Casting dimensional stability and tolerances

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High pressure die casting dimensional and geometrical accuracy depends on the following details:

- die thermal balance
- die mechanical strength and stiffness
- dragging during ejection
- parting line position
- moving cores position

Die thermal balance

Die thermal balance influences casting dimensional and geometrical accuracy in many different mechanisms. Basically there are two subjects of the mechanisms: die and the casting itself.

Die steels have certain coefficients of thermal expansion, which have been noticed as a part of the casting shrinkage factor. Basically the casting shrinkage factor consists of thermal expansion of the casting alloy at the casting ejection temperature and thermal expansion of the die steel. The casting ejection temperature may vary from cycle to cycle depending on the die temperature; temperature of the alloy; and heat losses during dosing and the casting shot. If the thermal conditions are stable, the ejection temperature variation is minimal. It may take 1 – 2 hours after production start-up before all equipments have reached a thermal balance. If there is even a 5 - 10 minutes break between machine cycles, the thermal balance is lost.

Thermal expansion of the die steel at the time of the ejection is very difficult to predict, because the die temperature varies between different parts inside the cavity and as a function of time. Heat flows rather slowly and as a result this phenomenon the die steel under cavity warms up a few seconds after the casting is already ejected. High and narrow projections tend to heat up after a few tens of casting shots. Narrow projections heat up more than cavity shapes and flat surfaces, because there is less heat conducting material. (See image below.)

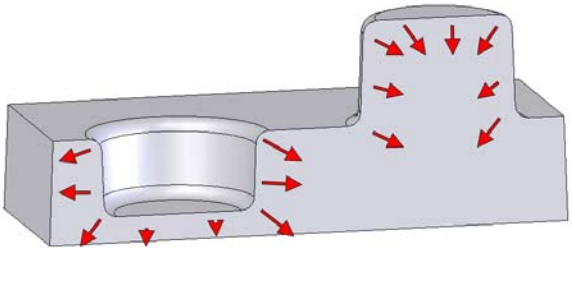

Image 1. A cavity or flat surfaces have more surrounding material to conduct heat than core surface. For this reason cores tend to heat up more than flat cavity areas.

Cores resist casting shrinkage. Flat area in a casting may shrink nearly twice as much as an area around a core. (See image below)

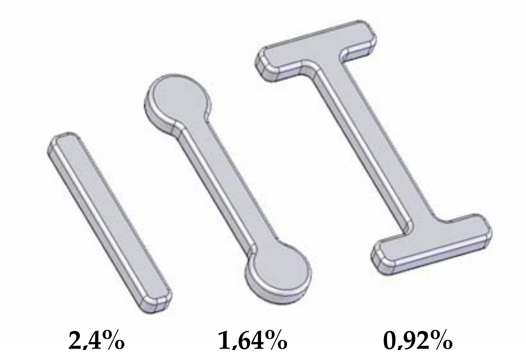

Image 2. Different casting shapes shrink differently. If the casting on the left were made of steel, the shrinkages would be as presented. The figure bases on J. Campbell, Castings, 2nd edit.

Basically the die cavity is machined a little larger than the wanted dimensions in a casting. The casting dimensions are multiplied with a coefficient called a shrinkage factor. It should be possible to determine the factor from linear thermal coefficients of the die material and the casting alloy, but as a result of all the described vagueness, the shrinkage factor is given as an empirically derived in house standard. The standard may be different for different casting types. Typical shrinkage in aluminum high pressure die casting is for example between 0,5% - 0,7% even though the coefficient of thermal expansion would foretell more.

If the casting has some important tolerated dimensions, the casting company should be able to maintain the thermal conditions inside the die as steady as possible. The casting ejection temperature variation has to be kept as small as possible. If requirements are especially tight, there should be some advanced temperature control systems in use. Traditional tempering devices with circulating hot oil do not control die temperature directly. They control only the oil temperature and with the oil temperature the die temperature. The control system does not have a link to temperatures inside the die. The same goes with spraying devices. If there is a need for accurate die temperature control, the system must have sensor for measuring temperature of critical places inside the die.

When the die material heats up it expands according to the linear thermal coefficients and temperatures of the different die parts. If the die materials have similar coefficients of linear thermal expansion and the temperature is the same in all die parts, the die maintains totally flat and the two die halves fit together as well as possible. Usually this is not the case. Usually the material near the die cavity surface is hotter than the other areas. And as a result the die will bend (Image 3 a) next page).

In ideal situation the die halves would be in the same temperature. Usually the core side tends to heat up more and cavity side less. The temperature difference between the die halves pose a situation presented in the same image b).

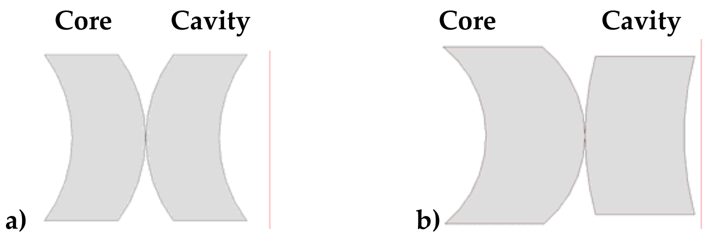

Image 3. a) Bending due to temperature differences inside die materials b) Bending due to temperature differences inside the die materials and between die halves. Core side typically tends to heat up more than the cavity side.

Minimum die guiding system consists of guide pillars and sleeves. With this minimum system the dimensional differences between the die halves can be balanced to a certain degree, but for more accurate dimensional control, the die designer should adopt side guides (See the following image).

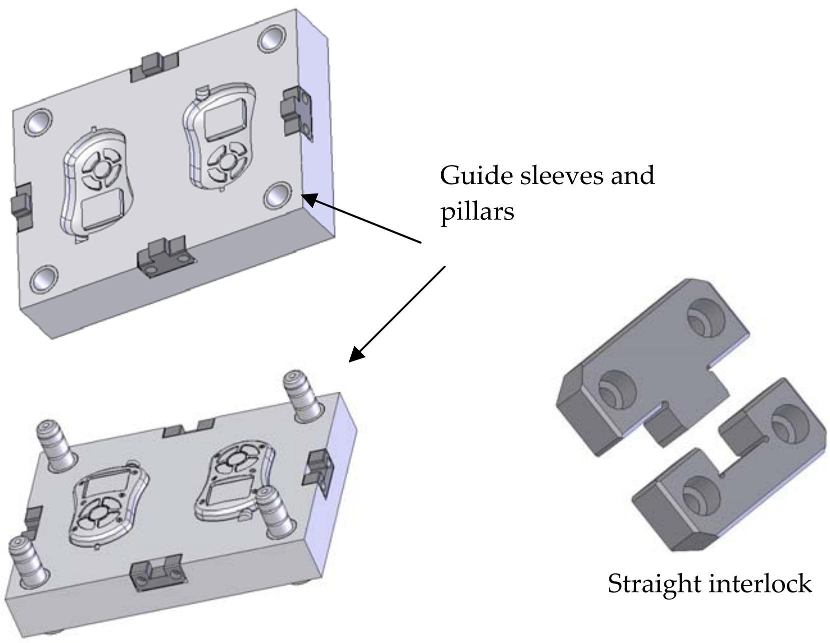

Image 4. Side interlocks for high pressure die casting die and for example for injection molding mould. Side interlocks will guide the die halves more accurately together than the standard guide pillar and sleeve system. Guide pillars and sleeves are manufactured to tolerate some thermal imbalance between the two die halves, but at the same time they allow some inaccuracy in positioning the die or mould halves.

If there are hot and cooler parts inside the die cavity, the die bends, but so does also the casting. The variations in die temperatures cause also other kinds of problems: Temperature variations cause variations in shrinkage and solidification conditions and the casting may build up internal stresses. After the casting is ejected, the internal stresses relieve and the casting bends. If the casting is designed with both thin and thick sections or sections, which will for some other reason, concentrate heat in the die, it may be very difficult to cope with these in the casting shop and difficult warpage problems arise.

If the internal stresses concentrate in an unfavorable way, the thicker sections may even break under service. The casting may have structures, which are similar to stress lattices. Special consideration should be taken when designing features similar to these (See image below).

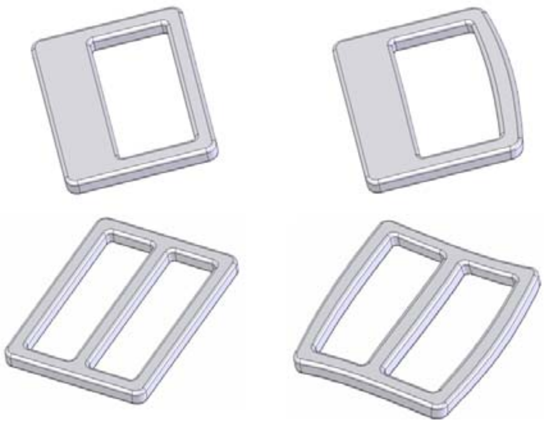

Image 5. Casting structures, which are similar to stress lattices. Different cooling rates cause warpage and internal stresses. The casting may even break from the thickest part under service conditions as a result of the stress concentrations. Fastening ribs may have similar effects if not carefully designed.

Die and machine mechanical strength and stiffness

Each casting shot poses a powerful stress to the cavity block of the die moving half and to the machine closing system. The moving half cavity plate rests on risers and there is no support from the machine platen like in the fixed side. For that reason the die is typically equipped with support pillars. Without the support pillars the in-cavity pressure would bend the cavity plate.

The high pressure die casting machine is equipped with a combined hydraulic and mechanical closing unit to keep the die halves together during the casting shot. In all-electric machines the closing unit is combined electrical and mechanical. If the machine is strong enough, the die halves stay tightly closed. If the machine closing force is not strong enough, the die opens slightly and lets some alloy to pass to the parting surface. The casting will have some flash around the parting line and also the dimensions perpendicular to the parting surface will be slightly larger than intended.

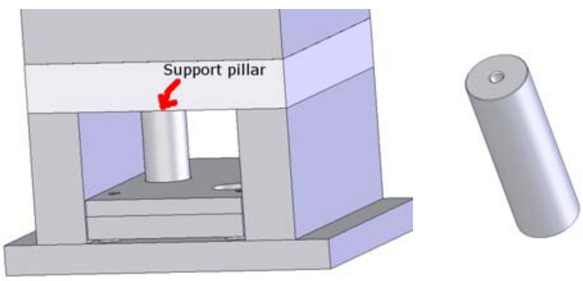

Image 6. A support pillar behind the die cavity plate in the moving side.

Dragging during ejection or mould opening

Dragging is a phenomenon that occurs if

- the casting is designed with too small draft angles
- there is a back draft condition
- the alloy (typically aluminium or zinc) solders to the die surface
- the tablet sticks to the plunger

Dragging breaks the casting surface and surface defects may solely cause rejection of the part. Dragging causes also dimensional instability. If tablet sticks between a plunger and a casting chamber, the casting usually breaks at a gate. Before the breaking occurs, the casting is affected with tensile stresses, which cause distortions and dimensional inaccuracy. Image 7 presents enlarged effect of a stuck tablet. The similar effect happens when the casting drags in the fixed die half as a consequence of soldering, a back draft condition or a zero draft condition. Next image (Image 9) shows an effect of a soldering or a zero/back draft condition in the moving die half. The die ejection system sets an uneven ejection force to the casting, because some parts of the casting release with ease and some do not. As a result the casting bends.

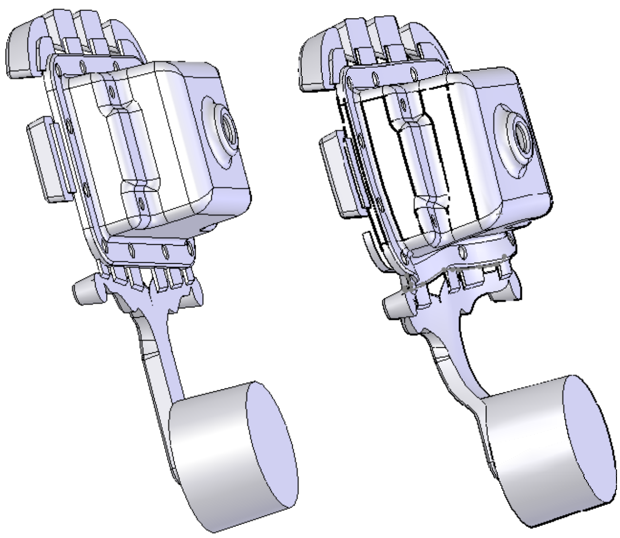

Image 7. Left: Undistorted runner system and dimensionally accurate casting. Right: Distorted runner and bent casting with dimensional inaccuracy. Bending due to a stuck cold chamber die casting tablet.

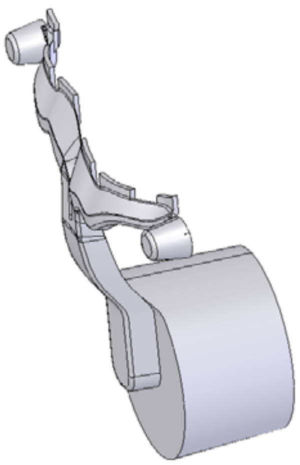

Image 8. Warpage of the runner. The runner may break from the thick, but still warm and soft parts or at the gate. Before the break occurs, casting is exposed to tensile stresses.

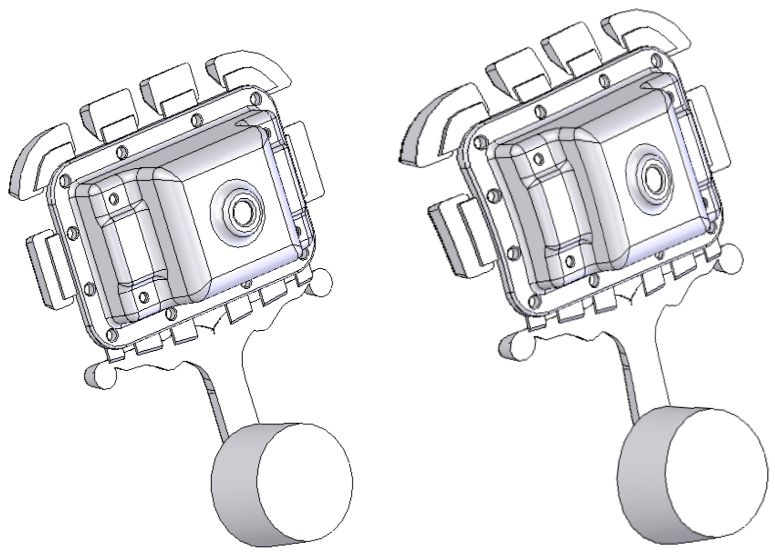

Image 9. Left: Normal, dimensionally accurate casting. Right: Distortion caused by uneven ejection forces. Enlarged effect. The whole ejection system may tilt if the casting sticks to the die during ejection.

Parting line and moving cores position and their effect to the casting tolerances

Selection of parting line position and positions of moving cores have an effect to the casting tolerances. According to the rules of the North American Die Casting Association (NADCA) the tolerance is calculated separately to dimensions or features inside one die half and dimensions between the opposite die halves. The parting line and moving cores add to tolerances in the + -direction. The international ISO standard mentions, that *"Many dimensions of a casting are affected by the presence of a mould joint or a core, requiring increased dimensional tolerance."* However, the standard does not give rules how to define the increase in tolerance.

Dimensions with critical tolerances should be in one die half if possible. Sometimes it is difficult to see whether the dimensions are only in one die half or crossing the parting line (See the following image).

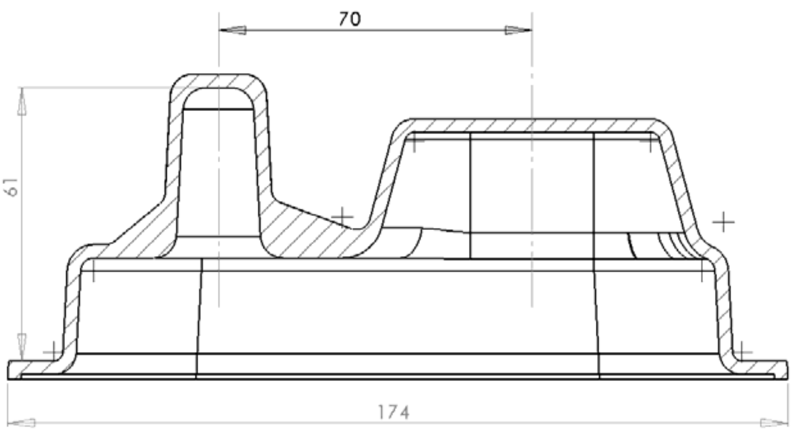

Image 10. Dimensions in one die half and across the parting line. Dimensions 174 mm and 70 mm are between features in one die half. Dimension 61 mm crosses the parting line, because it is a dimension between the part outer and inner surfaces.

Setting of tolerances

The North American Die Casting Association (NADCA) has standard specifications for setting high pressure die casting tolerances. There is also an international ISO standard series, which focuses on casting tolerances. This series replaces the former ISO 8062:1994. ISO 8062:1994 did not have specifications to high pressure die castings. The new standard series covers them also.

The new ISO 8062-1…3 series defines casting tolerances as DCT (Dimensional Casting Tolerance) grades and GCT (Geometrical Casting Tolerance) grades. The former ISO 8062 defined tolerances only as CT (Casting Tolerance) grades.

ISO 8062-1…3 consists of the following titles.

- ISO 8062-1:2007 Geometrical product specifications (GPS) -- Dimensional and geometrical tolerances for moulded parts -- Part 1: Vocabulary
- ISO/TS 8062-2 Geometrical product specifications (GPS) -- Dimensional and geometrical tolerances for moulded parts -- Part 2: Rules (Not published yet)
- ISO 8062-3:2007 Geometrical product specifications (GPS) -- Dimensional and geometrical tolerances for moulded parts -- Part 3: General dimensional and geometrical tolerances and machining allowances for castings

According to NADCA specifications, high pressure die casting tolerances are divided into two groups: normal and precision tolerances. International ISO standard does not use these terms, but specifies the tightest geometrical tolerance grade as one to be used only by special agreement. The precision tolerances may be more costly to achieve, because the die caster has to pay more attention to the thermal stability during casting cycles and also the die has to be more rigid and well tested. Usually rigidity requires thicker plates and these add to the die costs.

NADCA specifications cover the following high pressure die casting tolerances[1]:

- dimensional tolerance
- angular tolerance, which includes flatness, parallelism and perpendicularity tolerances
- concentricity tolerance
- parting line shift tolerance
- flatness tolerance

ISO 8062 covers the following tolerances:

- dimensional tolerances
- combined roundness, parallelism, perpendicularity and symmetry tolerance
- concentricity tolerance
- straightness tolerance
- flatness tolerance

[1] NADCA: Product Specification Standards for Die Castings, USA, 2006

Dimensional tolerances

Dimensional tolerances cover tolerances for dimensions in one die half and dimensions over parting line. ISO 8062-3 standard asks to notice the dimensions over parting line, but does not give precise rules how.

Table 1. NADCA dimensional tolerances, dimensions in one die half

Standard	Aluminum	Magnesium	Zinc	Copper
Normal	+/- 0,25 mm per 25 mm + additional +/- 0,025 mm per each full 25 mm			+/- 0,36 mm per 25 mm + additional +/- 0,076 mm per each full 25 mm
Precision	+/- 0,05 mm per 25 mm + additional +/- 0,025 mm per each full 25 mm			+/- 0,18 mm per 25 mm + additional +/- 0,05 mm per each full 25 mm

Table 2. ISO 8062-3:2007 dimensional tolerances

Largest overall dimensio	Aluminum	Magnesium	Zinc	Copper
≤ 50 mm	DCTG 6:		DCTG 3 – 6	DCTG 6 – 8
> 50 mm ≤ 180 mm	DCTG 7			
> 180 mm ≤ 500 mm	DCTG 8			
> 500 mm	DCTG 9			

Table 3. NADCA dimensional tolerances, dimension over parting line; normal (and precision) tolerances

Projected area of the casting	Zinc	Aluminum	Magnesium	Copper
65 cm2	+0,114 mm (+0,076) mm	+0,14 mm (0,089) mm	+0,14 mm (+0,089) mm	+0,20 mm (+0,20) mm
65 – 130 cm2	+0,13 mm (+0,089) mm	+0,165 mm (+0,102) mm	+0,165 mm (+0,102) mm	+0,23 mm (+0,23) mm
130 – 325 cm2	+0,15 mm (+0,102) mm	+0,19 mm (+0,153) mm	+0,19 mm (+0,153) mm	+0,25 mm (+0,25) mm
325 – 650 cm2	+0,23 mm (+0,153) mm	+0,30 mm (+0,203) mm	+0,30 mm (+0,203) mm	-
650 – 1300 cm2	+0,30 mm (+0,203) mm	+0,46 mm (+0,305) mm	+0,46 mm (+0,305) mm	-
1300 – 1950 cm2	+0,46 mm (+0,305) mm	+0,61 mm (+0,406) mm	+0,61 mm (+0,406) mm	-

Table 4. NADCA dimensional tolerances, dimension towards a moving core; normal (and precision) tolerances

Projected area of the casting	Zinc	Aluminum	Magnesium	Copper
65 cm2	+0,15 mm (+0,127) mm	+0,20 mm (0,152) mm	+0,20 mm (+0,127) mm	+0,12 mm (+0,254) mm
65 – 130 cm2	+0,23 mm (+0,178) mm	+0,33 mm (+0,254) mm	+0,33 mm (+0,178) mm	-
130 – 325 cm2	+0,33 mm (+0,254) mm	+0,48 mm (+0,356) mm	+0,48 mm (+0,254) mm	-
325 – 650 cm2	+0,48 mm (+0,356) mm	+0,61 mm (+0,457) mm	+0,61 mm (+0,356) mm	-
650 – 1300 cm2	+0,66 mm (+0,483) mm	+0,81 mm (+0,61) mm	+0,81 mm (+0,483) mm	-
1300 – 1950 cm2	+0,81 mm (+0,61) mm	+0,1 mm (+0,762) mm	+0,1 mm (+0,61) mm	-

Geometrical tolerances

Geometrical tolerances include straightness, flatness, combined roundness, parallelism, perpendicularity and symmetry tolerance, concentricity, parting line shift and flatness tolerance.

Table 5. ISO 8062-3 straightness tolerance

Raw casting basic dimension (mm)		Geometrical casting tolerance grade GCTG for straightness		
From	To	2: Only by special agreement	3: Common castings without back draft features with moving die components	4: Complex castings and castings with moving die compo-nents
—	10	0,08	0,12	0,18
> 10	30	0,12	0,18	0,27
> 30	100	0,18	0,27	0,4
> 100	300	0,27	0,4	0,6
> 300	1000	0,4	0,6	0,9

Table 6. ISO 8062-3 and NADCA flatness tolerances

Raw casting basic dimension (mm)		Geometrical casting tolerance grade GCTG for flatness			NADCA casting tolerance for flatness
From	To	2: Only by special agreement	3: Common castings without back draft features with moving die components	4: Complex castings and castings with moving die components	
–	10	0,12	0,18	0,27	At the first 75 mm 0,20 mm + 0,08 mm after each additional 25 mm[2]
> 10	30	0,18	0,27	0,4	
> 30	100	0,27	0,4	0,6	
> 100	300	0,4	0,6	0,9	
> 300	1000	0,6	0,9	1,4	

Tolerance mm

Table 7. NADCA parting line shift tolerance

Projected area	Tolerance
< 325 cm2	± 0,102 mm
325 - 650 cm2	± 0,152 mm
650 - 1290 cm2	± 0,203 mm
1290 - 1940 cm2	± 0,279 mm
1940 - 3225 cm2	± 0,406 mm
3225 - 5160 cm2	± 0,508 mm
5160 - 7740 cm2	± 0,635 mm

[2] Calculated for the largest dimension, for example diameter, measure from corner to corner in the case of rectangular objects, etc.

Table 8. ISO 8062-3:2007 combined tolerance for roundness, parallelism, perpendicularity and symmetry

Raw casting basic dimension (mm)		2: Only by special agreement	3: Common castings without back draft features with moving die components	4: Complex castings and castings with moving die components
From	To			
–	10	0,18	0,27	0,4
> 10	30	0,27	0,4	0,6
> 30	100	0,4	0,6	0,9
> 100	300	0,6	0,9	1,4
> 300	1000	0,9	1,4	2

Tolerance mm

Table 9. NADCA angular tolerance (combined flatness, parallelism and perpendicularity tolerance)

Standard	Both surfaces in the same die half	Surfaces across the parting line or the other surface parting surface	Both surfaces in the same die half, the other surface is a moving core surface	Surfaces across the parting line or the other surface parting surface, tolerance towards a moving core surface
Normal	0,13 mm per 75 mm + 0,025 mm per each additional 25 mm	0,20 mm per 75 mm + 0,038 mm per each additional 25 mm	0,20 mm per 75 mm + 0,038 mm per each additional 25 mm	0,28 mm per 75 mm + 0,076 mm per each additional 25 mm
Precision	0,08 mm per 75 mm + 0,025 mm per each additional 25 mm	0,13 mm per 75 mm + 0,025 mm per each additional 25 mm	0,13 mm per 75 mm + 0,025 mm per each additional 25 mm	0,20 mm per 75 mm + 0,05 mm per each additional 25 mm

Table 10. *ISO 8062-3:2007 cocentricity tolerances*

<table>
<tr><th colspan="2">Raw casting basic dimension (mm)</th><th rowspan="2">2: Only by special agreement</th><th rowspan="2">3: Common castings without back draft features with moving die components</th><th rowspan="2">4: Complex castings and castings with moving die components</th></tr>
<tr><th>From</th><th>To</th></tr>
<tr><td>—</td><td>10</td><td>0,27</td><td>0,4</td><td>0,6</td></tr>
<tr><td>> 10</td><td>30</td><td>0,4</td><td>0,6</td><td>0,9</td></tr>
<tr><td>> 30</td><td>100</td><td>0,6</td><td>0,9</td><td>1,4</td></tr>
<tr><td>> 100</td><td>300</td><td>0,9</td><td>1,4</td><td>2</td></tr>
<tr><td>> 300</td><td>1000</td><td>1,4</td><td>2</td><td>3</td></tr>
</table>

Tolerance mm

Table 11. *NADCA concentricity tolerances*

<table>
<tr><th>Projected area</th><th>Both surfaces in the same die half</th><th>Surfaces across the parting line, additional tolerance</th></tr>
<tr><td>< 325 cm2</td><td rowspan="4">0,20 mm per 75 mm + 0,05 mm to each additional 25 mm</td><td>0,20 mm</td></tr>
<tr><td>325 – 650 cm2</td><td>0,30 mm</td></tr>
<tr><td>650 – 1290 cm2</td><td>0,41 mm</td></tr>
<tr><td>1290 - 1940 cm2</td><td>0,56 mm</td></tr>
</table>

Annex 1: ISO 8062:2007 Dimensional casting tolerance grades (DCTG)

The table presents the grades and dimension intervals, which are workable for high pressure die castings.

Raw casting basic dimension (mm)		Dimensional casting tolerance grade DCTG									
From	To	1	2	3	4	5	6	7	8	9	10
—	10	±0,09	±0,13	±0,18	±0,26	±0,36	±0,52	±0,74	±1	±1,5	±2
10	16	±0,1	±0,14	±0,2	±0,28	±0,38	±0,54	±0,78	±1,1	±1,6	±2,2
16	25	±0,11	±0,15	±0,22	±0,3	±0,42	±0,58	±0,82	±1,2	±1,7	±2,4
25	40	±0,12	±0,17	±0,24	±0,32	±0,46	±0,64	±0,9	±1,3	±1,8	±2,6
40	63	±0,13	±0,18	±0,26	±0,36	±0,5	±0,7	±1	±1,4	±2	±2,8
63	100	±0,14	±0,2	±0,28	±0,4	±0,56	±0,78	±1,1	±1,6	±2,2	±3,2
100	160	±0,15	±0,22	±0,3	±0,44	±0,62	±0,88	±1,2	±1,8	±2,5	±3,6
160	250	—	±0,24	±0,34	±0,5	±0,7	±1	±1,4	±2	±2,8	±4
250	400	—	—	±0,4	±0,56	±0,78	±1,1	±1,6	±2,2	±3,2	±4,4
400	630	—	—	—	±0,64	±0,9	±1,2	±1,8	±2,6	±3,6	±5
630	1 000	—	—	—	—	±1	±1,4	±2	±2,8	±4	±6
1 000	1 600	—	—	—	—	—	±1,6	±2,2	±3,2	±4,6	±7

Tolerance ± mm

Annex 2: ISO 8062:1994 Casting tolerance grades (CTG)

The tolerance grade is described with CT. It varies depending on the casting method and also on used material and alloy. Normal high pressure die casting tolerance grade is CT 5-7 for aluminium and magnesium, CT 6-8 for copper and CT 4-6 for zinc.

Raw casting basic dimension (mm)		Casting tolerance grade CTG										
From	To	4	5	6	7	8	9	10	11	12	13	14
-	10	0,26	0,36	0,52	0,75	1,00	1,5	2,0	2,8	4,2	-	-
10	16	0,28	0,38	0,54	0,78	1,10	1,6	2,2	3,0	4,4	-	-
16	25	0,30	0,42	0,58	0,82	1,20	1,7	2,4	3,2	4,6	6,0	8,0
25	40	0,32	0,46	0,64	0,90	1,30	1,8	2,6	3,6	5,0	7,0	9,0
40	63	0,36	0,50	0,70	1,00	1,40	2,0	2,8	4,0	5,6	8,0	10,0
63	100	0,40	0,56	0,78	1,10	1,60	2,2	3,2	4,4	6,0	9,0	11,0
100	160	0,44	0,62	0,88	1,20	1,80	2,5	3,6	5,0	7,0	10,0	12,0
160	250	0,50	0,70	1,00	1,40	2,00	2,8	4,0	5,6	8,0	11,0	14,0
250	400	0,56	0,78	1,10	1,60	2,20	3,2	4,4	6,2	9,0	12,0	16,0
400	630	0,64	0,90	1,20	1,80	2,60	3,6	5,0	7,0	10,0	14,0	18,0
630	1000	-	1,00	1,40	2,00	2,80	4,0	6,0	8,0	11,0	16,0	20,0
1000	1600	-	-	1,6	2,2	3,0	4,6	7,0	9,0	13,0	18,0	23,0

Tolerance ± mm

References

J. Campbell, Castings, 2nd edition, Elsevier, UK, 2005

ISO 8062: 1994 Castings – System of dimensional tolerances and machining allowances

EN ISO 8062-3:2007 Geometrical Product Specifications (GPS). Dimensional and geometrical tolerances for moulded parts. Part 3: General dimensional and geometrical tolerances and machining allowances for castings

Product Design for Die Casting, NADCA, USA 1998

Product Specification Standards for Die Castings, NADCA, USA, 2006