BDG Reference Sheet
VDG-Merkblatt

P690
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Investment castings

Dimensional tolerances, surface condition, machining allowance

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1 Standard references

The documents cited below are necessary to apply this document. In dated references, only the edition referred to is valid. In dateless references the current edition of the document is authoritative (including all modifications).

DIN 406-10	Technische Zeichnungen; Maßeintragungen; Begriffe, allgemeine Grundlagen
DIN 406-11	Technische Zeichnungen; Maßeintragungen; Grundlagen der Anwendung
DIN 406-11	Beiblatt 1 - Technische Zeichnungen - Maßeintragungen - Teil 11: Grundlagen und Anwendung; Ausgang der Bearbeitung an Rohteilen
DIN 406-12	Technische Zeichnungen; Maßeintragungen; Eintragung von Toleranzen für Längen- und Winkelmaße
DIN 1451	Teil 1 - 4 Schriften - Serifenlose Linear-Antiqua
ISO 5459	Technical drawings - Geometrical tolerancing - Datums and datum-systems for geometrical tolerances
EN ISO 1101	Geometrical Product Specifications (GPS) - Geometrical tolerancing - Tolerances of form, orientation, location and run-out
EN ISO 1302	Geometrical Product Specifications (GPS) - Indication of surface texture in technical product documentation
EN ISO 1302	Geometrical Product Specifications (GPS) - Indication of surface texture in technical product documentation, Corrigendum to DIN EN ISO 1302:2002-06

Compiled by the BDG technical committee "Investment Casting"

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EN ISO 5459	Draft standard - Geometrical product specifications (GPS) - Geometrical tolerancing - atums and datum-systems
EN ISO 8062-2	Geometrical Product Specifications (GPS) - Dimensional and geometrical tolerances for moulded parts - Part 2: Rules
EN ISO 8062-3	Geometrical Product Specifications (GPS) - Dimensional and geometrical tolerances for moulded parts - Part 3: General dimensional and geometrical tolerances and machining allowances for castings
ISO 19959	Visual examination of the surface condition of investment castings - Steel, nickel alloys and cobalt alloys
BDG-Reference Sheet P 510	Maßliche Erstbemusterung auf der Basis von 3D-CAD-Daten
VDG-Reference Sheet P 701	Kennzeichnung von Gussteilen

2 Definition and field of application

2.1 DEFINITION

Investment casting is an industrial precision casting process using in contrast to other moulding processes a melt out pattern (lost pattern) to create an undivided ceramic mould (lost mould). In those metals and alloys based on iron, aluminium, nickel, cobalt, titanium, copper and magnesium are cast. Castings manufactured like this are distinguished by their dimensionally accuracy and their high surface quality. The process is also known as "Lost Wax Moulding", "Lost Wax Process" or "Fonte à Cire Perdue".

2.2 FIELD OF APPLICATION

This reference sheet does not apply to precious metals cast by means of the lost-wax process, products of the jewellery industry, dental laboratories or artistic castings.

2.3 RAPID PROTOTYPING

Dimensional and surface tolerances of castings produced in rapid prototyping might vary. They must be agreed upon separately between producer and user of investment castings.

3 Objective

3.1 TARGET

The reference sheet defines dimensional tolerances, machining allowances and surface roughness which represent the state of the art in investment casting. It is the basis to promote optimum co-operation between producers and users of investment castings.

3.2 SURFACES

The technical data given in this Reference sheet apply for the shot-blasted or pickled surfaces of castings. The delivery state might vary, e. g. because of additional surface treatment. Exceptions must be agreed on in advance when processes are involved which may alter the dimensional tolerances.

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3.3 AGREEMENT

Unless otherwise agreed, first-off samples will be supplied for the first order. These are intended to define and coordinate product characteristics in the interests of both parties. The first-off samples must be tested by the user. After testing release for serial production must be given to the foundry in written form. Any deviations, which are accepted by the release for serial production or the approval of the first-off samples, are binding for the production process and must be included in the (casting) drawing.

4 Dimensional accuracy

4.1 SHRINKAGE, CONTRACTION

When cast metals cool down and solidify, a contraction in volume takes place which causes shrinkage. Other important factors influencing the production of investment castings are the shrinkage of the lost patterns and the expansion of moulds during heating. The sum of these factors is taken into account by the manufacturer of the injection patterns in the contraction allowance. These are empirical values which are dependent on the casting contours, the pattern material, the ceramic mould material and the metal itself as well as on the specific production methods of individual foundries.

4.2 DATUM PLANES AND DATUM POINTS

For producing castings, it is necessary to enter datum planes and datum points (so-called locating points) systematically in the drawings or CAD-data to ensure that dimensional inspection and subsequent machining are properly matching. These datum points and planes must already be determined between the designer and the investment-casting foundry. The zero position of the datum planes is defined precisely by the dimensions of the datum points.

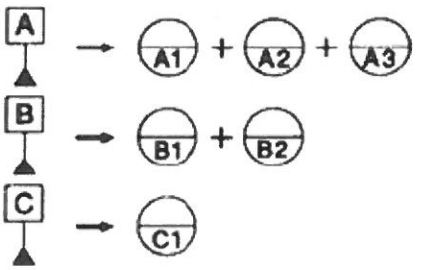

Figure 1 Datum plane – datum points

The primary datum plane „A" is fixed by the three datum points A1, A2 and A3. It should correspond to the largest surface of the casting.

The secondary datum plane „B" has the two datum points B1 and B2. If possible, these should be located on the lengthwise axis. The tertiary datum plane „C" has only one datum point C1, which should be located in the centre of the casting or in the vicinity thereof.

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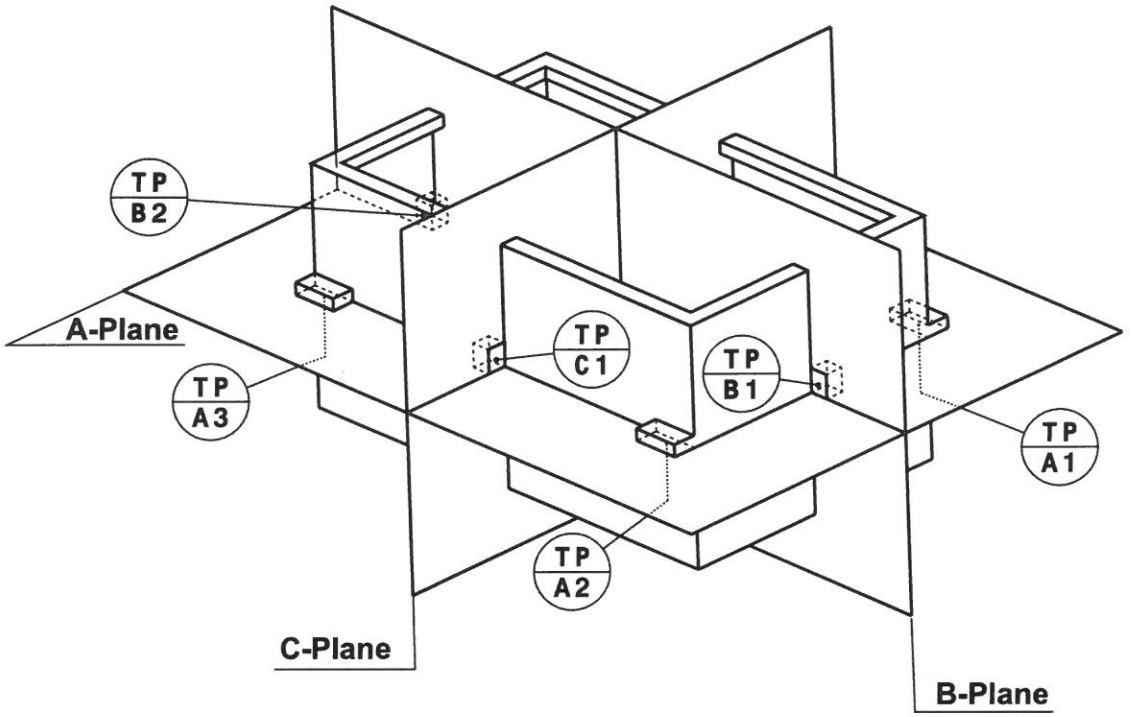

Figure 2 Reference system (Schematic example)

The datum planes are laid through the symmetry axis of the casting. All datum points should be arranged in such a way that they cannot be altered or removed by subsequent machining operations. The datum points should be located on the outer surface of the investment casting. They may be either recessed or raised in relation to the casting surface. In the case of castings with narrow tolerances of shape and position, raised datum points are advantageous.

When fixing the position of the datum points, it should be ensured that they are not in the vicinity of a sprue/ ingate. Complex shapes of castings can be accurately positioned by (pre-) machining the locating points.

4.3 OVER-DEFINITION/REDUNDANT DIMENSIONING

In accordance with DIN 406, over-definition/ redundant dimensioning should be avoided. Wall thicknesses must always be stated.

4.4 MOULD AND PATTERN DRAFT

As a rule, mould and pattern drafts are not required. Any exceptions due to technical requirements must be agreed on between the supplier and the customer (cf. DIN EN ISO 8062-3, Amendment F) (Not yet published at date of printing).

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5 Dimensional tolerances

5.1 LINEAR TOLERANCES

The dimensional tolerances achievable on investment castings are dependent on the following factors:

> casting material
> casting dimensions and shape

5.1.1 Casting materials

In production, the tolerance range of dispersion is affected by the varying characteristics of the materials, For this reason, different tolerance series apply for different groups of casting materials (**table 1**):

Material-group D:	*Accuracy grade*
alloys based on iron nickel, cobalt and cooper	D_1 to D_3
Material-group A:	
alloys based on aluminium and magnesium	A_1 to A_3
Material-group T:	
alloys based on titanium	T_1 to T_3

5.1.2 Validity of accuracy grades

Three accuracy grades are stated for each of the material groups D, A and T.

Accuracy grade 1 applies for all free sized dimensions. **Accuracy grade 2** applies for all dimensions to be toleranced. **Accuracy grade 3** can only be met for certain dimensions and must be agreed with the casting manufacturer, as additional production processes and costly tooling adjustments are necessary.

Tabelle 1a: Linear dimensional casting tolerances (DCT in mm) for dimensional casting tolerance grades (DCTG) material group D

FREE SIZE | TOLERENCED | AGREED

Nominal dimension range	D1		D2		D3	
	DCT	DCTG	DCT	DCTG	DCT	DCTG
up to 6	0,3	5	0,24	4	0,2	4
over 6 up to 10	0,36		0,28	5	0,22	
over 10 up to 18	0,44	6	0,34		0,28	
over 18 up to 30	0,52		0,4		0,34	5
over 30 up to 50	0,8	7	0,62	6	0,5	
over 50 up to 80	0,9		0,74		0,6	6
over 80 up to 120	1,1		0,88		0,7	
over 120 up to 180	1,6	8	1,3	7	1,0	
over 180 up to 250	2,4	9	1,9	8	1,5	8
over 250 up to 315	2,6		2,2		1,6	7
over 315 up to 400	3,6	10	2,8	9		
over 400 up to 500	4,0		3,2			
over 500 up to 630	5,4	11	4,4	10		
over 630 up to 800	6,2		5,0			
over 800 up to 1000	7,2					
over 1000 up to 1250						

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Table 1b: Linear dimensional casting tolerances (DCT in mm) for dimensional casting tolerance grades (DCTG) material group A

Nominal dimension range	A1		A2		A3	
	DCT	DCTG	DCT	DCTG	DCT	DCTG
up to 6	0,3	5	0,24	4	0,2	4
over 6 up to 10	0,36		0,28	5	0,22	
over 10 up to 18	0,44	6	0,34		0,28	
over 18 up to 30	0,52		0,4		0,34	5
over 30 up to 50	0,8	7	0,62	6	0,5	
over 50 up to 80	0,9		0,74		0,6	6
over 80 up to 120	1,1		0,88		0,7	
over 120 up to 180	1,6	8	1,3	7	1,0	
over 180 up to 250	1,9		1,5	8	1,2	7
over 250 up to 315	2,6	9	2,2		1,6	
over 315 up to 400	2,8		2,4	9	1,7	8
over 400 up to 500	3,2		2,6	8	1,9	
over 500 up to 630	4,4	10	3,4	9		
over 630 up to 800	5,0		4,0			
over 800 up to 1000	5,6		4,6	10		
over 1000 up to 1250	6,6					

Table 1c: Linear dimensional casting tolerances (DCT in mm) for dimensional casting tolerance grades (DCTG) material group T

Nominal dimension range	T1		T2		T3	
	DCT	DCTG	DCT	DCTG	DCT	DCTG
up to 6	0,5	6	0,4	6	0,4	6
over 6 up to 10	0,6	7	0,4		0,4	
over 10 up to 18	0,7		0,5		0,44	
over 18 up to 30	0,8		0,7	7	0,52	
over 30 up to 50	1,0		0,8		0,62	
over 50 up to 80	1,5	8	1,2	8	0,9	7
over 80 up to 120	1,7		1,4		1,1	
over 120 up to 180	2,0		1,6		1,3	
over 180 up to 250	2,4	9	1,9		1,5	8
over 250 up to 315	3,2		2,6	9		
over 315 up to 400	3,6	10	2,8			
over 400 up to 500	4,0		3,2			
over 500 up to 630	5,4	11	4,4	10		
over 630 up to 800	6,2		5,0			
over 800 up to 1000	7,2					
over 1000 up to 1250						

5.1.3 Position of tolerance zone

The position of the tolerance zone in relation to the nominal dimension can be freely selected. It is advisable to place the tolerance zone evenly on each side of the nominal dimension. In the case of surfaces to be machined mechanically, the sum or difference of tolerance zone and machining allowance must be taken into account (see item 7).

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5.2 TOLERANCES OF SHAPE AND POSITION

Tolerances of shape and position limit the deviations of the shape feature from its theoretically precise

> shape or
> direction, or
> from its exact - location

independently from the actual dimension of the shaped element. Tolerances of shape and position require that datum surfaces and datum points (see item 4.2) are fixed, based on DIN ISO 1101. If tolerances of shape and position are fixed by the order, they must be stated individually and entered in the drawing in accordance with DIN EN 1101 .

Three accuracy grades are available. The higher the degree of accuracy, the bigger the production complexity. Accuracy grade 3 (according to table 1) can only be met for certain dimensions and must be agreed on with the castings manufacturer, as additional production process steps and costly tooling adjustments are necessary.

5.3 ANGLE TOLERANCES FOR MATERIAL GROUPS D, A AND T

Nominal dimension range [1]	Accuracy[3]					
	1		2		3	
	Allowed deviation of direction					
	Angular minute	mm per 100 mm	Angular minute	mm per 100 mm	Angular minute	mm per 100 mm
up to 30 mm	30 [2]	0,87	30 [2]	0,87	20 [2]	0,58
over 30 up to 100 mm	30 [2]	0,87	20 [2]	0,58	15 [2]	0,44
over 100 up to 200 mm	30 [2]	0,87	15 [2]	0,44	10 [2]	0,29
over 200 mm	30 [2]	0,58	15 [2]	0,44	10 [2]	0,29

1) The nominal-dimension range is determined by the length of the shorter side
2) The angle may deviate in both directions Tolerances of angle differing from those given in table 3 must be agreed between supplier and user, and entered in the drawing in accordance with DIN ISO 1101.
3) For investment castings based on Titanium alloys accuracy grade 1 has to be applied

Table 2: Angle tolerances

Tolerances deviating from **table 2** must be agreed on between supplier and user and entered in the drawing in accordance with DIN ISO 1101.

5.4 RADIUS OF CURVATURE

The tolerances stated apply for the material groups D, A and T.

Nominal dimension range	Accuracy[1]		
	1	2	3
	Radius of curvature [mm]		
up to 5 mm	± 0,30	± 0,20	± 0,15
over 5 up to 10 mm	± 0,45	± 0,35	± 0,25
over 10 up to 120 mm	± 0,70	± 0,50	± 0,40
over 120 mm	linear (cf. table 1)		

1) For investment castings based on Titanium alloys accuracy grade 1 is generally valid

Table 3: Radius of curvature for material groups D, A and T

Radii of curvature deviating from **table 3** must be agreed on with the investment casting foundry.

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5.5 DIMENSIONAL TOLERANCE FOR WALL THICKNESSES

The tolerances of wall thickness are dependent on:

> the size of the ceramic shell mould
> its uninterrupted surface
> its possible thermal deformation
> its possible thermal deformation

Tolerances for wall thickness are therefore not dependent on the degree of accuracy. They are limited (or reduced) by thicker edge areas, openings (holes, webs) ribs etc., all of which relieve stress on the wall thickness.

For the applicable tolerance range, refer to **table 4**. This contains the lengths of the smallest side of a surface (with reference to material group) on which the wall-thickness tolerance depends. The tolerances apply for unmachined surfaces only.

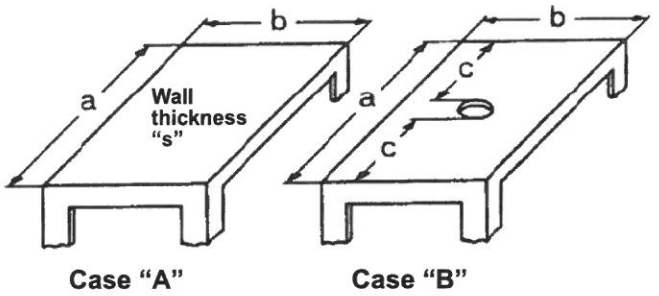

Figure 3: Example for wall-thickness tolerance

Case A: The surface formed by dimensions a and b is not interrupted. Dimension b is smaller than dimension a. Dimension b determines the tolerance of wall thickness. **Case B:** The area formed by dimensions a and b is interrupted by a hole in the centre. The uninterrupted surface is therefore formed by dimensions b and c. Dimension c is smaller than dimension b. The wall-thickness tolerance is therefore determined by dimension c.

Smallest lateral length of a surface (Figure 3)	Material group D [mm]	Material group A [mm]	Material group T [mm]
up to 50 mm	± 0,25	± 0,25	± 0,30
over 50 up to 100 mm	± 0,30	± 0,30	± 0,40
over 100 up to 180 mm	± 0,40	± 0,40	± 0,50
over 180 up to 315 mm	± 0,50	± 0,50	± 0,60
up to 315 mm	± 0,60	± 0,60	± 0,70

Table 4: Wall-thickness tolerances

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5.6 DIMENSIONAL TOLERANCES FOR PRE-FABRICATED INSERTS AND CAST-ON PARTS

Diese sind mit der Gießerei zu vereinbaren.

6 Surface quality

For cast surfaces, R_a (CLA) shall be applied in accordance with **table 5**.

Surface standards	Material group D		Material group A		Material group T	
	CLA [µinch]	R_a [µm]	CLA [µinch]	R_a [µm]	CLA [µinch]	R_a [µm]
N 7	63	1,6				
N 8	125	3,2	125	3,2		
N 9	250	6,3	250	6,3	250	6,3

Table 5: Surface roughness

Zone N7, N8 and special surface treatment must be agreed separately and entered in the drawing in accordance with DIN ISO 1302. Unless otherwise agreed, N9 in shot-blasted state is the standard delivery condition.

7 Machining allowances

Fit sizes on surfaces or low surface roughness, which cannot be achieved by investment casting, receive machining allowances. The allowance must take account of the specific material characteristics and the mathematically least favourable position within the tolerance zone including the tolerances of shape and dimension.

8 Additional notes and data

8.1 INNER RADII

Radii at inner corners and edges (concave fillets) prevent casting defects and reduce the notch tension in the casting during use. The minimum radius should be about 20% of the biggest wall thickness, but not less than 0.5 mm. It is recommended to select an inner radius which is at least equivalent to the lowest wall thickness.

8.2 OUTER RADII AND OUTER CHAMFERS

8.2.1 Material Groups D and A

Unmachined investment castings do not have sharp edges with R=O. For this reason, outer radii and outer chamfers are always stated as maximum radii, e.g. R< 0.5 max

8.2.2 Material Group T

Investment castings based on a titanium alloy might have sharp edges due to manufacturing reasons. Chamfering those edges must be agreed upon between supplier and user.

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8.3 HOLES, BLIND HOLES, CHANNELS, SLOTS AND GROOVES

In order to cast through holes, blind holes, channels, slots and grooves as economically as possible, i.e. without preformed ceramic cores, the figures given in **tables 6** and **7** should be taken into account.

∅ or D	Max. length or depth	
d [mm]	through (l)	blind (t)
2 to 4	≈ 1 x d	≈ 0,6 x d
over 4 up to 6	≈ 2 x d	≈ 1,0 x d
over 6 up to 10	≈ 3 x d	≈ 1,6 x d
over 10	≈ 4 x d	≈ 2,0 x d

Table 6: Dimensions for holes, blind holes and channels

Width b	Biggest depth below	
[mm]	open (l)	closed (t)
2 up to 4	≈ 1 x b	≈ 1,0 x b
over 4 up to 6	≈ 2 x b	≈ 1,0 x b
over 6 up to 10	≈ 3 x b	≈ 1,6 x b
over 10	≈ 4 x b	≈ 2,0 x b

Table 7: Dimensions for slots and grooves

8.4 IDENTIFICATION OF CASTINGS

If the castings are to be labelled, the letter size (to DIN 1451 „medium") and the location on the casting must be agreed on. The VDG reference sheet no. P 701 „Identification of Castings" should be used as guidance. The label may be either cast raised or recessed. Raised letters in a recessed field are preferred. If the drawing does not contain any instructions, the kind of labelling should be fixed by the supplier.

9 Further reading

The entire casting process is described in detail in a brochure entitled „Feingießen Herstellung - Eigenschaften - Anwendung", special print of the series „konstruieren + giessen" , No. 1, published by the BDG, Düsseldorf. It contains practical notes on materials, design and numerous examples of the economy of the investment casting process. Company brochures and material data sheets of the German investment-casting foundries in the BDG are available for more information on the products manufactured by individual foundries.

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