pure aluminum shrinks about 6.6%. However, with the addition of silicon to make an alloy, the shrinkage can be reduced to 3.8% at the eutectic mixture of about 12% silicon in aluminum. Magnesium shrinks about 4% and zinc about 6%. #3 zinc alloy with approximately 4% aluminum in it shrinks 2.98%. If a property of a casting is pressure tightness, a material with low shrinkage should be selected.

Material	**Solidification Shrinkage, % β**
Aluminum	6.6 (1); 6.5 (2)
Al-4.5% Cu	6.3 (1)
Al-12% Si (Eutectic)	3.8 (1)
Copper	4.9 (1); 4.2 (2)
70% Cu-30% Zn	4.5 (1)
90% Cu-10% A	4.0 (1)
Lead	3.5 (2)
Magnesium	4.2 (1); 4.1 (2)
Tin	2.3 (2)
Zinc	6.5 (1); 4.7 (2)
Zn-4% Al	2.98 (3)

Figure 2-9 - Solidification shrinkage of various materials

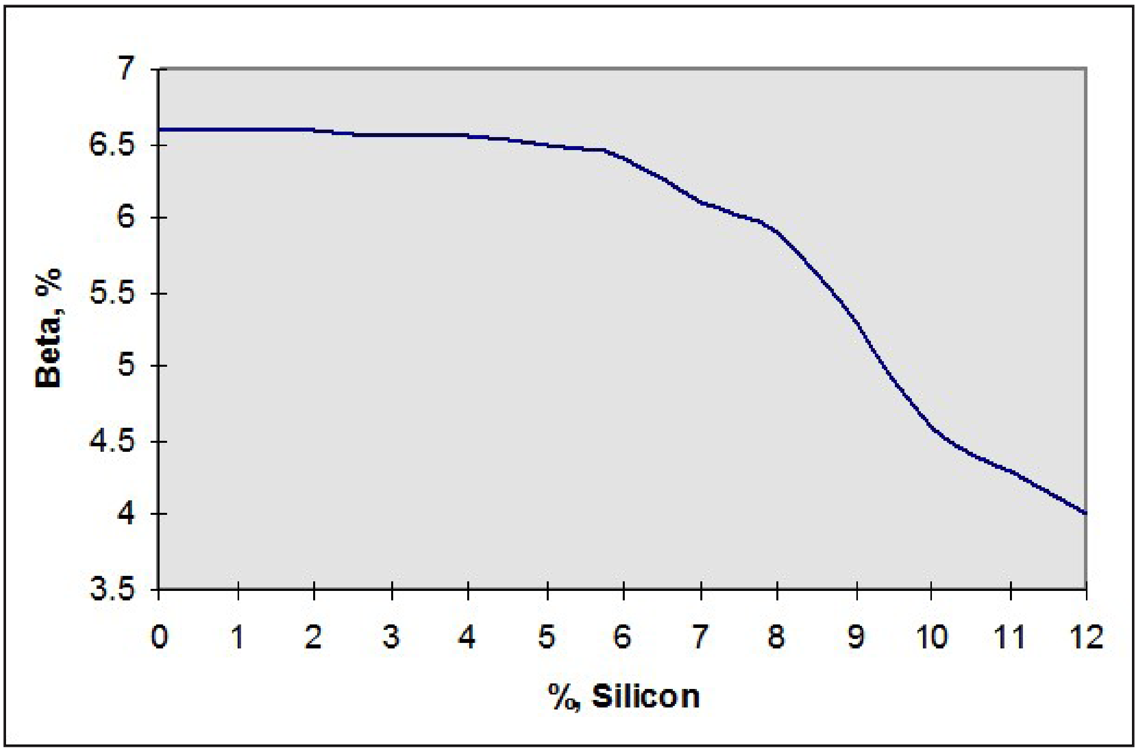


Figure 2-10 - Solidification shrinkage is a function of the silicon content

Solidification shrinkage should not be confused with dimensional changes that occur after the casting has been ejected from the die. If a solid metal is heated it usually expands, and as it cools, it contracts. These changes are predictable by the laws governing thermal expansion.

Thermal Conductivity

Thermal conductivity is another material property that is important for the die cast operator to understand. This is the property of a material that describes the material's ability to conduct heat. Materials that have high values of thermal conductivity transfer heat readily. Materials such as aluminum and copper have high valves of thermal conductivity. A material such as glass is not a good thermal conductor. The thermal conductivity of the various die casting alloys will control how easily they will give up their heat to the casting die once they have solidified. Of the common die casting alloys, the zinc alloys have the best thermal conductivity, ranging from 60.5 BTU/ft-hr-°F for Zamak #2 to 72.5 BTU/ft- hr-°F for ZA-27. The aluminum alloys range from 55.6 BTU/ft- hr-°F for 380 aluminum to 82.2 BTU/ft- hr-°F for 443 aluminum. The magnesium alloys have considerably less thermal conductivity at 35 BTU/ft- hr-°F for AM20 to 41.8 BTU/ft- hr-°F for AZ91D.

SELF TEST 1

True or False

1. Pure metals freeze at constant temperature.

   True False

2. Most die casting alloys exhibit a temperature freezing range.

   True False

3. "Latent heat of fusion" is the energy given up when a material changes from liquid to solid.

   True False

Multiple choice - Identify all the correct answers:

4. When alloy is melted two types of heat energy are put into the alloy, they are:

   a. superheat
   b. sensible heat
   c. radiant heat
   d. latent heat of fusion

5. Among the three common die casting materials, the one that puts the most heat into the die is:

   a. aluminum
   b. magnesium
   c. zinc
   d. none of the above

6. "Shrinkage" of the alloy means:

   a. the casting is undersize
   b. the casting is deteriorating due to moisture
   c. reduced volume due to conversion from liquid to solid
   d. voids on the surface due to corrosion

DIE CAST ALLOY CHEMISTRY

The chemistry of the alloy can have a big affect on castability. It is important for the operator to be aware of this and understand how it works. The term chemistry means the elements in the alloy and the amounts of the various elements in the alloy. This lesson explains the chemistry of the most popular die cast alloys, aluminum and zinc, what can change the chemistry and how that can affect the casting process.

Aluminum Alloy Systems

Commercial:	360.000	A380
ANSI/AA:	360.000	A380.0
Nominal Comp	Mg 0.5	Cu 3.5
	Si 9.5	Si 8.5
Silicon (Si)	9.0-10.0	7.5-9.5
Iron (Fe)	2.000	1.300
Copper (Cu)	0.600	3.0-4.0
Manganese (Mn)	0.350	0.500
Magnesium (Mg)	0.4-0.6	0.100
Nickel (Ni)	0.500	0.500
Zinc(Zn)	0.500	3.000
Tin (Sn)	0.150	0.350
Titanium (Ti)	-	-
Aluminum (Al)	balance	balance

Figure 2-11 - Common aluminum alloys and chemical constituents

As has been noted previously, alloys are mixtures of various metals. The aluminum alloys that are used for die casting fall into four alloy systems. The alloy system is determined by the main alloying ingredient or ingredients. The alloys and systems for aluminum are:

443, 413	Aluminum-Silicon system
380, 383, 384	Aluminum-Silicon-Copper system
360, 364	Aluminum-Silicon-Magnesium system
518	Aluminum-Magnesium system

Aluminum is one of the most significant base metals for die casting alloys. This group of alloys provides a wide range of physical and chemical properties, and can be manufactured efficiently.

Die casting alloys contain controlled concentrations of impurities, along with the alloying elements, this is not only tolerable but also desirable to minimize soldering and increase hot strength. The effects of impurities are generally the same on all aluminum base alloys.

Aluminum-Silicon Alloys

For the die casting process, silicon is the most important element to be combined with aluminum since it imparts more than any other element, the desired casting characteristics demanded by the die casting process. Of greatest significance is the progressive increase in fluidity.

As an element with a relatively high melting point, it is extremely hard and brittle. Silicon increases the hot strength of the casting, or conversely, decreases its hot cracking tendencies. Hot strength is the ability to develop mechanical strength quickly at temperatures just below the solidus (lowest freezing temperature). This characteristic is important for castings that must cool in rigid dies and in facilitating ejection from the die at high temperature associated with fast production rates.

During solidification, alloys containing silicon undergo a smaller volume change than the 6.6% for pure aluminum. The greater the silicon content, the more this shrinkage is reduced. If aluminum-silicon alloys are used, it is easier to produce castings free of internal shrinkage and shrinkage cracks. The minimization of internal shrinkage voids and the improvement of hot strength imparted by the higher silicon content is extremely important in the production of pressure tight castings.

Since silicon is less dense than aluminum, 0.084 lbs/in3 verses 0.097 lbs/in3, increasing the silicon content will reduce the specific gravity of the alloy.

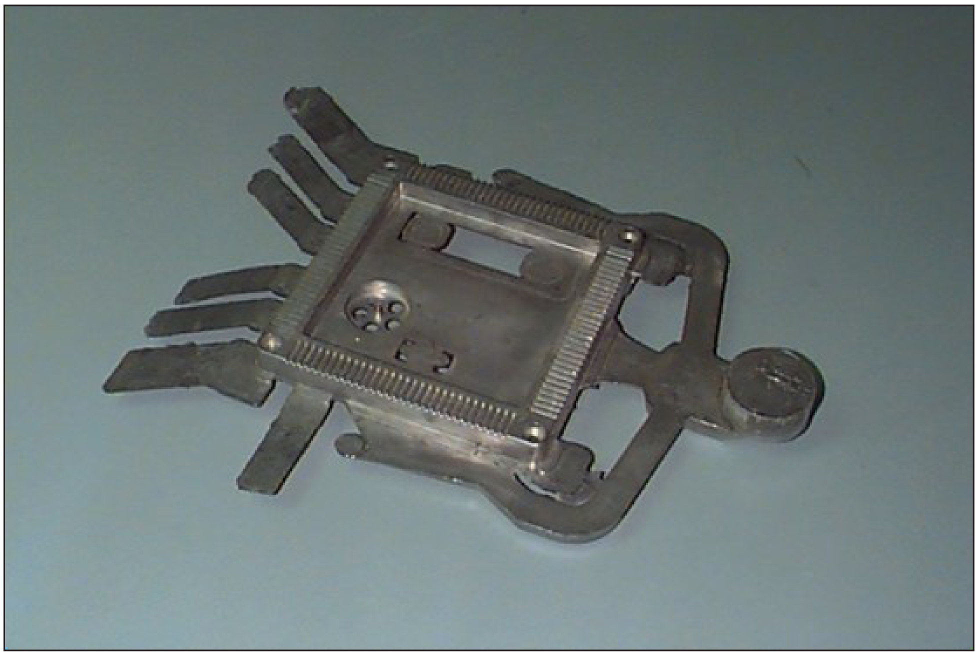


Figure 2-11(a) - Typical Al-Si castings (413 Alloy)

Aluminum-Silicon-Copper Alloys

The most widely used aluminum base alloy in die casting is the ternary alloy of aluminum, silicon and copper, A380/380. From the die casters point of view 380 exhibits the best overall combination of foundry characteristics.

The addition of copper to the aluminum-silicon alloy will add to the strength and hardness of the alloy, particularly the hot strength. This additional strength improves the alloy properties at elevated temperatures.

The addition of copper moderately reduces fluidity of the alloy.

As the amount of copper in the alloy increases, the corrosion resistance of the alloy is reduced. Generally, aluminum alloys have very good corrosion resistance compared to other alloys. For superior corrosion resistance a copper specification of 0.60% maximum is recommended. This is the typical specification for alloys 443, and 360. The copper limit for 413 alloy is 1.0% maximum. There is a consensus that this level of copper enhances pressure tightness.

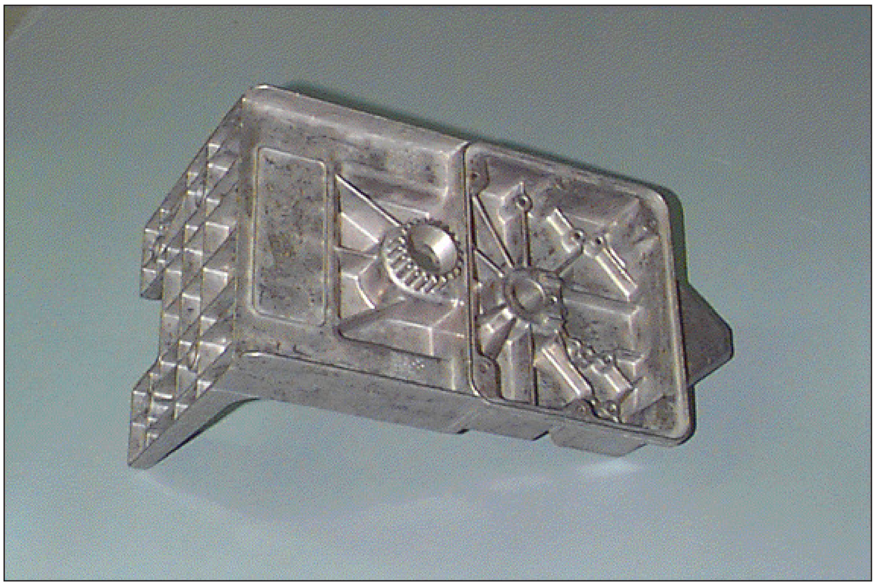


Figure 2-11(b) - Typical Al-Si-Cu castings (380 Alloy)

Aluminum-Silicon-Magnesium Alloys

This system includes several alloys that are important for die casting applications that demand superior corrosion resistance, strength, and ductility.

The most common die casting alloy in this series is 360 alloy. Two dominant characteristics are good ductility and the ability to produce pressure tight castings. Because of the low copper content, 360 alloy has excellent corrosion resistance. The die filling characteristics of 360 alloy are essentially equal to 380 alloy and it exhibits excellent resistance to hot cracking.

364 alloy represents a somewhat improved version of 360 alloy with higher ductility, superior corrosion resistance, and good casting characteristics. It differs from 360 alloy having a lower copper maximum of 0.20%. Chromium is controlled to 0.25-0.50% and the alloy has a beryllium addition of 0.02-0.04%. The beryllium is added to inhibit the oxidation of magnesium and the chromium is added to assist in changing the iron constituent. As a result greater ductility is achieved. Because of the low copper content, the alloys in this group may not machine as well as the 380 type alloys.

Impurities in Aluminum Die Casting Alloys

Iron

Iron is a natural impurity in aluminum, and is generally present in lower concentrations than found in die casting alloys. Small amounts of iron increase strength and hardness. Iron in controlled amounts, adds to the hot strength and reduces the tendency to hot cracking.

An important factor about iron is that it retards the attack of aluminum on iron and steel. With iron content controlled in the range 0.7-1.2% in aluminum alloys, the solvent action on melting pots and welding (soldering) to steel dies is minimized.

Zinc

Zinc content up to 3% is acceptable for 380 alloys. The zinc has little affect on the casting properties except a slight change in density.

If excessive amounts of zinc get into the aluminum alloy, well above the 3% maximum specification a serious problem with hot shortness or hot cracking in the die will occur.

Magnesium

In 413 and 380 alloys the specification restricts magnesium to 0.10%. At this level the magnesium has no affect on the properties of the alloy.

As magnesium content is increased, yield strength, hardness, and stiffness increase, and fluidity decreases. The lower the magnesium content, particularly in the presence of silicon, the more ductile a given alloy will be.

Chromium and Manganese

Chromium and Manganese have the beneficial affect of changing the microstructure of iron in the alloy. The needlelike structure of the iron is modified and this iron structure improves ductility and impact strength. These elements also improve the tensile properties of the alloy.

Bismuth, Cadmium, Lead, and Tin

Concentrations of these alloys in excess of the specification will result in hot cracking and excessive drossing.

Nickel

Nickel is not a serious contaminant in die casting alloys and most specifications allow 0.50%.

Phosphorus, Sodium, Calcium, Strontium

These elements are seldom encountered in die casting alloys since they chemically react with chlorine during fluxing. They also evaporate (sublime) and oxidize readily when the surface oxide film is broken on the molten alloy during holding, transferring and remelting. These elements are limited to a maximum of 0.1% each.

Titanium

As found in die casting alloys, titanium is considered to have the same effect as iron. Its concentration is limited to 0.1% maximum.

Hydrogen

The role of hydrogen in aluminum die casting alloys is widely misunderstood. In the die casting process, hydrogen in controlled amounts is of little consequence, if any. Molecular hydrogen (H_2) is insoluble in liquid or solid aluminum. Ionized hydrogen (H^+) has very little solubility in liquid aluminum at temperatures below 1200°F. As a consequence, normal holding temperatures of 1200°F preclude the absorption of hydrogen in the alloy even if the ionized hydrogen is available.

Oxygen

By the strict definition of impurities, oxygen must be considered the most serious contaminant encountered in aluminum die casting. Oxygen has a very high affinity for aluminum; forming aluminum oxide (Al_2O_3). Aluminum is a very active metal. Its behavior is stabilized by its ability to rapidly form an oxide skin.

Most metal losses occur during metal transfer operations. Metal transfer should be accomplished with a minimum of disturbing the alloy, pouring should be done from minimum heights and troughs should be as short as possible. Increasing oxide content reduces fluidity and also could cause excessive tool wear during machining operations.

Sludging (Fe-Mn-Cr)

Iron, manganese, and chromium, all available in aluminum die casting alloys, form complex intermetallic compounds possessing extreme hardness and high melting points.

If present in aluminum alloys in sufficient amounts, primary crystals of these elements precipitate from the alloy solution. These crystals have a higher specific gravity than the alloy and sink to the bottom of the alloy bath. Once the crystals combine chemically to form complex intermetallic compounds they acquire high melting points and are difficult to re-dissolve into the alloy solution. Finally, they gather together at the bottom of the furnace and form a sand or sludge.

Studies on segregation in aluminum melts have shown manganese to be a very powerful agent in the formation of sludge. Chromium has an even stronger influence. Fortunately, it is only found in small concentrations in secondary alloys. Sludge is formed at various holding furnace temperatures depending on the concentration of iron, manganese and chromium. For example, if a melt of alloy at 1400°F containing 1% of iron and manganese is allowed to cool to 1200°F and maintained still, it will form sludge.

One way to control sludge is to specify the alloy to have a minimum of the sludge forming elements. A formula commonly used to express the maximum of these elements is:

% iron + 2 x % manganese + 3 x % chromium = 1.80 max.

If this sludge finds its way into the die casting, it will cause machining problems. In addition to a problem with sludge inclusions in the casting, aluminum alloys that have sludge experience a decrease in iron content. If the alloy originally was 0.8-1.0% iron, the iron content could be as low as 0.5-0.6% after sludging has occurred. Once this iron reduction has occurred, the metal has a strong tendency to solder to the die. If a die exhibits an unusually high amount of soldering, it may be advisable to have the alloy bath chemically analyzed for iron to insure that it has not sludged down to a dangerous level.

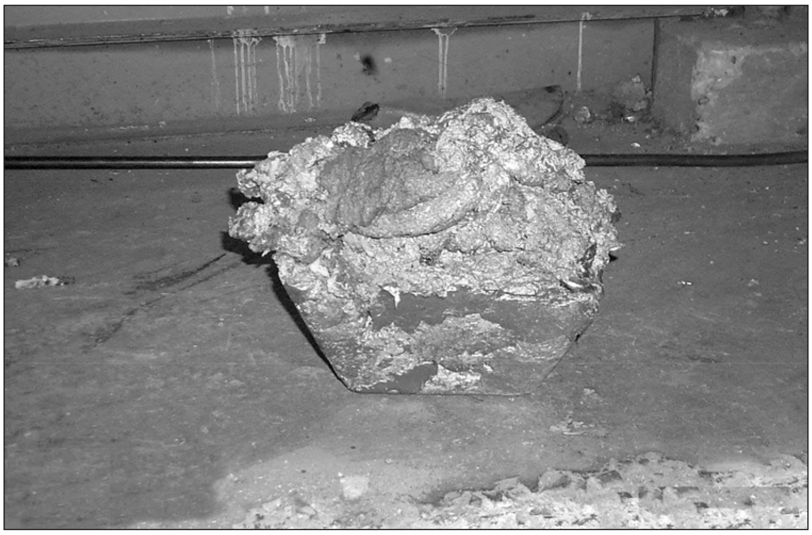


Figure 2-12 - Sludge

When sludging is encountered it is somewhat practical to superheat the bath 100-150°F above the holding furnace temperature and stir the bath with some vigor. It should then be allowed to sit quietly for settling as it cools back to a normal casting temperature. Much of the sludge will have been re-dissolved. The sludge that settles out should then be raked from the bottom and discarded. If allowed to build up it will become somewhat like a refactory material and impair the thermal efficiency of the furnace.

Since sludge forms when the concentrations of the sludge forming elements are high and the furnace temperature is low, or varies from high to low, one way to avoid sludge formation is to maintain as uniform a furnace temperature as possible. This can be accomplished by charging small amounts of alloy frequently or continuously.

Zinc Alloy Systems

The alloys that are used for die casting fall into three alloy systems. The alloys and systems are:

No.3	Zinc-Aluminum System
No.2, No.5, ZA-8,	Zinc-Aluminum-Copper System
ZA-12, ZA-27	
No.7	Zinc-Aluminum-Nickel System

Zinc die casting alloys probably represent the highest degree of purity of any metals used in comparable commercial quantities. If certain types of impurities are exceeded, this can lead to a catastrophic defect known as intergranular corrosion.

Commercial:	**No. 3**	**ZA-8**
Nominal Comp	**Al 4.0**	**Al 8.4**
	Mg 0.035	**Mg 0.023**
		Cu 1.0
Aluminum (Al)	3.5-4.3	8.0-8.8
Magnesium (Mg)	0.02-0.05	0.015-0.030
Copper (Cu)	0.25 max	0.8-1.3
Iron (Fe)	0.100	0.075
Lead (Pb)	0.005	0.006
Cadium (Cd) max	0.004	0.006
Tin (Sb) max	0.003	0.003
Nickel (Ni)	-	-
Zinc (Zn)	balance	balance

Figure 2-13 - Chart of zinc alloys and chemical constituents

Intergranular corrosion is a phenomenon in which impurities such as arsenic, bismuth, calcium, indium, lead, mercury, selenium, sodium, tantalum, thallium, thorium, tin, and tungsten can migrate to the grain boundaries and under conditions of warmth and humidity the impurities are subject to chemical attack resulting in subsurface intergranular corrosion. When this occurs, there is first a swelling effect at the grain boundary and then a fracturing of the casting. Most of these impurities are rarely encountered in zinc alloys today and only lead (0.005%), cadmium (0.004%), and tin (0.003%) are enumerated in the alloy specifications.

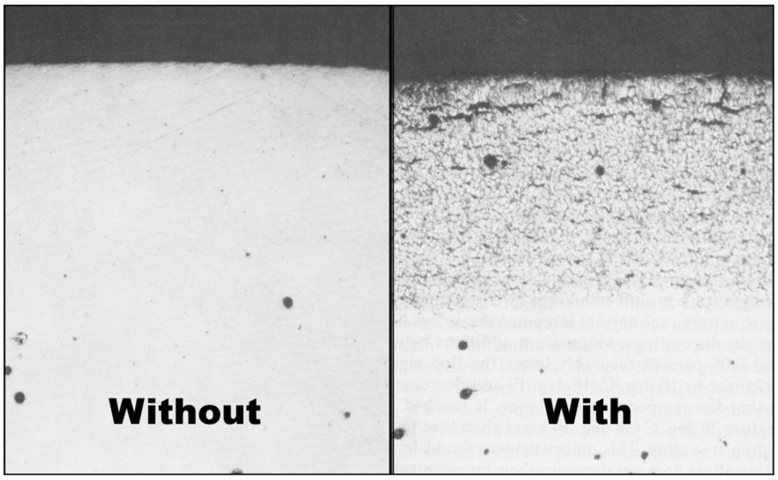


Figure 2-14 - Intergranular corrosion

Pure zinc (99.990% pure) permits the use of minimal magnesium. Magnesium is present in all the zinc alloys. In concentrations up to 0.05%, its main role is to act as a scavenger to collect and tie up the various elements, which induce intergranular corrosion. If the lead, cadmium, and tin are at or below their alloy specification levels, magnesium as low as 0.02% is adequate to prevent intergranular corrosion. Greater concentrations of magnesium, more than 0.05%, will result in hot shortness, low ductility, and poor fluidity.

Solidification shrinkage for pure zinc is 7.28% (greater than the 6.6% for aluminum). For No. 3 alloy the solidification shrinkage is 2.98%. Depending on the alloy, it may be important to avoid heavy cross-sections, and use uniform walls and employ metal savers wherever possible.

Zinc-Aluminum System

Zinc with 5.0% aluminum has a melting point of 720˚F. No.3 alloy is known as a hypoeutectic alloy because the amount of aluminum in it is less than 5.0%. The specification for No.3 is 3.5-4.3%. This same specification applies to alloys No.2, 5 and 7.

Properties

At the eutectic combination, fluidity is at its best. Zinc alloys have excellent fluidity. Intricate details can be produced on castings and very good surface finishes can be achieved. Under the proper conditions, these surfaces can be plated with little or no preparation.

Another critical property is impact strength. Impact strength drops substantially as the Zn-Al combination approaches the eutectic composition. Test data shows that the aluminum content should not exceed 4.25% for the best hypoeutectic die casting alloy composition. Another factor affecting impact strength is temperature. Zinc alloy makes a transition from a brittle material at sub-zero temperatures to a ductile material at room temperature. A brittle material is one having low impact strength verses a ductile material that has high impact strength. It should be noted that the impact strength of zinc at low temperatures (when it is brittle) is comparable to aluminum and magnesium castings.

Aging

Some dimensional change occurs in zinc alloys due to the decreasing solid solubility of the alloying constituents. Aging changes to castings that are air cooled range from 0.0007 in/in for No.3 alloy to 0.0009 in/in for No.5 alloy. For water quenched castings, the maximum expected shrinkage will be as much as 0.0011 in/in. Approximately 2/3 of this shrinkage occurs within a month after the castings are made and the balance of shrinkage occurs over years. To achieve dimensional stability, annealing treatments at relatively low temperatures can be used. Castings given aging treatments usually exhibit 1/3 additional shrinkage compared to untreated castings.

Zinc-Aluminum-Copper System

Small quantities of castings are produced from No. 5 alloy. This has an addition of up to 1.0% copper maximum. The purpose of this addition is to give added hardness and strength. No. 5 alloy is commonly used for small and intricate lock components. This copper addition reduces ductility and impact strength.

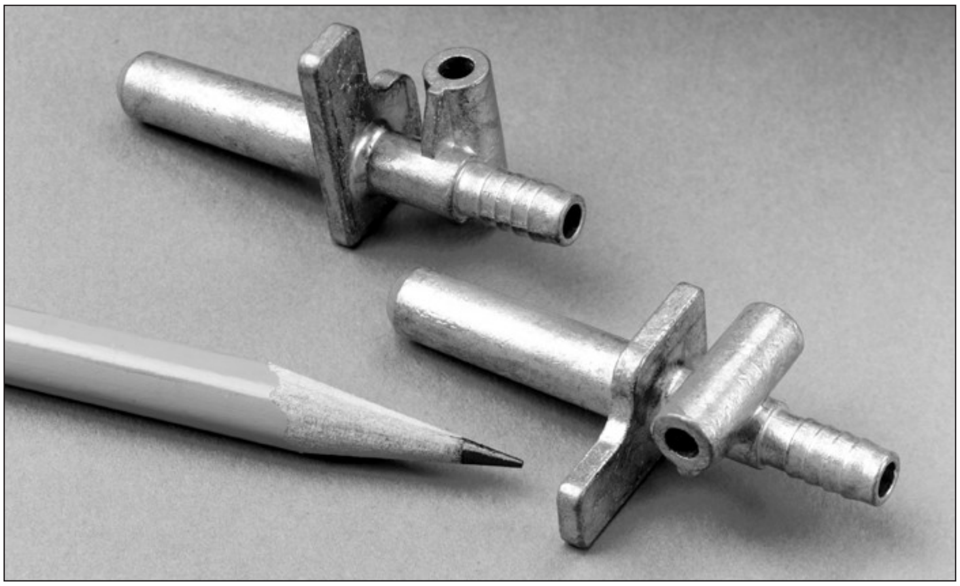


Figure 2-15(a) - Small zinc castings

No. 2 alloy has a copper specification of 2.5-3.0%. Again the additional copper has the affect of increasing hardness and strength, and reducing ductility and impact strength beyond that of the No.5 alloy. This alloy was primarily specified for gear castings and is used in stamping dies.

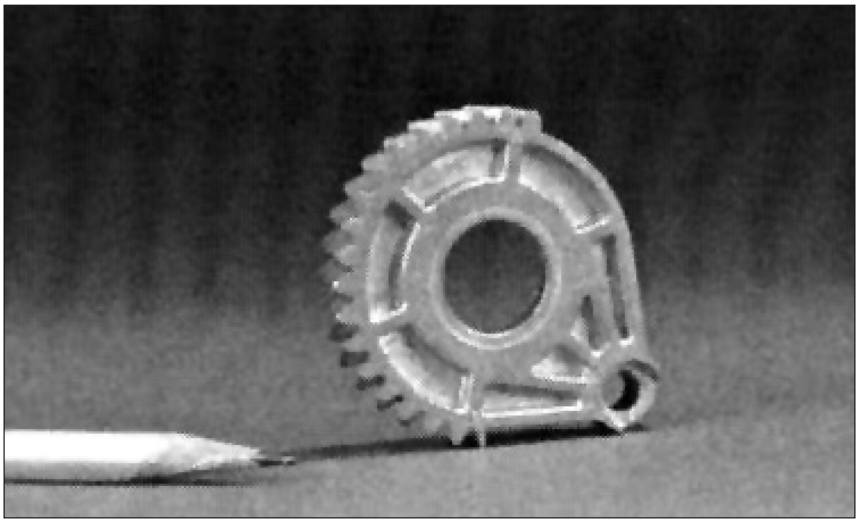


Figure 2-15(b) - Zinc gear castings

The hypereutectic alloys ZA-8, ZA-12, and ZA-27 are relatively new, having been developed in the late 1970's. These alloys are of interest because of their improved mechanical properties compared to the "standard" alloys. The number trailing the "ZA-" designation is the nominal percentage of aluminum in the alloy. Because of their high aluminum contents ZA-12 and ZA-27 should be cast in the cold chamber process. ZA-8 can be cast in hot chamber machines, but the wear on the injection components will be noticeable compared to No.3 alloy. These alloys require special handing and treatment. Electric induction furnaces generally provide sufficient stirring to maintain the alloys mixture when power is on. If power is off, additional stirring may be required. Normal casting temperatures are below 1100°F.

ZA-27 alloy exhibits excellent bearing qualities in many applications under continuous lubrication in addition to high strength and hardness.

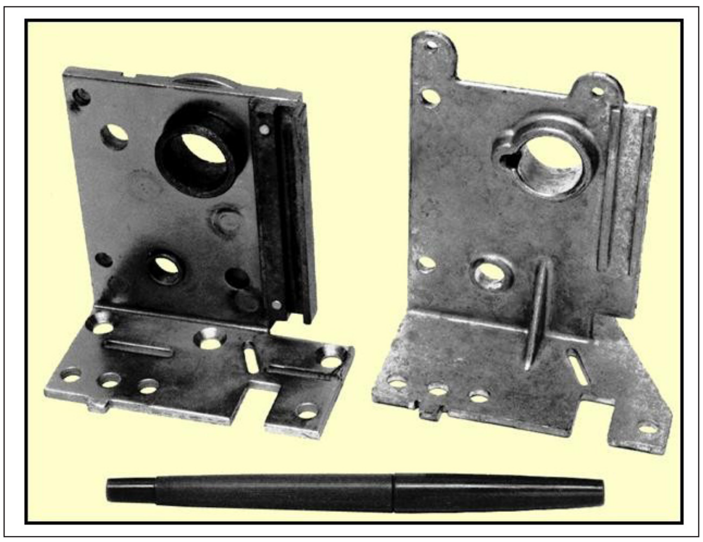


Figure 2-15(c) - Bearing casting

Zinc-Aluminum-Nickel System

No.7 alloy is rather new, having less magnesium the No.3 or No.5 but with a minor addition of nickel and more restrictive limits to lead, cadmium and tin. This alloy was developed because of its improved fluidity and potential to produce a better hardware finish on die castings (compared to No.3 alloy). The reduced magnesium content gives this alloy improved fluidity.

Impurities

Iron

The zinc alloys will attack and dissolve iron, particularly at excessive temperatures, above 850˚F. The iron that is dissolved will come from cast iron furnace pot and the injection components such as the gooseneck. It is possible to get concentrations in excess of the allowable 0.1% iron. This can result in the formation of dross and skimmings; the $FeAl_3$ is lighter than the zinc alloy and will float to the top of the bath. At high temperatures this dross formation could be excessive and result in the depletion of aluminum from the bath. This can result in decreased fluidity, and flow lines or marks on the finished casting. If the iron exceeds the allowable 0.1% limit, cracking could result in subsequent staking or cold working operations. The best way to avoid these problems is careful control of the alloy temperatures.

Copper

Copper, is considered an impurity up to 1.25% and has no affect on the zinc based die casting alloys. Above this level excessive aging and growth could occur.

Magnesium

When magnesium exceeds the limits of the specification, loss of fluidity and hot cracking may be encountered. Some magnesium is desirable to inhibit intergranular corrosion.

Nickel

The maximum solid solubility of nickel in zinc based alloys is 0.02%. Above this level complex aluminum-nickel compounds form and can cause surface blemishes and machining problems. Small amounts of nickel, below the solid solubility level help to neutralize those elements that cause intergranular corrosion.

Lead

With a minimum magnesium content of 0.02%, lead may be tolerated up to 0.005% without the detrimental effects of intergranular corrosion. Above this limit, the solid solubility of lead is exceeded and the lead migrates to the grain boundaries of the die castings. This could cause intergranular corrosion and hot cracking.

Cadmium

Concentrations above 0.1% cadmium are detrimental to mechanical properties. At this level and even at lower levels, cadmium can promote drossing, hot shortness and poor castability.

Tin

Tin seriously promotes intergranular corrosion and excessive growth in die castings due to aging if the 0.002% limit is exceeded. It can also result in hot cracking in the die.

Chromium

In excess of its solid solubility limit of 0.02%, it will form complex intermetallic compounds with aluminum and float to the surface. If chromium aluminum compounds are formed and find their way into the die casting, they will lead to machining problems.

Manganese

Small quantities of manganese are usually found in most grades of zinc and aluminum used to produce die castings. These are rarely more than trace amounts. No harmful affects have been experienced up to 0.5% levels, which is the maximum specification.

Magnesium Alloy Systems

The magnesium alloys that are used for die casting fall into two systems. The alloys and systems are:

AZ91D, AZ81	Magnesium-Aluminum-Zinc System
AM60B, AM50B	Magnesium-Aluminum System

Magnesium is one of the lightest of structural metals, which has very good mechanical properties. The solidification shrinkage is one of the lowest of all cast metals, being approximately 4%. An additional 2% volume change occurs during cooling from the melting point to room temperature. The energy requirement for melting and holding is relatively low. This low heat capacity provides the advantage that heat exchange in the die occurs rapidly so that solidification times are short.

Commercial:	AZ91D	AM 60B

Nominal Comp	Al 9.0	Al 6.0
	Zn 0.7	Mn 0.3
	Mn 0.2	
Aluminum (Al)	8.3-9.7	5.5-6.5
Zinc(Zn)	0.35-1.0	0.22 max
Manganese (Mn)	0.15-0.5	0.24-0.6
Silicon (Si)	0.10 max	0.1 max
Iron (Fe)	0.005	0.005
Copper Max(Cu)	0.030	0.010
Nickel Max(Ni)	0.002	0.002
Rare Earth Total	-	-
Total Others	0.020	0.020
Aluminum (Al)	balance	balance

Figure 2-16 - Chart of magnesium alloys and chemical constituents

Among magnesium's unique properties is its very high affinity for oxygen. This characteristic makes special protective or inert atmospheres necessary during melting and holding, while temperatures are above the minimum burning temperature of 790°F. Molten magnesium also reacts violently with water (releasing hydrogen) and with metal oxides such as iron scale.

Magnesium is free machining. It offers low resistance to cutting and rapidly generates large volumes of chips. Fine machining chips and sawing dust must be handled with care. Water cannot be used on magnesium fires because of the danger of explosion. Magnesium flux, dry sand, or dry cast iron chips should be kept available to smother fires while they are small. The key to fire prevention when machining magnesium is good housekeeping.

Magnesium-Aluminum-Zinc System

High purity magnesium alloy AZ91D dominates the magnesium die casting field. This is an Mg-Al-Zn ternary alloy. This alloy is more resistant to salt water corrosion than previous alloys in this family. The melting range is 1100-830°F; normal casting temperatures are similar to those used for aluminum.

Corrosion Resistance

Magnesium base alloys do not attack iron or steel. They also do not alloy with iron or chromium and only slightly with manganese. Copper, nickel, and iron impair corrosion resistance. An iron to manganese ratio of 32:1 or less appears to be necessary to achieve the best corrosion performance of the high purity metals.

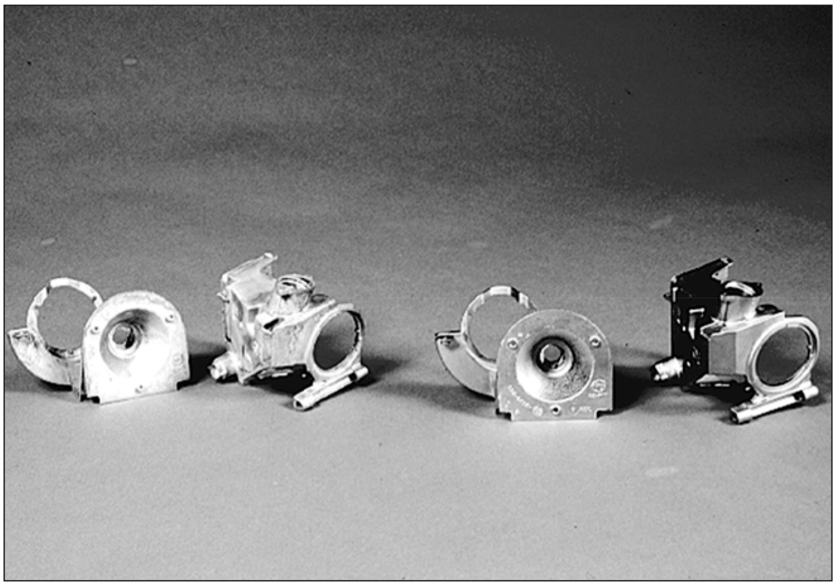


Figure 2-17 - Photo of magnesium castings

Magnesium-Aluminum System

AM50B, a binary alloy of aluminum and magnesium was introduced for the production of magnesium die cast automobile wheels. This alloy was designed for optimum toughness and ductility with good castability. A slightly higher casting temperature of 1240-1260°F is required.

SELF TEST 2

True or False

1. There are four common alloying systems for die cast aluminum.

   True False

2. An alloy system is determined by the main alloying ingredient or ingredients.

   True False

3. There are four common alloying systems for die cast zinc.

   True False

Multiple choice; Identify all correct answers.

4. The most common die cast alloy for aluminum is:

   a. 413
   b. 380
   c. 390
   d. 360

5. The most important alloying ingredient in aluminum is:

   a. copper
   b. iron
   c. magnesium
   d. silicon

6. The most common die cast alloy for zinc is:

   a. # 3 zinc
   b. ZA-27
   c. # 7 zinc
   d. none of the above

7. The most common alloying ingredient in zinc is:

   a. aluminum
   b. copper
   c. iron

d. magnesium

Heat in the Process

The proper rate of production is the cycle time that makes acceptable castings, meets productivity requirements for profitability and maximizes the dies' life. The die casting process is a process that exchanges heat. Heat is put into the alloy to liquefy it, the liquid is injected into the die and heat is removed to solidify the alloy and form the casting. The more efficiently this heat exchange is accomplished, the better the process will run. To produce efficiently, you want to exchange as little heat as possible. This means you want to inject the alloy at the lowest possible temperature and remove the casting at the highest possible temperature. Remember, in the Materials lesson, the amount of heat energy in the various alloys was discussed. To understand how to optimize the die casting process, you must look at how the heat energy is processed. This will be done with an example, the bracket casting.

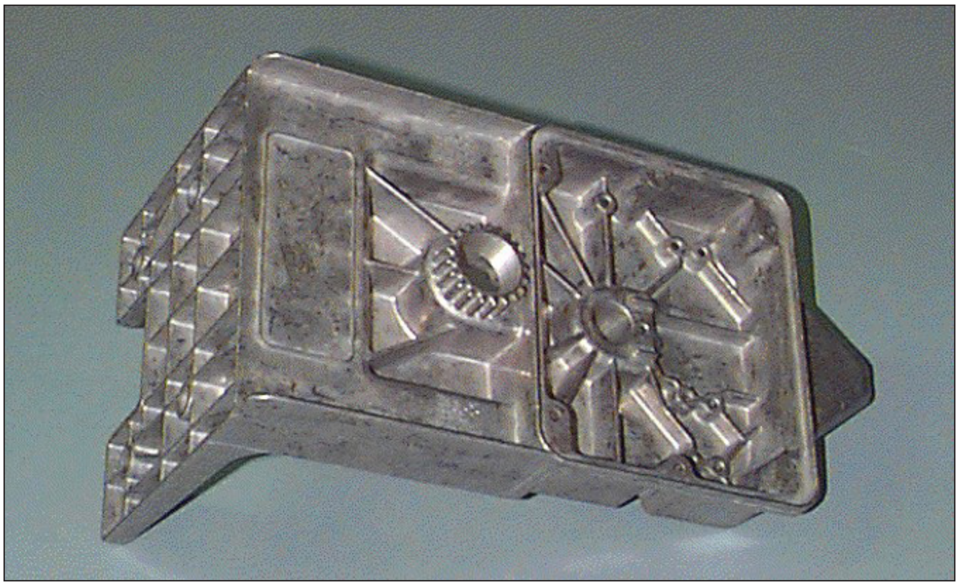


Figure 2-18 - Bracket casting

The bracket casting weighs 6.5 pounds (2.95 kg.) and is made from 380 aluminum alloy. It is cast at 1220°F (660°C) and is ejected at 700°F (370°C). These are typical temperature readings from production when things appear to be running well. From these temperatures you can estimate the amount of heat energy that is exchanged to the casting die every cycle.

The amount of heat energy given up to the casting die is the sum of sensible heat and latent heat. Sensible heat is heat given up due to the temperature change from the injection temperature to the ejection temperature. You know the ejection temperature; the casting temperature was measured to be 700°F (370°C) at ejection. You do not know the injection temperature. You can take the holding furnace temperature, estimate the temperature loss occurring when transferring the alloy from the furnace to the cold chamber and holding the alloy in the cold chamber before injection. Typically, this temperature loss is estimated to be 50-90°F (28-50°C). In this example the loss is estimated at 50°F (28°C). The specific heat for 380 aluminum is known to be 0.025 BTU's per cubic inch, per Fahrenheit degree (0.00069 ca/cm3-°C). The Latent heat of fusion for aluminum is 17.0 BTU's per cubic inch (.261 cal/cm3).

In this example, the sensible heat given up to the die is:

Q = (65.66 in3) (0.025 BTU/in3-°F) (700- 1170°F)

= - 771.5 BTU

Q = (1076 cm3) (0.0007 cal/ cm3-°C) (261°C)

= -194.4 cal

The latent heat given up to the die is:

Q = Latent heat

= (65.66 in3) (-17.0 BTU/in3)

= -1116.2 BTU

Q = (1076 cm3) (-0.262 cal/ cm3)

= - 281 cal

Total heat going into the die every cycle is the sum of the specific and latent heats.

Qtotal = -771.5 + (-1116.2)

Qtotal = -1887.7 BTU

Qtotal = -194.4 cal + (-281 cal)

Qtotal = -475 cal

The minus sign means the heat is flowing out of the alloy.

The production rate for this casting is 45 pieces per hour. Therefore the amount of heat going into the die every hour is 84,946.5 BTU.

This means, every hour the die has to remove about 85,000 BTU from the alloy to balance the heat going into it. If the die is incapable of processing this amount of heat, the die temperature will increase. If the die has too much cooling capacity, the die temperature will go down. You can control the cooling capacity of the die.

Mechanisms of Heat Flow

There are three mechanisms that heat uses to flow from one location to another. They are conduction, convection, and radiation. All these mechanisms are at work in die casting.

Conduction

An example of heat conduction is dipping one end of a metal rod into boiling water and then feeling the other end of the rod heat up with your finger tips. Heat from the boiling water heats the portion of rod in the water; the heat then conducts up the rod to your finger tips.

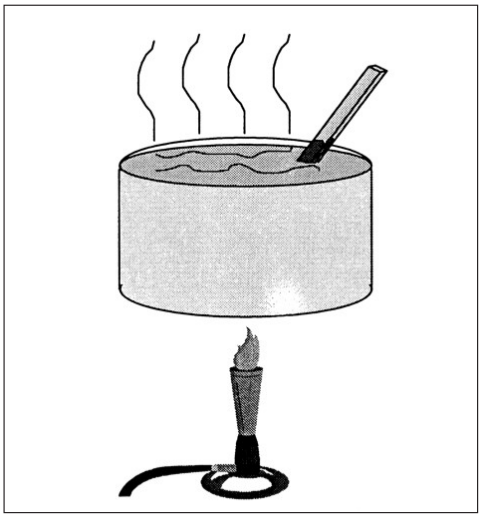


Figure 2-19 - Illustration of boiling water and rod heating

Conduction of heat depends on several factors or variables.

These factors of the conductor are:

- Material of the conductor.
- Cross-sectional area of the conductor.
- Length of the conductor.
- The temperature difference from one end of the conductor to the other end.

How these factors work together to conduct heat is straight forward. The material that transfers the heat is the conductor. The opposite of a conductor is an insulator. You certainly are familiar with materials that are insulators and conductors. Glass and air are insulators, or poor conductors. Silver, copper and aluminum are the very best conductors. Many metals are good conductors. If rapid heat transfer is required, the choice of a good conductor is very important. Most plunger tips in cold chamber die casting are made from a copper alloy because copper is a good heat conductor. The property of a material that describes its ability to conduct heat is the Coefficient of Thermal Conductivity. The larger this number is, the better the material is able to conduct heat. The thermal conductivity of 380 aluminum is 4.6 BTU/ in. hr°F (0.82 cal/ cm hr°C). The thermal conductivity of H13 steel is 1.25 BTU/ in. hr°F (0.22 cal/ cm hr°C).

The second factor that facilitates heat conduction is the area available for the heat to flow through. The larger the cross-sectional area for the heat to flow through, the less resistance there is to the heat flow. This is similar to fluid flow in various sizes of pipe. If you have two pipes, one with a 2 in. (5 cm) diameter and the other with a 1 in. (2.54 cm) diameter and water under 40 PSI (2.8 kg/cm2) pressure is flowing through both pipes. The pipe with the greater cross-sectional area will allow more water to flow. The same is true with heat flow, the greater the cross-sectional area, the more heat that will flow.

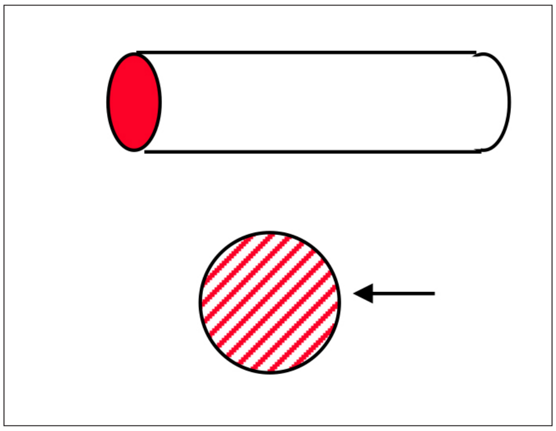


Figure 2-20 - Cross-sectional area

The third factor that facilitates heat flow is temperature difference: the temperature difference between the heat source and the heat sink. The temperature difference is the driving force for the movement of heat just as voltage difference drives electricity and pressure difference drives fluid flow. Heat will only flow if there is a temperature difference. The direction of the heat flow is easy to determine. Heat flows downhill, downhill on the temperature scale. Heat flows from hot to cold. When preheating the die, heat flows from the torch or heater to the cold die and the bigger the temperature difference, the more heat that will flow.

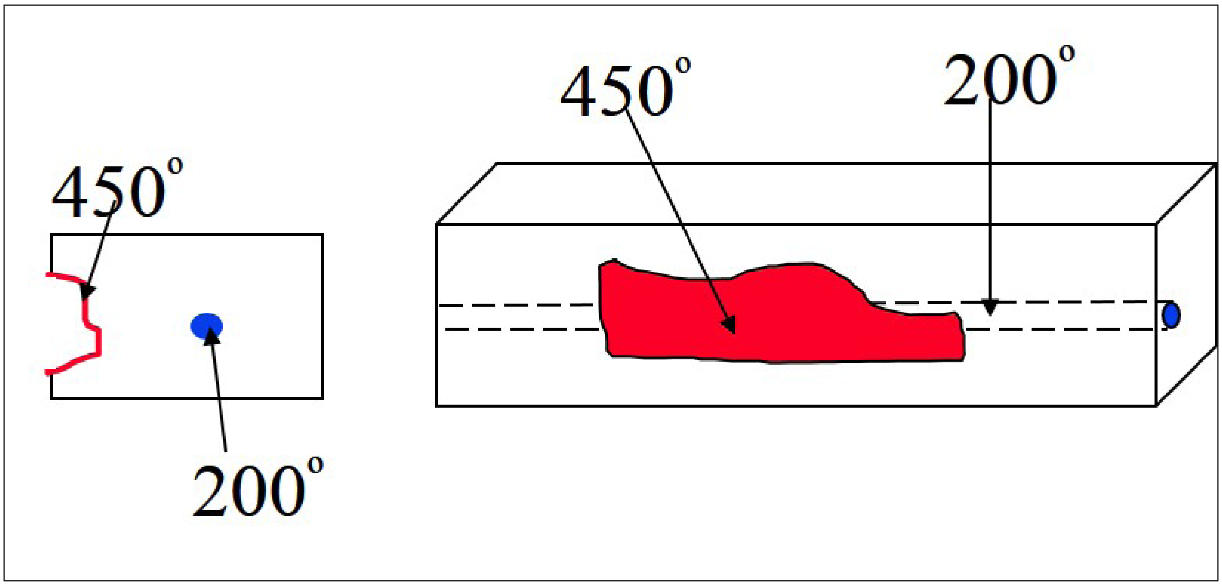


Figure 2-21 - Sketch of temperature difference

The fourth factor involved in heat conduction is the distance the heat must flow. The relationship of this factor is referred to as an inverse relationship. This means that as the distance the heat must flow goes up, the amount of heat that will flow goes down. Therefore, the longer the distance for the heat to travel, the less the amount of heat that will flow.

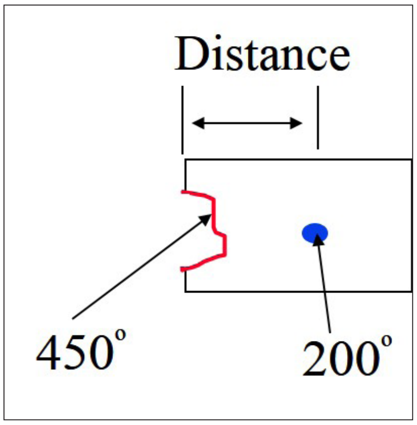


Figure 2-22 - Sketch of distance

Summarizing, the material, the area and the temperature difference are directly related to heat flow. As these factors go up, the heat flow goes up. The distance the heat must flow is an inverse factor, as the distance goes up, the heat flow goes down. The engineering formula that expresses these relationships is:

$Q = (C \times A \times \Delta T)/D$

Q = heat in BTU/hr (cal/hr)

C = coefficient of thermal conductivity in BTU/in. hr°F.

(cal/cm hr°C)

A = area square inches (cm2)

ΔT = temperature difference in °F. (°C)

D = distance in inches. (cm)

For example: How much heat will flow if the cavity surface temperature is 450°F, the temperature at the cooling line is 250°F, the die material is H13 steel, the cross-sectional area available for heat flow is 5 square inches, and the distance to the cooling line is 2 inches?

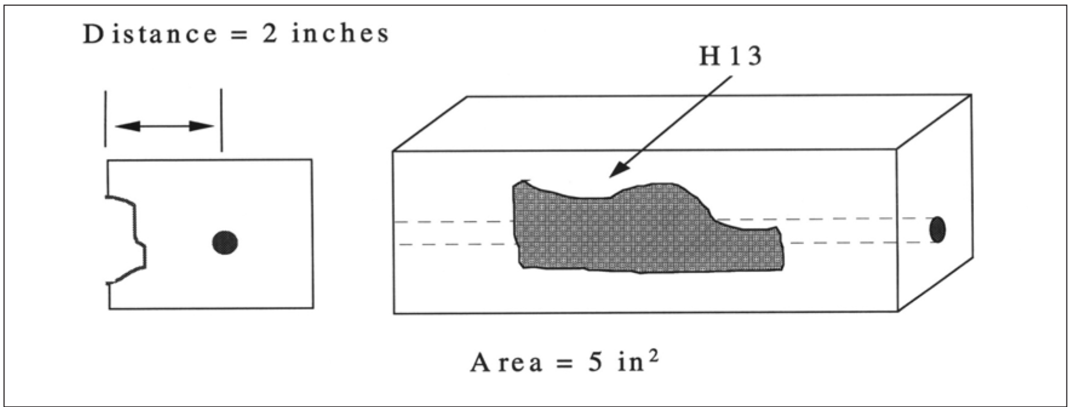


Figure 2-23 - Sketch of example

Substituting into the formula:

$$Q = \frac{(1.25\ \text{BTU/in. hr°F})(5\ \text{in}^2)(450°\text{F} - 250°\text{F})}{2\ \text{in}}$$

Q = 625.0 BTU/hr

$$Q = \frac{(0.223\ \text{cal/cm hr°C})(32.3\ \text{cm}^2)(111°\text{C})}{5.08\ \text{cm}}$$

Q = 157.4 cal/hr

In this example the heat flow is 625 BTU per hour (157.4 cal/hr). This is not very much.

Convection

The second important mechanism for heat flow is convection. Convection is heat transfer that occurs when a cold fluid passes over or through a hot object. There are two types of convection, natural convection and forced convection. For example, if your house is heated with forced hot air, this is forced convection with air as the fluid. Using the furnace fan, cold air is blown over the heat exchanger in the furnace. The hot air is then distributed to the house. Another example is heating a house with a hot water gravity system. A gravity heating system distributes the heat with natural convection. Cold water, the fluid, passes through the tubes in the boiler, picks up heat, becomes less dense and rises in the piping system. The hot water is replaced by more dense cold water that displaces the hot water because of the force of gravity. Another example of natural convection is the hot die in the machine with the safety doors closed. Air will come in contact with the die; the air will become warm and less dense, rise from the die and be replaced by cool air. This cycle will continue and cool the die. If you open the safety doors and point a fan at the die, this is forced convection, and will cool the die faster than natural convection. Convective heat flow depends on several factors or variables.

Figure 2-24 - Natural convection

These factors for convection are:

- convection film coefficient (CFC)
- contact area for heat transfer
- the temperature difference between the hot object and cold fluid

Determining the convection film coefficient is not as simple as determining a conduction coefficient. The convective film coefficient is dependent on several variables. This means there is a particular value of CFC for each combination of variable. The variables are:

- natural or forced convection
- the convection fluid
- the velocity of the convection fluid

In die casting the cooling situation is mostly forced convection, particularly in the case of internal cooling. CFC's have been determined experimentally for various combinations of cooling oil and water at various flow rates in various cooling line sizes. A typical value for a CFC is 3.5 BTU/hr. in2°F (0.246 cal/hr. cm2°C) for a 7/16 in. (1.1 cm) diameter waterline at a flow rate of 1 gallon per minute (3.78 l/min). Under these same conditions the CFC for oil is 1.4 BTU/hr. in2°F (0.098 cal/hr. cm2°C). As velocity of the fluid increases the CFC increases. Finally, as the CFC increases the amount of heat transferred increases.

The second important factor is area. The area is defined as that area in contact with the convection fluid. This could be the internal area of a cooling line or the outside surface of the die with air blowing over it.

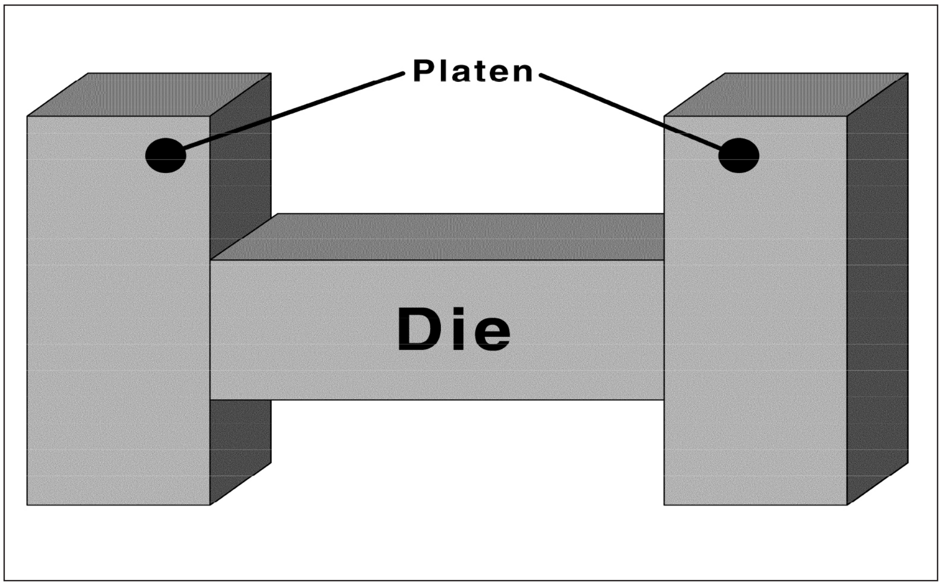


Figure 2-25 - Area of outside of the die

The last factor that facilitates convective heat flow is temperature difference. The temperature difference is the driving force for the movement of heat. Again the bigger the temperature difference, the more heat that will flow.

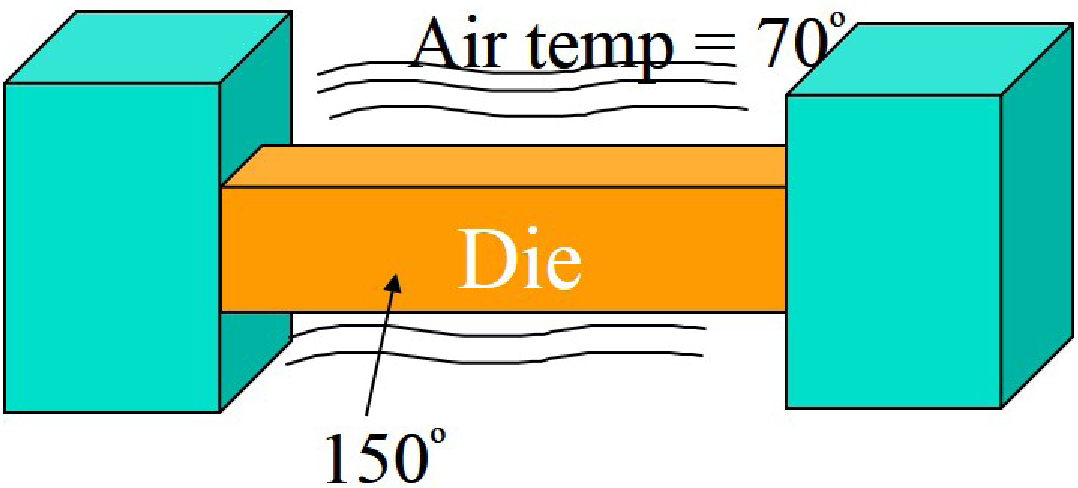


Figure 2-26 - Sketch of temperature difference between hot die and cool air

Summarizing, the combination of fluid and velocity, and the area and the temperature difference directly control convective heat flow. As these factors go up, the heat flow goes up. The engineering formula that expresses these relationships is:

Q = (H x A x ΔT)

Q = heat in BTU/hr (cal/hr)

H = convective film coefficient in BTU/in2 hr°F.

(cal/hr cm2°C)

A = area square inches (cm)

ΔT = temperature difference in °F. (°C)

For example, how much heat will flow if the temperature at the cooling line is 250°F (121°C), the coolant fluid is

90°F (32°C), and the constant area available for heat flow is 20 square inches (129 cm2), with a convective film coefficient of 3.5 (0.246) for water in a 0.44 (1.1 cm) diameter waterline at a 1 gallon per minute flow rate (3.8 l/min).

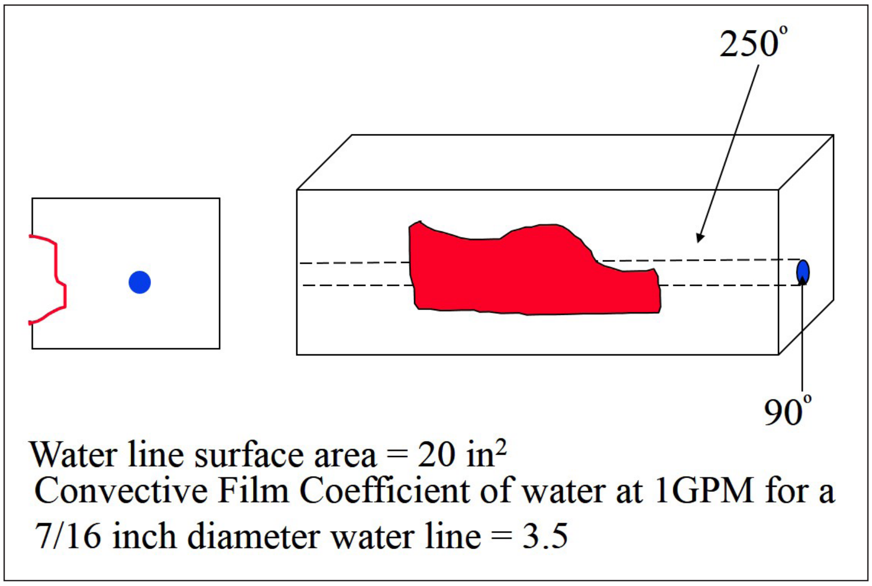


Figure 2-27 - Sketch of example

Substituting into the formula:

Q = (3.5 BTU/in2 hr°F)(20 in2)(250°F -90°F)

Q = 11200 BTU/hr.

Q = (0.246 cal/cm2 hr°C)(129 cm2)(89°C)

Q = 2824 cal/hr

In this example the heat flow is 11200 BTU per hour (2824 cal/hr). This is a significant amount of heat removal.

Radiation

Radiation is the third mechanism for heat transfer. You are familiar with radiant heat transfer. This is how the sun heats the earth. Radiant heat transfer is not a big factor at the die and machine, unless you use radiant gas or electric heaters to preheat the casting die. One important thing to know about radiant heat transfer is the amount of heat transferred falls off very quickly with distance.

Radiant heat transfer is common in the melting and holding of the die casting alloy. Gas and electric reverbatory melting and holding furnaces use radiant heat transfer. If you are involved in furnace cleaning you know what radiant heat feels like. If you open the door to a reverb furnace, even with the burners off, you will feel a rush of heat. This is radiant heat, there is no fan blowing out of the furnace at you. You must protect yourself from radiant heat just as you would from sunburn. The most effective protection is to fully cover-up, wear long sleeves and gloves and shield your face and head with a reflective face shield and helmet.

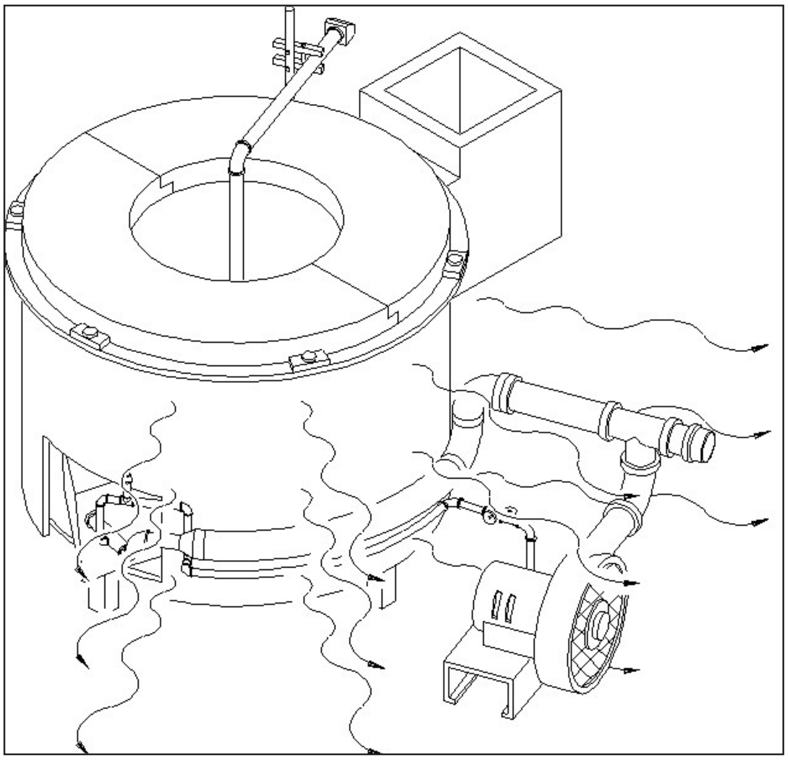


Figure 2-28 - Radiant heat from furnace

Heat Flow from the Die

Heat is removed from the die by various means. Internal cooling lines are the most effective means for heat removal. Heat is conducted to the cooling line from the surface of the die cavity. The coolant then convects the heat from the surface around the cooling line. However, one of the problems engineers have is that it is not always possible to get effective cooling into all areas of the cavity. Then other methods of heat removal must be used.

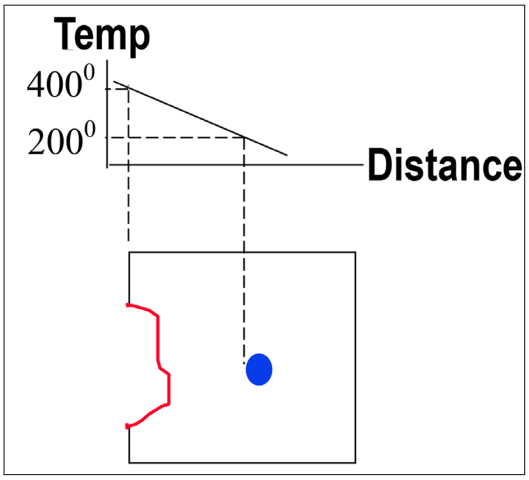


Figure 2-29 - Temperature distribution in cavity

Die spray is used to remove heat on a spot basis. If external spray is relied upon to carry the cooling load, spraying with atomized water is recommended because excessive lube will cause staining. External spray usually removes about 0.15 BTU/in2 sec (0.006 cal/cm2 sec). For example, if you spray a cavity having a surface area of 50 in2 (322 cm2) for 6 seconds, the heat removal will be 45 BTU (11.5 cal).

Heat is lost to the machine by conduction from the mold base to the machine. Some heat will be lost to the atmosphere by natural convection. These normal losses are from 0.2 to 0.5 BTU/in2 shot (0.008 to 0.300 cal/cm2 shot).

Operator Control of Heat Flow

As the operator, you have a great deal of control over the heat flow from the die. Your objective is to balance the heat flow out of the die with the heat flow into the die.

The first step in balancing heat flow out of the die is to establish a consistent heat input. Consistent heat input to the die is a result of:

- consistent cycle time
- consistent metal temperature
- consistent shot size

The second step in balancing heat flow is to establish consistent heat output. Consistent heat removal from the die is a result of:

- consistent cycle time
- consistent spray application
- consistent die temperature

The consistent cycle is necessary to optimize the die casting process. As the cycle begins the die is at a relatively low temperature, possibly 450°F (232°C). The die closes and alloy is injected. Immediately the cavity surface temperature rises, its temperature may reach 700-900°F (370-480°C), depending on the size of the shot and other characteristics like wall sections. As the steel at the cavity surface heats up due to contact with the molten alloy it expands. The amount of expansion depends on the temperature change that it experiences. Immediately below the cavity surface is more steel. In fact, you can try to picture the die steel as a series of layers of steel below the die cavity.

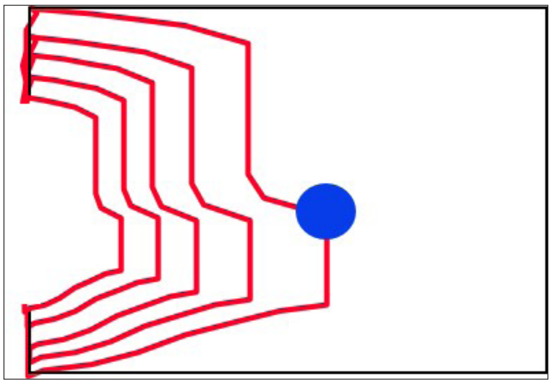


Figure 2-30 - Sketch of cavity and various layers of steel

As the first layer heats and expands from contact with the alloy, the second layer, because of its contact with the first layer, picks up some heat, and expands. As the heat moves from the cavity surface to the back of the cavity insert or to a cooling line, it looses energy and temperature. It is this temperature difference that causes the heat to flow.

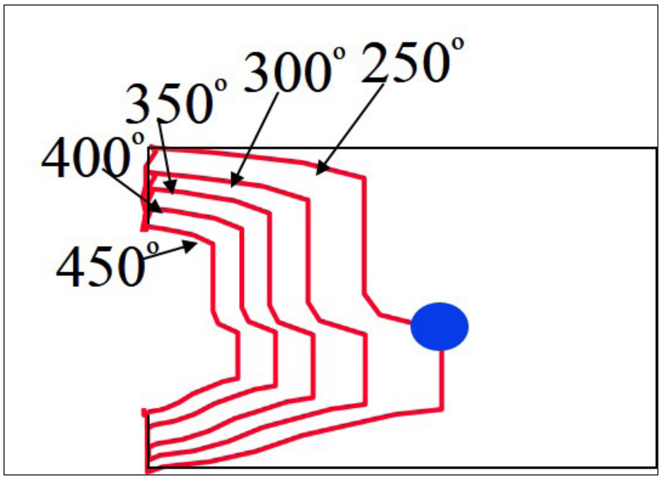


Figure 2-31- Sketch of temperature isothermals along heat flow path

During a single cycle, two things are happening to the cavity steel with respect to temperature. First, the cavity surface is cool before the alloy is injected, immediately upon injection it becomes very hot. Then during the dwell portion of the cycle it begins to cool. Once the casting is ejected, heat is no longer going into the die, so it continues to cool. Then the die surface is sprayed with die release. The surface immediately drops in temperature. After spray, the die surface begins to heat again, because of heat in the cavity insert.

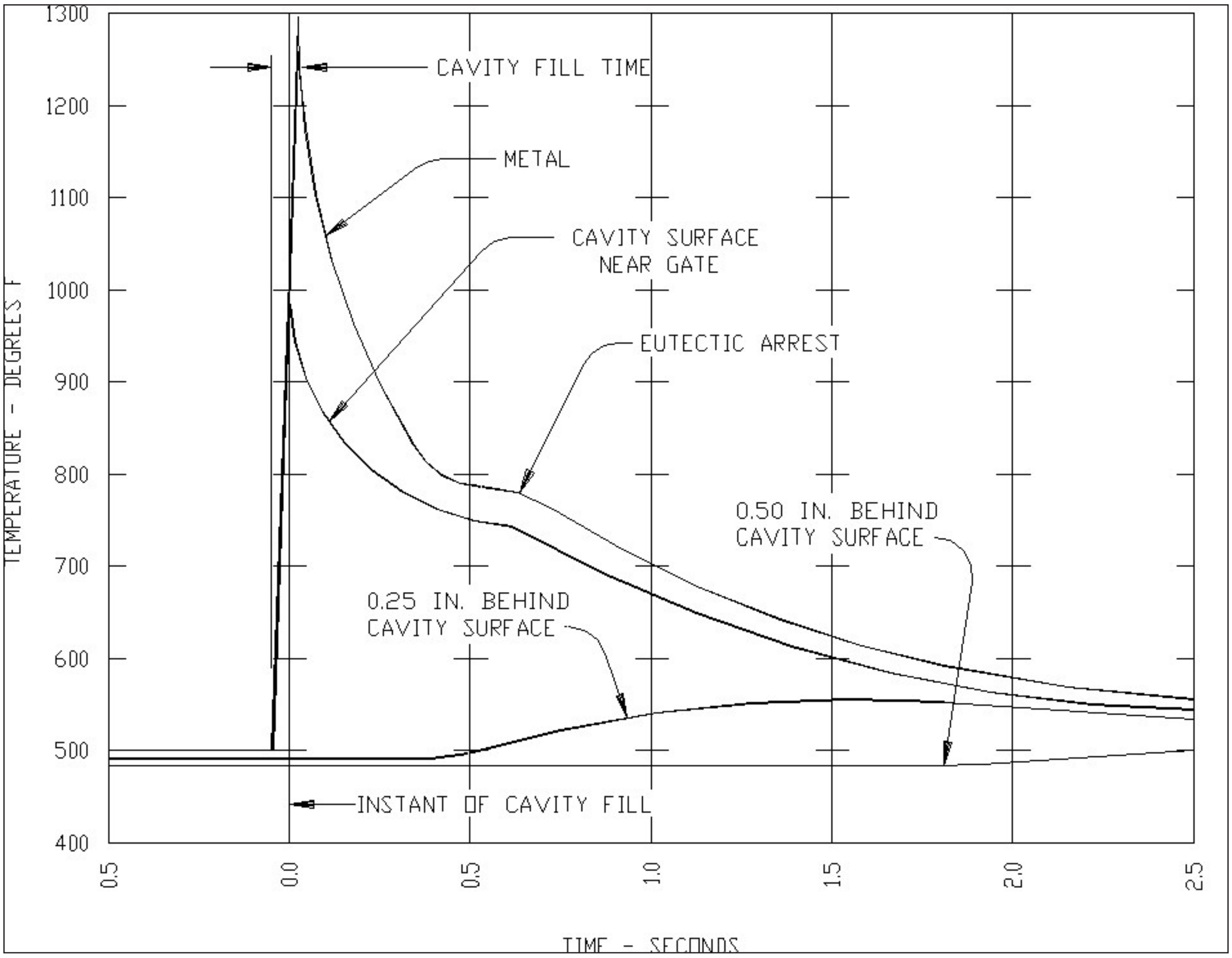


Figure 2-32 - Plot of cavity surface temperatures and temperatures below the surface, for one cycle

Below the cavity surface, the temperature changes are not as dramatic. The temperatures go up and down just as at the surface, but not the same amounts. The further you get from the cavity surface, and the closer to a cooling line or back of the cavity, the smaller the temperature range is for each cycle. This means that the thermal expansion and contraction varies throughout the cavity block every cycle and also depending on location relative to the cavity surface.

The differences in thermal expansion due to differences in temperature are the cause for heat checking. If you can minimize the temperature differences, you can prolong the time for the onset of heat checking. You minimize the temperature differences by running the die as hot as possible, putting the minimum of heat into the die, and reducing the temperature differences in the cavity insert. This should result in the longest die life, the highest productivity, and the lowest scrap.

The consistent casting cycle will put into and take out of the die the same amount of heat every cycle. As an operator you can control or should be monitoring the following variables in order to achieve consistent cycle times.

The metal temperature should be constant. If metal temperature goes up or down, the value of specific heat going into the die, and the number of BTU's going into the die will change. The amount of metal being cast should be constant. If you pour different amounts of metal every cycle, the amount of heat will vary based on different volumes of alloy. This is generally not a problem at the cavity, but could become a problem at the biscuit. If the biscuit gets to big, you may not have adequate cooling time to let it solidify completely. This could result in an accident if the biscuit bursts. Dwell or hold time is based on a predictable amount of heat going into the die every cycle. If too much heat gets into the die, the casting may not be strong enough to withstand the forces of opening or ejection. It could stick in either half of the die. Spray time and volume must be consistent each cycle. This means the time spent spraying the die should be the same every cycle. One technique operators use is to count the seconds when spraying, "one thousand-one, one thousand-two....." The amount of spray flowing from the nozzle should be the same each cycle. This should be calibrated, so the amount of flow can be set accurately for each casting. Cooling lines should be adjusted for flow rate, gallons per minute, and the temperature of the coolant must be controlled. Each cycle element must take the same amount of time to achieve an overall consistent cycle time.

If the above steps are followed, the die will reach a base equilibrium temperature around which the cyclic temperature variations will occur.

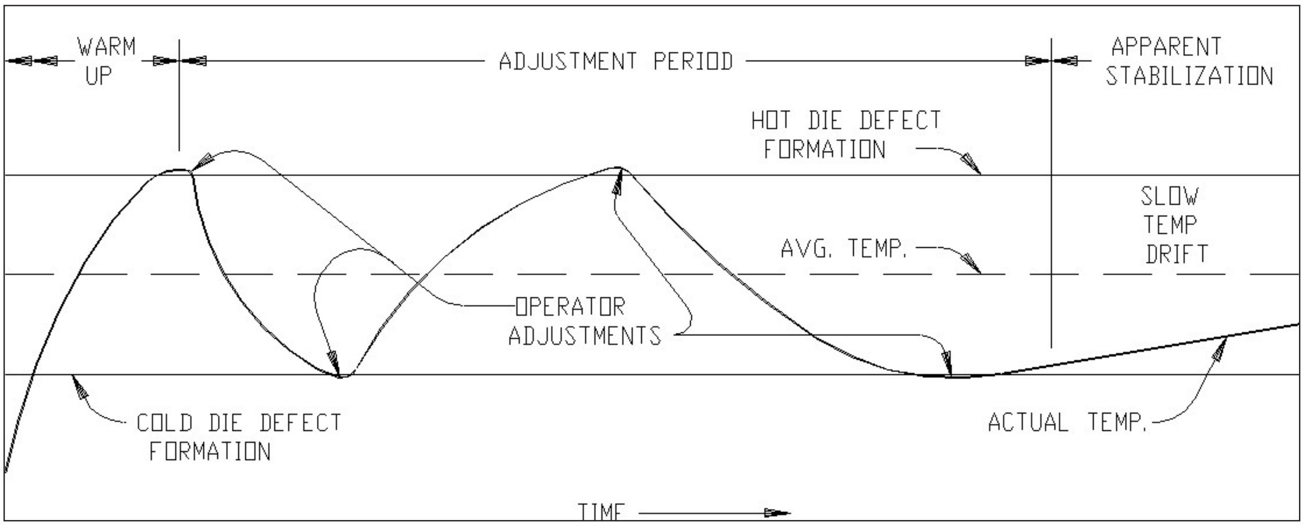


Figure 2-33 - Plot of cavity surface temperatures for several cycles, showing a base equilibrium temperature

As you monitor the above process variables you will be aware of changes occurring during the cycle. You will know when the holding furnace temperature drops or creeps up. You will be aware of how spraying is affecting the cavity surfaces. You will be aware of cooling lines flowing properly or if flow rates are changing, or is the coolant boiling? The important thing is to be aware of changes and then knowing if these changes are affecting the quality of your castings. If everything is running well, the casting quality is acceptable and a process change occurs, you should be know quickly if the process change affects your casting quality. If defects occur, they are usually related to some change in the process.

SELF TEST 3

True or False

1. 1. The heat put into the die is a combination of latent and sensible heat.

   True False

2. 2. Heat moves from the cavity surface to the cooling line by radiation.

   True False

3. 3. Heat is taken out of the die, by cooling lines conducting the heat out.

   True False

4. 4. A fan blowing air over the die is an example of forced convection.

   True False

Multiple choice - Identify all the correct answers

5. Conductive heat flow depends on the following variables:
   a. the conduction material
   b. the distance for heat to flow
   c. the area for the heat to flow through
   d. a temperature difference

6. Convective heat flow depends on:
   a. the convective film coefficient
   b. the distance for heat to flow
   c. the area for the heat to flow through
   d. a temperature difference

7. The operator can control heat flow by
   a. making sure the holding furnace temperature is consistent
   b. maintaining a consistent cycle time

c. applying die release evenly in the same amount of time
d. taking frequent, but short breaks

Internal Defects

Internal defects are detrimental to the die casting because they result in reduced mechanical properties of the casting, loss of pressure tightness in the casting, and poor machineability.

The mechanical properties of a casting are tensile strength, elongation, hardness, impact strength and others. These properties have been measured on samples made from the die cast alloys and are published to help designers pick a material that is appropriate for their design. These properties were measured on solid and dense samples. If a sample were made from porous materials, the values of the properties would not be as high. In order to meet the design requirement, you must make the casting as dense and solid as possible with good clean alloy.

Figure 2-34 - Pressure testing a casting

Internal defects also will affect the machineability of the casting. This includes both porosity and inclusion defects.

Porosity describes a void, whereas an inclusion is material that should not be present. Inclusions and voids will result in tool breakage and excessive tool wear.

INCLUSIONS

Al2O3 Aluminum oxide

The vast majority of inclusions are non-metallic aluminum oxide, Al2O3. Aluminum is a powerful reducing agent (oxidizing), and consequently oxidizes (combines with oxygen) easily. This is one of the reasons for build-up inside furnaces. The oxides of aluminum are polymorphic, which means that in certain environments the properties of the alumina crystals change drastically. When aluminum oxide first forms it is the soft gamma type with a specific gravity of approximately 2.8. This is very similar to the alloy from which it is formed. As this material is heated above 1500˚F (815˚C), it is transformed into a much denser and harder variety called alpha Al2O3. This is commonly called corundum and is rated right next to diamond on the hardness scale. The build-up on the sidewalls of furnaces is essentially pure corundum. Excess air and moisture in the furnace atmosphere greatly accelerates side wall build-up. Air in the furnace atmosphere comes from two sources, either primarily, from an oxidizing fuel mixture, or secondarily, from air leakage around doors, burner ports or cracks in the roof or walls. Invariably massive oxide inclusions or hardspots trace their origin to the sidewalls of the melting or holding furnace. Since the specific gravity of corundum is approximately 4, it is expected to sink to the bottom of the furnace bath.

Aluminum oxide finds its way into the alloy bath during the wall cleaning process. It is in the spading or cleaning of the side wall or even wall contact with the furnace tools during routine fluxing that this build-up of corundum is broken up and dislodged. It becomes mixed with flux, parent alloy from the bath, air, and flue gasses. The resulting particles may vary widely in size and density. Some does sink to the bottom, but most is skimmed off as dross. An appreciable fraction, however, may have a density similar to the metal in the bath and will remain suspended in the melt ultimately finding its way into the dip well, and into the castings.

The color of Al2O3 as it appears in castings is a dull gray to black. The gradations in color from dull gray to dull black are undoubtedly related to the variations in the intense heat that transformed gamma to alpha Al2O3 and the time frame in which it was formed. The size and shape of the individual corundum particles may vary widely.

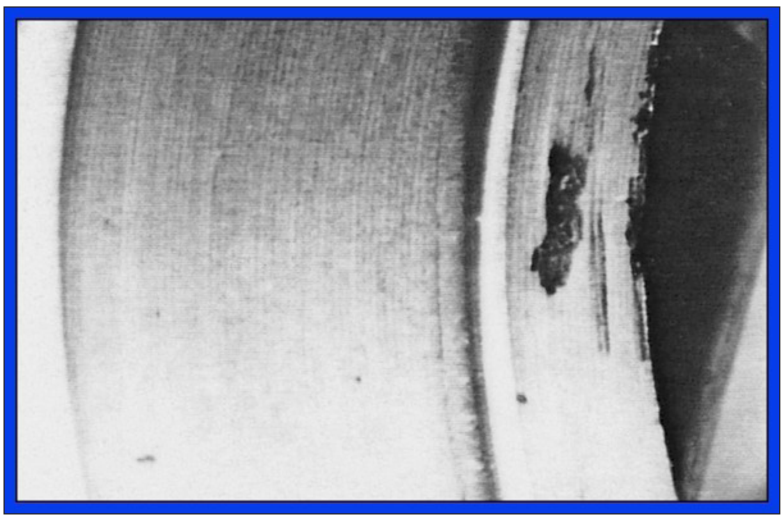


Figure 2-35 - Aluminum oxide in a casting

Shotted alloy

Shotted alloy is alloy that has solidified into small spheres or globules prior to or during injection. These small balls are incased in oxide and as such do not assimilate with the parent alloy. Because they are not homogenous with the alloy they can result in excessive tool wear, provide a leak path, or become the initiation site for a fracture.

Shotting is usually caused by splashing the alloy against the cold wall in the cold chamber, and is aided if the alloy is to cold. If the melt contains fine corundum particles the formation of shotted alloy is enhanced.

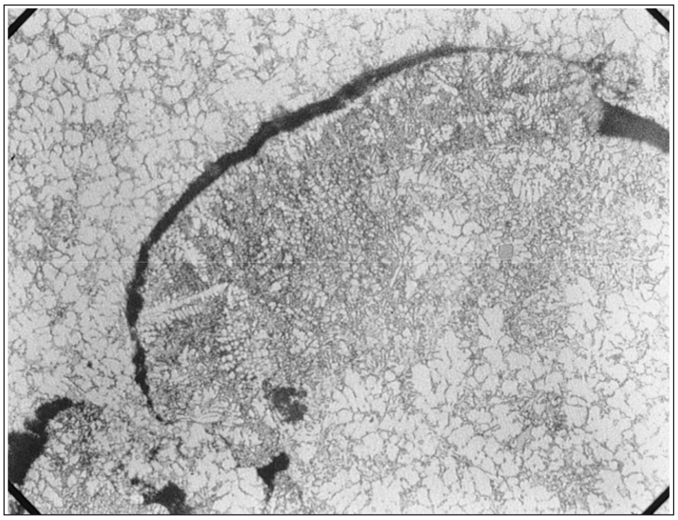


Figure 2-36 - Photo of shotted alloy

Oxide films and dross inclusions

Inclusions of oxide films and dross are a major cause for leakers and excessive tool wear. This is generally gamma aluminum oxide, the soft variety. The source of these thin films is the cold chamber, the runner or in the die from splashes of alloy ahead of the main alloy stream. The splashes and jets are usually a result of poor gate and runner design or by improper speed control of the plunger.

The real problem of the oxide films is that they prevent divergent alloy steams knitting together properly as the cavity fills. This will result in the formation of discontinuities such as laminations, orange peels, or cold shuts. If these films envelop air or vaporized die lube, blisters or excessive internal porosity result.

Silicon carbide refractories

Silicon carbide refractories can find their way into castings if furnace cleaning practices are not maintained. SiC, silicon carbide is as damaging as corundum because of its hardness. It is encountered infrequently compared to corundum and may be distinguished by it very black, glasslike coloring.

Their source can be chips from carbide crucibles or from grinding wheels used to remove soldering from the die surfaces.

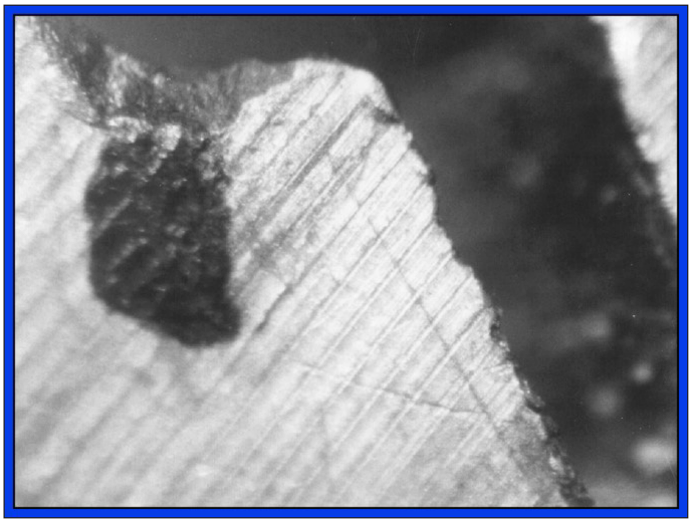


Figure 2-37 - Silicon carbide inclusions

Flux

Flux inclusions are not usually recognized during a cursory visual inspection. A simple test to determine whether or not castings contain flux inclusions is to simply submerge the casting in city water overnight. If flux inclusions are present, they will grow crystals on the casting surface since flux is composed of salt. The corrosive products that developed appear as light mottling on all surfaces of the casting.

Flux inclusions can be identified by a gray crystalline appearance, similar to rock salt. Flux inclusions are often associated with shrink voids, dross or hard spot inclusions.

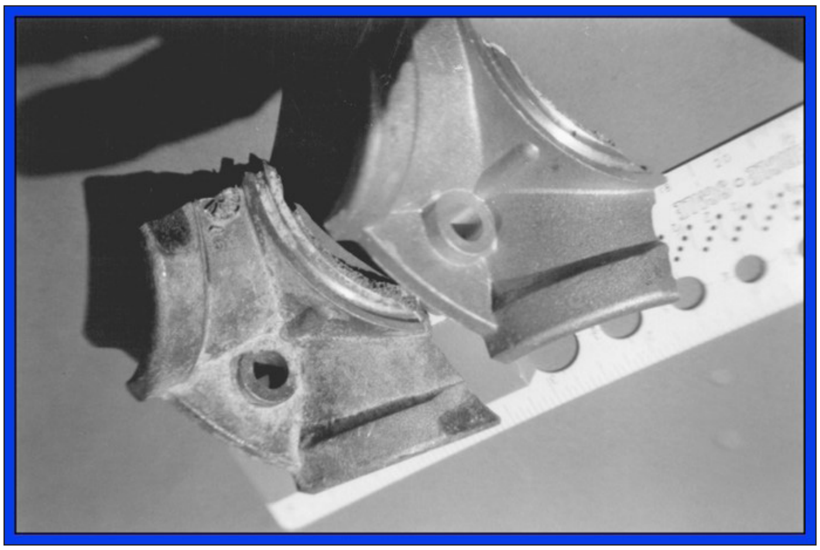


Figure 2-38 - Photo of flux covered casting

Flux inclusions will cause problems when coating such as anodizing or alodining are applied, preventing adhesion. Shelf life of finished components with flux inclusions will be short. Storing parts in a humid atmosphere will result in discoloration.

Sludge

Sludge is another inclusion considered to be a hard spot. Sludge is composed of complex inter-metallic compounds of Al-Si-Fe-Mn-Cr having melting points above the liquidus temperature of the alloy from which they are formed. Sludge is quite hard, and in a casting will surely damage cutter tooling. Under high magnification sludge is easily recognized by the extremely fine primary crystals and their pentagonal shape.

The components necessary to form sludge are always present in aluminum die casting. The tendency to form sludge can be minimized by purchasing alloy that is low in the sludge forming ingredients as the first step. The next step is to maintain good furnace temperature control.

A frequently used formula to specify the maximum for sludge forming ingredients is:

%Fe + 2 x %Mn + 3 x %Cr = 1.75% max

This means the sum of the iron percentage and two times the manganese percentage and three times the chromium percentage should not exceed 1.75%. If holding furnace temperatures are routinely less than 1200°F (815°C), an even lower sludge factor should be specified.

You can check for sludging by raking the bottom of the furnace. Sludge is a silvery sandy material at the bottom of the furnace. It is best just to rake the material off the furnace bottom and discard it.

Since sludging depletes the iron in the bath, if the iron is not replaced, soldering can be expected with jobs that normally do not experience soldering problems. Also, reduced iron in the casting can result in hot cracking at die opening and ejection.

3 DIE CASTING MACHINES AND CELL AREA EQUIPMENT

OBJECTIVES

- To learn the names of the major machine components of conventional machines.
- To learn the purpose of the major machine components.
- To learn how the components work, both independently and together.
- To learn the differences in the hot and cold chamber die casting machines.
- To learn the requirements for safely working with the various machine components.
- To learn about forces developed by the tie bars.

PERSPECTIVE

The die casting machine is the most important machine in the die casting plant. All activities in the plant focus on keeping the machine running, and producing acceptable castings. The die casting machine is a complex assembly of components that must work in concert with each other to produce the forces, speeds, and withstand the high temperatures required to make a die casting. To be given the responsibility to run a die casting machine is similar to being given the keys to a finely tuned racing car, except the die cast machine may cost more.

In this lesson we will assemble a die cast machine from the ground up. We will identify all the components that make up the machine and define their function. Along the way we will show a number of illustrations to clarify and give you a good picture of the machine. The machine we assemble will be generic in nature and will closely resemble the machine you are working on. At the conclusion of this lesson you will be able to identify the major machine components, explain their function and know the safety requirements related to running the machine.

There are two major die casting processes; hot chamber and cold chamber die casting. They get their name from the temperature of their metal pump relative to the temperature of the metal. In hot chamber die casting, the metal pump, or gooseneck, is submerged in the metal and is the same temperature as the metal.

In cold chamber die casting, the metal pump, cold chamber or shot sleeve, is outside the furnace, and is cold relative to the metal ladled into it.

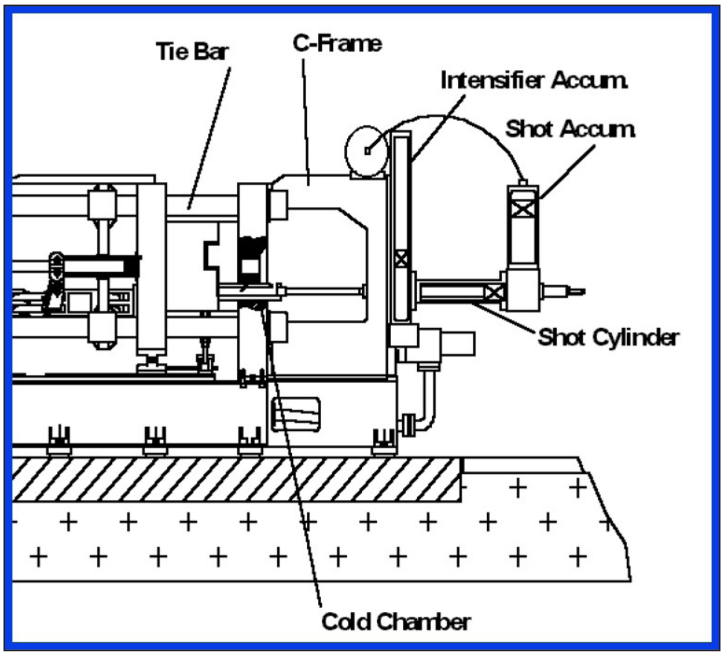


Figure 3-1(a) - Cold chamber shot end

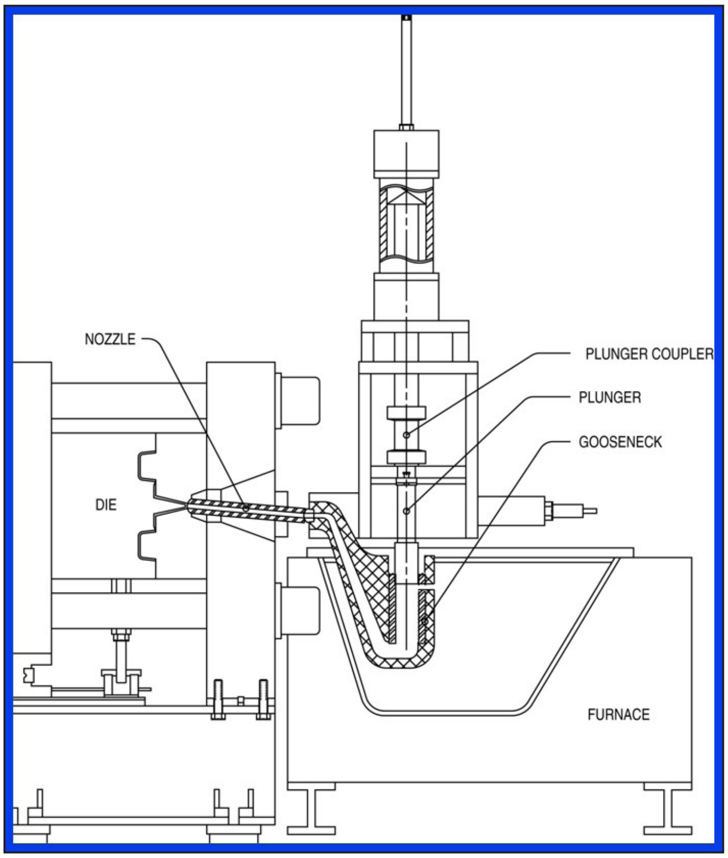


Figure 3-1(b) - Hot chamber shot end

In addition to conventional die casting machines, there are a number of specialty die casting machines. These will be discussed after the conventional machines. Conventional machines open and close on a horizontal or vertical axis (most are horizontal). The machines will have tie bars or a solid cast frame and operate with hot or cold chamber metal pumps.

STRUCTURAL COMPONENTS

Machine Base

The machine base is a steel fabrication that supports the major machine components. It is generally a rectangular box, but the shape may vary based on the machine size and manufacturer. The base has several important functions.

First, it serves as a platform for the heavy steel plates to rest on. At small machines the height of the machine base is adjusted to place the work area of the machine at a convenient height for the operator. At large machines, a platform must be built for the operator.

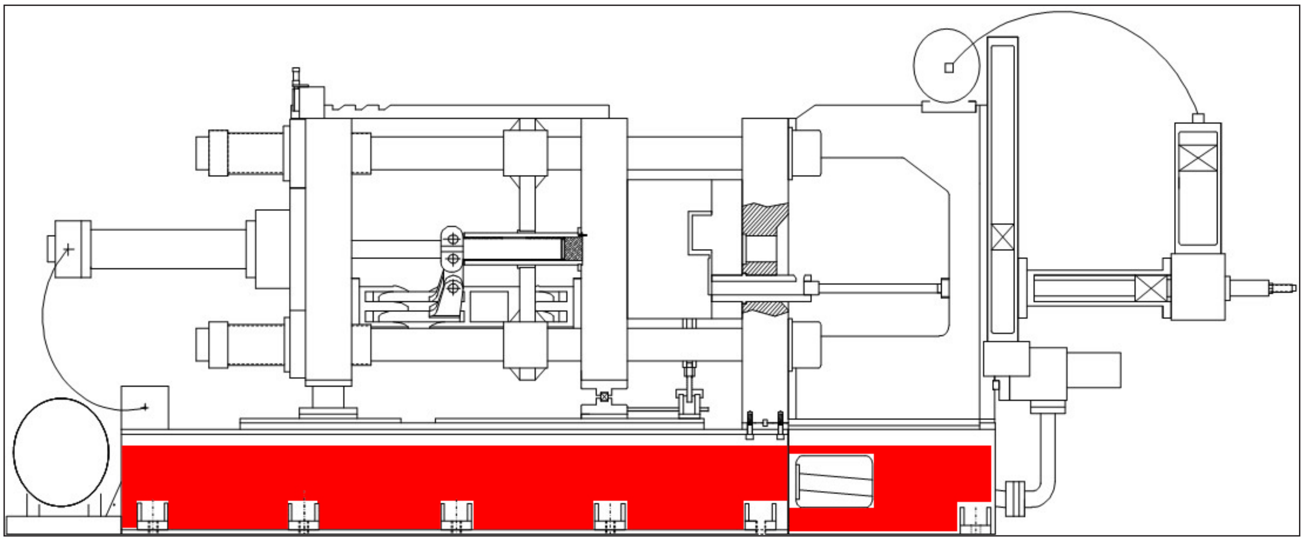


Figure 3-2 - Machine base and reservoir highlighted

Many machine manufacturers enclose the rear portion of the machine base to form a steel tank. This tank becomes a reservoir for the hydraulic fluid that powers the machine. During operation the hydraulic fluid in the reservoir and machine will heat. For safe operation hydraulic fluid manufacturers recommend that the operating temperature of the oil should not exceed 125˚F. If it gets too hot, it can lose its lubricity and fire resistance. For the hydraulic fluid to operate efficiently it must be kept clean. An effort must be made to keep the area of the reservoir clean and free of dirt and debris. The reservoir area should not be stacked with tools, castings and other materials.

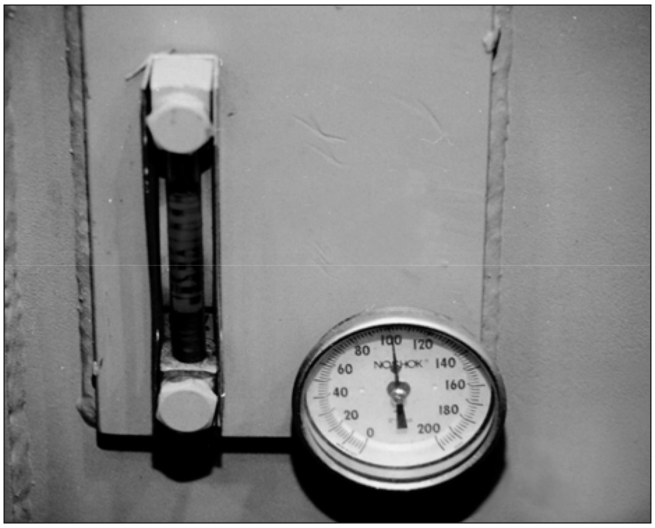


Figure 3-3 - Sight glass and thermometer

The reservoir is specially built to be an oil tank. To maintain temperature a thermometer is usually built in. Also, there is usually a “sight” glass somewhere on the side of the tank so it is easy to determine the level of fluid in the tank. Because of the high volume flow of hydraulic oil into and out of the tank, many tanks will be equipped with baffles and a breather. The purpose of the breather is to accommodate air flow in and out of the reservoir. You should make sure that the area around the breather is clear and air flow is not restricted. Baffles are placed in the tank to prevent turbulence and foaming of the hydraulic oil.

The “rear” or “clamp end” of the machine is the end opposite the injection end. This is generally where the electrical utilities, motors, and pumps are located.

The machine base must be strong enough to support the platens without sagging and must be rigid enough to withstand twisting that could occur if the machine were improperly locked.

The area around the base should be free of hoses and cords that could become trip-fall hazards.

Platens

The platens are the three large plates that support the machine loads. They rest on the machine base. They are known as the Stationary platen, Moving platen, and Rear platen. Their functions are fairly straight forward. The Stationary platen, located at the “shot” or injection end of the machine, holds the stationary die half on the die space side. The injection or shot end is usually mounted on the other side. The moving platen is located between the stationary and rear platens. The moving or ejector half of the die is mounted to the moving platen on the die space side.
The rear platen is located at the rear of the machine. The moving and rear platens are generally resting on “shoes” that slide on replaceable wear plates. Both the moving and rear platens move every cycle. The moving platen slides back and forth to open and close the die. The rear platen slides a little as the tie bars stretch. The rear platen is also known as the “adjustable” platen due to its movement to accommodate shut height adjustment and because it is adjusted for differing die heights.

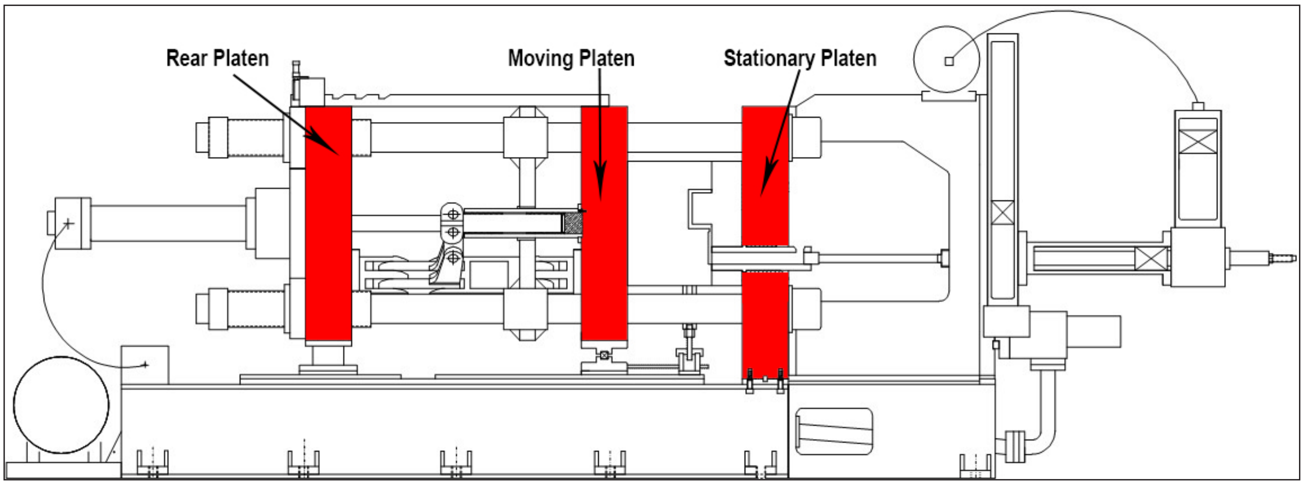


Figure 3-4 - Platens highlighted and labeled

The platens must be kept clean, particularly the die mounting surfaces of the moving and stationary platens. These must be cleaned every set-up to assure that there is good heat transfer from the die to the platens and that the die parting lines and faces are kept parallel to the machine platens.

The surfaces of the stationary and moving platens in the die space will have Tee slots or tapped holes for clamping the die. Care must be taken during set-up and operation to make sure these features are not damaged.

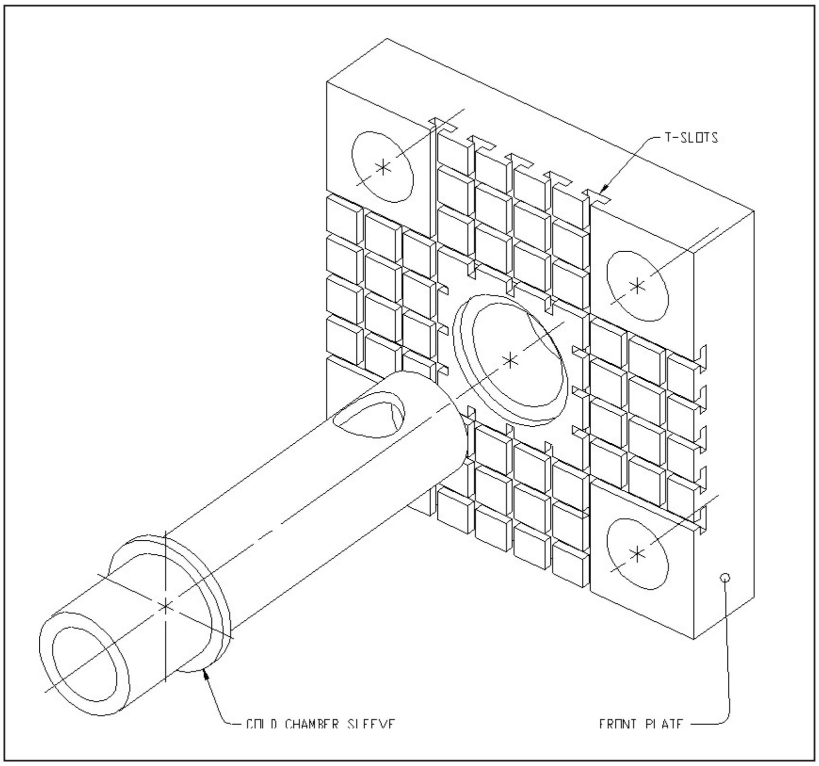


Figure 3-5 - Platens showing Tee slots or mounting holes

The stationary and moving platens may become hot enough to burn during operation, particularly the stationary platens of hot chamber machines. Some machines have water lines in the stationary platens to cool them.

By its very nature, the moving platen can become a strike hazard. Items attached to the moving platen or items attached and projecting from the platens may be a snag hazards. Care must be exercised around the moving platen to make sure all guards are in place and properly mounted.

Tie bars

Most machines have four tie bars. The tie bars are long, solid columns mounted through the four corners of the platens. They are used to orient and position the platens. The moving platen actually slides along the tie bars. The size and strength of the tie bars determines the size of the machine. Every cycle the tie bars actually stretch to develop the force that is necessary to hold the die together against the force of injection. If the machine is improperly set-up or somehow a tie bar becomes over-stressed, it is possible to break the tie bar. There is at least one machine manufacturer, Lester Machines, which replaced the tie bars with a solid frame made from a casting. These machines are no longer being manufactured but many are still in operation. A detailed discussion of the tie bar strength is developed at the end of this lesson in the “Process Math and Science for the Die Cast Operator”.

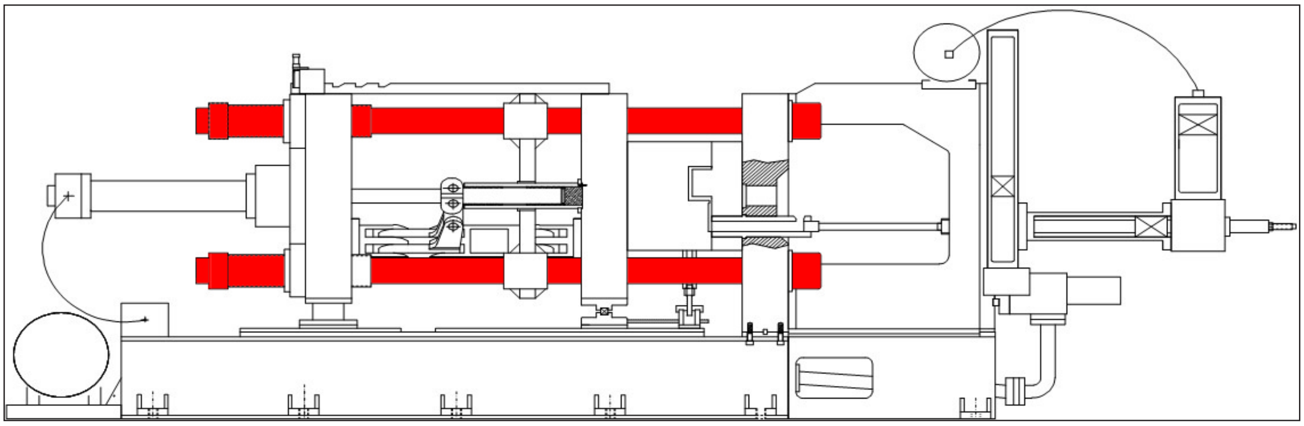


Figure 3-6 - Tie bars shaded

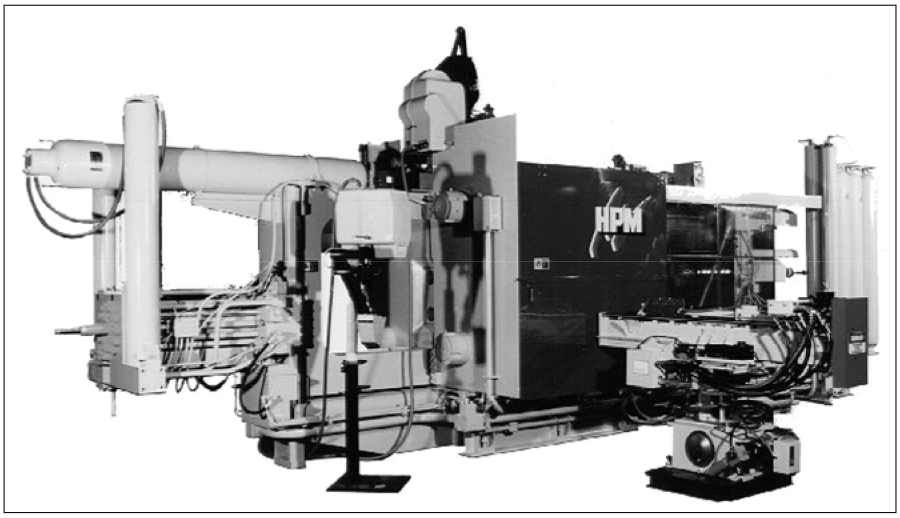


Figure 3-7 - Die casting machine

Toggle linkage mechanism

The Rear and Moving platens are connected to each other with the toggle linkage mechanism. This mechanism may look different depending upon the machine manufacturer, but it always performs the same function. It takes a great deal of force to stretch the tie bars and lock the machine. If this were to be accomplished with a hydraulic cylinder, the cylinder required would be very large and move very slowly because of the large amount of oil that would be needed. Indeed, some older machines in the 1940's did have very large cylinders. Die casting machine engineers developed the toggle linkage to overcome the deficiencies of using a large cylinder. The toggles act as levers and gain a mechanical advantage during die close and locking. This allows the use of smaller closing cylinders that can operate at higher speeds.

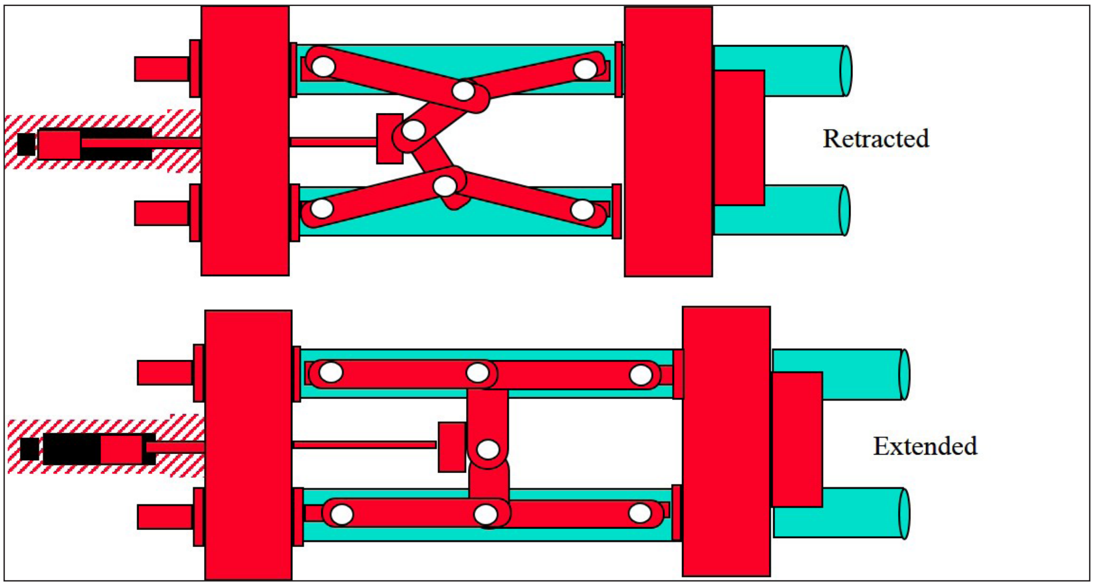


Figure 3-8 - Toggle mechanism, retracted and extended

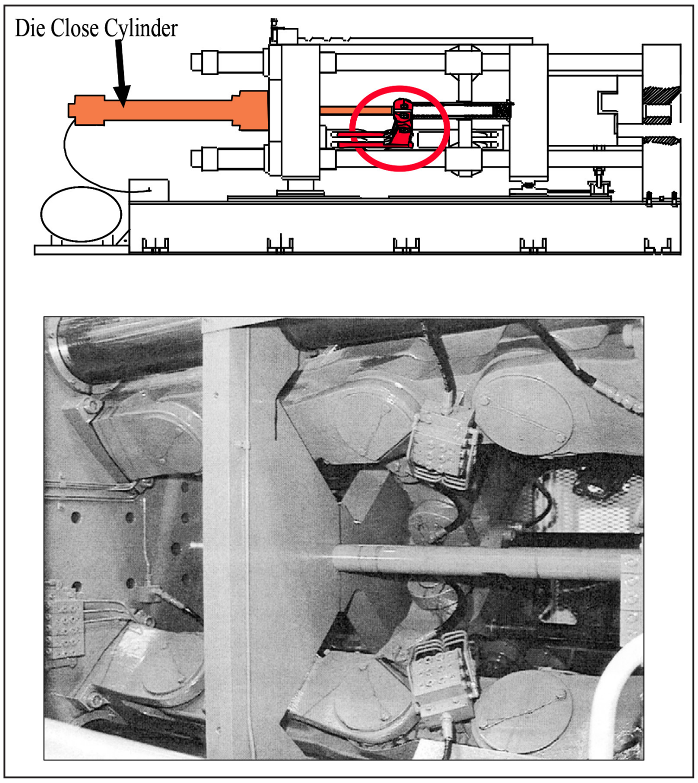


Figure 3-9 - Toggle mechanism

The toggle linkage area contains many pinch points that can be hazardous when the machine is operating. Guards should always be in place when the machine is operating or being set-up. If the toggle linkage area needs maintenance, the machine must be locked out and in a zero energy state (ZES) to prevent injury.

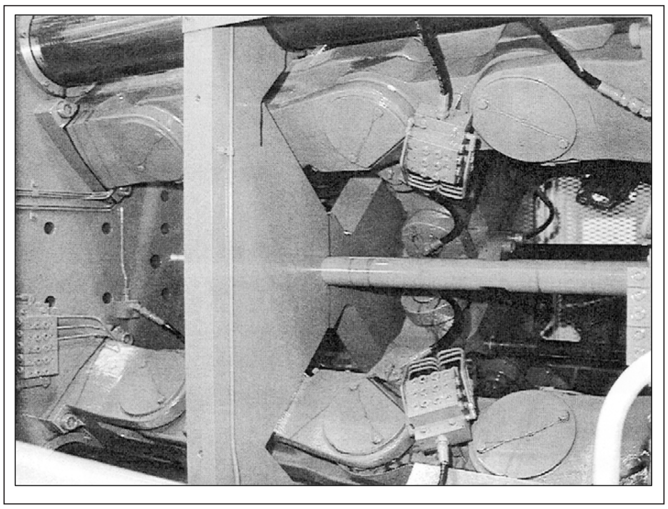


Figure 3-10 - Toggle mechanism without guards

SELF TEST 1

True or False

1. The major feature of the machine base is a large box that supports the platens.

   True False

2. The machine base usually contains a hydraulic reservoir.

   True False

Multiple choice; Identify all correct answers.

3. The front platen is a major machine component. The following components are mounted to it:

   a. shot end frame
   b. tie bars
   c. stationary die half
   d. ejector cylinder

4. The moveable platen is a major machine component. The following components are mounted to it:

   a. tie bars
   b. ejector cylinder
   c. ejector die half
   d. hydraulic core pulls

5. The rear platen is a major machine component, and it supports the:

   a. tie bars
   b. clamping mechanism
   c. die close cylinder
   d. ejector cylinder

6. The rear platen moves:

   a. every cycle
   b. for die height adjustment
   c. never
   d. when a tie bar is broken

Figure 3-11 - Lock-out tag

ELECTRICAL SYSTEM

Motor and Control Panel

An electric motor or motors provide the power for the machine. The motor is directly coupled to a hydraulic pump or generally to two pumps. Electrical power is converted into hydraulic power when the electric motor spins the hydraulic pumps. The pumps force oil into the hydraulic lines under pressure. The motor is located at the rear of the machine, usually on or adjacent to the reservoir. Near the rear of the machine will be an electric power cabinet that will enclose the motor starters and the machine control logic. A disconnect switch is mounted on the outside of this panel along with the lockout tag. The motor(s) operate at high voltage, usually 440/480 volts. This area must be kept clean and dry in order to avoid an electric shock hazard. The couplings between the motor and pump must be guarded because these rotate at high speed and could cause injury if contacted.

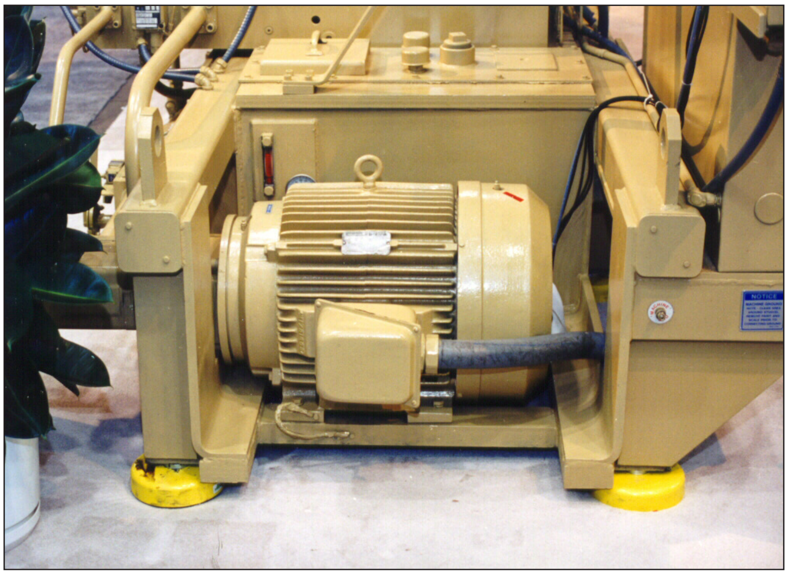


Figure 3-12 - Motor

Solenoids

Solenoids are used to shift valves to control the volume and direction of hydraulic fluid flow. A solenoid is an electromagnet that shifts a metal core. This core is attached to a valve spool to control and direct the oil flow. The solenoid/valves are relatively robust but should not be used as steps or otherwise abused.

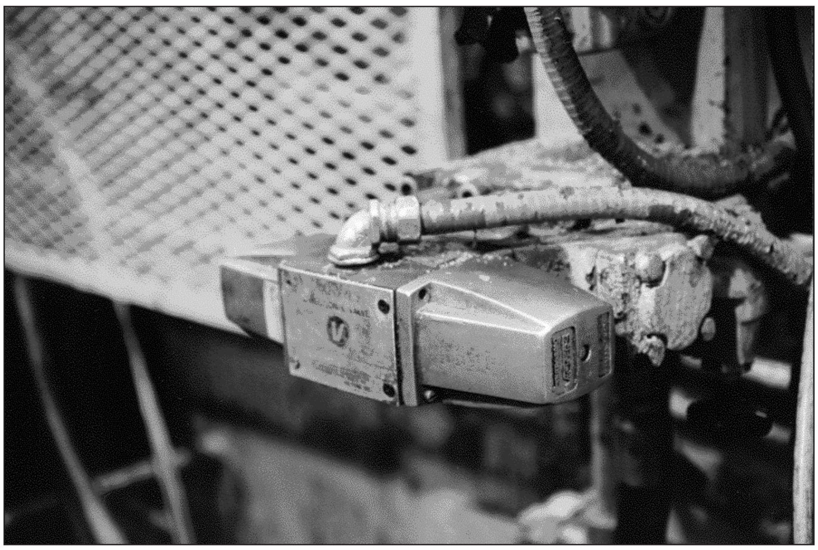


Figure 3-13 - Shot of solenoid valves

Limit Switches

Limit switches are the sensors, eyes and ears, of the electrical control system. They are located in many different places on the die casting machine. They are used to sense the position of doors, guards, cylinders and other moving components on the die casting machine. Their maintenance is essential to the safe operation of the machine. Limit switches must never be defeated or tied back. Broken connectors and exposed wiring at limit switches should be repaired immediately in order to assure safe operation of the machine. The trip rods or actuating mechanisms at the limit switch will cause pinch points.

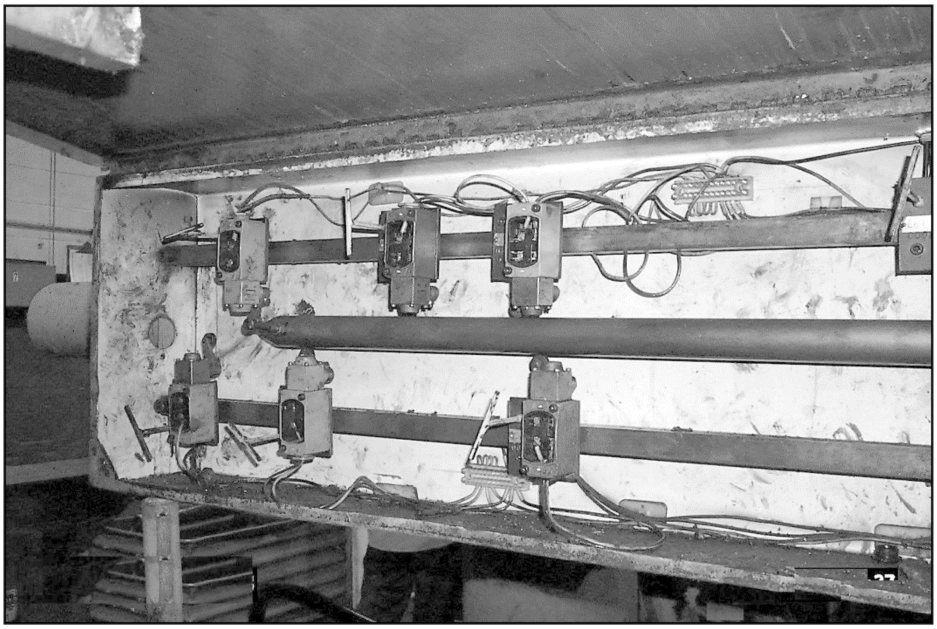


Figure 3-14 - Limit switch and trip rod

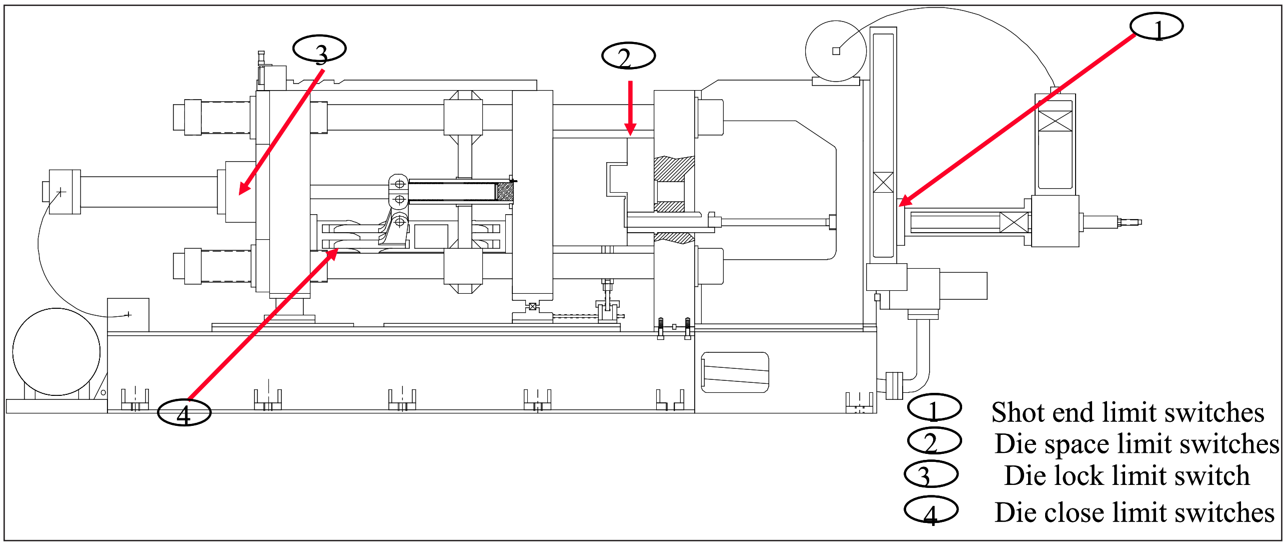


Figure 3-15 - Overall machine view, with arrows locating limit switches

The machine may also have other types of switches and sensors. Some of the limit switch functions may be accomplished with proximity switches. There may be pressure switches that react to a given level of hydraulic pressure.

HYDRAULIC SYSTEM

The die casting machine functions are operated by a hydraulic system. This means that fluid, usually fire resistant oil, is used to power the cylinders that make the machine move. This hydraulic system operates at high pressures and high flow rates. For those reasons alone, we need to keep safety in mind.

The hydraulic fluid is hot and can cause burns. Leaks and spills should be repaired and cleaned up quickly. These not only waste costly oil but also can cause slippery surfaces that could result in injuries if someone slips and falls.

Hydraulic Pumps

A die casting machine usually has a minimum of two hydraulic pumps. One pump is capable of providing oil at high pressures but in low volumes. A second pump would be capable of providing a high volume of oil at low pressures. For example, the pumping capabilities of a 400 ton machine may be 8 gallons per minute of 2000 PSI oil from the high pressure pump and 40 gallons per minute of 200 PSI oil from the low pressure pump. This type of pumping capability is used to solve the various demands of the die casting machine. The die close cylinder requires a large amount of oil to open and close the moving platen. Once the die faces close, only a small volume of high pressure oil is required to stretch the tie bars and lock the die. Just the act of closing requires the output of both pumps.

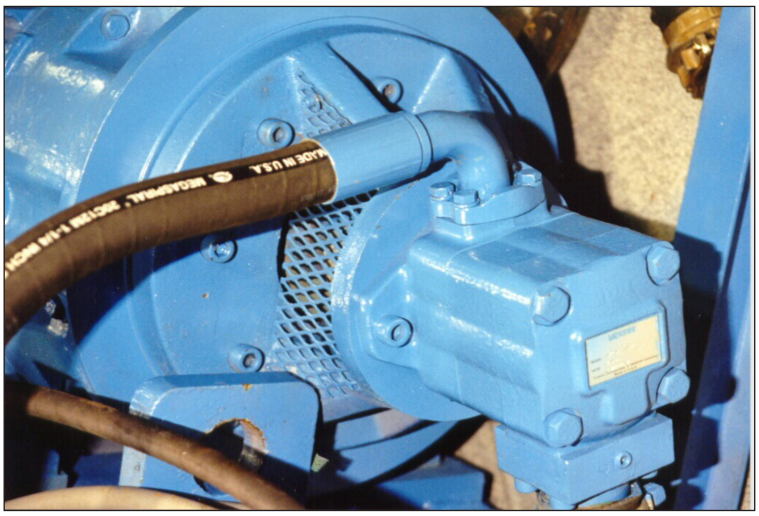


Figure 3-16 - Close-in of hydraulic pumps and motors

Filters

Filter(s) are required to keep the hydraulic fluid clean. The filter(s) are located at the outlet of the pumps to assure that clean oil is sent to the various valves and cylinders. The filters require routine maintenance to make sure they work properly. Most filters have a visual differential pressure gage on them that should be checked frequently to make sure the oil is clean. Small dirt particles in the oil can cause valves to fail because of the small clearances in the valves.

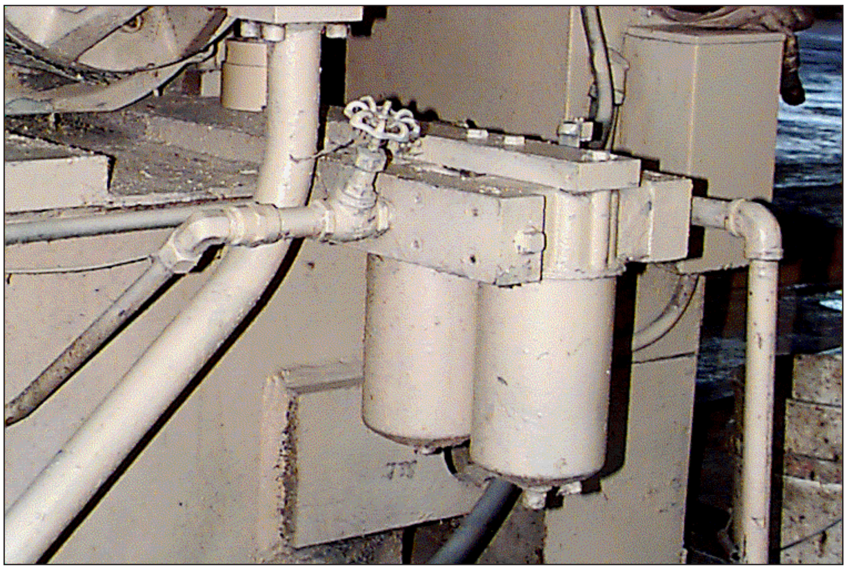


Figure 3-17 - View of several filters

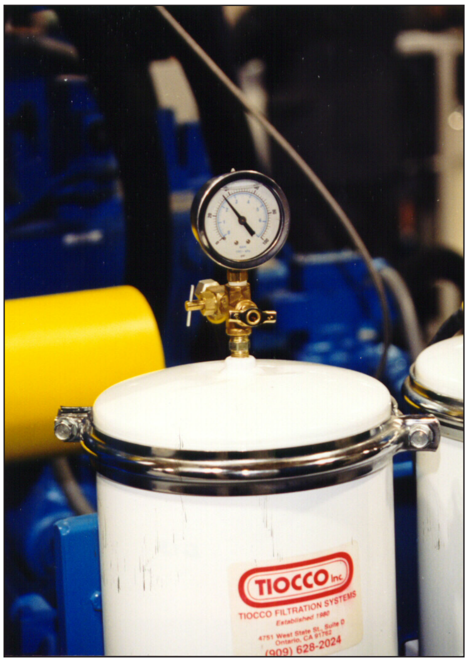


Figure 3-18 - Close-up of differential pressure gauge on filter

Valves

Valves are used to control the amount and direction of oil flow. Solenoid operated valves are used to direct the flow to the head or rod side of a cylinder or they may direct oil to shift a large valve, such as the pilot operated (P.O.) check valve at the base of the accumulator.

Some of the valves may be manually operated. For example, the valves controlling the speeds of injection or die closing may be fitted with large hand wheels. These valves are used to control or shut off the oil flow.

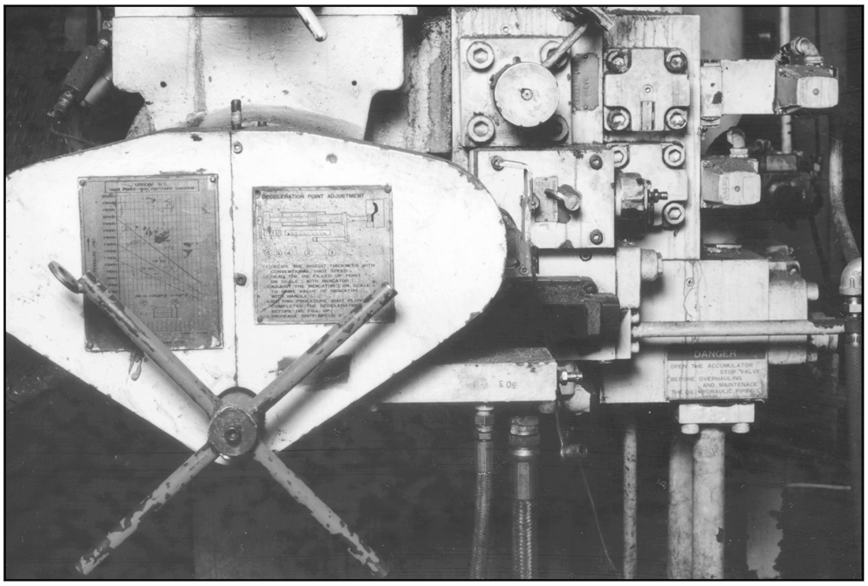


Figure 3-19 - Speed control valve for shot cylinder

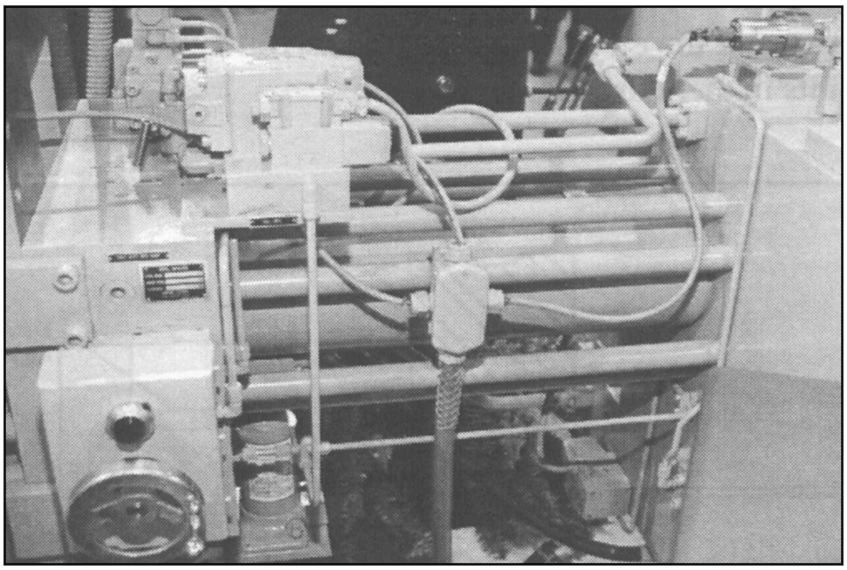


Figure 3-20 - Speed control valve for die close cylinder

On more modern machines the speed control of machine functions is controlled by a series of valves mounted on a manifold. The manifold provides a centrally located source of hydraulic fluid for the speed control valves.

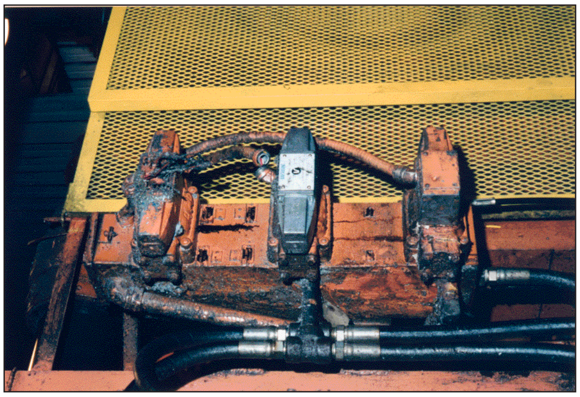


Figure 3-21 - Close-up of solenoid valves

Heat Exchanger

Most machines will have a heat exchanger to cool the DCM's hydraulic fluid. This is a large tubular tank located adjacent to the reservoir. It operates similar to a boiler. Internally the heat exchanger will have a large number of pipes going through. Cooling water will circulate through these pipes. Hydraulic fluid will be let into one end of the heat exchanger; the fluid will flow over the water cooled piping and give up heat to the water. The fluid will then flow out the exit. Factors affecting the efficiency of the heat exchanger are the same as those affecting die cooling. If the water lines fill up with lime (calcium), heat flow is reduced. If fluid flow is to slow, heat flow is reduced.

Leakage in the heat exchanger can be troublesome in two ways. First the hydraulic oil can be contaminated by too much water. Second the recirculating water will be contaminated by the hydraulic fluid. As an operator, you should be aware of the hydraulic fluid temperature. If it gets too hot, then check for flow through the heat exchanger, both hydraulic oil and coolant.

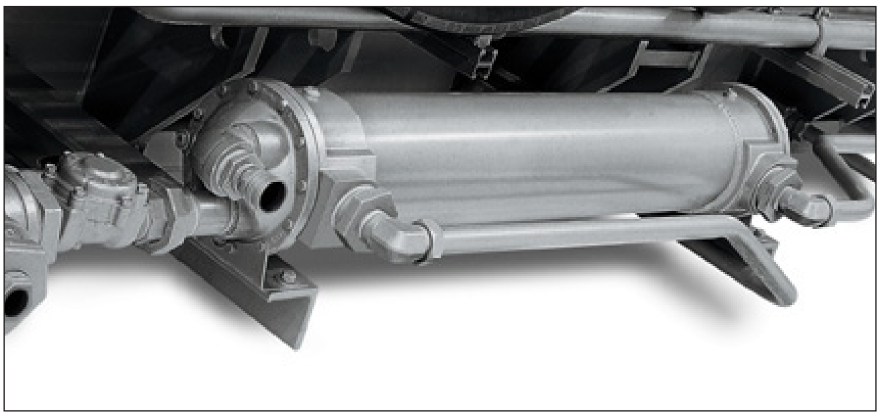


Figure 3-22 - Heat exchanger

Cylinders

Hydraulic cylinders are used to open and close the machine, to inject the metal into the die, and may be used to operate the ejection system, move slides on the die, actuate a safety ratchet and open and close a safety door at the die parting line. These cylinders may be liquid or air operated. Cylinders operate very simply; a fluid comes in one end and pushes an internal piston to the end of the cylinder. In order to accomplish work one end of a rod is connected to the piston and the other end of the rod is connected to whatever we want to move. Hydraulic cylinders can be very powerful. The force that a cylinder can develop depends on its size and the pressure of the hydraulic fluid.

Die Close Cylinder

The die close cylinder is used to open and close the die. It is mounted on the rear platen, with the cylinder rod extending through the platen and connected to the crosshead, or center of the toggle linkage.

Figure 3-23 - Die close cylinder

Ejection Cylinder

Some machines have cylinders to actuate the ejection system on the die. The ejector cylinder is mounted to the moving platen on the toggle linkage side. It may be a single cylinder with a rod that connects to the ejector plate in the die, or there could be several cylinders that are used to move a large plate that will actuate “bump pins” that operate between this large plate and the ejector plate in the die. The area of the ejector bumper plate is usually covered by the guards that cover the toggle area. You must be sure that the pinch points in these areas are protected.

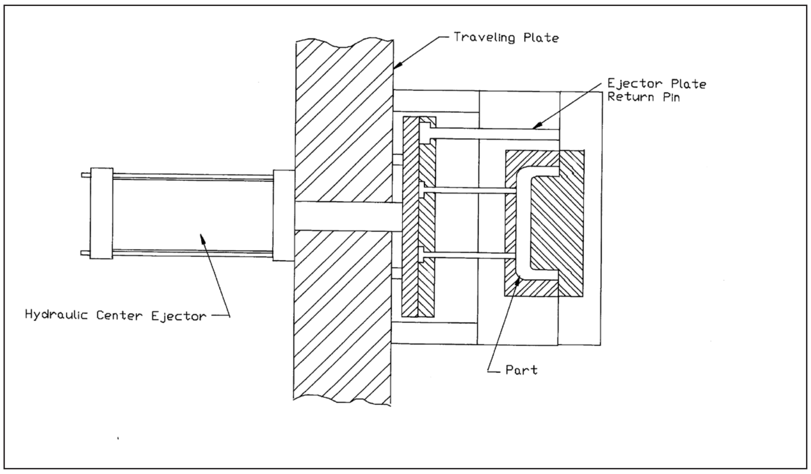


Figure 3-24 - Sketch of center hydraulic ejection cylinder

Shot Cylinder

The shot cylinder is used to inject the metal into the die. On hot chamber machines the cylinder rod is connected to a plunger that is located in the gooseneck. This cylinder is mounted to an “A” frame that is supported by smaller tie bars from the furnace side of the stationary platen.

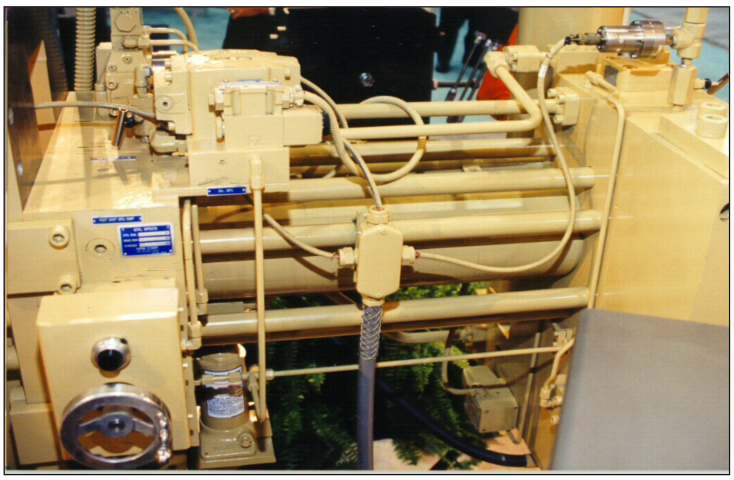


Figure 3-25 - Shot cylinder

On a cold chamber machine the cylinder rod is connected to a plunger that is located in the cold chamber. The shot cylinder is mounted to a "C" frame that is mounted to the stationary platen.

SELF TEST 2

True or False

1. The purpose of filters is to smooth the oil flow.

   True False

2. Hydraulic pumps supply high and low pressure oil.

   True False

3. Valves control the amount and direction of oil flow.

   True False

4. The heat exchanger is used to heat the die.

   True False

Multiple choice - Identify all correct answers:

5. The following are typical hydraulic components found on a die casting machine:

   a. accumulators
   b. valves
   c. bump bars
   d. filters

6. Hydraulic cylinders at the machine are used for:

   a. closing
   b. injection
   c. ejection
   d. hydraulic core pulls

Injection Components

The hot chamber injection components include the shot cylinder, plunger coupling, plunger, rings, gooseneck, bushing, and nozzle. An “A” frame supports all of these components. The plunger rings are assembled to the plunger tip just as piston rings are fit to an automotive piston. The purpose of the rings is to prevent metal leaking past the plunger tip and to maintain metal pressure in the die cavity at the end of cavity filling. The bushing and nozzle connect the gooseneck to the casting die. The metal to metal contacts between the die, nozzle, bushing, and gooseneck must not leak during operation as the spitting metal could be a burn hazard to anyone in the area. During operation these components are all very hot and could burn if touched.

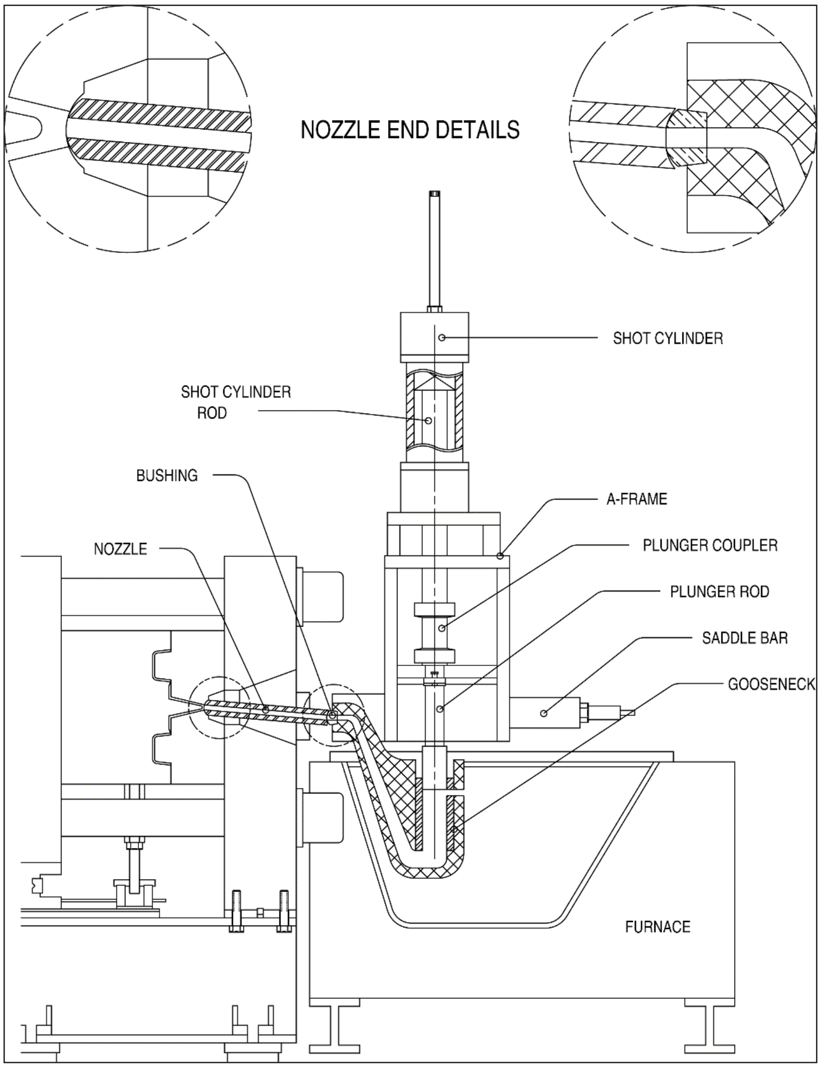


Figure 3-26(a) - Injection components, hot chamber

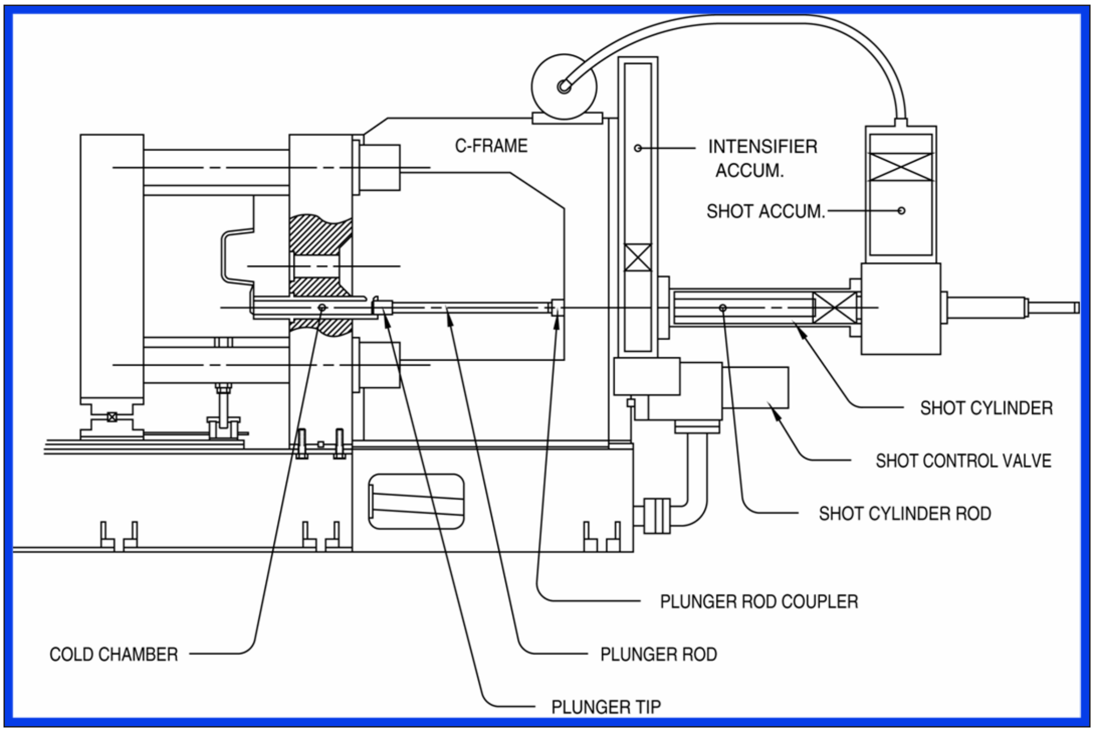


Figure 3-26(b) - Injection components, cold chamber

For efficient operation, care must be taken during set-up to assure that the shot cylinder and plunger are in proper alignment. This will assure a minimum of wear and operating problems.

The cold chamber components include the shot cylinder, plunger rod and tip, coupling and the cold chamber. Alignment of the chamber, tip and rod, and shot cylinder is critical to the efficient operation of the injection system. The shot cylinder rod extends from the shot cylinder and is connected to the plunger rod with a coupling. Care must be taken to avoid damage to the cylinder rod. It is a precision machined component that extends through a packing gland that seals the high pressure oil into the shot cylinder. This should not be used as a step or tool rest. In some cases the position and velocity transducers for the shot cylinder are machined into the cylinder rod. The plunger tip is usually made from a beryllium copper alloy in order to achieve fast cooling of the cast biscuit or plug at the end of the cold chamber. Proper cooling and temperature control of the tip is necessary to prevent metal from bypassing the tip and spitting out of the chamber. This can be hazardous. Sticking tips can also be a problem and proper training is necessary before one attempts to remove a stuck plunger.

Accumulator

The accumulator is simply a large steel tank. This tank is partially filled with hydraulic fluid above which is a column of high pressure nitrogen gas. An accumulator is used when large volumes of hydraulic oil are required. This could be during die open or close, or during injection and intensification.

For example, during the fast shot phase of injection, the valve at the base of the accumulator is opened and oil is supplied to the shot cylinder. Neither of the hydraulic pumps can supply the gallons per second of oil needed for cavity filling. Once the accumulator is discharged its job is complete. During another portion of the casting cycle, the oil is pumped back into the accumulator, recharging it.

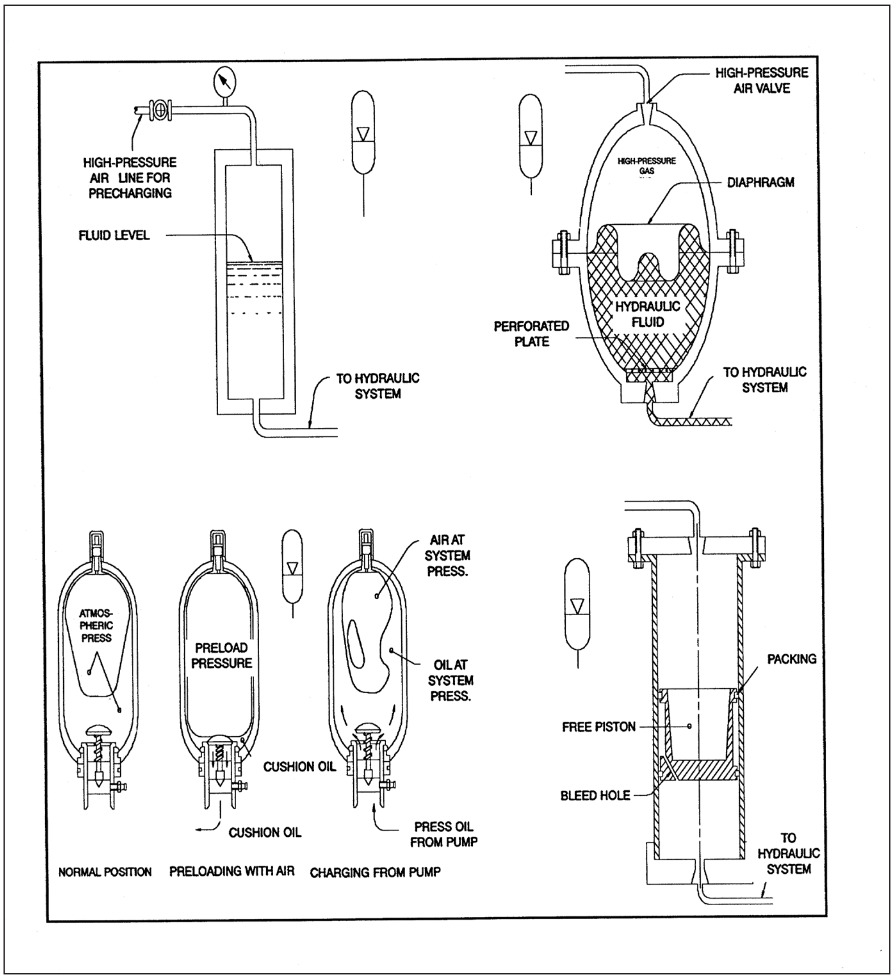


Figure 3-27 - Various types of accumulators

The accumulator stores a large amount of oil under high pressure. This could be potentially hazardous. When maintenance to the machine or die is required, activities that require the machine to be “locked out”, the accumulator must be returned to a “zero energy state”, or ZES. This will require relieving the pressure in the accumulator to eliminate the possibility that a hydraulic cylinder could move.

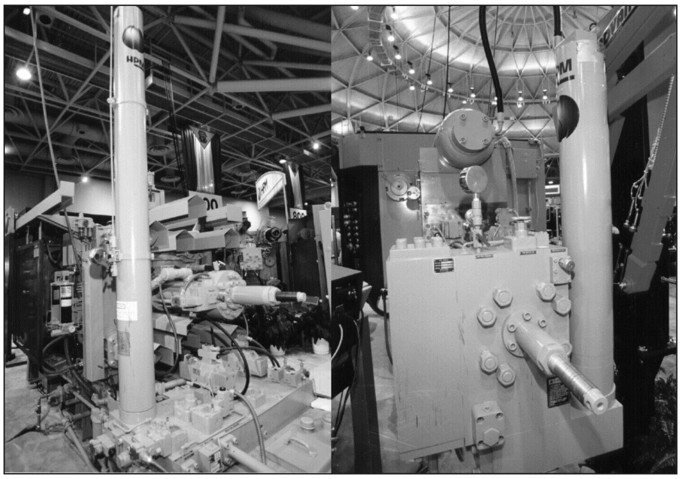


Figure 3-28 - Shot accumulators

Intensifier

The intensifier is a hydraulic device that increases the hydraulic fluid pressure at the end of the injection stroke. The purpose of this high pressure is to dramatically increase the metal pressure in order to squeeze additional metal into the die cavity as the metal shrinks and to further compress trapped gases.

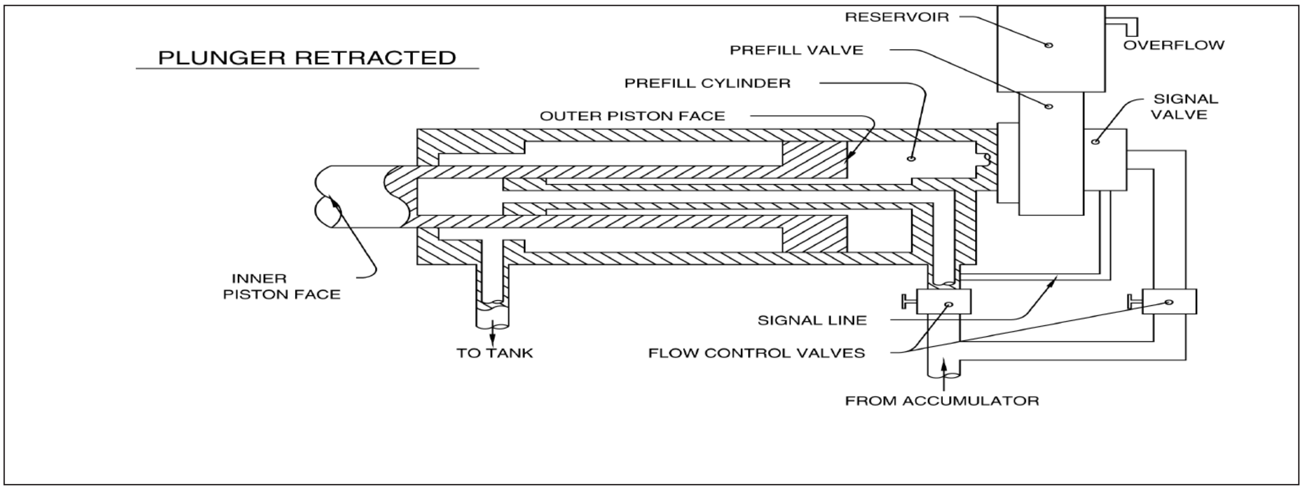


Figure 3-29 - Schematic of passageways from the intensifier accumulator to the plunger in order to increase pressure at the end of the shot stroke.

SELF TEST 3

True or False

1. The accumulator supplies the hydraulic fluid during cavity filling.

   True False

2. The intensifier squeezes the metal during cavity filling.

   True False

3. High volume pumps are generally low pressure pumps.

   True False

4. High pressure pumps are generally low volume.

   True False

Multiple choice - Identify all correct answers:

5. Cold chamber shot end components include:

   a. cold chamber
   b. tip
   c. rod
   d. rings

6. Hot chamber shot end components include

   a. gooseneck
   b. nozzle
   c. plunger
   d. coupling

7. The purpose of the first stage of injection is to:

   a. purge dirty metal from the metal flow path
   b. vent air and gases in the metal flow path
   c. advance the metal in a sinusoidal wave form
   d. allow some of the metal to form solids

VARIATIONS IN CONVENTIONAL MACHINES

Most die casting machines operate along a horizontal axis. Pivoting these machines on the shot end and orienting them along a vertical axis created another family of machines. A major advantage of this type of machine is in making castings that require cast-in inserts. Gravity is used to hold the inserts in the stationary die half. Also, unloading can be simplified by using gravity to drop the castings on an unloader after ejection.

Figure 3-30 - Vertical die casting machine

Another variation of the conventional horizontal machine is one that is used to cast and trim in the same die space. In this special machine both a casting die and trim die are mounted to the machine platens. A specialized unloading mechanism then rotates the casting from the casting die to the trim die, finishing a casting every cycle. During the first cycle one casting is cast. After die opening this casting is rotated to the trim die. The next cycle makes a new casting and trims the first. Thereafter, a casting is cast and trimmed every cycle.

Non-Conventional Machines

“Four-slide Machines” are specialty die cast machines used for the production of small castings with the hot chamber process. The machine consists of a frame used to support a furnace, small pivoting gooseneck and large plate that is angled 5-10° from vertical. The dies are actually two to four slides that are mounted to the plate and open and close along the horizontal and vertical axis of the machine. Some machines use air as their pneumatic fluid. The closing forces are very low and manufacture is limited to very small parts. These machines run at very high production rates, 20-30 cycles per minute. Tooling is usually designed to run with minimal draft and flash free to eliminate any secondary operations. Also, tool costs are very low when compared to conventional tooling.

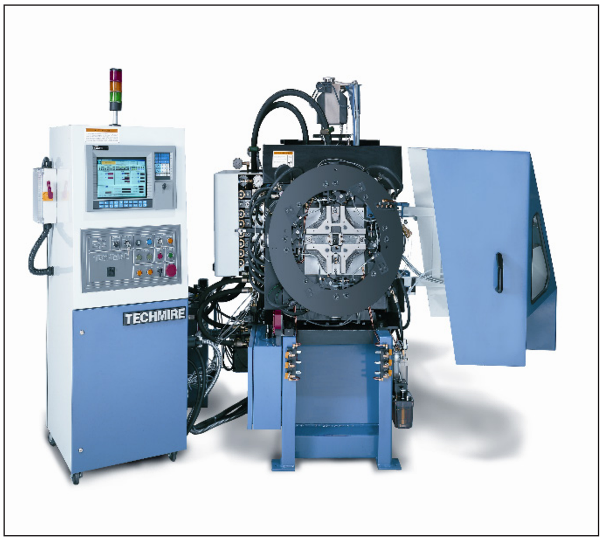


Figure 3-31 - Techmire machine

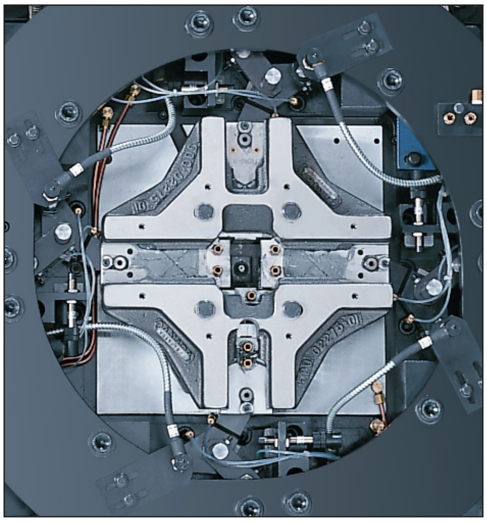


Figure 3-32 - Close-up of Techmire machine

"Low pressure Machines" are die cast machines that have been designed to run on a process that is similar to conventional die casting. The low-pressure process uses metal pressures on the order of 5 PSI. The low pressure machine has a vertical opening and closing stroke and is mounted over the holding furnace. The process injects metal by pressurizing the air above the metal in the furnace and forcing the metal up a tube into the die. The characteristics of metal flow are very similar to sand or permanent mold gravity casting. Compared to conventional die casting, the tooling cost is low and the cycles are very long. Internal quality of the castings is usually better, but the process does not have the ability to fill the thin walls that conventional die casting can.

DIE LUBRICANTS/RELEASE

Another major material in the die casting process is the release material that is used between injection cycles. The application of this material will occur every cycle or at a some regular frequency. This material has several functions, first and foremost is to act as a parting or release agent. A second purpose is to provide cooling in order to obtain a uniform temperature distribution. A third function is to aid lubricity and metal flow.

In recent years die releases have been converted from solvent based agents to water born agents. Solvent based agents have been deemed undesirable because they tend to burn or decompose and release undesirable hydrocarbons. One of the biggest differences with this change is the amount of heat removed by the release agent. The water born die releases remove much more heat than the solvent based release agents.

The components in release agent are organic, inorganic, or synthetic. The organic materials are based on carbon chains; these materials include most oils, waxes, fats, and silicones. Inorganic materials are crystalline solid materials usually in the form of small particles, including graphite's, boron nitride, MoS2 (molybdenum sulfide), and others. Synthetics are carefully made reaction products, usually organic, which contain very few impurities.

Functions

The first function is to provide lubrication and release. This is accomplished by applying a thin layer of lubricant on the die steel; this results in a carbon barrier as thin as 1/1,000,000 of an inch. This prevents soldering of the aluminum in the alloy with the steel/iron in the die. If the lubricant is applied to heavily, the lubricant can build-up. This build up is a combination of aluminum and carbon that can be removed readily. Minerals can build-up from water based lubricants. These minerals, like lime build-up in waterlines, is more difficult to remove. Build-up of the lubricant can impair proper venting if left on the die face.

The second function of the water based die lubricant is to provide cooling at the die surface. Some die casters feel cooling might be best accomplished by just spraying the die with atomized water.

Figure 3-33 - Spraying water on die to cool it

The last important function of the die lubricant is to control the lubricity and metal flow of the alloy.

Some key features of die lubes are low gas generation, noninterference with finishing, good cleanliness, low smoke and odor generation, ease of mixing and handling, and an acceptable ecological profile.

Lubricant Application

Spray wand

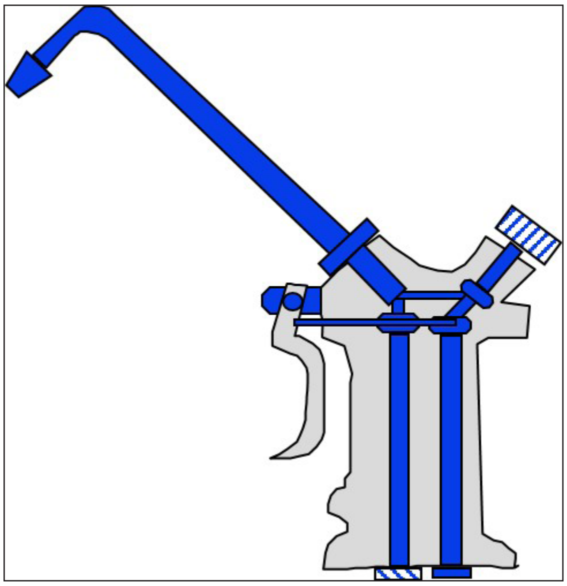


Figure 3-34 - Cut-away of a spray wand

Die release can be applied in a number of ways. The most common method of application is manually with a spray wand having a single nozzle. This method is under control of the die cast machine operator. You are responsible to determine how the die must be sprayed to achieve maximum quality and productivity. The typical controls the operator has over the spray application are:

1. Nozzle adjustment for spray pattern.
2. Air pressure at nozzle.
3. Lubricant volume at nozzle.
4. Spray location.
5. Spray duration or time.

Spray pattern

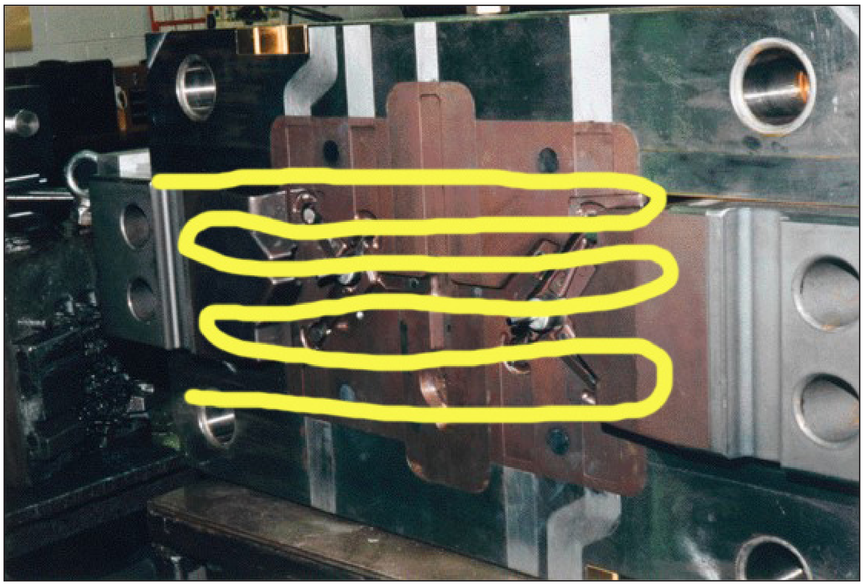


Figure 3-35 - Graphic of various spray pattern

A specific nozzle type can be selected to provide a circular spray pattern, or a nozzle may be selected to provide an oval shaped pattern. Some nozzles are adjustable and can be varied to supply a circular or elongated pattern.

Air pressure adjustment

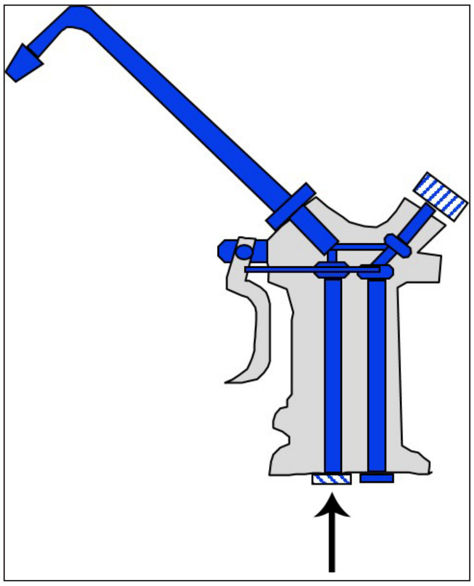


Figure 3-36(a) - Cut-away of a air adjusting screw

Most spray wands will have an adjustment for the volume of air flow at the nozzle. Two things are important when making adjustments to the air-lube mixture. First we want to achieve atomization, to provide a fine layer of lubricant to the die surface. Second, we need adequate air pressure to force this mist into the deep recesses of the die. The air pressure regulator is usually mounted to the air supply pipe. You must know maximum air pressures recommended for your spray wand, so they are not exceeded.

Lubricant volume at nozzle

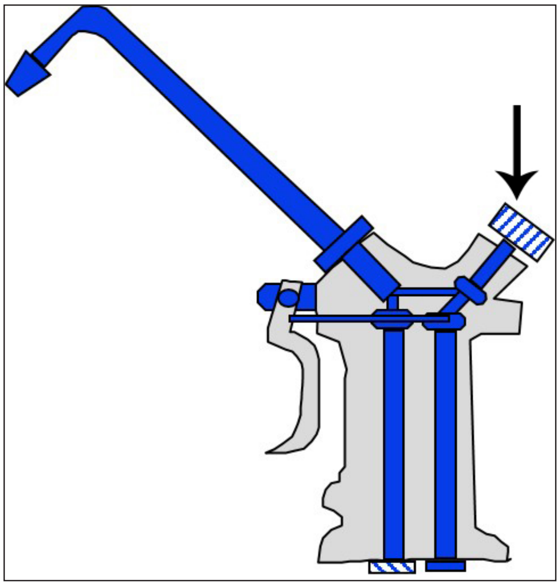


Figure 3-36(b) - Lubricant adjustor identified

As with air, the flow of lubricant must be controlled to achieve atomization and also to flow enough volume to coat the cavity in a reasonable amount of time.

Spray location

A very important part of your job as an operator is to apply the die release where it is required, to avoid excessive application, and to blow excessive or trapped lube out of recesses and corners. You must be able to look at the casting and be able to “read” the surface finish for defects and temperature in order to be able to gauge the application of die release for the next cycle.

Spray duration or time

Spray duration is the dominant variable with respect to heat removal from the die. It is more effective than increased volume. For example, if spray were being applied at a rate of 20 in^3/min. for 3 seconds. Doubling the spray volume to 40 in^3/min will not double the heat removal. But doubling the spray time from 3 seconds to 6 seconds will double the heat removal.

Fixed Head Spray application

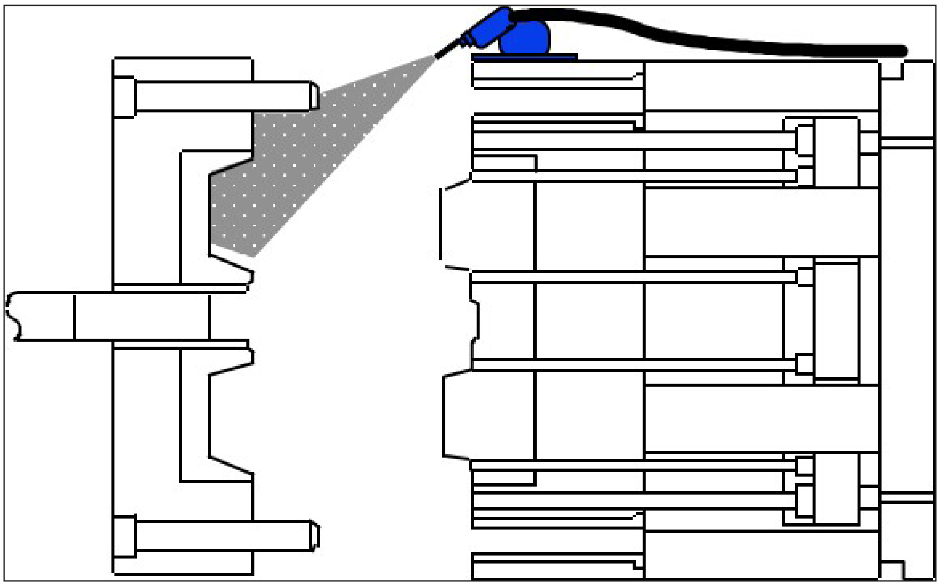


Figure 3-37 - Fixed spray head

Fixed spray nozzles are another method of die release application. With this method individual nozzles are mounted around the periphery of the die or machine platen, on both halves. The nozzles must be pointed at the proper locations, with proper adjustments to the volumes and pressures of the air and lubricant.

Reciprocating Spray Heads

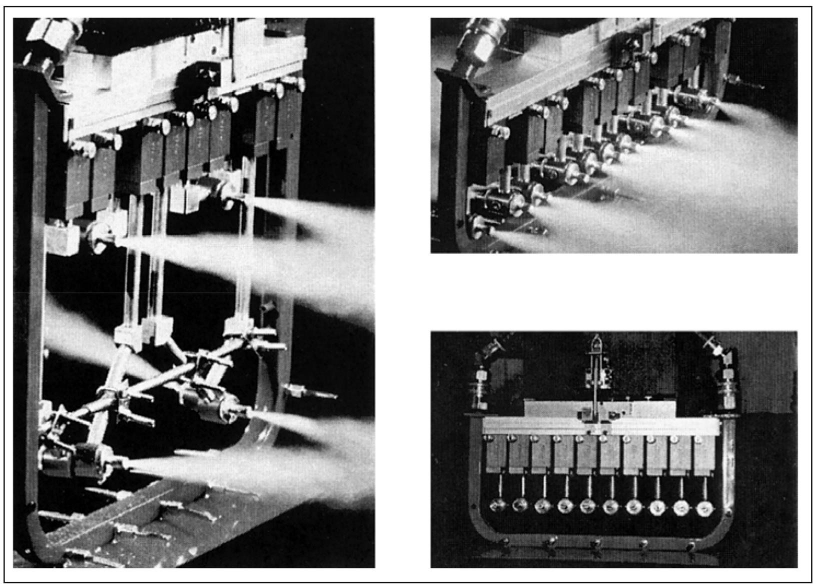


Figure 3-38 - Reciprocating sprayers and manifolds

Another method of applying die spray is through the use of a reciprocating applicator. Reciprocators usually have multiple nozzles that can be adjusted for direction, volume and pattern. Additionally, reciprocators have adjustments for travel and dwell. To simplify set-up and repeatability some die casters will have dedicated manifolds with nozzles for important jobs.

Characteristics of Lubricant Application

Atomization has previously been mentioned as one of the goals to be achieved when setting up the die spray nozzle. It has been found that the smaller droplet size is better in obtaining good contact with the die steels. Larger droplets will have a tendency to form a steam barrier that the lube cannot penetrate. If a droplet of lube can contact the solid surface, the molecules on the surface will be more attracted to the solid surface than to the liquid. The droplet then spreads, increasing the surface area contact. This is called “wetting”.

If a lube can wet the die surface quickly, spray time can be reduced, and cycle time reduced. This could cause the die to run hotter, improving filling and reducing thermal shock. This should result in better die life.

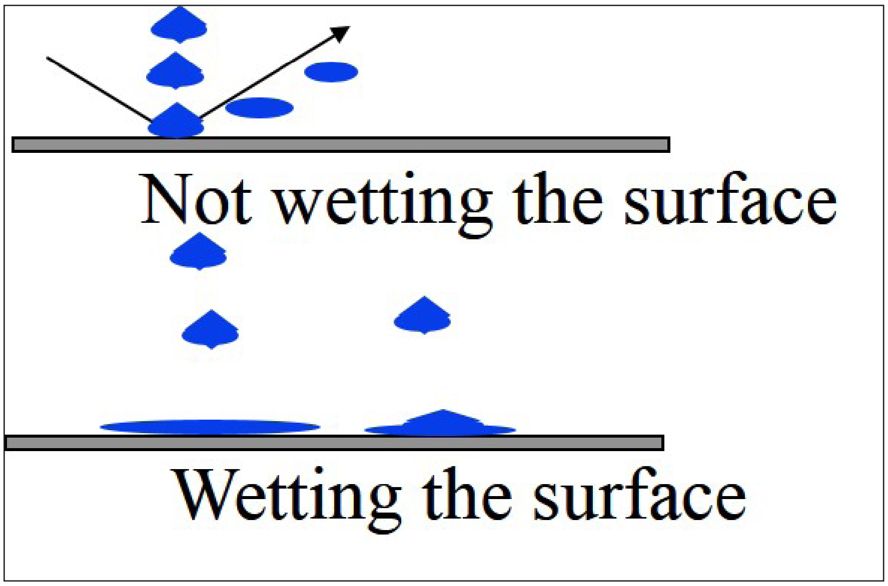


Figure 3-39 - Die lube wetting

Die lube will run away from hot spots in the cavity. Also, radiant heat will resist die lube. Pre-cooling with water could be solution to hot spots, prior to applying the die spray.

Air currents will affect the die spray application. In the case of multiple nozzles spraying on a cavity, the interaction of the sprays should be reviewed and the nozzles redirected if necessary. Converging spray patterns could work against getting lube where it is required.

Lastly, a most important characteristic of the lube will be its concentration in its carrier. 50:1 dilutions with water are common, and some die casters have extended as much as 100 and 200:1. A dilution of 50:1 means 50 parts of water to 1 part of lube. Whatever dilution is required, proper instructions for mixing must be given and the ratio should be checked on a periodic basis.

HYDRAULIC FLUIDS

Function

Hydraulic fluid is the medium that converts electrical power into mechanical action; it transmits power from one point to another point. The fluid also lubricates the surfaces it contacts. Lubrication is a very important function because of the tight tolerances of components, such as gears, valves and pistons in the hydraulic system.

Properties

The physical properties of the hydraulic fluid are very important. The most important physical property is viscosity. Viscosity of a fluid describes its thickness, or resistance to flow. It is a measure of the internal friction of the fluid. Viscosity is measured in a unit called SUS, or the Saybolt Universal Second. A viscosity number is the amount of time it takes 60 cubic centimeters to drain from a container at given temperatures, usually 100°F and 210°F.

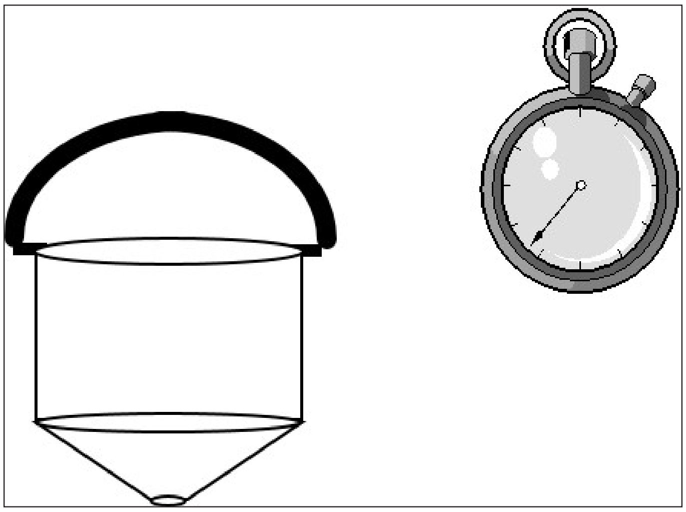


Figure 3-40 - Viscosity cup and stopwatch

Viscosity changes with temperature. As temperature goes up the viscosity goes down and vice versa. A good hydraulic fluid is one that has a relatively constant viscosity over the entire temperature operating range of the system.

The Viscosity Index (VI) is a measure of how much the viscosity of the fluid varies from 100-210°F. Water based fluids do not have a VI. This is because their viscosity varies with the percentage of water in the fluid.

Viscosity also varies with pressure. The VI increases with pressure. In other words, as pressure goes up the change in viscosity between 100-210°F goes up.

Another important property of the hydraulic fluid is its “pour point”. This is the lowest temperature at which the fluid will flow.

Chemical Properties

The most important chemical property that the fluid must have is resistance to oxidation. If the fluid oxidizes, its viscosity increases, it darkens in color, it decomposes and forms varnishes and gums that jam components and plug orifices. This is the most common factor in shortening the fluid life. Oxidation in hydraulic systems can be controlled by using the proper equipment, proper chemical formulation, and proper maintenance.

Other contaminants that affect the performance of the hydraulic fluid are water, air, foaming and corrosion.

In some systems, water in the form of water vapor, and air get into the hydraulic fluid and form an emulsion. These water emulsions can be thin slurries, pasty, or heavy gummy mixes; all depending on the fluid viscosity and water content. These emulsions will promote the collection of impurities (dirt) that lead to increased friction and wear. These emulsions are not stable and during periods of shutdown demulsification or breakdown of the fluid takes place. When this happens, the water settles out, causes corrosion and lack of lubrication.

Dissolved air in the fluid can also be a problem. Air gets into the system when it is picked up at the pump suction filter in the reservoir, or through leaks in piping and seals. Air in the fluid causes oxidation. If the fluid has too much air in it, it will foam. This can cause erratic operation of the machine because of sudden pressure drops due to the compressibility of the fluid with air. If foaming is a problem it can be managed with screens and splash plates or chemical additives.

Corrosion and rusting can occur in the hydraulic system as the result the fluid oxidizing. Some of the products of oxidation of the fluid are acids that cause corrosion. Also air and water trapped in the fluid will cause rust. The corrosion resistance of most hydraulic fluids is excellent, except, water glycols will attack magnesium, and zinc. Additionally, the water glycols have low lubricity when compared to petroleum based oils.

Fluid Types

The hydraulic fluids available in die casting are petroleum oil, water emulsions, water glycols or phosphate esters. Each of these has characteristics that make them more desirable in a particular application. It may simply be the price. The comparison table rates some of the important characteristics.

Hydraulic Fluid Comparison Chart

Fire Resistance	Petroleum	Water Emulsion	Water Glycol	Phosphate Ester
Bare flame	poor	fair	very good	good
Hot surface	poor	fair	good	very good
Cost (times petroleum)	1	1	2-2.5	3.5
Stability	excellent	good	excellent	excellent
Lubricity vane pump	excellent	good	very good	excellent
Gear pump	excellent	excellent	excellent	excellent
Corrosion protection	very good	good	good	very good
Compatibility	excellent	very good (except paint)	very good (except paint)	good (except paind, rubber, plastic)

Operating Characteristics

As an operator it is important that you understand how the viscosity of the hydraulic fluid changes during the die casting process, you should also note if the hydraulic fluid is undergoing changes that will lead to its degradation.

At machine start-up the hydraulic fluid viscosity is high, it is thick and cold. This means the machine performance will not be up to expectations. For example,

- There will be a greater overall pressure drop at all the various components.
- Overall the system experiences increased drag and is sluggish.
- Noise levels will be higher.
- Power consumption will be higher because of greater resistance in the system.
- There will be a greater vacuum at the pump inlet.

This means that time must be allowed at the start-up to warm up the hydraulic fluid. Some dry cycling should take place to redistribute lubricant and move fluid through the various components.

Once the machine is warmed up normal operation should be expected. If abnormal things happen such as erratic shot performance, or pump cavitation, this could be an indication of foaming or excessive air in the fluid. These types of problems should be referred to your supervisor.

One of the things that can go wrong during normal production is overheating of the hydraulic fluid. Most manufacturers of hydraulic fluid will specify a recommended operating range for those fluids. For die casting machines, the maximum temperature is about 125°F. If the fluid overheats it will loose its viscosity and the following problems could occur:

- Leakage can increase at valves and actuators.
- Leakage at gaskets, seals, and connections.
- Increased pump slippage.
- Increased wear.
- Shortened service life of the fluid.

As an operator you should monitor the temperature the fluid. Most reservoirs have a thermometer on them. A good time to check the temperature is at breaks, after periods of extended operation. High fluid temperature could be an indication of a heat exchanger that is plugged or not open.

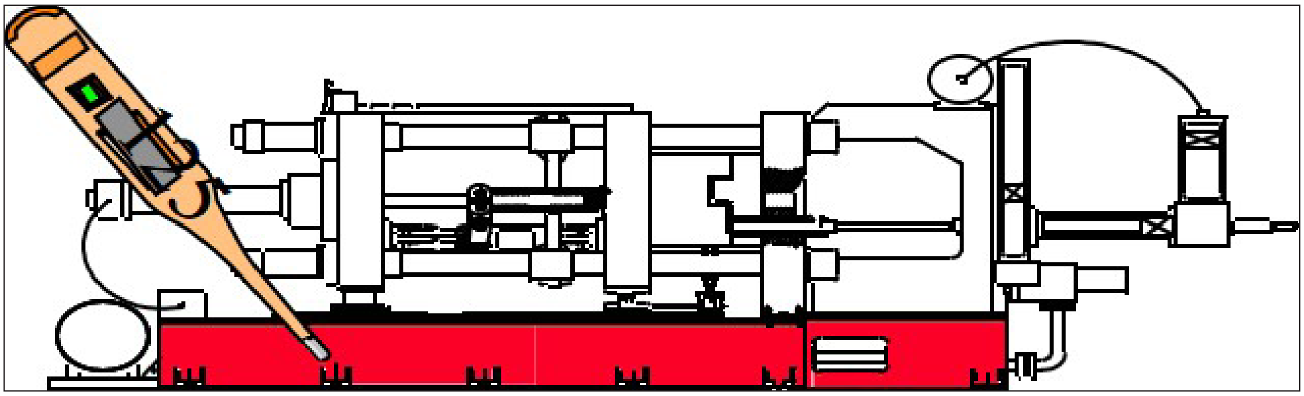


Figure 3-41 - Know the temperature of the oil!

SELF TEST 4

True or False

1. The main purpose of die release is to cool the die.

   True False

2. Hydraulic fluids such as water glycols are very fire resistant.

   True False

3. Die release should always be diluted at 50 parts of water to 1 part concentrate.

   True False

Multiple choice - Identify all the correct answers:

4. Die release should:

   a. mix easily
   b. not interfere with finishing operations
   c. be free of noxious odors
   d. not be full of dirt

5. Die release is most effective when:

   a. it atomizes
   b. wets the cavity surface
   c. It is properly diluted
   d. none of the above

6. Hydraulic fluids will deteriorate if:

   a. exposed to air
   b. gets dirty
   c. due to rust in the piping
   d. operated above 125ºF

7. When the machine is started, and the hydraulic fluid is cold,

   a. it will be noisier than usual
   b. the fluid will be more viscous (have higher viscosity)
   c. the machine will consume more power
   d. the machine will operate normally

DETAIL DESCRIPTION OF THE MACHINE CYCLE ELEMENTS

Modes of Operation

The casting machine will have several modes of operation. The most common modes are Manual, Automatic, and Semi-automatic. The mode of operation is chosen with a selector switch.

The modes of operation are explained as follows:

Semi-automatic, the machine completes one cycle and stops. A machine operator issues the cycle start command for each new cycle. The machine completes only one cycle at a time.

Automatic, the machine runs one cycle at a time and receives a cycle start command each cycle from an automated sensing device that determines if the previous cycle has been completed successfully or the machine runs continuously.

Manual, the machine performs each individual machine function as commanded from the control panel for as long as the command is sent. Other names for this mode are inch or jog. This mode is used for set-up. At set-up further control over the functions is achieved by throttling the speed valves that supply the various actuators or cylinders.

Machine/Die Close

Cycle Start

To run a casting machine cycle, the cycle start must be actuated. There are several acceptable methods for starting the casting machines cycle. Whatever method your company has selected as being safe should not be disregarded.

Double palm buttons- many companies have the operators simultaneously actuate double palm buttons to start the machine cycle. The palm buttons must be held until the operator safety door is closed and access to the parting line blocked. The machine will close after the safety door is shut.

Safety door closure- another technique is to have the machine operator close and hold/latch the safety door closed until the die is locked.

Safety door/cycle start- another variation is to have the operator close the safety door and push the cycle start button. Once the safety door is closed, the machine cannot close and lock the die until all safety conditions and cycle sequence conditions have been satisfied. These conditions are as follows:

At the die:

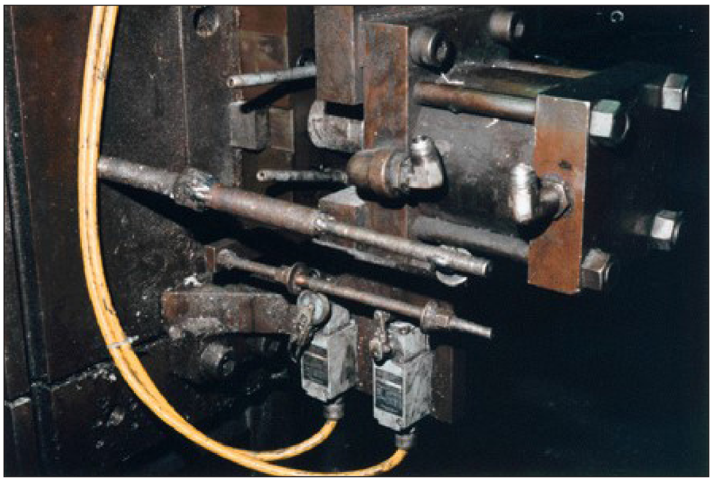


Figure 3-42 - Limit switch locations at a hydraulic cylinder on die

For machines and dies employing hydraulic coupled ejection, the ejector plate must be "home" in the returned position. This must be done if ejector pins are located under slides and would interfere with a slide in the "home" position. (The "home" position is the ready to cast position of all components, slides in and ejectors back.) An ejector plate limit switch is required to prove the ejector plate is home.

A die with ejector half hydraulic cores must have the cores in the withdrawn position, cores out. This must be proved with a limit switch.

A die with stationary half hydraulic cores must have the cores in the withdrawn position, cores out. This must be proved with a limit switch.

At the machine:

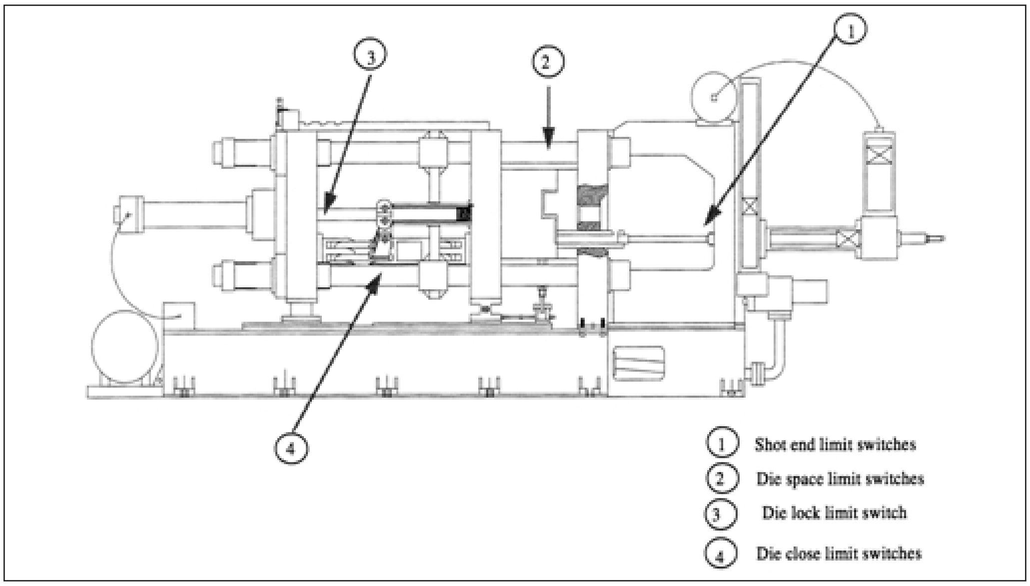


Figure 3-43 - Limit switch locations detailed at the machine

The safety pawl is engaged.

- Guards are in place over and around the toggle/linkage mechanism.
- Safety doors are in place, preventing access to the die parting line.
- Ejection cylinder is returned, home.
- The die close cylinder is in the open position.
- The injection cylinder is in the home position.

After all the conditions are satisfied the safety pawl is withdrawn and the machine can begin closing. The machine will close rapidly, but under low pressure. The speed of die closing can be controlled by opening or closing a throttle valve, or if cartridge valves are used, by programming the logic controller. A properly setup machine will close using low pressure hydraulic oil. In case an obstruction is encountered, the machine will stop, not having enough power to overcome the obstruction and cause damage. The setting is only good to prevent damage to tooling and equipment and should not be considered a personnel safety device. A limit switch setting should determine the transition from low to high pressure. This should be at about 0.030” of the die faces meeting. High pressure oil is used to close the die faces, stretch the tie bars and lock the die.

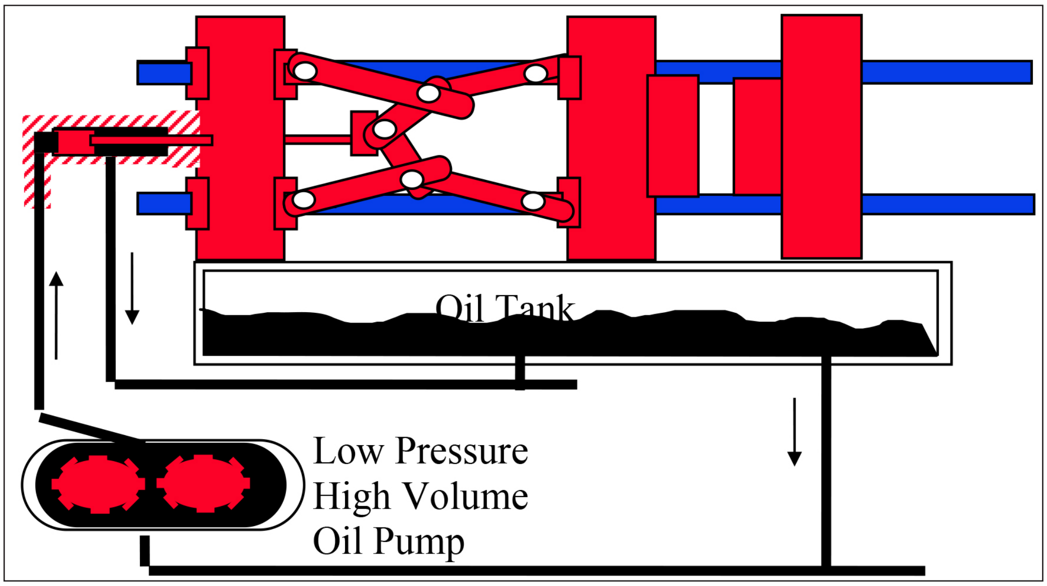


Figure 3-44 - Hydraulic schematic showing low pressure die close

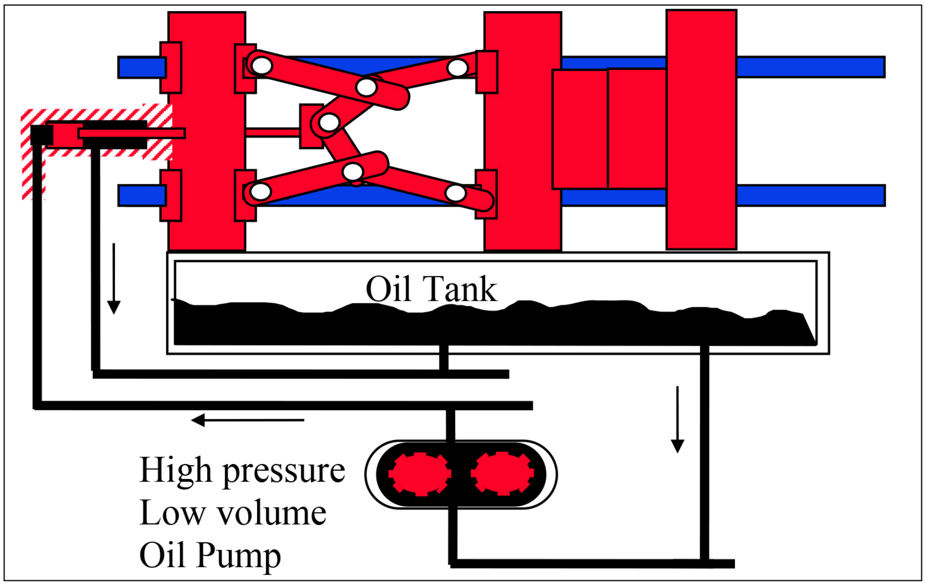


Figure 3-45 - Hydraulic schematic showing high pressure die closing

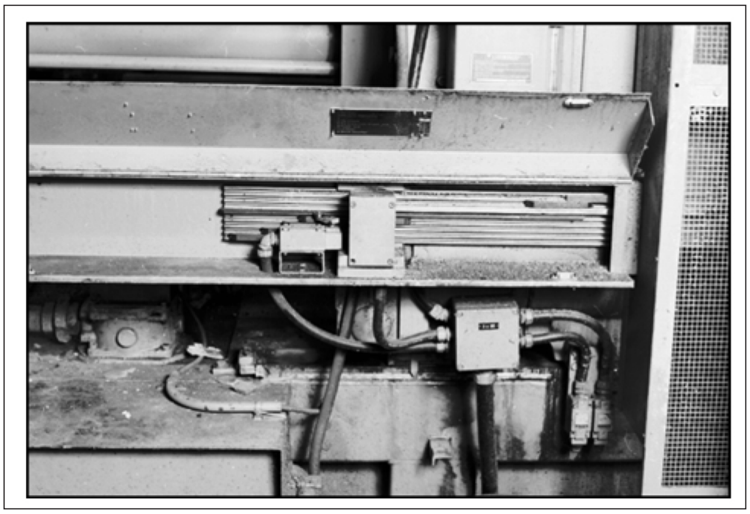


Figure 3-46 - Low pressure limit switch

If you review the hydraulic schematics for the two stages of die closing you will note the differences in oil volume and pressure requirements. During the first stage of die closing the cylinder has to move a long distance, whatever the die closing stroke is. During this stage the only resistance the cylinder must overcome is the static friction to get the platen moving and then a lesser dynamic friction to keep the platen moving. You need a lot of oil, but at relatively low pressure. Most machines have enough low pressure pump capacity to supply this oil directly from the pump. At the second stage of die closing, the die faces are in contact, so the cylinder travel requirement will be relatively small, but it will take a great effort to stretch the tie bars to lock the machine. For the second stage of die close, the high pressure pump supplies a small volume of oil at very high pressure. Once the toggles are locked, a limit switch senses their position.

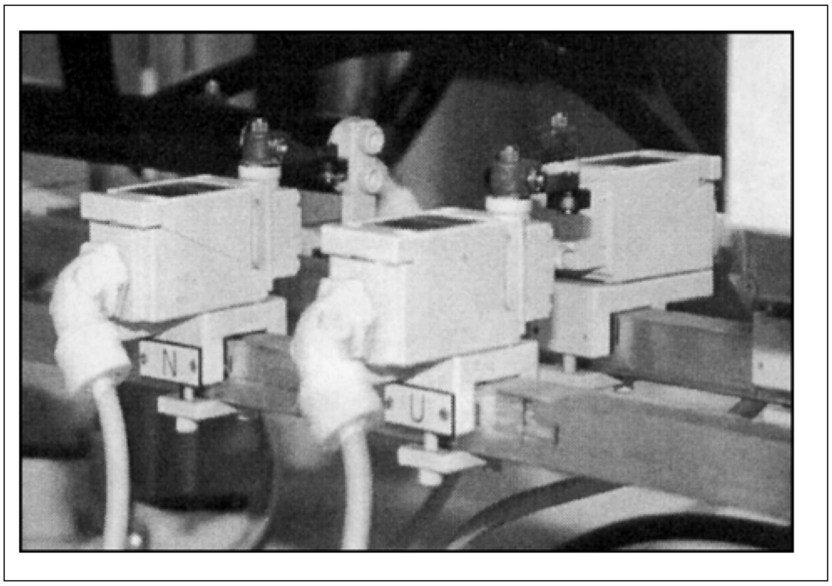


Figure 3-47 - Die lock limit switch location

Die locking, or in other words, tie bar loading is one of the major die casting process variables. As the machine operator, you should be aware of this and observe the lock up sequence as frequently as possible. The tie bar loading, or amount of stretching, can vary from cycle to cycle. Usually these changes are not large or important, but when they are, you should be aware of them in order to take corrective action. The amount of tie bar stretching can be measured. By measuring the stretch of each tie bar every cycle and observing the readings you will know if a change has occurred. If this is not practical, other methods of monitoring the tie bar strain will have to be developed.

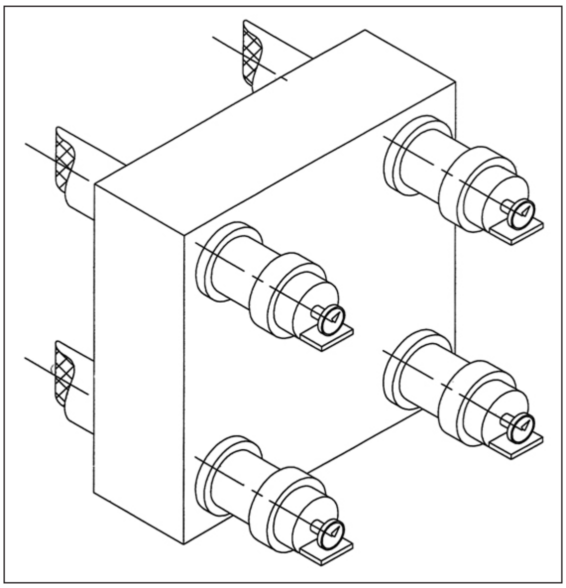


Figure 3-48 - Tie bar strain indicators

Tie Bar Stretch (strain)

When you refer to a die casting machine as a 600 ton machine, you are saying that it can develop a closing force of 600 tons (not that it weighs 600 tons). This means that the machine can hold a die together, against an injection force of up to 600 tons. If that 600 tons is exceeded, the die will pop open and spit metal. If the force is exceeded by a large amount, the machine, or a tie bar, could break. This is not a common occurrence, but it does happen when people are ignoring what is going on in the process. The die casting machine develops this closing and holding force by stretching, or preloading, the tie bars. For proper operation of the machine it is important that each tie bar be stretched the same amount. If this is not the case, the machine will twist with the imbalanced load and may not hold the die together.

The amount of stretching can be measured. This is called "strain", which is a mechanical property of many materials. Strain is predictable depending on the material, the size of the material and how much stretching force is applied to the material. The material of the tie bar is steel and the size is its cross-sectional area (or circular area). Strain is defined as the amount of stretch (elongation) divided by length over which the stretch was measured. For example, if a tie bar stretches 0.008" over a distance of 8.0", the strain is:

Strain = 0.008in/8.0in = 0.001in/in

(Strain = 0.2mm/200mm = 0.001mm/mm)

The strain is equal to one one-thousandth of an inch per inch. Or every inch of the tie bar stretches 0.001". A 10 foot long tie bar, 120 inches long, would stretch 0.120"; almost an 1/8th of an inch.

(The strain is equal to one one-thousandth of a mm per mm. Or every mm of the tie bar stretches 0.001mm. A 3.048m long tie bar, 3048mm long, would stretch 3.05mm.)

The tie bar strain can be measured a number of ways. The simplest method is to drill a tie bar to a specific depth and measure the strain over the depth of the hole.

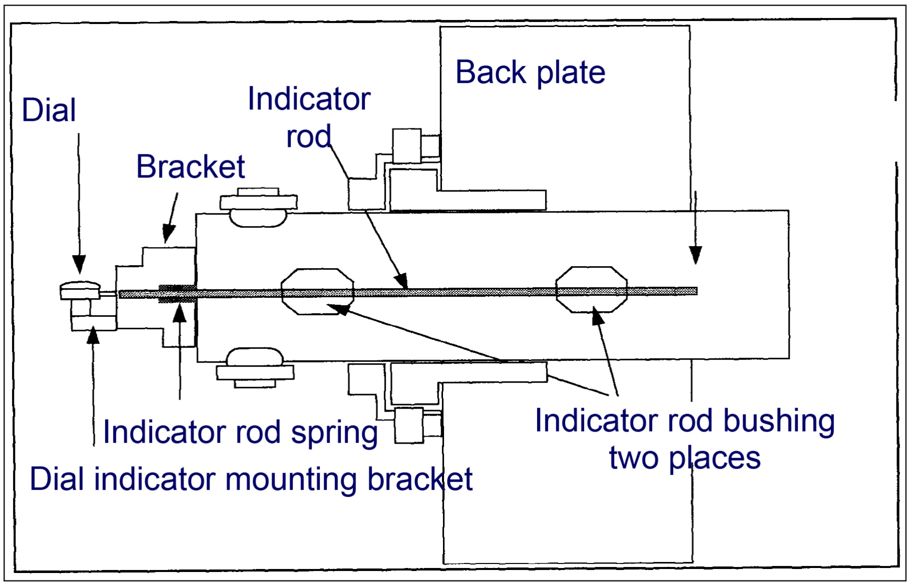


Figure 3-49 - Tie bar strain in drilled tie bar

Another method is to use a temporary magnetic device with a dial indicator that clamps to the tie bar and measures the amount stretch between the magnets.

Figure 3-50 - Magnetic tie bar strain device

Changes to die locking

As noted previously, die locking/tie bar strain is an important process variable and you as the operator should be continually aware of how the die lock is behaving. Under normal operating conditions the machine cycle will have a particular rhythm. The normal cycle will have various noises, such the sprayers, the shot and the hydraulic pumps and motors. You should be aware when changes to this normal cycle occur, be aware of the exceptions. In the case of die locking, is the machine slowing down and straining more to lock the die? Has the machine sped up and is it locking with less effort? Is the machine straining and twisting, or bending? Is the machine "popping" or jumping when it unlocks? Machine locking and unlocking should be fluid movements with a hesitation when the machine locks and stretches the tie bars.

The objective of the die is to maintain a consistent and uniform lock, straining the tie bars uniformly. If the die lock changes during production you should try to determine why the change occurred and correct the problem. There are several common causes for the die lock changing. They are:

- Temperature
- Flash
- Loose fittings

As the die heats up to operating temperature, you can expect it to expand. This means the shut height dimension will get longer. As the die gets bigger, it will be tougher and tougher for the machine to lock up. When this occurs, you will have to open the shut height to adjust for the larger die.

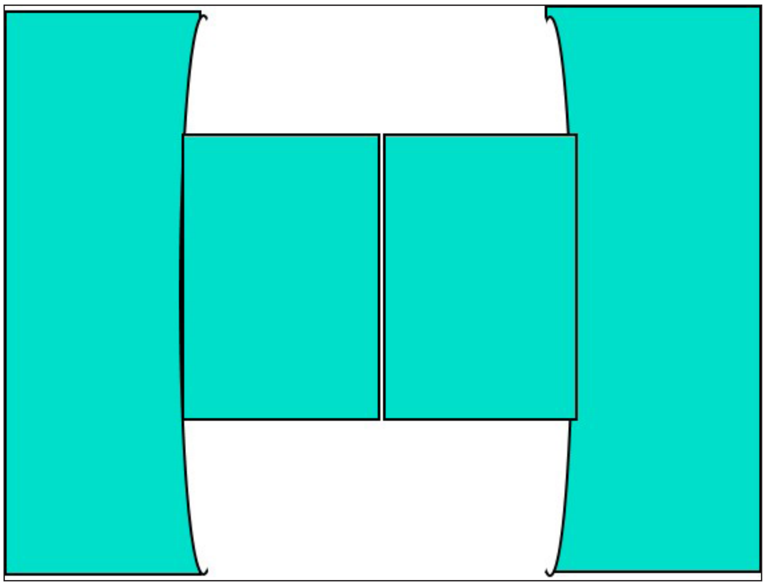


Figure 3-51 - Die expanding

As with the die, during production the machine also warms up. It is possible that the tie bars could increase in temperature by 20-30°F(10-15°C). This will cause the tie bars to expand (get longer). If this happens the lock will get looser. The shut height will have to reduce to tighten the lock.

Flash stuck to the die faces will make the die thicker. This is similar to the die expanding due to heat, except it can be more of a problem. First, changes due to flash are usually greater than expansion. Second, the flash is not uniform and causes a load imbalance. Excessive flash has been responsible for a large number of broken tie bars.

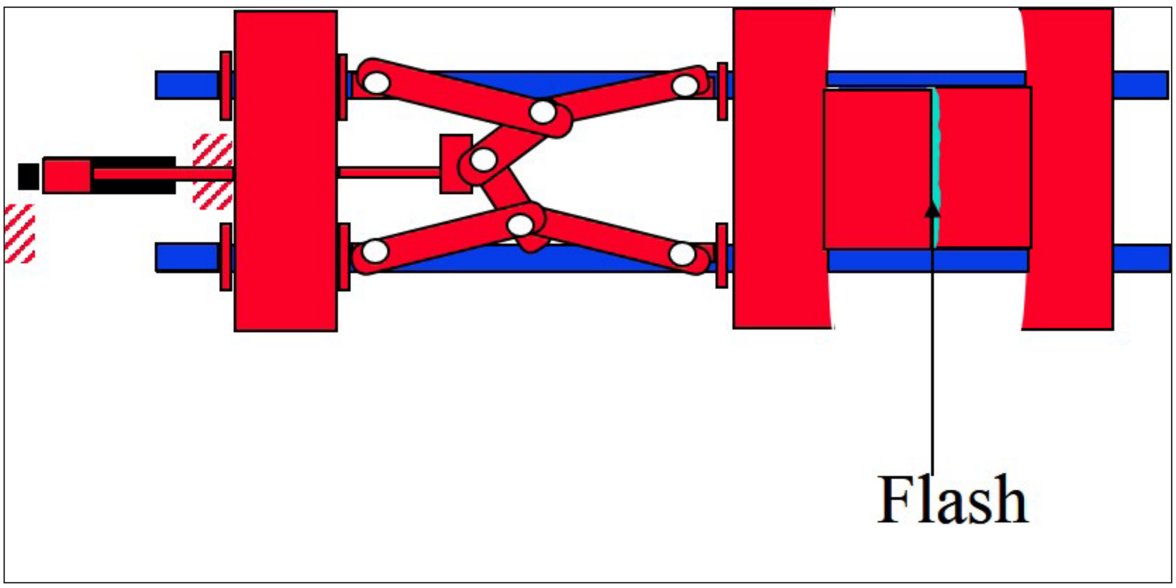


Figure 3-52 - Flash straining the tie bar

As the machine locks, it squeezes the die faces together and pushes against the stationary and rear platens. The platens in turn push on the tie bar nuts. The tie bar nuts grip and stretch the tie bars. If the nuts are loose and can rotate on their thread, the die lock can change. Each nut will have a hold down device to prevent the nut from turning. You should make sure on a daily basis that the nuts are secure. This should be part of your machine start up inspection.

Figure 3-53 - Loose nut at the tie bar

INJECTION / MAKING THE SHOT

Before injection will occur a number of process and safety conditions must be satisfied.

- The die must be locked.
- The plunger must be at the home position.
- All safety doors and barriers must be in place.
- Plunger tip has been lubed and is cooling properly.

The injection sequence begins when metal is poured into the cold chamber. The metal should be dipped from the holding furnace and transferred to the cold chamber as quickly as possible, to minimize heat loss, and with as little disturbance as possible. Agitation at this time would only add to oxidation problems.

The details of injection are presented in Lesson 4.

MACHINE DWELL/HOLD

After the shot has been completed, and prior to die and machine opening the metal must be allowed to freeze and gain strength. Intensification can be released after 3-4 seconds, the gate and runner are frozen and metal pressure cannot be transmitted to the casting. At this time the machine can recharge the accumulator. The high pressure pump is used to refill the accumulator, to pump the oil into the bottle against the nitrogen charge.

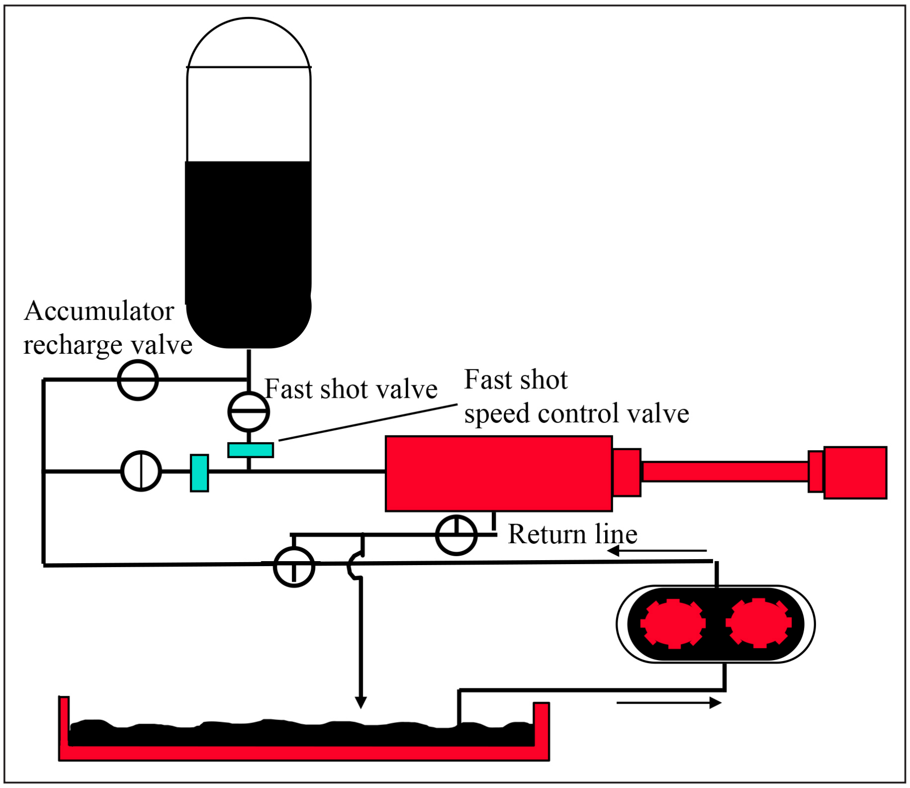


Figure 3-54 - Hydraulic diagram for accumulator recharge circuit

During dwell the casting is cooling in the die. The casting would also like to contract (opposite of expand), get smaller, but it cannot because it is trapped in the die. Because the casting cannot get smaller as it cools, the stress that would otherwise be released along with the heat energy, stays in the casting and becomes what is known as an internal stress. This is similar to having a box with a tensioned spring in it, if the cover is removed, the spring is released and pops out (don't have your face in its way). If the casting is kept in the die too long, and this internal stress is greater than the strength of casting, the casting will crack.

Dwell time is determined by experience and experimentation. Initially, the dwell time is set long enough to insure that the biscuit will freeze and not become an explosion hazard. Slowly, dwell time is reduced, to a point where a lack of hot strength is indicated. An indicator of lack of hot strength would be ejector pin bulges, or in the worst case, the part sticking in the ejector half with the pins poking through. Another indicator would be pieces of the casting sticking in the stationary die have.

The amount of time that the casting dwells in the die will also affect its final dimensions. The longer the casting stays in the die, the cooler it gets, and smaller its dimensional changes will be once it is ejected from the die.

Dimensional changes to the casting during air quenching are governed by the law of thermal expansion. This law states that the dimensional change of the casting is directly related to the casting material, the magnitude of the dimension involved, and the difference in temperature involved.

A casting that is subjected to a long dwell time will be difficult to remove from the die. The shrink forces onto core features in the die will be great. It will be difficult to strip the casting off of stationary cores and it will also be difficult to eject the casting from ejector half cores.

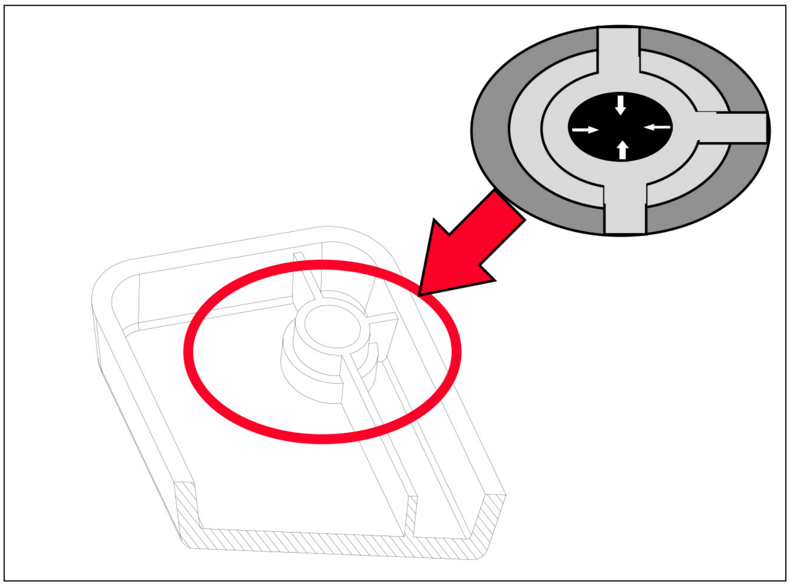


Figure 3-55 - Illustrations showing shrink onto cores and away from cavities

MACHINE OPENING

As the machine opens, you should be observing what is happening. You should be listening for exceptions to the normal sound associated with the machine cycle. Are the leader pins squealing? Is the die shifting as it slips off the leader pins? Are slides galling as they withdraw? Is ejection smooth and quiet? Did the plunger push the biscuit out properly? There are a lot of things that can go wrong, you need to be paying attention, every cycle.

Just as with die locking, die opening requires high pressure to relieve the tie bars. Initially, the machine needs to move slowly, because the plunger needs to push out the biscuit and keep it in contact with the ejector die until it is fully out of the cold chamber. Otherwise the biscuit might stick in the sleeve and bend the runner and casting. The oil supply to the shot cylinder is provided by the low pressure pump. At this same time the machine is unlocking with the high pressure pump supplying oil to the die close cylinder.

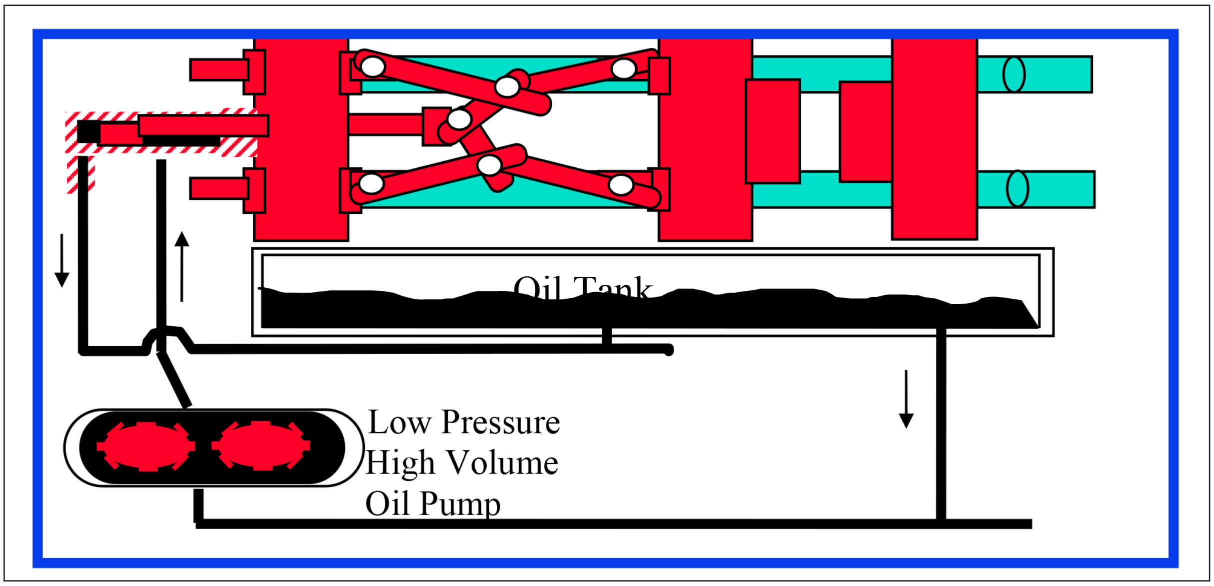


Figure 3-56a - Hydraulic diagram for die open

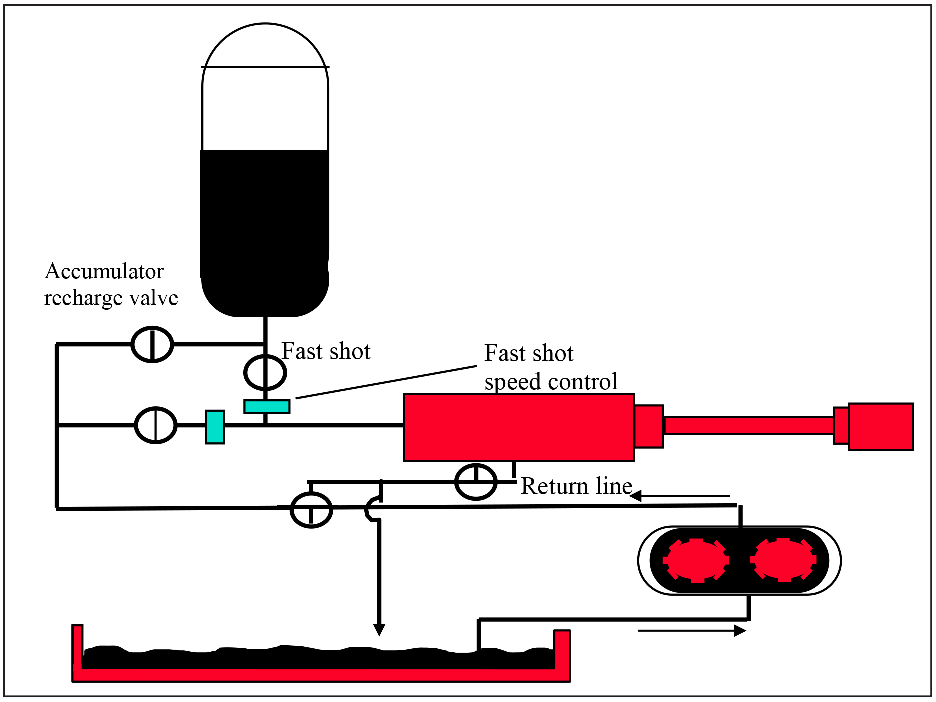


Figure 3-56b - Hydraulic diagram for plunger push-out

If die opening is uneventful, the casting will be sticking in the ejector half cavity of the die. With some castings there is no way of predicting in which half the casting will remain. In those cases we must take action to assure the casting remains in the ejector half. If the casting has mechanical slides, a slight delay can be built into slide withdrawal by adding clearance to the cam pin hole in the slide carrier.

EJECTION

The next step in the cycle is ejection. Ejection can be accomplished with a number of different methods. The simplest ejection is “bump” ejection. This means that some sort of actuator supplied by the machine simply bumps the ejector plate of the die, pushing the casting out of the die. This does not require any coupling between the die and the machine. After the part is ejected, the pins remain extended until the die closes and the ejector plate is pushed home when the ejector return pins “kiss” the parting line. The actuator for bump ejection can take several forms.

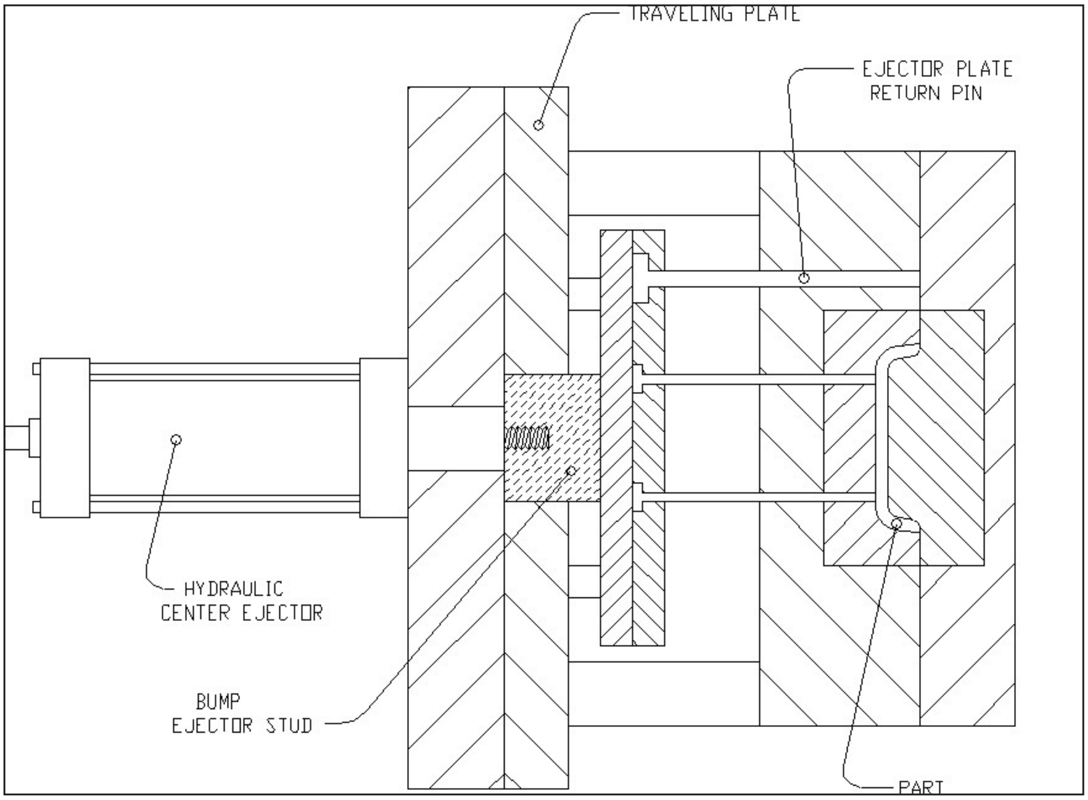


Figure 3-57 - Bump ejection stud

Some machine manufacturers provide a hydraulic ejection cylinder in the center of the moving platen. A stud can be threaded into the cylinder rod to provide a bumper.

Another machine manufacturer provides a fixed plate behind the moving platen. Long pins or knock-out rods are placed in holes in the moving platen, and extend from the die ejector plate to within several inches of the fixed plate. when the machine opens, the knock-out rods are squeezed between the fixed plate and the ejector plate of the die, pushing the ejector plate forward. Again, the ejector pins remain extended until the die closes and the ejector plate is pushed home when the ejector return pins “kiss” the parting line.

Other, more sophisticated methods can be used to actuate ejection. Another common method is to couple a hydraulically operated bump plate to the die ejector plate with threaded knock-out rods.

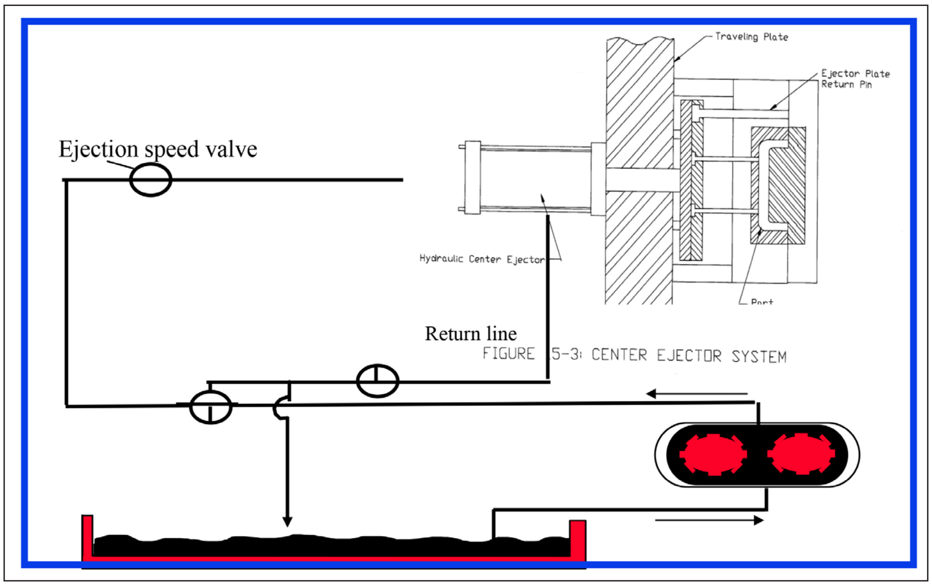


Figure 3-58 - Hydraulic diagram of ejection

CASTING REMOVAL

After the casting is ejected, it must be removed from the die. Removal of the casting must be done with care, if not, the die and casting can be damaged. A pliers or tongs should be used to grip the biscuit or runner to remove the casting from the die. The tool should not be used to grip the casting directly, as this could leave damaging marks on the casting. The use of a tool for removal is recommended for several reasons. The tool will provide leverage to get a firm grip on the casting without having to squeeze the tool very tightly. Over a shift this can ease the work load to the hand and wrist. The tool will get hot from repeated handling of hot castings, but using insulated grips or hose over the grips will insulate you from the hot casting. This way your gloves will not burn up and you will not get burned through holes in the gloves.

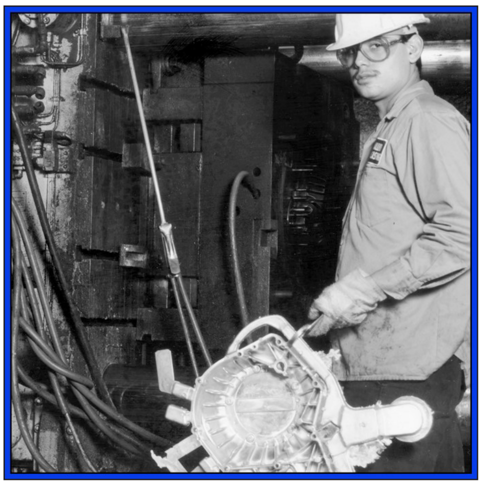


Figure 3-59 - Using tongs to remove a casting

The casting should be pulled straight off of the ejector pins. If the casting is wiggled and twisted, the ejector pins will flex and bend, and put pressure on the ejector pin hole causing it to wear and become bell mouthed. This bell mouthed condition will cause the ejector pin hole to flash, which will aggravate the casting removal.

Fragile or thin walled parts may be damaged; nicked, or bent if they are too difficult to remove.

Some operators prefer to remove castings with gloved hands. If this is an approved method in your plant, you should make sure you use clean gloves. Grease and oil stains burnt into a casting from dirty gloves can not be removed by normal cleaning and washing.

Recently ejected castings are hot and are a burn hazard. Typical ejection temperatures for die castings are 750 -550°F (400 - 290°C). Castings cool at different rates. Thin walls will cool readily, while it may take half an hour or longer to cool a biscuit or sprue.

Castings usually have flash on them that is sharp and jagged and can cut quite easily. The castings must be gripped firmly when handling them to avoid loosing your grip and getting cut.

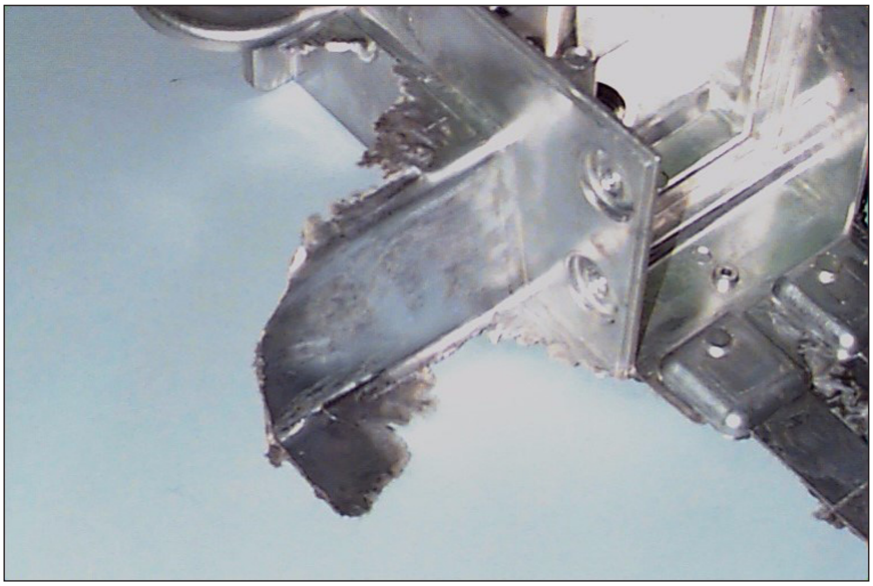


Figure 3-60 - Example of flashy casting

INSPECTION

After the casting has been removed, but before it is set aside, it should be given a brief inspection for completeness and obvious visual defects. This is done before you address the next cycle step, die spray.

At this cursory inspection you are looking to make sure that none of the casting is stuck in the die. You may be checking a particular area to watch the progress of soldering. You may be looking for flash at a particular feature.

This inspection is kept short in order to maintain the rhythm of the cycle time. After the die spraying is complete and the die has been recycled, during the dwell time, a more thorough examination of the part can be made.

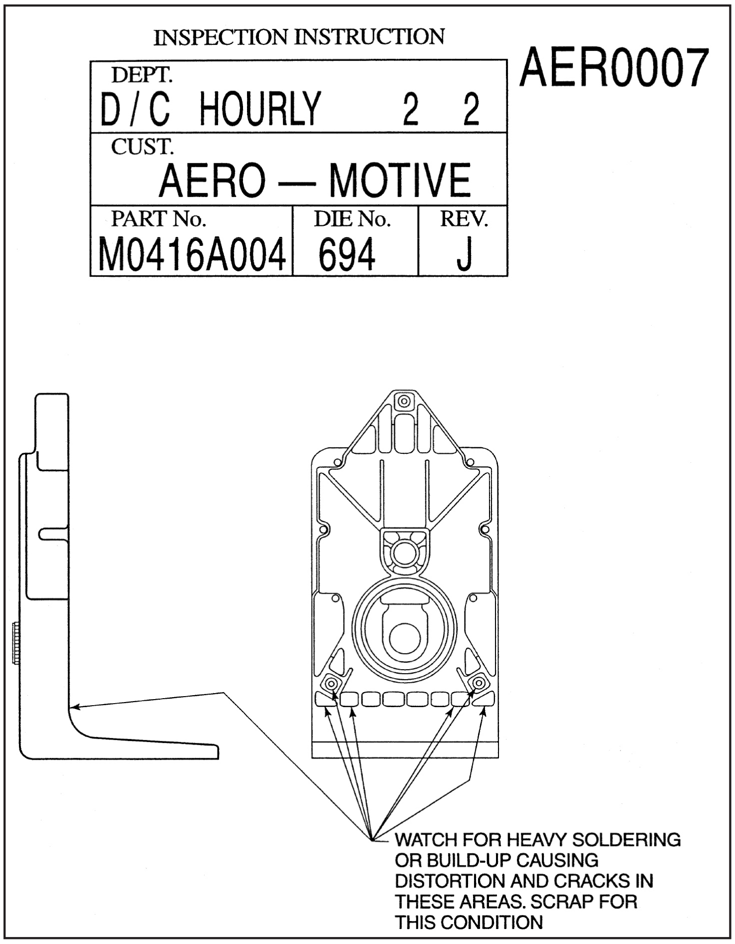


Figure 3-61 - Example of an inspection plan for visual check

DIE SPRAY

Applying die release is the next step in the casting cycle. This is your opportunity to inspect the die. The die should be inspected for flash, on the parting line, in the vents, and in slide pockets. Also the die should be inspected for soldering and lube build-up.

As you spray, you should develop a consistent spray pattern. When you have worked out the pattern that works best, this should be documented, and this record kept for the next time the job is run. These notes would best be kept on a set-up sheet.

The objective of the die spray is to put a protective barrier on the die, to shield it from the aluminum in the die casting alloy. This barrier is only one millionth of an inch thick, and is replaced every cycle.

The development of die spray and its application is an extensive science. The die is best sprayed with a very fine mist, with very small droplet sizes. The small droplet size is less likely to form a steam barrier to the lube. In addition to being a fine droplet, it has to have enough velocity and energy to reach the deep pockets in the die cavities.

Die spray also can be used to remove heat from areas that are not accessible to internal cooling. Die spray should not be considered the cure all for thermal problems because an excessive application of spray will result in the spray washing off the die face. If excessive cooling is required, use atomized water first an follow up with die spray before the die cavity is too cold. Die spray should not run from the face of the die.

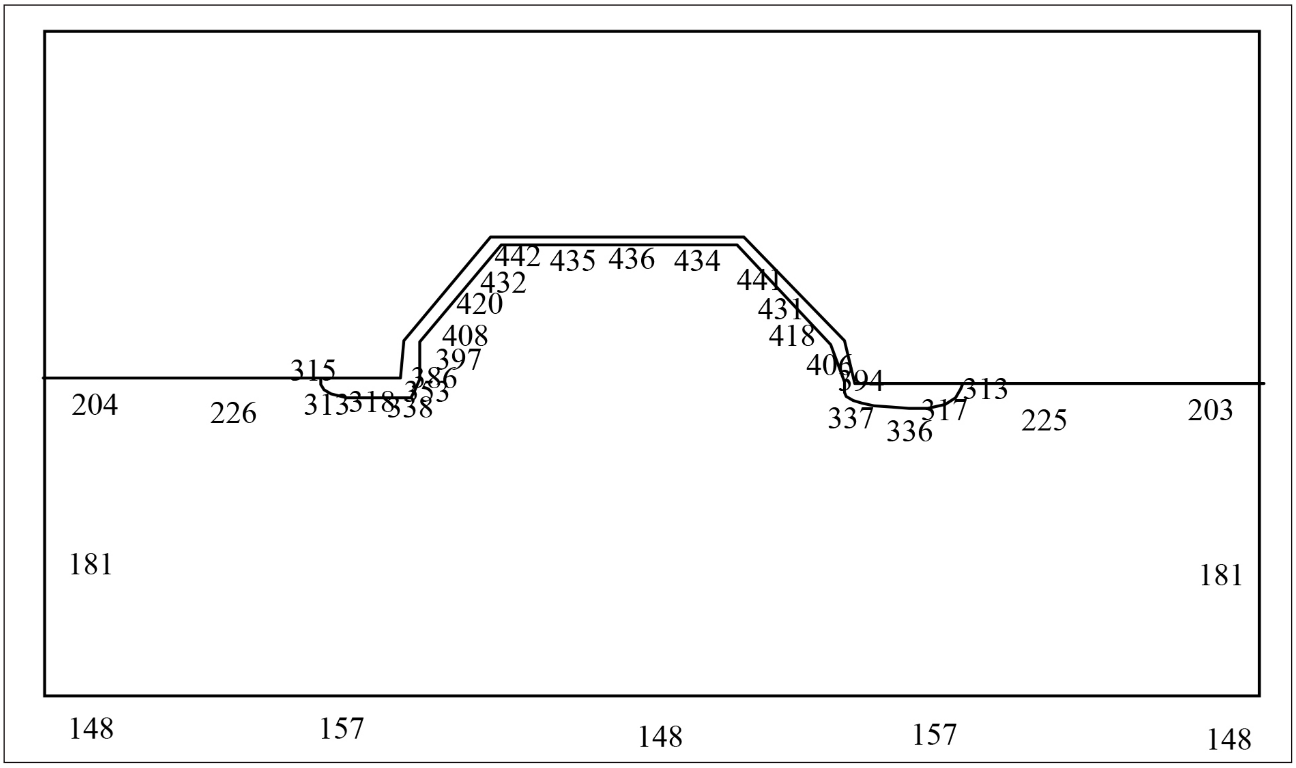


Figure 3-62 - Example of a Castherm printout showing the effect of die spray

After die spraying is complete, the die should be blown off with high pressure air to assure that no liquid is left in the die cavities. Also, that die parting line should be cleaned to remove any flash.

SELF TEST 5

True or False

1. For the machine to close the die, the safety ratchet must be locked.

   True False

2. The initial die closing is done with high pressure hydraulic oil because of the relative weight of the moving platen.

   True False

3. The tie bars must stretch to develop locking force, this could be called "straining the tie bars".

   True False

4. The force of injection relieves the strain in the tie bars momentarily.

   True False

Multiple choice; Identify all correct answers.

5. If you change to a larger plunger size and make no other changes to the machine settings:

   a. metal pressure goes up
   b. plunger speed goes up
   c. gate speed goes up
   d. cavity fill time goes up

6. The critical slow shot velocity is required to:

   a. give air in the cold chamber time to escape
   b. prevent the loss of heat
   c. maintain uniform metal pressure
   d. push air out ahead of the metal and avoid mixing the air in the metal

7. The intensifier is used to

   a. fill the corners of the cavity
   b. compress air trapped in the casting
   c. feed shrinkage
   d. push the plunger out when the die opens

PROCESS MATH AND SCIENCE FOR DIE CAST OPERATORS

The amount of stress developed in the tie bar is determined by its diameter, its material, and the amount that it is stretched.

Its cross-sectional area defines its size, whether that is a circle or a rectangle. For a circle the area is A = ∏r2, and for a rectangle the area is A = L x W.

The material property that is important to the tie bar is the Modulus of Elasticity. This is the ability of the material to resist stretching without yielding, (taking a permanent set). Modulus of Elasticity, also known as Young's Modulus is the slope of the stress-strain curve for the particular material that the tie bar is made from. For steel the Modulus of Elasticity is 30,000,000 lbs/in2.

The amount the material is stretched is a property known as strain. Strain is defined as the amount of stretch divided by the overall length, or ΔL in/L in

The formula that describes the force developed by the tie bar is:

$$F = \frac{U \times A \times E}{2000 \text{ lbs/Ton}}$$

$U = \Delta L$ in/L in
$A = \prod r^2$ or L x W in square inches
$E = 30{,}000{,}000$ lbs/in^2

What force is exerted by a 6 inch diameter steel tie bar that had a measured strain of 0.008 in. in 12 inches length?

$$F = \frac{U \times A \times E}{2000 \text{ lbs/Ton}}$$

$U = \Delta L$ in/L in = 0.008 in/12.0 in
$U = 0.00067$ in/in

A = ∏r2 = (3.14)(3 in)(3 in)=28.27 in2

$$F = \frac{(0.00067 \text{ in/in})\ (28.27\text{in}^2)\ (30{,}000{,}000 \text{ lbs/in}^2)}{2000 \text{ lbs/ton}}$$

F = 284 tons

Are these numbers typical of a 1200 ton machine?

GLOSSARY

A-frame *- an "A" shaped frame work at the shot end of the machine used to support the shot cylinder and gooseneck on most hot chamber machines.*

Accumulator *- storage tank(s) for hydraulic oil under pressure of an inert gas, to supply oil when high volumes are required in excess of pump capacity.*

C-frame *- a "C" shaped framework at the shot end of the machine used to support the shot cylinder on many cold chamber machines.*

Clamp end *- the end of the machine with the toggle linkage.*

Cold Chamber *- the die casting process in which the metal pump is outside of the holding furnace, the actual cylinder of the cold chamber metal pump.*

Die close cylinder *- hydraulic cylinder mounted to rear platen, connected to linkage, for opening and closing the die.*

Hot Chamber *- die cast process with metal pump (gooseneck) submersed in the molten metal.*

Intensifier *- special hydraulic cylinder used to increase oil pressure, usually 2-4 times.*

Limit Switch *- electric switch with a moveable arm that is moved by an operator connected to a moving machine member, used to signal position of machine or die member.*

Linkage *- Steel beams connected to moving platen and die close cylinder, arranged as levers to gain mechanical advantage to stretch tie bars.*

Platen *- the large steel plates, held together by the tie bars, to which the die and toggle linkages are mounted.*

Safety Ratchet *- a ratchet and plunger mounted on top of the rear platen that prevents die closing if the plunger is extended. The plunger is usually air operated.*

Shot Cylinder *- hydraulic cylinder responsible for injecting molten metal mounted to A, C, frames or tie bars.*

Shot end *-the end of the machine with the shot cylinder.*

Tie bars *-the large steel columns that connect platens. When the die is locked, the tie bars stretch to generate the clamping force.*

VALVES:

Fast shot valve *- volume flow control valve for shot cylinder.*

Relief valve *- a valve at the pump outlet that opens and allows oil to flow back to the reservoir when a preset pressure is reached.*

4 HOW IT WORKS - THE SHOT END

OBJECTIVES

- To learn about the function of the shot end.
- To learn the various elements of the shot cycle.
- To learn the components of the shot system.

PERSPECTIVE

In our third lesson you learned about the die casting machine. In this lesson you are going to learn about the system that injects the molten metal into the die. This is the shot end.

INJECTION / MAKING THE SHOT

Before injection will occur a number of process and safety conditions must be satisfied.

- The die must be locked.
- The plunger must be at the home position.
- All safety doors and barriers must be in place.
- Plunger tip has been lubed and is cooling properly.

The injection sequence begins when metal is poured into the cold chamber. The metal should be dipped from the holding furnace and transferred to the cold chamber as quickly as possible, to minimize heat loss, and with as little disturbance as possible. Agitation at this time would only add to oxidation problems.

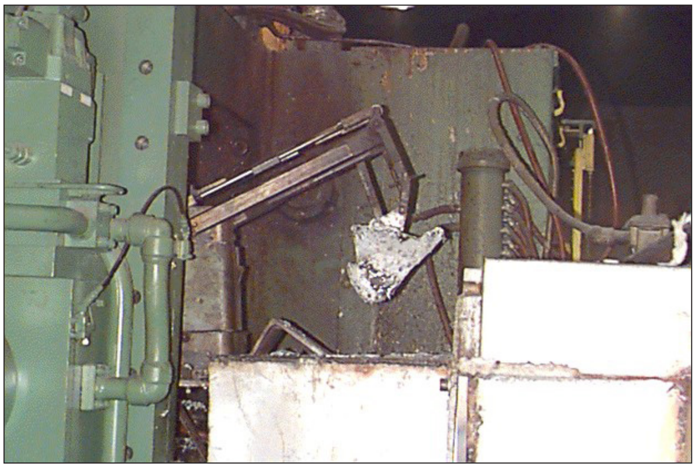


Figure 4-1 - Metal being transferred to the cold chamber

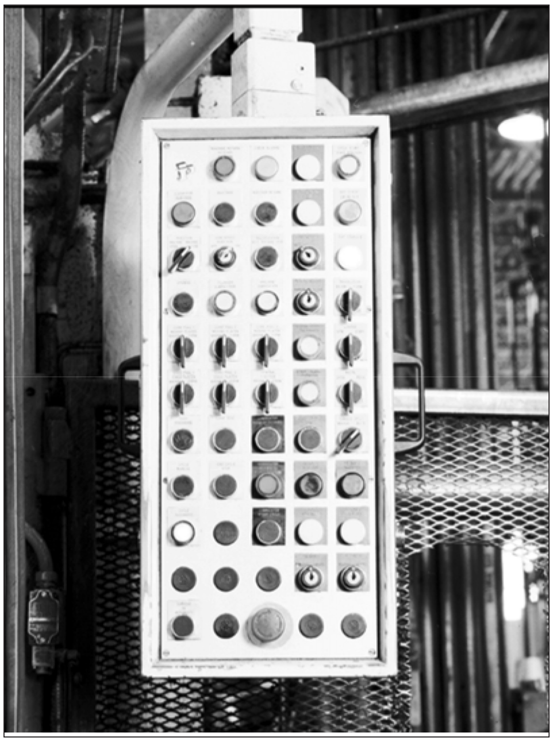


Figure 4-2 - Shot push-button

The alloy should be poured into the cold chamber quickly, but without agitation. It has been estimated that the heat lost during alloy transfer could be as much as 20-30°F (10-15°C) per second. Then the shot button is depressed, initiating injection. The wave formation during slow was discussed previously. You can watch a wave form as the alloy is poured into the sleeve. The alloy quickly runs down to the biscuit block of the die and is reflected back to the pour hole. The ideal time to start the shot is when the wave arrives back at the shot hole and is reflected to the biscuit block. An alternative is to pour slowly and try not to start a wave.

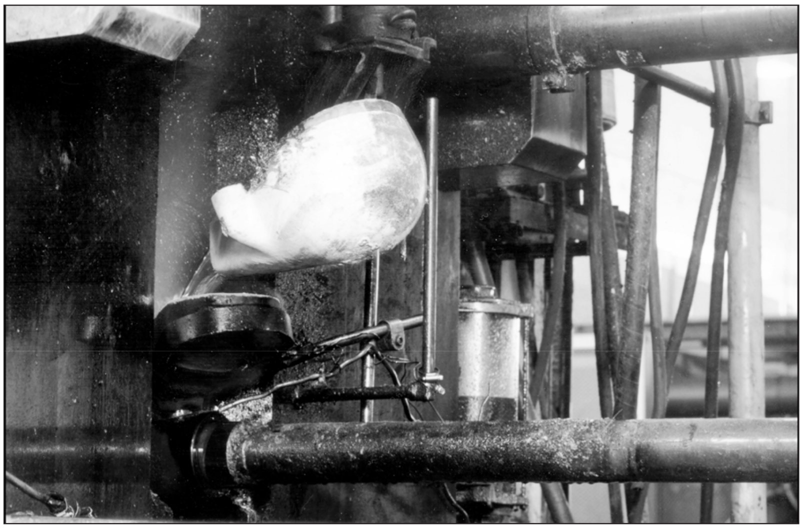


Figure 4-3 - Alloy pouring into the cold chamber

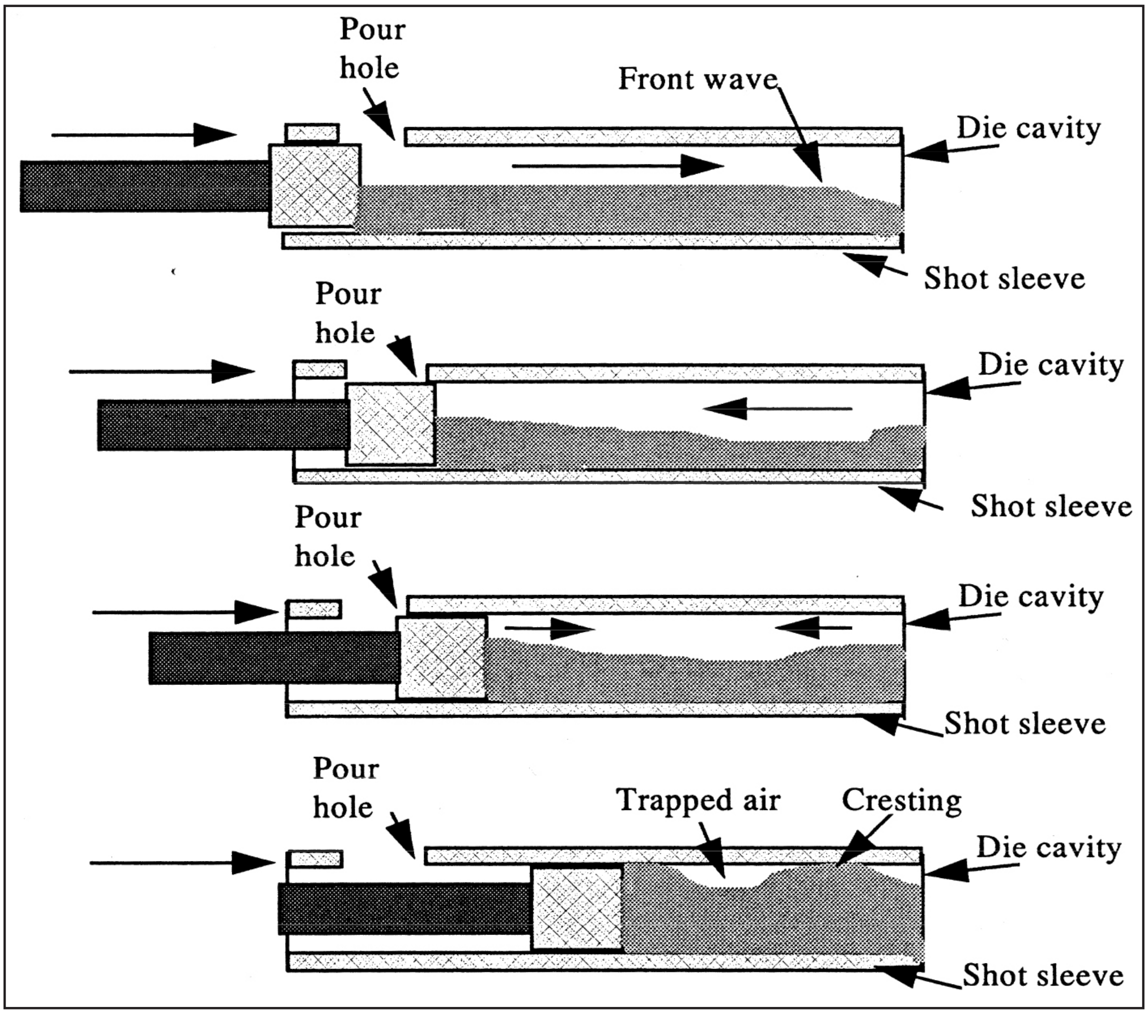


Figure 4-4 - Graphic of wave in the cold chamber

During injection a number of important process characteristics are executed, characteristics that have a great influence on the casting quality. These characteristics (and variables) are:

- Critical slow shot speed (csss)
- Fast shot shift point
- Fast shot speed/fill time
- Static pressure
- Intensification start time and ramp time

The ideal slow shot speed is the speed that is slow enough to allow the air in the cold chamber to escape through the die and fast enough to prevent a significant amount of alloy to freeze and loose temperature in the cold chamber. For the case of non-vacuum die casting, this is called the "critical slow shot speed" or csss. The csss should be reached as soon as the plunger passes the pour hole. Usually a very slow speed is necessary to get past the pour hole without spitting metal out of it. The csss speed is dependent on the sleeve diameter and the amount of metal poured into the sleeve on a percentage basis. This speed can be calculated from the following formula:

$$csss = \frac{K \text{ x } (100\% - \%fill) \text{ x } (P\Phi)^{0.5}}{100\%}$$

Where

K = 22.8in. 0.5/sec

(57.9cm0.5/sec)

PΦ = plunger diameter

%fill = percent of shot sleeve filling

If vacuum is being used, the slow shot speed is set to allow enough time to draw a vacuum. This may be 1.5 - 2.0 seconds.

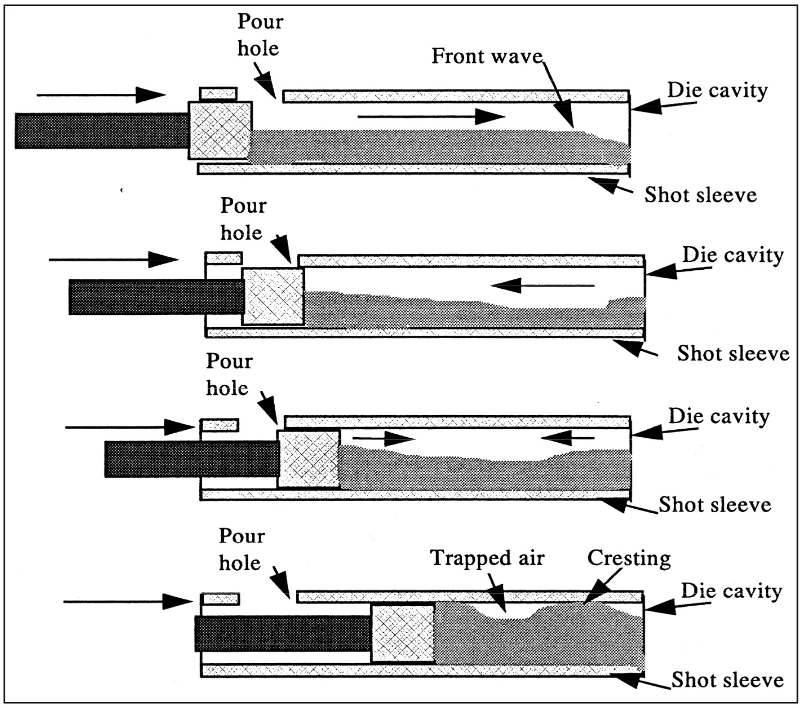


Figure 4-5 - Schematics showing various wave forms in the cold chamber

During slow shot, hydraulic oil is pumped to the shot cylinder from the low pressure, high volume hydraulic pump.

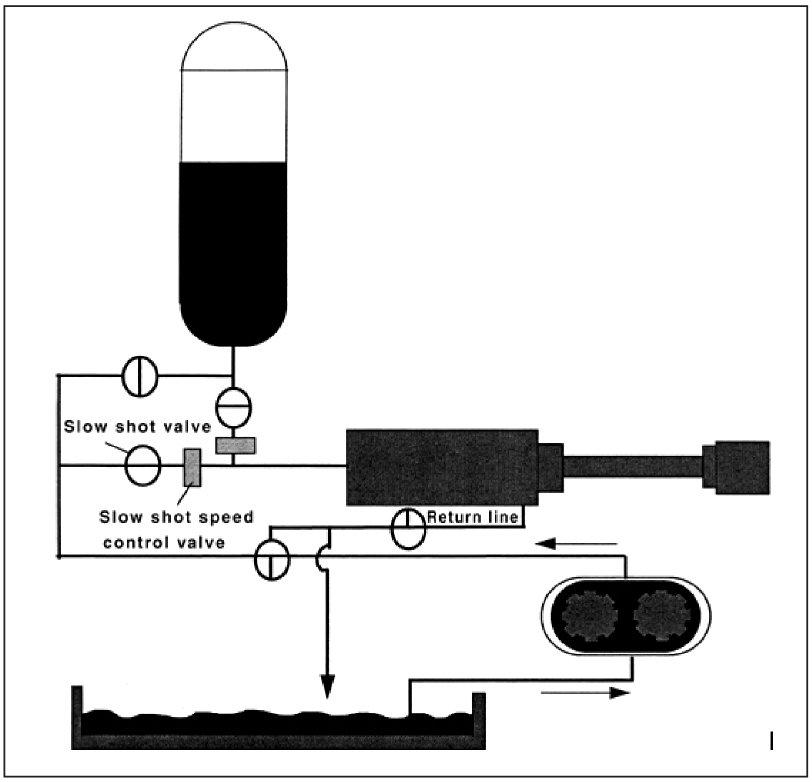


Figure 4-6 - Hydraulic schematic showing slow shot

Many older machines do not have enough low pressure pump capacity to supply oil required to maintain the csss. You can calculate the pump requirements if you know your shot cylinder diameter.

Fast shot length

Once the cold chamber is filled with metal, you need to consider when the fast shot should start. When the metal arrives at the gate, you want it to have reached its desired gate velocity. You can calculate the ideal length of fast shot by determining the volume of metal required to fill the die cavity, and converting this volume to a cylinder having the same diameter as the plunger and the cylinder height would be equal to the plunger stroke needed to fill the cavity.

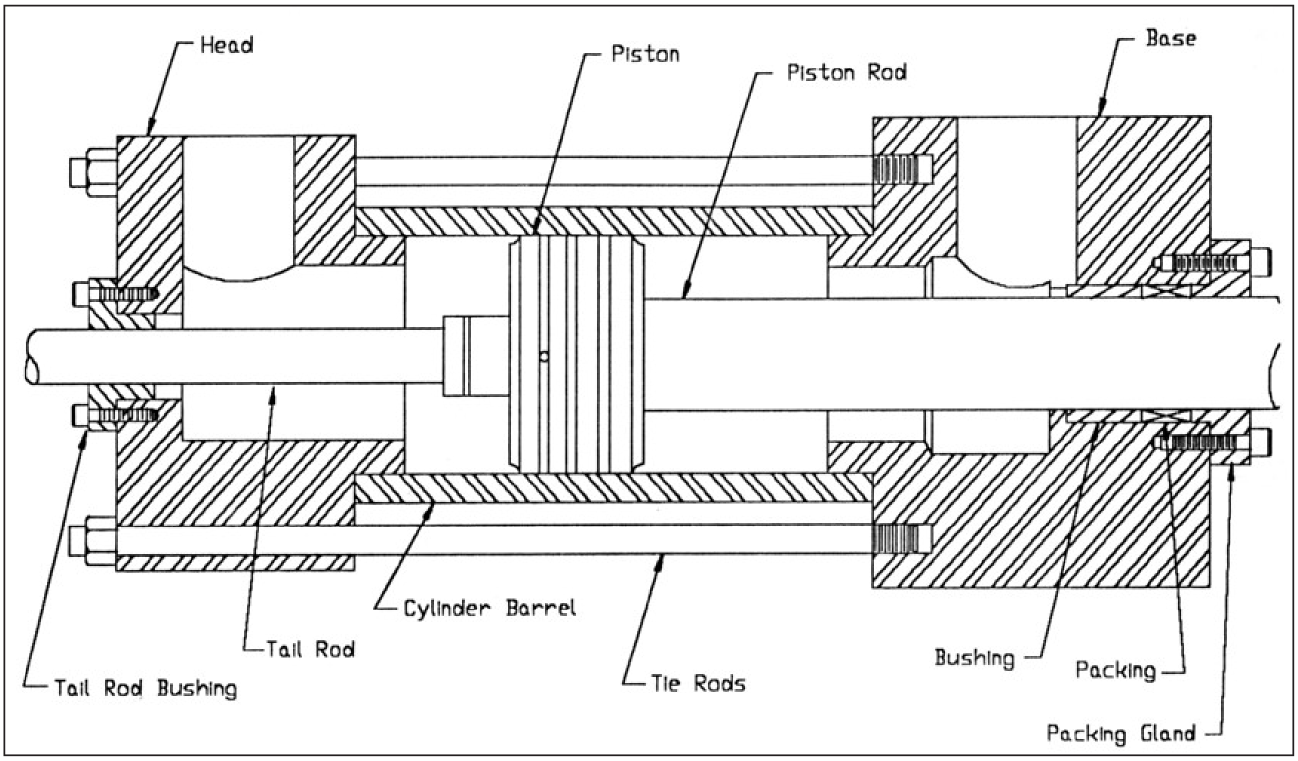


Figure 4-7 - Schematic of a cylinder

For example, if the metal through the gate has a volume of 22 cubic inches (142 cm3) and the cold chamber is 2.5 inches (6.35cm) in diameter. What shot stroke length is required to fill the cavity?

Volumecyl = Areacyl x Heightcyl

Areacyl = (∏ x Diameter2)/4

Volumecyl = ((∏ x Diameter2) 4) x Heightcyl

$$Height_{cyl} = \frac{Volume_{cyl}}{(\prod \text{ x } Diameter^2)/4}$$

$$Height_{cyl} = \frac{22 \text{ in}^3}{(3.1416 \text{ x } 2.5^2)/4}$$

$$Height_{cyl} = \frac{360.5 \text{ cm}^3}{(3.1416 \text{ x } 6.35\text{cm}2)/4}$$

Heightcyl = 4.48 inches

Heightcyl = 11.5cm

For this example, the minimum length of fast shot would be about 4.5 inches (11.5cm). It is not possible for the machine to instantly shift from slow to fast shot. This transition takes time. You should determine how much plunger travel is required for this transition to take place. For most machines this can be 1-2 inches (2.5-5.0mm) of travel. This transition length should be added to the previously calculated minimum fast shot length.

If your transition from slow to fast shot requires 2 inches (51 mm) travel, the minimum fast shot length would then be 6.5 inches (4.5" +2" = 6.5") (16.5cm). This transition point is usually controlled by the fast shot limit switch.

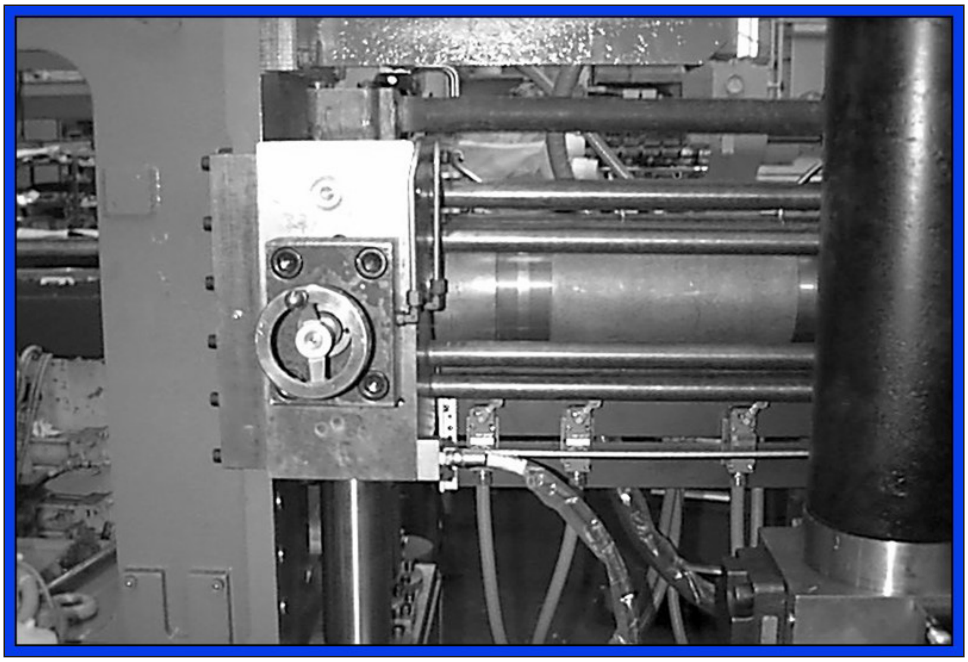


Figure 4-8 - Fast shot limit switch and tail rod or follower

Fast Shot Speed

The fast shot speed is one of the most important process variables. This speed will determine the gate velocity and the cavity fill time. When the die is engineered, a lot of effort goes into determining the best gating, both gate size and flow pattern. This is based on the best estimate of a maximum allowable time to fill the die cavity and achieving atomization of the metal during filling. The calculation of cavity fill time is based on the casting geometry (mostly wall thickness) and die and metal temperatures. When a cavity fill time is calculated, this is the best estimate of the maximum time available to make an acceptable casting. This is an estimate or starting point that is then refined by experience. Fast shot speed is very important, since only one speed will give the best initial combination of gate velocity and fill time. The relationship between gate velocity, fill time and fast shot speed is as follows.

The die casting machine pumps the metal at a given fill rate, it pumps "Q" cubic inches of metal in a second. In fact, the shot end of a machine is rated by its maximum pumping capacity or filling rate for a give plunger size. The pumping rate for a particular job is determined by multiplying the plunger area times the plunger speed, or

Q (in3/sec) = plunger area (AP) x plunger speed (VP)

For example, if a 2 inch diameter plunger is traveling at a fast shot speed of 60 inches per second, what is its filling rate?

Q (in3/sec) = (AP) x (VP)

AP = (∏ x Diameter2)/ 4

Q (in3/sec) = ((∏ x Diameter2)/ 4) x (VP)

Q (in3/sec) = ((3.1416 x 2 inches2)/ 4) x (60 inches/second)

Q (in3/sec) = ((3.1416 inches2) x (60 inches/second)

Q (in3/sec) = 188.5 inches3/second

Q (cm3/sec) = ((3.1416 x 5.08cm2)/ 4) x (152 cm/sec)

Q (cm3/sec) = (20.26cm2) x (152cm/sec)

Q (cm3/sec) = 3081 cm3 /sec

Once the filling rate or pumping capacity for a given plunger diameter and plunger speed is known, you can determine the gate velocity and fill time straight away.

The fill time is equal to the volume of the metal through the gate (casting and overflows) divided by the filling rate.

fill time (sec) = volume in3 ÷ Q in3/sec

For this example with a casting and overflow volume of 10 cubic inches, the fill time is 53 milliseconds.

fill time (sec) = 10.0 in3 ÷ 188.5 in3/sec

(fill time (sec) = 164 cm3 ÷ 3089 cm3/sec)

fill time (sec) = 0.0530 seconds or 53 milliseconds

The gate velocity is equal to the filling rate divided by the gate area. If this example has a gate area of 0.125 square inches, the gate velocity of speed of metal through the gate is 1508 inches per second.

$$V_G = \frac{Q(in^3/sec)}{(A_p\ in^2)}$$

$$V_G = \frac{188.5(in^3/sec)}{(0.125\ in^2)}$$

$$V_G = \frac{3089\ cm^3/sec}{(0.806\ cm^2)}$$

VG = 1508 in/sec

VG = 3830 cm/sec

The machine hydraulic pumps do not have enough capacity to supply oil to the shot cylinder to achieve the fast shot speeds that are necessary to inject the metal. For this reason a device known as an accumulator is used. The accumulator is an energy storage device, it stores a volume of oil under very high pressure. When the fast shot is called for, the accumulator is switched into the hydraulic circuit and discharges pressurized oil into the shot cylinder.

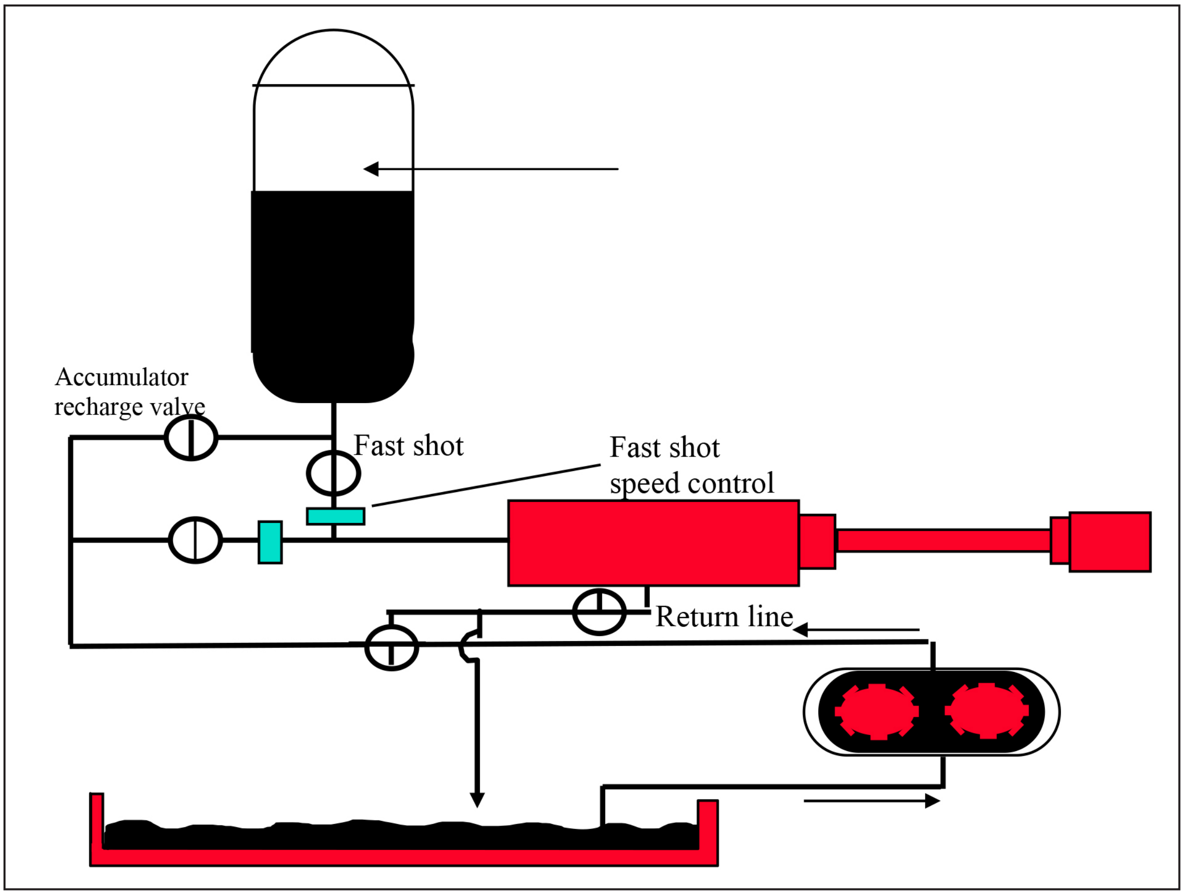


Figure 4-9 - Schematic of accumulator in the hydraulic diagram

Static pressure

When the plunger comes to rest at the end of the fast shot, the hydraulic systems comes to rest and the oil pressure in the system reaches its maximum value. This pressure multiplied by the ratio of the square of the shot cylinder diameter to the square of the plunger diameter determines the static pressure on the metal.

$$P_{METAL} = \frac{P_{HYDRAULIC} \times (D_{HYDRAULIC\ CYL})^2}{(D_{PLUNGER\ TIP})^2}$$

This is the pressure available to squeeze porosity and feed solidification shrinkage until the intensifier is turned on. Typical values for static pressure would be 3500-6000 PSI (245-425 Kg/cm2). If porosity is a problem, static pressure should be increased to 5000-7500 PSI (350-525 Kg/cm2). Beyond that, spitting can become a problem.

Intensification time

Solidification of the metal begins as soon as the cavity begins to fill with metal. Therefore, the intensifier should be activated as soon as the static pressure reaches maximum. The intensifier multiplies the static pressure from 2-4 times depending on the die casting machine.

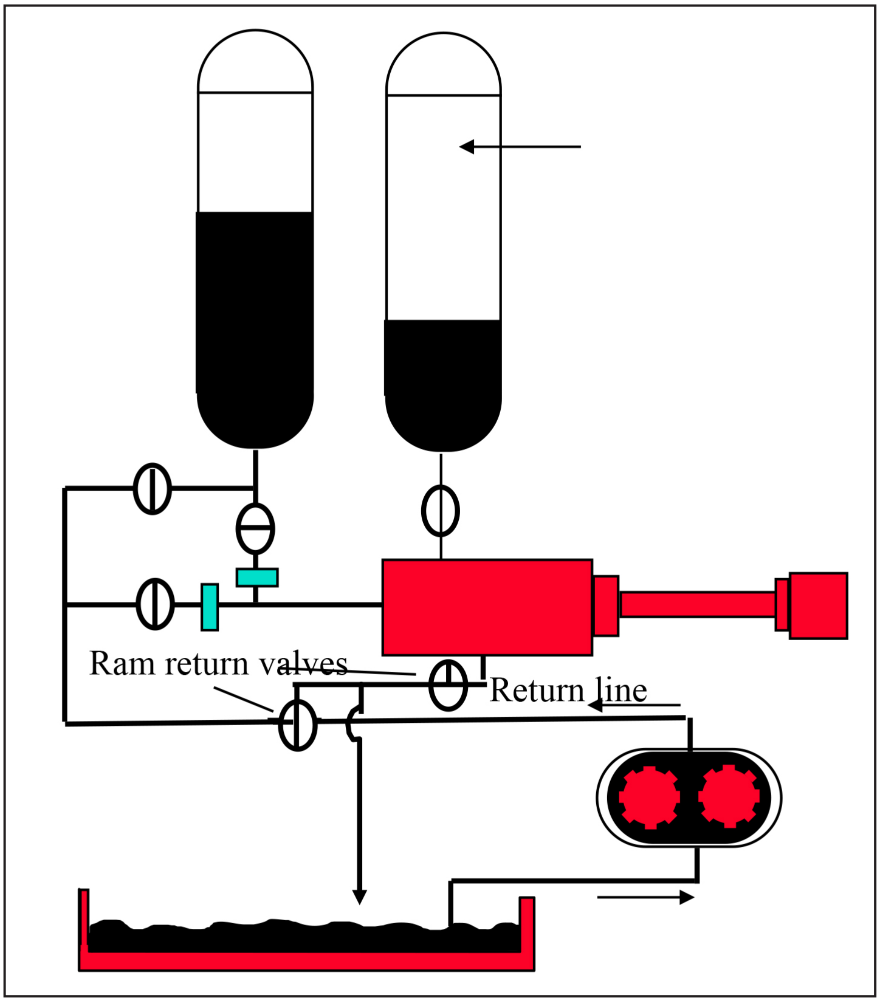


Figure 4-10 - Schematic of intensifier in the hydraulic diagram

The intensification pressure will build up as rapidly as the dynamics and control settings of the mechanism will allow. The time delay from cavity fill to application of full intensified pressure may be critical. If it is too short, the high pressure could flash the die open. If the time is too long, intensification will be ineffective for “feeding” metal through the gate into the solidifying casting.

The minimum delay for intensification is a function of the machine dynamics and must be measured or obtained from the manufacturer. The pressure build up times can be controlled and adjusted on some machines. There is no way to calculate the optimum delay and build up times. These are usually determined by experimentation.

Shot profile

You must have some way of measuring the shot end speeds and pressures. A printout of these measurements is referred to as a shot profile. The shot profile records the pressures and speeds of the shot cylinder with respect to plunger position and / or elapsed time. Without measurement there is no way to know how the shot cylinder is actually performing.

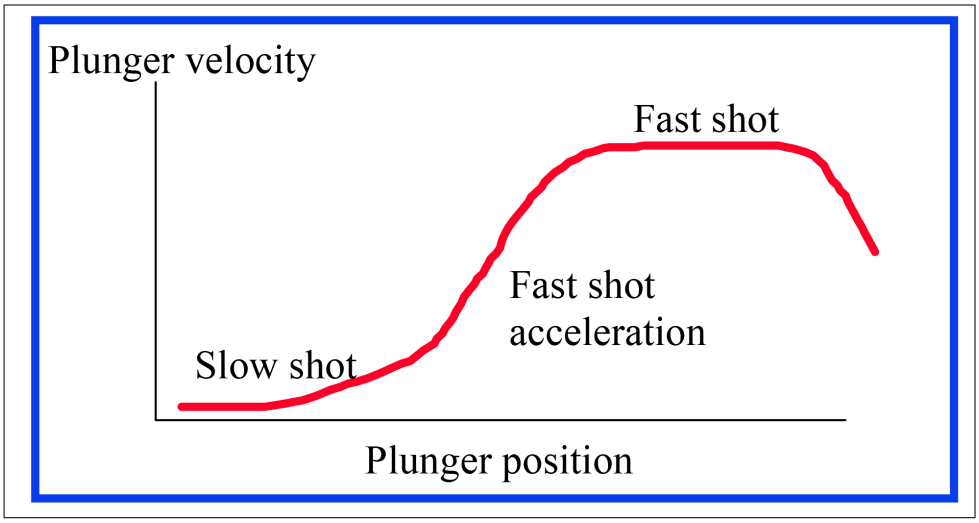


Figure 4-11 - Shot profile

As the operator, there are several things that you should be watching for during every shot. First, note the stopped position of the plunger at the end of the shot. If the plunger has not reached its normal end of stroke position this could be an indication of a thick biscuit or some other hazardous problem. Next, watch to see that the plunger moves smoothly, no stuttering or lurching. This could be an indication of lack of lubrication, metal build up, or inadequate cooling. Watch for metal bypassing the plunger tip. This could indicate the tip is worn out and needs replacement.

MACHINE DWELL/HOLD

After the shot has been completed, and prior to die and machine opening the metal must be allowed to freeze and gain strength. Intensification can be released after 3-4 seconds, the gate and runner are frozen and metal pressure cannot be transmitted to the casting. At this time the machine can recharge the accumulator. The high pressure pump is used to refill the accumulator, to pump the oil into the bottle against the nitrogen charge.

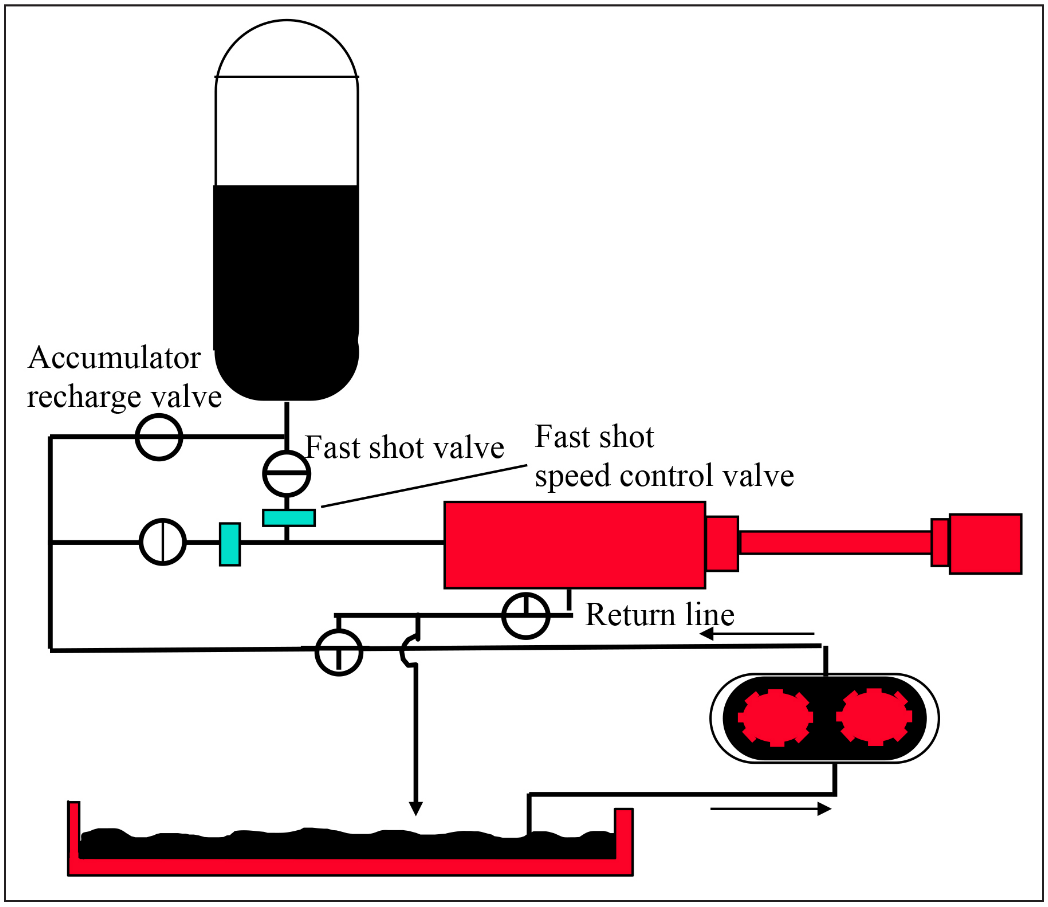


Figure 4-12 - Hydraulic diagram for accumulator recharge circuit

During dwell the casting is cooling in the die. The casting would also like to contract (opposite of expand), get smaller, but it cannot because it is trapped in the die. Because the casting cannot get smaller as it cools, the stress that would otherwise be released along with the heat energy, stays in the casting and becomes what is known as an internal stress. This is similar to having a box with a tensioned spring in it, if the cover is removed, the spring is released and pops out (don't have your face in its way). If the casting is kept in the die too long, and this internal stress is greater than the strength of casting, the casting will crack.

Dwell time is determined by experience and experimentation. Initially, the dwell time is set long enough to insure that the biscuit will freeze and not become an explosion hazard. Slowly, dwell time is reduced, to a point where a lack of hot strength is indicated. An indicator of lack of hot strength would be ejector pin bulges, or in the worst case, the part sticking in the ejector half with the pins poking through. Another indicator would be pieces of the casting sticking in the stationary die have.

The amount of time that the casting dwells in the die will also affect its final dimensions. The longer the casting stays in the die, the cooler it gets, and smaller its dimensional changes will be once it is ejected from the die.

Dimensional changes to the casting during air quenching are governed by the law of thermal expansion. This law states that the dimensional change of the casting is directly related to the casting material, the magnitude of the dimension involved, and the difference in temperature involved.

A casting that is subjected to a long dwell time will be difficult to remove from the die. The shrink forces onto core features in the die will be great. It will be difficult to strip the casting off of stationary cores and it will also be difficult to eject the casting from ejector half cores.

Process Math and Science for Die Cast Operator

This course will include a small amount of math and science in it. The formulas and calculations that are required will be reviewed in detail. Math requirements are adding, subtracting, multiplying and dividing. There will be some rearranging of formulas (algebra) and some area calculations (geometry). When formulas are needed, they will be provided. You should take it upon yourself to try to memorize the formulas and how they are used.

Force and pressure

Understanding the difference between the terms force and pressure is very important for the die caster.

Force is measured in terms of pounds (lbs), ounces (oz), or tons (T) (grams (gr), kilograms (kg), or metric tons (Mt) in the metric system). For example, your weight is the force that you exert on the earth, or floor due to gravity. If you weigh 200 pounds (90.0 kg), you exert a force of 200 pounds (90.0 kg) on the floor.

If you push against a door, a door that is held shut with a spring, you must exert a force that will overcome the spring in order for the door to open.

Pressure is the force divided by the area to which the force is applied. This relationship is expressed by the following formula:

Pressure = Force ÷ Area

If you take your weight and divide it buy the area of both your shoes, the result will be pressure that you exert on the floor in the exact place that you are standing.

For example, an average shoe is approximately 3 inches (7.62 cm) wide and 10 inches (25.4 cm) long. In this example we have approximated the shoe as a 3 inch by 10 inch (7.62 cm by 25.4 cm) rectangle. The area of a rectangle is the width multiplied by its length.

The area of the shoe is:

3 in x 10 in = 30 in^2

7.62 cm x 25.4 cm = 193.5 cm^2

Both shoes will have a total area of 60 in^2 (387.1 cm^2).

If you divide the example weight of 200 pounds (90.9 kg) by the total area of both shoes, 60 in^2 (387.1 cm^2), the resulting pressure is 3.33 pounds per square inch (0.235 kg/cm^2).

This is not much pressure; the pressure of air at sea level on the earth is 14.7 lbs/in^2 (1 bar).

Shot end forces and pressures

At the shot end of a die casting machine, both force and pressure are important. During metal injection, the force and pressure act according to the following sequence.

When the shot cylinder is activated, a hydraulic fluid, under pressure enters the cylinder and pushes against a piston tip. The piston tip has area. This develops a force that is transmitted to the plunger through a coupling.

Force = Pressure x Area

The force on the plunger develops a pressure (metal) at the plunger tip and biscuit dependent on the size and area of the plunger tip.

Pressure = Force ÷ Area

The metal pressure at the biscuit is transmitted through the liquid metal, to the projected area of the casting. This develops a force that tries to open the die. This force is resisted by the machine that has been preloaded, locked, to hold the die shut.

Force = Pressure x Area

Example 1:

Determine the force of the atmosphere on top of a house that has a 20 ft by 30 ft roof. Atmospheric pressure is 14.7 pounds per square inch.

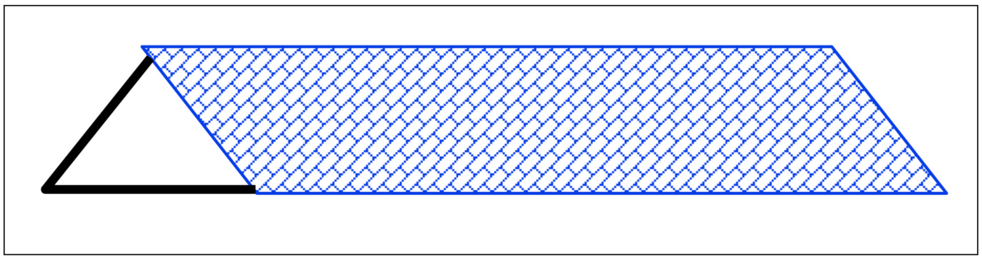


Figure 4-13 - 20 x 30 roof

Use

Force = Pressure x Area

The area of the roof, a 20 ft by 30 ft rectangle is:

A = Length x Width = 20 ft x 30 ft = 600 ft^2

Next we see that we have mixed units, both square feet and square inches. Since the pressure has the units of square inches in it, we will convert the area to square inches from square feet. A square foot is 12 inches on each side. Therefore a square foot has 12 inches times 12 inches or 144 square inches in a square foot. To convert the 600 square feet to square inches, multiply the 600 ft2 times 144 in^2 per ft^2.

Conversion: 600 ft^2 x 144 in^2/ft^2 = 86,400 in^2

Therefore

Force = Pressure x Area = 14.7 lbs/in^2 x 86,400 in^2

Force = 1,270,080 lbs

Example 2:

Determine the force developed by a 4 ½ inch diameter shot cylinder operating at 1800 pounds per square inch of oil pressure.

Answer:

Apply the formula F = P x A (Force = Pressure x Area)

First, determine the area of the shot cylinder piston head.

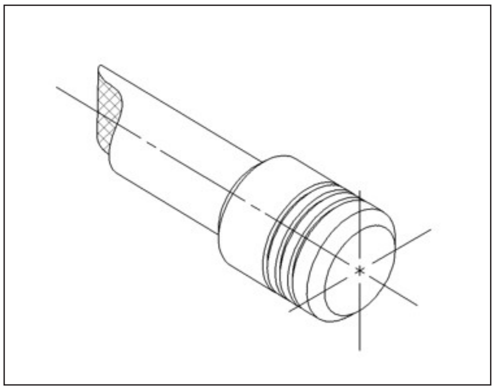


Figure 4-14 - Sketch of 4.5 diameter piston

The area of a circle, the shot piston, is:

A = ∏ x r^2 or ∏ x r x r

r = radius of the piston

r = diameter ÷ 2 or d/2

∏ = 3.14 a constant

A = (3.14) x (2.25 in) x (2.25 in)

A = 15.9 in^2 the area of a 4.5 in diameter circle

Next, apply the force formula:

Force = Pressure x Area = (1800 lbs/in^2) x (15.9 in^2)

Force = 28,620 lbs

Example 3:

Determine the metal pressure at a 2 ½ inch diameter plunger tip given a shot cylinder force of 28,620 pounds.

Answer:

Apply the formula P = F ÷ A (Pressure = Force ÷ Area)

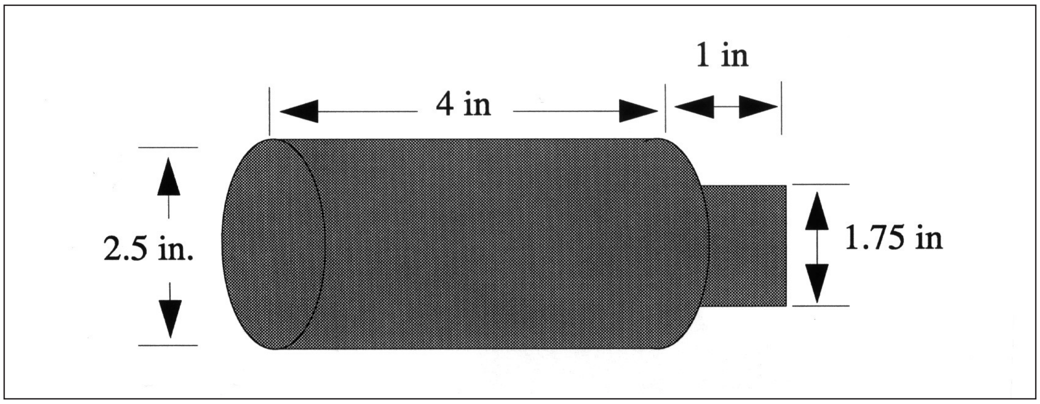


Figure 4-15 - Sketch of 2.5 diameter tip

First, determine the area of the plunger tip.

The area of a circle, the shot plunger tip, is:

A = ∏ x r+ or ∏ x r x r

r = radius of the tip

r = diameter ÷ 2 or d/2

∏ = 3.14 a constant

A = (3.14) x (1.25 in) x (1.25 in)

A = 4.9 in^2 the area of a 2.5 inch diameter circle

Next, apply the pressure formula:

Pressure = Force ÷ Area = (28,620 lbs) ÷ (4.9 in^2)

Force = 5841 lbs/in^2

Example 4:

Determine the force that is trying to open the machine given a metal pressure of 5841 pounds per square inch and a shot having a projected area of 200 square inches.

Answer:

Apply the formula F = P x A (Force = Pressure x Area)

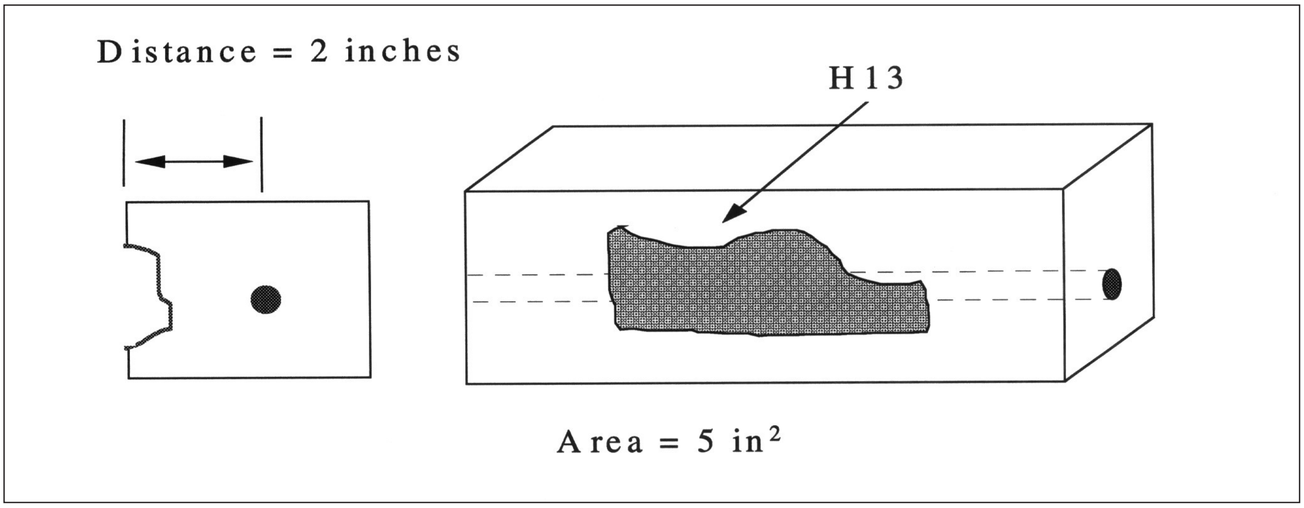


Figure 4-16 - Sketch of projected area

Apply the force formula:

Force = Pressure x Area = (5841 lbs/in^2) x (200 in^2)

Force = 1,168,200 lbs

This answer can also expressed in tons if we convert the pounds to tons. To convert pounds to tons, divide the pounds by 2000 pounds per ton.

$$\frac{1{,}166{,}400 \text{ lbs}}{2000 \text{ lbs/T}} = 584.1 \text{ T}$$

SELF TEST 1

Multiple choice; Identify all correct answers.

1. My weight is:
   a. a pressure
   b. an area
   c. too much
   d. a force

2. Atmospheric pressure of 14.7 lbs/in2 represents:
   a. the speed of air flow
   b. hydraulic pressure in the shot cylinder
   c. the weight of the atmosphere divided by the earth's surface area
   d. none of the above

3. Pressure is defined as:
   a. lots of tension
   b. force divided by area
   c. area times force
   d. none of the above

4. To increase the force the shot cylinder develops, all I have to do is:
   a. lock the die tighter
   b. increase the hydraulic oil pressure
   c. decrease the plunger size
   d. increase the plunger size

5. To reduce the metal pressure because the die is spitting, I can:
   a. lock the die tighter
   b. increase the size of the plunger tip
   c. reduce the hydraulic oil pressure
   d. increase the shot cylinder size

5 WHY SHOT MONITORS ARE IMPORTANT

OBJECTIVES

- To learn about shot monitors and how they help manage the die casting process.
- To learn about the importance of the various parts of the metal injection cycle.
- To learn about shot monitors detect shifts in shot end performance.

PERSPECTIVE

In recent years, the development of electronics technology has allowed the die casting industry to greatly improve its ability to control the die casting process. One of the most important pieces of technology utilized by modern die casting facilities is the shot monitor. This equipment permits the precise control of many aspects of the die casting process, but especially the critical injection of the molten metal into the die. In this lesson, the shot monitor is described in detail and how it can be used by the machine operator is presented.

Basic Shot End Dynamics and Process Requirements

The die casting shot end is made up of several configurations. The conventional cold chamber shot end, shown below in Figure 5-1, has the shot sleeve at a 90 degree angle from the parting line. The vertical cold chamber machine either has the machine platens and shot end rotated vertically, shown in Figure 5-2, or has the shot sleeve on the parting line. The hot chamber machine, shown in Figure 5-3, has the shot sleeve mounted vertically with the nozzle at about an 80 degree angle from the parting line.

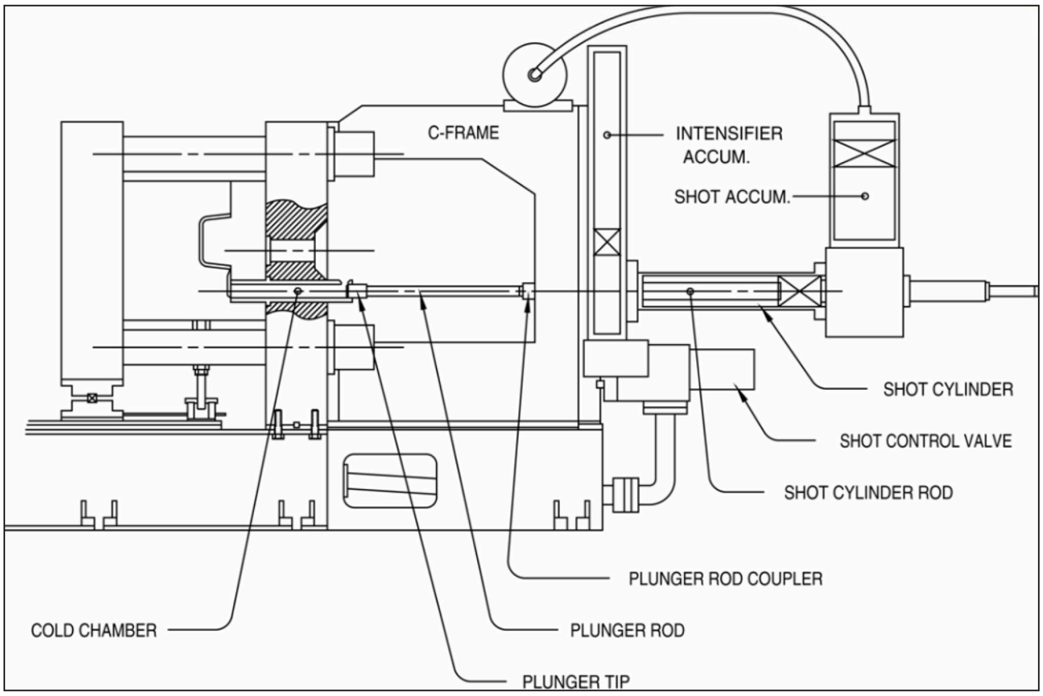


Figure 5-1 - Injection components, cold champer

There are three critical components to the shot end. These components are the accumulators, the hydraulic shot cylinder, and metal chamber.

The accumulators are typically nitrogen (N_2) over hydraulic fluid pressure vessels. Most accumulators have pistons to separate the N_2 from the hydraulic fluid. Some have a bladder to contain the hydraulic fluid in the accumulator. Some have nothing separating the N_2 from the hydraulic fluid. The most efficient of these is the accumulator with nothing separating the N_2 from the hydraulic fluid. However, this system may allow N^2 or aerated hydraulic fluid into the shot cylinder.

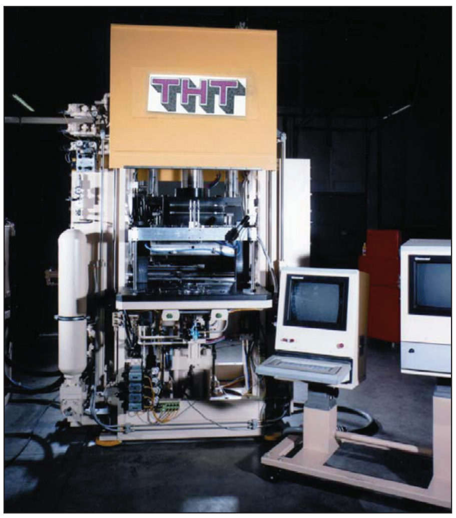


Figure 5-2 - Vertical Die Casting Machine

All die casting machines have a shot accumulator. Cold chamber machines usually have intensification accumulators. These accumulators are required to provide hydraulic power to the shot end. Providing this power causes a loss of volume of hydraulic fluid. The reduced volume of fluid results in a pressure drop within the accumulator. Therefore, the die casting machine must recharge these accumulators with hydraulic fluid to replace the lost volume during each shot. The result is that if the correct amount of hydraulic fluid is replaced, the accumulator pressure will be the same as the last shot. Die casting machines control the recharge process during each shot using a pressure relief valve. This pressure relief valve resides between the hydraulic pump and the accumulators. The pressure relief valve is a spring loaded valve that will open and allow hydraulic pressure to go to the hydraulic accumulator if the spring pressure is not exceeded. Once the spring pressure is exceeded, the valve closes flow to the accumulator and reroutes the flow to the hydraulic fluid tank. The spring pressure is typically established using a screw that compresses the spring. Die casting employees set the relief pressure with a screw driver while watching a pressure gauge on the accumulator. It is important to verify accumulator pressure settings by verifying the initial head side pressure in the shot profile or by using a transducer that is directly connected to the accumulator. This is important because of inaccuracy in the screw setting and in the pressure gauges used for setting the relief valve.

The pressure in the accumulators should be visually audited periodically by the die casting operator and monitored each shot by the PLC or shot monitoring system. This requires the use of a hydraulic pressure transducer (See Appendix 2: Transducers).

The motion of the shot end also must be monitored. This is done by a position and velocity transducer. There are several position transducers types shown in Appendix 2.

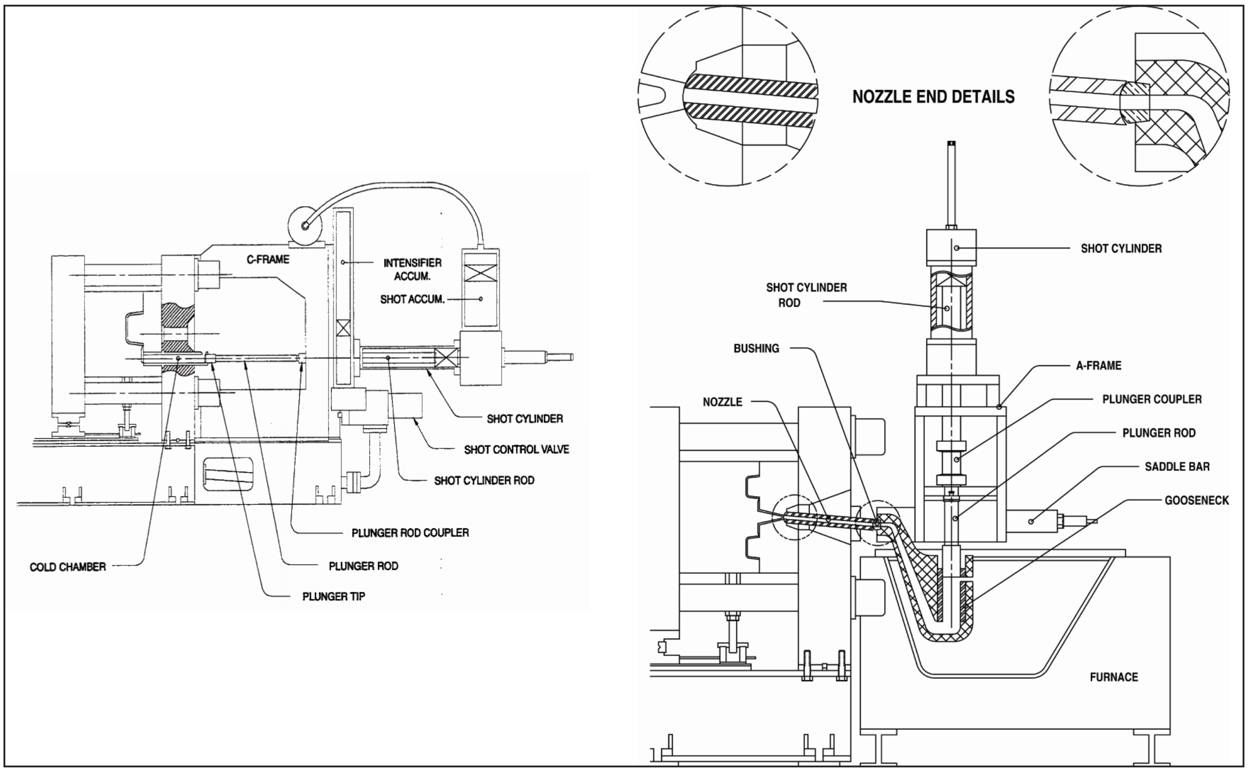


Figure 5-3 - The basic simplicity of the die casting machine is obscured by the auxiliary equipment, pumps, motors, pipes, control valves, etc., which are needed for efficient operation of the process.

Process Variables Before Cavity Fill (Cold Chamber only)

The cold chamber machine with a horizontal shot end has a significant disadvantage over other die casting processes. The metal is introduced using a horizontal sleeve. This process provides opportunity for temperature loss, metal contamination, air entrapment, frictional losses due to the sleeve and tip, and a 90 degree turn in the metal path. The shot end process can help to minimize the temperature loss and air entrapment through control of several process parameters before the metal reaches the cavity. These process parameters are:

Shot Delay Time – The shot delay time is the amount of time from when the ladle has completed the pour into the cold chamber to when the shot motion begins. This time should be dictated by the amount of time for the metal wave within the shot sleeve to go to the parting line and then return to the shot tip. The shot motion should start at the instant that the metal wave hits the shot tip. This time should be tested during process development, and then controlled during production by the PLC, and documented within the process setup book.

Pour Hole Velocity – The pour hole velocity is the plunger speed average from the start of the plunger motion to the point where the pour hole is closed by the plunger. This speed needs to be as fast as possible without allowing metal to escape the cold chamber fill hole during the pour hole closing phase of the shot.

Slow Shot Start Position – The slow shot start position is the position where the slow shot velocity is initiated. This setting should be equal to or slightly before the pour hole closed position. The slow shot may be set to start before pour hole closed because of the hydraulic and electronic delay in initiating the slow shot speed. The means to control this position accurately is to have accurate, closed loop measurement of position via the PLC. When the desired start position is achieved, the PLC should trigger the slow shot to begin. Please note that when using the PLC for position based shot control, the normal PLC scan should be interrupted so that timely control of the position based outputs may be completed. However, this interruption should not be higher in priority than safety functions of the die casting machine.

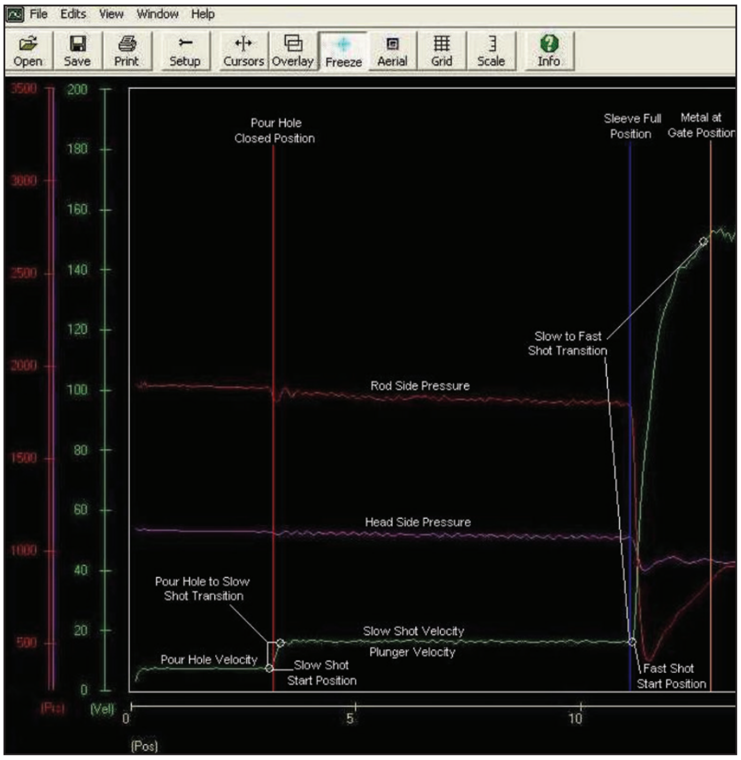


Figure 5-4 - Process variables before cavity fill (Provided by Buhler-Prince, edited to indicate process variables before cavity fill)

Slow Shot Velocity – The slow shot velocity is the average plunger velocity between the pour hole closed position and the sleeve full position. The value for the slow shot velocity is critical to minimize air entrapment. The critical slow shot velocity calculation provides a good starting point for the slow shot velocity setting. See Appendix 1: Calculations, for the critical slow shot velocity formula. Please note that the best velocity for slow shot is at or slightly above (+ 2 inches per second) the critical slow shot calculation. Control of slow shot velocity is best done through closed loop control of a servo or proportional valve.

Slow Shot Acceleration Rate – Some more advanced machines allow for constant acceleration of the shot tip during the slow shot phase. This has been proven by research to provide the best conditions to minimize air entrapment and shot time. The acceleration value has a broad range of good conditions. Therefore, the best scenario is when acceleration matches the desired fast shot velocity at the metal at gate position. This calculation is shown in Appendix 1.

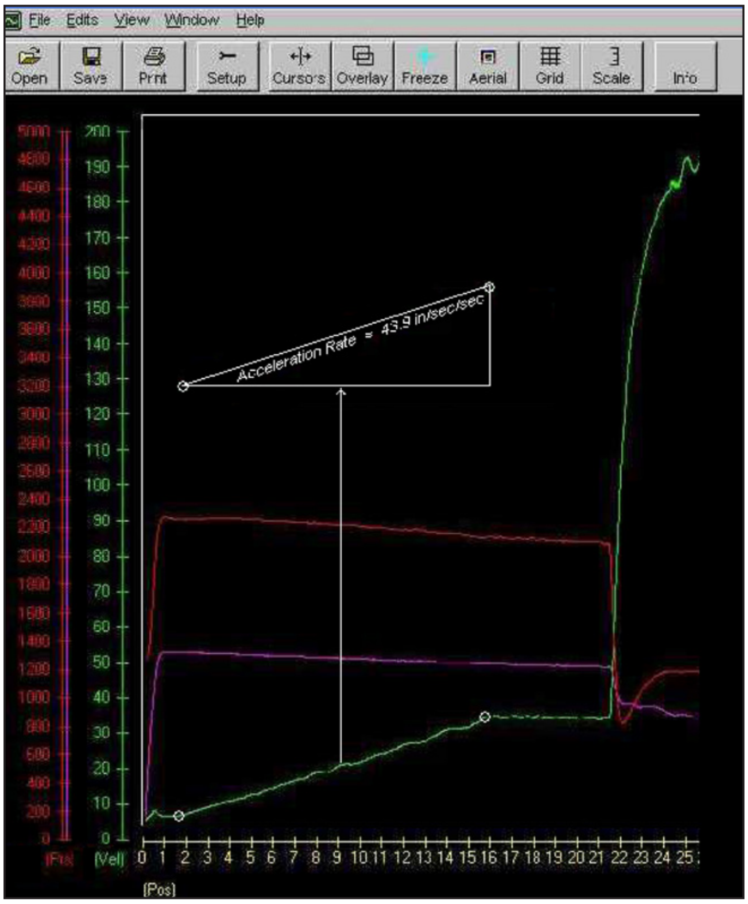


Figure 5-5 - Acceleration Profile (Provided by Buhler-Prince)

Fast Shot Start Position – At the sleeve full position, the cold chamber die casting machine should initiate the fast shot. The means to control this position accurately is to have accurate closed loop measurement of position via the PLC. When the desired start position is achieved, the PLC should trigger the fast shot to begin. Please note that when using the PLC for position based shot control, the normal PLC scan should be interrupted so that timely control of the position based outputs may be completed. However, this interrupt should not be higher in priority than safety functions of the die casting machine.

Slow to Fast Acceleration Rate – It is important that the machine is capable of completing the acceleration to the desired fast shot speed before the metal reaches the casting in-gate. To determine if this is possible, the fast shot acceleration rate must be known. This can be calculated by measuring the change in velocity over the change in time on a current shot profile. This acceleration should be documented as a machine capability characteristic. The required acceleration rate, which is based upon the runner volume, can also be calculated. If the required acceleration rate is lower than the machines capability, then the process will work well. If the required acceleration rate is higher than the machines capability, then the fast shot may need to be started early by some time. The calculation for required acceleration rate is shown in Appendix 1. Therefore, the control mechanism is to watch the actual acceleration rate and look for downward trends over time. If the rate drops, machine maintenance staff should be involved to identify the reason for the problem.

Two Speed Machines

If a two speed cold chamber machine is used, there is no pour hole velocity phase. In this case, the critical slow shot velocity must be calculated with a pour hole closed position setting of 0 inches. Although some metal may come out of the shot sleeve each shot, this calculation should still be used to determine the slow shot velocity. The slow shot start position will also be 0 inches.

To determine the best settings for these process parameters, several values must be known. These values are:

Total Shot Volume – This can be determined in the CAD geometry file in the design phase or by a weight scale on the production floor.

Liquid Metal Density – This varies by alloy and chemistry and should be known.

Distance from Plunger Start to Pour Hole Closed –

This is required to determine slow shot start position.

Sleeve Full Position – This value can be calculated from the impact position using the entire pour weight, liquid metal density, and plunger area.

Casting and Overflow Volume – This value can either be determined from CAD geometry, estimated, or measured.

Metal at In-Gate Position – This value can be calculated from the impact position using the weight of the metal through the gate, liquid metal density, and plunger area.

The calculations for these values are shown in Appendix 1: Calculations.

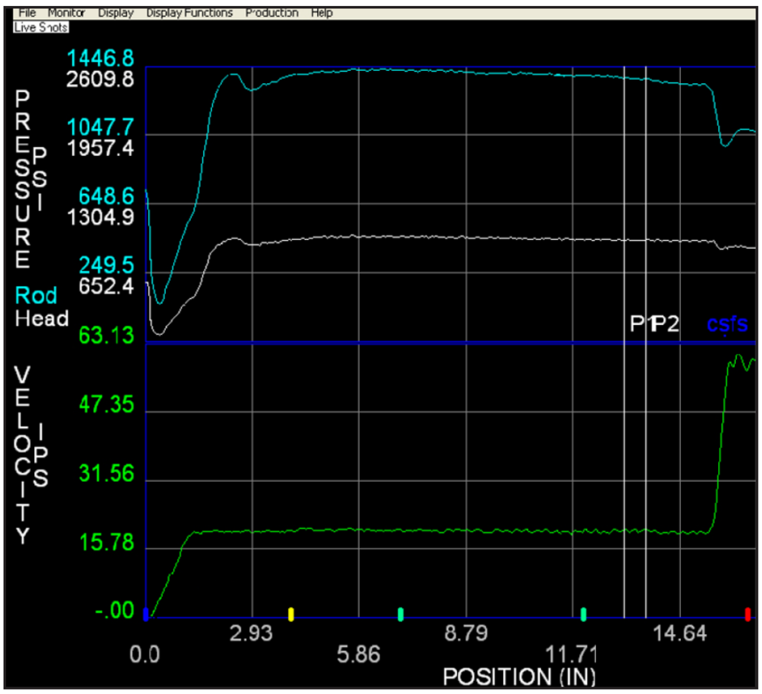


Figure 5-6 - Two Speed Shot Profile (Provided by Visi-Trak Worldwide)

Process Variables during Cavity Fill

The cavity fill event is equally critical to all die casting processes. The high pressure die casting process is characterized by a fast fill time with high in-gate velocity. The purpose of the high fill rate and high in-gate velocity is to provide a net shape product with thin walls, high internal integrity, and good surface finish. Therefore, the process variables that we must watch carefully are:

Fill Time – This is the amount of time to fill out the die casting part cavity. This does not include the time to fill the overflows. Specifically, it is the amount of time to go from the metal at in-gate position to the metal at overflow gate position.

The desired fill time should be determined prior to runner design and die build, and then should be controlled during the process. The NADCA fill time formula is shown in Appendix 1. The fill time will have a strong influence over the resulting casting surface finish and will affect the amount of internal porosity.

Control of fill time is done by controlling the velocity of the plunger between the metal at in-gate position and the metal at the overflow gate position. The methods to control the fill time are open or closed loop control (described in the previous chapter on Closed Loop and Open Loop Control). For fill times above 0.050 seconds, closed loop systems work well. However, the overall best practice is to use an accurate proportional valve with open loop control. Many of these types of valves are available to the die casting market.

Average In-Gate Velocity – This is the average metal velocity through the in-gate during the fill time. In the process monitoring system, it should be calculated by first determining Q (the volume flow rate of metal) and the gate area. The in-gate velocity is then equal to Q divided by gate area.

The desired in-gate velocity should also be determined prior to runner design and die build. The in-gate velocity needs to be high enough to assure good atomization so that internal porosity is effectively dissipated (finely distributed within the casting) and die erosion is minimized. To calculate the average in-gate velocity, the average plunger velocity during cavity fill must be calculated. The average plunger velocity must then be multiplied by the ratio of plunger area to gate area. The atomization velocity and gate velocity equations are shown in Appendix 1.

For a given gate area, in-gate velocity is inversely proportionate to fill time. Therefore, if a problem exists with the in-gate velocity, it is directly related to the fill time.

In-Gate Velocity at Metal at Gate Position – This value should be at least as high as the average in-gate velocity to assure that the cavity fill begins with an in-gate velocity that provides proper initial atomization when the metal first travels through the in-gate. If the in-gate velocity at metal at gate position is below the desired in-gate velocity, the atomization desired during fill may be compromised.

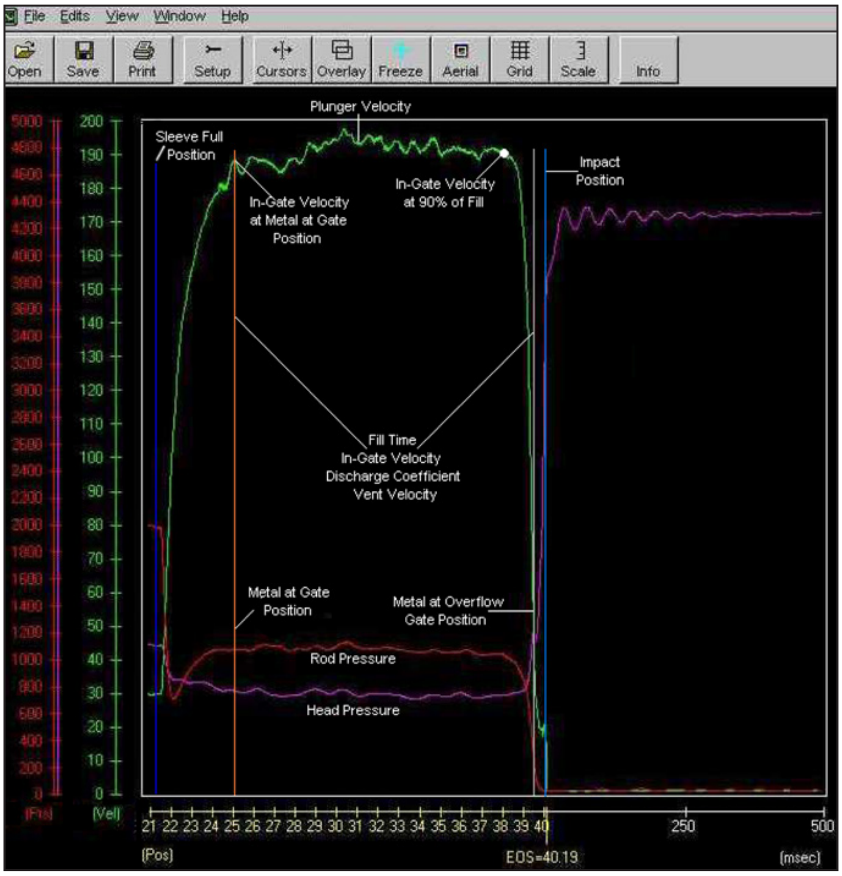


Figure 5-7 - Shot Profile during Cavity Fill (Provided by Buhler-Prince)

If a problem occurs with the in-gate velocity at the metal at gate position, the fast shot start position is starting too late or the slow to fast acceleration is too slow.

In-Gate Velocity at 90% Fill – Near the end of cavity fill the resistance to flow increases significantly. The increased resistance often causes the plunger velocity to drop and the in-gate velocity to drop. If this drop is significant, the metal flow may no longer be atomized. If this happens, there will be an increase in die erosion depending upon the part size and geometry. Therefore, it is important to monitor this velocity and correct the machine problem, if necessary, so that die erosion problems may be addressed.

Discharge Coefficient during Cavity Fill – The discharge coefficient is the hydraulic efficiency during the cavity fill time. The value for Cd has no unit. In the past, NADCA texts have suggested that Cd should be 0.5 for cold chamber and 0.65 for hot chamber. Research have shown that Cd is rarely this high in either process. Cd also is critical when evaluating PQ Squared graphs. It determines the angle of the die performance curve. See Figure 5-10.

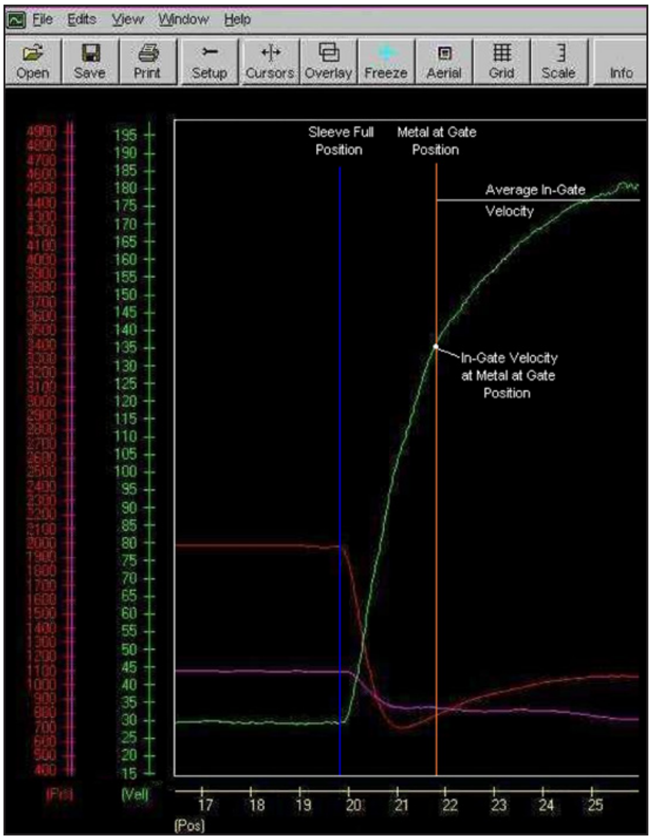


Figure 5-8 - Low Initial Gate Velocity (Provided by Buhler-Prince)

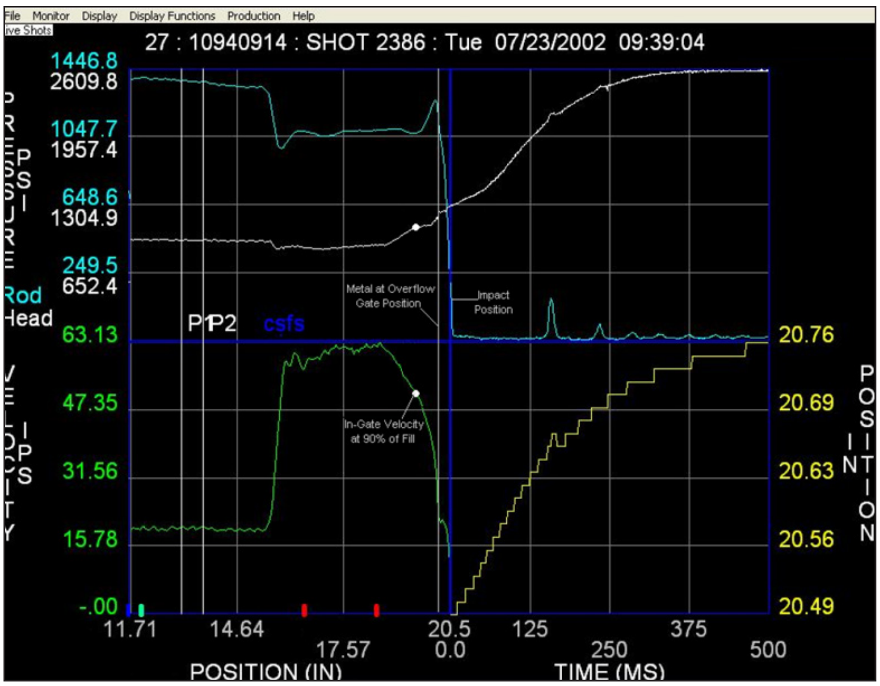


Figure 5-9 - Low Gate Velocity at 90% of Fill
(Provided by Visi-Trak Worldwide)

To calculate Cd, the process monitoring system must accurately calculate the head side pressure average during cavity fill, the rod side pressure average during cavity fill, and the average in-gate velocity. Cd should be calculated every shot and tracked via SPC within the process monitor. A standard for the minimum value for Cd should be established. See the calculation for Cd in Appendix 1.

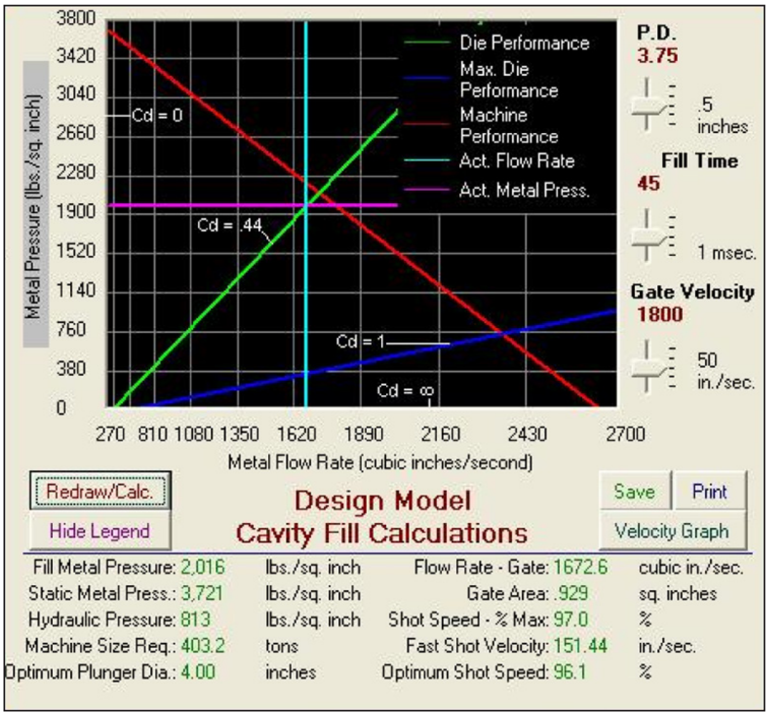


Figure 5-10 - PQ^2 Diagram Illustrating Discharge Coefficient (Die Cast Process Planner provided by Bisnet)

As a rule of thumb, a good cold chamber standard minimum would be between 0.32 and 0.36 and a good hot chamber standard minimum would be between 0.45 and 0.50. If the Cd falls below the minimum, this indicates that excessive shot end force is required to achieve the desired fill velocity. This may result in lower than desired fill time or flashing problems.

Vent Velocity – The vent velocity is critical to assure that air can easily escape the die cavity without allowing metal to flash out of the die cavity. The range of typically accepted vent velocity is 4,000 to 8,000 inches per second (or 100 to 200 meters per second). Vent velocity below 4,000 inches per second indicates a large vent area, which will often lead to flashing problems. Vent velocity above 8,000 inches per second nears the speed of sound (the speed of sound is between 13,000 and 16,000 inches per second depending upon air temperature). When the vent velocity exceeds 8,000 inches per second, air pressure builds exponentially and restricts venting. To calculate the vent velocity, the average plunger velocity during cavity fill must be divided by the ratio of plunger area to the minimum vent opening area. See Appendix 1 for the calculation of Vent Velocity.

To control vent velocity, the vent area at the smallest opening should be accurately measured and maintained. The vent opening may become smaller over time due to the die closing force deflecting and flattening the die parting surface.

To calculate the above cavity fill parameters, several other process variables must be determined:

Average Plunger Velocity – This is the average velocity during cavity fill.

Metal at Overflow Gate Position – The monitor must know this position to accurately calculate the cavity fill variables. A shot monitor can calculate this by finding the impact position and then subtracting the distance that the plunger tip must travel to fill the overflows.

Average Head Pressure During Cavity Fill – This value is important for the discharge coefficient calculation and for shot end preventive maintenance.

Average Rod Pressure During Cavity Fill – This value is important for the discharge coefficient calculation and for shot end preventive maintenance.

The gate area is the sum of the areas of all in-gates in the die casting mold. It should be measured often to assure accuracy. In a large cold chamber machine using aluminum, the gate area may need to be measured at every setup. In a small hot chamber machine using zinc, the gate area should be measured every six months to one year. The gate area is critical to the in-gate velocity and discharge coefficient calculations.

Plunger Area – The plunger area is equivalent to the plunger diameter squared multiplied by π/4.

Vent Area – The vent area is the sum of the areas of all vents in the die casting mold. The vent area should be measured at the smallest point because the vent velocity is important at the point of greatest air flow restriction.

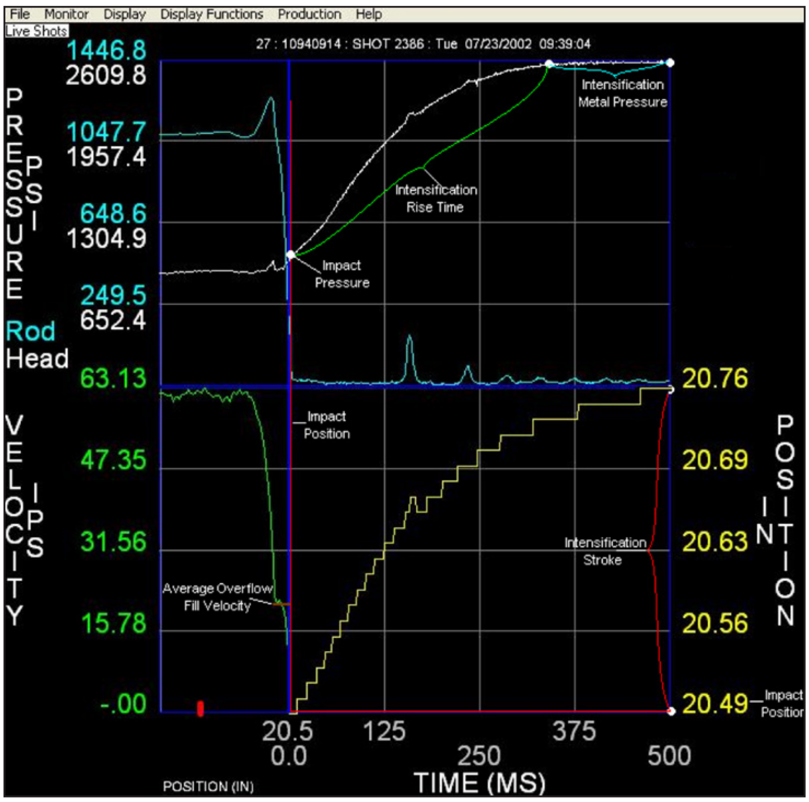


Figure 5-11 - Process Variables after Cavity Fill
(Provided by Visi-Trak Worldwide)

Process Variables After Cavity Fill

There are several parameters that must be monitored and controlled at cavity fill and after cavity fill. These parameters are:

Impact Pressure – The impact pressure is the highest hydraulic head pressure measured by the pressure transducer near the end of cavity fill (or overflow fill). The impact pressure is critical with regard to flashing and dimensional control issues related to die and slide blow problems. The impact force is a combination of static force from the residual accumulator pressure at the point of impact and kinetic force from the stopping of the moving mass of hydraulic fluid, shot end components, and metal.

Two means used by the industry to control impact pressure are programmable shot control systems that are capable of decelerating the shot system near the end of cavity fill. Another is SoftSHOT Technology – a series of especially designed overflows positioned at the point of final filling in the cavity, the purpose of which is to stall out the kinetic energy of the shot system.

Impact Position – The impact position is the plunger position when the impact pressure occurs. This position is critical because it should be used to calculate other critical position points within the process. These critical position points are the overflow gate position, the metal at in-gate position, and the sleeve full position.

Impact position is affected (in order of importance) by pour weight, flashing, slide blow, and die temperature. These items need to be monitored. These items may need to be controlled using the appropriate technologies if impact variation causes process problems.

Intensification Metal Pressure (Cold Chamber) – The intensification metal pressure is the metal pressure, typically in pounds per square inch, applied to the biscuit during the intensification phase of the shot. It is best to calculate the metal pressure, which is the intensifier accumulator pressure multiplied by the hydraulic cylinder area then divided by the plunger area, to understand the pressure on the metal during intensification. It is known that pressure tight castings or castings requiring low levels of porosity may require intensification metal pressure of at least 8,000 psi up to 20,000 psi. The calculation for intensification metal pressure is shown in Appendix 1.

Hold Metal Pressure (Hot Chamber) – Hold Metal Pressure is the average metal pressure held after the impact position. Hold metal pressure can affect shrinkage porosity. Small plunger diameters cause larger hold metal pressure while larger plungers cause lower hold metal pressure.

Intensification Stroke (Cold Chamber) – The intensification stroke is the distance traveled after the impact position. The intensification stroke indicates how much shrinkage volume in the casting is replaced during intensification. This value can be compared to the shot volume to determine the percentage of shrinkage eliminated during intensification.

Average Overflow Fill Velocity – The average overflow fill velocity can either be the plunger velocity during overflow fill or the overflow gate velocity during overflow fill. This value is an important determinant of impact force. If the plunger velocity during the overflow fill is close to the fill velocity, the impact force may be too high because the plunger did not decelerate much as the overflows filled. If this value is between one-third and one-half of the plunger velocity during fill, the impact force should be minimized. If this value is below one-third of the plunger velocity during fill, the peak impact pressure may occur before the overflows fill. If the peak impact pressure happens before the overflows fill, the overflows may not be venting air and dirty metal well enough and flashing problems may occur.

Plunger Drift Velocity (Hot Chamber) – The plunger drift is the plungers over-travel after impact. The majority of the movement during plunger drift is leakage of metal by the rings in the hot chamber system. The best way to measure this is by a RATE of movement or velocity. Maximum standards for plunger drift velocity should be set by plant or by job. If the plunger drift velocity standard is exceeded, the machine is no longer maintaining adequate metal pressure as the casting is freezing. If this occurs, the rings, plunger, or gooseneck (in that order) may need to be changed.

To calculate the above parameters at cavity fill and after cavity fill, several other process variables must be determined:

Impact Velocity – This is the velocity required by the monitoring system to detect the impact pressure. The impact velocity is typically between 5 and 12 inches per second. The monitoring system should start at the end of the velocity data array and look backwards in the data array to find when this velocity was first exceeded. Then the monitoring system can look for the peak pressure, which would be identified as the impact pressure, within a range of time (milliseconds) before and after the impact velocity is found.

End of Shot Velocity – This is determined by assigning a velocity at which impact has occurred. Some monitoring systems can be armed (somewhere in the fast shot) to begin looking for this velocity (typically above 5 – 12 IPS). As the die becomes full and the plunger has nowhere to go the velocity reduces very quickly. This technique is very good at finding the impact position.

A good way to find the impact pressure is to define a window (say 0.5” before the impact position, and =15 mS after the impact position) and then take the greatest pressure seen on the head side pressure transducer in the window.

Hydraulic Cylinder Area – The hydraulic cylinder area is the hydraulic cylinder diameter squared multiplied by π/4.

Plunger Area – The plunger area is equivalent to the plunger diameter squared multiplied by π/4.

Overflow Volume – The overflow volume is the overflow weight divided by the liquid metal density.

Other Shot End Monitoring Features

Position Based versus Time Shot Profile

Position based and time based shot profiles have long been used in the die casting industry to characterize the shot profile graphically. Position based profiles are typically considered to be better during the shot until the impact position. After impact, time based profiling demonstrates post impact variables best during slow plunger motion.

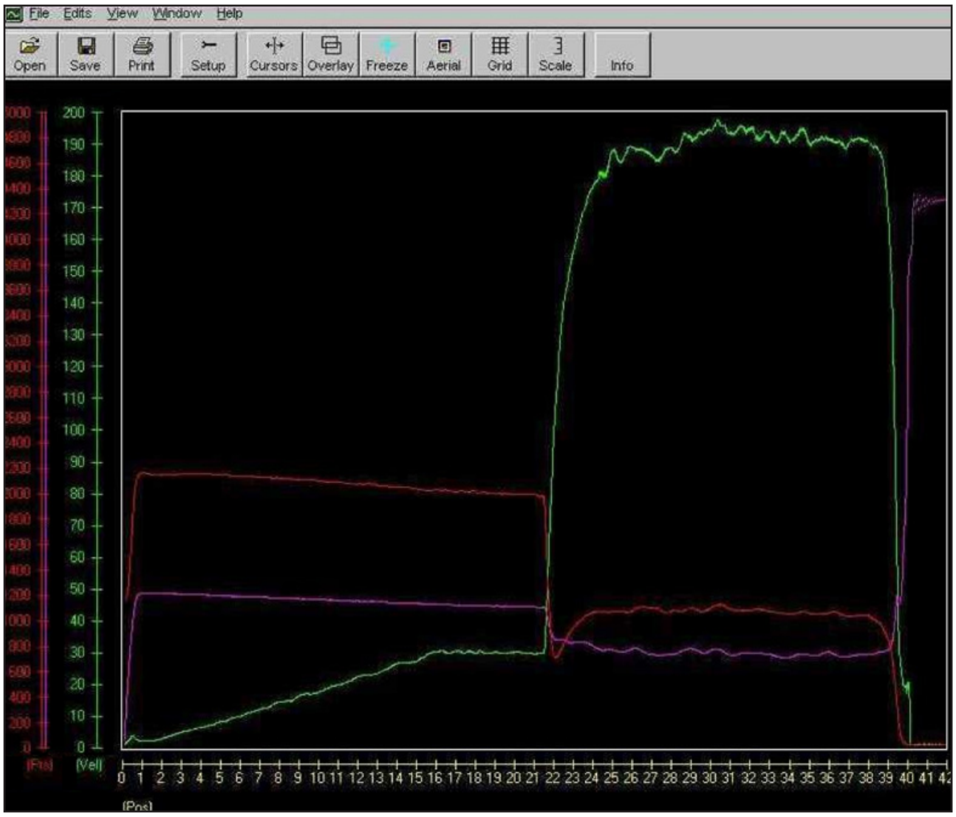


Figure 5-12 - Position Based Shot Profile (Provided by Buhler-Prince)

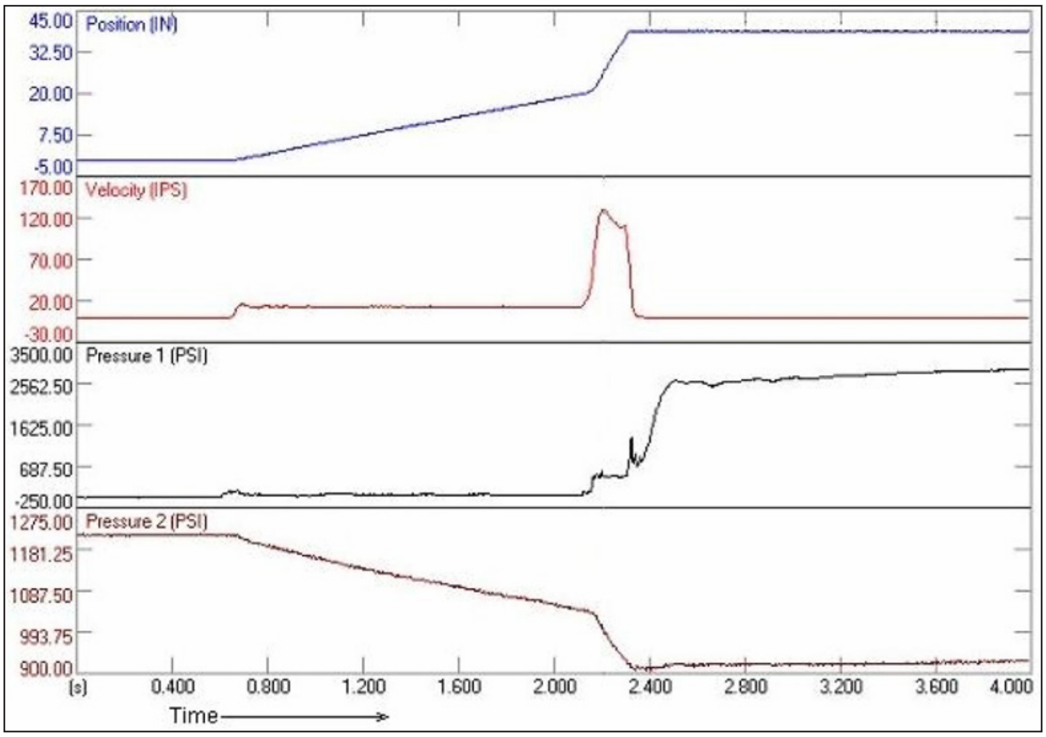


Figure 5-13 - Time Based Shot Profile (Provided by Shotscope division of Moldflow)

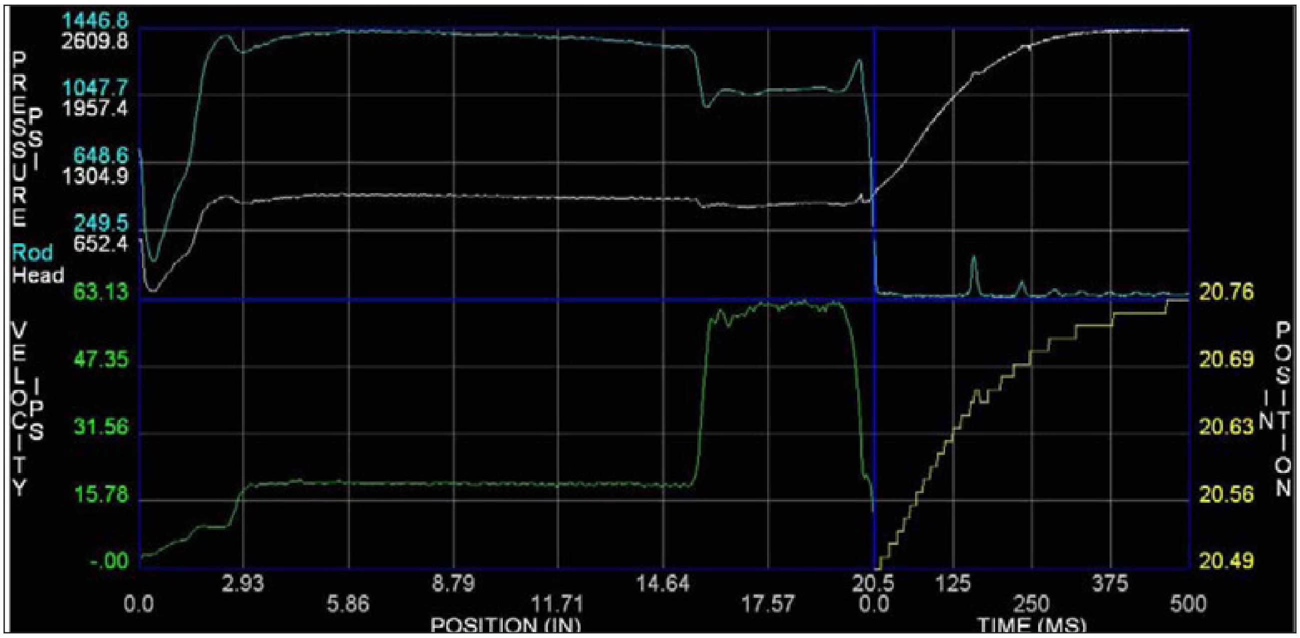


Figure 5-14 - Position (before impact) and Time (after Impact) Profile (Provided by Shotscope division of Moldflow)

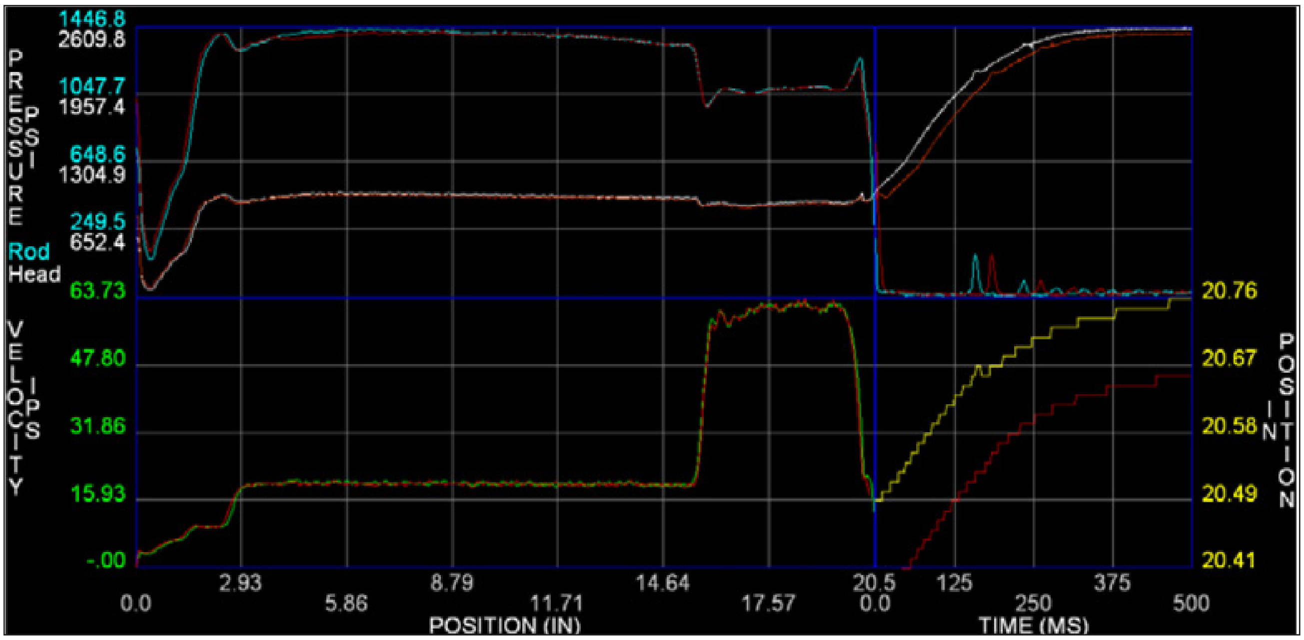


Figure 5-15 - Reference Profile Example - Reference Traces Shown in Red (Provided by Visi-Trak Worldwide)

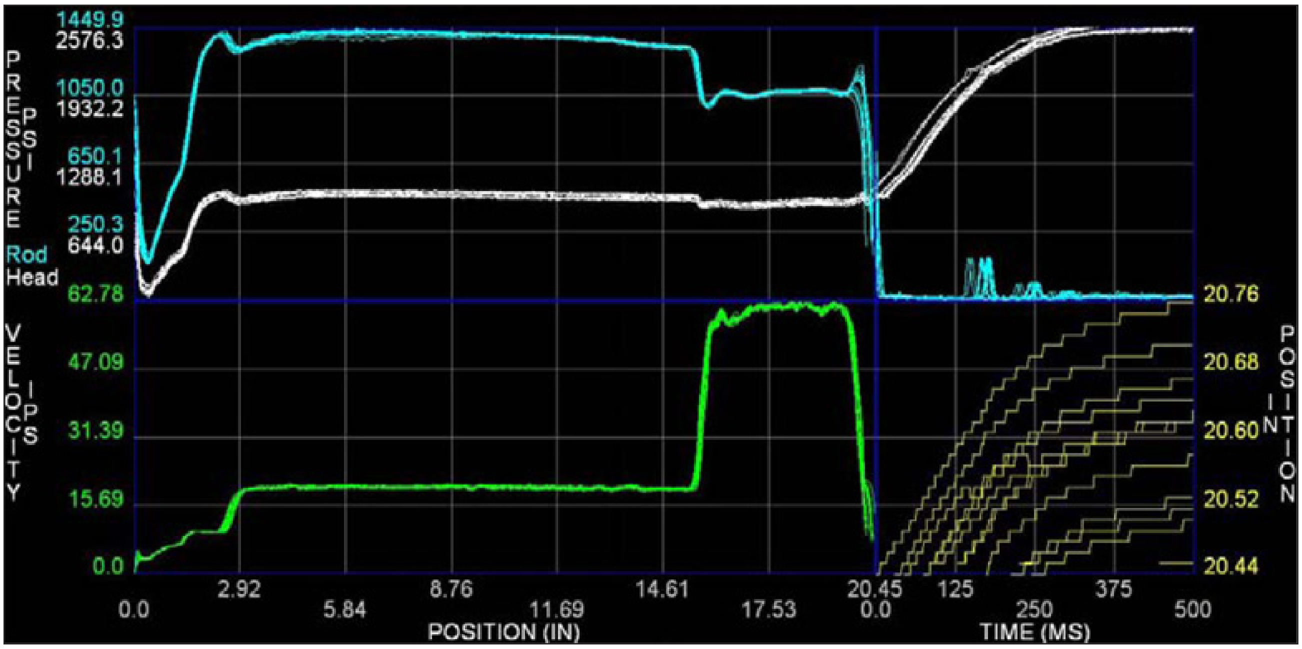


Figure 5-16 - Profile Overlay Example (Provided by Visi-Trak Worldwide)

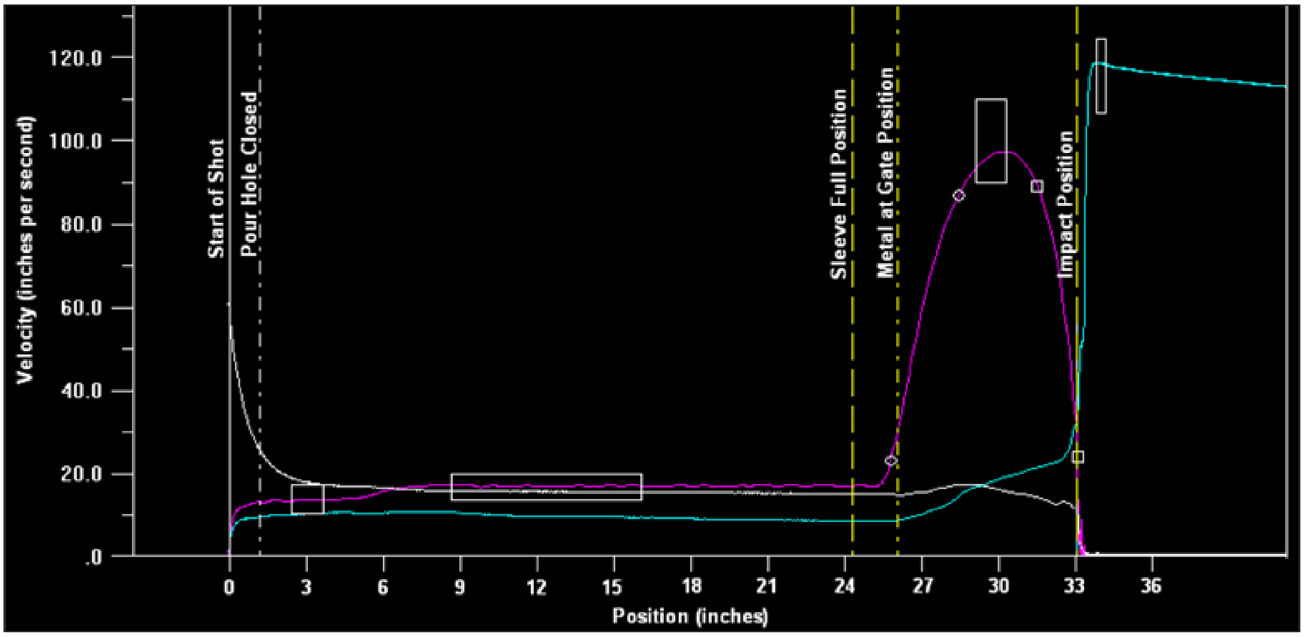


Figure 5-17 - Positioned Based Outputs (Provided by Bisnet)

Shot Profile Master

Once a process has been developed and proven to be effective, shot end process variables can be documented. A very good way to verify the shot profile is by saving a master profile. All of the process monitoring software suppliers provide this feature. Not only does this feature provide more information on the shot profile itself, but it also enables the die cast user to perform preventive maintenance activity on the machine shot end.

Shot Profile Overlays

The shot overlay feature allows for multiple traces to be displayed over the top of one another. The shot overlay feature is designed to enable the die cast user to view shot to shot consistency. All the monitoring suppliers provide this feature. This feature is also very valuable for shot end preventive maintenance.

Position Based Graph Lines and Outputs

The slow shot start, fast shot start, low impact, and intensification systems are started using position based signals, often using limit switches. Monitoring suppliers realized that they could provide a simple way to view these positions, relative to the shot profile, within the monitor.

Some monitoring suppliers have provided an accurate and easy method to change positions within the shot monitor. The monitoring system sends a digital signal to the PLC or shot end valves once the position transducer indicates that pre-determined positions have been achieved. Position based graph lines and outputs are visually effective ways to control a basic part of the process.

Figure 5-18 - Best Shot Profile

Shot End Summary (Suggested Process Variables)

In the opinion of the author, the profile approach that best describes the die casting process to the user is shown as Figure 5-18. The profile is displayed in position base before impact and time base after impact. Velocity is the focus before impact and pressure is the focus after impact.

The following process variable lists do not reflect any of the current process monitoring systems. However, these lists for hot chamber and cold chamber encompass the important process variables needed to support the best casting process design and product quality.

Suggested Process Variables

Cold Chamber

Shot Delay Time

Pour Hole Velocity

Slow Shot Start Position

Slow Shot Velocity

Slow Shot Acceleration Rate (Constant Acceleration Shot End Only)

Fast Shot Start Position

Slow to Fast Acceleration Rate

Fill Time

Average In-Gate Velocity

In-Gate Velocity at Metal at Gate Position

In-Gate Velocity at 90% Fill

Discharge Coefficient during Cavity Fill

Vent Velocity

Impact Pressure

Impact Position

Intensification Pressure Rise Time

Intensification Metal Pressure

Intensification Stroke

Average Overflow Fill Velocity

Hot Chamber

Slow Shot Velocity

Fast Shot Start Position

Fill Time

Average In-Gate Velocity

In-Gate Velocity at Metal at Gate Position

In-Gate Velocity at 90% Fill

Discharge Coefficient during Cavity Fill

Vent Velocity

Impact Pressure

Impact Position

Hold Metal Pressure

Plunger Drift Velocity

Average Overflow Fill Velocity

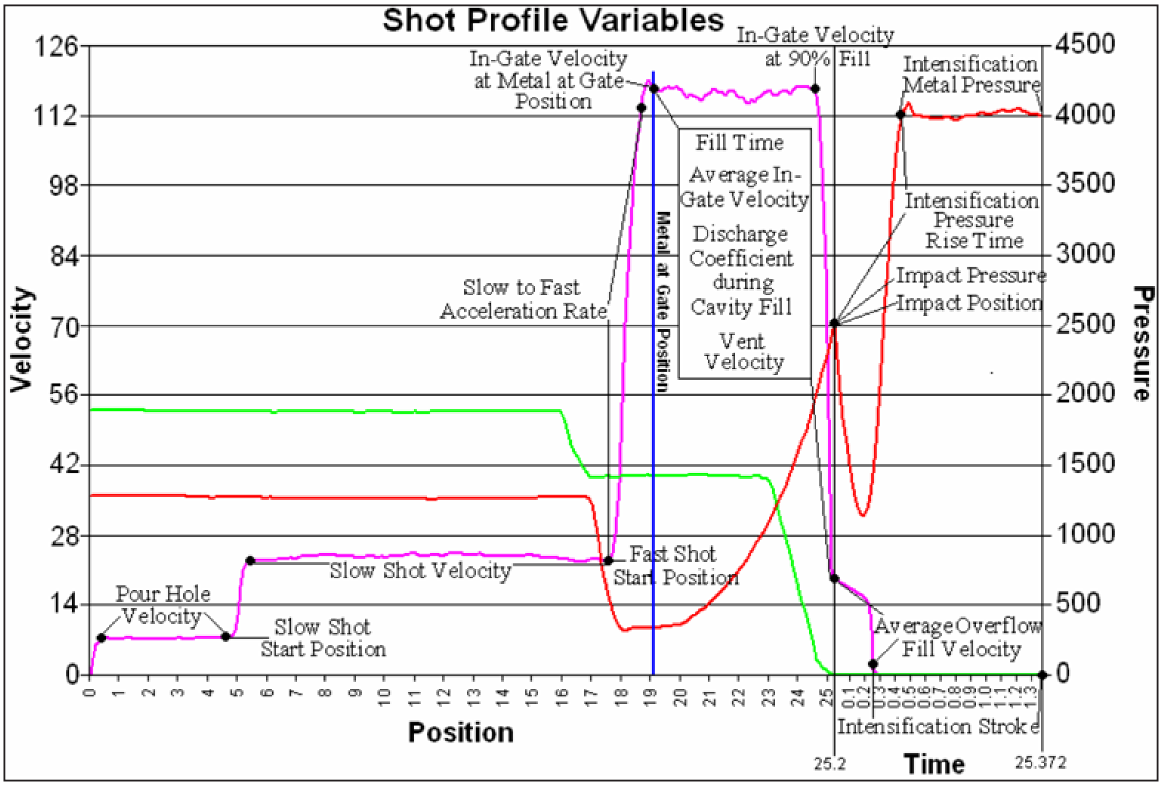


Figure 5-19 - Shot Profile with Suggest Process Variables

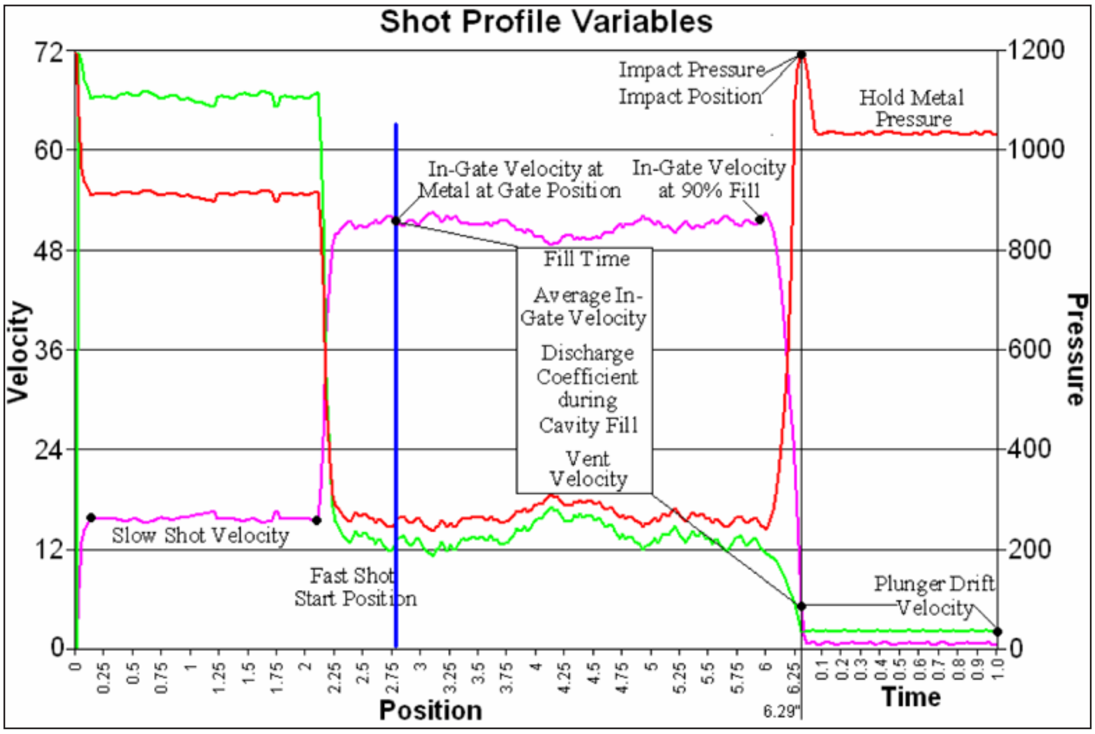


Figure 5-20 - Hot Chamber Shot Profile with Suggested Variables

APPENDIX 1: SHOT END PROCESS CALCULATIONS

General Note: A variable with an exponent to the 0.5 power is a square root $()^{0.5}$

Process Variables for Calculations

SV – Shot Volume

TV - Total sleeve Volume

PD – Plunger Diameter

V1 – Velocity at a position early in the slow shot

V2 – Velocity at a position late in the slow shot

T1 – Time at V1w

T2 – Time at V2

FSV – Fast Shot Velocity

SSV – Slow Shot Velocity

RV – Runner Volume

PA – Plunger Area

TSW – Total Shot Weight

D – Liquid Metal Density

COV – Casting and Overflow Volume

COW – Casting and Overflow Weight

OV – Overflow Volume

OW – Overflow Weight

SFP – Sleeve Full Position

PLP – Parting Line Position (tip to end sleeve distance)

MGP – Metal at in-Gate Position

MOP – Metal at Overflow Gate Position

t - Fill Time

k - Die Material / Alloy Heat Flow Constant

T_i - Metal Injection Temperature

T_f - Minimum Flow Temperature

T_d – Average Die Temperature

T_h – Casting Thickness

%S – Percent Solids Allowed during Fill

Z – Percent Solids Alloy Constant

AV – Atomization Velocity

J – Fluidity Factor

Gt – Gate Thickness

GV – Gate Velocity Target

FDF – Fill Distance Factor (See Gating and Process Planning text)

VV – Vent Velocity

VA – Vent Area

IMP – Intensification Metal Pressure

IP – Hydraulic Intensification Pressure

CA – Cylinder Area

Critical Slow Shot Velocity

$CSSV = 22.8 \times (1 - SV / TV) \times PD^{0.5}$

Slow Shot Acceleration Rate in Constant

Acceleration Machine

$SSAC = (V2 - V1) / (T2 - T1)$

Plunger Area

$PA = PD^2 \times 0.7854$

Slow to Fast Acceleration Required

$SSAR = (FSV - SSV)^2 / (RV / PA)$

Slow to Fast Acceleration Rate

$SSAC = (V2 - V1) / (T2 - T1)$

Total Shot Volume

$TSV = TSW / D$

Casting and Overflow Volume

$COV = COW / D$

Overflow Volume

$OV = OW / D$

Sleeve Full Position

SFP = PLP – TSV / PA

Metal at In-Gate Position

MGP = PLP – COV / PA

Metal at Overflow-Gate Position

MOP = PLP – OV / D

Fill Time Formula

$t = k \times \{(T_i - T_f + \%S \times Z) / (T_f - T_d)\} \times T_h$

Atomization Formula

$AV = \{J / (Gt \times D)\}^{0.588}$

Gate Velocity Formula

GV = AV x FDF

Discharge Coefficient Calculation (refer to Appendix 4)

Vent Velocity Formula

VV = (COV – OV) / (t x VA)

Intensification Metal Pressure

IMP = IP x CA / PA

APPENDIX 2: TRANSDUCERS

Position Transducers

Position transducers detect the position of the shot rod and therefore the plunger. Some position transducers also directly measure velocity. Other transducers rely upon the monitoring computer to calculate the velocity signal from the position signal. The following are the types of transducers used in the die casting industry.

Threaded Cylinder Rod or Tail Rod

A very accurate means of position measurement is done through creating an accurate thread on the shot cylinder rod or on the tail rod. The number of threads per inch must be very accurate. Once the threads are place on the rod, the rod must be chromed over to create a flat surface down the length of the rod. A Hall effect sensor can then be used to detect the motion of the rod across the face of the sensor. Typically, two Hall effect sensors are used. The sensors are offset by ¼ of the thread pitch. The result of the combination of the two sensors is a quadrature signal. The quadrature signal can measure forward and backward movement of the shot cylinder. The rod and signal output are shown in Figure 5-21.

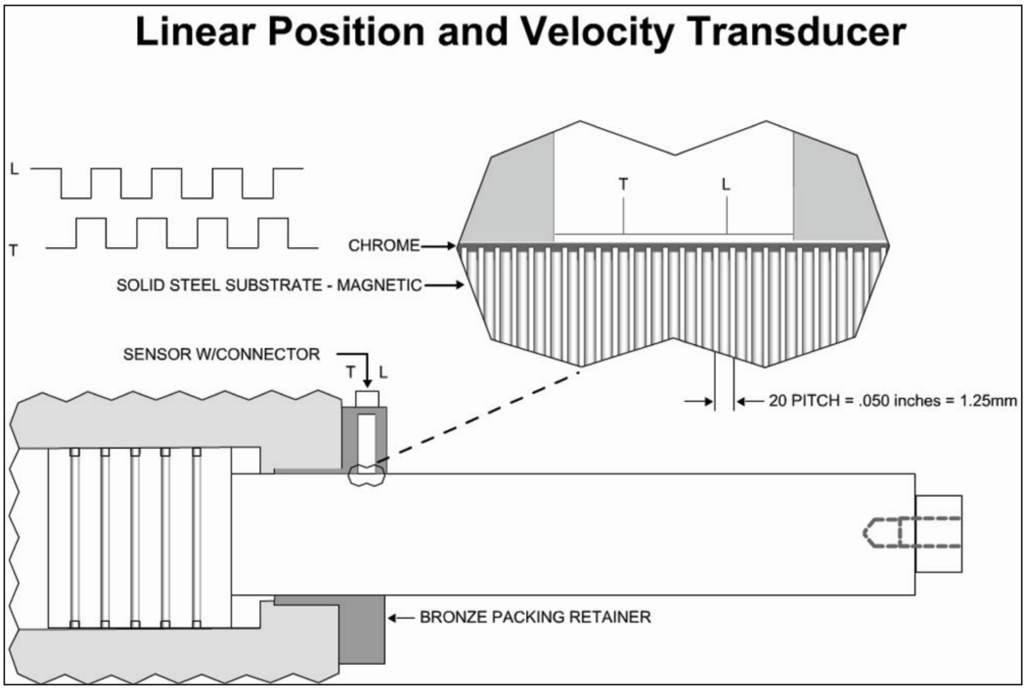


Figure 5-21 - Threated Cylinder Rod with Quadrature Signal (Provided by Visi-Trak Worldwide)

The advantage of the quadrature output is high speed, accurate measurement of cylinder movement. It can have accuracy of between +/-0.005 and +/- 0.0125 of an inch. The biggest problem with the threaded rod is in the sensor. The sensor's can fail due to high heat, impact from bouncing of the threaded rod, or poor signal because the distance from the sensor to the rod is not maintained. Most all die casting plants that use this technology have been able to work through the problems.

Wand Style Transducer

A wand style transducer has a rod that has alternating magnetic plates within the rod. The transducer body sends an electronic signal down the wand. A round magnet, which is connected to a moving part of the shot end, reflects the electronic signal as it crosses the alternating plates. The wand style transducer is very accurate; however, it is sometimes difficult to mount effectively. Rigid mounting tends to cause the wand to bend or break. Compliant mounting tends to induce vibration in the position and velocity signal. The best means of mounting the wand style transducer is by placing it within the shot cylinder. The magnet is mounted in the cylinder piston with a hole drilled within the cylinder piston and shot rod for clearance of the wand. This means of mounting often results in transducer life of more than 5 years.

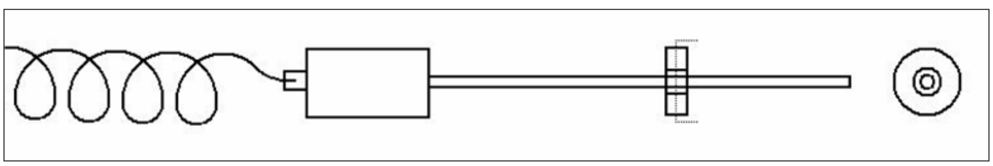


Figure 5-22 - Wand Style Transducer

Rotary Encoder

A rotary encoder uses a rack and pinion connected to the shot end as shown in Figure 5-21. The encoder spindle sends a signal, either a pulse or a voltage step, a fixed number of times per rotation. The number of signals is calibrated to the length of the pinion and the number of notches in the rotary encoder wheel. Rotary encoders are calibrated to 0.020”, 0.050”, or 0.100” per signal. A rotary encoder with 0.020” is the most accurate.

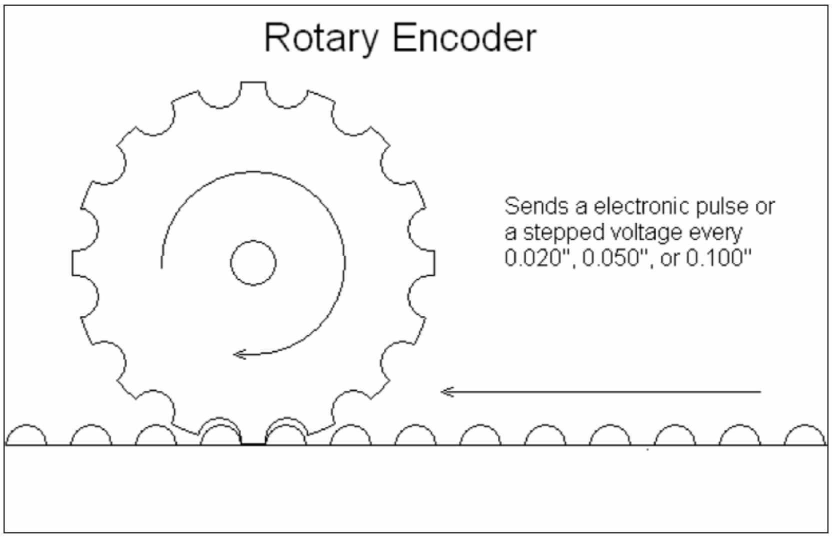


Figure 5-23 - Rotary Encoder

String Encoder

A string encoder uses a wire that connects to a moving component on the shot end. The wire is wound around a spring loaded spindle within a steel box. Electronically, the string encoder works exactly like a rotary encoder. String encoders are less expensive and just as effective as rotary encoders, except the wire can easily unwind from the spring loaded spindle. This happens most often when the wire is released while it is extended.

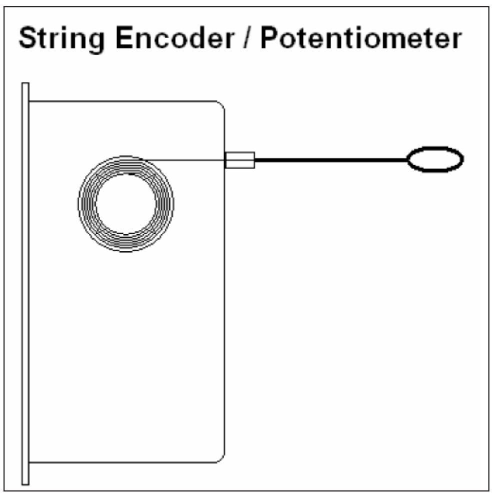


Figure 5-24 - String Encoder or Potentiometer

String Potentiometer

A string potentiometer looks and mechanically works just like a string encoder. The only difference is that it uses a potentiometer. A potentiometer is a variable resistor. When the string is not extended string potentiometers have infinite resistance. When the string is fully extended a string potentiometer will have zero resistance. The process monitoring system sends an excitation voltage to the string potentiometer, if the string is not extended it will have infinite resistance and will send back a voltage of zero. If the string potentiometer is extended fully it will have zero resistance and will send back a voltage equal to the excitation voltage. The potentiometer has a gain and calibration so that the voltage change is linear with position change.

Pressure Transducer

Most all lower cost pressure transducers used in the die casting industry work in the same way. The pressure transducer has a treaded fitting on one end that is hydraulically connected via a narrow tube to a rubber or metal diaphragm. The diaphragm has a strain gage on the opposite side of the hydraulic fluid. Higher pressure causes the diaphragm to stretch which results in higher resistance in the strain gage. The transducer includes electronics that are powered by the excitation voltage provided to the pressure transducer. These electronics measure the resistance of the strain gage, calibrate the measurement, and then provide a linear voltage signal to the process monitoring system.

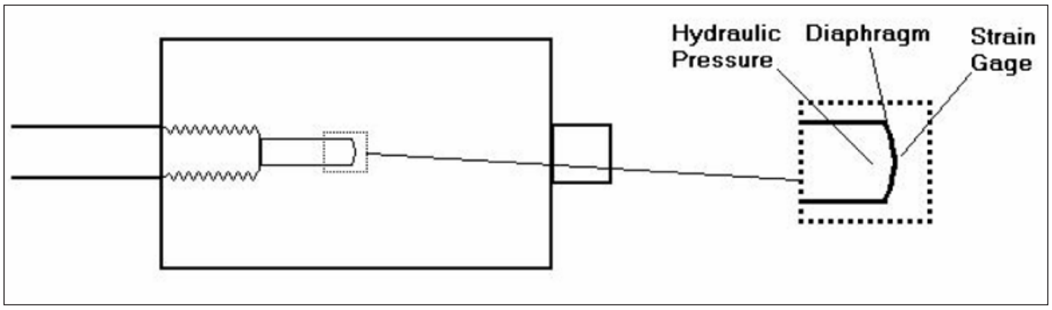


Figure 5-25 - Pressure Transducer

6 DIE COMPONENTS AND THEIR FUNCTIONS

OBJECTIVES

- To learn the names of the major die components of conventional die.
- To learn the purpose of the major die components
- To learn the requirements for safely working with the various die components.
- To learn how the die is made.
- To learn how the die works.
- To learn the factors that control die life.

PERSPECTIVE

Along with the machine, the casting die is the other major component in the die casting system. The casting die has four major functions according to E.A. Herman, author of NADCA's *Die Casting Dies: Designing*. These four functions are:

1. Hold the molten metal in the shape of the desired casting.
2. Provide means for molten metal to get into the space where it is to be held in the desired shape.
3. Remove heat from the molten metal to solidify the metal.
4. Provide for removal of the solidified metal.

Conventional production dies come in various forms. A die may be a single cavity die, meaning that it produces one casting per cycle. It could be a multiple cavity die, meaning that the die produces multiples of the same casting per cycle. It might be a multiple cavity die with multiple part numbers, also known as a "family" die, or it might be a unit type die. The unit die is a special form of a conventional die; the particular differences will be explained later. If your job requires that you handle the die cast dies, this must be done with care. First for safety reasons, the dies can be heavy and unwieldy. Therefore, they must be secure when moved. Secondly, the dies are very expensive, like jewelry, it takes many hours of skilled work to manufacture a die. Figure 1 shows the various die configurations.

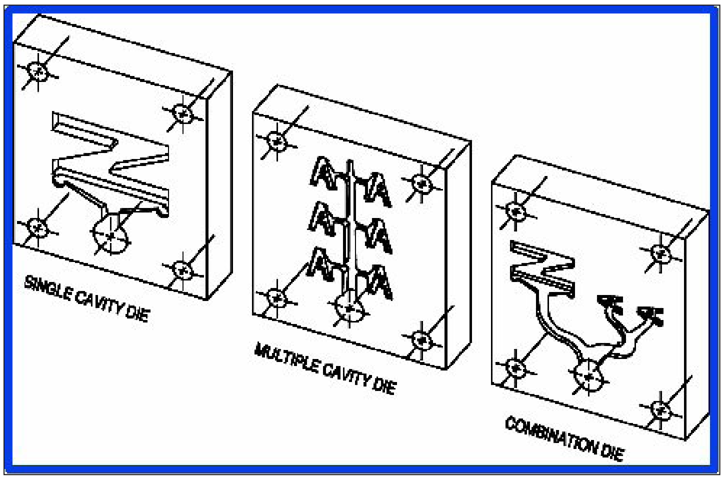


Figure 6-1 - Conventional single cavity, multiple cavity and family die

This lesson on the casting die will teach the names and function of the major components of conventional dies. Additionally, it will teach us to work safely with the die and how to care for the die.

Conventional dies have two halves. These are the stationary half, also known variously as the "cover" half, "hot" half, or "A" half and the moving half, also known as the "ejector" half, or "B" half, or "cold" half.

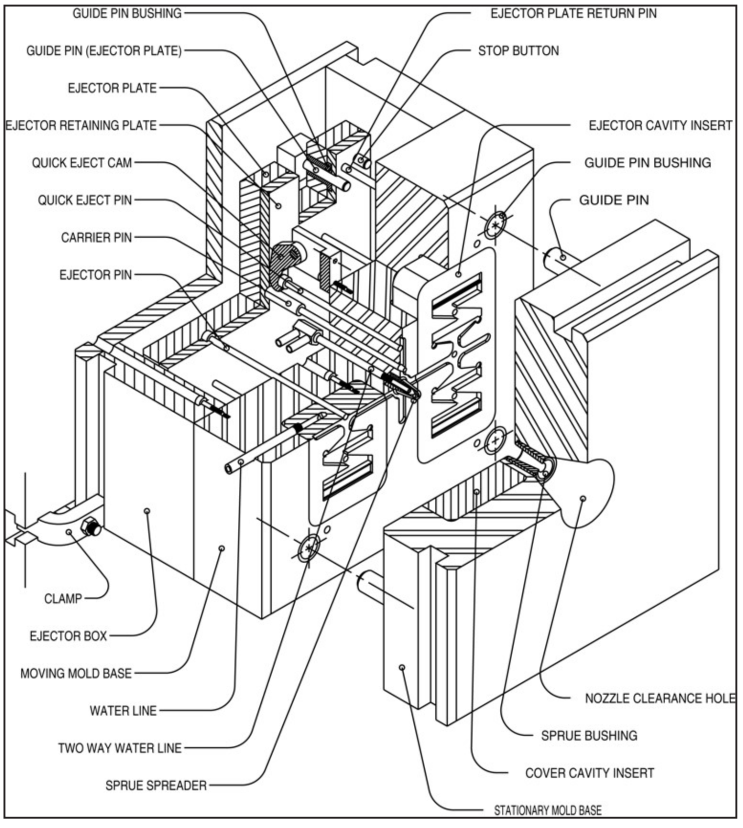


Figure 6-2 - Nomenclature of the two die halves

MAJOR DIE COMPONENTS

Mold base

The mold base is the steel envelope that is designed to hold all the other die components together. It is split or parted into two halves, "stationary" and "moving". This split is known as the parting line. During normal operation, the opening and closing of the die creates a pinch hazard at the parting line. We must always be aware of this pinch hazard, as it can be very dangerous. The die parting line can also spit metal if the die is not completely closed during injection. This can be a burn hazard to anyone in the vicinity of the die. This area is normally protected with safety doors and shields.

The mold base encloses the components that actually make the casting. The stationary mold base is mounted to the stationary machine platen. The stationary half is coupled to the machine injection system with either a cold chamber or a nozzle to the hot chamber gooseneck. The moving half mold base is mounted to the moving machine platen via the ejector box.

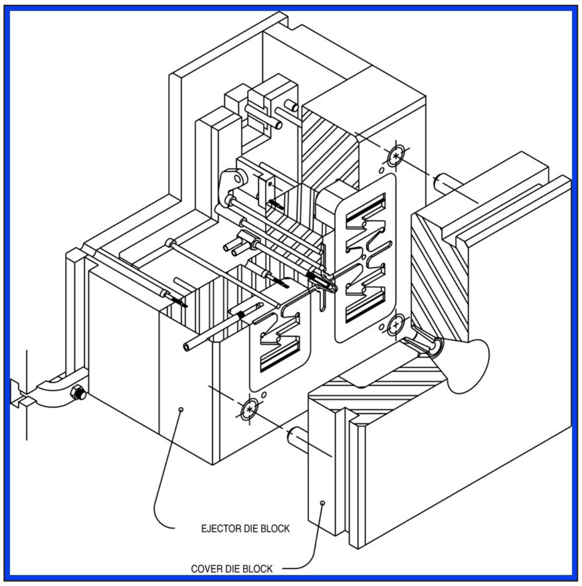


Figure 6-3 - Die with mold base shaded

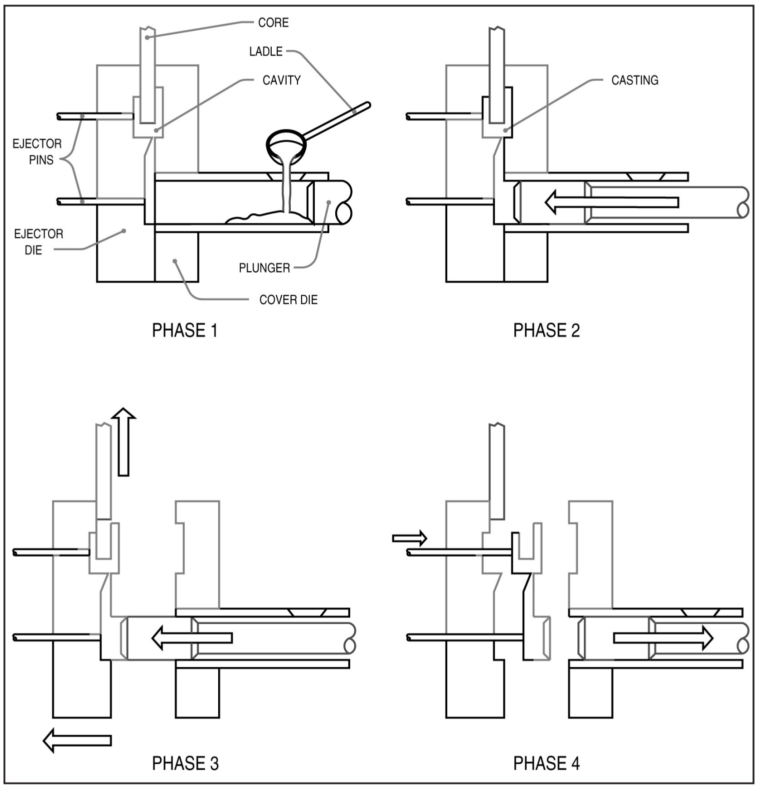


Figure 6-4 - Section through cold chamber die with cold chamber

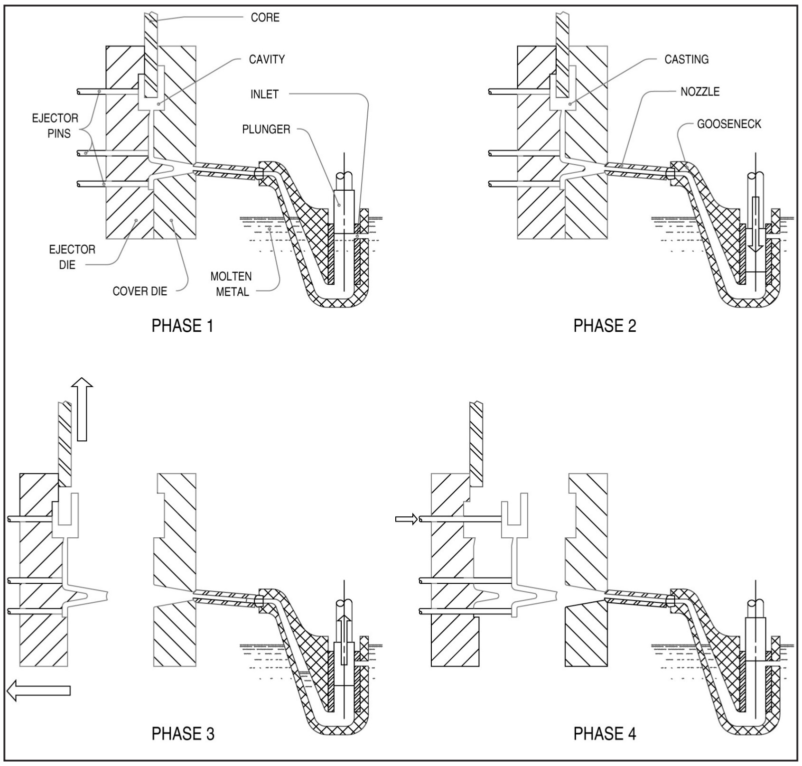


Figure 6-5 - Section through hot chamber die with nozzle and gooseneck

The mold base is usually made from pre-hardened steel such as a P-20 or AISI 4140. This is a very tough steel, but not necessarily very hard. Care must be taken when handling the mold base to avoid damage to it. It can be nicked or dented by rough handling, and this could cause set-up problems if the mold base does not fit flush on the machine platens.

Stationary half mold base

The stationary half mold base has a number of components and features that are important to the die's function. Its most important function is to act as a container for the die cavities. Additionally, it provides a means for attaching the stationary die half to the machine, it couples the injection system of the machine to the die, and it provides a means for aligning the two die halves.

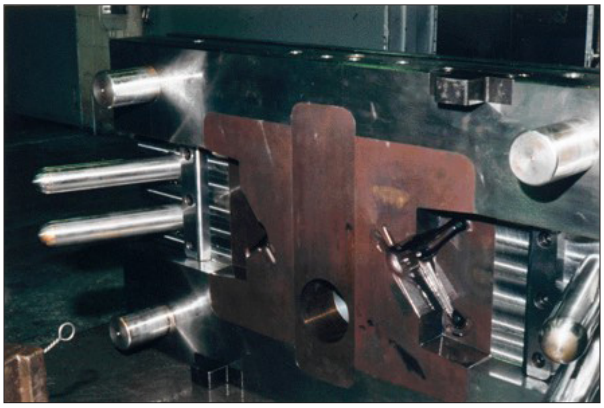


Figure 6-6 - Stationary mold base from parting line

Clamp slots- usually a clamping slot is found around the outside perimeter of the stationary mold base. This slot is normally a standard distance from the platen mounting surface with a standard width and depth to accommodate the die/clamps that are available in the die cast shop. In some shops the clamp slots may only exist on the horizontal or vertical sides. In some other shops, a clamp hole may exist instead of the slot. Slots around the perimeter are recommended, as these would give the greatest versatility for clamping.

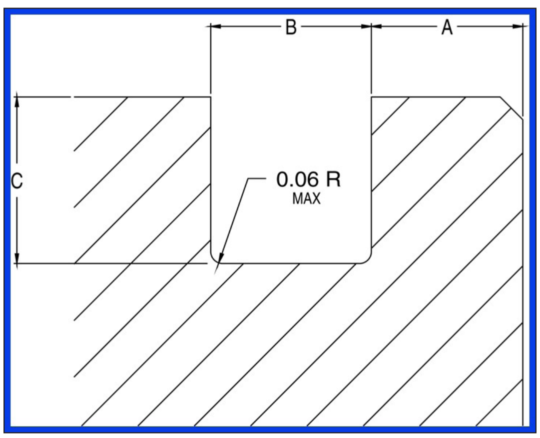


Figure 6-7 - Clamp slots

Guide pins- are round pins located at the four corners of the die. The purpose of the guide pins is to assure the alignment of the two die halves. Sometimes a casting may have critical dimensional alignment requirements from a feature in the stationary die half related to a feature in the moving die half, the guide pins in one half and the bushings in the other die half are used to maintain this alignment. The guide pins could be located in either die half. Since the guide pins project from the parting line they can become a snag hazard when castings are removed from the die, or the die is being sprayed with die release. The guide pins also operate at an elevated temperature and could be a burn hazard. Usually, one of the four guide pins is offset in order to prevent incorrect assembly of the die. In some special cases, these pins may be rectangular instead of round. These are called guide blocks and work in conjunction with wear plates in the opposite die half.

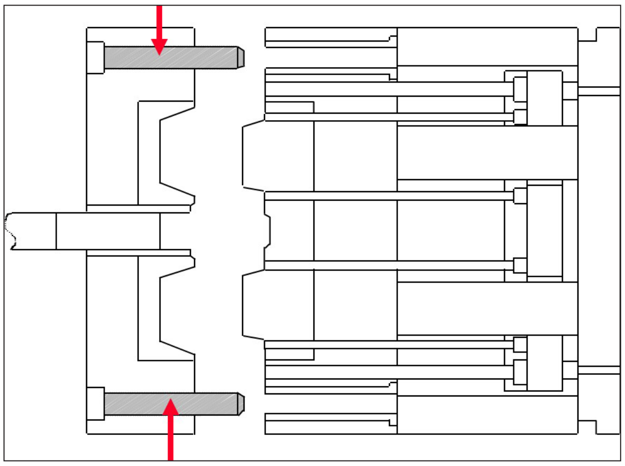


Figure 6-8(a) - Guide pins

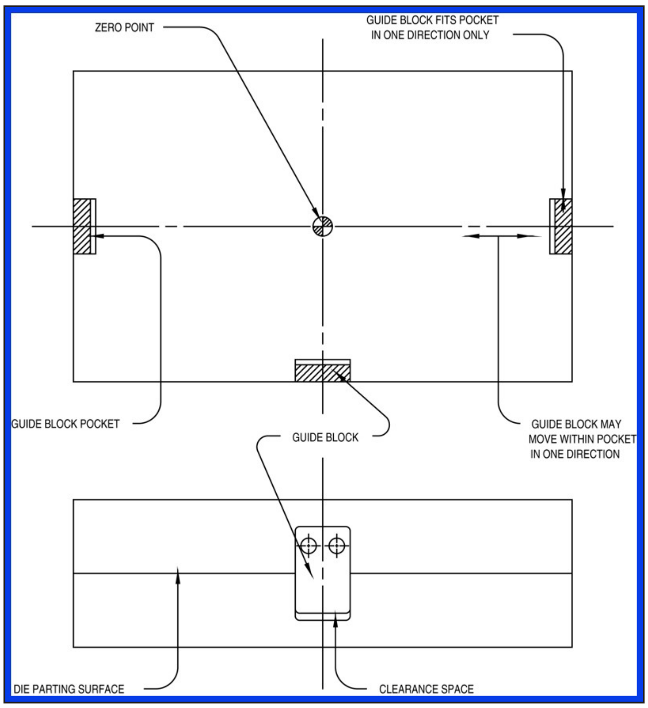


Figure 6-8(b) - Guide blocks

Pryslots- are gaps at the parting line of the die, located at the corners adjacent to the guide pins. If the die must be opened, and it is not on the machine, it usually has to be pried or worked open. A pry bar or wedge shaped tool is inserted at the pryslot, and worked like a lever to open the die. This levering must be done at all the corners, sequentially, in order to move the die half off the guide pins or out of the bushings. Because the prying action tends to bind at the pins and bushings, the pryslots are located near them.

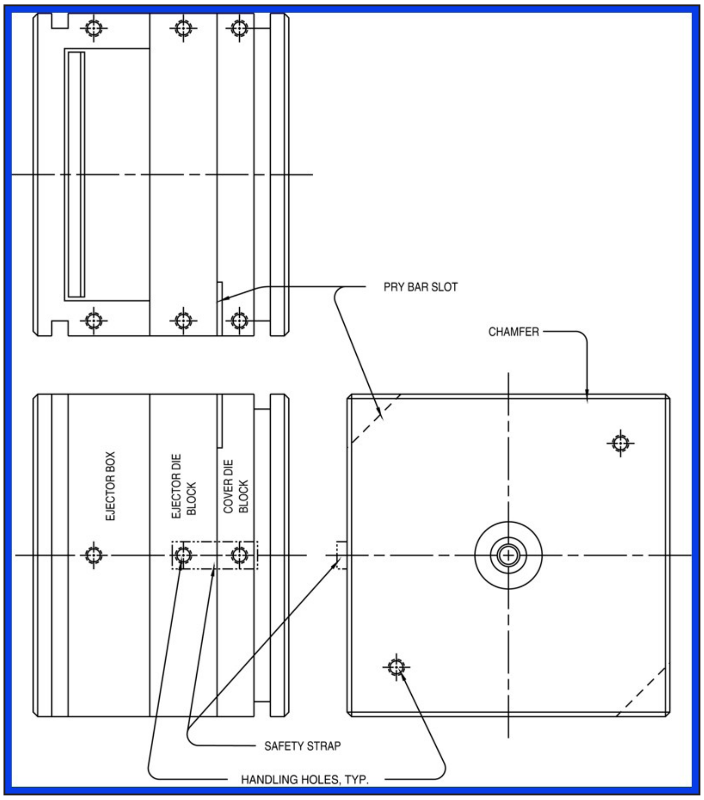


Figure 6-9 – Pryslots

Additionally, the stationary mold base will have a lot of holes in it. The holes are there to accommodate the cold chamber or sprue bushing. There will be pockets for the cavities and there will be assorted holes for cooling lines and mounting holes.

Mounting/Clamp plate- some dies will have a clamp plate bolted to the stationary mold base. The purpose of this plate is to accommodate standardized or automated clamping systems or sometimes it is just a spacer to adjust the shut height of the die. These plates are discouraged because they become a barrier to heat transfer to the machine and do not add to the rigidity of the die.

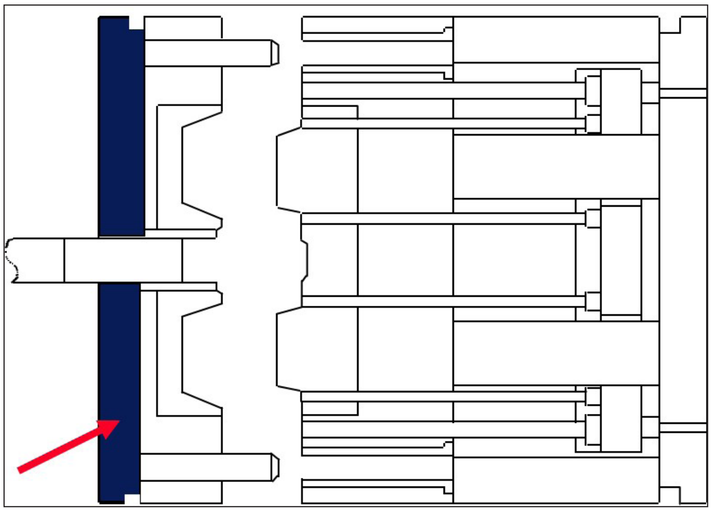


Figure 6-10 - Clamp plate mounted to the stationary die half

Moving half mold base

The functions of the moving half mold base are very similar to those of the stationary half mold base. Again, its most important function is to act as a container for the die cavities. Additionally, it couples the ejection system to the cavities, and it provides a means for aligning the two die halves. The ejector systems of the die and ejector box are mounted to the moving half mold base. This mold base will also be full of holes; to create pockets for the die cavities, for the cooling lines, ejector pins, and a variety of mounting holes.

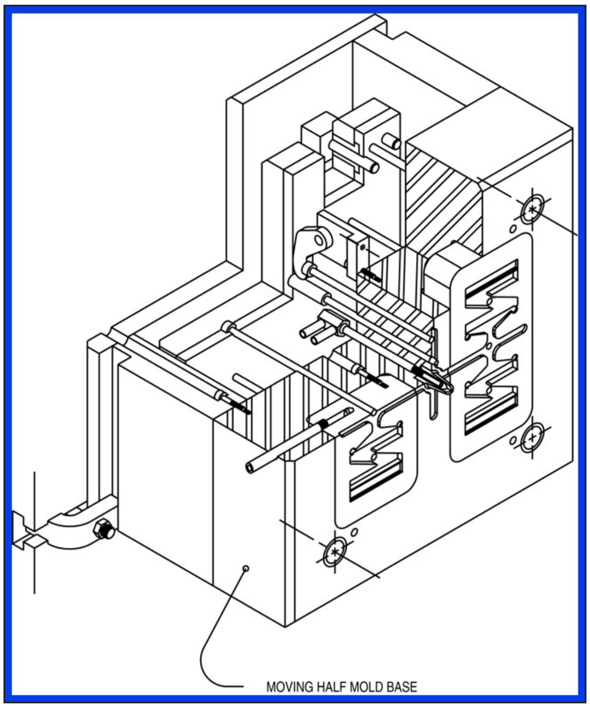


Figure 6-11 - Moving half with mold base highlighted

Guide bushings- are round holes located at the four corners of the die, designed to accept the guide pins. With the guide pins, their purpose is to align the two die halves. If the die uses guide blocks, the bushings are replaced with wear plates for two sides of the guide blocks.

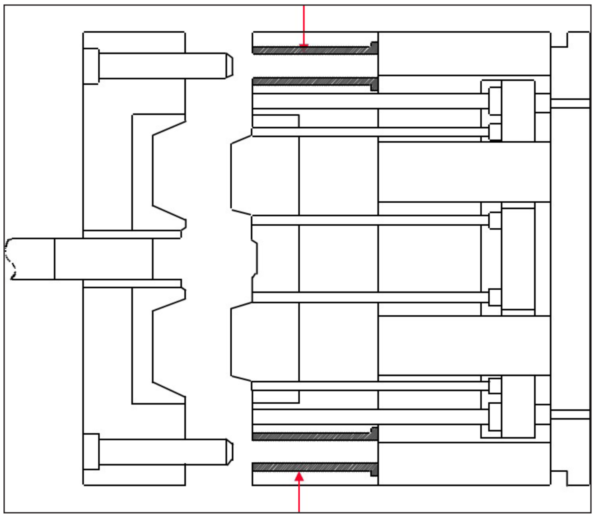


Figure 6-12 - Guide bushings and wear plates

Ejector box

The ejector box refers to the area that encloses the ejector system of the casting die. There are no specific rules as to how this area of the die is to be constructed. It must provide a means for mounting the moving half mold base to the moving machine platen. Additionally, the ejector box must support the moving half mold base against the machine closing force and the force of injection. It must couple the machine ejector system to the die ejector system. In some cases the ejector box will totally enclose the ejector system, in other cases only top and bottom or operator and helper sides will be enclosed.

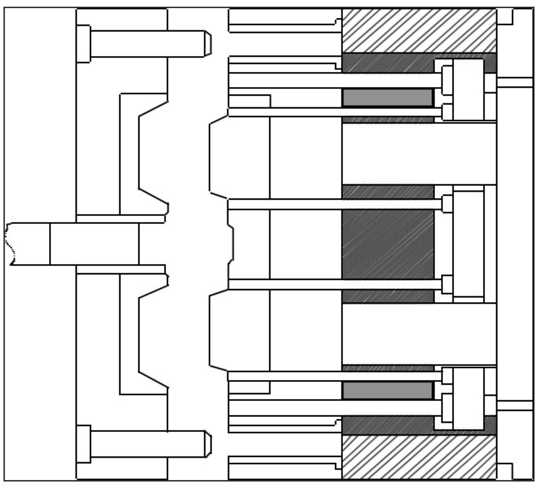


Figure 6-13 - Moving half with ejector box highlighted

Parallels/rails- parallels are steel plates that extend from machine side of the moving half mold base to the machine moving platen for clamping or to a clamp plate. They are called parallels because the "contact" surfaces are parallel. The parallels may have clamp slots cut into them to mount the moving die half to the moving machine platen. In other cases the parallels act as a spacer between the moving half mold base and a clamping plate. The parallels are usually made from steel plate such as AISI 1020. The parallels must be strong enough to prevent them being "squished" or compressed. Remember, if the machine exerts a locking force of 1000 tons to hold the die shut, the parallels must support these 1000 tons.

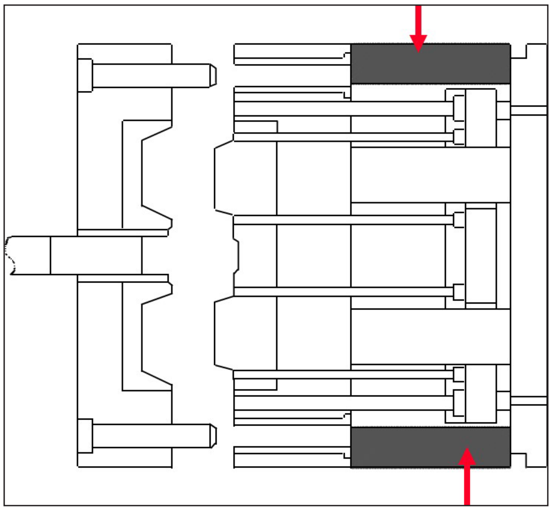


Figure 6-14 - Parallels

Clamp plate- some dies will have a plate bolted to the parallels for the purpose of clamping the moving half mold base to the machine. This plate, depending on its thickness, will have clamp slot of a specific height and depth cut into it.

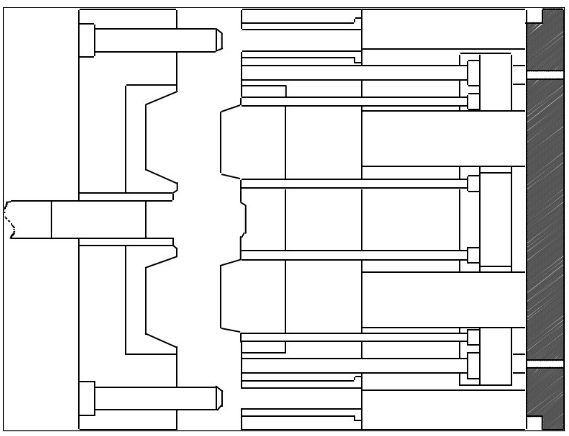


Figure 6-15 - Clamp plate

Support pillars- inside the ejector box there may be columns extending from the moving half mold base, through the ejector plates to the machine platen or clamp plate. These columns, round or rectangular, are located in line with the die cavities and are designed to support the mold base against the force of injection.

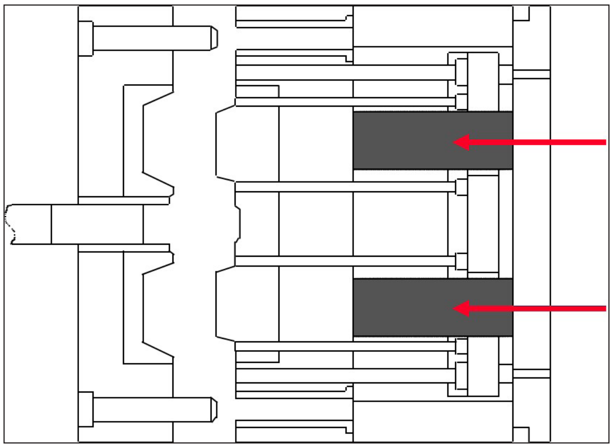


Figure 6-16 - Support pillars

Ejector system

Inside the ejector box is the ejector system. This provides one of the four critical die functions: Provide for removal of the solidified metal.

The ejector system includes plates and pins as a minimum, and may additionally include guide pins and bushings and other sophisticated components to provide specialized ejection features.

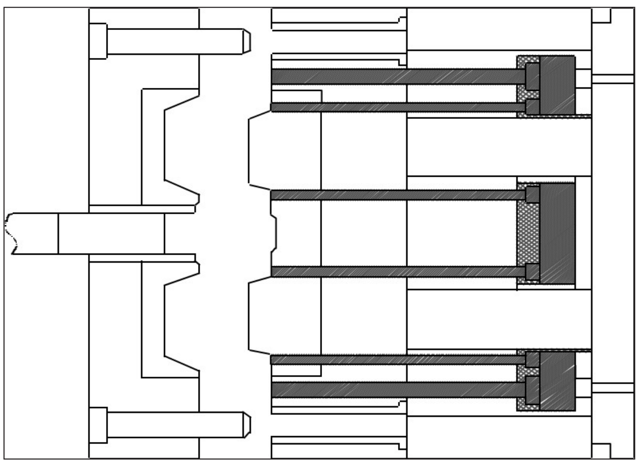


Figure 6-17 - Moving half with ejector system cross-hatched

Ejector pins- are pins that extend from the ejector plate to the casting. They may actually be located on the casting and/or at other locations on the "shot". (The "shot" is all the injected material). The ejector pins will leave marks on the casting. These ejector pin marks may vary in height, with respect to the adjacent casting surface, and may be subject to special quality requirements. For example, the height of these ejector pin marks may be subject to a dimensional requirement such as "flush to 0.020 depressed" with respect to the casting surface. If the ejector pin is too long it will leave an indentation that may make it difficult to remove the casting from the die. If the ejector pin is too short it will leave a raised boss on the casting that may be objectionable.

There may be a maximum flash requirement at the ejector pin mark. Since the ejector pin is a component that is subject to many stresses during operation, failure is not uncommon. As an operator, it is your job to minimize breakage. This means you must make sure the pin is properly lubricated and is not bent or bumped during operation.

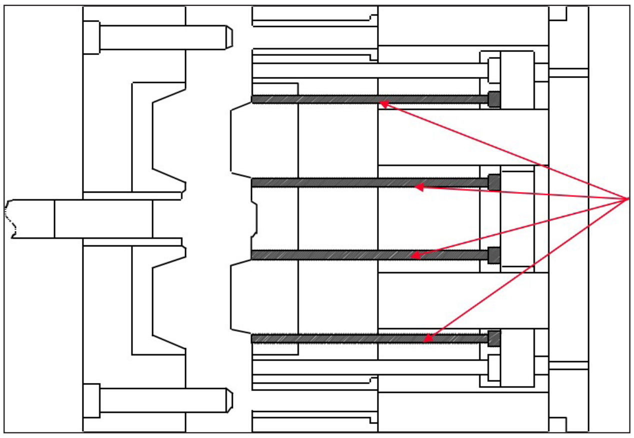
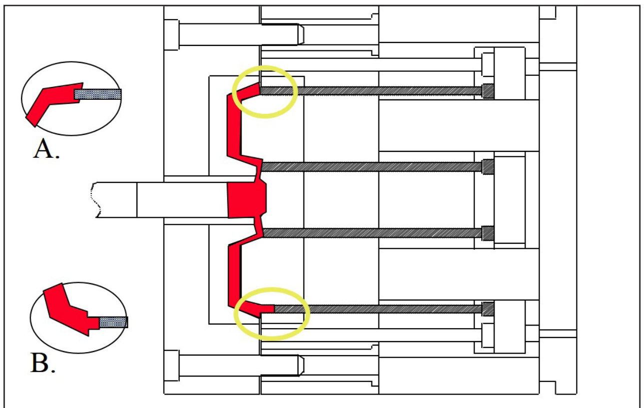


Figure 6-18(a) - Ejector pins



A. Ejector pin depressed into casting.
B. Short ejector pin leaves raised ejector pin mark.

Figure 6-18(b) - Ejector pins, raised and depressed, and with flash

Ejector pins, when extended, pose both burn and snag hazards. When reaching in to remove the shot, the operator must be aware of the ejector pin locations in order to avoid contacting or snagging on them.

Return pins- are pins that are used to return the ejector system to its "home" position before the next shot. The return pins extend from the ejector plate to the parting line. During the ejection stroke the return pins do not push on anything, but just extend above the parting line. When the machine closes, the return pins contact the stationary half parting line and push the ejector plate back to the "home" position. On some machines the ejector plate is coupled directly to the casting machine and the ejector cylinder pulls the plate back to the home position before die closing and the return pins become redundant. Even with this redundancy, return pins are recommended to provide returning of the ejector plates in case of failure.

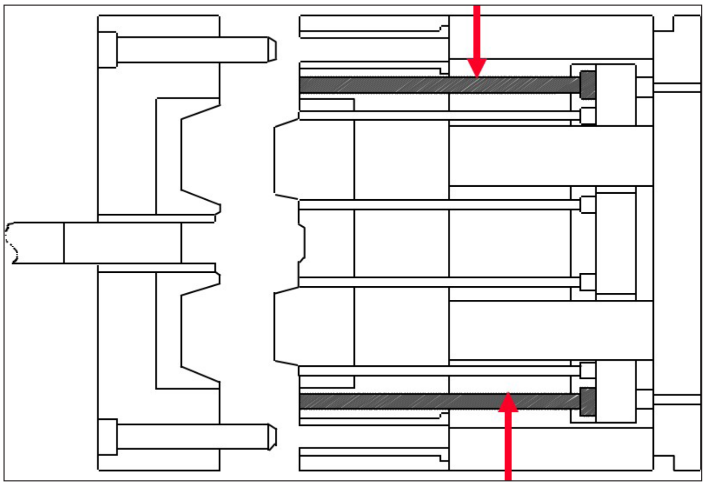


Figure 6-19 - Return pins

Return pins, when extended, pose both burn and snag hazards. When reaching in to remove the shot the operator must be aware of the return pin locations in order to avoid contacting or snagging them.

Ejector plate- the heads of all the ejector pins rest on the ejector plate. As the ejector plate moves forward, it pushes on the pins and ejects the casting. A machine motion moves the ejector plate forward. This could be accomplished by knock-out rods that operate between the ejector plate and a fixed plate or surface on the machine as the machine opens. Another alternative is to have a machine, hydraulically operated bumper plate or an ejector cylinder.

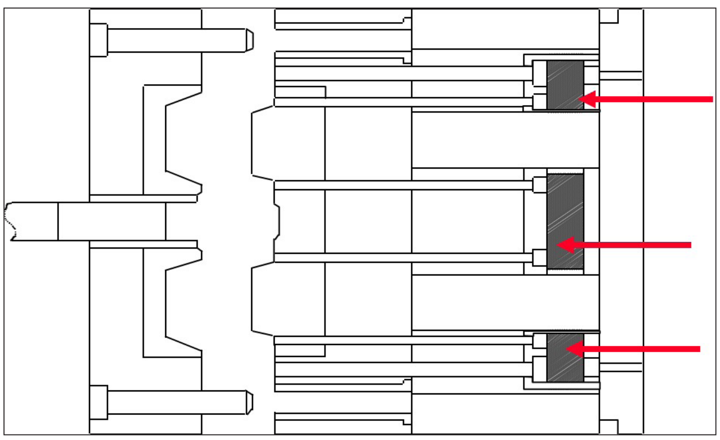


Figure 6-20 - Ejector plate

Ejector retainer plate- this plate retains the heads of all the ejector pins and is bolted to the ejector plate. This plate is necessary to hold the pins in place when the ejector system is returned to the “home” position.

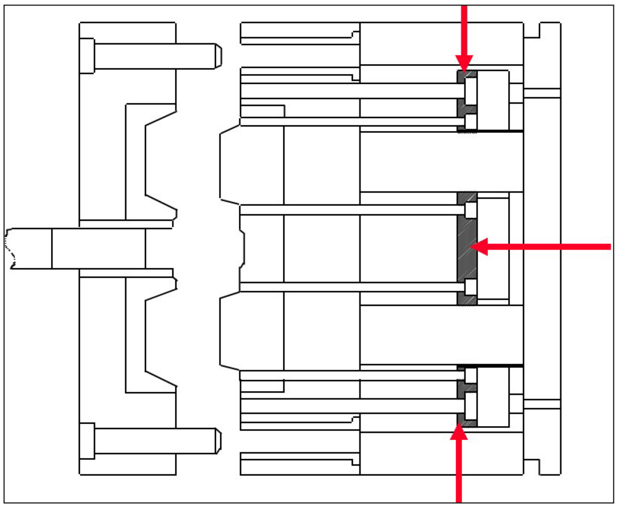


Figure 6-21 - Ejector retainer plate

As the ejector plate and ejector retainer plate assembly move back and forth between stops during normal operation pinch hazards are created in these areas. If the ejector box is not totally enclosed, access to these pinch areas is possible.

Guided ejection- sometimes it is necessary to make sure the ejector system operates smoothly and uniformly. To achieve this, guide pins and bushings are added to the ejector system.

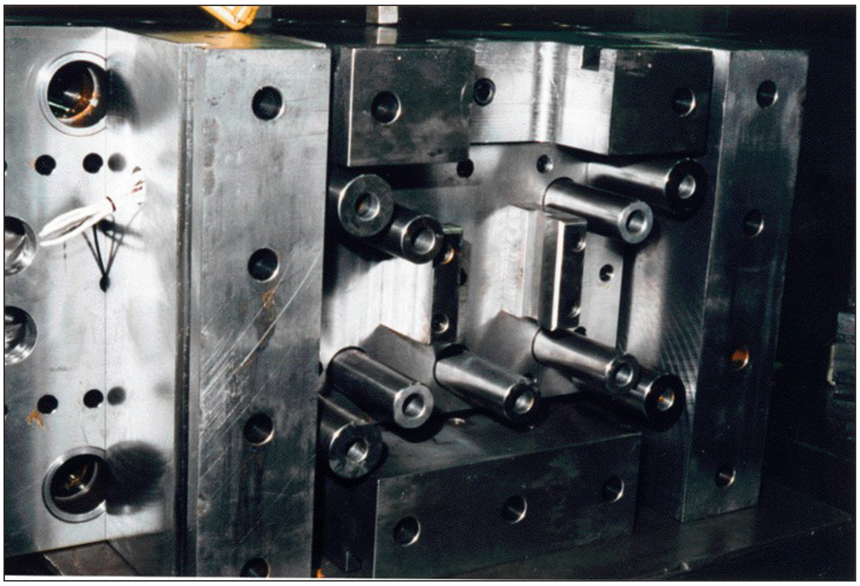


Figure 6-22 - Ejector guide pins and bushings

SELF TEST 1

True or False

1. Die casting dies are very expensive because they require many hours of skilled work to manufacture.

   True False

2. The stationary half is also known as the cold half or fixed half.

   True False

3. The purpose of parallels is to frame an opening for the ejector system and support the die against the closing force of the machine.

   True False

Multiple choice; Identify all correct answers.

4. Alignment between the die halves in achieved by the:

   a. ejector guide pins
   b. support pillars
   c. guide pins and bushings
   d. ejector return pins

5. Items inside the ejector box include:

   a. return pins
   b. ejector plate
   c. ejector guide pins and bushings
   d. core pins

6. The moving half mold base:

   a. provides a means for aligning the die halves
   b. functions as a container for the die cavities
   c. couples the ejection system to the cavities
   d. all of the above

Cavity

Cavity blocks- the term cavity blocks includes all the specialized tool steel that is used to form the actual casting. This could include core pins, interchangeable inserts within the cavity blocks and various slide cavity components. These pieces are usually made from AISI H-13 steel. This is a specialized hot work tool steel that is made to exacting specifications for chemical analysis, density, homogeneity, and grain size, to name a few. This steel is comparatively expensive to purchase, and after the toolwork is done, it is subjected to rigorous heat treatment that must also conform to a series of exacting specifications.

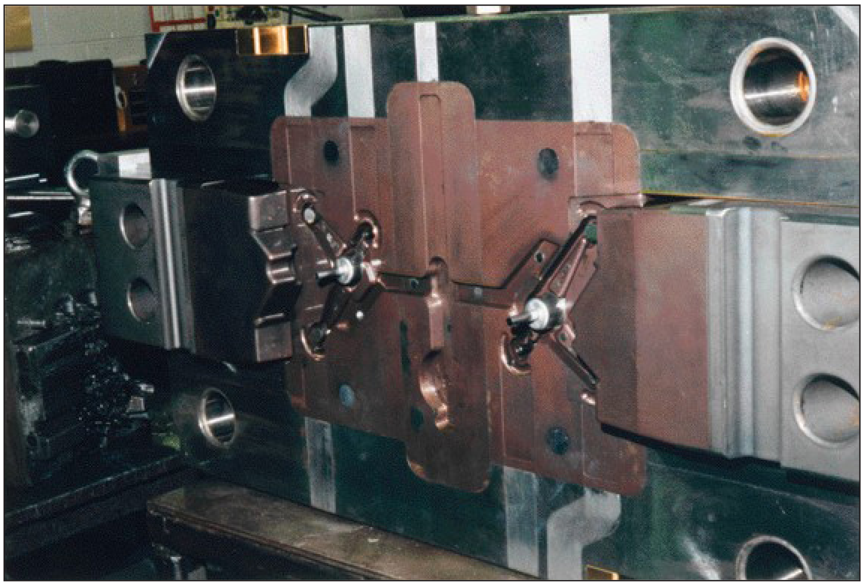


Figure 6-23 - Photo of several die cavities

The cavity blocks, although hard, can easily be nicked or damaged. For that reason, they must be handled as if they were expensive jewelry. If they are nicked or damaged, those defects will show up on the casting. This also means that if a casting or piece gets stuck, it must be removed with care. The tools used should be softer than the cavity block, brass is usually recommended, not screw drivers or wedge ground ejector pins. The cavities can also be damaged in a less obvious way, by how the die is run. The cavities will last the longest if they are always preheated to a minimum of 350°F and if they normally run within a temperature range of 450-550°F.

Core pins- these are very similar to ejector pins, their size tolerances are slightly different. Core pins are usually used to cast round holes in the part, but their shape is not restricted to being round, only the shape of the core pin body must be round. Core pins can be very fragile and fail if not taken care of. It is important that they are properly sprayed with die release in order to prevent the build-up of solder.

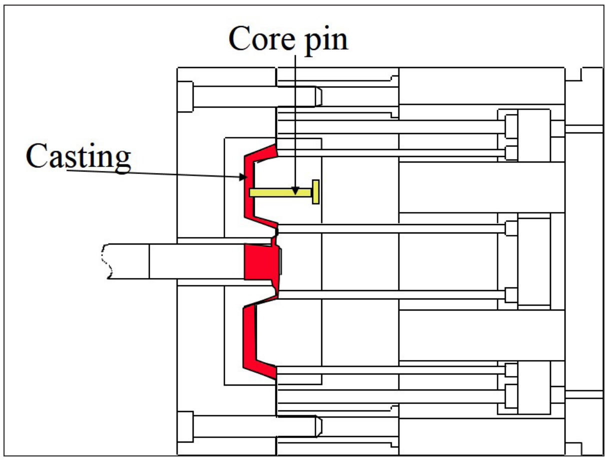


Figure 6-24 - Core pins

Slides- sometimes it is necessary to cast features that cannot be created with the normal opening and closing of the die. This can be done with a component called a “slide”. The motion of a slide will be in a direction different than normal opening and closing. A cavity feature can be mounted on a slide, and then this slide is withdrawn from the casting before the casting is ejected. If the slide is mounted in the stationary die half, the slide must be withdrawn before the machine opens the die. The slides may be actuated either with a hydraulic cylinder or mechanically with a cam pin.

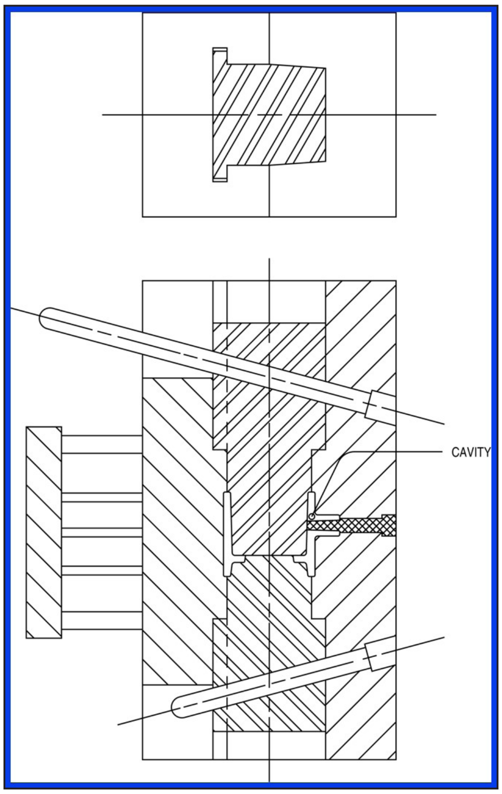


Figure 6-25(a) - Slide assembly with cavity highlighted

The in and out motions of slides will create numerous pinch and strike hazards. The operator must be aware of the location of these hazards in order to avoid being caught by them. Some slide mechanisms rely on springs to hold the slides in position when the die is open. In the event the spring or part of the carrier was to fail, they could become a projectile and a strike hazard.

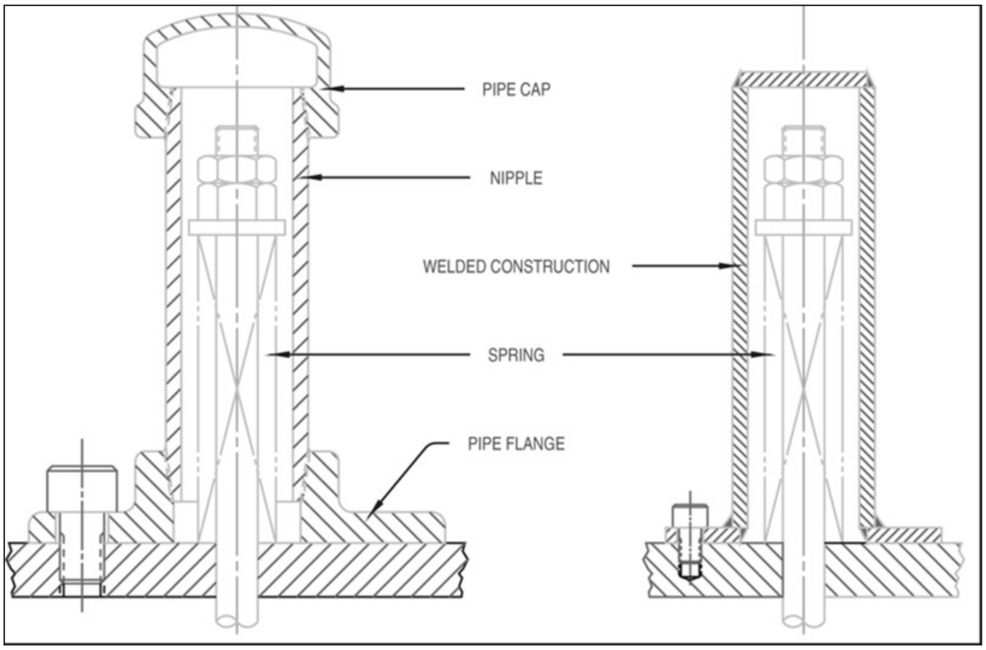


Figure 6-25(b) - Springs for core return mechanisms can be guarded with standard pipe fittings, (left), or with welded covers, (right)

Carrier- the cavity portion of the slide is normally mounted to a carrier. The carrier either moves the cavity back and forth with a cam pin or hydraulic cylinder.

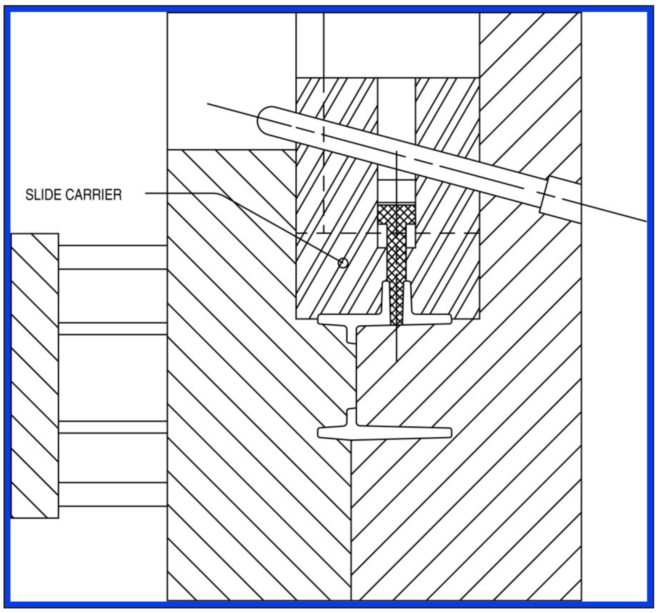


Figure 6-26 - Slide carrier

Wedgelock- the carrier is held in place with a wedgelock. The wedgelock is a piece of steel with an angled surface that is forced against the carrier to hold it in place against the force of injected metal.

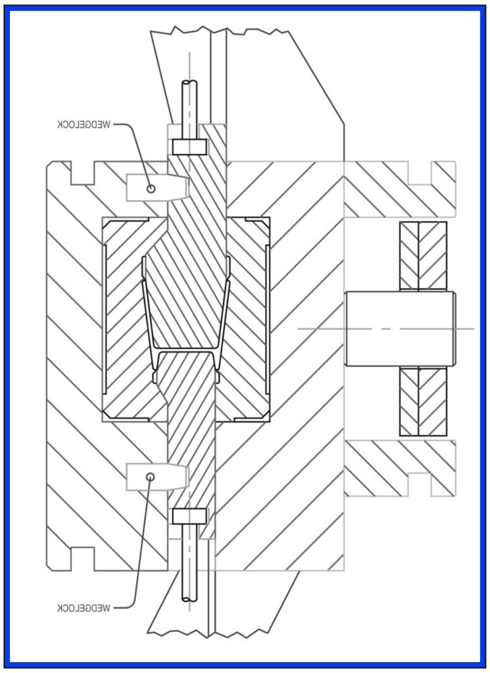


Figure 6-27 - Slide wedge lock

Cam pin- is a pin mounted into the stationary mold base at an angle. It fits through a hole in the slide carrier and causes it to slide in and out with the closing and opening motion of the machine.

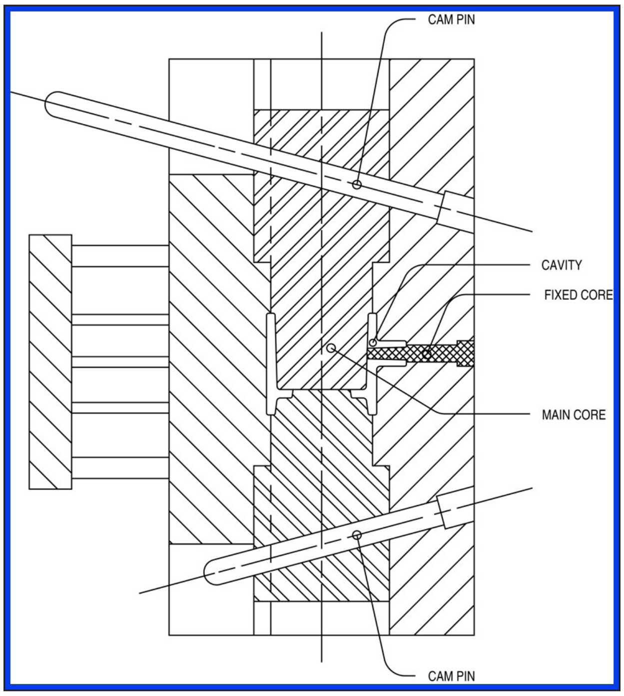


Figure 6-28 - Cam pin

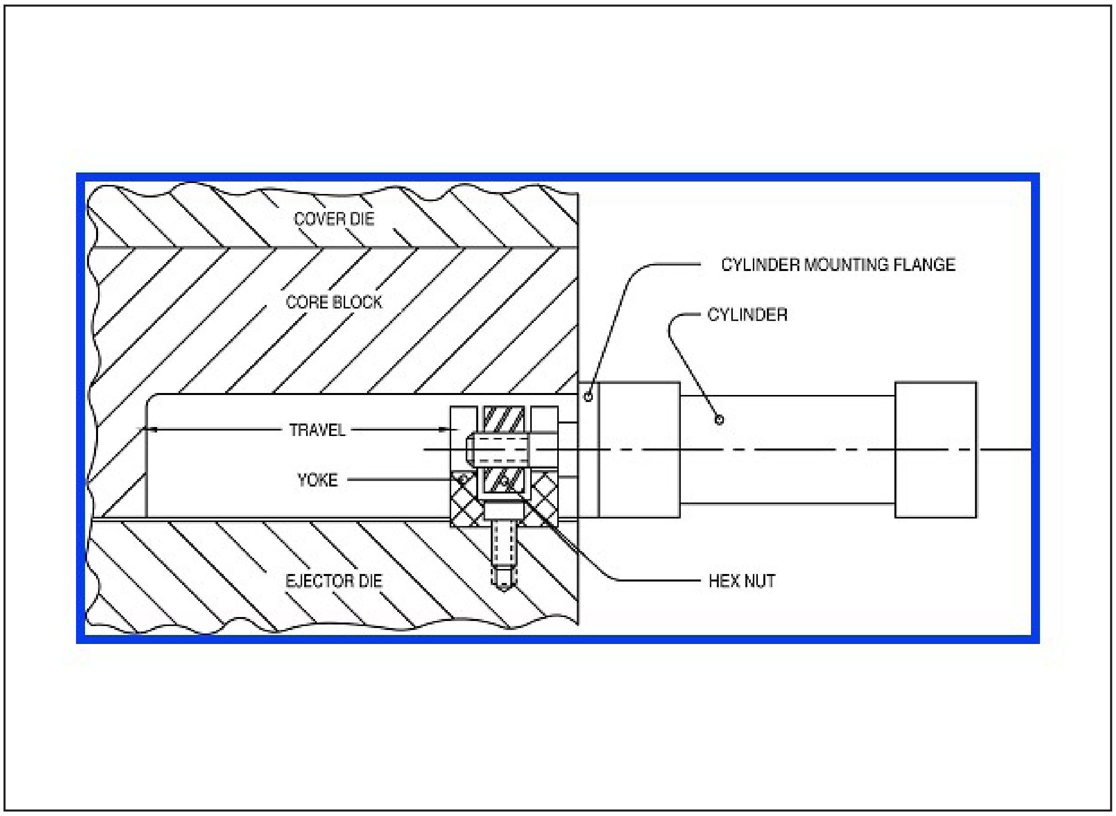


Figure 6-29 - Hydraulic cylinder to move slide

Cam pins, when extended, pose both burn and snag hazards. When reaching in to remove the shot the operator must be aware of the cam pin locations in order to avoid contacting or snagging them.

Cooling lines- most cavity blocks will have cooling lines in them. These are necessary to perform one of the basic die functions: Remove heat from the molten metal to solidify the metal. The cooling lines may be designed to carry either water or oil as a cooling medium. In some cases the lines will be equipped with special high pressure and high temperature hoses and fittings. It is important that these be maintained in good repair. Failure could result in a burn hazard. In addition to the burn hazard the fittings should be maintained to prevent leakage and leaks should be quickly repaired because of the danger of a slip-fall hazard.

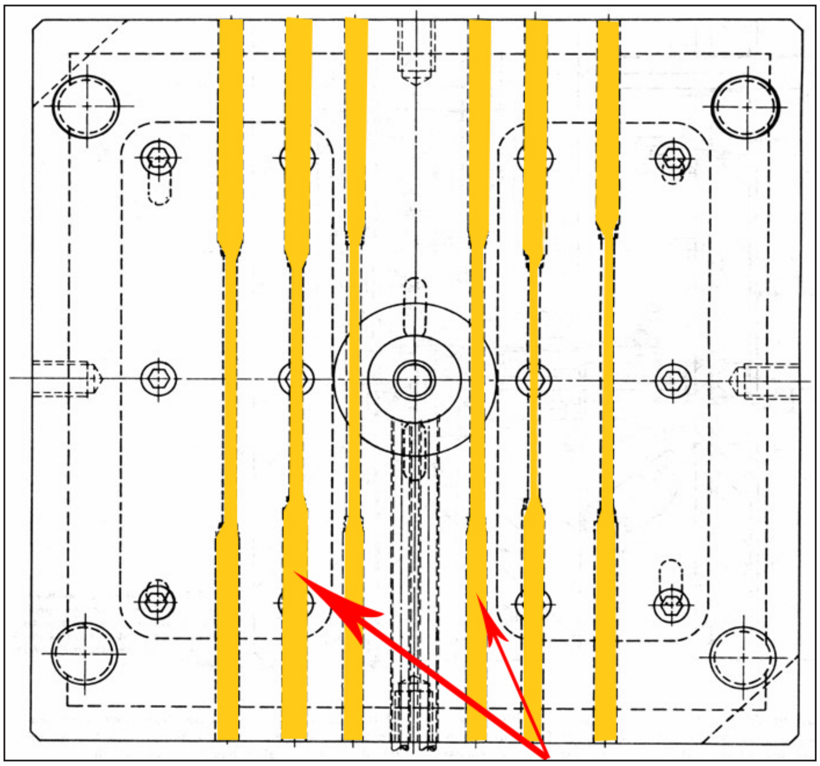


Figure 6-30 - Cooling lines

Heaters- some dies may use electric cartridge heaters to control temperature instead of cooling lines or in addition to cooling lines. These heaters will have wiring associated with them to power them. The wiring can pose a shock hazard if not properly maintained.

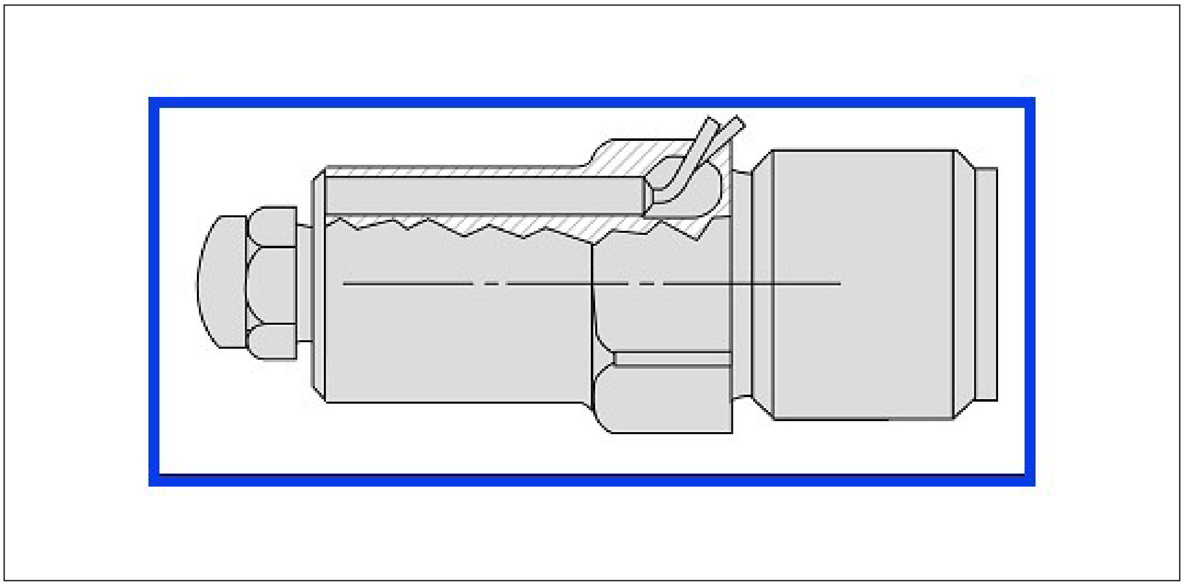


Figure 31 - Cartridge heaters

SELF TEST 2

True or False

1. Cavity blocks are made from ordinary recycled steel.

   True False

2. Cooling lines can be designed for water and hot oil.

   True False

3. Electric heaters can be used to add heat to the die.

   True False

Multiple choice - Identify all the correct answers:

4. The cavity blocks can be damaged if:

   a. they are overheated
   b. they are started at 350¤F
   c. brass chisels are used to remove stuck pieces
   d. if they are dropped

5. Cavity blocks are made from H-13 steel that has been prepared to meet standards for:

   a. chemistry
   b. density
   c. astrological sign
   d. homogeneity

6. Ejector pins can cause the following defects associated with them:

   a. bulges
   b. too deep
   c. raised marks
   d. excessive flash

Die / Shot Terminology

There are a number of cavity features that share the same terminology as the cast shot. These are the sprue, runner, gate, overflows and vents.

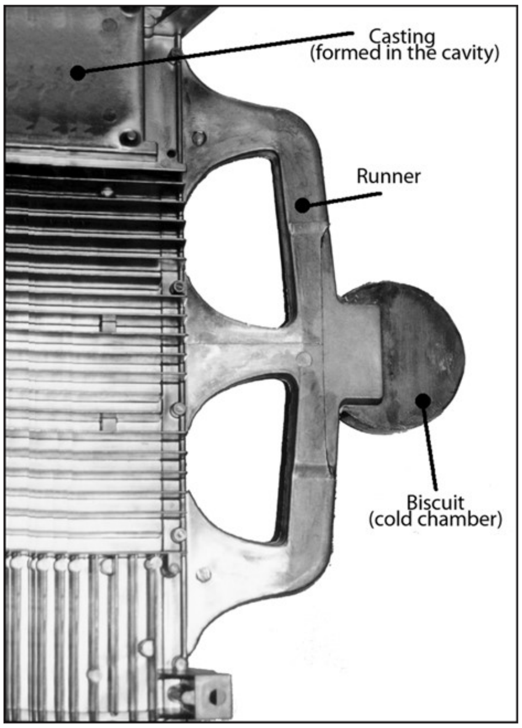


Figure 6-32 - Shot/die with items identified

Runner- the runner is the die cast alloy distribution system within the casting die. It takes the alloy from the biscuit or sprue and directs it to the die cavities, where the casting is actually made. The runner terminates at the gate.

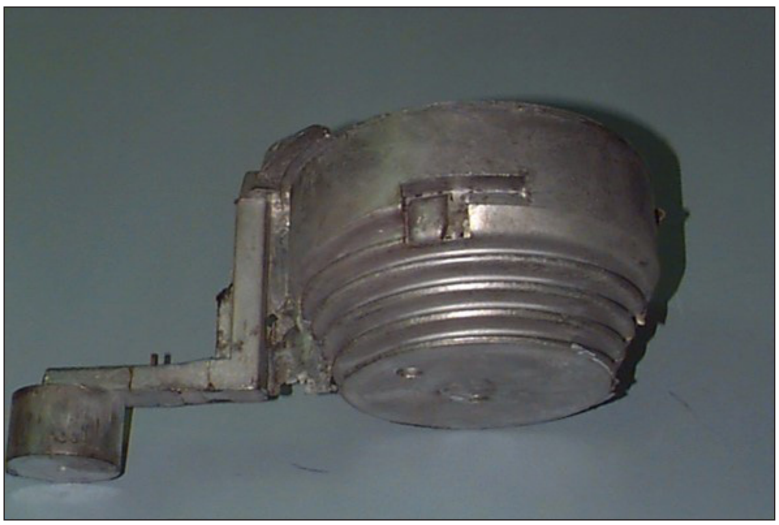


Figure 6-33 - A Runner

Gate- is the smallest restriction in the alloy flow path, located at the edge of the casting. The gate is used to control the flow of the alloy into the die cavity.

Figure 6-34 - Gates identified

Overflows, lifters- the overflows are small pockets of alloy located around the edge of the casting. They can be used to perform several jobs. If an ejector pin is located on the overflow, it can be used to help lift the casting out of the die cavity, hence the name “lifter”. If the cavity has a cold spot, placement of an overflow near that location can be used to add heat to the die. An overflow can be used to direct air flow out of the die or be a location to trap air outside of the cavity.

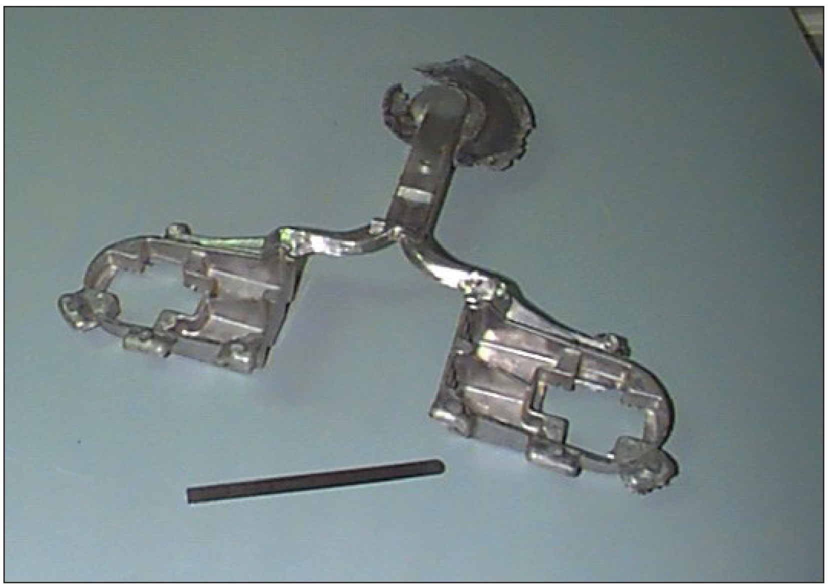


Figure 6-35 - Overflows

Vents- a vent is a path from the die cavity to outside the die. Vents usually start at an overflow, but they can start at the edge of the cavity if necessary. The vent usually varies in depth, getting thinner as it nears the edge of the die. When production is run, the vents must be kept clear of flash and debris every cycle. If alloy is allowed to build-up in the vents, the vents can become blocked and not work, or the build-up could be so great that the die does not close properly and will spit alloy and become a burn hazard.

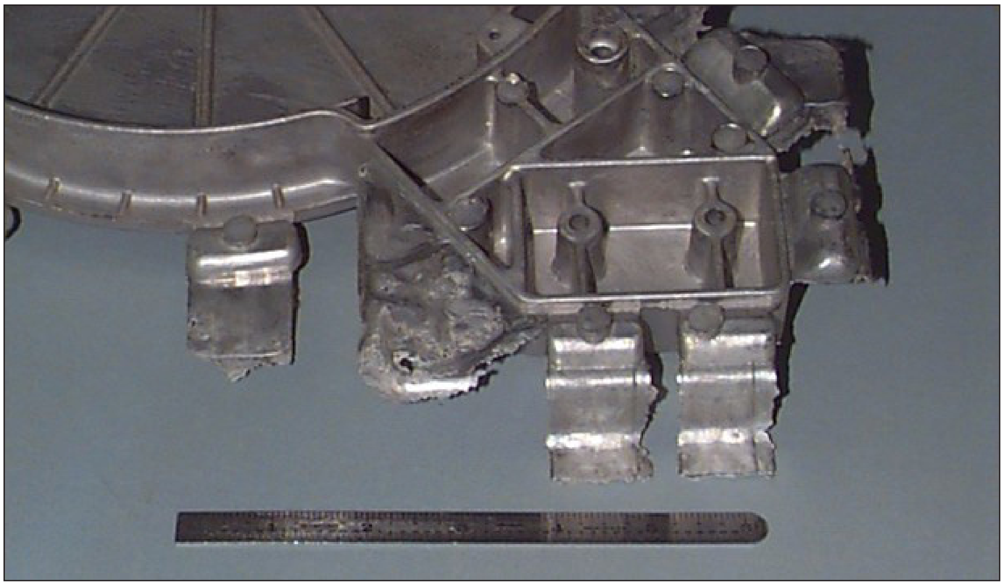


Figure 6-36 - Vents

Vacuum vent- some die casting systems use vacuum to help get the air out of the die cavity. This venting system will be somewhat different than an atmospheric vent and will terminate in either a valve or chill block.

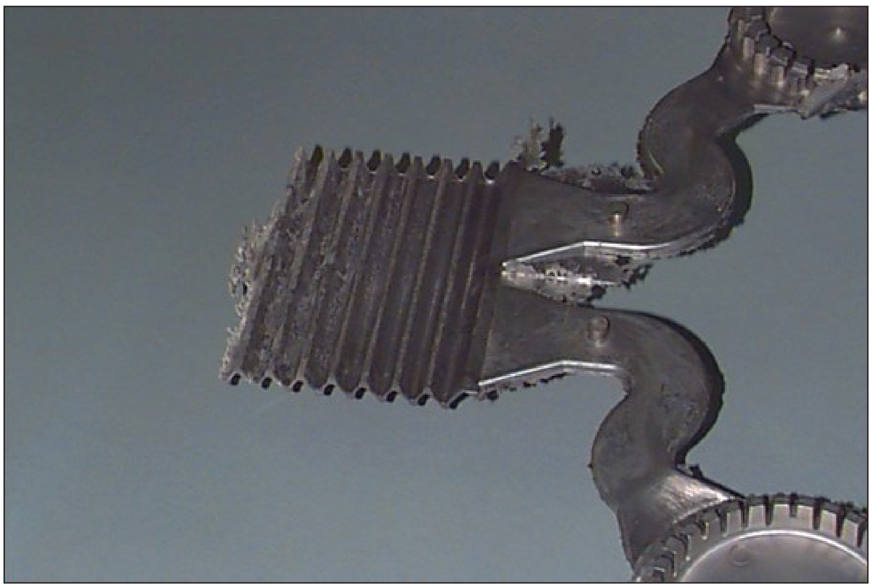


Figure 6-37 - A vacuum vent

Miscellaneous components

Biscuit block- generally cold chamber dies will have a separate piece of H-13 steel in the moving die half opposite the cold chamber. This block is the beginning of the metal distribution system (runner) to the casting cavities. Since all the metal in the shot flows past this block, adequate cooling is very important.

Figure 6-38 - A biscuit block highlighted in assembly

Sprue bushing - in the hot chamber system, the sprue bushing has the important job of being the liquid metal to solid metal interface. At the junction of the nozzle and sprue bushing, the metal in the nozzle must always remain a liquid and the metal in the sprue bushing must solidify.

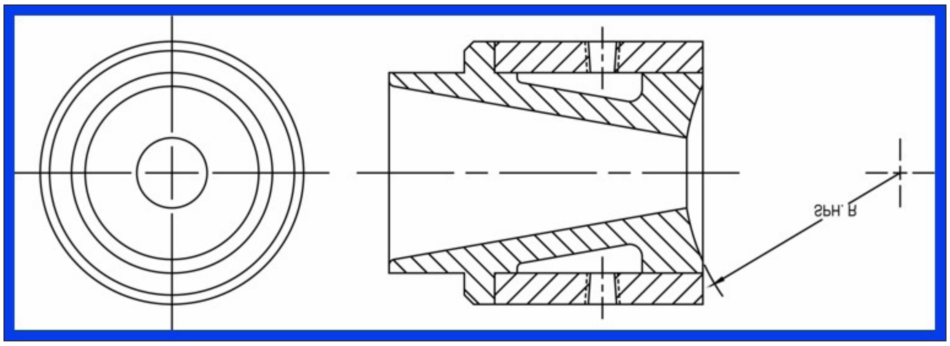


Figure 6-39 - A sprue bushing

Sprue post- the sprue post has a job similar to that of the biscuit block. The post is the beginning of the metal distribution system. Proper cooling in the post is very important to consistent operation of the die.

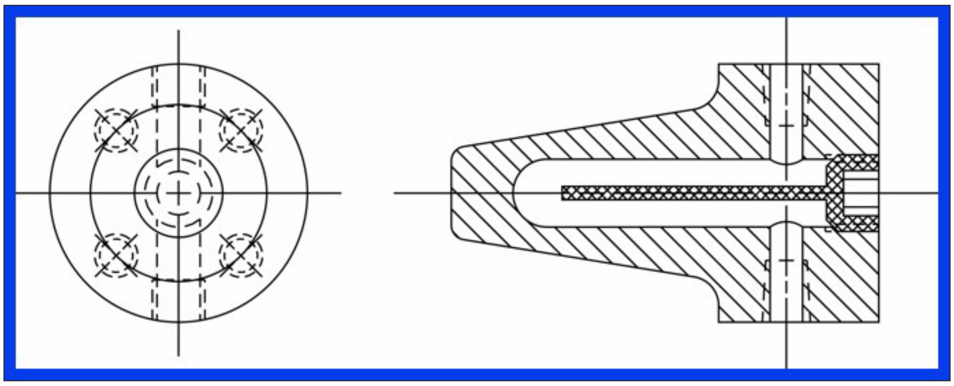


Figure 6-40 - A sprue post

DIE MANUFACTURING

The process of building the die begins with the casting design. A major effort should be made during the casting design phase to assure that the casting can be manufactured with relative ease. This is achieved when the following goals are met:

1. The casting will fill easily and completely with alloy.
2. The casting will solidify completely without defects.
3. The casting will eject readily from the die.

The die manufacturing process is very complex. Successful die manufacturers are at the forefront of machining technology. Many of the machine tools used today are computer controlled and run without direct supervision. The result of this technology, when properly applied is; tools are manufactured in less time, with fewer errors and at lower cost.

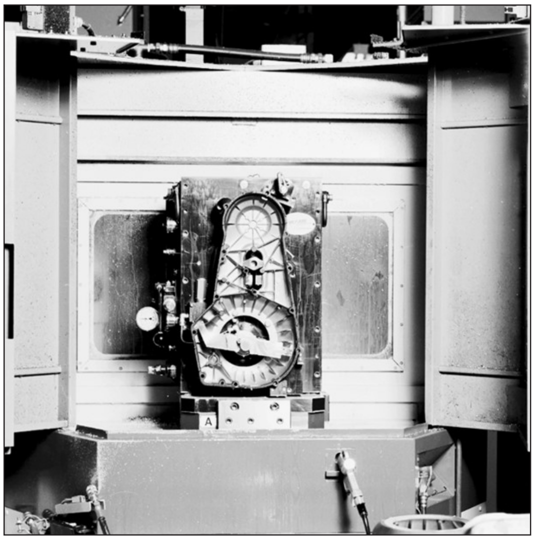


Figure 6-41 - Machine tools, grinder, CNC mill, EDM machine

Dimensions and Tolerances

The toolmakers job is to manufacture all the tool components and assemble them. This involves a number of manufacturing processes including; grinding, milling, EDMing, polishing, and assembling. The die actually is a high precision tool. It is not uncommon for us to expect the toolmaker to hold tolerances as small as ±0.002 of an inch (±0.05mm). For some small precision zinc dies the tolerance may be as small as ±0.0002 of an inch (±0.005mm). With these types of tools at our disposal, it is our responsibility to take care of them. The cost of a single die can range from $1000 to over $1,000,000.

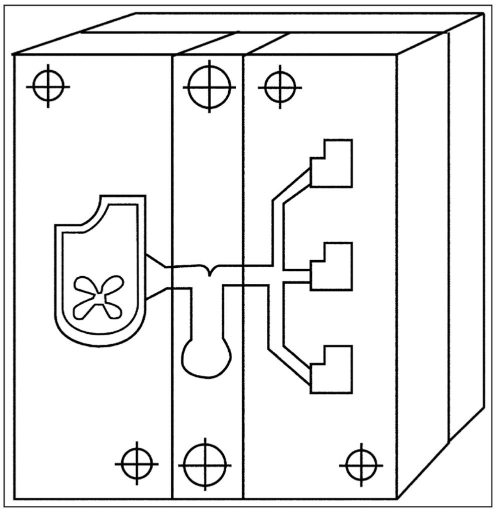


Figure 6-42 - Unit die

Thermal Expansion

In order to obtain satisfactory dimensional control, the toolmaker and die cast machine operator must understand the concept of thermal expansion. Thermal expansion is the property of a material that predicts dimensional changes based on changes in temperature. W e know that during hot summer weather that the electric and telephone wires get longer and sag further between the poles as compared to the sag during cold winter weather. If we heat a core pin it will get longer.

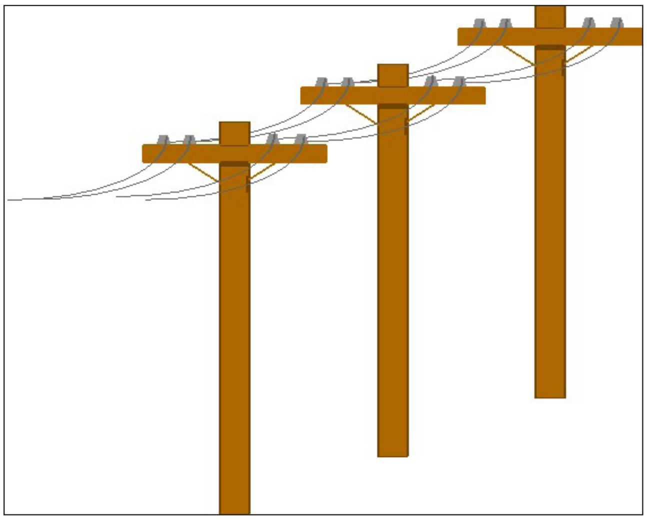


Figure 6-43 - Sagging electric lines

The formula that predicts thermal expansion is:

$\Delta L = C \times L \times \Delta T$

ΔL = change in length

C = coefficient of thermal expansion

L = length

ΔT = change in temperature

This formula means that the amount of thermal expansion depends on the type of material (coefficient of thermal expansion), on how long the dimension is (length), and how much the temperature changes (ΔT).

(C), Different materials have different coefficients of thermal expansion. Die cast aluminum alloy has a coefficient of thermal expansion that is almost double that of H-13 die steel.

(L), If the dimension is long, it will have a lot of expansion. If the dimension is short, the expansion will be less.

(ΔT), As the temperature goes up the dimension gets longer, as it goes down the dimension gets shorter.

When the toolmaker builds the die cavities, he anticipates the affects of thermal expansion and applies a shrink factor to each cavity dimension. (The shrink factor accounts for the shrinking or contraction that takes place when a casting cools.) A typical shrink factor is 0.006 inch/inch (0.006mm/mm). This means the tool maker will increase all the casting dimensions by 0.006 inch (0.006mm) for each inch (mm) of dimension length. Another way to look at this is to multiply each dimension by 1.006. A 2.000 inch (50.80mm) dimension on a casting would be 2.012 inches (51.10mm) in the die (2.000in x 1.006 = 2.012in) (50.80mm x 1.006 = 51.10mm).

This is not the same as shrinkage, which will be discussed in the materials lesson.

Die Life Factors

There are several factors under the toolmaker's control that will affect the life of the tool. To maximize the life of the die, the toolmaker must use the best materials, and the best manufacturing processes. The best material for cavity tool steel is Premium grade H-13 steel that meets the NADCA specification#207-90. Following the EDM (Electrical Discharge Machining) process, the damaged "white layer" of material must be removed. The heat treating process must follow the recommended procedures as specified by NADCA in their document entitled "NADCA Recommended Procedures for H-13 Tool Steel".

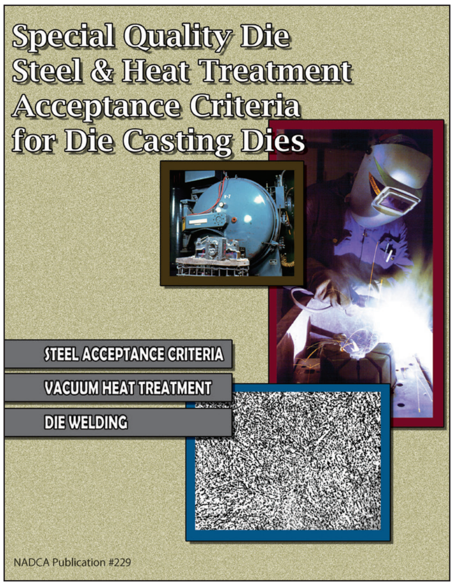


Figure 6-44 - NADCA Recommended Die Procedures, H-13 Tool Steel

After the toolmaker implements the above measures, it is the responsibility of die cast operators to take the steps under their control that will extend the life of the die. The four things that the operator must do are:

- Preheat the die to a minimum of 350°F (175°C) before injecting metal into it.
- Run the die at a consistent cycle to maintain minimal temperature changes.
- Preventing soldering.
- Take care to make sure the die is not damaged.

Die steel fails in three ways:

1. It is subjected to an excessive thermal shock and suffers a gross crack or break
2. It wears out and heat checks
3. It is damaged through carelessness or negligence.

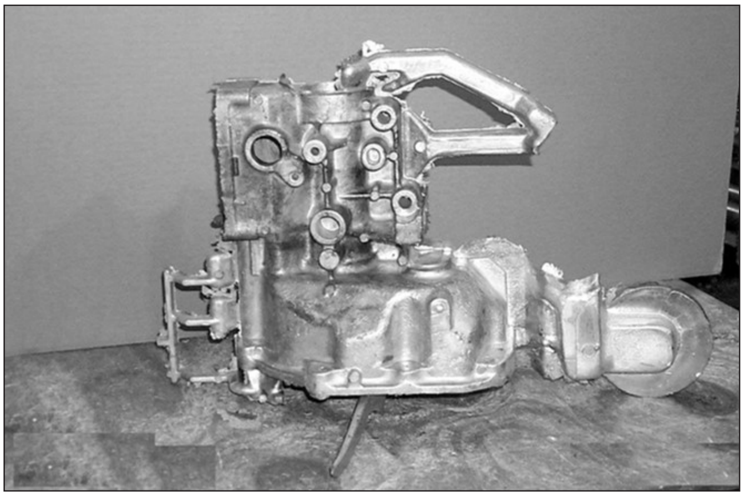


Figure 6-45 - Photo of gross failure

Figure 6-46 - Photo of heat checking

Thermal shock can occur if the die steel is subjected to a big temperature difference. This could be when a die is started in production. If the die is cold compared to the temperature of the alloy being injected, it will see a thermal shock. A thermal shock could also occur if the die were running and suddenly we remember to turn on or open a cooling line. If the die is preheated, the intensity of the thermal shock is reduced. The reason preheating is very important is to avoid thermal shock. Metals have properties that vary with temperature. One of these properties is toughness. Toughness is the ability to absorb a shock. If a metal is tough, it can absorb a shock, we refer to that material as being ductile. If a metal is not tough, cannot absorb shock, it is referred to as being brittle. This property varies with temperature. This means that the same metal may be brittle at one temperature and ductile at another temperature. Zinc die cast alloy is brittle at temperature below 30°F (0°C) and ductile at temperatures above 70°F (21°C). H-13 die steel behaves the same way, at temperatures below 250°F -275°F (120-135°C) the steel is brittle, and temperatures above 350°F (175°C) the steel is ductile.

Thermal fatigue or heat checking is a sign that the die cavity is wearing out. Every cycle the steel at the surface of the die cavity is heated by the incoming alloy and then cooled internally or with die spray. This means the surface steel is stretching and relaxing every cycle. This is very stressful on the die steel and ultimately it will break down, initially by cracking and finally with pieces of steel actually breaking out. By running the die consistently we can minimize the high temperatures and maximize the low temperatures, and reduce the temperature change that occurs every cycle.

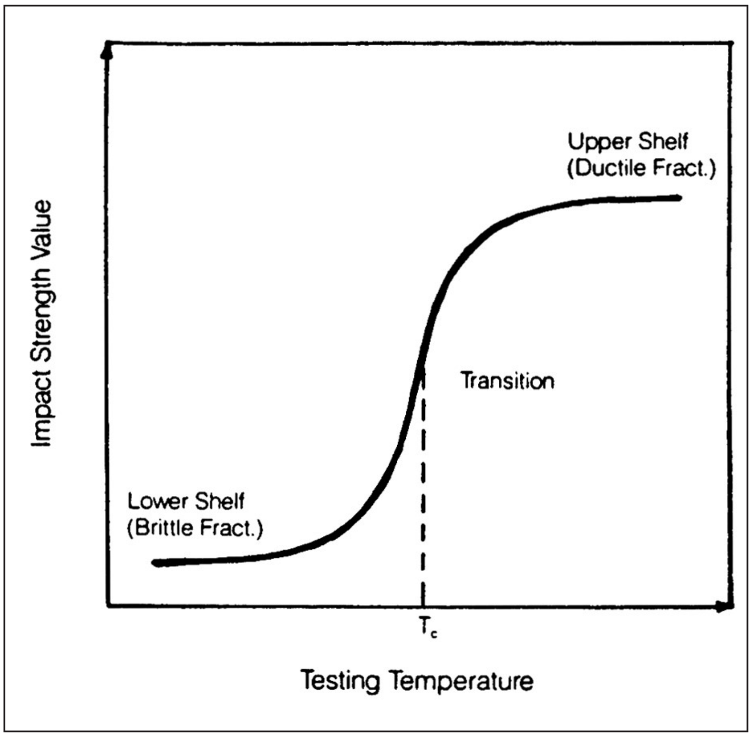


Figure 6-47 - Graph of brittle to ductile transition

Lastly, the operator must take actions to prevent the die from being damaged. For example, if a casting gets stuck in the die, and heat is applied to help remove the casting, it must be applied carefully. Too much heat, like heat from an acetylene torch or gas torch can re-heat treat the cavity steel and soften the steel. The steel will begin to change properties if it is heated in excess of 1000˚F. W e can't see this temperature change. If we are working on the die with a torch and the steel begins to change color (red), we have gone too far and the properties of the steel have been changed.

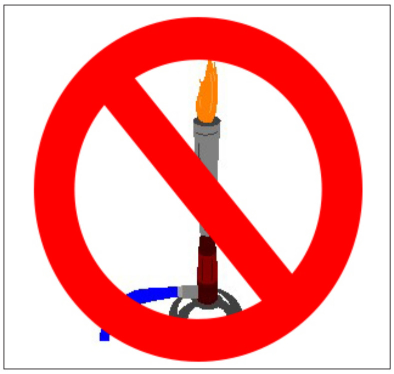


Figure 6-48 - Acetylene torch

Again, in the case of a stuck casting, the proper tools must be selected to remove the stuck piece. Tools that are harder than the die steel should not be selected because they can damage the die cavities. These might be screwdrivers, chisels, pliers, or ejector pins. The correct tool to use would be softer than the H-13, a material such as brass. Care must also be taken to handle the cavity blocks with care. They should not be dropped or used as tool rests.

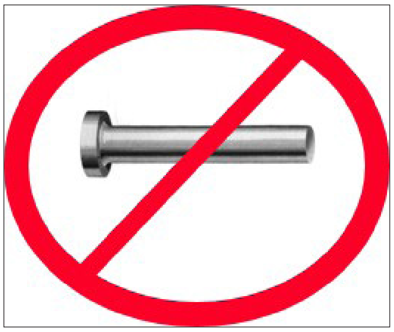


Figure 6-49 - Ejector pin

The list below is a number of actions the die cast machine operator can take in order to prevent damage to the die:

- Keep the parting line and slides free of flash.
- Run the die in a fashion that will prevent flash formation.
- Properly pre-heat the die, to avoid thermal shock.
- Keep the moving components lubricated.
- Use the proper tools and techniques to remove stuck pieces.
- Do not close the machine on stuck pieces to remove them.
- Maintain consistent cycle times.
- Be aware of unusual occurrences during the cycle.

SELF TEST 3

True or False

1. Toolmakers do not affect die life.

   True False

2. Die cavities fail because of thermal shock.

   True False

3. Die cavities fail due to fatigue.

   True False

4. Overflows can be used to add heat to a cold spot in the die.

   True False

Multiple choice; Identify all the correct answers:

5. The operator can extend die life by:

   a. running the die at a consistent cycle
   b. preheating the die to 3500 F
   c. using brass chisels to remove stuck pieces
   d. preventing soldering

6. For a die to withstand a thermal shock:

   a. it must be hard
   b. it must be brittle
   c. it must be tough
   d. it must be strong

7. Thermal expansion is directly related to the:

   a. type of material
   b. length of the dimension
   c. temperature difference
   d. tolerance

GLOSSARY

Cam pin- a pin, similar to a guide pin, mounted at an angle with the general parting line, used to pull a slide in and out of the die during the machine die opening and closing portion of the cycle.

Cavity- the empty space in the cavity block that is filled with alloy to make the casting.

Cavity Blocks- die components that form the casting; usually made from AISI H-13 steel.

Clamp Plate- plates that are used for mounting the die to the machine.

Core Pins- round pins used to cast holes in the casting; usually made from AISI H-13 steel.

Ejector Pins- pins used to push the casting out of the cavity.

Ejector Plate- steel plate that pushes on the ejector pins to push the casting out of the cavity.

Ejector Retainer Plate- the steel plate mounted to the ejector plate that sandwiches the ejector pin heads to hold the pins and pulls them back to the home position after ejection is complete.

Ejector Return Pin- the ejector pin that is used to push the ejector plate to the home position when ejection is complete.

H-13 Steel- the material that most cavity blocks and cavity components are made from.

Mold Base- the steel envelope that contains the cavity components.

Parallels- steel plates mounted between the moving half mold base and machine that must support the die against the machine clamping force. They are spacers used to establish a space for the ejection system.

Solder- mechanical bond between aluminum in alloy and iron in the die steel. The aluminum molecules actually penetrate the steel structure at the molecular level.

Support Pillars- steel posts that are located behind the cavity blocks, used to support the forces of injection.

7 EVERYBODY IS INVOLVED IN DIE SETUP

OBJECTIVES

- To learn about the importance of die setup in die casting operations.
- To learn the fundaments of SMED, Single Minute, Exchange of Dies.
- To learn basic Lean Manufacturing principles such as 5S, 3M's, and Waste.

PERSPECTIVE

Die casting operations are often required to change the die that is production because of schedules, downtime, or quality issues. The die changes reduce the amount of castings that can be produced and disrupt the overall operation of the plant. Therefore, it is important for machine operators to be involved in the die setups and to understand the principles of die change that permit these changes to be made quickly and effectively.

In recent years, many industrial plants have adopted Lean Manufacturing practices. These practices include 5S and Visual Controls, Pull Manufacturing, Six Sigma, and SMED, Single Minute Exchange of Dies. This lesson will review SMED and help the machine operator understand its use to be able to make die setups more quickly.

SMED is an acronym for Single Minute Exchange of Dies. This means that the entire die change process, from last good part to first good part is completed in less than 10 minutes. This is the goal. Some die casters with both large and small dies have already achieved this goal.

Today, SMED is one of a number of disciplines that constitute "Lean" production. For example, all of the following are activities that fall into the scope of "lean" thinking:

Lean Manufacturing
5S & Visual Controls
Kaizen
Value Streams
Pull Manufacturing
Mistake Proofing
Quick Changeovers-SMED
Six Sigma
Lean Accounting
Theory of Constraints
Human Factors

The goal of all these efforts is to achieve Customer Satisfaction and also to stay in business. This is accomplished by providing the highest quality, lowest cost, and shortest lead-time by continually reducing waste. Additionally, our customers require that we work safely, are good stewards of the environment and treat our employees fairly.

Although this is a guide to understanding and implementing SMED, there are some basic concepts we need to understand and embrace from "lean" thinking. "Lean" thinking is all about reducing waste or Muda (Japanese for "waste"). Think of waste as any activity that your customer is unwilling to pay for. Your customer is willing to pay for the alloy, for the alloy to be cast, for the casting to be trimmed (but not in all circumstances), for the casting to be packed and shipped. Your customer is not willing to pay for scrap, rework, delays, or excess inventory. In short, your customer is unwilling to pay for activities that do not add value to the casting.

One way of looking at the die casting process is to break down the various activities involved in making the casting into three categories.

1. Actual work: activity that adds value to the alloy.
2. Auxiliary work: activity that supports actual work usually precedes or follows actual work.
3. Waste: activity or motion that adds no value. For example, an activity, when stopped, has no adverse effect on the casting.

In die casting:

- The actual work is melting, injecting, solidifying and cooling the alloy.
- Auxiliary work is ladling the alloy, removing the die casting from the machine and setting dies.
- Waste includes start-up scrap, making excess castings, and unnecessary transport of the casting.

3M's

The three M's are the Japanese words that describe intolerable conditions. The words are Muda, Mura, and Muri. These are all heavy sounding words. Think of them as a heavy unacceptable load!

MUDA: Muda is waste, activities for which your customer is unwilling to pay.

MURA: Mura is irregularity, unevenness, and fluctuation in work. Usually due to poor planning or lack of standardization. Operations need to be standardized and discipline maintained to assure the operations do not change.

MURI: Means "hard to do", this may be because of variations in production or poor job, fixture and layout design. This could result in excessive strain and stress (frustration).

Waste

The Toyota Production System lists eight different types of waste. In fact, it claims that the ratio of value to waste is 5:95 in most operations. If this is true, there is a lot of opportunity for improvement.

The eight classifications of waste are:

Motion	Over-processing
Waiting	Over-production
Conveyance	Inventory
Correction	Knowledge disconnection

Motion

Wasted motion can be both human motion and machine motion. Wasted human motion is usually related to workplace ergonomics. If the workplace is not organized or setup properly productivity and quality will suffer. This waste includes walking, reaching or twisting. Spending time walking searching for the die to setup is this kind of waste. It is thought that about half of workplace injuries are due to poor ergonomics. The risk factors involved in these types of injuries include force, repetition and posture. In terms of die setup, we must be sure that we do not put our employee at risk of these types of injuries. Force and posture are the two risk factors to be most aware of when considering setup work.

Two simple examples of wasted die casting machine (DCM) motion are more than required die opening and closing stroke and more than necessary injection stroke. All DCM motions must be reviewed and optimized.

Waiting/Delay

This waste occurs when an activity is delayed waiting for material to be found and retrieved. For example, during setup you may discover that a hydraulic fitting has been damaged and cannot be connected. A delay results waiting for the fitting and replacing it. Or a delay may occur as you wait for materials to be cleared from a required work area.

Delays add to lead-time:

Lead-time = Processing time + Retention time.

Processing time: actual work being done to the part.

Retention time: delays, waiting for actual work.

Conveyance

Conveyance is a necessary waste since materials must be moved, to the work site and through the plant. However, this waste must be minimized. This is accomplished by efficient work place layout and efficient layout of tools and work pieces. For example, when setting the die we need to assure that all the tools and components have been gathered or staged prior to movement to the DCM. Once at the DCM all the required tools are arrayed in such a manner to be easily accessible when they are required.

Correction

Correction or rework is the waste incurred when something is done incorrectly. A hose connection improperly secured, leaking or being blown off its fitting is an example of this. This requires reconnecting the fitting and cleaning up the mess that occurred. Your motto should be "Do it right the first time."

Over-processing

Doing more work than required. An example related to die setup would be applying excessive torque to clamping bolts, using a 3-foot long extension (cheater bar) on a wrench to tighten a nut.

Inventory

Inventory waste is the keeping of unnecessary materials. For the purposes of doing a setup, this means the correct components and correct number of components to do the setup are provided. This also includes tools.

Over-production

This is a waste not generally associated with setup. This refers to making things that do not sell. It could be related to setup if we keep the machine running because we are not ready to do the die exchange.

Long set-ups lead to over-production. The inability to conduct single minute die changes increases batch sizes and eliminates the opportunity for "make to order" batch sizes.

Knowledge Disconnection

This waste exists when there is a disconnect within the company or between the company and its customers. During a setup, this could be as simple as stopping the setup because of a defective connector and waiting for a new connector to be delivered. As opposed to moving on to the next setup step and continuing the setup process.

Lean thinking is more than seeing and eliminating waste. It is also about balancing work efforts and simplifying the work. In order to minimize the setup time for a die, two or more persons may be required to accomplish a particular task. Those persons must be available when required. Some tasks may be difficult to accomplish and require an inordinate amount of skill to be done correctly. These tasks should be simplified.

For example, 6000 pounds of castings that are in stackable 1000-pound containers have to be moved with a 2500-pound capacity forklift. What is the best and safest method for moving the castings?

The alternatives are:

1. Six trips at 1000 pounds per trip.
2. Two trips at 2000 pounds and two trips at 1000 pounds.
3. Two trips at 3000 pounds.
4. Three trips at 2000 pounds.

Number 4 is best; it has the minimum number of uniform loads within the forklift capacity.

Number 1 is wasteful with too many trips. (Muda)

Number 2 has too many trips and the loads are not uniform, unbalanced. (Mura)

Number 3 is unsafe as it overloads the forklift, difficult not simple. (Muri)

As we begin to think about implementing the SMED discipline there is another discipline we should have in place or plan to do concurrently because they complement each other. This is the 5S & Visual Controls discipline.

5S & VISUAL CONTROLS

5S is considered the foundation of improvement activities. The 5 S's are:

Sort

Set in Order

Shine

Standardize

Sustain

(Some would add a sixth S for safety.)

Sort

This means that you remove from the workplace all items that are not needed for current production. This could include equipment and machinery.

Set in Order

This is arranging needed items so they are as close to the point of use as possible and identifying them so they are easy to find and put away.

Shine

This means cleaning. Sweeping floors, picking up trash, wiping off excess die release from the DCM and making sure everything in the plant stays clean. This improves safety, brightens the workplace for inspection and uncovers maintenance opportunities.

Standardize

This is the method used to maintain the first three S's. It is related to Sort, Set in Order and Shine, however, most strongly to Shine. It results when the machines and their surroundings are free of debris, oil and dirt.

Sustain

This means making a habit of properly maintaining correct procedures. Employees must be committed to maintaining 5S conditions. This will require hourly, daily, weekly and yearly efforts.

If your plant has already implemented the 5S discipline, introducing and implementing SMED should be fairly straightforward. This is because many of the disciplines and cultural changes required for 5S are also requirements for SMED. In light of this kind of thinking, we must now apply these principals and disciplines to the reduction of setup time.

One more thought in this chapter on perspective. We should recognize the contributions of Dr. Shigeo Shingo. Dr. Shigeo was an international consultant with the greatest impact on manufacturing with his teachings in three concepts:

- Just in time (JIT)
- Single Minute Exchange of Dies (SMED)
- Zero Quality Control

As part of JIT, Dr. Shigeo pioneered the concept of SMED. SMED was developed in order to reduce the fixed cost associated with the setup and changeover of dies. The basic elements driving the SMED concept are to reduce the setup time of dies, which directly result in smaller batch sizes of parts. A smaller batch size translates as lower cost associated with work in process (wip) inventory storage, as well as raw material and finished goods inventories. This concept is especially beneficial as it allows the manufacturing system to quickly adjust to engineering design changes with very little costs. In addition, SMED allows higher machine utilization and in turn results in higher productivity.

Dr. Shigeo's approach to developing the SMED concept was to isolate and identify the setup time as two entities: internal setup time and external setup time. According to him, a simple approach to achieving a quick setup and changeover of dies can be done in the following steps:

- Separating internal and external as it is existing
- Converting internal to external setup
- Streamlining all aspects of the setup operation

Finally, a common example of how SMED principals can be applied to shorten the time of a changeover. How long does it take you to change a tire on your car after you have stopped? 15 minutes? Could the tire be changed in 15 seconds? How about 8 seconds?

When Dale Earnhart Jr. pulls into the pits at a NASCAR race, his four tires are changed and the car filled with fuel in about 15 seconds.

When Michael Schumacher pulls into the pits during a Formula 1 race, he gets four tires and a load of fuel in about 8 seconds. Of course he as twice the number of tire changers that Dale Jr. has. Also, only one lug nut/spinner per wheel.

Implementing SMED

Implementing SMED is a team effort. Choosing the team members is very important. Each member brings specific skills to the set-up. The pit crew analogy is very helpful in understanding how SMED is put into practice. In fact, "Setup" Crew and Crew Chief" are the best names to use for the various participants. Another useful analogy is to think of the set-up as theater, a one act play. Each actor/crew member has specific tasks to be completed in a specific amount of time in a predetermined order. Each actor/crew member must know their activities (lines) and timing. Preparing for the set-up requires practice, practice, practice (rehearsal), until everyone is completely trained.

The SMED discipline is implemented in four steps.

1. Analyzing your setup operation
2. Separating internal and external setup
3. Converting internal setup to external setup
4. Streamlining all aspects of the setup

Manufacturing processes and Setup operations are very similar. Manufacturing processes are characterized by four phases: processing, inspection, transport and storage. Processing includes all the operations that modify the shape or quality of the casting. Inspection is simply the comparison of the casting to a standard. Transport is the moving of the casting from one location to another. Storage is the period of time when no work, transportation or inspection is being done.

Setup operation is the preparation or adjustment performed before and following the manufacturing process. There are only two kinds of setup activities.

Internal Setup: this is work that must be done on the machine when it is shutdown. For example, the stationary die half can only be attached to the stationary machine platen when the machine is shut down.

External Setup: this work can be done while the machine is still running. For example, the plunger tip and plunger rod can be assembled.

Traditional setup operation in a manner similar to manufacturing processing is made up of the following four steps:

1. Preparation, after-process adjustments, checking of materials and tools.
2. Mounting and removing of tools or parts.
3. Measurements, setting and calibration.
4. Trial runs and adjustments.

Preparation, after-process adjustments, checking of materials and tools

Typically, preparation is done after the machine has stopped. This step includes making sure all the tools are in their proper location and functioning properly. Also included are returning items to storage and cleaning of tools and machinery. This could be as much as 35% of the total setup time.

Mounting and removing of tools or parts

This is the removal and mounting of the die and components. This must be done with the machine shut down. This may account for about 5% of the total setup time.

Measurements, setting and calibration

This is the measurement and calibration that is done in order for the process to operate correctly. An example would be adjusting the shut-height of the DCM to achieve the correct clamping force. This is usually done with the machine on and off. These types of adjustment may account for as much as 15% of the setup time.

Trial runs and adjustments

These are adjustments to the process made after a sample casting has been made. These are for qualifying the casting dimensionally, for internal soundness and surface finish. Depending on how well the process has been engineered and setup in the previous step, this could be as high as 50% of the setup time. In a typical die casting operation this is more likely to be less than 25% of the total setup time. The objective is to eliminate trials and adjustments, the first shot should be an acceptable casting.

Analyzing your setup operation

The first step in preparing for SMED is to establish your setup baseline. Your company probably has copious amounts of data that show how long a setup takes. This data will vary with machine size, casting die and process complexity, and should be used for reference only. However, data not available and required in order to separate internal and external tasks is each of the individual tasks required for the setup and the time for each task. In order to determine the required tasks and their time, a setup analysis must be done. This analysis is undertaken with the following steps:

Step 1. Videotape the entire setup operation. Use the camera’s time and date function to record elapsed time for each task. Focus on the hand, eye and body movements of the setup person(s) Step 2. Show the video to the setup person and persons involved in the setup and determine a description for every activity. Step 3. Study the video in detail; define the task and time for each step of the setup.

Once the analysis is complete, the three stages of SMED implementation can begin.

Stage 1: Separating Internal and External Setup

This is the most important step in SMED. The ability to separate internal and external activities will determine how close we can get to our SMED goal. The obvious things, such as, preparing and staging the tooling could save as much as 50% of the baseline setup time.

Stage 2: Converting Internal to External Setup

After the obvious activities, achieving SMED will take more effort and ingenuity. First, the operation must be re-examined to determine whether the steps were wrongly assumed to be internal activities. Second, methods must be established to convert these activities to external operations.

Stage 3: Streamlining All Aspects of the Setup Operation

To further reduce setup time, each element of the setup must be analyzed in detail. Can time be saved by doing activities in parallel with more personnel? Can the need for adjustments be eliminated or at least minimized? Can some of the activities be mechanized? These principals as well as others should be applied to all the internal activities in the effort to reduce the machine down time.

Installation Steps

To understand how SMED can be installed, the setup of a 1215 DME unit die will be used as an example. A unit die is a tooling concept used to minimize tooling and casting cost. It can be described as a system of interchangeable cavities with a common mold base. In the simplest case the items to be setup are the stationary cavities, the moving cavities and the ejector plates/pins. Likewise, these are the items to be removed from the machine for the job that has been completed. The unit die is used as the first example since some of the SMED techniques have already been designed into this tooling system.

STAGE 1: SEPARATING INTERNAL AND EXTERNAL SETUP

A number of tasks should be completed before production at the Die Casting Machine (DCM) is stopped. These include making repairs and assuring the casting die (CD) is ready for production, lining up the right people for the setup (Setup Crew), and staging the CD, components and tools at the DCM. These are all external setup items.

There are three techniques that can be used to separate internal and external tasks. They are checklists, function checks and improving tool movement, transport.

Checklist

A checklist can be used to list everything that is required for the setup.

This includes:

- Tools, and people
- Operating parameters, process set points
- Quality criteria, visual and dimensional required from the operation.

Initially, “everything” will be unknown. Video taping of the set-up will help to define what “everything” will be.

Equipment: **200 DCM**
Operation: **Die 3000 SU**

Date: **Jun-05**

Employees trained for setup and operation

- ☐ John B.
- ☐ Ted A.
- ☐ Alice Z.
- ☐ China B.

Tools needed & Location

- ☐ impact wrench, 1/2 & 3/4 drivers
- ☐ 2T hoist
- ☐ Tool/cleanup Cart
- ☐ Die preheat station, 30 min. or 350F.
- ☐ Prybar

Parts needed

- ☐ Vee clamps, use from existing SU
- ☐ 2x-3/4 x 2 SHCS for ej. Plate, use from existing SU
- ☐ 4x-Hose disconnects, use from existing SU
- ☐ vacuum, scraper, solvent, brushes for clean-up

Standard Operating Procedure

- ☐ SOP 001 (setup)
- ☐ SOP 002 (cleanup)
- ☐ SOP 003 (preheating)

Example Checklist for setup of D/N 3000.

Function Checks

These are checks done well before the CD is staged for setup. These are done to assure the CD is in working order and all repairs have been completed. These are done to make sure the CD is ready to set, so no problem will be detected during the setup.

CstgDie 3000
Operation: Function Check

Date: Jun-05

Employees trained for function check

- ☐ John B.
- ☐ Ted A.

Visual check

- ☐ Cover cavity: cores and mounting screws tight
- ☐ Eject. Cavity: cores, ejector pins, mounting screws tight
- ☐ Tool/cleanup Cart
- ☐ Ejector plate: Pins free and lubed, mounting screws tight
- ☐ Ejector plate: Insert spacer block, check heights of all ej. Pins in cavity to spec.

Tools required

- ☐ 3/4 Allen key
- ☐ 1/2 Allen key
- ☐ 1215 master ejector spacer block

Standard Operating Procedure

- ☐ SOP F3000 (Function check)

Example Function check D/N 3000

Transport of Part and Die

Movement of dies and tools to the DCM and away from the DCM are done as external operations. If the DCM is run manually, another member of the setup crew is required to provide for the movement of this equipment. Tools and dies are staged near the DCM; prior to it being shut down in order to minimize the distance these items must be moved during the internal setup.

Example:

1215 Standard DME unit die setup on the operator side of a two-station mold base.

External Activities Before DCM shutdown

1. Function check of CD, CD ready. The Function Checklist can be used as a visual tag on the CD to confirm it is ready.
2. Notify setup crew members of anticipated setup and time. In the case of the 1215 CD setup, only two crew persons are required.
3. A SU Crew member begins to pre-stage required CD and components in staging area, per the information on the Setup Checklist.
4. Items that require the longest time to pre-stage are done first. For the 1215 a 30-minute minimum or 350F requirement is specified. In this case the die preheat station is moved to a predetermined location at the DCM, and the DN 3000 is staged and preheating is started. Figure 4-3 is a sketch of a portable preheating station that could be moved adjacent to the DCM.

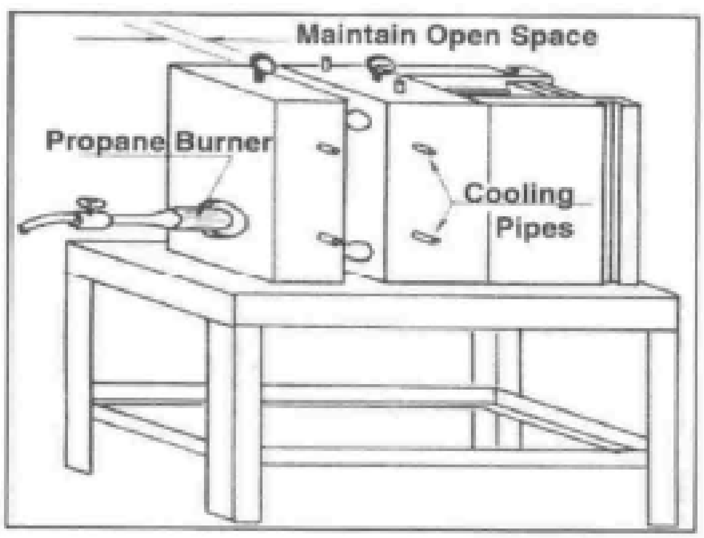


Figure 7-3 - A portable preheating station

a. Next the Tool/Cleanup cart is retrieved and checked for all necessary cleaning materials.

b. Impact wrench is obtained from tool board or chest, hooked-up and tested.

c. 2 Ton hoist is moved and pre-positioned above the machine.

d. Just prior to the DCM shutdown, the area around the operator's side of the DCM that must be accessible for the SU is cleaned up. Material handling containers are moved out, whatever blocks access to areas where work must be done, including the control panel, must be moved out of the way. This moving of materials is not done in a random fashion, but in a pre-planned way. Locations for the various containers/equipment should be marked on the floor, even if they are temporary locations. This is to make sure that they are clear when needed

e. The Tool/Cleanup cart is moved into position and the setup may commence.

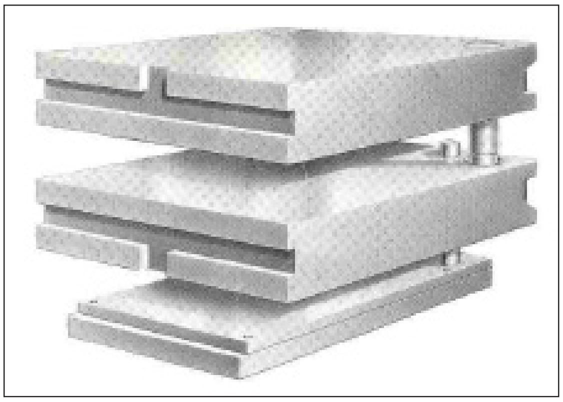


Figure7-4 - DME 1215 Unit Die

Note: keyways for locating the two die halves on the mastermold. Also, the ejector plate fits under the ejector retainer plate of the mastermold.

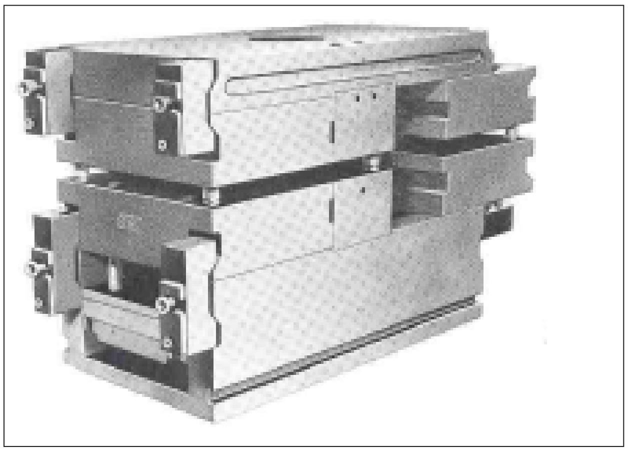


Figure 7-5 - Two stastion DME 1215 Mastermold.

Note: the two wedge type clamps for die half. Also note the "C" type washers used under the SHCS.

Internal SU commences when the DCM is shut down.	
#1 Crew Activity	**#2 Crew Activity**
1. Leave die open, return ejector plate, change to manual mode turn off cooling. 2. At stationary half, disconnect cooling lines, drain first and then inlet. 3. Unbolt two clamps from the stationary die half and attach hoist. 4. Use pry bar to move die half off of keyway and guide die out of die space. 5. Clean-up die space in area of the stationary die half. 6. Locate DN 3000 on keyway and clamp into place. Disconnect hoist. 7. At moving half, disconnect cooling lines, drain first and then inlet. 8. Attach hoist, unbolt two clamps and unscrew two ejector plate retaining screws. 9. Use pry bar to move die half off of keyway and guide die out of die space. The moving die half. 10. Clean-up die space in area of the stationary die half. 11. Locate DN 3000, moving half, on keyway and clamp into place. Disconnect hoist12. Insert and install two ejector plate restraining screws. 12. Insert and install two ejector plate restraining screws. 13. Reconnect cooling lines to the moving half. 14. Reconnect cooling lines to the stationary die half. Adjust to low flow to fill die with coolant. 15. Close die, check lock. 16. All satisfactory, set DCM to Semi-Auto cycle and make first shot.	1. Lower hoist into position above stationary die half. 2. Add slight tension to hoist. 3. Lift die half out of DCM and place in stage in "removed die holding area" 4. Obtain the stationary half of DN 3000 from the die pre-heating station and lift into die space. Wait for operator to locate die on keyway. 5. Lower hoist into position above the moving stationary die half. 6. Add slight tension to hoist. 7. Lift die half out of DCM and 8. place in "removed die holding area" 9. Obtain the moving half of DN 3000 from the die pre-heating station and lift into die space. Wait for operator to locate die on keyway. 10. Move hoist away from above the DCM. 11. Reset DCM machine settings if necessary. 12. Readjust die sprayers as necessary. 13. Readjust autoladle if necessary. 14. Remove Tool/Cleanup cart. 15. Replace material handling containers for the new castings.

External Activities After the DCM is restarted

1. Return portable die preheat station to its designated location.
2. Return Tool/Cleanup cart to it designated location.
3. Return impact wrench and drivers to their storage locations.

This completes the die setup. The unit die setup is pretty simple and already contains some of the techniques that are used to reduce setup time. For example, the keyway on the mold base that fits into the key slot in the unit die pre-positions the die half in exactly the correct location and orientation.

STAGE 2: CONVERTING INTERNAL SETUP TO EXTERNAL SETUP

Now look at implementing Stage 2 of SMED on our current 1215 unit die example. Stage 2 consists of converting Internal activities to External activities. There are two steps to follow to get this done:

1. Look at the true purpose of each internal activity in our current setup operation.
2. Find ways to convert the activities to external activities.

There are three practical techniques to follow in converting internal activities to external activities. They are:

Prepare operating conditions in advance.

- Standardization of essential functions.
- Using intermediary jigs/fixtures.
- Prepare operating conditions in advance

In our example, we have done a reasonable job of preparing the job site prior to the commencement of the setup. We preheated the CD off line on a special portable table designed for that purpose. We moved equipment out of the way and prepositioned the Tool/Ceanup cart where it would be accessible for the setup.

Standardization of essential functions

Again the unit die example is very good in terms of standardizing essential functions. Examples of standard functions include handling, alignment, clamping, cooling and die spray. The methods used to standardize and simplify these functions was as follows:

Handling:

- Permanent eyebolts are attached to each die half (they could be tack welded to prevent their loss).
- They are selected at a standard size to fit the hoist hook.

- They are installed in the top of the die to provide orientation.
- They are located to best balance the die.

Alignment

- The keys in the master mold base and keyways in the unit die provide alignment and positioning of the unit dies on their respect mold base halves.
- Additional alignment between the die halve is provided by leader pins or bushings in each unit die half.

Clamping:

- Two wedge clamps are used to force the die half onto the keyway and hold it against the clamp plate or support parallel.
- The clamps are standard and interchangeable for this unit system.
- Clamping heights/die thickness are standard for the unit die system.

Cooling:

- The individual cooling lines on the unit die are color coded to indicate if they are an inlet or drain. Inlets are blue (cool water in) and drains are red (warm water out).

Die Spray:

- Standardization of this area is difficult because casting shapes may be very different. In our example, individual spray nozzles had to adjusted to conform to the requirements of the casting.
- An instruction sheet was provided, indication where the spray nozzles must be pointed and the shape of the spray pattern. The duration of spray was fixed and the amount of spray was the process variable.
- Castings with similar geometries may work with standardized spray patterns.
- The unit die system has a lot of standardization in its original design. This does not mean it cannot be improved.

STAGE 3: STREAMLINING EXTERNAL AND INTERNAL SETUP

Finally, look at implementing Stage 3 of SMED on our current 1215 unit die example. Stage 3 consists of streamlining all aspects of the setup operation. This means streamlining External and Internal activities.

The External activities were primarily logistical and checking. Moving the die from storage, checking the die, procuring tools, organizing the Tool/Cleanup cart, moving and starting the die preheat station, and moving out material handing equipment from the setup work area and moving in the Tool/Cleanup cart. These are storage and transport functions, and can be improved using the 5S discipline.

First, improvement is achieved if you do not have to "look for" a required tool or component. Every die and tool should have an easily located storage address "a place for everything and everything in its place".

Second, the handling and removal of items from storage should be safe and simple. For example, if dies are stored on pallets, they must be secured to the pallet to prevent them slipping off the pallet when handled. The dies could be uniformly oriented on the pallet and prepositioned in such a manner the entire pallet could be set on the die preheating station, eliminating the need to move the die from the pallet to the preheating station.

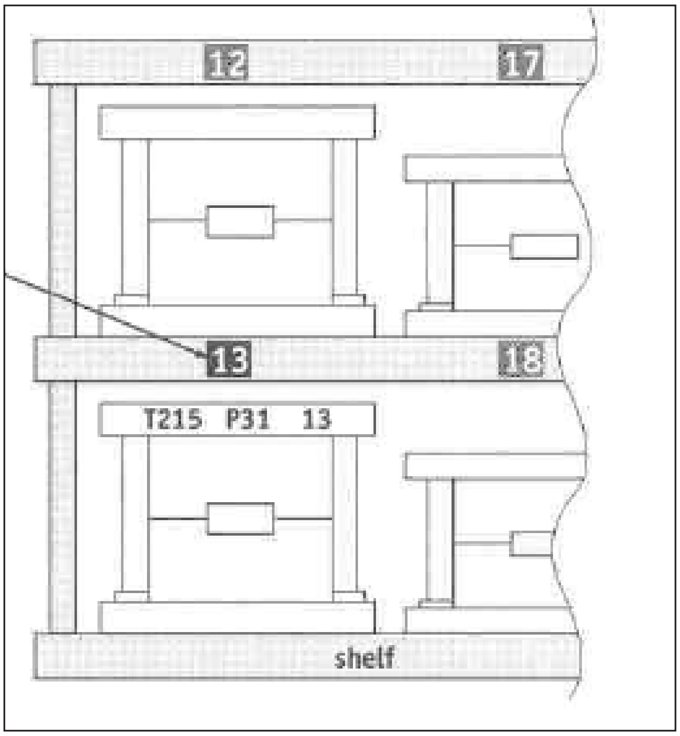


Figure 7-6 - Die storage using addresses to locate the dies.

Streamlining internal operations is next. This is done by:

1. Implementing parallel tasks
2. Using functional clamps
3. Eliminating adjustments
4. Mechanization

Implementing parallel tasks

The only factors limiting the number of persons working on a setup are safety, the sequential nature of some tasks and the ability of each person to stay out of the way of other person.

In our simple unit die setup example, we started with two persons working on the setup. The internal activities sheet shows the order and task of each of the setup crew. Since no times are assigned to each task, we are unable to determine if the tasks are balanced or there are excessive wait times for either person. There are some activities that could be done by a third crew member. Items 10, 11 and 12 on the crew member list appear to be candidates for a third person. However, without times being defined, this would have to be confirmed.

Using functional clamps

Removing the four wedge clamps, four SHCS, and two ejector plate retaining SHCS is an invitation for lost time. First, all the pieces are loose, can fall on the floor or otherwise get lost, particularly the screws. Also, they need to be placed somewhere that make them easy to retrieve when needed. A clamping solution that avoids these problems would be welcome.

The clamps could be revised so that they are loosened enough to clear the clamping surfaces and then rotated 90 degrees. This would gain enough space to slide the unit die half out without totally disengaging the clamp. The clamp would be left hanging from the SHCS in the master mold base.

A similar technique can be applied to the ejector plate mounting screws. In this case the objective is to have the mounting screws retained by the ejector plate. This would be accomplished by cutting a thread in the ejector retainer plate, the ejector plate would then have a clearance hole through it. The SHCS would be relieved of threads for a distance of two diameters from under the head. With this technique, once the SHCS is threaded through the retainer plate, it is captured by the retainer plate in the relieved area of the screw.

There are other types of clamping methods that can be employed to simplify the camping operation. One way to reduce clamping time is to limit the number of turns that are required to tighten a fastener. SHCS are notorious for requiring may turns to fasten them. A rule of them for SHCS is to have one and one half diameters of thread engagement. Using a ½-13 SHCS as an example, it would require 3/4ths of an inch engagement, or 1 ½ diameters. This would be 9.75 turns (0.75 x 13) If this type of fastener is required, a power driver is a necessity, preferably battery operated, no cords or hoses. An alternative may be to develop a fastener that clamps and tightens in one turn. The following figures show a number of alternatives for One-Turn Functional clamping.

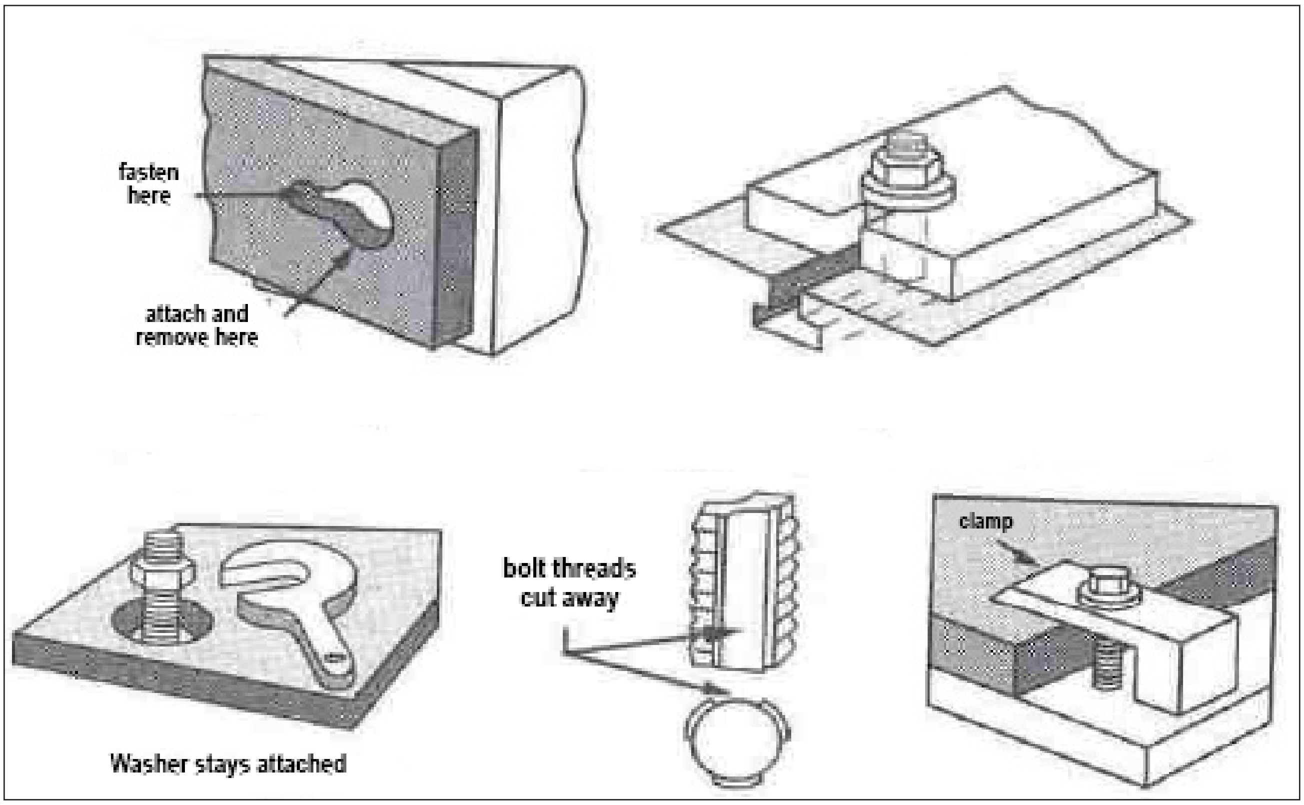


Figure 7-7 - One Turn Functional Clamping

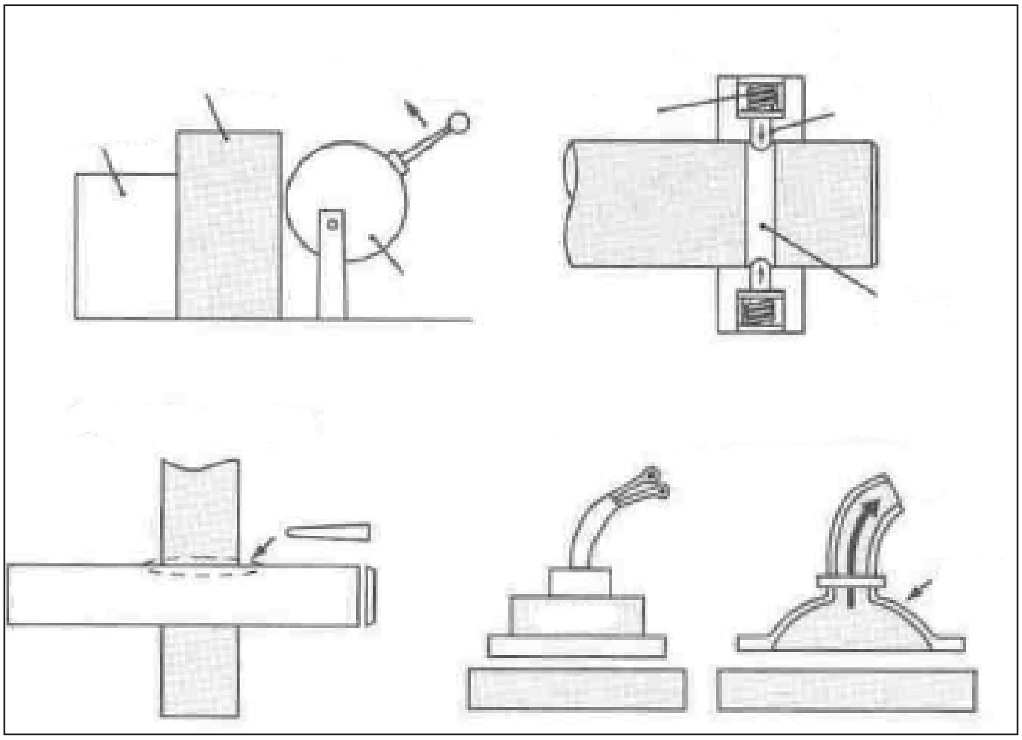


Figure 7-8 - One Motion Clamping

Another type of clamping is referred to as One-motion methods. These are cam and clamps, wedges and taper pins, spring stops and detents and magnets or vacuum. All of these devices have been used in the die casting plant in various locations and many are familiar to us. These methods are shown above.

Another method for holding two components together is to interlock them. This is similar to using a wedge, but in this case one of the components is a wedge. This technique relies on a good fit between the mating components and a slight amount of interference.

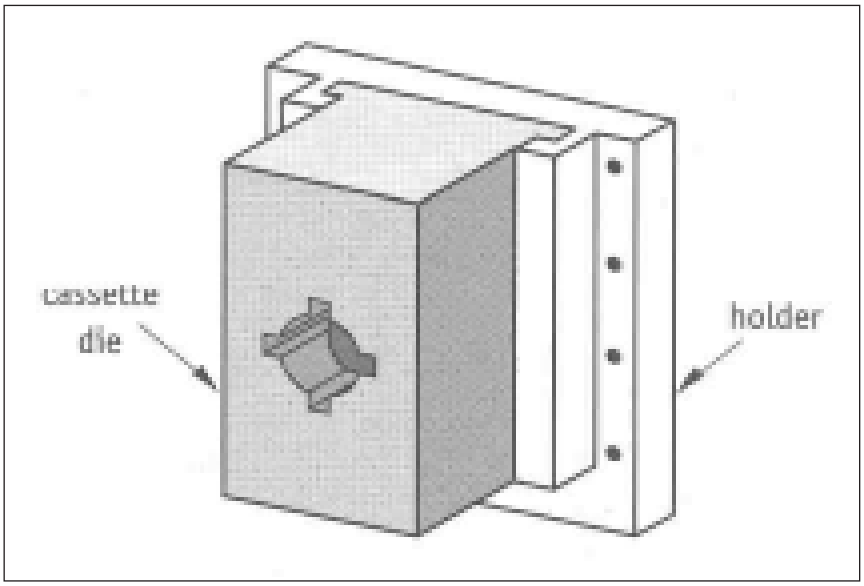


Figure 7-9 - The die is slid into a tapered holder to clamp the die

ELIMINATING ADJUSTMENTS

With traditional setup, adjustments and trial runs can account for as much as 50% of the setup time. So the simple message is to adjust the machine setting correct the first time. There are three techniques for eliminating adjustments, they are:

- Use fixed numerical settings and make standardized settings.
- Make imaginary centerlines and imaginary reference plane visible.
- Using the Least Common Multiple (LCM) system.

Fixed Numerical Settings

Using numerical settings is far superior to intuition. Intuition varies among operators and even an operator may not be consistent from day to day. One way of making numerical setting is to use a graduated scale.

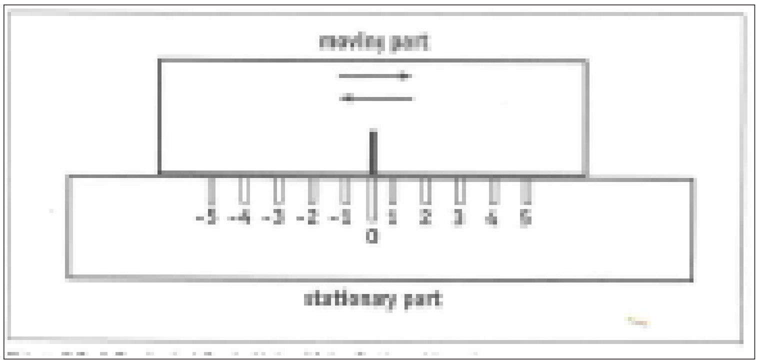


Figure 7-10 - This graduated scale is similar to a vernier used in measurement.

This graduated scale is a numerical method for making an accurate machine setting. In the case of the scale in Figure 7-10, a setting of –3 could be set uniformly by the operator or different operator.

The graduated scale is similar to the types of scales one would see on a vernier caliper measuring tool. This type of technique could be extended in order to make valve setting uniform also. Think of the valve stem as being the thimble of a micrometer with a scale inscribed on it and the fixed portion of the valve with a scale, again similar to the sleeve of the micrometer.

Accuracy of settings on a graduated scale are usually within 0.020 inches. Settings made with dial gages can be accurate to within 0.005 of an inch. Digital devices can even achieve greater precision with the proper type of transducers.

Another technique to make accurate setting is the use of gages (JO blocks) or shims. These can be stacked to achieve accurate numerical dimensions. Spacers could be ground to a particular height to achieve an accurate setting.

Visible centerlines and reference planes

In traditional setup centerlines and reference plane are not visible. In order to setup tools at the machine or injection centerlines, tools have to be modified to find these locations. For example, in hot chamber die casting a setup ring or collar is installed in the die at the sprue. The setup ring fits into the nozzle hole in the stationary platen and aligns the die with the nozzle. Another method for pre-positioning the die in the die space is to attach a bracket to the top of the die that has two V-blocks attached. The die is dropped into the machine from the top, the V-blocks straddle the tie bars and position the die in the machine die space.

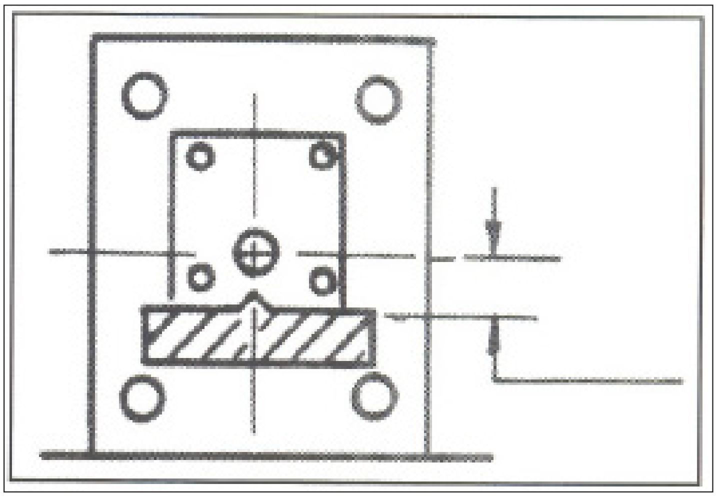


Figure 7-11 - Using V-block used to preposition a work piece.

Least Common Multiple System (LCM)

The principle for this system is to leave the machine mechanism alone and only modify its function, and make settings not adjustments. For example, there is a tailrod attached to the crosshead of the DCM. There is a limit switch, when activated by this tailrod, that stops the die opening, in effect controlling the die opening. This switch must be adjusted during setup to determine the optimum stroke. In order to eliminate this adjustment, several limit switches are mounted to be activated by the tailrod, and then the switch closest to the optimum opening stroke is selected for the particular die being setup. See Figure 7-12 below.

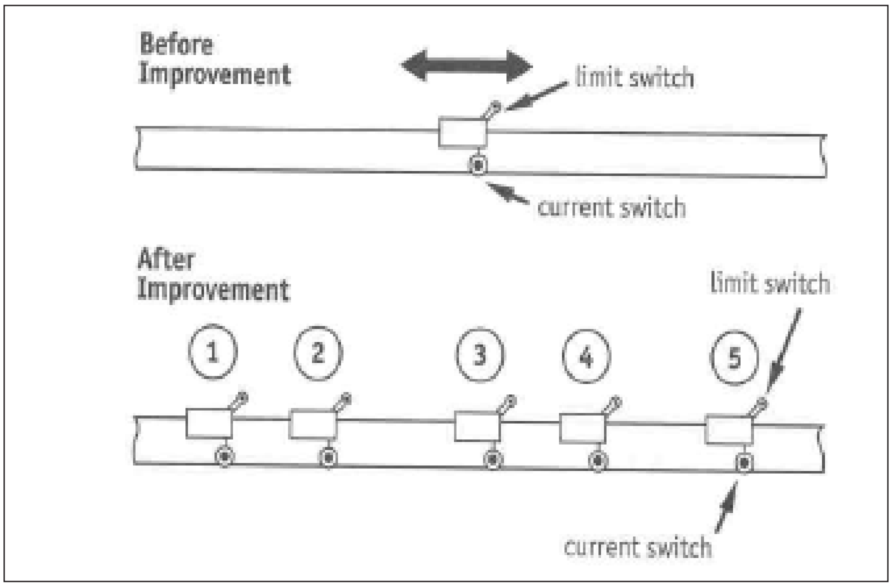


Figure 7-12 - Avoiding adjustment by placing limit switches a various die opening distances.

A selector switch can now be used to select the limit switch closest to the optimum die spacing. Again, this technique avoids having to adjust the limit switch position. If the DCM is run with a PLC, the limit switch selection would be part of the program for the particular die being set.

Mechanization

Mechanization is considered only after the first three techniques have been exhausted. Mechanization does not usually yield large savings in time because most of the time saving have already been achieved by the time we get to mechanization. Also, mechanizing an inefficient operation is not advantageous. Think of mechanization as a process for fine tuning, not quantum leaps in improvement. Mechanization is essential for moving large tools including large casting dies.

Mechanization techniques include:

- Using forklift to place die in the DCM
- Moving large dies on bolster plates
- Clamping and unclamping by remote control
- Using electric drive to change shut heights
- Using machine energy to move dies

From the list above, all are already being done in die casting.

IMPROVING SETUP OF SELF CONTAINED DIES

The unit die example shows that some of the SMED techniques are already part of the unit die design. How does the setup of a unit die differ from the setup of a self-contained die (SCD)?

Below is a list of the general tasks that must be completed to setup a self-contained die in a cold chamber DCM. These are internal activities.

Activity		SCD	UNIT
1.	Remove CD from DCM machine space	Y	N
2.	Place next CD in machine space (both halves, together)	Y	N
3.	Install cold chamber	Y	N
4.	Clamp stationary half of CD onto Stationary platen of DCM	Y	Y
5.	Close DCM	Y	N
6.	Couple ejector system of CD to the DCM	Y	Y
7.	Close DCM and adjust shut height of DCM to reach CD	Y	N
8.	Clamp moving half of the CD to the moving platen of the DCM	Y	Y
9.	Adjust DCM locking tonnage	Y	Y
10.	Connect cooling lines (if required)	Y	Y
11.	Connect hydraulic hoses (if required)	Y	Y
12.	Connect electrical limit switches (if required)	Y	Y
13.	Change DCM process settings	Y	Y/N

As can be seen from the previous list, a unit die setup is simple compared to the self-contained die. The unit die setup is simpler because of standardization and limited activities.

- The unit die does not require coupling to the injection system.
- Clamping is standard, both the type of clamp and their location, and there are only four clamps.
- The unit die is coupled to the ejector system with two SHCS (socket head cap screw).
- The unit die does not require shut height adjustment because this dimension is fixed.
- The use of hydraulics and electrical interlocks depends on the complexity of the casting and could be required of either type of die.

Now lets look at the setup of a self-contained hot chamber die, starting with traditional setup and then convert the setup using SMED techniques. We will use the setup that is enumerated in Chapter 6 of the “Operating the Die Casting Machine” handbook. This setup lists 33 sequential steps beginning with:

1. Deactivate shot
2. Open DCM
3. Clean die mounting surface
4. Clean mounting surfaces of die
5. Insert eyebolts into die
6. Install cooling line pipes
7. Attach crane or chain fall
8. Install bumper pins
9. Place die in DCM
10. Close DCM
11. Install ejector pinion
12. Secure die
13. Remove crane
14. Check die closing
15. Set DCM stock
16. Set ejector
17. Install nozzle
18. Heat nozzle
19. Connect cooling lines
20. Set safety ratchet
21. Set deceleration
22. lubricate die
23. Install die heating
24. Install release spray
25. Close safety doors
26. Tighten nozzle
27. Replace shot plunger
28. Set all timers and metal temperatures
29. Check Hydralic lines
30. Check machine lube system
31. Turn off die heating torches
32. Check lock-up sequence
33. Make shot

How can this setup sequence be improved using the techniques that have been discussed the previous sections? First, setup begins when the last shot of the previous run is complete. Second, we will use a setup crew to do the job; the number of crew members required is not limited except by practical considerations of space and safety.Third, we will define the activities as external or internal activities.

Listed above are all 33 activities that were internal activities in the traditional setup as first enumerated.

Stage one of SMED is to sort these activities into external and internal activities. The column shown as stage 1 shows how the activities have been separated. The following items have been sorted as external activities:

5. **Insert eyebolts into die -** Eyebolts will be installed into each die half permanently, they could be tack welded to make sure they do not get lost and also prevent rotation.

6. **Install cooling pipe in die -** All cooling pipes are installed into the die as it comes from die repair; the only time cooling pipes are removed is for repair and maintenance.

18. **Heat nozzle -** Nozzle can be pre-heated just as the die is pre-heated off-line.

20. **Set safety ratchet -** Operation of the safety ratchet can be observed as an external activity. Adjustment is not necessary.

22. **Lubricate die -** Die lubricated as part of die maintenance.

23. **Install die heating -** Die is pre-heated at the die pre-heat station and will be set hot.

27. **Replace shot plunger -** Plunger does not have to be removed for the setup as long as it is physically blocked and cannot move or drift.

29. **Check hydraulic lines -** Hydraulic lines are checked as part of a preventative maintenance program

30. **Check machine lube system -** The machine lube system is checked as part of a preventative maintenance program

31. **Turnoff die heating torches -** Die is pre-heated at the die pre-heat station and will be set hot.

LARGE CASTING DIES

For purposes of this publication, large “CD’s” are CASTING DIE’s run on 2000 ton or larger machines.

The same SMED principles applied to small dies are used for large dies. The issue with large dies is they have a large mass and must be moved and adjusted carefully. A large mass moving at high speed has a lot of momentum (mass x velocity = momentum). You do not want the CD becoming a pendulum. When moving large dies, mechanically aids, as opposed to manpower, are required. If the movement can be controlled robotically through programming, that is even better. Then accelerations and decelerations can be controlled and the large CD mass can be positioned accurately without impacting the DCM. Keep in mind for safeties sake, there is little that you can move or adjust on a large die, manually.

Moving dies in and out of large die casting machines is aided by machines equipped with automatic tie bar pullers. With tie bar(s) out of the way the assembled CD can be lowered into the die space from above or slid in from the side. One of the first decisions to be made, when considering SMED for large dies, is will the CD be installed from the top or a side. This will depend on the CD configuration. If there are no appendages hanging below the CD, it should be slid or rolled in from the side. If the CD mounts below the lower tie bars, once it is in the die space, it can be lowered into its mounting position by use of an elevator style table or lift. Today, most large CDs and DCMs employ automated clamping systems.

When considering External verses Internal activities for large CDs, minimizing movement of the large mass is one of the first considerations. This means the CD is staged as closely as possible to its terminal location. If the CD must be loaded into the die space by lifting over a tie bar or from the top of the machine, an objective the external activities is to get the CD as close to the DCM and as high as necessary before internal activities commence.

Once the CD is clamped into the DCM, utilities can be connected to the CD. This would include cooling lines, electrical interlocks and any other miscellaneous requirements. To speed and foolproof utility connections, they should be color coded, and the connector fittings, plugs and receptacles varied to make incorrect connections improbable.

8 PROPER CARE AND TREATMENT OF DIES DURING PRODUCTION

OBJECTIVES

- To learn about the operation of die casting dies in production.
- To review the many pieces of equipment utilized during production.
- To learn about the things that can go wrong during production and how to prevent them.

PERSPECTIVE

In the third lesson, the various components of the die casting machine were presented. In the sixth lesson, all of the components of the die casting die were discussed. In this lesson, all of this equipment will be put together and its combined operation is presented. How each piece of equipment affects the process, and especially the die casting die, will be examined in detail.

Equipment in the work cell includes the:

Holding furnace	
Ladle	
Die sprayer	
Plunger tip lubricator	optional
Extractor/robot	optional
Quench	optional
Conveyors	optional
Die heaters	optional
Trim press/die	optional

HOLDING FURNACE (COLD CHAMBER)

The purpose of the holding furnace is to maintain the casting alloy at a preselected temperature within a very small tolerance, and keep the alloy free of contamination from air or other sources. A typical holding furnace will have three distinct chambers, a charge well, the bath, and a dip well.

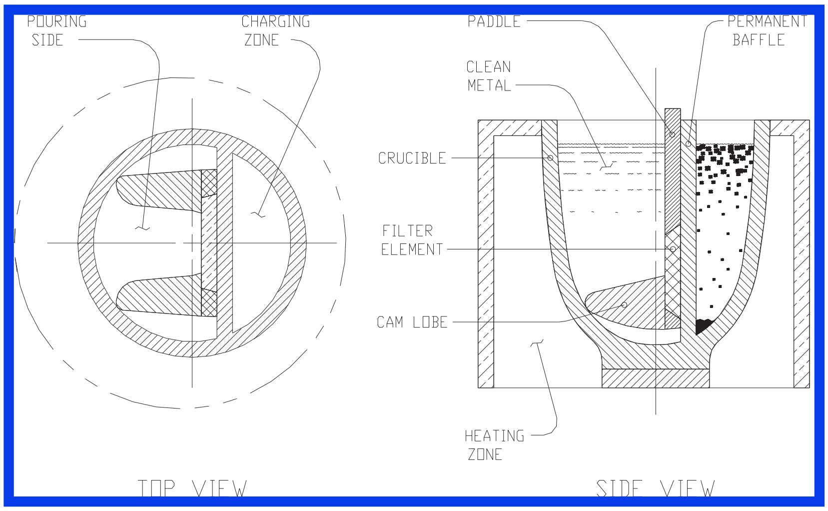


Figure 8-1 - A cold chamber holding furnace

Alloy enters the furnace at the charge well. This alloy is usually delivered to the holding furnace in liquid form, from the remelt furnace. In some cases alloy may be charged as ingot or gates and runners. When not in use, the charge well should be covered to prevent oxidation. The cover will also prevent any other extraneous material from getting into the alloy and covers a potential burn hazard. Lastly, the cover will prevent heat escaping from the alloy and save energy. Covers should be handled with care so that they can perform the function of sealing the wells.

The furnace bath is the main section of the furnace and contains the bulk of the alloy. The bath is isolated from the charge and dip wells by arches or door blades that prevent air getting into the main bath. This is the section of the furnace that is heated, either by a fuel fired flame or by electrical heating elements. If the furnace is fueled by gas or oil, the ratio of the mixture between the fuel and air is important. If the mixture is “rich”, meaning too much fuel compared to air, the fuel is not completely burned, and the atmosphere above the alloy becomes rich in combustion products that can contaminate the alloy. If the mixture is “lean”, meaning too much air is in the space above the alloy, this space becomes rich in air that will cause the alloy to oxidize. This will cause the alloy to be contaminated with oxides that will lower alloy quality and waste material. If the fuel mixture ratio is incorrect, the alloy will require cleaning in excess of the normal schedule and cause additional waste and alloy loss.

Furnaces that are electrically heated do not have the problems associated fuels. However, to avoid oxidation losses, these furnaces must also be kept sealed. These furnaces are more fragile than gas furnaces. When cleaning, alloy must not be splashed on the elements as this can destroy them. Also, after cleaning has been completed, care must be taken to make sure the doors and covers are properly placed to prevent air getting into the bath area.

Figure 8-2 - Electric furnace

Finally, the dip well is the third alloy chamber. This is the well from which the alloy is ladled or dipped and then transported to the cold chamber. This well should be covered when not in use. Alloy quality can be improved if a filter is placed between the main alloy bath and the dip well. As alloy flows from the bath to the dip well, it passes through the filter, which removes contaminants and oxides.

As the operator, you should be aware that many areas around the furnace can be hot and be burn hazards. Also, spilled and dripped alloy can form sharp drips of frozen alloy that can cut or puncture you. You should be continually collecting this spilled alloy, to recycle it and keep the work area neat and clean. Gas fired furnaces will have a lot of piping and controls outside them. Care must be taken that these devices and piping are not abused or damaged. Leaking gas can be poisonous and cause fires and explosions. The piping and controls should never be used in place of a ladder.

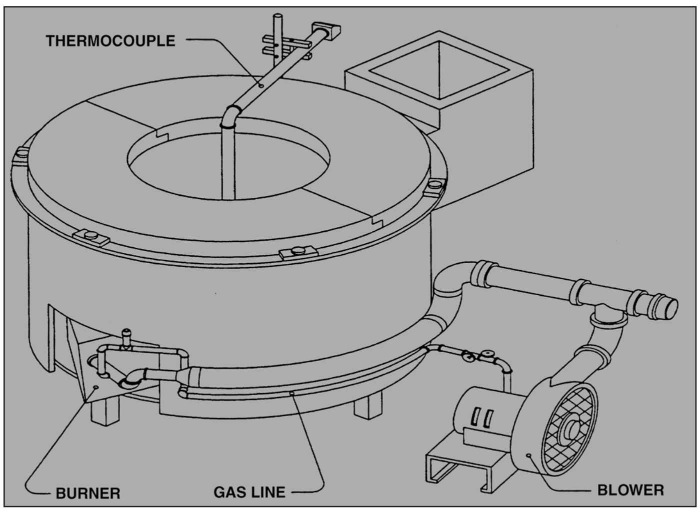


Figure 8-3 - Typical gas fired holding furnace

The holding furnace temperature is controlled with a thermocouple, for most holding furnaces this thermocouple is located in the dip well. This will give you best control of the temperature closest to the machine. As the operator, you need to make sure the thermocouple is plugged in and operating correctly. The thermocouple is enclosed in a long sheath known as the “protection tube”. This tube is usually cast iron, a material that can be dissolved by the aluminum in the alloy. The thermocouple tube should be inspected every shift to make sure it is not eroded or washed out; a failure could cause the alloy temperature to go out of control. The thermocouple protection tubes are usually coated with a die wash to prevent erosion. This coating must be totally dry before the thermocouple is immersed in the alloy.

Metal temperature and quality are two of the important die casting process variables. You, as the operator must do everything possible to maintain the metal quality at its highest level, and you must do everything possible to keep the temperature in the furnace constant.

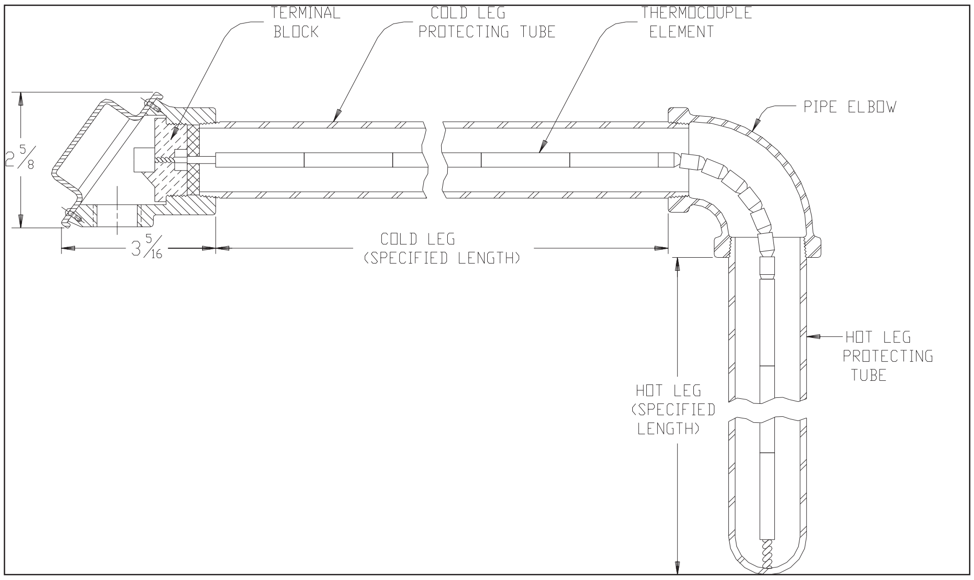


Figure 8-4 - Thermocouple cutaway

HOLDING FURNACE (HOT CHAMBER)

The holding furnace at a hot chamber machine is quite a bit simpler than the cold chamber holding furnace. Hot chamber alloys, with the exception of magnesium, are less reactive with oxygen than cold chamber alloys. These furnaces typically are open crucibles. They can either be fuel or electrically heated. They generally are not covered. They would benefit from being covered, both in terms of energy and oxidation losses.

As with cold chamber holding furnaces, the objective is to maintain a consistent alloy temperature and good alloy quality. When not in use they should be covered, or shut down depending on production requirements.

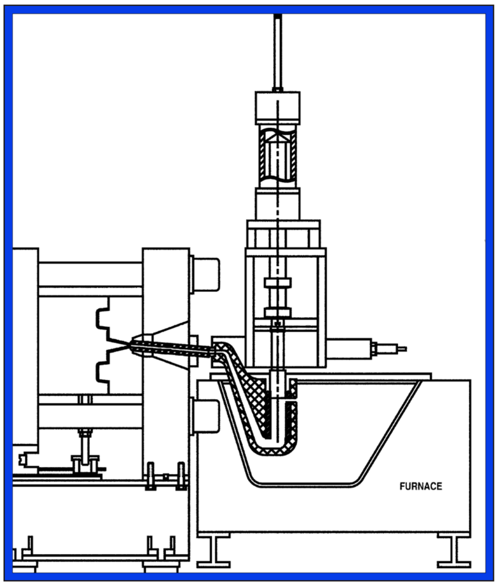


Figure 8-5 - Hot chamber holding furnace

Ladle

When you are ladling the alloy, you should have several objectives in mind. First, you want to ladle the correct amount of alloy. The correct amount of alloy is that amount that will completely fill the cavity and runner system and end with a biscuit that is thick enough to remain liquid as the casting freezes so pressure can be applied to the casting through the gate. Generally, the biscuit should be 1½-2 times thicker than the main runner leading from the biscuit. For example, if the runner going away from the biscuit is ½ inches (13mm) thick, then the biscuit should be ¾-1 inches (19-25mm) thick as a rule of thumb. The cooling at the biscuit, the plunger tip and the biscuit block is very effective and you want the biscuit to freeze last. If the biscuit or runner freeze before the alloy in the die cavity does, you will be ineffective in applying intense metal pressure to the casting as it solidifies. This will result in defects if this happens.

Next, the amount of alloy to be ladled must be consistent. When the shot is made, the transition point from slow to fast shot, and the point of intensification depend on the alloy volume. The transition from slow to fast shot takes place after the sleeve has filled with alloy and before the alloy reaches the gate. Similarly, intensification is started as soon as the cavity is completely filled with alloy. The settings for these transition points, slow to fast shot and intensification, are usually determined by positioning a limit switch along the plunger travel. When the plunger passes the (slow to) fast limit switch, it trips the arm and activates the fast shot. Similarly, near the end of the injection stroke, another limit switch is tripped activating the intensifier. If too much alloy is ladled, the sleeve will fill quickly and alloy will also fill the runner and gate before the plunger reaches the (slow to) fast limit switch. In this case the alloy could start filling the cavity at very low velocity causing defects and possibly freezing at the gate. If too little alloy is ladled, the plunger will arrive at the fast shot limit switch before the chamber is filled with alloy. This could result in lots of turbulence and mixing air with alloy in the sleeve and porosity defects in the casting. A biscuit size difference as small as 1/4 inch (6mm) can be very significant with respect to forming defects; for this reason it is important to ladle a consistent amount of alloy.

Another objective of ladling is to pour clean alloy. Since the dip well of the holding furnace is usually not covered during operation, the alloy is exposed to air. When this happens, the alloy in contact with the air oxidizes, or forms a chemical bond with the oxygen on the air. In the case of aluminum it forms aluminum oxide and with zinc it forms zinc oxide. It is undesirable to have these oxides in the casting. For the most part, these oxides float on top of the alloy bath and are referred to as “dross”. Avoiding the oxides is usually not a problem in hot chamber die casting because the gooseneck filling holes are below the alloy level in the holding furnace. However, in cold chamber die casting, ladling can be a problem because the alloy is dipped from the top of the bath in the dip well. In this case the dipping technique is important. You must make sure the accumulated oxides are not allowed into the ladle. The recommended procedure is to use the ladle to push the dross back from the surface and dip out clean alloy.

If ladling is done manually, you must be aware of the proper ladling technique and use it consistently. You will notice that the dross in the dip well will build up over time. This occurs slowly, every cycle, as you push the accumulated dross out of the way to dip out clean alloy, a fresh alloy surface is exposed to the air and a new layer of oxide forms. This cannot be avoided, but the amount of build-up can be minimized by disturbing a minimum of the alloy at the surface and by how you dip out the alloy. Your technique should be smooth and fluid with little disruption to the alloy surface. Every once in a while the build-up of dross will have to be skimmed from the top of the bath. Again this should be done with smooth and fluid motions to disrupt the surface of the bath as little as possible. It would be a good idea to leave a thin layer of dross on the surface of the bath to act as a cover from further oxidation as opposed to trying to achieve a bright and shiny surface on the alloy.

As noted earlier, ladling the correct and consistent amount is important. One technique used by operators that are ladling manually to assure a consistent amount is to cut a notch at the back of the ladle to spill off excess alloy.

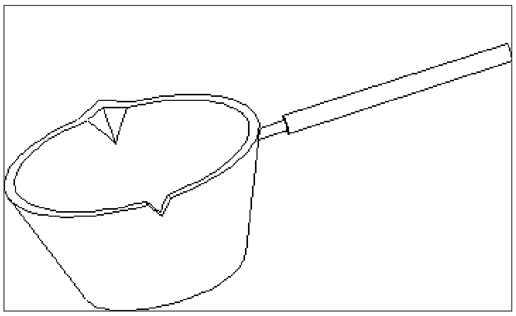


Figure 8-6 - Notched ladle

If you are using an autoladle, its dipping technique will also push the dross out of the way to dip out clean alloy. Periodically, the dross must be skimmed from the top of the dip well, or eventually it will get into the ladle. Autoladles are very good at pouring a consistent amount of alloy unless something goes wrong. It is part of your responsibility as the cell operator to learn what variables in the autoladle process cause problems, and anticipate and prevent them from causing failures and downtime.

Once alloy is removed from the holding furnace, it begins to give-up heat, or loose temperature. If too much heat is lost the alloy will begin to solidify and may become difficult to cast. This means that the amount of time that ladling takes could become an important process variable. If the ladling process takes a long time, heat is given up by the alloy, it begins to freeze and become slushy, it is difficult for the plunger to push this alloy through the gate and fill the cavity, resulting in poor filling defects.

Autoladles usually operate at a slower pace than a man, particularly, in the case of small shots, less than 5 pounds. Setting up the autoladle sequence and monitoring the consistency of operation is important. The autoladle should dip out the alloy, transfer to the cold chamber, and pour the alloy without any delays. You do not want the ladle to wait, with alloy loosing heat and temperature, while the machine is completing its cycle.

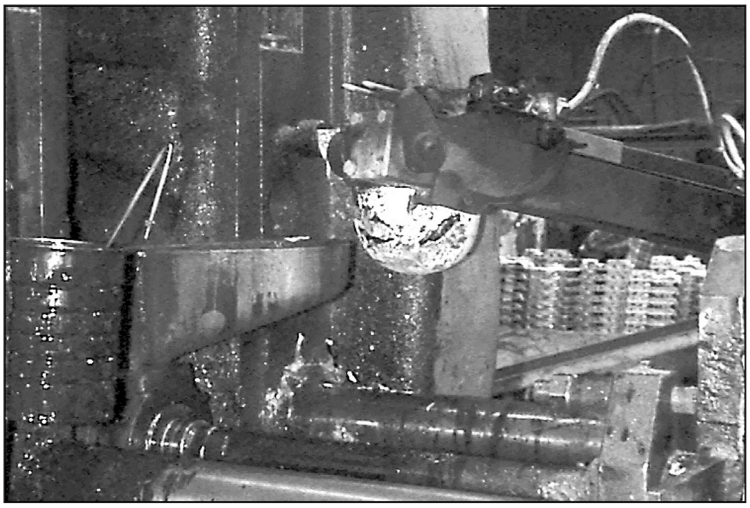


Figure 8-7 - Ladle above cold chamber, waiting, loosing heat

Die Spray

The appliances for die spray can be a manually held spray wand, individual spray nozzles mounted in fixed positions on the machine or die, or a series of spray nozzles mounted on a moving arm that reciprocates in and out between the open die faces. The reciprocating arm could be mounted to the machine, or the floor, or the boom of an extractor. Each of these application methods has advantages and disadvantages.

Figure 8-8 - Reciprocators

The objective of the die spray is to apply a protective coating of release material on the die face with a minimum of die spray. A secondary objective is to provide cooling in areas that cannot be reached internally. At the end of die spray, you must make sure that any excess die spray is blown out of the die cavity and flash or build-up is blown from the die face. Excess spray if left in the die cavity will turn to steam and end up as gas porosity in the casting. Excess build-up and flash at the parting line could cause the vents to plug. Excess flash can also hold the parting line open and cause dimensional problems and spitting.

As with ladling, a key to successful die spray application is consistency. If spraying is done with the manual spray wand, several important process variables are under your control. They are:

- Spray pattern
- Spray time
- Spray amount

The spray pattern is important to assure that the release material is getting to the die cavity surfaces that need release material. These surfaces are features that are directly in the metal flow path, in front of the gate, where the metal has high velocity and the cavity is prone to washout. Such as surfaces perpendicular to the parting line that have minimal draft and surfaces that are not adequately cooled and need additional cooling. As an operator you have probably learned the spray pattern by experience, you spray the die, and over a period of time and cycles you watch to see how the die surface and casting respond. For example, you would watch for the beginning of soldering, or for cold defects on the casting. In time you develop a pattern that minimizes problems.

The time that it takes to apply the die spray is very important because it directly affects the total cycle time. Cycle time is another of die casting's major process variables. It controls the temperature balance between the die and casting. The relationship between die spray time and cycle time is "direct". This means that as die spray time increases, cycle time increases, and as die spray time decreases, cycle time decreases. The overall objective of cycle time is; to run as short a cycle as possible, keep the die as hot as possible, and use as little die spray as possible. Consistency in spray time will lead to consistency in cycle time because spray time is one of the elements of the cycle that is under your control if the die spray application is manual. The amount of time spent spraying also has a direct relationship to the amount of heat that is removed. The amount of heat removed will double if the time spent spraying doubles, and conversely, the amount of heat removed will be halved if the spray time is cut in half.

The amount of die spray applied is also another important process variable. You should apply the minimum amount. Die spray works best when applied at temperatures of 450-550°F (230-290°C). If you keep the die hot, castings will have a better finish and the die surface will last longer. Die spray should not be running from the face of the die flooding the floor. If a lot of cooling is needed, this should be done with clear water. Excessive flooding with die spray will only wash the die spray off. You must also make sure that the excess die spray is blown out of the die prior to the die closing.

Fixed position sprayers that are mounted to the die or machine platens have seen lots of success in hot chamber die casting. Hot chamber alloys have little or no aluminum in them, reducing the amount of die spray that is necessary. In some cases, the die can be sprayed intermittently, every 3, 4, or 5 cycles. Fixed head sprayers are also limited as to the areas that they can reach. A major advantage of the fixed head sprayer is that it can apply spray quickly. It is always in position to spray when the die is open. If high shot rates are to be achieved (short cycle times), 300-400+ shots per hour, a fixed sprayer is the only alternative, for a maximum of 1-2 seconds spray in an overall cycle of 10 seconds.

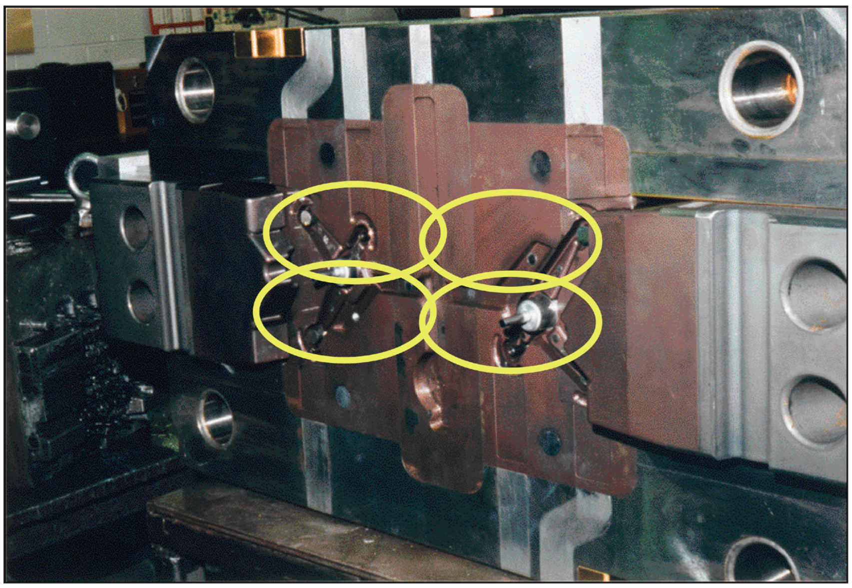


Figure 8-9 - Fixed head spray pattern

A reciprocator has the advantage of multiple nozzles. If a large area has to be sprayed, a reciprocator should be the fastest. It is also the most flexible. A reciprocator can be programmed to position itself at various locations between the die faces, it can spray and blow-off for various time periods, and even multiple liquids can be used, such as die spray and water.

In recent years, robotic spray units have been introduced. These are the most flexible of the machines and can emulate an operator. They are most consistent, but not necessarily the fastest alternative.

Figure 8-10 - A reciprocator at various positions between the die faces

Plunger Lubricator

Lubricant must be applied to the plunger tip when using a cold chamber. There is a host of methods available for applying tip lube from a simple brush and pail to sophisticated methods for applying liquids, beads, and powders.

The objective of the plunger lube is to lubricate the tip without leaving excess in the sleeve that will mix with and contaminate the alloy. This is most easily accomplished with lubricants that are applied behind the tip, with the excess being wiped out of the sleeve on the return stroke.

Some methods of application include mounting a fixed nozzle above the cold chamber pour hole and spraying a water based lube into the cold chamber. An alternative and similar method is to drill the plunger rod with exit holes behind the tip, connect this line to a spray nozzle, and spray lube into the sleeve during the return stroke. Newer methods in various stages of development and practice include dropping small beads of lube into the pour hole and spraying powdered lubricant inside the sleeve. Other common practices include brushing heavy petroleum lubes into grooves in the plunger tip or dripping the lube on the tip every cycle.

Lack of proper plunger tip lube is the most common cause for erratic shot end performance. As the operator, it is your responsibility to confirm that lube is being applied effectively in order to prevent shot end problems. If you are applying the lube manually, you may determine that it is not necessary to apply lube every cycle. This would be consistent with your overall objective of minimizing waste and conserving resources.

Casting Removal

Casting removal can be accomplished manually, with a mechanical aid, or with a mechanized extractor or robot. Manual removal is still most common.

With manual removal, you as the operator are aware of the safety hazards you are exposed to any time you reach into the die area. You can minimize this exposure by using tongs or a gripping tool to reach the casting and take it out of the die. If you must reach between the die faces be aware of the burn hazard presented by the hot die. Also, pins and components projecting beyond the parting line can be puncture and snag hazards. In addition to your safety concerns, the casting must be removed without damage to the casting or damage to the die. Sometimes the castings will stick to the ejector pins, due to flash or shrinkage. It may be necessary to strike the shot to break it free. Care should be taken to apply this force to the biscuit or runner and not to the casting.

If your die casting cell uses an extractor to remove the casting from the die, you must become familiar with all the important variables of the extractor. For example, the extractor has to have enough strength to pick the casting off the ejector pins. It cannot reach in, slap the shot and grab it. You will have to learn the things that control the extractor. On many extractors, the reach (stroke), rotation, pivoting and other motions are controlled and regulated by limit switches, similar to the fast shot and intensifier of the die cast machine. Newer extractors use encoders to determine the position of the boom and various other functions. These are the same types of encoders that are used in shot monitoring equipment.

Again, it is your responsibility to learn about these pieces of equipment, so you can anticipate and prevent breakdowns and problems.

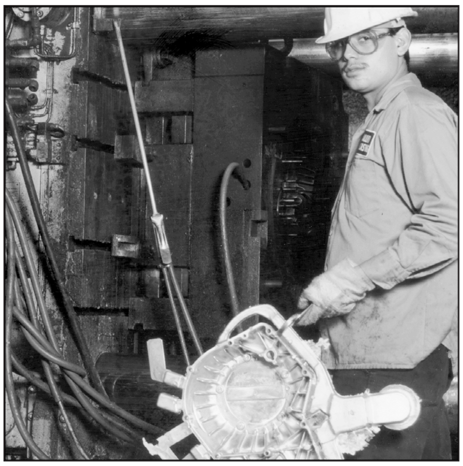


Figure 8-11 - Manual part removal

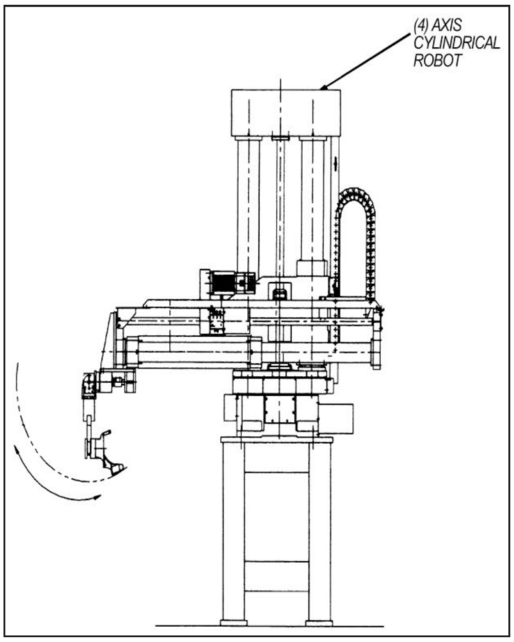


Figure 8-12 - An extractor removing a casting

Quenching

Quenching is the forced cooling of the die casting. Quenching is used to achieve dimensional stability. As the casting cools to room temperature from its ejection temperature it is changing size, getting smaller. If the die cast cell includes trimming and other secondary operations, it is best to do them on castings that are dimensionally stable. If the castings are force cooled to room temperature they will be dimensionally stable. The most common form of quenching is to dip the hot casting into cold water. This has the advantage of working very quickly. There are several disadvantages. After the quench all water must be removed from the casting or it will oxidize and possibly corrode. Inhibitors can be added to the quench water to minimize this problem. A water quench can be very messy; water gets on the floor, gets tracked all over, and becomes a slip-fall hazard. Additionally, spilled water must be cleaned-up and disposed of properly. Lastly, a very rapid quench can cause high levels of internal stress.

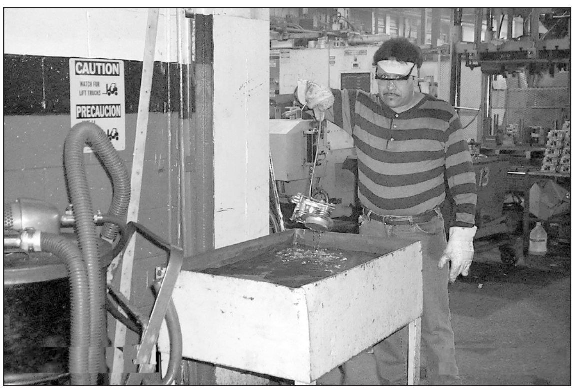


Figure 8-13 - Water quench tank

In recent years, forced air quenching has gained in popularity. Forced air quenching is blowing cool air over the hot castings to cool them. This takes a little longer to cool the casting, but this appears to be offset by the advantages of eliminating the water mess and disposal problems.

Figure 8-14 - Air quench conveyor

Conveyor/Material Handling Equipment

The die casting cell may include conveyors, chutes, and slides for moving the castings to the next operation, or to move scrap back to the remelt furnaces. Or it may have baskets or pallets for stacking castings in batches for subsequent operations. There may be other containers for accumulating scrap. All this equipment, in your cell is your responsibility.

Conveyors that do not work when rollers are broken because of carelessness, or chutes and slides that nothing will slide down because they are full of dirt and grease hinder your ability to work effectively. You must take the initiative to make sure your tools are not abused or destroyed.

Die Heaters

Die heaters are important to the die casting process. Their first function is to preheat the casting die prior to startup. Their second function is to maintain the die temperature during production.

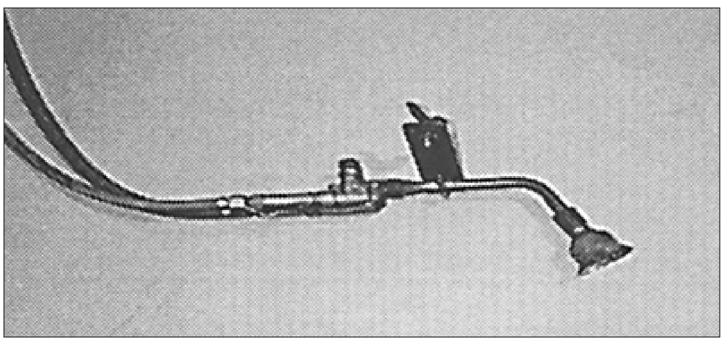


Figure 8-15 - Hand torch

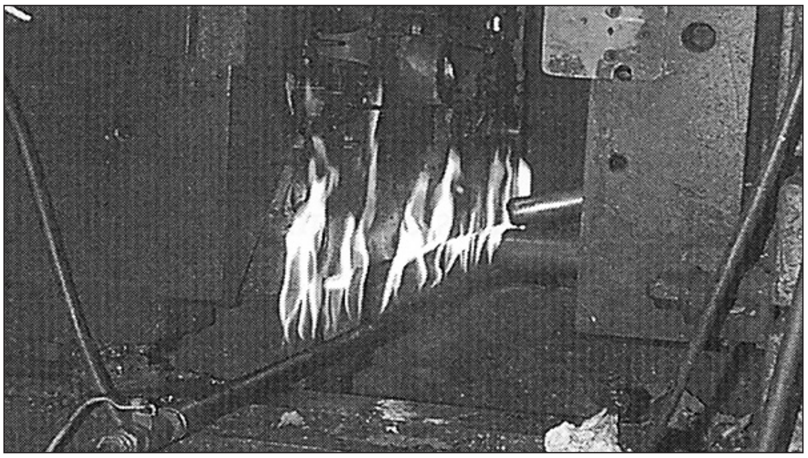


Figure 8-16 - Stick torch

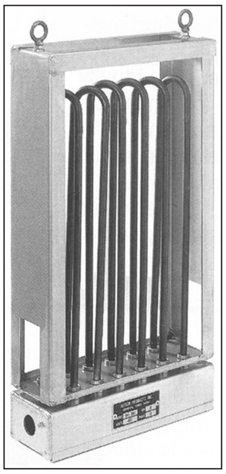


Figure 8-17 - Electric radiant die heater

Some die heaters are used exclusively to preheat the die prior to production. These can be stick torches, hand torches, or electric radiant heaters. The importance of die preheating can not be understated. The objective of preheating the die is to get it to a minimum temperature of 350°F (175°C) before subjecting it to the thermal shock of the first shot. Putting hot metal into a cold die is a considerable shock. A mechanical property of steel known as the impact strength is a measure of the steels ability to withstand a shock. This characteristic, impact strength, varies with temperature. Simply stated, at low temperatures, impact strength is low, and at high temperatures, impact strength is high. This means the die temperature should be high in order to have high impact strength and resist thermal shock.

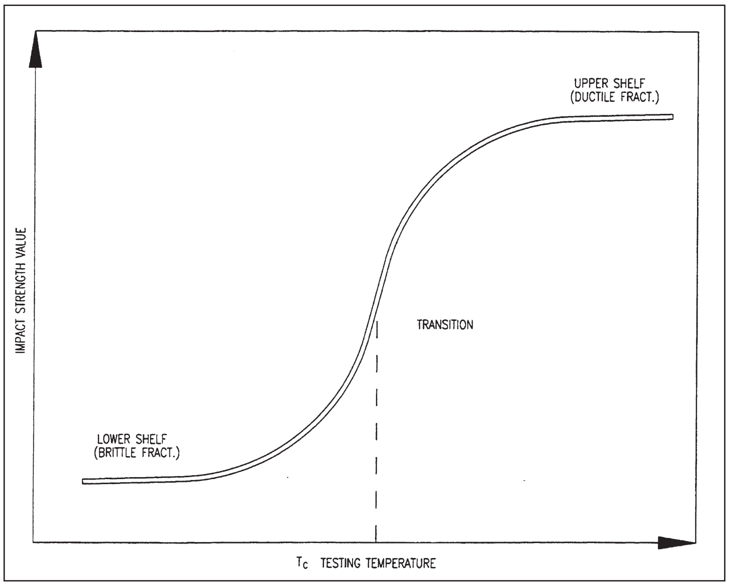


Figure 8-18 - Graphic of brittle to ductile transition curve for H-13 steel

If you preheat the die with gas torches care must be taken to avoid overheating parts of the cavity and not adequately heating other areas of the cavity. For example, if a stick torch is resting on the leader pins in a partially open die, the flame will impinge on projections from the cavities and no heat will reach the recesses. If a projection, such as a core pin were to get so hot that it begins to change color, a deep cherry red, this core has been overheated, and its heat treatment destroyed. Care must be taken with the open flame not to overheat die components. If a hand torch is used, not acetylene, it must be moved continuously to avoid excessive heating.

Electric radiant heaters should heat the cavities more uniformly, from top to bottom, but will have some difficulty in heating deep pockets. If you have an electric heater at your disposal, treat it with respect. Electric heaters operate at voltages 2-4 times greater than household voltages and can be a shock hazard. Always make sure wires are in good condition, not frayed or bare, and that all connectors are secure and all boxes covered. Do not stand on a wet floor when working with electric die heaters.

Probably the best option to achieve die preheating is to use some form of internal heating, either electric cartridge heaters or circulating hot oil. These will heat from the inside to the outside and also have some sort of temperature control associated with them.

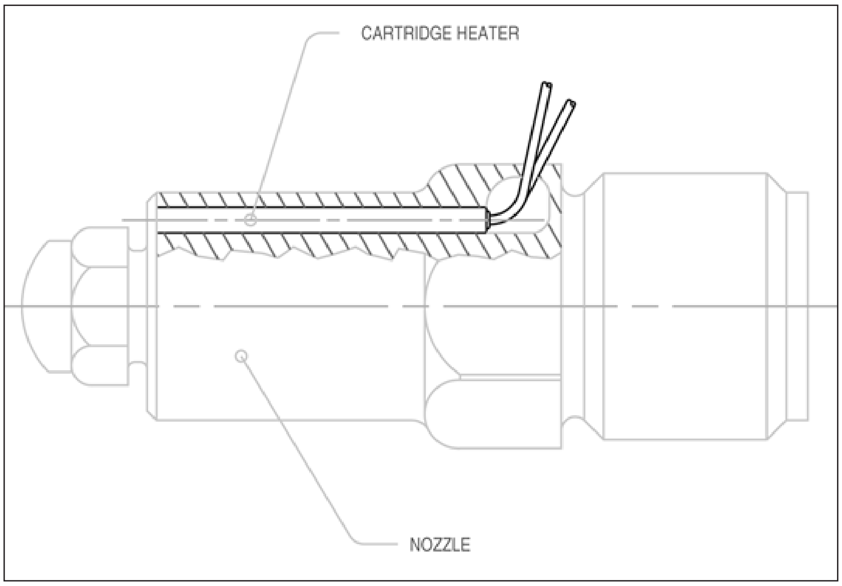


Figure 8-19 - Cartridge heaters in a nozzle

Figure 20 - Hot oil heater

If the die is large it will be difficult to preheat. Several alternatives could be used. The die can be preheated off line and then set hot. This is not any different than pulling a hot die. Also, the machine does not become a big heat sink. Another idea is to cover the die with an insulating blanket. And lastly, make sure that no fan is blowing cold air over the die.

A second job of die heaters is to maintain the die temperature once the die is in production. This is best accomplished with internal cartridge heaters or hot oil circulating in cooling lines. The die casting process is a heat exchange process, heat is put into the metal to melt it in a furnace, the metal is injected into the die, and the metal solidifies, cools and gives up heat to the die. The more uniform this process becomes in term of temperatures and times; the more predictable it will be in terms of dimensions and defects. Uniform cavity temperatures will yield uniform shrinkage and predictable dimensions.

Trim Press/Secondary Machines

It is not uncommon for the die cast work cell to include a trim press or other machinery and equipment. Your job as operator may include running the trim press or additional secondary machining equipment, such as a drill press, tapper, or grinder.

You must be come familiar with this equipment to operate it in a safe and efficient manner.

Cell Environment

In addition to the machinery and equipment in the cell, you need to be concerned with the utilities provided to the cell, housekeeping, and the set-up of the work stations.

Utilities such as high pressure air and electricity are delivered in hoses and wires. You are responsible to make sure that the hoses and wires are not damaged and become a hazard. These utilities are best tied down and secured.

The floor space must be kept free of safety hazards such as wires, hoses, piping, grease and dirt. In general, housekeeping must be maintained. Work platforms must be elevated to the proper height in order to ease the strain on you. The work station should be arranged to minimize the amount of work that must be done. Convenience trays and tables are arranged to simplify and ease the work load. Remember, the definition of work is carrying or moving a mass through a distance.

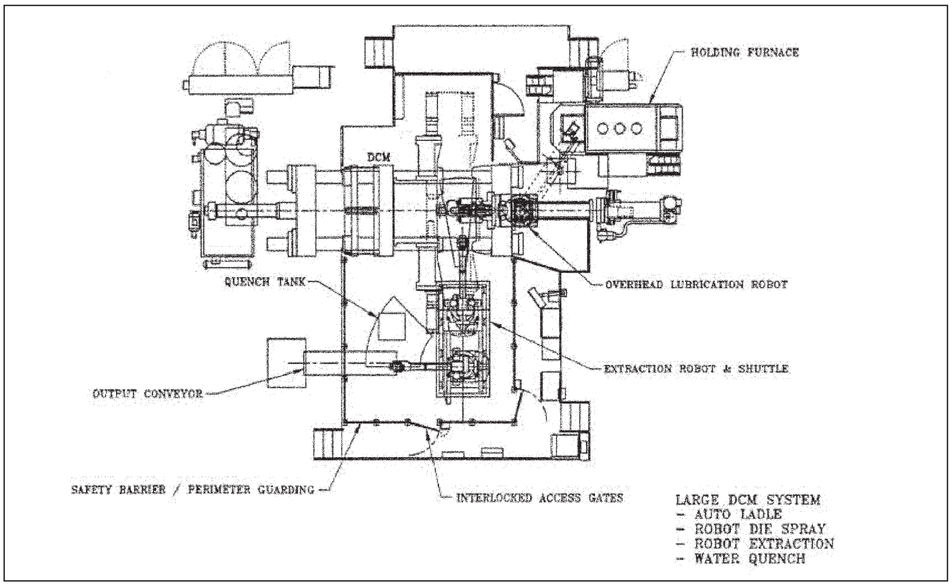


Figure 21 - Complete die casting work cell

SELF TEST 1

True or False

1. The purpose of the holding furnace at the machine is to maintain the metal temperature within a narrow temperature range for casting.

   True False

2. Biscuit thickness is not an important variable with respect to ladling.

   True False

3. Applying as much spray as possible is more effective with respect to cooling than extending the time spent spraying.

   True False

4. Lack of proper plunger lubrication can cause the need for excessive hydraulic pressure during injection.

   True False

Multiple choice:

5. Several of the important process variables with respect to die spray are:

   a. spray concentration
   b. spray duration
   c. spray location
   d. all of the above

6. Improper casting removal from the die will result in:

   a. damage to the die
   b. damage to the casting
   c. injury to the operator
   d. all of the above

7. The purpose of a hot oil die heater is

   a. to preheat the die at start-up
   b. to maintain the die temperature during breaks
   c. to reduce the amount of heat flow out of the die
   d. to heat treat the die cavities

ELEMENTS OF A TYPICAL DIE CASTING CYCLE (COLD CHAMBER)

Having reviewed the machinery in a typical die casting work cell or station, one typical die casting cycle will be run. A typical cycle consists of:

- Machine close
- Making the shot
- Dwell
- Machine opening

Machine/Die close

The machine cycle starts with the die open and the machine at rest. Prior to initiating the cycle start, you must check to make sure several tasks have been completed.

- The die cavity is clean, there are not stuck pieces in the die.
- The die does not have any broken cores, ejector pins or components.
- The vents and die faces are clean.
- Die release has been applied.

Starting the machine cycle may be accomplished in a number of ways, depending on the conventions in your plant. Several accepted methods are listed. Some plants start the machine cycle by having the operator close the safety door. Once the safety door is closed a limit switch is activated, telling the machine that you are ready for the die to close. The machine then checks all its safety limit switches, limit switches that assure all the other parting line doors and covers are in place, and that the barriers in front of the toggle linkage are in place. When the machine proves all the safeties correctly, it closes the machine. The limit switches are safety devices and must not be tied back. If a safety device is broken, it must be repaired before production can proceed.

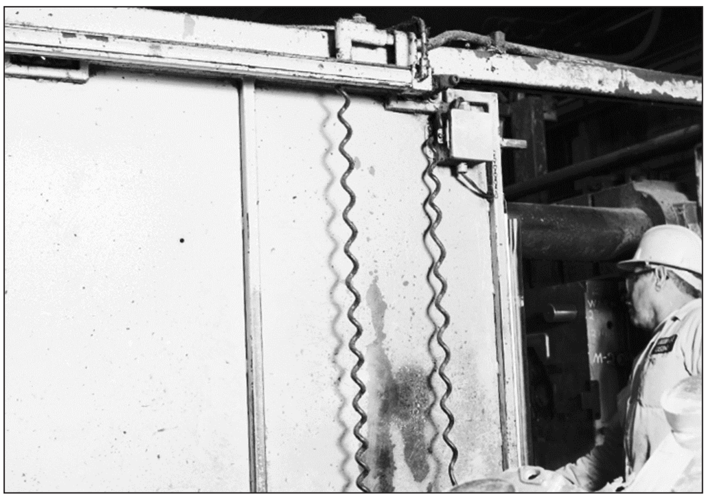


Figure 8-22 - Safety door and limit switches

Another variation for starting the cycle is for you to close the safety door and then press a "cycle start" push button to actuate the machine.

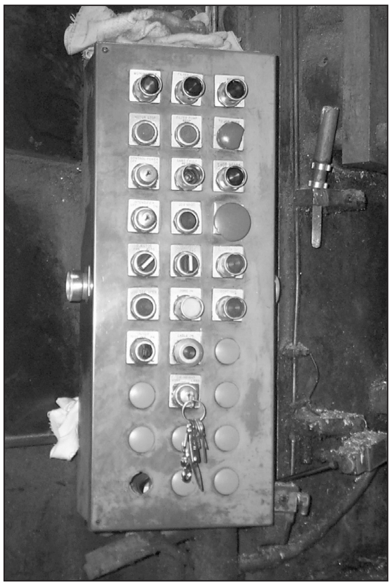


Figure 8-23 - Cycle start push-button

A third variation is for the operator to hold in two cycle start palm buttons while the safety door closes and proves the limit switches. Once the machine acknowledges that all the parting line and toggle guards are closed, the machine will start to close.

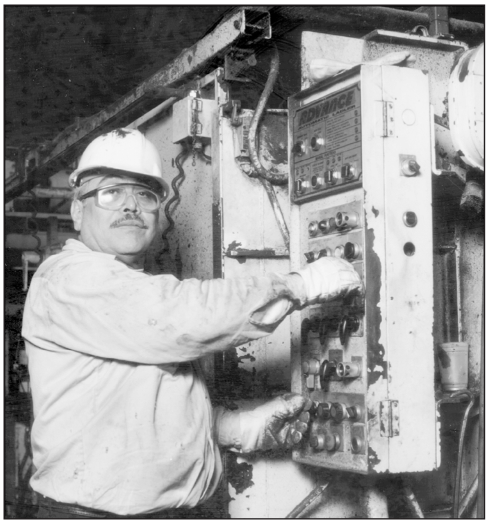


Figure 8-24 - Two palm button start push-buttons

You need to be aware that the closing safety door and closing machine can be pinch hazards. Once the machine has closed and locked, a signal light at the shot end illuminates signaling that the die is locked.

Making the shot

The next step in the machine cycle is injecting the metal or "making the shot". Prior to making the shot, you should inspect the shot end to make sure no hazards exist.

- The die must be locked, note the signal light.
- The plunger must be at "home", completely withdrawn to the end of the cold chamber.
- The pour hole must be clear, free of metal drippings.
- The plunger tip should have been lubed

Once you are satisfied that the machine is ready, a ladle of alloy is drawn according to the practice that was previously discussed to minimize the inclusions. The ladle of alloy is poured into the cold chamber pour hole. The "shot" button is pressed and the plunger starts past the pour hole, into slow shot, then fast shot, and intensification.

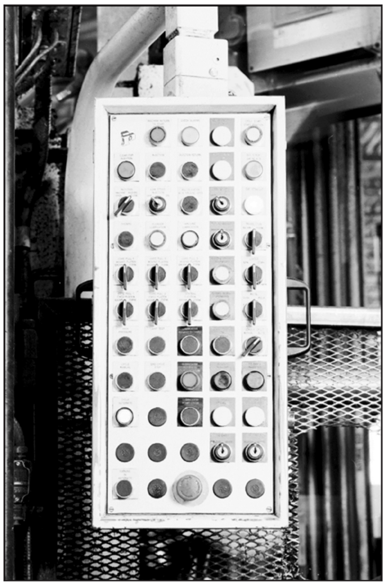


Figure 8-25 - Shot push button

The purpose of the slow shot is to push the air, trapped in the cold chamber, out through the runner system, die cavity and die vents. You will notice, after the alloy has been ladled into the cold chamber, it is only partially filled with alloy. The rest of the space in the cold chamber is filled with air. If this air is mixed with the alloy, it will end up as porosity in the casting. In order to avoid mixing this air with the alloy in the cold chamber, the plunger must travel at a "critical slow shot" speed, to form a wave front that will push the air out in front of the advancing alloy. The critical slow shot speed is dependent on the size (diameter) of the cold chamber and the amount of alloy in the cold chamber (% of fill).

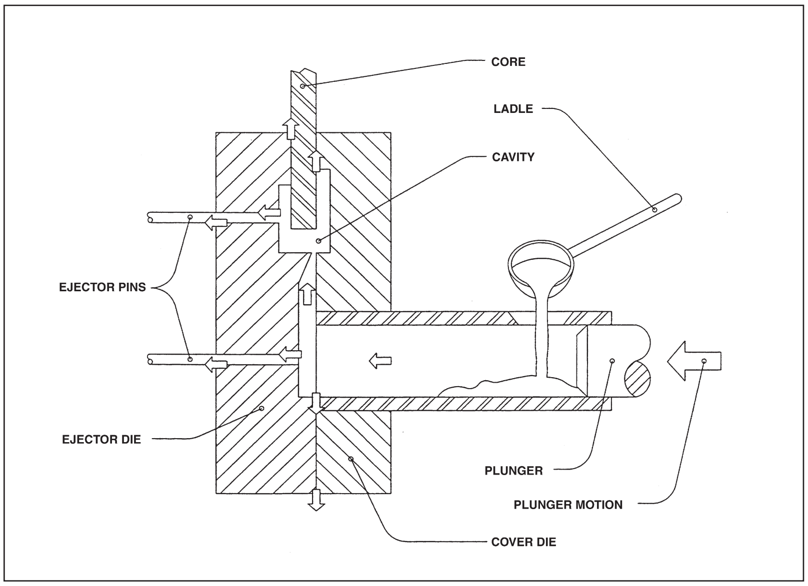


Figure 8-26 - Schematic showing path of air out of cold chamber

At a predetermined point of plunger travel, the machine shifts to fast shot. The fast shot is used to fill the cavity with alloy and get this done in the minimum fill time required by the casting geometry. In addition to filling the cavity within the fill time requirement, the velocity of alloy traveling through the gate has to be fast enough to achieve atomization. Atomization means the alloy has been broken up into a fine particle spray with lots of energy to flow throughout the cavity and fill the far corners and thin walls.

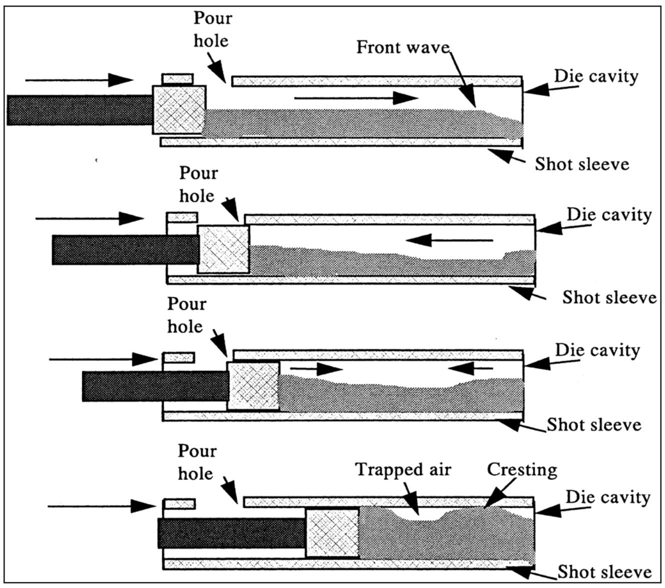


Figure 8-27 - Various wave forms in the cold chamber

Once the cavity is filled the plunger comes to an abrupt stop. The alloy begins to freeze and shrink. When most liquid metals freeze, become a solid, they shrink and occupy less space. When 100 cubic inches (100cm3) of aluminum freezes, it occupies 94 cubic inches (94 cm3), 6% of the volume is lost. An example of this is the ingots of alloy that are charged into the remelt furnace. If you turn an ingot over, with the wide end up, you will see cracks and voids that run the length of the ingot. These are shrinkage voids that formed when the ingot solidified. These shrinkage voids will form in the last areas of the casting to freeze. Once the cavity is full of alloy, the plunger stops, then the intensifier is turned on to generate a high metal pressure. The objective of this high metal pressure is to squeeze more metal through the gate and push it into the cavity to make up for the shrinkage taking place.

Figure 8-28 - Photo of the top of an ingot showing shrinkage

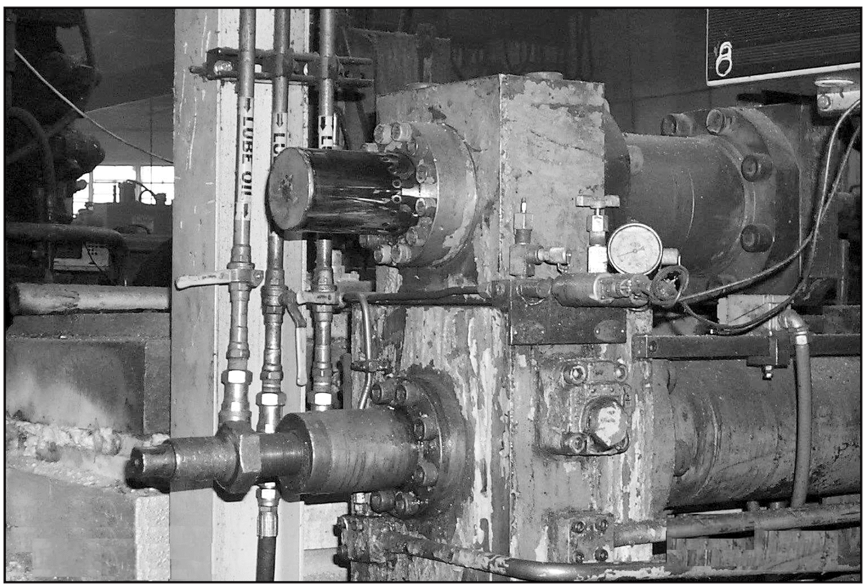


Figure 8-29 - Intensifier

Machine Dwell/Hold

After intensification the machine remains closed for a predetermined amount of time while the casting cools and gains strength in the die. You would like the dwell time to be as short as possible in order to reduce cycle time and increase production. The dwell time is determined by several factors. The casting must have enough “hot strength” to be able to withstand the forces of the die opening. You do not want the casting tearing apart leaving pieces stuck in the stationary die half. The casting must have enough hot strength to withstand the force of ejection. You do not want the casting to stick in the ejector half with the ejector pins poking through. Lastly, you do not want the machine to open and have the biscuit blowing up and spraying metal all over as soon it is free of the cold chamber.

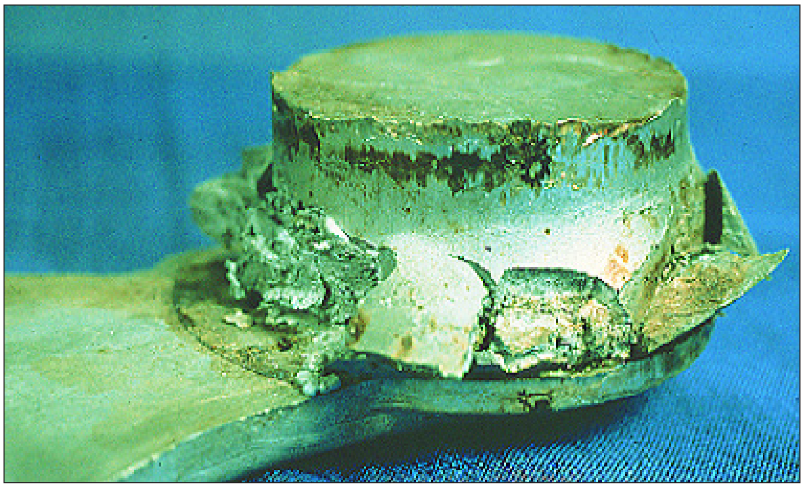


Figure 8-30 - Blown up biscuit

Machine Opens

As the machine opens, the plunger follows through to the end of its stroke and pushes the biscuit out of the cold chamber. The initial die opening should be slow enough to allow the plunger to keep pressure on the biscuit until it is free of the cold chamber. If the biscuit sticks in the cold chamber, this can cause problems in twisting and bending the runner and casting resulting in dimensional problems.

At die opening, the casting is expected to stay in the ejector half. When the machine is fully open the casting is ejected from the cavity. At this time the machine cycle is complete with respect to making the casting. In the background, the machine will now get ready for the next cycle. Oil will be pumped back into the accumulator and it will be recharged. You now remove the casting from the die. You must be aware the casting is hot, and will have flash and sharp edges that can be hazardous. The casting is set aside for further inspection.

At this time you inspect the die and apply die spray. Watch the spray turn to steam and after cooling is complete, watch the liquid wet and coat the die cavity. Also making sure that the excess spray is blown out of the cavity and that flash is blown from the die parting line and vents.

There may be some additional tasks or elements of the machine cycle that take place during die opening.

Special Considerations

Stationary core slides

If the die has slides that are mounted on the stationary die half, these slides must be extracted before the machine opens. They are usually hydraulically operated and controlled with limit switches.

Mid-die Stop

Some machines incorporate a feature known as mid-die stop. This would be better described as mid-open stop. The machines stop when it is half open to hydraulically pull ejector half slides or shear a biscuit on a three plate die. After the function is complete, the machine opens fully.

Cast in inserts

Some castings require the metal to be cast around special inserts. These inserts must be loaded every cycle. As the operator you are required to load the insert before the start of the next machine cycle.

ELEMENTS OF A TYPICAL DIE CASTING CYCLE (HOT CHAMBER)

Having reviewed a typical cold chamber die casting cycle, a typical hot chamber cycle will be run.

- Machine close
- Making the shot
- Dwell
- Machine opening

Machine/Die close (same as cold chamber)

The machine cycle starts with the die open and the machine at rest. Prior to initiating the cycle start, you must check to make sure several tasks have been completed.

- The die cavity is clean, there are not stuck pieces in the die.
- The die does not have any broken cores, ejector pins or components.
- The vents and die faces are clean.
- Die release has been applied.

Starting the machine cycle may be accomplished in a number of ways, depending on the conventions in your plant. Below are several accepted methods.

Some plants start the machine cycle by having the operator close the safety door. Once the safety door is closed a limit switch is activated, telling the machine that you are ready for the die to close. The machine then checks all its safety limit switches, limit switches that assure all the other parting line doors and covers are in place and that the barriers in front of the toggle linkage are in place. When the machine proves all the safeties correctly, it closes the machine. The limit switches are safety devices and must not be tied back. If a safety device is broken, it must be repaired before production can proceed.

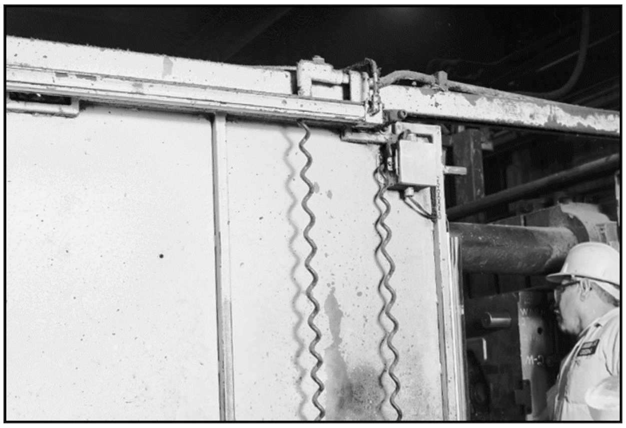


Figure 8-31 - Safety door and limit switches

Another variation for starting the cycle is for you to close the safety door and then press a "cycle start" push button to actuate the machine.

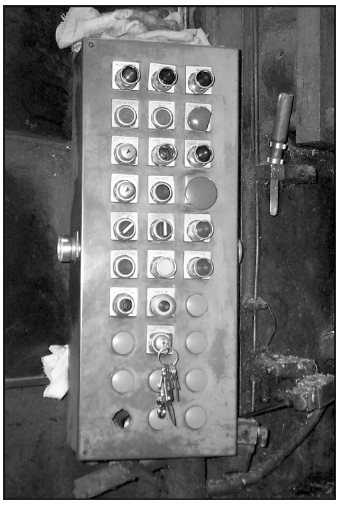


Figure 8-32 - Cycle start push-button

A third variation is for the operator to hold in two cycle start palm buttons while the safety door closes and proves the limit switches. Once the machine acknowledges that all the parting line and toggle guards are closed, the machine will start to close.

Figure 8-33 - Two palm button start push-buttons

You need to be aware that the closing safety door and closing machine can be pinch hazards. Once the machine has closed and locked, a signal light at the shot end illuminates signaling that the die is locked.

Making the shot

The next step in the machine cycle is injecting the metal or "making the shot". The hot chamber machine will make the shot as soon as it has detected that the machine has locked. A manually operated shot function is available, but rarely used.

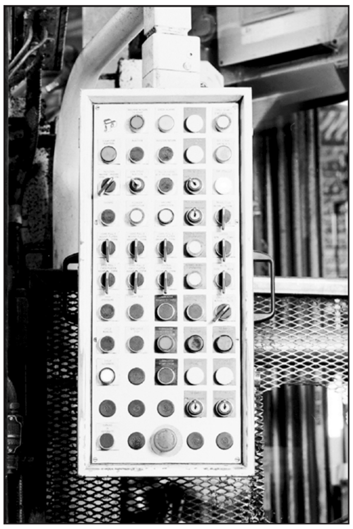


Figure 8-34 - Shot push button

Some, but not all, hot chamber machines have a slow shot function. The purpose of the slow shot is to push the air, trapped in the gooseneck above the metal level in the furnace, out through the runner system, die cavity and die vents.

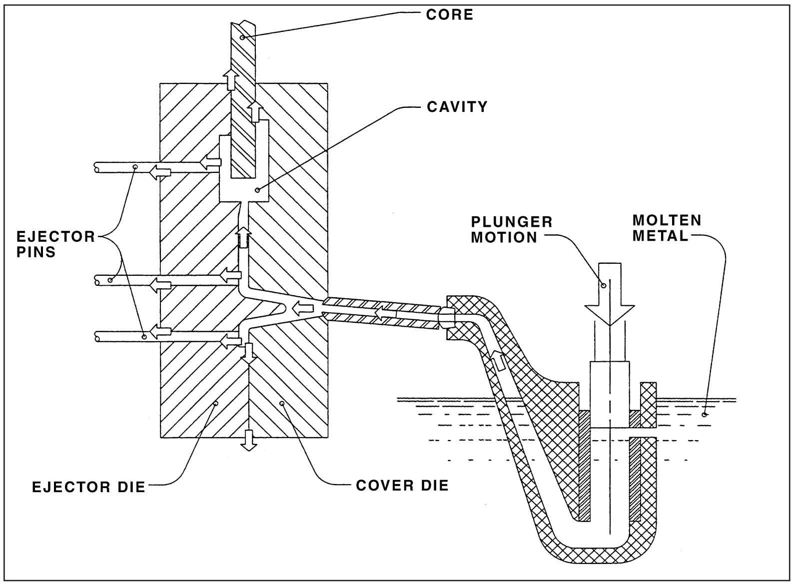


Figure 8-35 - Schematic showing path of air out of hot chamber

At a predetermined point of plunger travel, the machine shifts to fast shot. The fast shot is used to fill the cavity with metal and get this done in the minimum allowable fill time required by the casting geometry. In addition to filling the cavity within the fill time requirement, the velocity of metal traveling through the gate has to be fast enough to achieve atomization.

Once the cavity is filled the plunger comes to an abrupt stop and holds pressure on the metal for a specified time, usually several seconds. When the shot timer times out, the plunger returns to the "home " position. Immediately the metal begins to freeze and shrink. Hot chamber alloys exhibit less shrinkage than aluminum. Zamak #3, the most common zinc alloy shrinks 2.98%. This is about half that of the common aluminum alloys. Additionally, the freezing range of Zamak #3 is so small that intensification is not practical.

Machine Dwell/Hold

After the plunger returns, the machine remains closed for a predetermined amount of time while the casting cools and gains strength in the die. You would like the dwell time to be as short as possible in order to reduce cycle time and increase production. The dwell time is determined by several factors. The casting must have enough "hot" strength to be able to withstand the forces of the die opening. You do not want the casting tearing apart leaving pieces stuck in the stationary die half. The casting must have enough hot strength to withstand the force of ejection. You do not want the casting to stick in the ejector half with the ejector pins poking through. Lastly, you do not want the machine to open and have the sprue be partially solidified and run out onto the stationary die face and floor.

Machine Opens

At die opening, the casting is expected to stay in the ejector half. When the machine is fully open the casting is ejected from the cavity. At this time the machine cycle is complete with respect to making the casting. In the background, the machine will now get ready for the next cycle. Oil will be pumped back into the accumulator and it will be recharged. You now remove the casting from the die. You must be aware the casting is hot, and will have flash and sharp edges that can be hazardous. The casting is set aside for further inspection.

At this time you inspect the die and apply die spray. Make sure that the excess spray is blown out of the cavity and that flash is blown from the die parting line and vents.

There may be some additional tasks or elements of the machine cycle that take place during die opening. Refer to the cold chamber cycle for details of the following elements:

- Stationary core slides
- Mid-die Stop
- Cast-in Inserts

SELF TEST 2

True or False

1. You must know what happens when you hit the emergency stop button.

   True False

2. The purpose of the critical slow shot is to slowly mix air with the metal to cushion the impact.

   True False

3. Hold or dwell is required to remove heat from the casting.

   True False

4. If the die opens prematurely, the casting may tear apart.

   True False

Multiple choice - Identify all correct answers:

5. Before the die closes, you must check to make sure:

   a. that there are no stuck pieces left in the die
   b. that the parting line is clean and vents are open
   c. that the excess die spray has been blown off the die
   d. that the accumulator has been recharged

6. In order to successfully make a shot, the following conditions must be satisfied :

   a. the die must be locked
   b. the plunger must be returned
   c. the cold chamber must be charged
   d. the accumulator must be charged

9 RECOGNIZING AND CONTROLLING FLOW DEFECTS

OBJECTIVES

- To learn the causes for surface defects.
- To learn what the operator can do to control surface defects.

PERSPECTIVE

You can consider the die casting process in control when you are producing acceptable castings (castings without rejectable defects) at the proper rate of production. An acceptable casting is a casting that your customer will buy without a complaint or rejection. This does not imply that the casting is perfect. In many cases a casting may have what may be considered to be a defect in one application and not a defect in another application. For example, a handle casting for cabinet hardware may be finished as a chrome plated handle and in another application may be powder painted. Surface defects such as cold flow will show through the chrome plating. These same defects would not be considered rejectable for a painted casting where the paint covers the cold flow. Another example of an acceptable defect could be heat checking. Heat checking is the deterioration of the die surface due to fatigue; the surface is wearing out. In many cases heat checking is acceptable. Although the casting surface is no longer smooth, the minor surface roughness may not impair the castings' fitness for use. In other cases, if a specific maximum surface roughness is specified and the heat checking exceeded the roughness specification, the casting would be rejectable.

DEFECTS

A major problem we have as die casters is that we have a limited number of defects, but the defects can have a number of root causes. For example, we cannot say that all cracks are due to uneven ejection. Cracks could be due to shrinkage, or a cold die, or some other cause. In the next portion of this lesson, you will look at a number of common defects in die casting and discuss their probable root causes. First we will look at surface defects.

Surface Defects

Common names for defects that appear on the surface of a die casting are:

1 Cold flow

2 Cold shut

3 Flow marks

4 Cold

5 Chill

6 Severe chill

7 Non-fill

8 Poor-fill

9 Laps

10 Flow lines

11 Swirls

12 Knit lines

13 Mis-run

14 Blisters

15 Cracks

16 Solder

This is by no means a complete list. The list may vary by shift, by plant, by state or by country. Within a given plant, the list should be simplified, with everyone understanding a particular defect.

Metal Flow Defects

Many of these surface defects are a result of how metal flows to and within the die. Many times these defects can be influenced by adjusting process variables. Other times you may not have any control over the causes for flow defects.

Flow defects that can be influenced by adjusting process variables occur when the alloy begins to freeze before the casting is completely filled out, or when several alloy flows converge but do not weld completely together. In both of these cases the alloy does not have enough heat energy to remain completely liquid during the fill time. These defects are usually surface blemishes that range widely in severity, from a deep crease to a barely discernible line. Or they may be as severe as a hole in a thin wall or a completely missing feature.

The list following is a number of factors that affect flow defects. Following the list is an explanation of each of the factors and then a discussion of who is responsible for this factor and how it may be controlled.

Factors affecting flow defects:

1 Fill time

2 Wall thickness

3 Die temperature

4 Alloy temperature

5 Flow distance

6 Gate velocity

7 Alloy type

8 Venting

Fill time

Fill time is the maximum allowable time to fill the die cavity resulting in an acceptable casting. It is assumed that if the fill time is exceeded, the casting will have some unacceptable defect. Fill time is a factor that engineers will calculate when establishing the die casting process specification. Once a fill time is established, the engineers can calculate the various combinations of plunger sizes and plunger velocities that will satisfy the fill time requirement. The fill time calculation is based on the alloy being cast, the alloy temperature, the die temperature, and the casting geometry. If any of these changes, the fill time also changes.

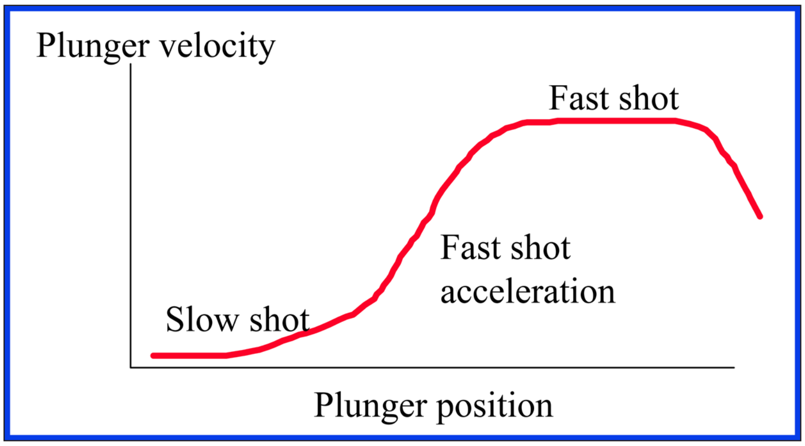


Figure 9-1 - Graphic of shot trace showing fill time

When the fill time is calculated the first time, estimates or assumptions of die and alloy temperature must be made. These are based on experience with your operation. The estimate of die temperature may be made based on a history of measurements of similar castings in your plant. The alloy temperature is approached the same way. If you run different alloys in your plant, chances are that each alloy has a preferred holding temperature. For example, you may hold 380 alloy at 1195˚F (646˚C) and 413 alloy at 1235˚F (668˚C). This would be based on experience with your plant.

Figure 9-2 - Photo of furnace pyrometer showing metal temperature

Casting geometry is a very important factor when determining fill time. Some castings are chunky, while others may be skinny. The engineer has to look at the casting geometry and make an estimate of how well the casting will give up heat to the die, or how well the casting will retain heat. If a casting has lots of volume and little surface area, similar to a casting with thick walls, this would be interpreted as a casting with a lot of heat (volume) and little ability to give up the heat (low surface area). If a casting has little volume and lots of surface area, this is interpreted as a casting with little heat (volume) and lots of ability to give up this heat (large surface area).

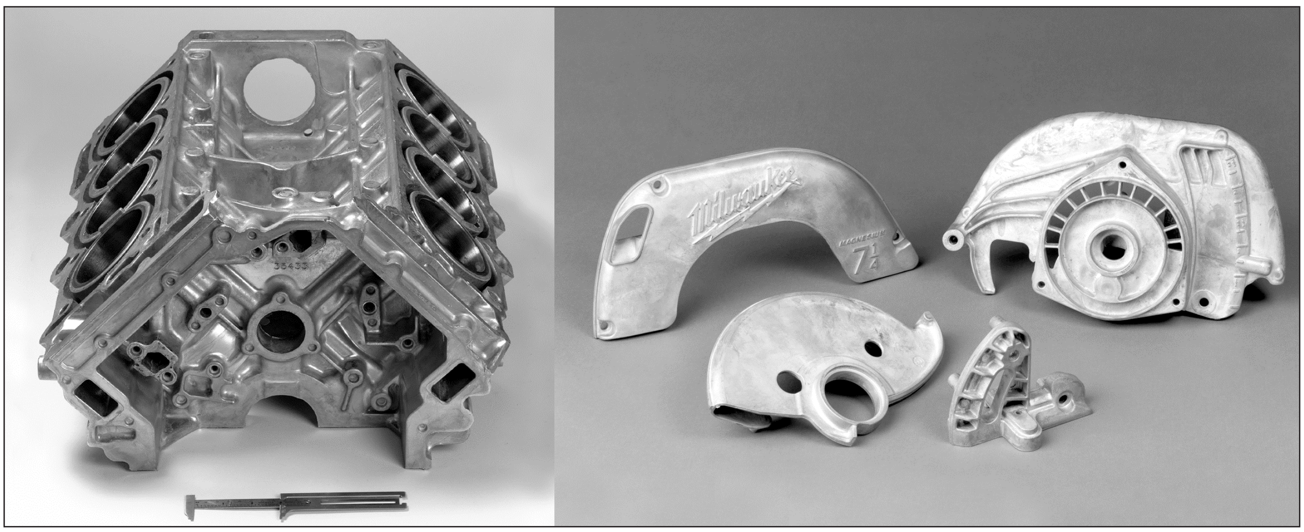


Figure 9-3 - Sample of chunky casting verses skinny casting

For purposes of calculating fill times, the engineer must come up with a numerical value for the casting geometry. Some methods for determining this numerical value are to calculate an average wall thickness, determine the thinnest wall thickness or to use a nominal wall thickness. Whatever system is used, it should be used consistently, and then modified based on experience.

A final factor to consider when calculating fill time is the alloy. Alloys behave differently when being cast. Some alloys are fluid and flow readily. Others lack fluidity and must be cast at higher temperatures. Some alloys tend to solder more readily than others. Some alloys freeze quicker than others. The alloy factor is also accounted for when calculating the fill time. As an operator, you have control of most of the factors that determine the fill time. (For the NADCA Fill Time Formula, see Appendix A.)

Alloy temperature you can observe by the furnace temperature. You know when it goes up and down, and you know what causes it to go up and down. As for die temperature, you know that die temperature is a result of how you run or manage the casting cycle. Actual fill time is a result of the combination of plunger speed and plunger size when the alloy is filling the cavity. As for the casting geometry, you cannot change the part, but you may have the opportunity to advice on factors that may make the part easier to manufacture.

Wall thickness

As an operator, you cannot designate the wall thickness of the casting. For the most part wall thickness is part of the geometry of the casting that you can not control. However, you can observe and note the varying wall thicknesses in the casting. As such, you can figure out what the different heating and cooling requirements in the die are. Heavy wall sections equate to a lot of heat and high cooling requirements. Thin walls equate to very little heat and minimal cooling requirements. This knowledge will help you to determine where and how long to spray. It will also help you determine which waterlines need to be turned on with full flow, reduced flow or no flow.

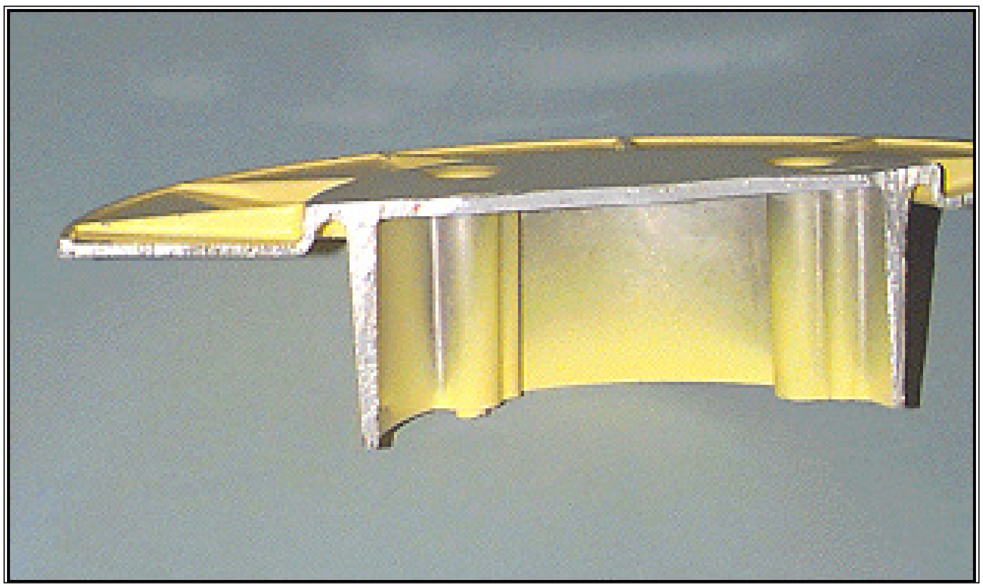


Figure 9-4 - Cut section of casting showing varying wall thickness

The die temperature

Die temperature, in the most inclusive sense, is the time averaged temperature of the die during sustained production. For aluminum dies, we would say we want a die temperature of 500˚F (260˚C). We know that the cavity surface temperature is changing all the time. We know that the temperature in the die cavities is not constant, but varies depending on the proximity to the cavity surface and cooling lines. So the concept of die temperature is somewhat nebulous. It is not something you can measure any time at any place in the die. If you are trying to solve a problem, you may try to determine a die temperature at a particular location in the die at a particular point in the casting cycle. Ideally, die temperature will be as high as possible, and still permit making the casting, and vary as little as possible over the entire cycle. It is not unusual to see time averaged temperature variation of over 100˚F (55˚C) in a die cavity.

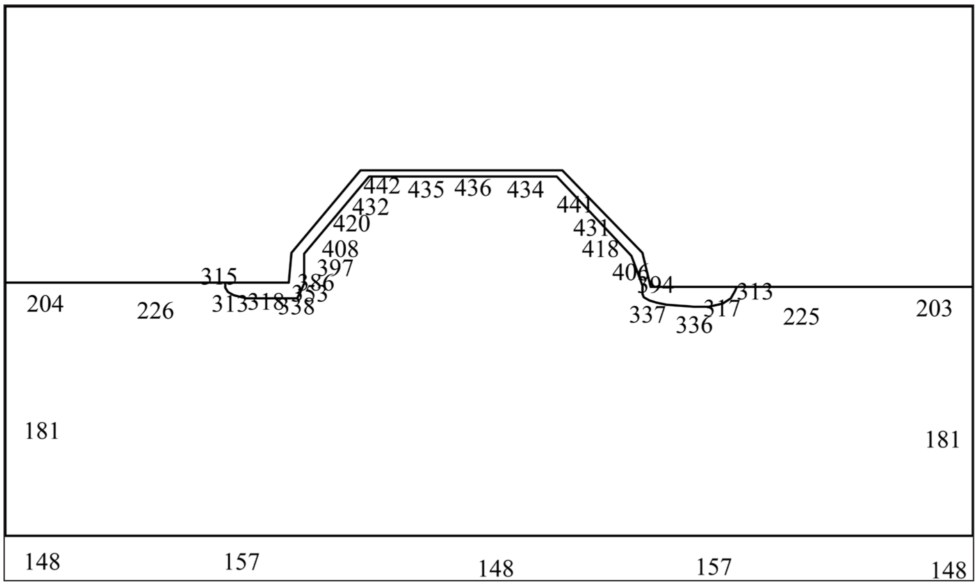


Figure 9-5 - Illustration of die temperatures

The alloy temperature

The alloy temperature is the temperature of the alloy as it begins to fill the die cavity, as the alloy passes through the gate. This has proven very hard to measure in real time as the casting is being made. Most people make an estimate of this temperature for the purpose of fill time calculations. Reasonable estimates are that the alloy looses 50-90˚F (28-50˚C) as it is transferred from the holding furnace to the cold chamber and injected. These temperature losses can be minimized by avoiding any delays in the alloy transfer. If the alloy is ladled automatically, there should not be any delays in the ladle cycle. The ladle should not have to wait for the machine to complete any functions.

Flow distance

Flow distance is an important variable. This is the distance that the metal must flow once it passes through the gate. It is important because you want the alloy to flow to its terminal location without freezing. If the flow distance is too long and if the alloy speed is too slow, it will be difficult for the metal to fill the cavity without beginning to freeze. As the alloy begins to freeze it is much more difficult to get it to flow.

The gate velocity

The gate velocity is the speed that the alloy travels as it passes through the gate. This is a critical variable for several reasons. First, if this velocity is not controlled it can be detrimental to the tooling causing washout and erosion. If the gate velocity is too low the alloy may not atomize and not have enough energy to reach the ends of the casting or to properly weld together.

Now that the definitions of the various factors affecting flow defects have been discussed, who has responsibility for maintaining them in control?

Let's start with alloy temperature and alloy type and follow the process for a cycle. As an operator, you should keep track of alloy temperature. Your process specifications will call for the alloy to be within a temperature range that results in the best quality and productivity. This temperature may range 20-50°F (10-25°C). If the temperature is excessive, has a lot of superheat, it flows readily and may have a tendency to spit. Additionally, the alloy will have too much heat and could extend the cycle time because it will require additional time to remove this heat. If the temperature is too low, too little superheat, the alloy may be partially solidified before it is cast, causing flow difficulties.

How and when does the alloy temperature get out of control? The holding furnace must be charged frequently enough to avoid upsetting the temperature balance in the furnace. Most holding furnaces are sized to maintain the alloy temperature, not melt it. If the furnace is allowed to run down to far, the next charge of alloy will increase the holding furnace temperature above the upper limit for temperature. Metal distributed from the breakdown furnace is usually 50-100°F (25-50°C) hotter than the holding furnace temperature.

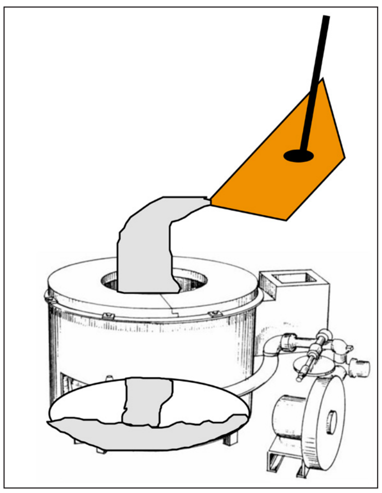


Figure 9-6 - Holding furnace run too low and large charge needed to replenish it

Another problem that may occur is the inability of the holding furnace and remelt furnace to keep up with production. When this occurs it is not uncommon to cold charge or add some ingots to the holding furnace. Again, this furnace does not have the capacity to melt and superheat the alloy. This will dramatically drop the furnace temperature and may prevent casting because the metal will not flow.

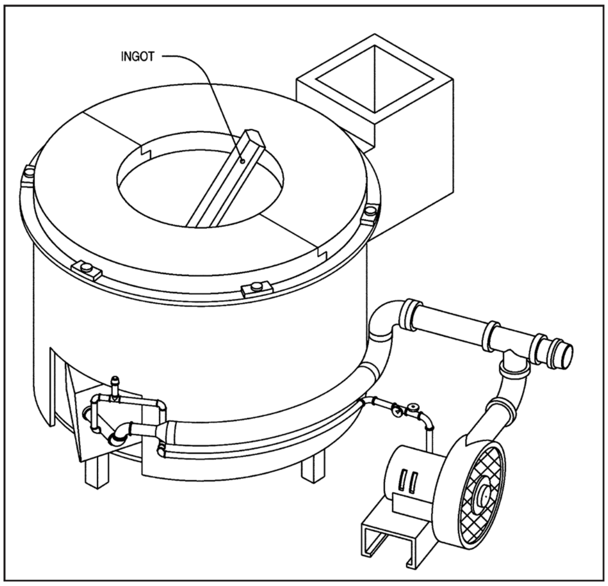


Figure 9-7 - Illustration with ingot stuck in the charge well of the holding furnace

If the alloy level in the holding furnace gets too low, air could pass under the arch at the dip well or under the door blade at the charge well. If this happens the alloy in the main bath will oxidize and you will have a whole series of problems related to casting alloy that is full of oxides and difficult to make flow. Additionally, getting large amounts of air into the bath area will also cause excessive cleaning problems.

The alloy type that is being cast also has an effect on flow. Your customer specifies the alloy type, based on the casting application. As the operator, you are responsible for the condition of the alloy. Both the chemistry of the alloy and its cleanliness will affect flow. If the alloy is maintained in a good condition it should cast without difficulty. Various chemical constituents in the alloy will affect the castability of the alloy. For example, aluminum alloys with increased amounts of silicon tend to flow better. Aluminum alloy with high amounts of iron (still within specification) are more sluggish. The most important thing you can do as an operator is to maintain the alloy as clean as possible. All the alloys, when in contact with air will oxidize. This oxidized material is no good and must be kept out of the casting. If you are manually ladling the alloy, the proper procedure is to use the ladle to push back the oxide layer and dip clean metal. When the oxide layer in the dip well gets too thick it must be removed. Auto-ladles automatically push the oxide out of the way when dipping. If the layer is too deep it must be removed from the autoladle dip well also. Always cover the furnace well when not in use to prevent oxidation and energy loss.

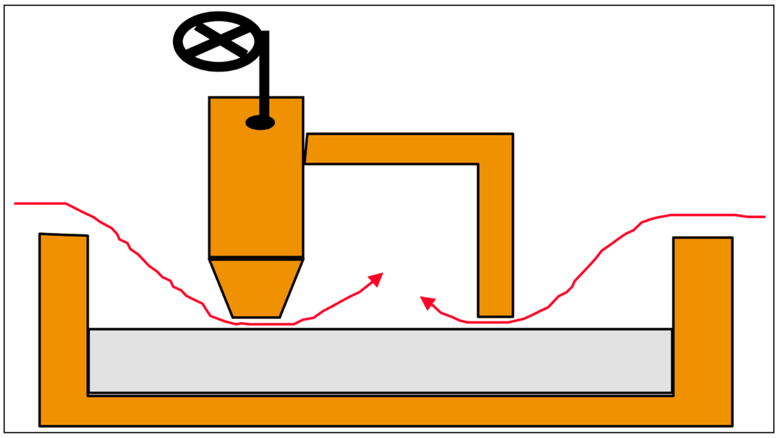


Figure 9-8 - Illustration showing air getting under the door blade or arches

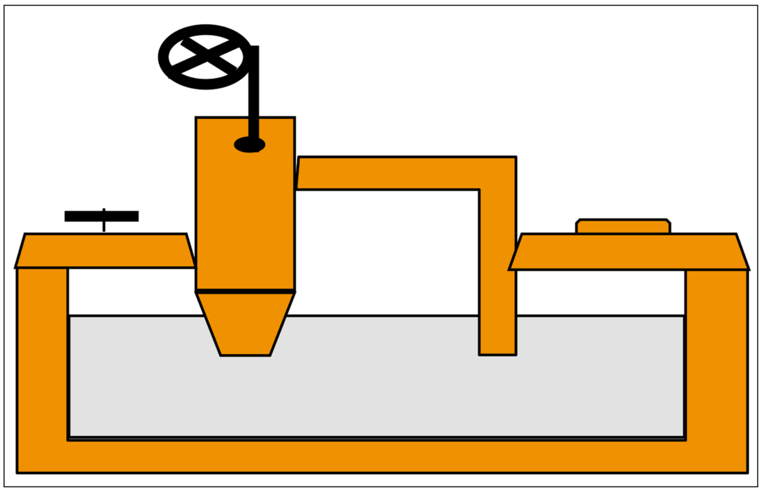


Figure 9-9 - Illustration showing furnace wells covered

The wall thickness specification, like casting geometry, is beyond the control of the operator. This is something that the customer's engineers specify to satisfy the needs of their product. If your company has a proactive die casting sales function, your die casting engineers may be able to work with your customer in order to help design the casting for manufacturability. This means striving for uniform walls and minimizing excessively thick or thin wall sections. There are some instances in which the operator has control over wall thickness.

Here are several examples:

Walls that are formed across the parting line will become thicker if the die is allowed to blow, or if flash is left on the parting line.

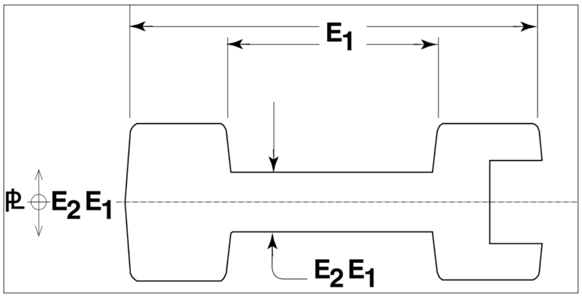


Figure 9-10 - Sketch of parting line wall section

Walls formed by slides will become thicker as the slide is allowed to back out.

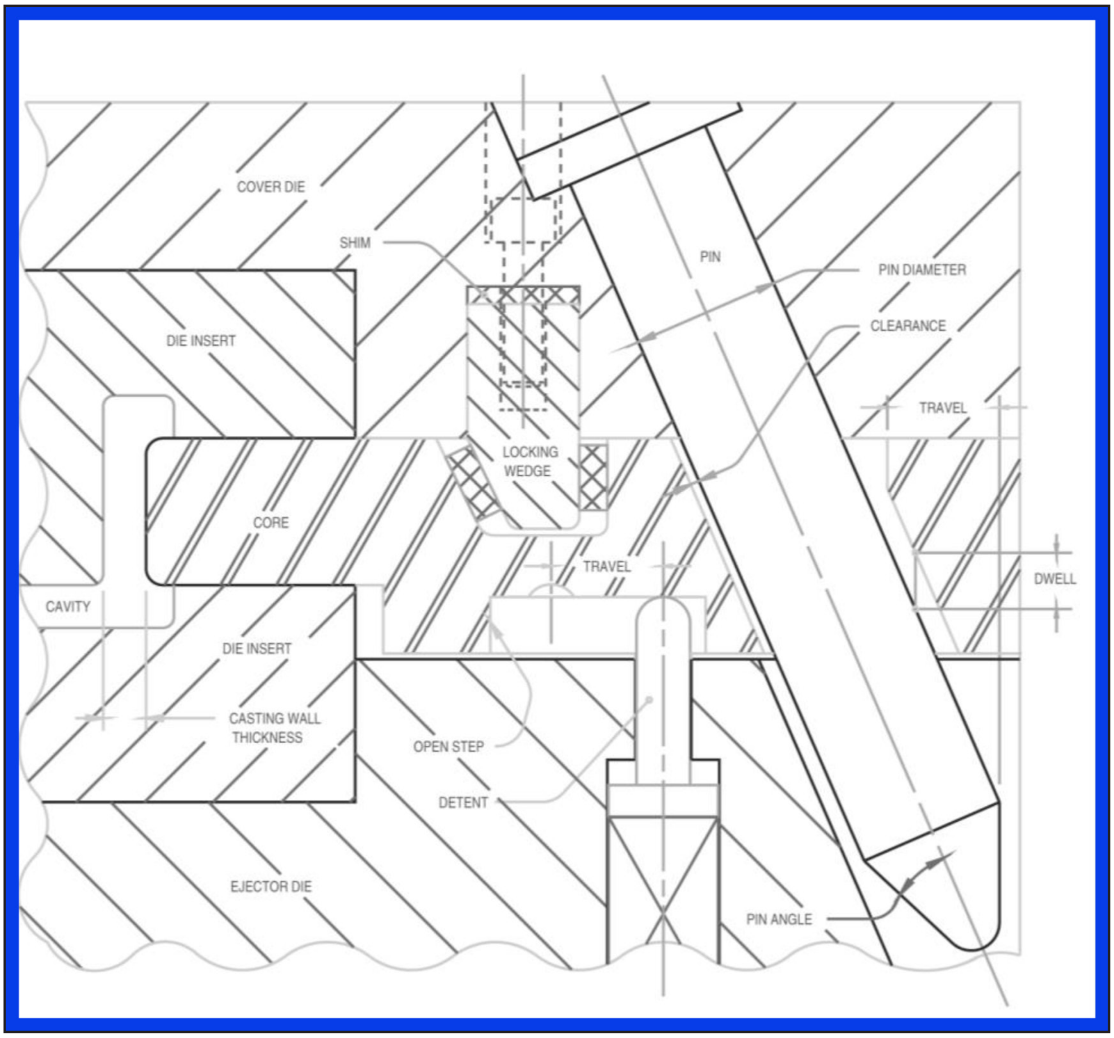


Figure 9-11 - Sketch of slide wall section

Misalignment or die shift between the stationary and moving die halves can cause walls to thicken or thin out dramatically.

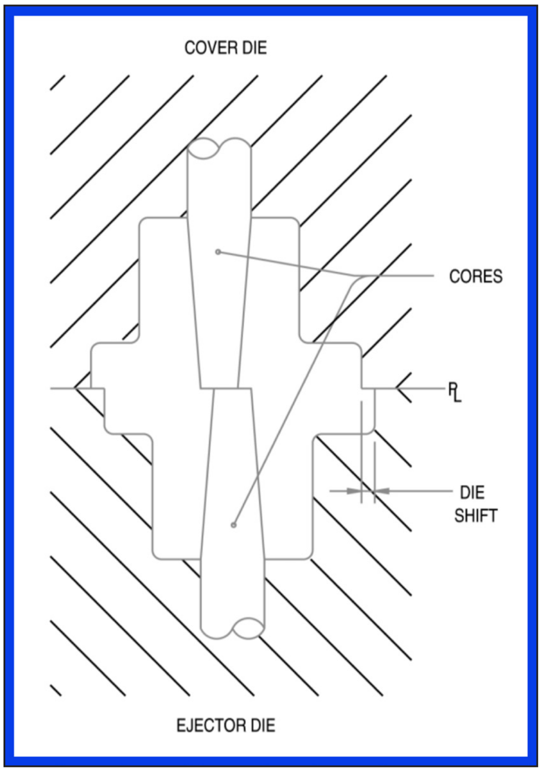


Figure 9-12 - Sketch of wall sections due to die misalignment

As the operator you must be aware of these causes and prevent them.

You, the operator, have direct control of die temperature. Die temperature is a direct result of cycle time and cooling, heat in verses heat out. You control the heat going into the die by the temperature of the alloy being cast, the volume of alloy that you ladle each shot and volume of alloy that you put through the die every hour. You control the heat going out of the die by adjusting the cooling lines, both flow rate and coolant temperature, by spraying die release on the die cavity, both duration of spray and volume of spray, and finally, by adjusting the machine dwell or hold time to control the casting ejection temperature.

Flow distance will be a function of the mold design, runner and gating layout. Once these have been established in the casting die they are difficult to change. Defects related to the flow distance will be difficult to overcome, and will probably not respond to the normal range of process changes. The best result with defects related to this cause will be with the machine at maximum performance, and maximum gate velocities. The corrective action may require reworking the entire filling plan for the casting.

You, the operator, also control fill time and gate velocity. These are a result of the plunger speed, and plunger size, together with the gate size. Long fill time is one of the primary causes of surface defects. After the die casting engineer has calculated a maximum fill time for a particular casting, he has to identify a machine that will be able to pump the alloy fast enough to meet the fill time requirement. This means, he has to find a machine that is capable of pumping a particular volume of alloy in a specific amount of time.

For example, if you have a 10 pound (4.54kg) 380 aluminum casting and a fill time of 0.060 seconds, what is the minimum pumping capability required of the machine?

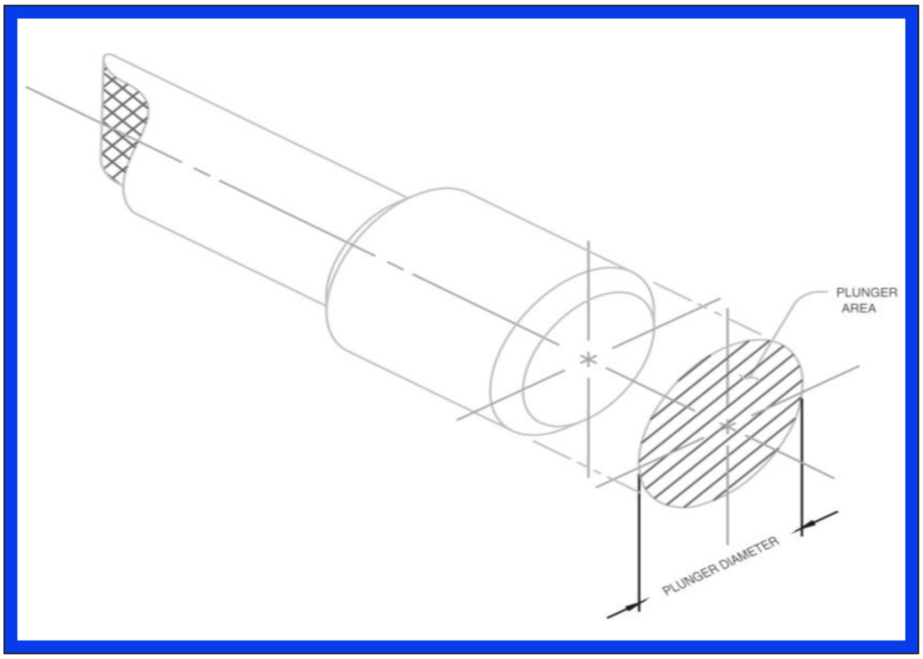


Figure 9-13 - Sketch of plunger showing diameter and high lighting plunger area

The machine must pump (or inject) the volume of a 10 pound (4.54kg) aluminum casting in 0.060 of a second (or 60 milliseconds).

The volume of a 10 pound (4.54kg) aluminum casting is the casting weight divided by the alloy density. The density of 380 aluminum is 0.095 pounds per cubic inch (2.75 g/cm^3).

Volume = weight ÷ density = 10 lbs ÷ 0.095 lbs/in3

Volume = 101 in3

Volume = (4.54 kg) (1000g/kg) ÷ (2.75 g/ cm3)

Volume = 1652 cm^3

The machine pumping requirement is the casting volume divided by the fill time. This is also known as a filling rate, or rate at which the cavity must fill.

fill rate = 101 in^3 ÷ 0.060 seconds

fill rate = 1683 in^3/sec

fill rate = 1652 cm^3 ÷ 0.060 seconds

fill rate = 27,533 cm^3/sec

This example requires a machine that can pump alloy at 1683 cubic inches per second (27,533 cm3/sec).

Once the machine has been identified, the engineer must then determine a combination of plunger tip size and plunger speed to meet the filling rate. The machine pumps alloy by moving the plunger at a given speed, in other words, the plunger tip has an area (square inches), depending on its diameter, as this area is moved at a given speed (inches/second), a filling rate (cubic inches per second) is achieved. Plunger tip area times plunger speed is the filling rate. In the above example, if a 4 inch (15.75 cm) diameter plunger (area = 12.6 in^2) (81.27 cm^2) is used, it would have to travel at a speed of 134 in/second (340.4 cm/second) to meet a 1683 cubic inch fill rate (27,661 cm^3/sec).

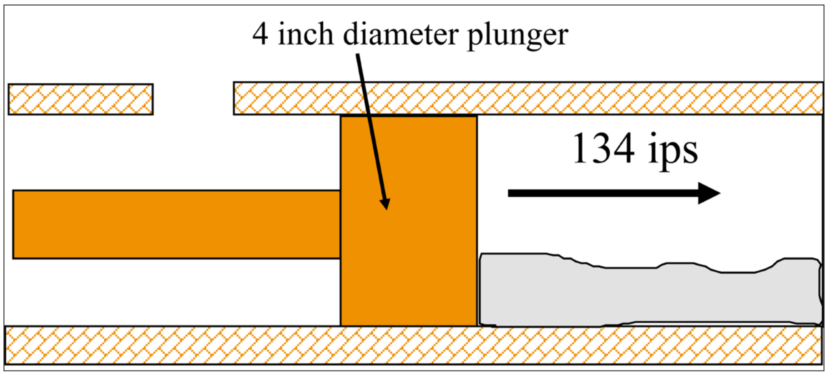


Figure 9-14 - Sketch of 4" dia. plunger moving at 134 ips

fill rate = plunger area x plunger speed

fill rate = 12.6 in^2 x 134 in/sec

fill rate = 1683 in^3/sec

fill rate = 81.27 cm^2 x 340.4 cm/sec

fill rate = 27,661 cm^3/sec

This is one plunger diameter and plunger speed combination that meets the filling rate requirement.

Gate velocity is the other injection variable that is of major interest. Once the gate has been cut into the die, the gate velocity is a function of filling rate. The filling rate at the gate is equal to the gate area (square inches) times the gate velocity (inches per second).

filling rate = gate area x gate velocity

Or if you know the filling rate and gate area, you can calculate the gate velocity:

gate velocity = filling rate ÷ gate area

For our example, if the gate area is 1.5 in^2 (9.68 cm^2), the gate velocity is 1122 inches per second (2850 cm/sec).

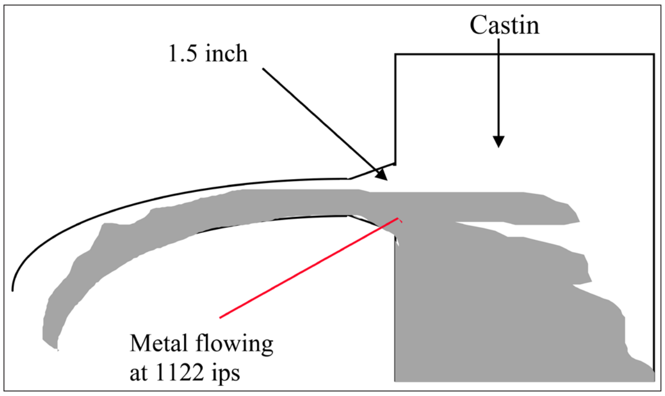


Figure 9-15 - Sketch of metal flowing through 1.5" gate at 1122 ips

gate velocity = 1683 in^3/sec ÷ 1.5 in^2 = 1122 in/sec

gate velocity = 27,579 cc/sec ÷ 9.68 cm^2 = 2850 cm/sec

What is the effect of increasing the plunger size to 4.5 inches (11.43 cm) in diameter (area is 15.9 in^2) (102.6 cm^2) if the plunger speed remains at 134 in/sec (340.4 cm/sec)?

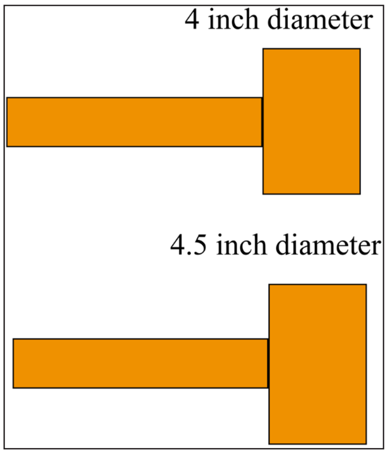


Figure 9-16 - Sketch of 4.0 and 4.5" dia. plungers

fill rate = plunger area x plunger speed

fill rate = 15.9 in^2 x 134 in/sec

fill rate = 2130 in^3 /sec

fill rate = 102.6 cm^2 x 340.4 cm/sec

fill rate = 34,900 cc/sec

A half inch increase in plunger diameter results in an increased filling rate of 2130 in^3/sec (34,900 cc/sec) from 1683 in^3/sec (27,580 cc/sec), a 26% increase.

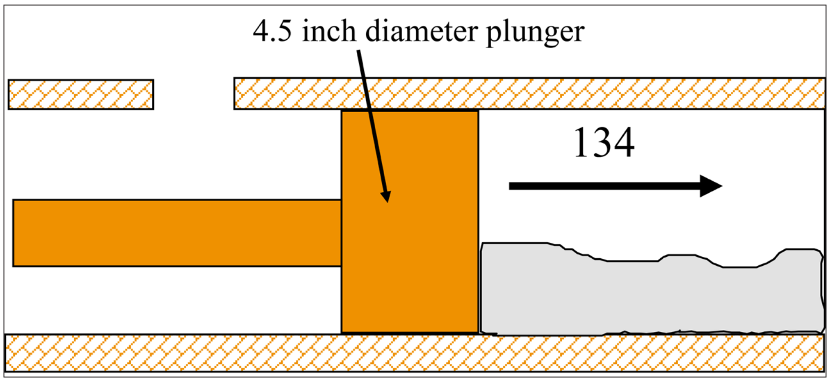


Figure 9-17 - Sketch of 4.5" dia. plunger moving at 134 ips

The gate velocity also increases:

gate velocity = filling rate ÷ gate area

gate velocity = 2130 in^3/sec ÷ 1.5 in^2 = 1420 in/sec

(gate velocity = 34,900 cm^3/sec ÷ 9.68 cm^2 = 1420 in/sec)

And the fill time decreases:

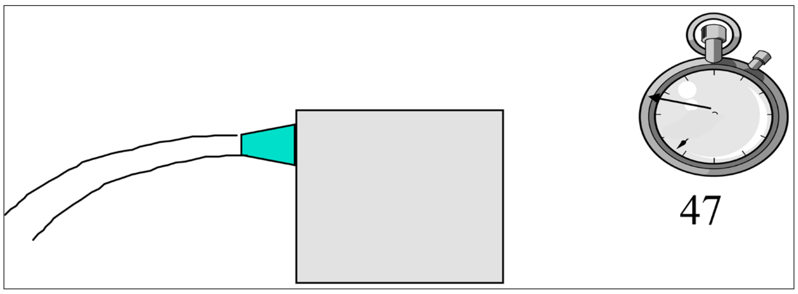


Figure 9-18 - Sketch of filled cavity and stopwatch at 47ms

fill time = volume ÷ filling rate

fill time = 101 in^3 ÷ 2130 in^3/sec

fill time = 0.047 seconds or 47 milliseconds

fill time = 1655.1 cc ÷ 34,900 cc/sec

fill time = 0.047 sec

As you can see from the above example, both the gate velocity and the fill time are related to the plunger speed and size. Some conclusions can be drawn about these relationships.

For a given plunger size,

- as plunger speed increases gate velocity increases
- as plunger speed increases fill time decreases

For a given plunger speed,

- as plunger size increases, gate velocity increases
- as plunger size increase, fill time decreases

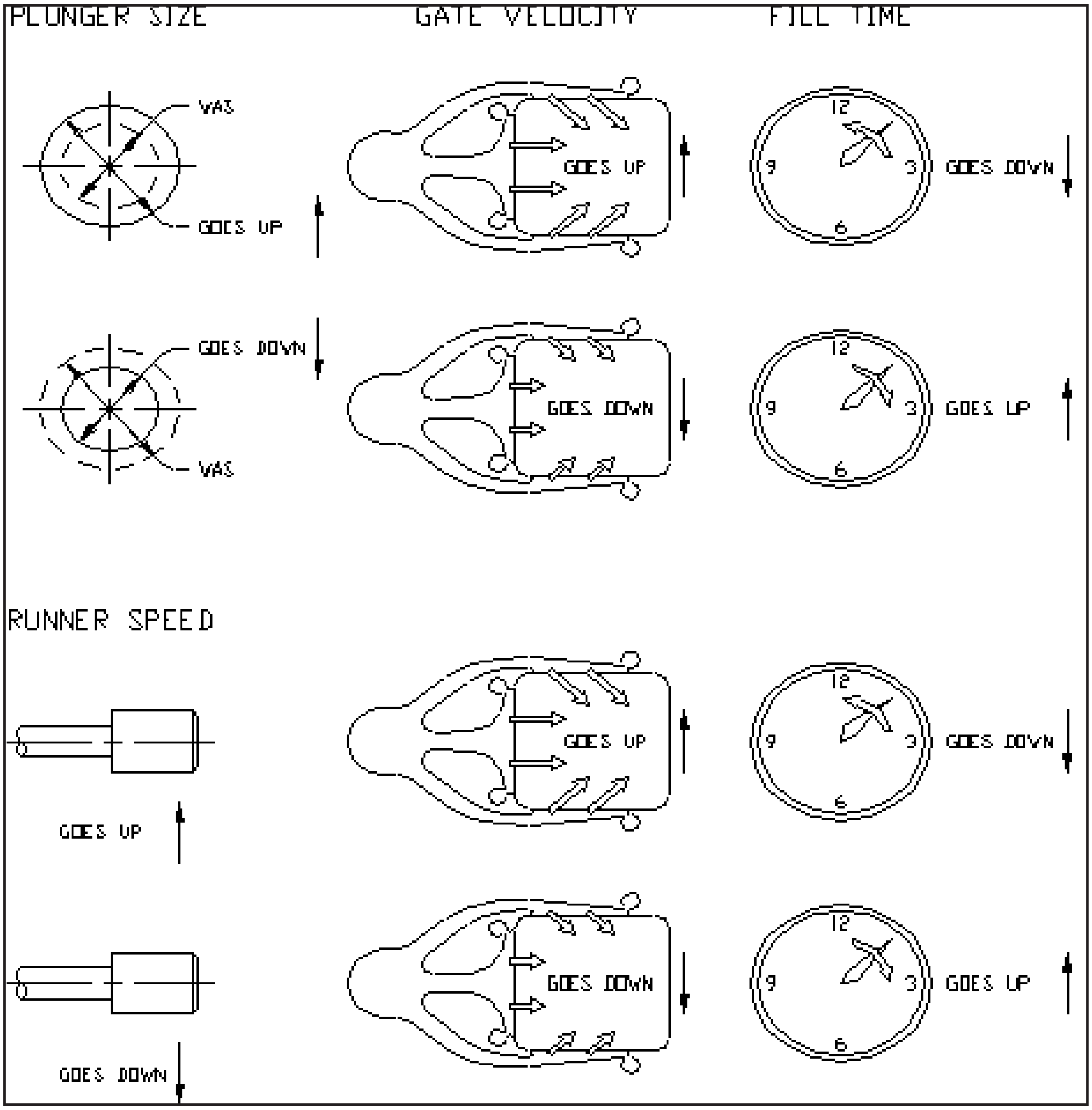


Figure 9-19 - Graphic of plunger relationships with velocity and fill time

You have seen that plunger speed is a very important variable, it directly impacts fill time and gate velocity. There are some other variables that are also affected by plunger speed that need to be mentioned, they are impact pressure (spitting) and venting.

What causes plunger speed to change?

Plunger speed is controlled with some sort of a speed valve. This may be a large gate valve with a hand wheel, or it could be a series of solenoids actuating a binary valve at a manifold. However this is done, you should know how this valve is set. Each job should have an optimum valve setting. Unless you have a shot monitoring system, you will not know what the plunger speed is. Plunger speeds cannot be measured accurately by eye or sound.

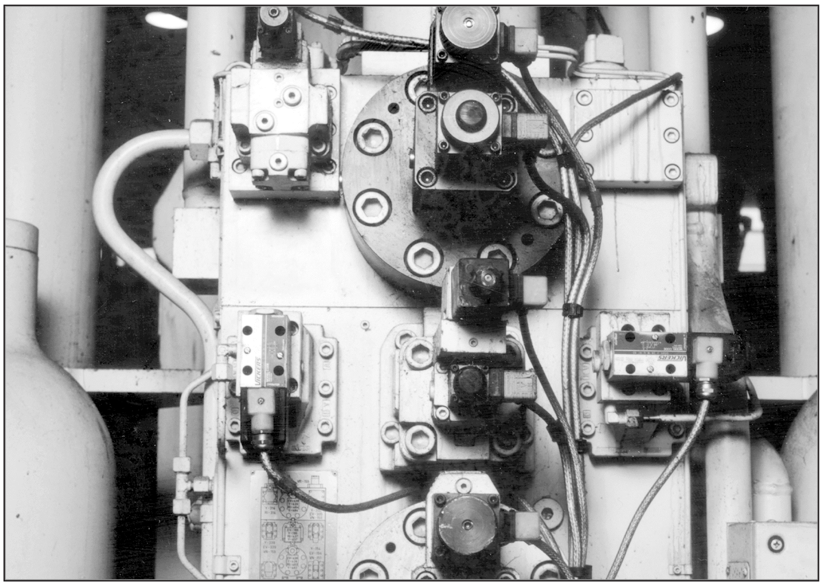


Figure 9-20 - Shot speed valve

The most common reason for plunger speed changes is lack of or improper tip lubrication. If the tip is not lubed, the machine does not have enough power to maintain the plunger speed and overcome the increased friction.

Other reasons for loss or plunger speed are improper cooling of the plunger tip. Inadequate cooling will cause the tip to expand and seize in the cold chamber. A worn tip will trap flash around it making it difficult to push the plunger. Mis-alignment between the cold chamber and machine will cause the plunger tip to wear excessively and possibly seize in the cold chamber. Partial loss or loss of the nitrogen charge in the accumulator will result in a loss of plunger speed.

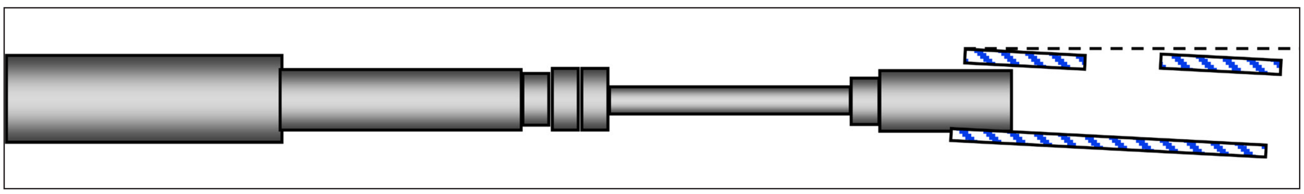


Figure 9-21 - Sketch of shot end mis-alignment

In a hot chamber machine, mis-alignment of the plunger and shot cylinder will result excessive friction and plunger speed losses. Worn or missing plunger rings could result in an unexpected increase is plunger speed due to reduced friction at the shot. This will result in filling problems due to a loss in metal pressure.

Reviewing flow defects

The major causes for flow defects are too long a fill time, too cold a casting die, and too cold alloy. As has been noted, all of these factors are under your control to some extent, or you are in a position to influence them.

APPENDIX A

NADCA Cavity Fill Time Formula

Fill time = k x (Ti - Tf + S x Z) x T

(Tf - TD)

k = alloy constant

T = wall thickness factor

Ti = metal temperature entering cavity

Tf = metal minimum flow temperature

TD = die temperature

S = estimate of % solids at end of cavity filling

Z = solids factor for units conversion

10 RECOGNIZING AND CONTROLLING POROSITY

OBJECTIVES

- To learn the causes of porosity in die castings.
- To learn what the operator can do to control porosity defects.

PERSPECTIVE

In lesson nine, the various types of flow defects in die castings and their causes were discussed. In this lesson, various types of porosity defects that frequently occur in die castings are presented. These defects are voids inside the casting that can cause the casting to leak, crack, or even fail after being assembled into a final product. Since the injection of molten metal into the die occurs very rapidly, the control of porosity is a critical part of the process.

POROSITY

Porosity is a void in the casting. This is a problem typical to all die casters. Porosity has two root causes, a trapped gas or the result of shrinkage.

Gas porosity

Trapped gas porosity has a distinctive appearance. It is round and smooth and looks like bubbles. Trapped gas causing gas porosity can come from many sources. If you are trying to solve a gas porosity problem you have to look at all sources of gas generation.

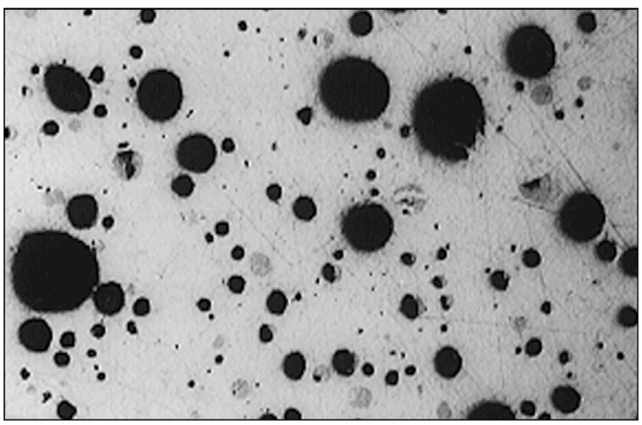


Figure 10-1 - Gas porosity

The common gas sources are:

1. Air mixed with the alloy in the cold chamber.
2. Air trapped in the die cavity because the vents are blocked.
3. Gas from excessive die lube left in the die.
4. Gas from plunger lube left in the cold chamber.
5. Steam from water leaking into the die cavity due to cooling line leaks, or leaks from cracked die cavities.
6. Gas from hydraulic fluid leaking into the cavities from leaking cylinders or connections.

Trapped Air

Trapped air is always present to some extent in conventional die casting because of the turbulent method used to fill the die cavity. We atomize the alloy flow at the gate using high gate velocities.

In addition to the air trapped in the die cavity at the moment of die filling, the most common source is air in the cold chamber. Obviously, filling the cold chamber with alloy can minimize the amount of air in the cold chamber. This may not be practical as you may have competing requirements for minimum fill times. If your process has any adjustment in it for reaching a greater percentage of fill in the cold chamber, this adjustment is recommended. If possible, the cold chamber should be 50-70% filled if trapped air porosity is a problem.

Other sources of trapped air are any time the alloy is subjected to turbulence in the presence of air. Ladling practices should stress minimizing the amount of turbulence when picking up and transporting alloy to the cold chamber. Pouring should be from minimum heights to reduce splashing. With autoladles the pour distance and pour rate should be evaluated and controlled.

The slow portion of the shot cycle must be controlled. First, the timing of the plunger start should be optimized. As the alloy is poured into the cold chamber, it runs down the sleeve to the parting line and is reflected at the die parting line. This wave comes back to the pour hole, and the pouring is complete, the plunger should start as soon as the wave reflects at the plunger tip. In this way the motion of the tip and wave are synchronized. The initial acceleration of the plunger is adjusted to get past the pour hole without spitting alloy. Once the plunger tip is past the pour hole, it should be accelerated to keep the crest of the wave moving down the sleeve without folding over and trapping air. The critical slow shot speed must be used at this time. Once the sleeve is filled with alloy, and the air is being pushed out through the runner system, cavity and vents, a smooth acceleration to the fast shot speed should follow.

All these things must be considered if the amount of trapped air in the cold chamber is to be reduced. Each step may seem to be small and insignificant, but taken together they can account for a major reduction in trapped air.

Some air can be trapped by improper runner design. As an operator, you are limited as to any action you can take to change a runner. But you can observe what happens and make suggestions if the opportunity presents itself. Properly designed runners have large smooth corners with area reductions, and no turbulent flow. This will mean the runners are large compared to the casting, if the runners are too small, the flow in them will be turbulent and the air will mix readily with the alloy. The transition from biscuit/sprue to the gate is constantly reducing and the alloy flow in the runner is always accelerating.

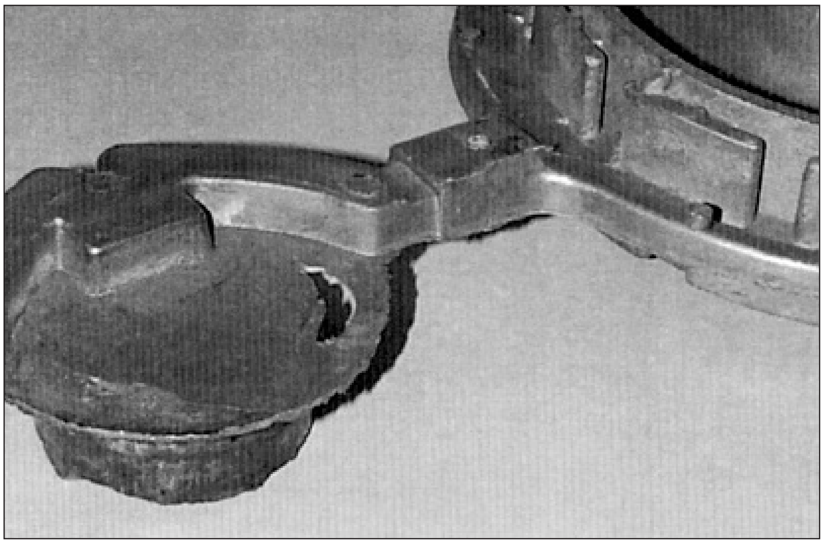


Figure 10-2 - Improper runner design

Improper venting is another cause for trapped air. You have a lot of control over venting. In fact, one of the most important jobs an operator can perform is keeping the vents clean, free of flash or lube build-up. The vents must be open to allow the air trapped above the alloy in the cold chamber to escape. If the vent is working properly, you should see a puff of air coming out of the vent as the plunger moves forward.

Trapped gas from excessive lubricants

Lubrication is a common cause for trapped gases. If die release is put on the cavities in an excessive manner it can result in gas from two sources. First, some of the die lube will burn up when the alloy hits it. This will result in the release of combustion products. A second problem is the most releases are diluted with water. If excess lube is left in the die, the water in the lube will turn to steam and produce a great volume of gas. For these reasons you should use adequate lube, but it should be controlled. After the lube has been applied to the cavities, any excess that has collected in low spots or becomes trapped in the die should be blown out with air. Another source of gas due to excessive lubrication is plunger tip lube. Plunger lube is a common source of trapped gas. This gas usually forms when the alloy runs over lube that has puddled in the cold chamber. The problem with this gas is that a lot of it is immediately trapped in the alloy and has little chance to escape in front of the alloy wave front. Just as with die release, the minimum of plunger lube should be used. If plunger problems occur and lube has been adequate, the solution is not to lube excessively, but solve the real problem.

Other sources

Cracks in the die cavity might allow fluid from the cooling line to leak into the die cavity. Water or oil in the cavity, when hit by alloy will form gas. There are several solutions to this type of problem. One is to abandon the cooling line by turning the coolant off. If cooling is critical and must be used the alternatives are to fix the leaking crack or to use a local cooling system that pulls the coolant through the die as opposed to pushing it through.

Sometimes the source for leakage into the cavity is not easily identified. All fluid sources need to be checked. Hydraulic cylinders can leak, and if they are above of the die cavities, hydraulic fluid can run into the cavities. Sources of leakage at the cylinder can be the seals at the rod or hose connections. Care must be taken when preheating the die to make sure the seals at the cylinder are not burned up.

Hydrogen gas is always discussed as a source for porosity. In die casting this is not a great source for porosity because of the minimal solubility of hydrogen in die casting alloys. At temperatures less that 1250°F (677°C) hydrogen solubility is very low. With other casting processes that require higher alloy temperatures, hydrogen gas porosity is a more significant problem.

Shrink Porosity

Shrink porosity or shrinkage is porosity that occurs if the alloy solidifies without pressure on it. As the alloy cools, it gives up its latent heat of fusion, it also shrinks. That is, it takes up less volume. Pure aluminum shrinks 6.6% by volume. If you start with 100 cubic inches (1638.7 cm^3) of liquid aluminum, and it freezes, similar to alloy freezing in an ingot mold, the frozen aluminum will only occupy 93.4 cubic inches (1530.5 cm^3) (100 in^3 - 6.6 in^0 = 93.4 in^3) (1638.7 cm^3 - 108.2 cm^3 = 1530.5 cm^3). Aluminum die casting alloys shrink from 3.8 to 6.5%, zinc alloys around 3-4%, and copper alloys around 4-5%.

In high pressure die casting, you try to force additional alloy into the die cavity as the alloy solidifies. This is accomplished by using intensifiers or other methods to dramatically increase the alloy pressure once the cavity has been filled with alloy. It is not uncommon for this pressure to be as high as 10-15,000 pounds per square inch (705-1060 kg/cm^2). For intensification to work, the alloy pressure must be transmitted from the biscuit through the gate. If the gate, runner, or biscuit freeze, the alloy pressure can not be applied to the cavity. You must pay attention to the cooling in these areas. Cooling that causes the gate to freeze prematurely needs to be reduced. Cooling at the biscuit is usually the most effective in the entire die. The plunger tip is made of a material that conducts heat readily, and the coolant flow in the tip is usually turbulent and unrestricted. For this reason the biscuit must not be too thin. A rule of thumb is to make sure the biscuit is at least 30-60% thicker than the runner behind the biscuit. This should assure that the biscuit freezes after the runner.

Shrink defects occur at the last place in the casting to freeze. They are easy to recognize. Shrink porosity is characterized by a rough and jagged appearance, in contrast to the smooth appearance of gas porosity. This rough appearance is caused by the alloy tearing apart as it freezes.

Shrink porosity tends to be continuous by nature. This means the porosity tends to string together into long groups of long interconnected voids. These voids can form a leakage path if they break through the surface.

As mentioned previously, shrink porosity will occur at locations that freeze last. For example, if a heavy section or boss is surrounded by thin walls, the thin wall freeze quickly and then the boss freezes without any chance of high pressure alloy reaching it. A void will then form in the boss as shrinkage occurs, of maybe a sink will occur at the surface.

Blisters

Blisters are bubble like bumps on the casting. They are caused by gases trapped in the casting, near the casting surface. These gases are under very high pressure. After all, you use high metal pressure or intensification at the end of the shot in order to compress the trapped gases. When the casting is ejected the casting surface over the blister is not strong enough to withstand the gas pressure of the blister. The surface yields and the blister forms.

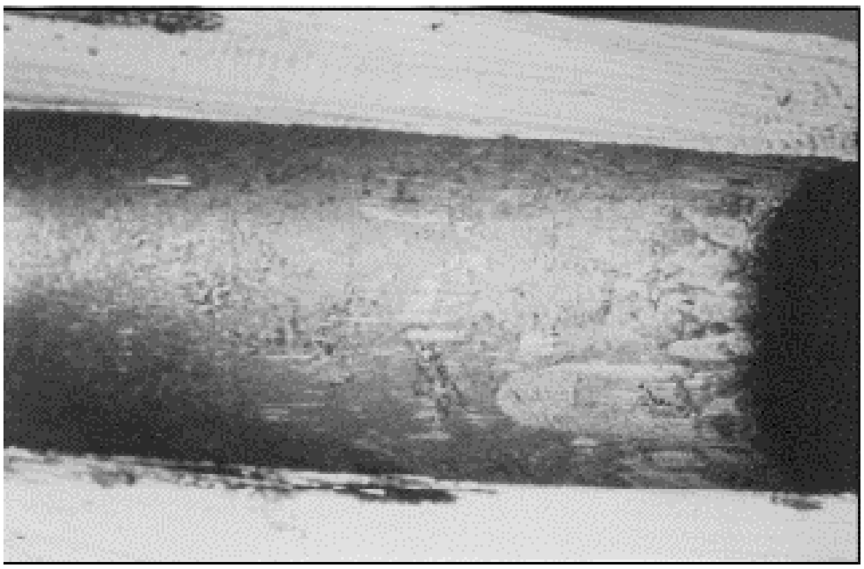


Figure 10-3 - Photo of a blister

The solution to blistering is to determine the source of the trapped air, and eliminate it. The discussion of internal defects will cover trapped gases in detail.

SELF TEST 2

True or False

1. Internal and external defects are a major cause for scrap.

   True False

2. Many external defects are due to the way metal flows in the cavity.

   True False

Multiple choice; Identify all correct answers.

3. Cavity fill time for a casting depends on:
   a. the casting shape, its geometry
   b. the temperature of the die release
   c. the surface temperature of the die cavity
   d. the temperature of the alloy being cast

4. A casting having varying wall sections will require:
   a. different die temperatures to cool it uniformly
   b. more cooling in the heavy walled areas
   c. no internal cooling at all
   d. no intensification, the heavy sections will feed the thin walls

5. The operator can reduce gate velocity by
   a. slowing the plunger
   b. decreasing the cavity fill time
   c. reducing the tip size (no other changes)
   d. increasing the metal pressure

11 ELIMINATING SOLDER AND FLASH DEFECTS

OBJECTIVES

- To learn the causes of solder and flash defects in die castings.
- To learn what the operator can do to control solder and flash defects.

PERSPECTIVE

This is the third lesson on the various types of die casting defects. In Lesson 9, flow defects were discussed. In Lesson 10, porosity defects were presented. In this lesson, solder and flash defects are discussed in detail. In particular, those things that the die cast operator needs to watch for to minimize these types of defects are presented. In addition, other types of dimensional control issues that arise during the production of die castings are discussed.

OTHER SURFACE DEFECTS

Soldering

Soldering is simply the fusion of aluminum in the die casting alloy with iron from the steel surface of the cavity. Typically, the die cavity will have an oxidized coating on it. This coating, analogous to anodizing, protects the cavity surface from the aluminum. If the alloy impinges on a portion of the die or on a core pin to the extent that a hot spot develops, the aluminum will break down the oxidized interface between the die surface and the casting. Once this happens, the aluminum will dissolve and alloy with the iron in the steel or the aluminum molecules actually penetrate and bond with the iron. Generally this is the same type of bonding that you get when you solder wires together using a lead-tin solder. When soldering occurs in the die casting die, the casting sticks in the cavity. The only way to get the casting out is to tear it away from the stuck surface. This is why the soldered surfaces have such a rough appearance. The alloy has been torn away. If the soldering is not removed it will leave a blemish on the casting. The only effective way to remove the soldered spot is to remove all the aluminum and steel that has been penetrated.

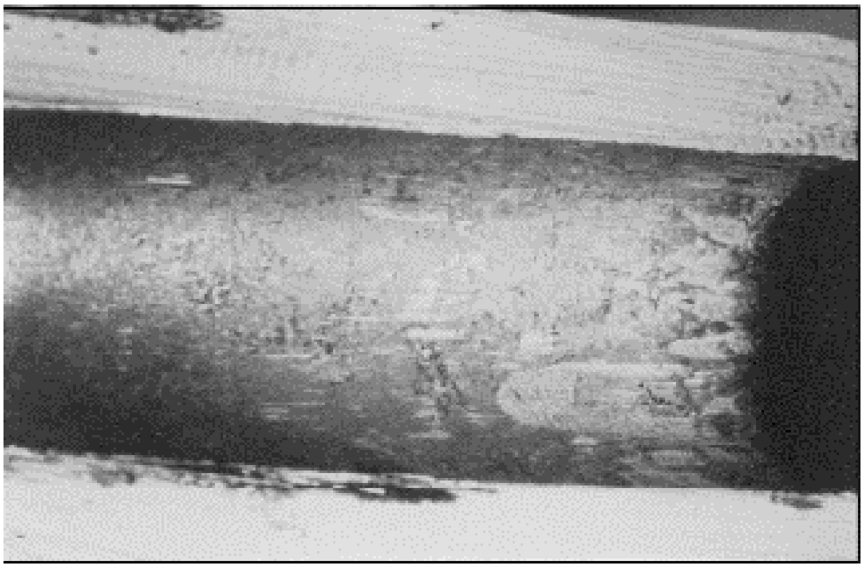


Figure 11-1 - Soldering

Soldering is frequently seen on cores or walls that are in the path of the incoming alloy. This situation is aggravated by higher than usual die temperatures, high gate velocities and high metal pressures.

Soldering is also enhanced if the iron content in the casting alloy is low. For aluminum alloys, the minimum iron content should be 0.8% iron. If the alloy has sludged, it is possible that the iron content is below the recommended minimum.

Insufficient draft angles will also lead to soldering. When the draft angle is small, areas of the cavity will be abraded by the casting at die opening and ejection. This rubbing action will remove any protective oxide film and actually “prime” the die surface for soldering.

Lastly, the purpose of die release is to provide a protective barrier. If the die release is ineffective, or casting conditions are such that the die release cannot get to the cavity surface or wet the surface, conditions for soldering will be present.

Remedies for soldering such as “the best anti-soldering coating” are usually unknown. The best fixes are to avoid conditions that promote soldering. If hot spots in the die cause soldering, then the cooling plan for the die should be re-evaluated to determine if any thing can be improved. If impingement or high velocities at the gate are causing soldering, can something be done to change the flow direction or speed? Can the injection parameters be changed while still maintaining critical metal flow conditions?

Dimensional Defects

Dimensional defects are another category of defect that the operator has a great deal of control over. Most dimensional defects will be related to die temperatures, the condition of the die, or the force of injection.

Dimensions and Die Temperatures

You know that a metal rod will get longer when it is heated. This is thermal expansion. Thermal expansion for the rod is related to the type of material

the rod is made from, the length of the rod and the temperature change experienced by the rod. In other words:

$$\Delta L = C \times L \times \Delta T$$

ΔL = change in length

C = coefficient of thermal expansion

L = length

ΔT = change in temperature

As objects cool they get smaller, this is called contraction. This behavior also acts in accordance with the above formula. The only difference is that instead of having a positive temperature change and adding length, the temperature change is negative, getting colder, and the object gets shorter or smaller. When a casting is ejected from the die and cools to room temperature, it gets smaller.

Generally all the dimensions on the casting also get smaller (there may be some specific instances where this does not happen, but those are special circumstances). The change is predictable according to the formula for thermal expansion/contraction. If you control your process and the casting always ejects at the same temperature, then it will always cool the same and the dimensions will be consistent and repeatable.

Do you ever have problems with dimensional repeatability? For example, you are making an aluminum casting with a 5.000 in. +/- 0.005 in (12.7 cm +/- 0.013 cm) tolerance on it and during the course of a shift the ejection temperature would vary from 600 to 700°F (315 to 370°C) should the be a cause for concern? In other words, how much change in length would a 100°F (370°C) temperature difference cause on a 5.000 in. (12.7 cm) dimension in an aluminum die casting?

The coefficient of thermal expansion for die cast aluminum is 0.0000122 inches for each inch of length and each degree of temperature change (0.000022 cm/cm-C°).

Evaluating the formula for thermal expansion:

$\Delta L = C \times L \times \Delta T$

ΔL = change in length

$C = 0.0000122$ in/in-°F

$L = 5.000$ in

$\Delta T = 100$°F

$\Delta L = (0.0000122 \text{ in/in-°F}) \times (5.000 \text{ in.}) \times (100\text{°F})$

$\Delta L = 0.0061$ inches

$\Delta L = (0.000022 \text{ cm/cm-C°}) \times (12.7 \text{ cm}) \times (55.5\text{°C})$

$\Delta L = 0.0155$ cm

This could be a cause for concern. If a casting that ejected at 700°F (371°C), cooled to room temperature, and measured 5.000 inches (12.7 cm); then a casting ejected at 600°F (316°C), cooled to room temperature would not contract as much. It would contract 0.0061 inches (0.0155 cm) less and measure 5.0061 (12.716 cm) inches and be out of tolerance. Your objective then is to get the casting to eject at a consistent temperature. To do this you must maintain a consistent cycle.

Another problem is when one half of the die is a lot hotter than the other half. This can be a problem for the die and the casting. If the stationary die half is a lot hotter than the moving half, then the guide pins will not line up with the bushings. If a casting is ejected with one half of the casting considerably hotter than the other half, one half of the casting will contract more than the other half. This will cause the casting to warp and bend.

The Condition of the Die

Many times the condition of the die will be responsible for a dimensional failure. If flash is allowed to build up at the parting line. The die will not close properly and dimensions across the parting line could be longer / thicker depending on the amount of flash. In addition to being a hazardous condition, flash at the parting line may cause an oversize dimension.

If the die has a slide that is to be held in position with a wedgelock, and there is flash at the parting line holding the die open, the wedgelock will not hold the slide in place, and the slide can back out causing further dimensional problems. A similar circumstance may be the buildup of flash in front of a slide. This could prevent the slide from going to the “ready to cast” position and hold the die open.

Another circumstance of die condition that may affect dimensions is soldering. Small core pins can be very susceptible to this type of problem. On many small cores, less than 1/4 (6.2 mm) inch in diameter, the size tolerance for features may only be three to four one thousandth's of an inch (0.076-0.102 mm). In these cases solder buildup and the associated roughness and dragging can easily cause an oversize out of tolerance condition.

Other places that can result in soldering and dimensional problems may be walls. If in a particular area impingement and soldering are a problem at a wall, the surface roughness may be so great that the material that is missing could cause an undersize or thin wall.

Force of Injection

If the force of injection overcomes the locking capability of the die cast machine, the tie bars will stretch and allow the die to flash. This flashing will add to the magnitude of the across parting line dimensions and could also cause slides to back out. The force of injection at the end of the shot is a combination of normal injection force, impact, and intensification. Of these three, impact can be most troublesome since most machines have no way to control it. Impact is the force generated when a mass comes to an abrupt halt. In the case of the shot end, the mass is the shot piston, coupling, rod and plunger and hydraulic oil that is propelling the shot. The faster that this mass slows at the end of cavity filling, the higher the impact will be. To reduce impact, you need to try to reduce the mass and speed of the injection system. Using the minimum possible shot speed that makes an acceptable casting is a good way to start. Reducing the mass of the system is usually beyond the capabilities of the operator. Normal injection force is determined by the hydraulic pressure of the machine, the shot cylinder size and the plunger size. The larger the plunger, the smaller the alloy pressure will be and the smaller the injection force. To minimize impact you would choose the largest suitable plunger and lowest hydraulic pressure. In most cases these are decisions that are made by engineering when the process is setup. Your feedback to engineering may be helpful. The final factor influencing impact is intensification. Intensification is the multiplying or intensifying of the alloy pressure. Typical multiplication is 2-4 times. When intensification is applied and how rapidly it builds up to maximum pressure are controls that the operator may be responsible for. Intensification needs to be applied before the gate freezes, otherwise you will not be able to get more alloy into the cavity to feed solidification shrinkage. Also, this pressure is needed to squeeze gaseous porosity as small as possible.

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