MANAGING ZINC DIE CASTING DIMENSIONAL CAPABILITY

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Records and Quality Assurance

Records

In order to confidently quote zinc die castings to the requested tolerances, a good data base of dimensional fcapabilities should be available by machine and casting size. As tolerances decrease and CPK's increase, the published standards become less relevant to use as a tool for quoting relative to the need for secondary operations. In addition, the cost of die correction, lost machine time, sampling, sorting, and rework can decrease the originally intended margin and put the die casting operation in financial jeopardy if the part cannot be made to quoted tolerances and CPK's. Therefore, it is good practice to collect dimensional data and build an individual data base as each die casting operation is unique in die design and construction, machine size and condition, process engineering and execution, etc. The smaller the machine size, the more relevant this is as published standards are less help for this market segment. The format for a die caster's internal standards can take the same form as NADCA for coordinate and geometric features. In addition, many design engineers are not experts in die casting. Typically they come to the die caster for advice on what tolerances can be held or what design changes could be made to increase capabilities. More customers are now asking for a 'full service' die caster who can assist in the part design. So there is a need for an internal tolerance database to accurately estimate tolerance expectations.

Quality Assurance

Inspection

A meeting should be held with the inspection personnel to cover the critical dimensions and datums of the part. There are many ways to fixture and measure the part, and a review should be made to determine the best metrology method for each critical dimension. The idea is to get the R & R (repeatability and reproducibility) numbers for the critical dimensions as low as possible. In addition, methods need to be determined to measure the critical dimensions on an ongoing production basis with the idea of minimizing the costs for data collection. A way of measuring on an ongoing basis is to set up an operation where the part is fixtured and critical dimensions are measured automatically with the data sent directly into the computer. This type of operation will have a higher R & R and reduces the need for indirect labor. Whatever method is arrived at, the customer's inspection personnel should be able to measure the same way and replicate the results. Consideration should be given as to where in the process (ideally after the secondary operations) the parts will be measured to address the stress relief and distortion issue. If special gages and fixtures are needed, then two or more identical sets should be made - one for the die caster and one for the customer.

Capability Studies

For capability studies to be meaningful, the die casting process used to obtain samples for the capability study should be very close to the process used later in production and should be running in thermal equilibrium before samples are taken. Once thermal equilibrium is reached, a minimum of 60 sets of parts are collected at selected intervals. Forty castings are used for the capability study and the others are used for trim die samples, secondary machining samples, archive samples, samples to be sectioned for porosity, etc. Each sample should be dated and numbered so that they are not confused with other samples cast later. If the capability study procedure is short cut, then the confidence in the results may not be high and the wrong die corrections could be made. Capability studies require order and procedure to have confidence that the right die corrections are made.

Dimensional Control Plan

To assure the production process is in control, there needs to be a sampling plan to measure and record the critical dimensions through time. In addition, there should be a reaction plan if dimensions fall out of statistical process control. These plans are summarized on the Dimensional Control Plan. A review should be held with inspection, engineering, production, and sometimes the customer's personnel to develop this plan. The plan should follow the Design FEMA whereby each critical dimension is considered relative to its potential for being out of control and the impact this would have on product performance. Features that are important to the function of the part or have low CPK's need to be monitored with larger sample sizes and with higher frequency. Items that are less important or have high CPK's would require smaller sample sizes and lower frequencies. The key is to match the efforts expended to collect and react to this data to the function and design intent of the part. Inspection does not add value to the product, so inspection resources available should be used to the best advantage. Usually the Dimensional Control Plan is comprehensive at the beginning of the program, and as CPK's are improved, time expended to execute the plan is reduced.

Cast Die Engineering

Gating

Good design of runners, ingates, outgates, overflows, and vents is fundamental to making good castings and controlling tolerances. The metal flow path, the ingate, the outgate, and vent velocities, the cavity fill, along with the runner design must be within the accepted norms of zinc die casting to get the most out of the process. The NADCA design method or its equivalent should be used on every die. There is now software available that can assist the gating design and produce a CAD drawing that can be sent directly to the tool designer or toolmaker. In any case, the seat of the pants, the pet theory, or the cut and weld approach should be abandoned and a bona fide gating method used. Once a gating system is built into the die, it should be very close to its final form with only minor adjustments required after the first sample cast. Time spent upfront to do a good gating design is a very small cost and should have no impact on lead time. Some general gating principles that apply to all zinc die castings are:

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Gating Principles

- All cavities and segments of cavities should be filled within a specified time.
- All cavities and segments of cavities should be filled as simultaneously as possible.
- The ingate metal velocity should be within specified high and low limits.
- There should be a way provided for the air to escape during cavity fill.
- The metal flow through the cavity from ingate to outgates should take the shortest path
- The cross sectional area of the runner system from the sprue to the ingates should decrease in size

A proper gating design will make good parts with low dimensional variation whereas a poor gating design will limit the potential of the zinc die cast process.

Thermal Engineering

The die can be thought of as a sink that absorbs heat from the molten metal causing it to freeze and which also happens to provide the impression making the part. Controlling the heat is proportional to controlling tolerances. Relatively hot and cold parts of the die will contribute to varying shrinkage rates and subsequent CPK performances. In all thermal analysis methods, a control volume is placed around the die where all heat added and removed accounted for. As a minimum, a thermal analysis using NADCA or similar methods should be done in which the input BTU/Hr (kW) are matched with the BTU/Hr (kW) transferred to either the atmosphere, die lube spray, or coolant circulating through the die. The NADCA method will yield faster running rates with better tolerance control than the die designer's or tool engineer's best judgment. In the past few years, software has been developed that takes the quality of the thermal analysis a step above the NADCA method. These methods use 3D CAD models and thermally simulate the die running on the computer. Successive iterative changes can be made to see the effects of coolant channel size and placement, coolant types and flow rates, steel types, ejection temperatures, etc. Temperature differences, whether hot or cold, can be addressed at the part design stage or the tool design stage to reduce potential distortion and shrinkage problems. Where the heat cannot be controlled using cooling channels or heat pins, then special steel alloys with higher conductivity might be considered. The simulation models can also help process engineering identify hot or cold spots that can help determine die lube spray patterns.

Tool Design and Construction

Like the part design, there are many options in designing die casting dies. It is a good idea to involve all participating functions such as die cast engineering, tool design, the tool maker, the die repairman, production personnel, the customer's design engineer, etc. All parties have differing perspectives, and the best dies involve everyone's ideas. Poorly designed or constructed dies can lead to excessive production costs and poor tolerance control no matter how good the part design or die cast machinery. The die is the heart of the die cast process. If a choice is necessary then it is preferable to have a good die in a poor machine than a bad die in a good machine. Without a good die, the chances of making economic castings with good dimensional capabilities and tight tolerance control may not be good. Here are some topics that should be explored at these meetings:

How the part works

An understanding of the part application, who it is for, and how the part works along with an explanation of the critical dimensions and tolerances is beneficial for everyone. The die should be designed to best meet the function of the part and to provide control for the critical dimensions and tolerances. Therefore, an understanding of how the part works by all involved in the die design and construction process yields the best chance of generating good ideas.

Tool print versus part print dimensions and steel safe conditions

The tool print dimensions will differ from the part print to account for shrinkage. This could be in the range of .005 to 0.007 in/in (mm/mm). Possibly someone with experience of similar parts can give a better estimate of the actual shrinkage for various features of the part. In addition, there are steel safe (maximum metal) concepts to consider. The question is, would it be better to be steel safe across the whole die and be prepared to adjust die steel for the critical dimensions to raise CPK's or would it be better to shoot for nominal steel sizes right from the start? The size of the casting will have something to do with these decisions because smaller dies will have less shrinkage and be more predictable. For very tightly toleranced positions, it may be better to cast cores on the small side and be prepared to move the centers with a jig grinder after the initial samples are die cast and the direction of the shrinkage is determined. If the core was made to nominal and the shrinkage surpasses the positional tolerance, an expensive adjustment would be required. Ideally, there should be no welding involved with making adjustments due to the effect of welding on tool life. Estimating the shrinkage rate for all sections of the casting can be difficult, so it is important to consider input from all parties with the goal of reducing the amount of subsequent die corrections.

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Thin steel conditions

The function of the die steel is to absorb heat and to form the impression. The greater the steel mass in a casting section, the better it can absorb and dissipate heat. If the steel is too thin and overwhelmed by the metal, it can distort, crack, or break causing problems in controlling tolerances or even making the part. Therefore, thin steel conditions should be avoided whenever possible. The cost of steel is inconsequential in the total cost structure of die casting. If thin steel conditions are unavoidable, then the fallback position is to concede premature steel failure and use special die steels that may last longer, or plan on inserting the section and replacing it on a regular basis.

Wall stock thickness

The thinner the wall stock, the harder it is to get the casting to fill. If thin walls are necessary, then consideration should be given as to where the metal flow path will be to feed the thin section and also where channels of hot oil or cartridge heaters should be placed to keep these die sections warm. Sometimes the wall stock dimension has enough tolerance that leaning to the high side of the tolerance helps. In this case, it is better not to specify steel safe conditions. If the nominal wall stock is .030 inch at +/-.005 inch (0.75mm at +/-0.1mm), then a 16% swing of .005 inch (0.1mm) within the tolerance range may make the difference between an acceptable fill or not. Another countermeasure for thin wall stock is stippling the surface if this does not detract from ejection. A stippled surface can help the fill in these areas.

Thick wall stock presents problems with long solidification times, so measures should be taken to remove the extra heat generated with spot coolers or heat transfer pins. If stippling is possible, it can help form a stronger skin that will resist sinks that sometimes form with thick sections.

Draft

The amount of draft must be considered for ejecting the casting off the die with minimum distortion. It is important to take advantage of all the draft given on the print. If the print has minimum draft in places, then consideration must be given to increasing the number or diameter of ejector pins in these areas. Sometimes process changes such as shorter hold times, richer die lube ratios, or different types of die lube may help minimize the sticking and distortion. Draw polishing the die to a fine finish using 600 paper or diamond compound can also help dragging, sticking and distortion in minimum draft areas.

Parting Lines

Alternate parting lines need to be evaluated for ejection, die insert impact, and metal flow patterns. For many castings, the parting lines are intuitive and easy to determine. For others there are choices. Ideally, there should be room for ejector pins so the casting comes off the die easily; the die insert steel should be thick and strong to absorb heat and resist distortion; the slide projected areas should be minimized with room for effective shutoffs; the metal flow path from the ingates to outgates should be minimized; there should be room for all the desired coolant channels; and, the main parting line shutoffs should be able to hold the metal in the cavity and also provide for adequate venting. Unfortunately, these demands invariably conflict in complex three-dimensional parts and tradeoffs have to be made. Input from all knowledgeable die casting personnel should be used in cases of alternate parting lines in order to arrive at the best compromise design.

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Shut offs

A fundamental of consistent dimensional control is to hold the metal in the die during the shot. If the metal escapes the die at the end of cavity fill, the part may be thicker, the slides may move back, flash may stick to the die for the next shot and act as a shim to hold the die open with permanent crushes made into the die steel, or metal may get behind the slides and into the carrier. These items will cause the final metal pressure to vary and affect dimensional and tolerance control adversely. Therefore, holding the metal in the die with good shut offs is very important. This may be easy to do along the main parting line and more difficult to do with slides due to the limited die area. All proposed shutoffs should be critiqued at the die design stage, because once the die is built, there may be little that can be done to change them.

Slide design and construction

Slides can make or break the die regarding dimensional control and efficient running. Items to consider with slides are: minimizing the projected areas to take as much force off the slide as possible, designing the shut offs so the metal is stopped, dealing with slide cooling and expansion relative to dimensions formed, designing the slide guidance mechanism to insure the slide registers consistently, designing the proper clearances so the slide or carrier do not gall when expansion occurs, designing lubricated and replaceable bearing surfaces, designing strong and well supported locks, determining the lock pre-load, and designing the mechanical or hydraulic mechanism to move the slide in and out. To design and build slides that are trouble free requires insight and skill in design and also craftsmanship and precision in tool making. NADCA's textbook, "Designing Die Casting Dies" by E. A. Herman, is a good starting point for addressing these issues. Each die casting operation should keep records of what works and does not work so a database is available for new slide design and construction.

Die registration

Registration is positioning the die halves relative to each other. When the toolmaker fits the die casting die at room temperature, registration is as good as it will be. However, when the die is in the machine and running, the force of gravity, the effects of unequal thermal expansion relative to the fixed and moving halves, and the mechanical imperfections of the die cast machine come into play. The larger and heavier the die, the more precision registration becomes a problem. The methods used to register dies vary with the type of machine. The four slide machine uses a crosshead that is relatively large and stable to position the die components. This is a reason four slide machines are capable of very tight dimensional tolerances. Conventional die cast machines register die halves with leader pins or locator blocks. The better method for conventional machines is zero taper locator blocks that individually locate in only one axis and are positioned perpendicular to the lines of die expansion. Leader pins must locate in two axes at the same time and consequently must be built with some clearance between the bushing and pin to account for unequal expansion of the fixed and moving halves. When leader pins are installed with tight clearances, the bushings eventually wear egg shaped. Another factor to consider in conventional machines is the force exerted by the slide locks. If the sum of the slide lock forces in either the 'x' or the 'y' axis is unequal, then the die parting line may shift. Counterlocks or zero taper locator locks can be used to oppose these unequal slide lock forces. On larger dies, the weight of the die may cause the moving platen to tilt forward causing the leader pins or locator blocks to wear more on one side than the other. Die carriers that ride on the die cast machine rails can help support the moving half and reduce parting line mismatch. Die registration is an important issue as the shut offs that are fit in the tool room can change in production due the problems discussed and adversely affect tolerance control.

Cavity placement

The tie bars on a die cast machine are mechanical springs that stretch every time the die locks. The load on the bars is a function of the metal pressure and the projected area of the shot. If the projected area of the shot is not perfectly centered, then the load on the tie bars will not be equal and the metal may flash out of the cavity and possibly the die. If flash occurs, metal pressure varies and tolerances are adversely affected. Therefore, the objective of the die design is to place the cavities so as to center the load between the tie bars. A perfect die design occurs with a center shot with all the cavities radiating out from the center to yield equal tie bar loading. However, not all parts lend themselves to this arrangement. So the die designer should place the cavities to achieve as best a balance as possible. This is done by calculating moments of projected area for the cavities, runners, and overflows using a Cartesian coordinate system whose origin is the center of the platen. The cavities are moved around on the proposed layout until the best tie bar balance is achieved.

Holder (Bolster) block size

Holder blocks hold the cavities and slides in position and also transmit the force of the shot to the platens. They should be centered on the platen to transmit the forces as equal as possible to the tie bars. Holders need to cover at least 70% of the daylight between tie bars to spread the force so that the compressive yield strength of the platens is not exceeded. If the platens become indented, then the die halves may end up ‘out of square’ to each other to varying degrees. This leads to parting line and slide shut off problems and less tolerance control. Die steel is relatively inexpensive, so holders should be made strong and large even for small cavities. A good idea is to standardize the holder block size for a particular size machine. If a plant’s die cast machines platens have become indented, then they need to be restored with milling in order to improve dimensional capabilities.

Die distortion

Dies distort due to thermal and mechanical stresses. The larger the die, the more distortion occurs. Distortion in the ‘x’ and ‘y’ axis can be minimized by reducing the difference in running temperatures between the fixed and the moving halves. To minimize the temperature difference, a thermal analysis can be done and the coolant channels placed accordingly. Distortion in the ‘z’ axis of the moving half can be minimized by designing a hefty holder block and reinforcing the back of the holder with adequate pillars. NADCA has software to determine the number and diameter of the pillars required as well as the size of the rails. Sometimes a problem occurs on larger dies in the ‘z’ axis of the moving half around the runners where excessive die steel expansion holds the die open at running temperatures causing perimeter flash. Larger coolant channels, more than normal die lube spray, and relieving the die steel in these areas are ways to remedy this problem.

Core design

Cores should be designed with adequate draft according to the charts supplied by NADCA. They should be draw polished to a fine finish. Coatings such as titanium nitride, diamond nitride, diamond carbide, etc. are now available that give promise of extending core life. The finish core design may take some trial and error due to the unpredictability of the metal shrink around cores. The die can be designed so that cores can be changed in the machine without pulling the inserts out of the holder block. A safe core length to diameter ratio is 4:1 with the minimum size core of .030 inch (0.75mm). If a core is .500 to 1.000 inch (12-25mm), then the ratio of core to diameter can be as much as 6:1 to 8: 1. All cores should have a small radius where they intersect a wall to reduce stress concentrations. It is possible to have opposing cores meet and cast with no flash. This requires a good prediction of how much the cores will expand. A method sometimes used for opposing cores or cores that shut off with die steel from the opposite side of the die is to mount Belleville washers behind the core and have the washers compress at die lock up thus casting flash free at the end of the core.

Ejector pins

Ejector pins need to be placed to get the casting off the die with a minimum of distortion. They are normally set at +.005/-.000 inch (0.1/0.0mm)in the cavity steel and -.050/-.100inch (1/2mm) in the runner and overflow steel. The recessed ejector pins in the runners and overflows help guide the casting straight for the first .050 inch of movement. If possible, they should be located so marks are not left on an area that would be objectionable. On flash free parts, the ejector pins should be located so that they can be attacked by vibratory deburr or some other means of automatic deflashing. The ejector pins should be precision fit to the bearing surfaces so there is no ejector pin flash and no squeaking when running at operating temperatures.

Self degating

Self degating dies can be very efficient. With self degating dies there is a two stage ejector pin motion whereby the parts are stripped off the runner by the first stage of ejection and then the runner is ejected with the second stage. Sometimes the reverse sequence is used where the runner is first ejected and then the parts. This all happens within a fraction of a second during the ejection process. The parts and runners drop onto a conveyor and into machines that separate the parts from the runners. In order for self degating to work, the gates must be .015 inch (0.4mm) or less. Whether the part can be made with gates this thin can be determined from the gating and PQ^2 analysis of the die and machine.

Component materials

Cavity and sprue steel for zinc dies has been traditionally been P20 or H13. There are other cavity materials available that can be reviewed with the steel suppliers. Die components should be specified DME standard or equivalent so that replacement parts are readily available. Anvilloy or TZM are two materials of high heat transfer capability which could be used for cores or other features which are difficult to cool.

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Coatings & Surface Treatments

There are coatings and surface treatments on the market that can extend component die life and resist solder. Some of these coatings are hard chrome, ferritic nitrocarburizing, titanium nitride, titanium carbonitide, chromium nitride, solvenite, chrome carbide, diamond chromium composite, etc. Troublesome cores or areas of the die that are exposed to high thermal stresses such as areas around the ingates or thick sections may benefit the most from these from coatings or treatments.

Soldering in casting metal buildup on the die surface, results when there is a flow separation in the injected metal, or erosion of the die surface resulting from metal imparting on the steel, such as core pin in the metal flow path. Soldering can usually be minimized by reducing die temperature or increasing draft angle.

Method of die manufacturing

The steel manufacturers supply a sequence for manufacturing operations for cavity steel inserts. How the die is manufactured has a bearing on its longevity and performance. With the advent of EDM, many cavities were sunk in one pass as it was the cheapest way to do it. However, the EDM process is not good for the steel as it leaves a layer of redeposited molten metal that is very hard and a layer of annealed soft metal underneath the hard layer. Once the hard layer is microscopically cracked by the thermal cycles of die casting, then heat checking proceeds rapidly in the soft layer underneath and the die will prematurely fail. The recommended sequence in die construction is for the cavity to be rough machined, stressed relieved, finished machined, heat treated, ground true, EDM'ed at a very low power rating to finish dimensions, then polished and stress relieved again before delivery and sample runs. With the pressure on die casters and tool makers to make the cheapest tooling possible, this sequence is sometimes bypassed. But cheaper tooling can be false economy in the long run as the die is the heart of the process and the key to economical production and tolerance control.

Heat treating

Heat treating should only be done at approved sources. The steel suppliers know the heat treaters in each area and their recommendations should be followed. The longevity of the die and its tolerance capability over time is a function of the quality of the heat treat process. NADCA will be issuing a standard in the near future for approved heat treat procedures. Records should be kept at each die cast facility to establish a heat treat database to be used as a reference for new die construction.

Stress Relieving

As the die cycles, it is subjected to molten metal at 800 ?F (420°C) followed by die lube spray at 100 ?F (40°C). This produces thermal stresses within the die that eventually cause the die to fail. When the die is pulled for servicing, it is recommended to stress relieve the die at about 50 ?F (30°C) below the last draw temperature to relieve internal stresses. Stress relieved dies last longer as thermal fatigue and heat checking are delayed. In the manufacturing or repair process, the die should be stress relieved after rough machining, after the last draw to harden, after the first sample run, and after any welding.

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Die Corrections

Die corrections are required because of tool maker error or inaccurate shrinkage estimation. The amount of die corrections depends on the skill at forecasting shrink and also the workmanship of the toolmaker. Ideally, the die was made steel safe, and the corrections required involve removing die steel and not welding the die to add material. For all corrections that involve machining, EDM burning, or welding, the insert should be polished and stress relieved. Sometimes successive corrections are made to achieve tolerance and CPK targets. Die corrections should only be made from measurements that have a reliable R & R and from castings made with a stable process.

Engineering Changes

Engineering changes can occur anytime during the life of the part, and each change needs to be quoted for cost and tolerance impact. When given the 'go ahead' by the customer, the print needs to be updated and distributed in the die cast plant using a controlled method. Having obsolete prints in various files in the plant can lead to problems in dimensional control. There should be a system to notify all involved personnel of engineering changes on a timely basis, and to keep the control documents used to service the die, make production, and control quality up to date.

Customer Contact

Clear lines of communication between the die caster and the customer by the functional groups should be established. This way information does not get lost along the way. Each functional group for both the die caster and the customer should have the responsibility to communicate data and developments within their own organizations. During the part and die development stages, some plants assign one engineer cradle-to-grave responsibility for the part and it is his responsibility to maintain contact with the customer and to communicate all developments within the die cast organization. It is important that all personnel involved with the project are made aware of information they need to proceed, stop, adjust, etc. for the part and die development phases.

Method of Information Transfer and Protocols

Transferring information via CAD is becoming more common. Problems occur when the customer, die caster, tool designer, or tool maker do not have compatible systems and information gets lost in the translation from one system to another. This issue should be addressed by all parties to assure that information is transmitted, processed, and handled accurately and efficiently.

Die Standards

Every die cast plant needs tooling standards for cast and trim dies so that tooling is built to a standard of excellence. The heart of the die cast process is the tooling. It is false economy to send the part out to vendors without standards and then pick the cheapest quote. It may turn out that the die produced is not capable of satisfying the performance targets for production or quality. The best system is for the die caster to release tool construction standards to be on file at the tool makers and to issue a preliminary die layout for quoting a particular job. Included in the tooling quote package would be any special notes

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for construction and the part's critical characteristics or features. Then the tool shops will be quoting the same thing and have an understanding of what is required to meet the design intent.

Process Planning and Development

Process planning and engineering is the next critical step in reducing the casting's dimensional variation and in holding tighter tolerances.

Planning

Process planning should start early by forming a cross functional team that includes engineering, inspection, die repair, production, etc. Topics that should be addressed are:

Process Flow Chart

A Process Flow Chart should be developed that includes all material movements, processes, and inspection operations. For each operation, the affected critical dimensions should be shown along with potential process parameters that have an impact on the critical dimensions. The flow chart is a summary of the process steps that can be quickly referred to by all involved to get an overview of the process.

Process Layout

A detailed process layout should be made for the die casting and secondary and operations. This layout would accurately show the position of all the machinery, equipment, utilities, operators, etc. for construction, production, and maintenance personnel to implement. Doing the detailed layout gives all the plant's personnel a bird's-eye-view of the planned work stations and reduces the risk of surprises when the cells are constructed and production commences.

Control Plan

The Control Plan is developed after the Process FEMA. Assignments to check and plot the critical dimensions every shift may be given to inspection personnel or operators. Assignments to check and fill the machine hydraulic oil and hot oil may be given to a maintenance person. An assignment to verify cycle time may be given to a production person. The purpose of the Control Plan is make assignments to people in the organization for all the relevant aspects of the process that will lead to control of the CPK's of the critical dimensions. For items that still may go out of control, a Reaction Plan is developed to inspect 100% or to make additional die or process adjustments that will bring the process in control.

Preventative Maintenance Plan

Part of the Control Plan is the Preventative Maintenance Plan. Rings wear, dross forms, hydraulic fluid loses viscosity, bearings need grease, etc. during the normal course of production. Routine items like skimming, oiling, cleaning the die lube sprayers, etc. need to be addressed before a critical dimension goes out of control or the machine stops because a component fails. The idea of running the process until something breaks is not the best way to maximize productivity or control critical tolerances. A way to develop a Preventative Maintenance Plan is to read the equipment manuals and do the items within the

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suggested timing. For items not specified in manuals, the experience of the production or maintenance people can be a good source of what to do to maintain the process. The Preventative Maintenance Plan can be computerized with daily, weekly, and monthly assignments automatically generated, or a simple sheet can be hung from the control panel of the die cast machine to assign and record the preventative maintenance items.

Operator Training

The success of any die casting program depends on the people who make the parts on an hour to hour and day to day basis. These people include supervisors, setup men, operators, inspectors, maintenance personnel, and die repairmen. A plan should be implemented to assure that these people are trained in all aspects of their jobs as they relate to controlling the process and subsequently controlling the critical dimensions and process. The Control Plan, Reaction Plan, how to adjust the process, etc. along with visual aids can be consolidated in books at the die cast cell, inspection stations, or at the secondary operations to serve as reference for what and how to do various aspects running the process. Tolerance control will only be as good as the people who execute the plans and make the parts.

Die Maintenance Plan

Dies deteriorate through time as ejector pins wear, solder builds up, lime or rust forms in the cooling passages, thermal stresses build up, etc. Before the die is incapable of holding critical dimensions or before a mechanical failure occurs, the die should be pulled from the process and serviced. A good procedure is for dies to go through a standard routine whereas they are disassembled, cleaned, stress relieved, lubricated, checked for damage, and reassembled. A tool repair card completed by production and inspection personnel should accompany all dies as they come off the floor into die repair, so that the die repairmen know what to fix besides the routine work to be performed. Otherwise the die may go back out into production with items not corrected and produce castings that do not satisfy the tolerance requirements. A record of all repairs to each die should be filed for future reference.

Other Control Documents

Other documents and references may be developed to assist in process and tolerance control such as inspection visual aids, operator manuals, inspector and operator checklists, safety checks, OSHA and EPA information, etc. Within a plant where people speak different languages, it is beneficial to publish duplicate information in the languages used on the shop floor.

Packaging

Material handling and packaging from the die cast machine to the customer needs to be engineered and developed as critical dimensions that are good at casting may be out of tolerance by the time they get to the customer due to material handling damage. Holding inventory and moving material does not add value to the product, so the system should be engineered not only to protect critical tolerances but to make the material handling and inventory system efficient. A packaging specification and method of handling should be specified for in-process material as well as shipments to the customer.

Process Development

Initial Process Development

The first part of process development is done during the gating and thermal analysis' portion of the die design as assumptions are made concerning the shot characteristics, cycle time, methods of extracting heat, etc. These preliminary process parameters need to be documented on process sheets that are used as a starting point for process development. Once the die is in the machine and running, experiments or operator experience can be used to fine tune the process to find the best combination of parameters that improve cycle time and generate castings that best satisfy the part's tolerance requirements. The formulas used to develop the die cast process parameters will normally require some fine tuning to make the best parts. Process development and die adjusting to improve dimensional capabilities sometimes occur in a short timeframe so the process and steel adjustments must be analyzed well. Die steel should only be moved after all feasible combinations of process parameters are exhausted. Once the steel is cut, it cannot be put back without weakening the die. After the process is developed, it should be clearly documented for the operating people to use. The worst scenario is when process development is left to the operators who then develop a different process for each shift and document the process on slips of paper that are not shared. Another bad scenario is when the die is successively welded and cut to tune it in to a process that changes every time sample castings are made.

Final Process Development

After the die is in production, changes to the process can be made to reduce process variability or to find a better combination of process parameters that better satisfy the dimension tolerances of the part. This may come about with a process improvement or with a better combination of process settings as a result of designed experiments or employee insight. Whatever the means of accomplishing the improvements, there is a need to keep all channels for good ideas open so that the CPK's may get larger and production costs are reduced. Sometimes programs are launched with this expectation with target CPK's moving higher and piece prices decreasing throughout the life of the program.

Process Execution

Executing the process is where most of the time is spent in die casting. After the part print is finalized, the die is qualified, and the process is established, production is run for the majority of the program time. Many items for successful production and execution have already been discussed. The following is a summary of these ideas:

Training

All personnel involved with making the parts need to be trained in executing the Control Plan and in running the machines that make the parts. In addition, these people need to understand the part's critical characteristics and why each step of the Control Plan is important. Visual aids, qualifying gages, operator checklists, control charts, etc. can all assist in qualifying the operating personnel to execute the plans to control critical dimension tolerances.

Execution

The objective of production is to execute the Process Plan, Control Plan, Preventative Maintenance Plan, and Inspection Plan. These plans should be followed exactly. As someone performs an element of a plan, there should be some record of it so that management can ascertain whether the plans are executed and can also evaluate the quality of the workmanship. Die casting is composed of many little items contributing to the final product. Without good execution, process control, and tolerance control, production costs may be jeopardized. On one hand, there should be a discipline to run to the documented process. On the other hand, there should be an openness to suggestion and improvements.

Monitoring

The die cast process should be monitored to insure the process stays in control. Casting parameters that can be monitored are:

Metal Temperature

For a given cycle time, the furnace metal temperature determines the BTU/Hr (kW) processed through the die and is an important factor in determining die temperature which, in turn, contributes to the shrinkage rate, the relative internal stress in the casting, and the degree of tolerance control. Ideally, the furnace metal temperature is constant, but this is rarely the case in actual practice. The degree of metal temperature variation when recorded over a 24-hour period is frequently larger than assumed. Metal temperature should be monitored with subsequent action taken as required to reduce the variation as much as possible.

Shot Parameters

Slow shot speed and length, fast shot speed, shot pressure, pressure drop during the shot, hydraulic oil temperatures and viscosity, and plunger retract speed all have a great deal to do with porosity, surface finish, solder formation, and tolerance control. They should be monitored at least daily. A capability study on the fast shot speed is useful to determine the variability of the shot end for each die cast machine. This information can be used to qualify machines to run castings with tight tolerances and others to run castings with less demanding specifications. It may also lead to capital investments to stabilize the die cast machines' shot parameters.

Die Start Up Temperatures

The die casting process can take up to an hour to reach thermal equilibrium. The closer the die start up temperature is to the final operating temperature, the shorter the time it will take to reach equilibrium and the less the dimensional variability of the castings. Die temperatures can be measured with an infrared sensor or with thermocouples imbedded in the die. Either type of sensor may be connected to the machine's controls so that the process will not start until the die is preheated to a minimum temperature. Starting the die near the operating temperature is not only good for tolerance control, but also good for die life as die steel toughness increases up to 400?F (200°C).

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Die Thermocouples & Infrared Sensors

A relative measure of the die temperature can be made with thermocouples strategically placed in the die or with fixed infrared sensors mounted on the platens. Much can be learned about the thermal stability of the process by recording temperatures over a period of time. The temperatures might be correlated with part quality standards so that automatic or manual separation of acceptable and unacceptable parts can occur. Die opening can also be initiated by the die temperatures as a cold die will require a short hold time and a hot die will require a longer hold time. The key to using thermocouples or infrared sensors advantageously is placement on some part of the cavity. A computer simulation of the die and process can be helpful in determining the best initial locations.

Nozzle Temperature

The nozzle connects the gooseneck to the die in conventional zinc die cast machines. If the nozzle temperature is too cold, the molten zinc is chilled; if it is too hot, the molten zinc is further superheated. In order to reduce process variability, the nozzle temperature should be consistent. This is difficult to do with gas torches as they serve as spot heaters and can be out of control from shift to shift or day to day. A better method for nozzle heating is with electric resistance heaters with a feedback thermocouple to a controller. The nozzle temperature will be more uniform across the nozzle and have less variation. With either method, strategically placed thermocouples will lead to less nozzle temperature variability, better process control, and more dimensionally consistent castings.

Hot Oil Temperatures and Placement

When hot oil is used to control the die's operating temperature, the oil's temperature and pressure should be monitored. Hot oil machines automatically regulate the oil temperature so a high or low condition different from the process set point indicates a problem. In addition, each system will have a characteristic pressure depending on the total hydraulic resistance of the pipes, hoses, and cooling channels. Resistance as measured by pressure is a function of the oil's viscosity that is a function of the oil's temperature. To assure the hot oil is within acceptable process limits, both temperature and pressure need to monitored. A kinked hose may cause the pressure to rise and the flow to decrease through a particular cooling channel, thereby changing the flow through all channels and causing changes to shrink and dimensions. Hard water may cause the heat exchanger to lose efficiency causing the oil temperature to rise and the pressure to drop again affecting tolerance control.

Cooling Water Flow Rates and Water Hardness

Water is a very efficient coolant, so the flow rate is an important variable to monitor. The valves provided on die cast machines are coarse and nonlinear. It is very difficult to repeat water flow rates with these valves since changes may occur from shift to shift and day to day. In addition, the cooling water pressure may vary in some plants depending on the number of die cast machines running at any point in time. This is further complicated by the degree of water hardness. These problems can be addressed by a cooling tower water specialist to insure the system is sized to handle the heat load for all seasons of the year. Flow meters and temperature gages can be installed on each water-cooled circuit of the die to provide repeatability.

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In addition, sensors can monitor water hardness and devices can add chemicals automatically to keep the minerals in suspension. A thin layer of lime on the inside of the cooling channels can reduce the heat transfer rates a significant amount. Many years ago die casting was referred to as a 'black art' and problems with the cooling water was one of the reasons. Subtle flow rate changes and lime deposits caused unexplainable thermal changes shift to shift and day to day. The process was a moving target. If the effects of the cooling water's hardness are neutralized and the flow rates and temperatures going though the die are stabilized, then process viability will be reduced and castings with better tolerance control can be made.

Cartridge Heaters

Cartridge heaters are sometimes used to heat the portion of the gooseneck protruding from the molten zinc and also to add heat to cold running sections of the casting die. Thermo-couples in each case can provide a feedback loop to the cartridge heater via a controller to maintain desired temperatures. Monitoring these temperatures and fixing set points can help reduce variability.

Cycle Time

Cycle time is a major factor in determining die temperature. In order to produce consistent parts with high CPK's, the cycle time variability from shot to shot must be as small as possible. The only way to do this is with automatic die lube spray, and extraction or ejection. Cycle times encompass many of the components of the process such as hold time, spray time, open and close time, etc. In the modern era of running low cycle times, a small change in cycle time can be a big percentage change thermally to the specified process. Therefore, cycle times should be specified, monitored, and controlled to get the most out of the zinc die casting process for dimensional capability.

Evaluate and Modify the Process to Achieve Better Dimensional Control

Much data can be collected about a particular zinc die cast process. However, it does not do any good unless actions are taken to reduce process variability or to find a better combination of process parameters that reduce dimensional variability. Often the best intentions for monitoring, analysis, and control are made only to be superseded by a crisis that refocuses resources and the original plans do not get fully implemented. This cuts the zinc die casting process short of its potential. Part of the problem may be with initial planning that is over-specified. Data is collected from important as well as irrelevant factors, but the program crashes because there are not enough resources to analyze and take action on the immensity of collected data. So the planning stage is critically important to identify the significant dimensional stability items to match the organization's ability to analyze and use the data advantageously. Design of experiments using partial orthogonal arrays is a useful tool to separate the 'grain from the chaff' and concentrate on what is important to the process. If the program is successful, process insights can be gained and variability may be reduced with easy fixes. A good program focuses priorities for the limited technical resources and capital available to derive the most benefit. A good program may also reduce the need for monitoring, reporting, and analyzing as the 'insignificant many' factors are identified and eliminated from monitoring. This leads to less manufacturing costs along with better dimensional control. Die casting can be complex. There are many process factors which influence casting quality directly or indirectly. Success in identifying and controlling the 'significant' few process factors can have a positive impact on costs and dimensional stability. If this is accomplished with modern technology, zinc die castings can be made to the tolerance control potential the process has to offer.

Further Reading

- "Short Term Dimensional Changes in Zinc Die Casting Alloys", ILZRO Project No. ZM-398, by D. Argo and R. J. Barnhurst, Centre de Technologie Noranda.
- "Dimensional Repeatability of the Die Casting Process", by E. A. Herman, North American Die Casting Association.
- "ILZRO Dimensional Study Project dor Zinc Die Castings", by W. Walkington and M. Ward, Walkington Engineering, ILZRO.
- "Product Design for Die Castings", Diecasting Development Council of the North American Die Casting Association.
- "Designing for Die Casting", The New Jersey Zinc Company.
- "Die Casting with Zinc", by W. M. Peirce, American Zinc Institute.
- "A Survey of Dimension Tolerance Capabilities of North American Die Casters" by Frank E Goodwin and William G. Walkington, Indianapolis Paper #T95-031, North American Die Casting Association
- "Zinc Casting for Close Tolerance Components" Eurozinc.
- "Die Cast Dies: Designing", by E. A. Herman, North American Die Casting Association.

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