DESIGNING & PRODUCING DIE CASTINGS WITH HIGH PRECISION TOLERANCES

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DESIGNING & PRODUCING DIE CASTINGS WITH HIGH PRECISION TOLERANCES

Review Of Current Worldwide Standards

NADCA Standards for North America

For many years the best source of information about tolerances was the 'E' Series Product Standards of the American Die Casting Institute (ADCI). The first issue of these standards was in 1955, and it contained tolerances for zinc, aluminum, magnesium, and copper die castings. These standards addressed linear, parting line, moving die component (slides), draft, and flatness tolerances and served as an industry guideline for almost 30 years. Recognizing improvements in tool making, machine building, process engineering and control, and a market shift to smaller tonnage zinc die cast machines, NADCA issued new standards in 1994, which were revised in 1997.

In 1994, the Standard tolerances were made somewhat tighter than the original ADCI 'E' Series standards, and the Precision tolerances were added and made as much as 65% tighter. The new standards were prepared by the Die Casting Development Council with broad industry participation. The 1997 (Third) edition of the NADCA Product Standards made a number of changes that allow customers to obtain die castings with tighter tolerances. Specifically, it expands the scope of the standards for zinc die castings; and more accurately than ever before, it reflects the actual situation in the market. One important addition is a new (and badly needed) special section for tolerances on small zinc castings. Note that tolerances given in the standards may not be attainable with die casting dies that are many years old, partly because of wear, but also because toolmaking technology and process management have improved considerably in quality and precision over the past few years.

Although tight tolerances are attainable the designer must be aware that they may incur additional cost and that the largest tolerance which is fit for function should always be specified. It is especially important to note that the precision category examples which follow, although not the more generous standard category, are still commercial tolerances. Where there are special requirements the designer is urged to consult with the diecaster or a casting consultant. It is often possible to attain much tighter tolerances, with little increase in cost, depending on the geometry of the part.

Part of the reason for tolerances is to accommodate unpredictable shrinkage on casting and cooling. At present this cannot be predicted with sufficient accuracy to further reduce the allowed tolerances. However, this variation can be dealt with by running trial shots with the tool after it is built and making modifications to set the nominal value at the center of the variation. This procedure only needs to be done once and can effectively reduce the tolerance by around 30%. Very critical dimensions may also require a low temperature heat treatment to stabilize the casting. Details on stabilizing heat treatments are discussed later.

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Typical Tolerances From The Nadca 2000 Standards (third edition)

The part shown below (courtesy of NADCA) will be used to illustrate each category of tolerance. Comments on what is necessary to improve each category of dimensional tolerance are included.

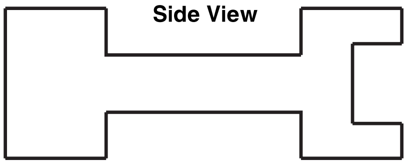

Figure 1. *Typical part shape as the designer conceived it.*

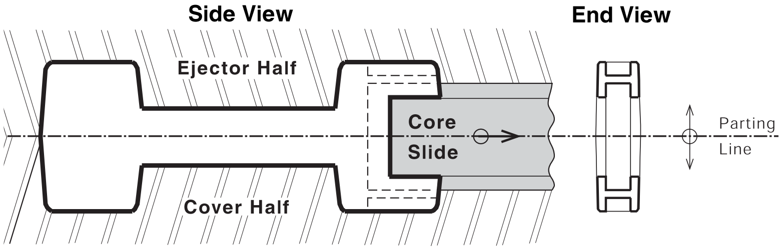

Figure 2. *Shape as die cast - this shape will illustrate the basic dimensional categories.*

There are five basic dimensional categories covered with die casting standards. These are listed below:

Linear Dimensions

Dimensions created entirely in the same die component. For example, dimensions between features cast all in the fixed half of the die.

These are the most stable and easy to manage dimensions. Once a critical dimension is established (perhaps by capability studies) as acceptable in one half of the die, it should remain very stable throughout the life of the die. Thus, if there are critical dimensions, the designer is advised do what is possible to put the critical dimensions one side of the parting line. This will give these dimensions the highest precision possible from the process.

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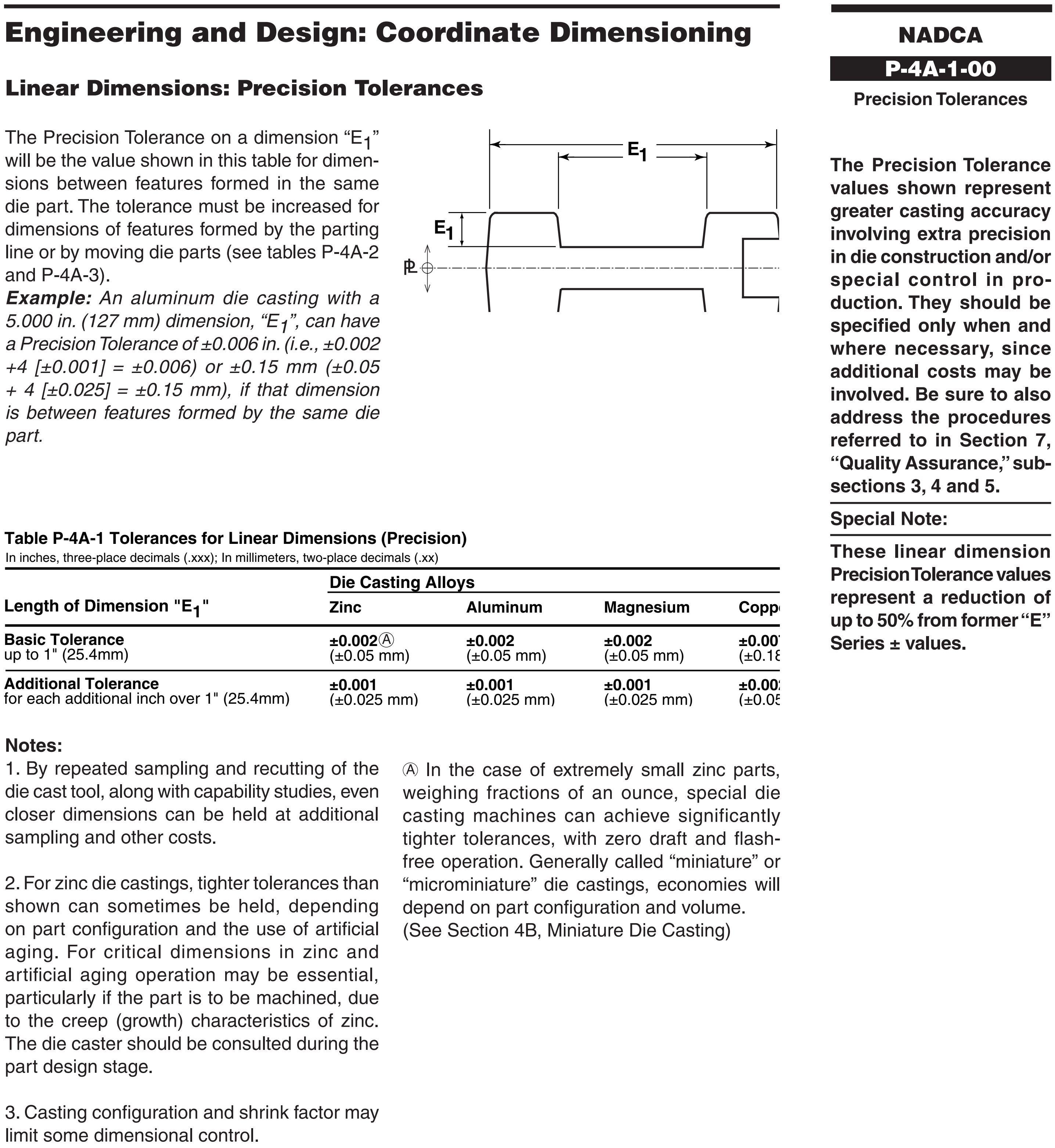
NADCA P-4A-1-00 Precision Tolerance for Zinc



Engineering and Design: Coordinate Dimensioning

Linear Dimensions: Precision Tolerances

NADCA

P-4A-1-00

Precision Tolerances

The Precision Tolerance on a dimension “E_1” will be the value shown in this table for dimensions between features formed in the same die part. The tolerance must be increased for dimensions of features formed by the parting line or by moving die parts (see tables P-4A-2 and P-4A-3).

Example: *An aluminum die casting with a 5.000 in. (127 mm) dimension, “E_1”, can have a Precision Tolerance of ±0.006 in. (i.e., ±0.002 +4 [±0.001] = ±0.006) or ±0.15 mm (±0.05 + 4 [±0.025] = ±0.15 mm), if that dimension is between features formed by the same die part.*

The Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved. Be sure to also address the procedures referred to in Section 7, “Quality Assurance,” subsections 3, 4 and 5.

Special Note:

These linear dimension Precision Tolerance values represent a reduction of up to 50% from former “E” Series ± values.

Table P-4A-1 Tolerances for Linear Dimensions (Precision)
In inches, three-place decimals (.xxx); In millimeters, two-place decimals (.xx)

	Die Casting Alloys			
Length of Dimension "E_1"	**Zinc**	**Aluminum**	**Magnesium**	**Copp**
Basic Tolerance up to 1" (25.4mm)	**±0.002**Ⓐ (±0.05 mm)	**±0.002** (±0.05 mm)	**±0.002** (±0.05 mm)	**±0.00** (±0.1
Additional Tolerance for each additional inch over 1" (25.4mm)	**±0.001** (±0.025 mm)	**±0.001** (±0.025 mm)	**±0.001** (±0.025 mm)	**±0.00** (±0.0

Notes:

1. By repeated sampling and recutting of the die cast tool, along with capability studies, even closer dimensions can be held at additional sampling and other costs.

2. For zinc die castings, tighter tolerances than shown can sometimes be held, depending on part configuration and the use of artificial aging. For critical dimensions in zinc and artificial aging operation may be essential, particularly if the part is to be machined, due to the creep (growth) characteristics of zinc. The die caster should be consulted during the part design stage.

3. Casting configuration and shrink factor may limit some dimensional control.

Ⓐ In the case of extremely small zinc parts, weighing fractions of an ounce, special die casting machines can achieve significantly tighter tolerances, with zero draft and flash-free operation. Generally called “miniature” or “microminiature” die castings, economies will depend on part configuration and volume. (See Section 4B, Miniature Die Casting)

Figure 3. *This is an example from the NADCA standards book, and shows the standards for precision linear dimensioning.*

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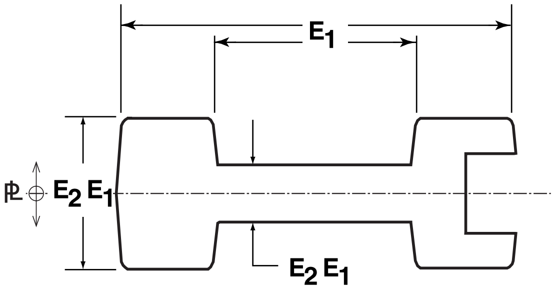
Parting Line Dimensions

Dimensions created across the die parting line. These tolerances are in addition to the linear tolerance for the dimension. For example, features formed in the fixed and moving halves of the die and measured across the main die parting line.

NADCA P-4A-2-00 Precision Tolerance for Zinc Parting Line Dimensions



Projected Area of the Die Casting inches^2	Tolerance
Up to 10 in^2 (64.5 cm^2)	+0.003 (+0.076 mm)
11 in^2 to 20 in^2 (71.0 cm^2 to 129.0 cm^2)	+0.0035 (+0.089 mm)
21 in^2 to 50 in^2 (135.5 cm^2 to 322.6 cm^2)	+0.004 (+0.102 mm)
51 in^2 to 100 in^2 (329.0 cm^2 to 645.2 cm^2)	+0.006 (+0.153 mm)
101 in^2 to 200 in^2 (651.6 cm^2 to 1290.3 cm^2)	+0.008 (+0.203 mm)
210 in^2 to 300 in^2 (1296.8 cm^2 to 1935.5 cm^2)	+0.012 (+0.305 mm)

Figure 4. *The dimension E2E1 is across the parting line, and the tolerances in the table apply.*

Note: This tolerance is listed as being dependent on the projected area of the casting, which is also a function of machine size. The larger the part and the larger the machine, the larger this tolerance needs to be. This tolerance can be held much tighter, if necessary, by additional process procedures which may introduce an additional cost.

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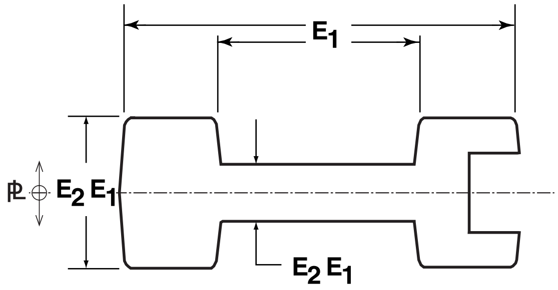
Moving Die Component Dimensions

Dimensions created perpendicular to the moving die component (slide) motion and to one or both of the main die halves. The tolerances are in addition to the linear tolerance for the dimension.

NADCA P-4A-3-00 Precision Tolerance for Zinc Moving Die Component Dimensions



Projected Area of the Die Casting inches^2	Tolerance
Up to 10 in^2 (64.5 cm^2)	+0.005 (+0.127 mm)
11 in^2 to 20 in^2 (71.0 cm^2 to 129.0 cm^2)	+0.007 (+0.178 mm)
21 in^2 to 50 in^2 (135.5 cm^2 to 322.6 cm^2)	+0.010 (+0.254 mm)
51 in^2 to 100 in^2 (329.0 cm^2 to 645.2 cm^2)	+0.014 (+0.356 mm)
101 in^2 to 200 in^2 (651.6 cm^2 to 1290.3 cm^2)	+0.019 (+0.483 mm)
210 in^2 to 300 in^2 (1296.8 cm^2 to 1935.5 cm^2)	+0.024 (+0.610 mm)

***Figure 5.** Moving die tolerance.*

Note: This tolerance is sensitive to die wear, and thus should be addressed with a very robust die design of the moving component, and with good maintenance procedures. Both of these affect the cost, at least to a minor extent, but they should be discussed up front to be sure the best performance is obtained from any given die.

Note: This tolerance is larger for bigger dies. This is because larger dies are harder to manage thermally, and there may be more temperature difference between different areas of the die, which can cause more variation in the dimension. Temperature control in the die can help, as will the most robust moving component design available.

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Draft Specifications

Draft, or taper, is created on die casting surfaces perpendicular to the parting line for proper ejection from the die. Recommended draft is a function of depth or length of the feature from the parting line.

NADCA P-4A-4-00 Precision Tolerance for Zinc
Draft Specifications

Draft Equation: D = (0.8 * L^.5)/C

Draft Angle Equation: A = (D/L)/.01746

where,

D = Draft in inches
L = Depth or length of feature from the parting line
C = Constant for type of feature, and
A = Draft angle in degrees

Values for C by Feature Type

Inside Wall	Outside Wall	Hole, Total Draft
60 (12.00 mm)	120 (24.00 mm)	40 (7.80 mm)

Figure 6. *Draft specifications.*

Note: This requirement is also determined partly by the shape of the part and how much the shape constrains the part from contracting as it cools in the die. Thus, if the design needs very low draft, the die caster or consultant should review the part because it may be possible to have less draft than the tolerance suggests. The draft on outside walls can often be zero degrees, and smaller critical areas of inside walls can often be made with zero draft. A recent ILZRO study illustrated that careful temperature control can be instrumental in maintaining zero draft on a large area without soldering.

The variation of draft with the length of the wall should be noted by the designer; a very short wall may need as much as 10 degrees of draft; thus a general note on the print may not be adequate to cover all situations. It is suggested that a solid model (or STL model) be done so that potential problems from draft angles can be visualized early. This can often save significantly in tool delivery time.

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Flatness Dimensions

Degree of surface deviation from a defined plane.

NADCA P-4A-5-00 Precision Tolerance for Zinc Flatness Dimensions

Maximum Dimension of Die Cast Surface	Tolerance
Up to 3.00 inch (76.20 mm)	+/-0.005 (+/-0.130 mm)
For each additional inch over 3 inch (76.20 mm)	+/-0.002 (+/-0.050 mm)

Figure 7. *Flatness specifications.*

Note: The flatness is determined by the die dimensions and by the operation of the process. It is often very difficult to predict the actual deflection in a given part (much more difficult than for a linear dimension); thus the method of using a capability study to determine the actual casting dimension, then correcting the die dimension to be in the center of the dimensional variation is often the best method of obtaining the optimum die shape.

The temperature of the die and the casting at ejection is also a critical variable because the amount of internal stress is established by these values, and the internal stress will cause some shape change after ejection. The best practice is to keep the temperatures consistent by using careful process control.

Software is being developed to predict the amount of variation. The die temperature at ejection must remain constant for the flatness to be controlled.

The NADCA Product Specification Standards also provide conversion charts and formulas to convert the above coordinate tolerances to geometric tolerances for flatness, perpendicularly, parallelism, runout, concentricity, maximum material conditions, and true position.

Again, the NADCA standards also point out that tighter tolerances are very often possible, and they suggest consulting with the die caster to determine the tolerance for a specific casting proposal.

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Small Zinc Machines (Four Slide and Others)

Small zinc castings, many of which are made on what is called a four slide machine, are very much in a class by themselves in die casting.

The small machines (the machines and the process they use are described later) have some special capabilities, and are given a separate class in the published standard tolerances. This is because they can hold much tighter tolerances than the larger machines, and they have the ability to produce at a lower cost.

The following NADCA tolerances are typical for miniature zinc die castings (again note that these can very often be exceeded for any given situation - contact a die caster specializing in this kind of work for any special questions).

Feature	Tolerance (inches)	Tolerance (mm)
Flatness	0.0015	0.04
Straightness	0.001	0.03
Roundness	0.001 (// to parting line)	0.03 (// to parting line)
Perpendicularity	0.001 inch/inch	0.001 mm/mm
Parallelism	0.001 inch/inch	0.001 mm/mm
Concentricity	0.002 (// to parting line)	0.05 (// to parting line)
True Position	0.0015 total	0.04 total
Minimum Wall Thickness	0.020	0.050
Surface Finish	16-64 microinches	0.4-1.6 microns
Gears	AGMA 6 - AGMA 8	
Threads - External as Cast	2A	6g

Figure 8. *Miniature casting specifications.*

Standards Used in Other Countries

Other major zinc die casting regions of the world have their own tolerance standards. They include ISO (Switzerland), DIN (Germany), ZADCA (England), and DCS (Japan). The following discussion reviews these standards and compares them with the current NADCA standard. All of the standards point out that it is not their intent to show the tightest tolerances that can be held due to the many die casting factors such as part geometry and process variation that can affect tolerances. They all recommend consultation with the die caster at the design stage to determine appropriate dimensional tolerances that may be closer than the published standards.

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ISO

ISO stands for the International Organization for Standardization and is published in Switzerland. The ISO standard addresses all common casting methods including sand manual, sand machine/shell casting, permanent mold (low pressure die casting), pressure (high pressure die casting) casting and investment casting. It also includes commonly cast materials including steel, gray iron, S.G. (ductile) iron, malleable iron, copper alloys, zinc alloys, light metal (aluminum and magnesium) alloys, nickel based alloys, and cobalt based alloys. There are 16 casting grades designated CT1 to CT16. Zinc die castings were originally indicated as falling into grades CT3 to CT5. How-ever, on revision this information was deleted pending a decision to indicate tighter tolerances. The categories for geometrical measurement include basic dimension, straightness, flatness, circularity, cylindricity, perpendicularly, parallelism, coaxiality, and symmetry. These tolerances are currently being developed but not yet issued. They appear to take the DIN (German) format with zinc die castings falling into three ‘tolerance grades’ versus NADCA’s 2 ‘tolerance grades’

DIN

DIN stands for German Institute for Norms and is published in Germany. Tolerances are a function of the size of the dimension, the grade of the casting, and the casting body diagonal. The casting body diagonal is the longest distance obtainable in a prismatic envelope surrounding the casting and compares with NADCA’s plan view area. Casting grades are referred to as GTA grades with zinc castings falling into grades 12 to 14. For each class of body diagonals there are two grades, precision and standard, and within each grade there are die dependent and die not dependent subdivisions. Die dependent and not die dependent are the almost the equivalent of NADCA’s linear, parting line and moving die component categories.

Zinc die casting is covered by DIN 1687 sheet 4.We can somewhat relate this standard to the linear, parting line, and moving die component section of the NADCA standard. Certainly some of these dimensions are tighter than the NADCA standards. In the DIN standards, there is a note that says it is necessary to have an agreement on all tolerances between the customer and the die caster as it is difficult to make standards for all casting geometries.

EUROZINC

EUROZINC is the imprint of the European Zinc Institute with member organizations from Belgium, Germany, Italy, the United Kingdom, Spain, the Netherlands, Italy, France, Norway, and Finland. The headquarters for the European Zinc Institute is in Brussels. Tolerance standards were published by the UK Zinc Alloy Die Casters Association in 1957 with updates occurring through the years with the last being 1974. It is no longer issued as the industry considers it does not represent current practice. Part of the standard remains a useful background document as it is one of the few to carefully define geometric features. The current Eurozinc publication on tolerances uses graphs to indicate the “best achievable” and the “usual” tolerances based on a recent survey of commercial practice.

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Japan Die Casting Association (DCS)

DCS E are the die casting tolerance standards for Japan and are published by the Japan Die Casting Association. These standards are very similar to the ADCI Standards released in 1958. Many of the illustrations and charts are exact copies of the ADCI material. Again, these standards are not so much as what can be done but serve as a very general guideline for designers and die casters.

Summary

After reviewing these different standards, it can be seen that there are different approaches to tolerancing, especially in the DIN standards from Germany. However, as noted in those standards and as noted here earlier, it is necessary to have agreement with the die caster about the tolerances. There will be some die casters with the capability to produce to tighter tolerances than the standards. In general, the tolerances listed in any of the standards represent guidelines that can be attained by many suppliers.

All countries will have different die casters with different experience histories and capabilities. Those designers that have specific requirements, even though they may be much more tighter tolerances than those listed in the standards, should confer with one or two die casters (or consultants); make modifications if necessary and then make the decisions on the final dimensional requirements for the part. Many times these final specifications can be tighter than the published tolerances.

It should be noted that differences between the capability of the casting producers is a function of engineering capability, of being able to design and build/purchase precision tooling, and of having disciplined process procedures; and is not necessarily a function of the country where the plant is located.

Topics For Designers and Die Cast Engineers

Design Considerations

The advantage of using a net shape manufacturing process that reduces or eliminates secondary machining or assembly operations has long been recognized. Of all the die casting alloys, zinc provides the best solution to producing economic net shape three dimensional components to the tightest dimensional tolerances relative to other die cast alloys. What can actually be achieved is a function of the design geometry, die construction, and the equipment process capabilities. Thus the knowledge and skill of the part designer and the die caster will define the success of any given project.

Designing a zinc die casting begins with some understanding of the casting process. First, molten metal at 800?F (420°C) is injected at high speed into a die that is around 300 to 400?F (150-200°C) so as to fill the cavity within a few milliseconds. This filling process must be very quick, and is therefore very turbulent - in fact it is very close to a metal spray process. The metal freezes and solidifies very quickly. After solidification, the casting cools and contracts in the die, causing internal stresses as the casting is restrained by the die. The die is made a nominal .005 to .007 inch per inch (mm/mm) larger than the casting to allow for some of this shape change (normally called toolmaker’s shrinkage allowance).

This process is complicated by the casting shape, for example thin sections freeze before thick sections. There are different die surface temperatures along the metal flow paths, and there are different constraints on the contraction due to different shapes (cores or walls that do not allow shape changes). These factors

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(and others) result in a number of design issues such as the desirability of having consistent wall thickness.

When the metal has solidified, the part is ejected from the die (which may add various internal stresses), and as the part cools to ambient, it continues to contract. The amount of shrinkage may be affected by the cooling medium, water or air, and also by the type of alloy cast. Once at room temperature, the shrinking process slowly continues at an ever declining rate. Dimensional changes continue for about 30 days, after which it is essentially stable. Over this time the internal stresses in the part gradually dissipate and the metallurgical structure attains equilibrium. The ultimate shape is a function of the geometry of the part, the alloy, and the process used in casting and quenching.

The aging shrinkage process can be accelerated by soaking the casting at 200 ?F (95°C) for about 2 to 8 hours. Aging curves have been developed for a number of zinc alloys, for most cases, such as those shown below for Alloys 2, 5 and ZA-12. The small dimensional changes are usually of no consequence and are only an issue for very tight dimensional tolerances. However, it is necessary to be aware of the die casting process in order to take counter measures in the casting design so as to get the most out of the process.

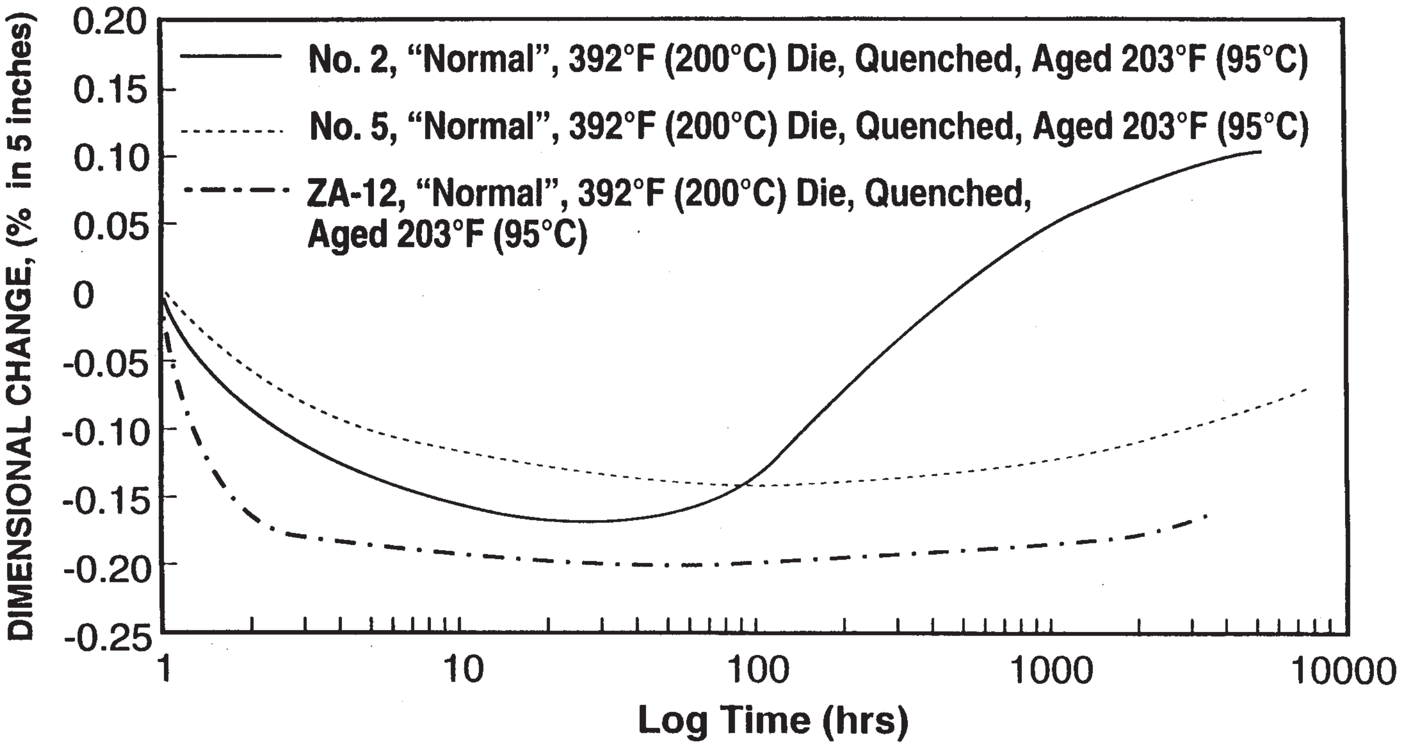

Figure 9. Aging curves for Alloys 2,5 and ZA-12 at 203°F (95°C). These castings had compositions at the midpoint of their specifications and were cast using a die temperature of 392°F (200°C). They were cooled in the die rather than ejecting and quenching.

Shrinkage and Distortion

The following list of design considerations may be helpful in controlling shrinkage and distortion and their effects on tolerance control:

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Uniform Wall Stock and Section Thickness

Casting wall stock should be as uniform as possible. This allows the casting to freeze at a uniform rate and allows it to be ejected sooner thus minimizing internal stresses. Thicker walls do not necessarily translate into stronger castings because much of the strength of die castings is contained in the rapidly solidified alloy that lies near their surfaces. In addition, avoiding thick sections can contribute to cost reduction as the extra metal adds to the cost and serves no function. In general, thinner walls are better; they reduce the amount of material required (and thus costs), they reduce weight, and they are almost as strong as thicker walls. However, walls of less than .04 inch (1 mm) become difficult to cast, and a wall thickness of .06 inch (1.5 mm) to .08 inch (2 mm) would provide a good compromise if other factors allow.

Metal savers (cores) are commonly used as aids in maintaining uniformity of section thickness. The thickness of a section should be proportional to the functional stresses anticipated in use. The addition of ribs and fillets will add to strength as well as stiffness without making a significant change in wall stock, and will make a lower cost design.

Figure 10. An example of consistent wall thickness design. Adding the metal saver (core) reduces weight and costs, it maintains cconsistent wall thickness for easier die casting, and it will have the same strength characteristics as the original design. The tooling costs will almost be the same.

Consistent wall thickness is desirable from a process as well as from a strength and cost standpoint. Having slightly different wall thickness can cause difficulty in metal flow, and should be avoided if possible. A consistent wall helps create a higher quality part - thus the designer should regard a consistent wall thickness as a very important design goal.

In particular, any thinner section (a thinner section here would be defined as below .08 inch (2 mm) should have smaller tolerances so the wall thickness will not vary in die construction. For example, a specification of .06 inch (1.5 mm) with a tolerance of ?.01 inch (.25 mm) would allow some walls to be .05 inch (1.25 mm) and others to be .07 inch (1.75 mm). This may not be an issue functionally, but it will be an issue for casting quality - having a lower tolerance (say ?.004 inch (.1 mm) would be better for die casting. (Many die casters would reduce the tolerance themselves.)

Fillets and Radii

Intersecting surfaces forming junctions should be radiused to minimize stress concentration in both the die and the casting. Even the smallest fillets have an appreciable strengthening effect. They also decrease defects that come from poor metal flow and the heat concen-tration at sharp corners. A minimum radius of .015 inch (0.4mm) is suggested for all sharp exterior corners and a minimum radius of .020 inch (0.5mm) on all inside corners. Shallow sections may have smaller fillets while deep pockets will benefit from larger fillets. Formulas for fillets and radii are shown on the design illustrations that follow.

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Ribs

Ribs can serve to stiffen the casting; reducing warpage and distortion and increasing strength while adding very little extra weight. Ribs are often placed near where the casting is gated to minimize warping. They are also placed around bosses to distribute the load over a larger area. By skillful use of ribs, it is often possible to use a lighter casting thereby making significant economies in the metal required. Guidelines for ribs are shown on the design illustrations that follow.

Draft

Draft is needed to allow the die casting to eject off the die. The contraction of the casting in the die causes it to grip the inside surfaces, and this force causes friction at ejection. At this time, the casting is at high temperature, and therefore weaker, so draft is required to prevent distortion. The greater the draft the easier the casting comes off and the less chance for distortion at ejection. Draft angle requirements vary inversely with wall depth. A very good guide for draft are the NADCA recommendations. Where there is not a good reason for using the minimum draft recommendations, generous draft should be allowed to minimize the potential for distortion during ejection and cool down.

The NADCA recommendations should be the guideline for draft dimensions, however, they were created for the general situation for all castings. The designer should keep in mind that there are many situations where the draft allowance can be reduced, even to zero, but these must be considered separately for each situation. If reduced draft is a requirement, the designer should always ask for what they need; while it sometimes is not possible, many times the casting companies have the engineering capability to provide for these special requirements. It is important to not limit the design because of these general guidelines.

Plain Flat Surfaces

Plain flat surfaces of any considerable area will tend to have some surface blemishes, and should be avoided if possible. They can be broken up with stippling, ribs, serrations, steps, or a crown of at least .015 inch/inch (0.4mm/25mm). These countermeasures will reduce distortion, increase strength, and will tend to mask slight surface imperfections thereby improving appearance.

Tolerances

Tolerances should be specified for the design intent required. It may cost more to hold and maintain close tolerances, so there is no point in demanding close tolerances when they do not serve a useful purpose. Completing a Design FEMA (Failure Effects Mode Analysis), making and testing models, or doing partial factorial experiments can help determine the importance of particular dimensions and their tolerances to meet the design intent economically.

Review the tolerance stack up, and be sure each component is reviewed. In die casting, as in other processes, review the tolerance requirements with the vendor or a consultant - often tighter tolerances can be permitted. Sometimes this will also require some other design concessions (i.e., change in parting line location, added draft, etc.).

Overtolerancing does not necessarily better satisfy the design intent as it may dissipate the customer's and die caster's scarce resources in trying to meet them. The objective should be to satisfy the design intent

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with relatively few critical dimensions that are tightly toleranced and are within the range of the capability of the die cast process.

Modeling

Models can be physically made and tested, or they can now be virtually made on the computer with 3D CAD and analyzed with software to determine metal flow, thermal conditions, stress points, part volume, etc. Currently, one of the best and most widely used visualization tools is an STL stereolithography (or SLA) model. This can be created by almost every CAD system, and can be read by many different visualization programs as well as other CAD systems. The STL image can be very quickly made and transmitted to those interested (casting vendors or consultants, mating parts manufacturers, etc.) where it can be magnified, rotated, and sectioned so that problems can be foreseen much easier. Providing the STL file to the die caster early in the design process is one of best available insurance policies against problems.

Solid models can be developed in the CAD systems and tested in simulation programs that predict stresses from simulated applications. Process simulation programs can also predict metal flow and thermal conditions during casting. These are only useful if they are run before the design is finalized; it is very likely that design changes will be indicated from the simulation. (Before we had simulation, these problems were discovered after the die was made and production was starting. We then had to live with the problems and higher costs that resulted.)

Simulation is becoming the accepted method of predicting the flow pattern and thermal conditions; they allow the testing of the proposed gating and thermal conditions before the die is built. It is a great help in preventing problems and in optimizing the gating and thermal conditions for best quality production. Thermal conditions are very critical to quality, and they also determine the casting cycle time. The use of simulation to predict the thermal conditions in the die is very effective at reducing cycle rate and thus in reducing costs.

Prototype dies can be made to produce actual die castings of proposed designs. The cost of all these design tools must be rationalized, but the potential savings in optimized design can be significant. Some of potential benefits of modeling are:

- *Performance of the part can be improved.*
- *Material can be taken out of the part.*
- *Changes can be made to reduce distortion.*
- *Engineering changes released after the start of production can be reduced.*
- *Design mistakes getting out into the field can be minimized or eliminated.*
- *Mating parts can be fit before building tools and fixtures*
- *The tool designer and tool maker can better visualize the part during the tool design and construction phases decreasing the chances for mistakes.*

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Materials

Many zinc alloys are available to suit different design needs. There are the Zamak alloys #2, #3, #5, and #7, and the ZA alloys ZA-8, ZA-12, and ZA-27.

These alloys have different mechanical characteristics to suit different needs. Alloy selection is a function of:

- *Alloy cost*
- *Process cost*
- *Structural properties*
- *Weight*
- *Impact strength*
- *Surface finish*
- *Wear resistance*

There are too many alloy selection issues to cover in this manual but it should be noted that the material characteristics of the zinc die casting alloys are much under-utilized because of lack of knowledge. ILZRO, the Die Casting Development Council, International Zinc Association, Interzinc, and zinc metal suppliers can provide detailed alloy properties to best meet the design intent at the least cost.

Dimensions

For the die caster to be able to design and build a die and to operate a process that will maintain stringent tolerances, there are many dimensional issues that need to be defined early in discussions with the part designer. The most important of these are outlined below.

Datums

Ideally, datums should be located through the center of the part in one half of the die where the effects of shrinkage and parting line variation will be the least. If the datums move, all the reported feature dimensions move, and die corrections may be made that do not necessarily make the part better. Datums that involve the main parting line, slides, or are located far away from the centerline of the part in each axis should be avoided as datum variation will invariably occur.

Many datums are located on surfaces that have draft; these datums should be defined as flat pads of zero draft on these surface. Even better, these surfaces can be raised slightly (.002 to .025 inches/ 0.05-0.5mm) so that they will be easier to find and to use. This small area of no draft can be accommodated in almost every casting, although if the datum is located on an inside surface (one that shrinks on), it may cause problems. The datum surface should be polished, and should be very carefully dimensioned and located in the die. Making the raised pad "steel safe (maximum metal)" will allow easy adjustment of the datum.

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Fixturing Surfaces

Fixturing surfaces need to be defined to minimize clamping stress and distortion in secondary operations. It can be frustrating when the critical dimensions of the casting change after a secondary operation due to where and how the part is held. The fixturing surfaces should be strong and stable to provide repeatability for inspection or secondary operations.

Machining

Machining starting points should be discussed for castings receiving a lot of machining or where datums are affected. When die castings are machined, internal stresses may be created or relieved causing the casting to distort to a new natural form. To hold tight tolerances, it may be necessary to sequence the machining in a certain way or to rough machine, release the casting from the clamps, re-clamp with a lighter grip, and finish machine.

References and notes

The design engineer and die caster should discuss all references and notes on the prints. Many of the notes are as important as the critical dimensions and tolerances and they should be understood by the die caster. The die caster also needs a copy of the customer's engineering standards that are referred to on the print.

Steel safe (maximum metal) concepts – Leaving excess metal on die to remove water

Steel safe concepts need to be addressed. The toolmaker will need tolerance for making the die and the prediction of shrinkage is sometimes difficult to do. It is good practice to lean towards the steel safe side of the tolerances and to correct the die after sample runs. On very tight positional core tolerances, it is best to make the cores undersize, and relocate the cores by jig grinding after the actual casting positional data is available. Steel safe concepts can help avoid welding on the die when making die corrections to improve tolerance control. In addition, high heat areas of the die may erode and heat check prematurely so it is prudent to be steel safe in these areas.

Distortion and shrinkage

Virtually all die castings will have internal stresses that lead to shrinkage and distortion over time. The problem in die casting is that all the factors that come into play may make distortion worse or better depending on the direction of the stress they induce and the amount of dragging that occurs during ejection. The issue to be addressed is this: "Can design changes be made to reduce anticipated stress and ejection drag?" As mentioned before, judicious use of metal savers, ribs, fillets, draft, and radii can help reduce distortion and shrinkage.

Weak die steel conditions

The part features should be critiqued with a vision of how the die will look in all sections. The function of the die is to absorb heat and to make the impression. The greater the amount of die steel, the better the die will perform its functions. In the die casting process the steel is subjected to large mechanical and thermal stresses. If the die steel is over-loaded with heat, then cyclic thermal stress can cause premature

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heat checking and cracking. In addition, excessive heat can cause a local section to expand more than the rest of the die causing dimensional problems and even mechanical problems by holding the die open and causing parting line flash. If shut-offs with slides are too small, then local stress concentrations may exceed the yield limit of the steel and cause plastic deformation and crushing. The die may start out capable of making the part but prematurely becomes incapable due to deformation. The intent at this stage of the design is to critique the part for changes that may remedy potentially weak die steel problems.

Captured features

Captured casting features may have excessive internal stress especially if they are thin and freeze before the heavier casting or runner sections. As the thin sections freeze and cool they shrink faster than the heavier sections. If they are constrained by the die steel, problems may be encountered in sticking to the die or with dragging during ejection. Design changes such as adding draft should be made to improve the castability of these captured sections. Can the thicker sections be made thinner with metal savers or ribs? It helps to visualize which way the shrinkage will occur and to take countermeasures to minimize the effects as the casting solidifies on the die.

Free wall sections

Free wall sections are like captured sections and need draft to ensure they come off the die at ejection without dragging and distorting. In addition, a stuck free wall section can cause a lot of downtime if the only way to get the casting out is to remove the die, take it apart, and extricate the stuck section in the tool room.

Die steel and metal temperature differences

As the metal travels through the cavity it gives up heat. The metal and die will be hotter where it enters the cavity and will be cooler were it exits. The relative shrinkage of the casting and subsequent distortion are proportional to these temperature differences. If metal can be removed from anticipated hot areas, or stiffeners such as stippling or ribs added, distortion may be reduced. Conversely, anticipated cold areas of the casting may benefit by adding extra metal.

Parting lines

Parting lines affect the die design, the part functionality, and degree of dimensional control. They can also affect where the metal can be brought into the cavity, the direction and speed of the metal flow within the cavity, where the air can go out, and how much air can get out during cavity fill. These many interacting factors can affect the quality of the fill, the die life, the cycle time, the level of porosity, and relative degree of dimensional stability reflected in tolerances attained, etc. It is important to study the parting lines and determined where they are best placed. For some castings, this is easy and intuitive, and for others there are alternate parting lines that can be evaluated to arrive at the best overall compromise. Sometimes the parting line is raised to provide a better metal flow path creating a section with opposite draft above and below the ingate. If the design will allow this then a better part will be made. Parting lines for slides should also be critiqued closely as slides can present problems for dimensional control. Long parting lines

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allow the heat from the incoming metal to be spread over a larger area allowing for more uniform die temperatures and thus better dimensional control.

Ingate and outgate placement

Ingates control the metal coming into the cavity and outgates control the metal and air going out of the cavity. Both ingates and outgates control the paths and velocities the metal takes through the cavity. These factors are important for the production of sound die castings with good surface finish, low porosity, and good dimensional control. As mentioned earlier, the thermal differences in the metal and steel temperatures across the die have much to do with the resultant internal stresses and degree of distortion produced. Therefore, the alternatives of ingate and outgate placement should be evaluated to choose the best overall design relative to dimensional stability, surface finish, and porosity. It is usually better to take the shortest path through the cavity between the ingates and outgates and to spread the heat of the incoming metal over as much of the casting as possible.

Venting opportunities

Vents are normally attached to the overflows but sometimes to the part itself. The function of the vents is to let the air out as the metal is coming into the cavity. The quality of the fill, degree of 'die and slide blow,' and the level of porosity is a function of vent placement and size. All of these items contribute to the relative dimensional stability produced. When the part design and parting lines are proposed, there should be a vision as to how venting opportunities are affected.

Porosity and leak test issues

All zinc die castings have some degree of porosity originating from two sources - entrapped air and metal shrinkage. Gas porosity occurs when the air is trapped in the cavity at the end of cavity fill. The amount of trapped air is a function of part geometry. Dead end features that have no opportunity for venting, parting lines that do not allow for the best fill pattern or do not allow for sufficient vent size, lead to air entrapment. Shrinkage porosity occurs because the metal contracts as it solidifies. The metal freezes from the outside surfaces towards the interior, and the shrinkage porosity will occur somewhere in the middle of the casting sections. When the design intent specifies a low porosity casting or a casting that must be leak tested, then thought must go into how the part can be designed to minimize the effects of porosity. One way is to provide parting lines with good material flow paths. Another suggestion is to avoid thick sections and use ribs or metal savers where porosity may cause a problem.

Slides

Slides can cause special problems in die casting depending on the geometry created and the size of the slide. As with the main parting line, generous draft should be used to minimize distortion as the slide retracts off the casting. The size of the slide is also of concern whereby the larger the slide the bigger the problem of thermal expansion. Shutoffs originally fitted at room temperature may expand causing the slide, or some part of the main parting line, to hold the die open. Both expansion situations may affect control of tolerances and should be discussed at the part design stage.

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Core Placement

Cores can be adversely affected if placed directly in the path of the incoming metal. The speed of the incoming metal is 800 to 1200 inches/second (25-45m/s) and direct impingement on cores can cause distortion or build up of solder which adversely affects tolerances. Another consideration is the relative placement of ejector pins adjacent to cores. Metal will shrink around a core as it solidifies and can cause distortion due to drags. Sometimes ejector pads are added to the part design to assist with ejection around cores as well as deep wall sections to minimize the effect of drags.

Secondary operation alternatives and options

Though an objective of die casting is to produce a net shape part, there are times when it is not possible or feasible to cast all the final features, and secondary operations are added. An example is a core that needs draft to cast yet requires tapping. In this case, the secondary operation would be to drill to remove the draft and then tap. Another case is where the tolerance of the hole is too tight to cast and a drilling or reaming operation is employed to produce the size and tolerance required. Sometimes slides are too awkward to put into the cast die and it is more feasible to machine certain features. The design engineer and die casting engineer should review each case with the possibility of changing the part design or tolerances to eliminate a secondary operation. Three principles are helpful:

* *Think function, not form Die castings can take different forms than machined parts and can look different to perform the same function.*

* *Performance must be sufficient, not greater than required Over-designed and specified parts are always more expensive than they need to be.*

* *Materials must be matched to the performance specifications There are many zinc alloys available that can be used to satisfy different needs.*

Significant cost savings can be realized by avoiding overdesign and figuring a way to reduce the need for secondary operations yet still satisfy the design intent for the part.

Method of information transfer-CAD

Most part drawings are now CAD generated. Files are designed and transmitted electronically, and the same files are used to program the machine tools that make the dies. For everything to work, compatible protocols must be established so information does not drop out and the die is made to the customer's design. One of the benefits of CAD is that everything must add up. Mistakes or conflicts on the part drawing will surface and the design engineer must be available to decide what corrections should be made prior to cutting the die steel. Timeliness in response is important because any part print changes may detract from the time available to meet the target sample or production dates.

Engineering changes

The protocol for engineering changes needs to be defined and the review practices established in order eliminate problems later. Usually an engineering change is reviewed by the die caster and a quotation is

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sent back to the design engineer or customer for authorization to proceed. The customer then updates the print and issues a purchase order to make the change. When this system is bypassed for the sake of time or expediency, there are many chances for misunderstanding. Making the change by just sending out the print or verbally describing the change and not sending out the print can lead to expensive fixes. In addition, all changes should be listed on the print's change column. If all the changes are not listed with a Revision Level Change, then the die caster or tool designer must compare every dimension on the print between revision levels and 'discover' the changes. This is a time consuming process that is not error free. Good communications and a standard system for processing changes are needed to make the engineering change system work.

Part Design Concepts, Examples and illustrations

The following illustrations indicate desirable and undesirable design concepts:

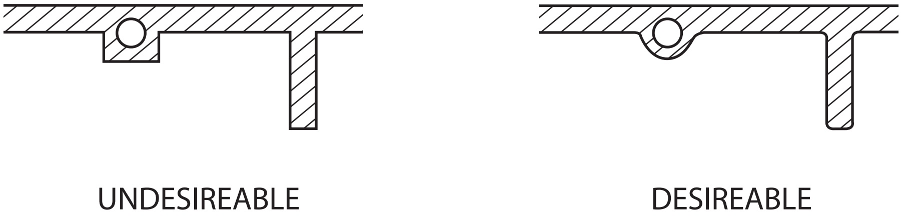

Figure 11. Basic design concepts.

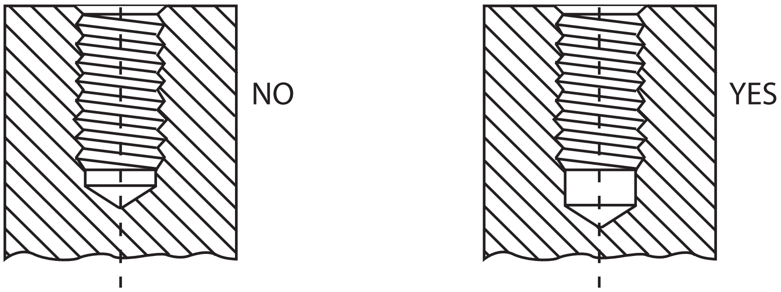

Figure 12. Always allow extra thread depth for tapping or self tapping operations.

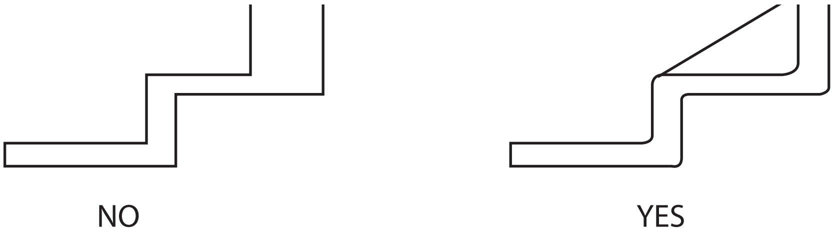

Figure 13. Basic design concepts.

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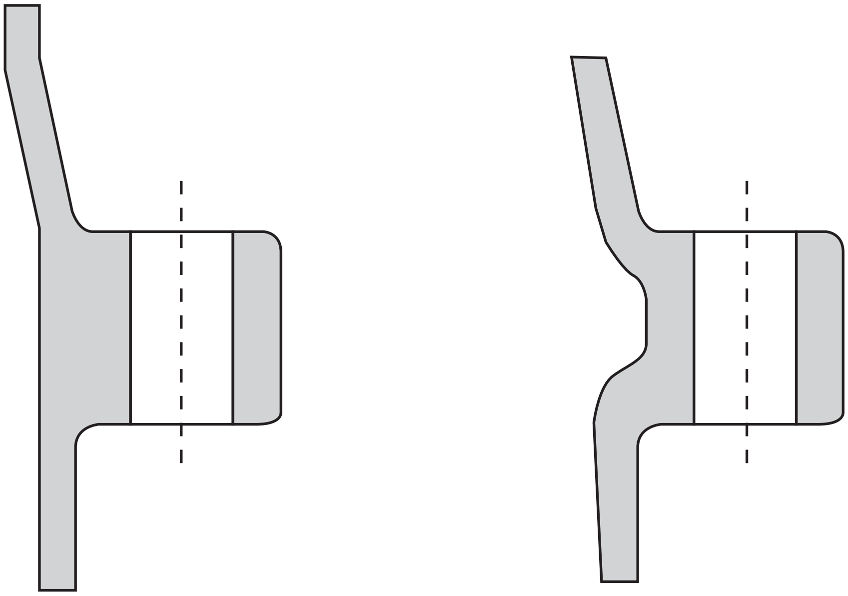


The design on the left should be changed to something like the design on the right for best metal flow, lower weight, and best strenght and quality

Figure 14. *Design concepts.*

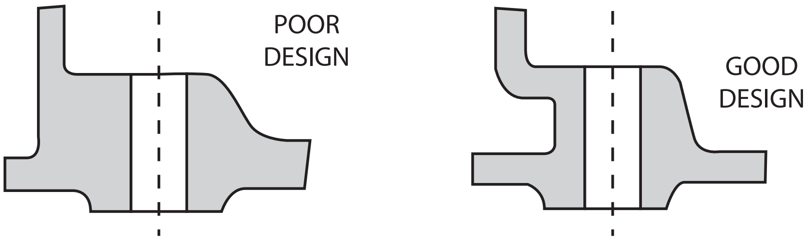
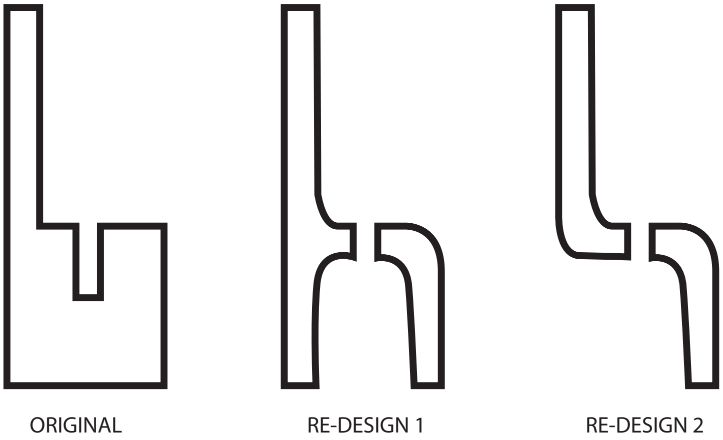


Figure 15. *Design concepts.*



ORIGINAL RE-DESIGN 1 RE-DESIGN 2

Figure 16. *Design concepts.*

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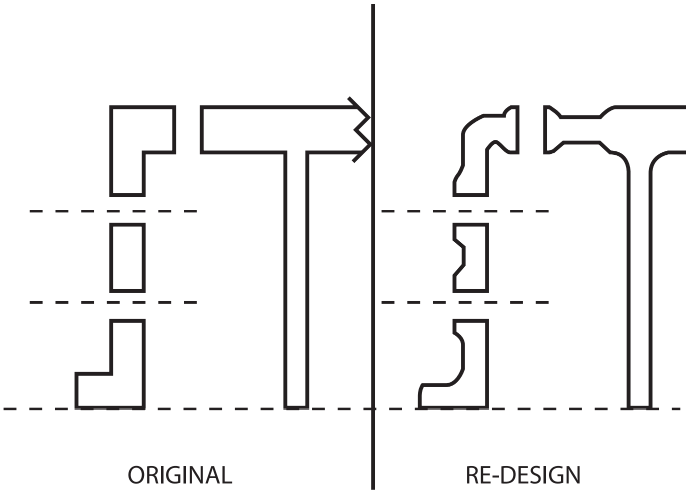
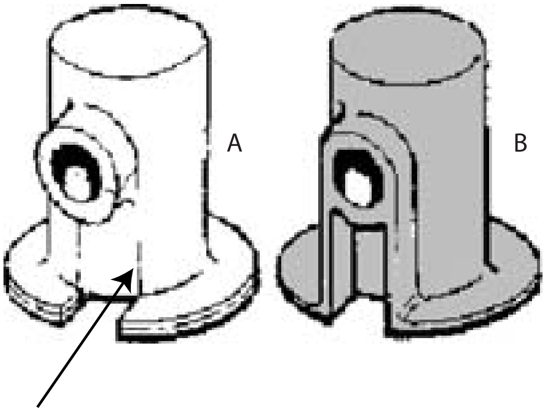
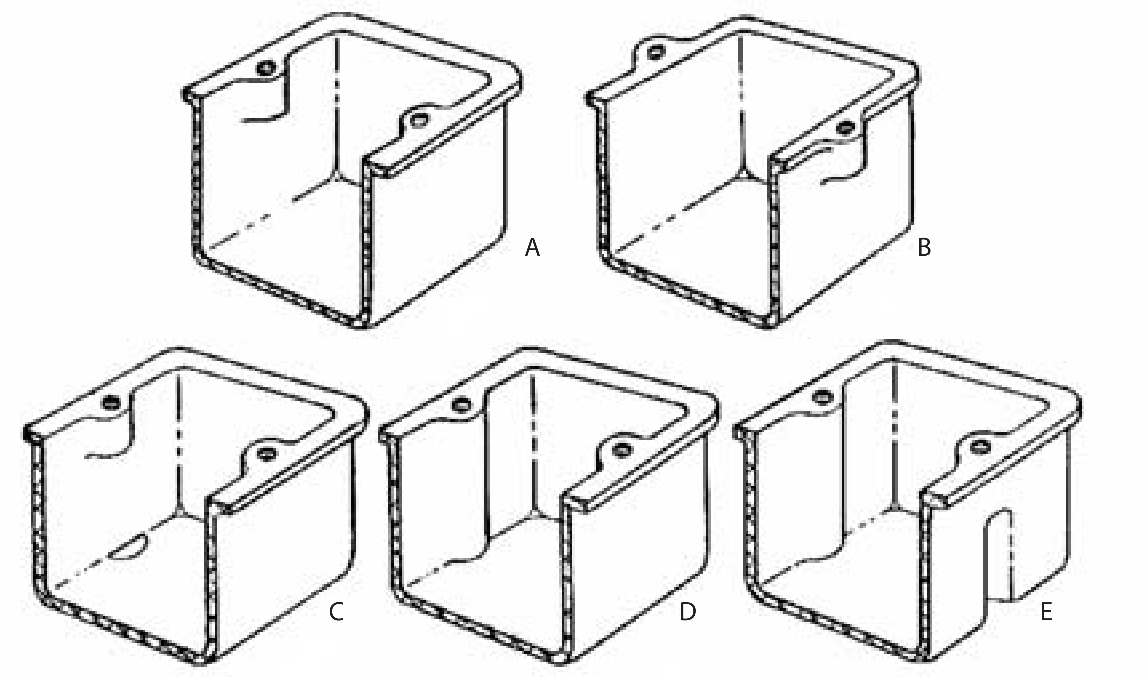


Figure 17. Design concepts.



The slide can be made in several shapes, but the shape B allows the entire surface to be trimmed easily, and could save an expensive extra operation. The arrow points to the flash that woll be developed with design A.

Figure 18. Another example of good design work that saves money and makes a better part.



The housing at A has internal undercuts under the bosses. Design B locates the bosses outside the housing. Design C uses retractable core members, which break through the bottom of the casting. Design D eliminates the undercut by extending the boss to the bottom of the hole. Design E similar to D on the inside surface, but maintains more uniform wall thickness.

Figure 19. *Another illustration of some of the design options for a mounting bolt.*

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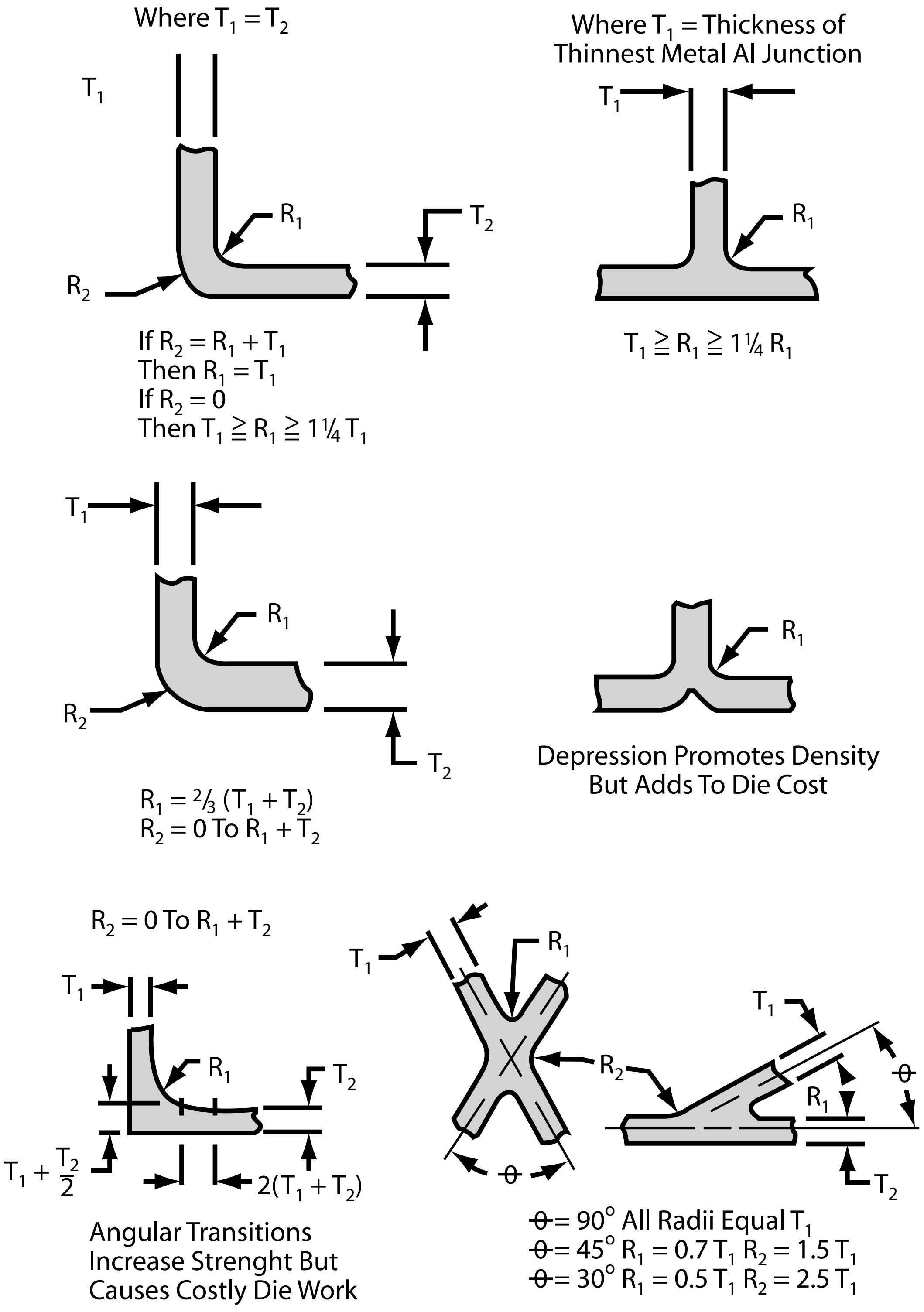

Figure 20. Design rules for the relationship between thickness and corner radius.

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Process Engineering Considerations

Process engineering factors for the designer and the die caster

Selecting the machine and process

The die designer and the die caster should meet early in the design process to look for shape changes that would optimize the die casting process and thus translate into lower prices. In addition to the casting shape, there needs to be a review of the process to be used by the die caster. Different die casters will have different equipment and different levels of experience in the engineering staff. The designer needs to locate a die caster with the engineering, the experience, and the equipment to do the particular job at hand while remembering that shops with a high level of support engineering (which will be required for tight tolerance jobs) will have a higher overhead and may not be the lowest cost producer.

The process selections will include: machine size, die size and type of die construction, selection of operational parameters (such as cavity fill time, machine maximum speed, die temperature control required, etc.). All of these selections will depend almost entirely on the part designers specifications for the quality requirements for the part. Thus, for example, if the part is specified to require a very high quality surface finish, and the part has a thin wall, then the machine must have very good speed and pressure capabilities, and will likely have to be a larger machine (with its attendant slower cycle time, more costly part handling, etc.).

Small machine advantages - and disadvantages

There is a strong tendency to use smaller machines for zinc castings. This trend is driven by the following advantages for the small machine:

* *Small machines can produce castings to a much tighter tolerance than large machines*

* *Small machines are faster than large machines, and can make more parts per hour - however, a large machine with multi-cavity dies can out-produce the small machine.*

* *There is less capital investment in the machines*

* *The die cost is significantly lower*

* *The small machine can be easier to run automatically*

* *The small machine can run castings that do not need trimming, thus eliminating the trim operation, which can be a very significant cost savings*

The disadvantages are:

* *Unless the part is very small, the small machines do not generally have the machine injection power required for the very high quality surface finish, such as that required for plumbing fixtures. The flash*

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free operation also tends to keep the impact velocity and the pressures on the low side, which make it difficult to make parts that require very good finishes.

* *The small machines cannot compete with the productivity of a large machine with multiple cavities.*

In general, however, the small machine category (as it is used here) will fit more than half of the zinc castings; thus it is important to the designer that any new casting project be reviewed by a die caster or consultant who specializes in this type of work.

The small machine category (as it is used here) includes those machines that can run without flash and without the need for trimming. Many of the machines in this category are called "four-slide" machines; these are machines that essentially have four moving platens or members that come together. The most common size of the four slide machines have a die face that is 2" by 2" (50x50mm) and run casting weights up to about 1.1 ounces (30g). Larger machines with die faces that are 4" by 4" (100x100mm) have been produced for several years; these can produce parts with a maximum dimension in any one dimension of about 2 inches (50mm) and parts that weigh up to about 3 ounces (90g). Currently, there are also four slide machines available that use a die area of up to about 6" X 6" inches (150x150mm), although they have not had wide acceptance. Small conventional machines can also achieve the tighter tolerances. These machines typically having an available insert area up to about 8" X 10" (200x250mm), and a clamp force rating from 5 to about 100 US tons. The most common size is around 60 tons with a die insert area of about 6" by 8" (150x200mm).

Small dies on small machines can hold tighter tolerances because the thermal and mechanical aspects of die casting are a function of size. An ILZRO study published in 1995 demonstrated that the close tolerance capabilities of the small zinc machines (and especially the four slide machines) make the old zinc standards somewhat meaningless. Until recently, none of the world's tolerance standards addressed the capabilities of this process; however, the latest version of the NADCA Product Standards has a section on small zinc castings.

Many of the small machines can operate with a system to break the gate and overflows off the part while it is still in the die and tooling is made to very tight tolerances (it is not unusual to have the tool dimensions at ? .0002" (.005 mm) or tighter in order to give flash free operation as well as close tolerance parts. This results in no trimming and the part is ready to ship as it comes out of the machine, or after tumbling to remove minor feathers of flash. This provides significant cost savings. Also the multi-slide machines can have movement in up to six directions which allows very complex shapes to be made. Designers can use this capability to develop a precision casting that can replace sheet metal or stamped assemblies of several parts. Many parts have been converted to precision zinc die casting (even though zinc was not the first choice of material) because of the significantly lower overall cost that comes from casting a precision part that does not need machining.

If the part size is appropriate for the small zinc machines, then the designer should contact a die caster that specializes in these types of parts. Be sure that the die caster has these machines in house, and is specialized in this kind of work. In the past, each of these die casters had their own set of tolerances, but the general set of standards from NADCA now cover this size of machines. However, an individual die caster may very well have better capability than the NADCA standards.

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It should be noted that there is a size limit to this technique at this time because in larger dies the disparity in temperature between different sections of the die and the insert cause difficult fitting problems. This results in flash, and the requirement for trimming. The largest size normally possible is roughly a part with a longest dimension of about 3.5 to 4 inches (90-100mm), although not every shape in this size range will be suitable.

The running of a de-gated, flash free, and tight tolerance part is highly dependent on the toolmaking technology employed. This technique has large advantages for some parts, but it cannot be done with the same technology as has been traditionally used for conventional die casting. The tooling is made with very tight tolerances, typically the tool will have most tolerances in the ? .0002 inch (0.005 mm) range; and should be done by tool shops that are specialized in this kind of work.

As mentioned also, while the machines can make parts with a good finish, a disadvantage of the small machine approach is that these machines generally do not have the injection power or the holding force to make the very high quality surface finish required for castings that need a very good plated finish.

Tight dimensional requirements

When the designer has dimensional requirements that are tighter than the standards, it doesn't mean that the part can't be made. Again, the standards are for the average shop, and there are die casters with special experience or additional engineering capabilities that can do better than the standards on a routine basis. ILZRO published a study in 1995 that describes the average process variation, using the dimensional categories used in the NADCA Standards.

Summary of ILZRO study on process variation

The results of this study are presented here in condensed form. Measurements were taken in 16 different plants with a wide variety of machines and operating conditions, most of which were not using any modern method of process control. Size of the samples was from less than an ounce up to 7 lbs (30g-3kg). Over 3,400 measurements were made and recorded and the data reflects what was being produced without special effort or controls in 1994.

The table below summarizes the results. The variation represents the projected total variation, when calculating the six ? value of the variation. The expected six ? variation for conditions where extra process control is used is expected to be better than these numbers. The tolerance used was the NADCA Standards issued in 1994; since that time the NADCA Standards have included a precision tolerance that is better than the tolerance used for these comparisons.

This data in Figure 21 was affected by the large castings that were included in the study. If the size of castings is limited to < 20 square inches (13,000 sqmm) of projected area, and the size of a slide is limited to 3 square inches (2000 sqmm), then the numbers would reflect a much larger number of typical zinc die castings. In figure 22 these revised values are compared with the tighter tolerances of the 1997 edition of the NADCA Standard.

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		Convention Al Machines		Small Zinc & Four Slide Machines	
Type of Measurement	No. of Measurements	Total Six σ Variation, Inches/mm	Percent of Tolerance	Total Six σ Variation, Inches/mm	Percent of Tolerance
Linear	1338	0.00505 /0.128	41.62%	0.00131/0.033	17.30%
Across The Parting Line	1150	0.00375/0.095	20.14%	0.00101/0.026	7.31%
Moving Die Member	660	0.00387/0.098	28.53%	0.00170/0.043	11.57%
Flatness	750	0.00634/0.161	51.42%	0.00210/0.053	27.00%

Figure 21. *A summary of the total predicted six σ variations as calculated from the samples taken at the time. The variation within each type of measurement will depend on the size of the part and other factors, and these should be considered before using any of this information. This is intended only to provide a very general picture of the results.*

			Convention Al Machines (less than 20 sq. in. proj. area, and slide area < 3 sq. in.		Small Zinc & Four Slide Machines	
Type of Measurement	No. of Measurements		Total Six σ Variation, Inches/mm	Percent of NADCA 1997 Precision Tolerance	Total Six σ Variation, Inches/mm	Percent of NADCA 1997 Precision Tolerance
	conv	small				
Linear	678	440	0.0032/0.081	53%	0.00131/0.033	58%
Across The Parting Line	480	520	0.00395/0.100	100%	0.00101/0.026	33%
Moving Die Member	360	280	0.00345/0.087	69%	0.00170/0.043	34%

Figure 22. *Revised data to show the results for zinc parts < 20 sq. in. projected area as compared to the 2000 NADCA Precision Standards.*

The data would indicate that a linear tolerance of ? .00156 inches (0.04 mm) would be the average linear variation if only castings with a projected area < 20 sq in (13,000 sqmm) are considered; and the number is about the same for the variation across the parting line and variation to a moving die member.

Further Dimensional Considerations

When reviewing the type of machine and process available from the die caster, the designer should be aware of some of the implications of the dimensioning and inspection methods. It is not unusual to have a part that would be easily achievable turned into something that is difficult or impossible to check by the methodology used in dimensioning and inspection.

For those high volume parts that must meet the highest quality levels, then further engineering work needs to be done between the designer (or others in the casting purchaser's organization) to make sure there is a smooth product launch. Several of these factors are considered next.

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Process Failure Effects Mode Analysis

One important step would be to develop a Failure Mode Effects Analysis (FEMA – or FMEA in UK). This must be a joint effort between the potential die caster and the user.

The Process FEMA (Failure Effects Mode Analysis) should be developed to address all issues that may influence the process and part dimensional variability. The strategy is to critique every step of the process and devise ways to reduce process variability and to develop reaction plans in the event that dimensions or process control factors go out of control. Each step of the process shown on the Process Flow Chart should be critiqued relative to its impact on process variability, critical dimensions, and tolerance variability. The current process controls are then evaluated relative to their effectiveness in controlling the critical dimensions and tolerances. A rating system is used to evaluate the consequences and probability of being out of tolerance for each critical dimension. If something can be done to improve control of the process, then an action item is generated for someone in the organization to accomplish. The successful implementation of this action item then decreases the probability of being out of tolerance for a particular critical dimension.

An example might be excessive cold flow in the casting where too high a cooling water pressure is leading to too high a water flow through the die. The action item might be to install a cooling water pressure regulator at the die cast machine to ensure the cooling water pressure is constant at 35 lb/in2 so that the flow rates through the die are stable and independent of other machines using cooling water at any particular time. Once the pressure regulator has been installed, the probability of cold flow in the castings decreases allowing for a lower overall rating for the product of; critical dimension seriousness, likelihood of occurrence, and detection numbers that make up the overall rating. The Process FEMA is a useful method to critique the process in an orderly fashion and to make improvements that improve tolerance control before the start of production.

There are manuals, training classes and software available to teach those who need to know about how to do a Process FEMA.

Critical dimensions and datums

One of the first requirements for the designer is to designate those dimensions that are critical for the design intent. This is done in different ways, sometimes there are two or three classes of dimensions, but there are usually a few dimensions that are critical to fit and function; and these must be especially designated some way on the print. This is critical and must be done. Datums must also be designated and discussed with the die caster.

Use of Process Capability Indices in die casting parts

CPK 's are a way of estimating the quality of a particular sample of parts relative to the print dimensions. None of the world's die casting tolerance standards include a discussion of CPK 's relative to tolerances, but they are now a real part of the manufacturing world. As CPK requirements increase, the effective manufacturing tolerances decrease. Doing the Design or Process FEMA or conducting partial factorial design experiments can help determine what dimensions are important to product functionality and can

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help focus where the die casters resources for improvement should be directed.

The CPK process has enhanced the way processes are engineered and executed; and is yielding improved quality and lower costs by quantitative statistical methods. Capability studies and CPK's attempt to get a greater percentage of parts closer to the print's critical nominal dimensions thus better satisfying the design intent and functioning of the part.

They take time to determine, so they are normally reserved for the critical features and dimensions that satisfy the design intent. To measure CPk 's, a small capability study is done. To do this, the die casting and secondary processes are run at steady state, and 30-60 samples are selected at predetermined intervals and then measured for the particular critical dimensions. For each dimension, the average and standard deviation is calculated and substituted into the following formula:

C_{PK} = the lesser of:

(Upper Tolerance Limit - Mean of Samples Measured)/3 Standard Deviations, and
(Mean of Samples Measured - Lower Tolerance Limit)/3 Standard Deviations.

The following issues need to be considered when the designer is selecting CPK 's:

Economics

The design engineer must recognize that higher (better) CPK 's cost money to implement and monitor. Die casting is a business like any other with limited resources and is part of the cost chain delivering value to the ultimate consumer. The key issue is to economically strive for higher CPK 's on the tolerances that count and that add value to the final product.

Normal Distribution

The standard routine for calculating CPK 's assumes a normal distribution. However, not all distributions in zinc die casting are normal. Parting line, moving member, and flatness variation are rarely negative so normal distributions do not exactly describe the CPK 's of these dimensions. If a normal distribution is assumed then it is possible to specify tolerances and CPK 's that statistically exceed the capabilities of the die cast process even though the actual part dimensions fall within the realm of part functionality. Pursuing impossible statistical targets can lead to extra costs in die modifications, chasing rejections, sorting, rework, and other unproductive activities that ultimately get passed on to the consumer.

Metrology

Measurement systems and inspectors are not perfect. Repeatability and Reproducibility (R&R) studies should be coincident with the capability studies to determine how much of the resulting variation is due to measurement error. As a rule of thumb, the accuracy and repeatability of the measurement method should be less than 10% of the tolerance. But as the tolerances decrease and the CPK 's increase, the limits of metrology performance can be surpassed. A meeting should occur before and after capability studies

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commence where the die caster and customer agree on the best way to measure and how the R & R data should be treated relative to CPK targets and die corrections.

Time

As previously mentioned zinc die castings shrink through time. Dimensions can also change with secondary operations such as vibratory deburr, machining, or surface coating, as some internal stresses are relieved and others are created. It is possible that the die caster and customer can produce different CPK 's for the same sample of parts just due to the difference in time frames or the process point at which the parts were measured. Therefore, it is important to recognize when and where CPK 's are determined and to make the right die or secondary corrections that improve the CPK 's going to the consumer.

Summary for Designing Zinc Die Castings

The biggest opportunities for cost savings and product effectiveness occur at the design stage. Here is a summary for designing zinc die castings.

Zinc Die Casting Design Guidelines

a. Follow the formulas and illustrations for die casting design Do's and Don'ts. Visualize the die and attempt to reduce thermal differences. Design for function not form.

b. Use the published tolerances as guidelines and consult with potential die casting suppliers early in the quote stage to select the best process and machine for this part. Ask for the die caster's or a consultant's input and suggestions to improve the design or to select a different machine or method.

c. Do a Design FEMA, make CAD and physical models or prototypes, or do partial factorial design of experiments to determine the critical characteristics and tolerances needed to satisfy the design intent. Match material properties of the available alloys to the performance specifications desired.

d. Establish the metrology method and account for R & R's both at the die caster and customer in the evaluation of CPK 's.

e. Determine the most economical set of tolerances and CPK 's that satisfy the design intent.

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