

Inspection-oriented Tolerancing Size, Form, and Location

Summarized by

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*If You Can't Measure It,
You Can't Manage It
(Peter F. Drucker, 1909-2005)*

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Dr. Robert Roithmeier

Contents

1	Introduction.....	10
1.1	Engineering in compliance with functional, manufacturing, and inspection requirements	10
1.2	Cooperation between the areas	14
2	Inspection-oriented tolerancing of size, form, and position	21
3	Form	25
3.1	Line-like form.....	31
3.1.1	Roundness (Circularity)	31
3.1.2	Straightness of a line in a plane.....	33
3.1.3	Straightness of an axis	35
3.1.4	Straightness of surface lines	37
3.1.5	Simple line profile.....	39
3.2	Surface-like form	40
3.2.1	Cylindricity	40
3.2.2	Surface flatness	42
3.2.3	Center plane flatness.....	43
3.2.4	Simple surface profile	44
4	Size.....	47
5	Envelope requirement and principle of independency	53
6	Datum	61
6.1	Datum feature	61
6.2	Datum reference frame	66
7	Orientation and angle.....	75
7.1	Variants of orientation tolerancing	76
7.1.1	Orientation of a plane	76
7.1.2	Orientation of an axis	79

7.1.3	Orientation of a surface line.....	81
7.2	Angularity instead of angular dimension.....	84
8	Location and distance.....	87
8.1	Location tolerancing.....	87
8.1.1	Position of a plane	89
8.1.2	Position of axes	91
8.1.3	Symmetry	93
8.1.4	Coaxiality and concentricity	95
8.2	Profile with datum.....	98
8.3	Location instead of distance.....	102
9	Bore pattern and composite tolerance	107
9.1	Position tolerancing on a bore pattern	107
9.2	Composite tolerancing	111
10	Runout	115
10.1	Axial runout on a plane	115
10.2	Radial runout on a surface area	117
11	Limits of form and position tolerances.....	119
11.1	Maximum material condition	119
11.2	Reverse tolerance limits	128
11.3	Least material requirement.....	130
12	Restricted tolerance zone and datum area	133
12.1	Restricted tolerance zone.....	133
12.2	Restricted datum area	135
12.3	Projected tolerance zone	137
13	General tolerances	139
14	Drawing specifications for the measurement strategy	145
14.1	Association	145

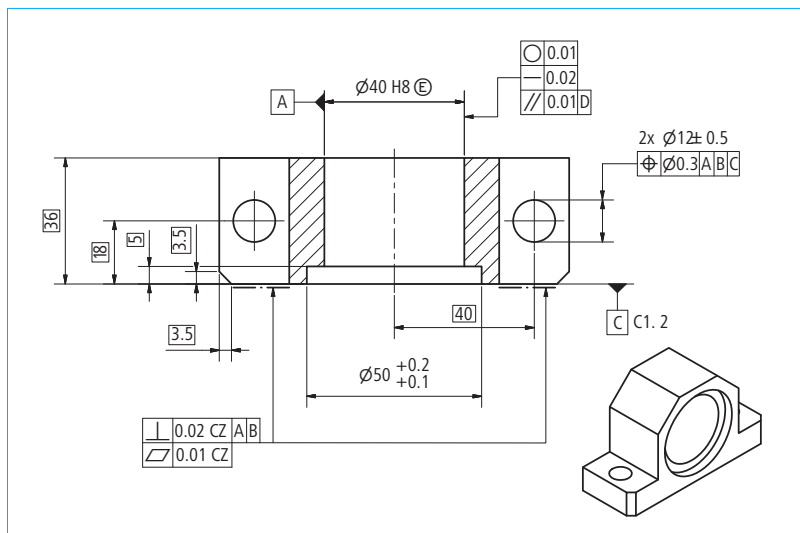
14.2	Filter specifications	147
14.3	Excursion into contour analysis	148
14.3.1	Digital filtering	157
14.3.2	Low-pass filter: analysis of the workpiece form	159
14.3.3	High-pass and band-pass filters	164
14.3.4	Notes on digital filtering	167
15	Suitability of measurement systems	171
15.1	Measurement system analysis: capability and GR&R- test	177
15.2	GUM and VDA 5	179
16	Final remarks	181
	Appendix	182
A	More books of ZEISS Academy Metrology	182
B	Important ISO, US, and DIN standards	184
C	Bibliography without standards	188
D	Illustrations and tables	192
E	Index	198

1 Introduction

1.1 Engineering in compliance with functional, manufacturing, and inspection requirements

In order to be competitive in international markets, the industry is forced to manufacture its products more efficiently and to become more productive. This is where engineering drawings of the workpieces to be produced come in, since they play a key role in this context. In industrial manufacturing, an engineering drawing is a core reference for a clear and complete product description. It is the most important means of communication between design, engineering, manufacturing, purchase, sales, and the customer – worldwide. No matter what format is used, this may be a traditional 2D engineering drawing on paper (see Illustration 1) or a digital data set [STEINBEIS 2014].

*Illustration 1:
Technical
drawing of a
bearing block
(extract)*



The drawing (or CAD data set) must include all specifications needed to guarantee functional safety, economical production, and reliable inspection of the workpiece in question. The technical drawing (or CAD description of the workpiece) must therefore be created with a view to meeting the requirements in terms of

- function
- production
- inspection.

This last point is often especially neglected, although it is one of the basic conditions for an economical production. That is why this book not only deals with the suitability of technical drawings and CAD descriptions for meeting functional and manufacturing requirements, but particularly focuses on their fitness for inspection purposes.

Thanks to the work of international standardization committees, a comprehensive descriptive language for geometrical product requirements has been created: the GPS standards¹. Based on these standards, geometric requirements can be described completely, clearly, and unambiguously in technical drawings and CAD files. The GPS standards contain a symbolized language and rules, which are constantly evolving. Any information needed to meet the requirements with regard to function, manufacturing, and inspection can thus be included in the drawing. This guarantees the functional properties of a product and ensures its suitability for mounting and inspection once the drawing has been released [GRÖGER 2013].

GPS standards

¹ GPS = Geometrical Product Specification; for details refer to [ISO 14638]

Furthermore, the GPS standards are supposed to promote communication between the different “worlds”, which the [ISO 22432] standard describes as follows:

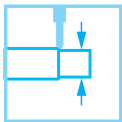
- product as conceived by the designer,
- manufactured product,
- measured product.

Function



The product conceived by the designer is a purely functional one. All geometric properties are chosen for the purpose of fulfilling the desired function. Geometric tolerances (size, form, position, and surface tolerances) are defined to guarantee that function. This means that the “imprecise” workpiece must be able to fulfill its intended function throughout the entire service life if its deviations are within the defined tolerance limits. It must be either unconditionally suitable for assembly (i.e., same parts can be exchanged at will) or conditionally suitable (i.e., same parts are combined or can only be exchanged together) [KLEIN 2014]. These are the function-related requirements to be met by the engineering drawing.

Production



The manufactured product is subject to typical deviations resulting from the production process. In practice, it is impossible to manufacture parts without deviations. Such deviations are caused by the effects of material properties and production conditions (e.g. tool type, shear force, production speed, clamping, residual stress of the workpiece, ...). Nevertheless, it must be possible to manufacture the workpiece within the defined tolerances, while ensuring cost-efficiency and process capability [KLEIN 2014]. According to this, a manufacturing-oriented drawing needs to meet other requirements than a function-oriented one: it must, for example, specify the points for clamping and include the allowances required for the various machining steps.

With regard to the measurement of a product in turn, additional criteria need to be met. It should be possible to inspect or measure the product reliably and as easily as possible. The drawing must include the essential features of a product to ensure its function and suitability for assembly [KLEIN 2014]. The drawing is supposed to allow clear and unambiguous interpretation of all tolerances in order to avoid different or incomparable measurement results and, consequently, unnecessary discussions with suppliers and other departments due to incompleteness, contradictions, and ambiguities. Reliable inspection is a precondition for reliable manufacturing. Therefore, both the function-oriented drawing and the manufacturing-oriented drawing (if available) need to be created with a view to meeting inspection requirements. However, two particular problem areas will have to be faced in this context, and this book aims to help you handle these difficulties:

Inspection



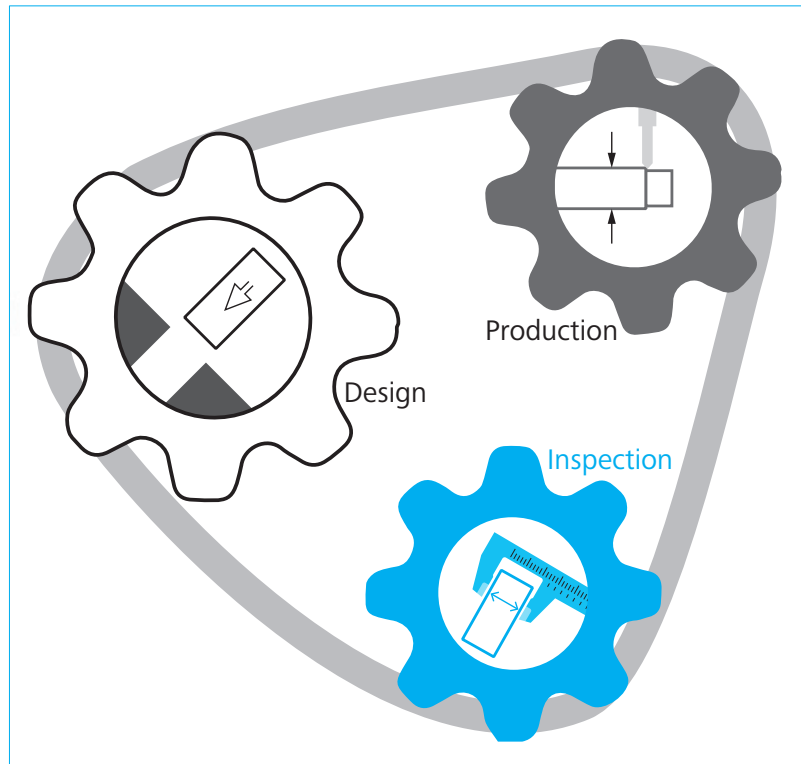
- The first issue to face is the large number of standards existing in the field of geometrical product specification (GPS). They cover far more than 2000 text pages, which have not all been read and understood by all those involved in the product manufacturing process. Consequently, only few quality professionals fully understand the information provided by a drawing [NPL 79] and the meaning of the symbols (e.g. 20h7 GN ACS 0.2 SR), or know how to perform the corresponding measurements.
- The second problem is that the symbols used in a technical drawing (e.g. \oplus or \odot) may apply to different tolerances and measurement methods, depending on the country, the drawing's date of creation, and the standard on which it is based.

1.2 Cooperation between the areas



Such challenges related to a function-, manufacturing-, and inspection-oriented geometrical product specification can only be tackled jointly. Even though the designer is always responsible for the product specification, it is only if design, manufacturing, and metrology staff act together that cost-efficiency, high quality, and operational reliability (also in terms of product liability) can be guaranteed.

*Illustration 2:
Cooperation in
industrial
production*



*Need for
communication*

Communication between the various stages is of fundamental importance in the course of a production process. Good metrology, in particular, should be a part of this process. It is not restricted to meas-

urements on the final product. According to the GPS system, tolerancing and measurement capability criteria should be considered for all stages of design, manufacturing, and inspection. It is usually much costlier to modify an engineering drawing later, for example when noticing that a specific functional feature cannot be measured as planned [NPL 79] or does not provide the desired information.

The following chapters will present various aspects of geometric dimensioning and tolerancing (“GD&T”) for design, manufacturing and inspection of workpieces. Furthermore, you will find an outline of the international system of ISO GPS standards, and the book will deal with advanced options for defining the measurement strategy in the technical drawing.

Fourteen rules of inspection-oriented GD&T are summarized below. Each rule will be dealt with in detail in the course of the book:

*14 rules of
analysis capability*

— Rule R1: inspection-oriented tolerancing of form

Form must be controlled for any geometric element that is relevant to function or will be used as a datum for other features. Furthermore, tolerances of size and position can be adhered only if the form of a feature is also controlled. (Page 25 et seqq.)

— Rule R2: inspection-oriented dimensional tolerancing

Modifiers are to be used for task-specific dimensional tolerancing. Such unambiguous metrological specifications allow better comparison of measurement results and target-oriented tolerancing in compliance with functional, manufacturing, and inspection requirements. (Page 47 et seqq.)

— Rule R3: inspection-oriented independency and envelope requirement

The separate verification of size and form tolerances is useful for

the manufacturing process (independency principle). The dimensional tolerance needs to be marked by E only in cases where the function requires adherence to the envelope condition. This is always preferable to a reduction of the individual size and form tolerances. Requesting the envelope requirement for all sizes would not be economical and defeat the purpose. If, instead of using the E symbol, you reduce the individual size and form tolerance ranges just to “be on the safe side”, you would unnecessarily increase the expenditure for production and inspection. (Page 53 et seqq.)

→ **Rule R4: inspection-oriented datums**

In order for a datum to be stable and suitable for analysis, its form deviation must be significantly smaller than that of the feature to be tolerated. Furthermore, when establishing datums, make sure that they are distinctive and accessible for measurement, and that the datum feature and the tolerated feature are not too far apart. (Page 61 et seqq.)

→ **Rule R5: inspection-oriented tolerancing of orientation**

Check whether it is possible to use angularity tolerances instead of angular dimension tolerances. They are usually easier to measure, especially in the area near the vertex. Moreover, the angularity tolerance provides separate results for the datum feature and the tolerated feature. (Page 75 et seqq.)

→ **Rule R6: inspection-oriented tolerancing of location**

Tolerancing is always preferable to dimensional distance tolerancing. It is easier to define positions than dimensions, and this reduces specification uncertainties significantly. The use of cylindrical or circular tolerance zones generally provides a larger tolerance surface while the functional requirements remain the same. This ensures optimized usage of the desired tolerance and better suitability for inspection purposes. (Page 87 et seqq.)

E Index

(A).....	35	0-L tolerancing.....	131
(AD).....	142	0-M tolerancing.....	128
(CA).....	48	3-2-1 datum.....	71
(CC).....	48	3-2-1 rule.....	71
(CV).....	48	Accuracy.....	171
(E).....	54, 58, 125, 139	ACS.....	32, 95
(F).....	73	All around zone.....	100
(GC).....	49	All over tolerance zone.....	100
(GG).....	48	ALS.....	33
(GN).....	48, 59	Amplitude.....	166
(GX).....	48, 59	Amplitude.....	149
(I).....	57	Analysis-capable datum.....	63
(L).....	130	Angular dimension.....	84
(LP).....	48	Angular dimension tolerancing.....	84
(LS).....	48	Angularity tolerance.....	75
(M).....	107, 119, 120	Any Cross Section.....	32
(P).....	137	Any Longitudinal Section.....	33
(R).....	128	Arrow.....	110
(S).....	132	Articulating system.....	175
(SA).....	50	ASME rule #1.....	55
(SD).....	50	ASME rule #2.....	32
(SM).....	50	ASME Y14.5.....	22, 42, 119
(SN).....	50, 59	Associated geometry.....	22
(SR).....	50	Association criterion.....	145
(SX).....	50, 59	At-line inspection.....	53
(T).....	78	AUKOM.....	19
(U).....	99	AVG.....	50
[CF].....	73	Axial runout tolerancing.....	115
[DF].....	73	Axis.....	35
[DV].....	73	Band-pass filter.....	157
[PL].....	136	Basic Dimension.....	51
[PT].....	136	Basic tolerance.....	47
[SL].....	136	Bore pattern.....	107
[u,v,w].....	136	C.....	145
[x,y,z].....	136	CAD data set.....	11
×.....	109, 136	Capability.....	173, 177

Cartesian coordinate system	69	Dial gage.....	116
Center plane.....	35	Diameter symbol	35
Center plane without form error	78	Digital filtering.....	157
Chatter mark	153	Dimension chain.....	103
Chatter marks.....	25	Dimension Origin	105
Chebyshev.....	72	Dimensional error.....	25
Circularity	31	Dimensional tolerancing of a distance	
Clamp-on gage.....	107	102
Coaxiality tolerance	87, 95	DIN 40680	141
Collection plane symbol.....	100	DIN 4760	25
Combined tolerance zone.....	36	DIN 6930-2	141
Combined zone	36	DIN 71606	141
Combined Zone	42	DIN 7167	55
Common datum	71	DIN 7526	141
Common Zone	36	DIN 7527	141
Compensator.....	132	DIN EN 10243	141
Composite tolerance.....	111	DIN EN 12020	141
Composite tolerance indicator	111	DIN EN 16742	141
Composite tolerancing.....	111	DIN EN 586-3.....	141
Concentricity tolerance	87, 95	DIN EN 755-9.....	141
Cones.....	25	Distance tolerancing.....	102
Contour.....	148	Duration.....	175
Coordinate measuring machine 32, 171		Eccentricity.....	152
Coplanarity.....	36	Engineering drawing	10
Cracks	25	Envelope principle	53
Cutoff wave number.....	158	Envelope requirement	53, 54
Cutoff wavelength.....	158	Evaluation method	145
Cylindrical tolerance zone	91	Extracted geometry	22
Cylindricity.....	40	Feature control frame.....	31
Cylindricity tolerance	40	Filter.....	147
CZ	36, 42, 109	Filter end range	160
Datum	61	Filter start range	160
Datum center point	87	First angle projection.....	29
Datum feature	61	Flatness error.....	25
Datum frame	61	Flatness tolerance of a center plane..	43
Datum order.....	70	Flatness tolerance of a surface.....	42
Datum reference frame.....	66	Floating tolerancing.....	37, 108
Datum target.....	71	Form error	25
Datum triangle	61	Form tester	32
Degree of freedom	66, 136	Fourier analysis.....	155
Deviations	12	Free state	73

Free-form surface	44	ISO 2768.....	139
Function	12	ISO 286.....	47
G	146, 147	ISO 5459.....	69, 73
Gage	54, 125	ISO 8015.....	53
Gaussian Best Fit	48	ISO 8062.....	141
Gaussian filter	147	ISO 9013.....	141
GD&T	15, 22	ISO committees.....	142
General tolerances	139	ISO size tolerance system	47
Geometrical product specification	13	ISO tolerance field.....	47
Golden rule of metrology	173	ISO/IEC Guide 98-3	179
GPS	142	Lambda.....	149
GPS standard chain	142	Leader arrow.....	31
GPS standards	11	Least Material Condition	130
GPS system	11, 142	Least Material Requirement.....	130
GR&R test.....	177	Least Material Requirement.....	130
Grooves	25, 153	Least square circle	146
GUM	179	Least square cone	146
Helix path.....	118	Least square cylinder	146
High-pass filter	157	Least square plane	146
Independence requirement.....	53	Least-squares method	48
Indicator for orientation	80	Length measuring error.....	173, 175
In-line inspection.....	53	LMC.....	130
Inner shell	54	LMR	130
Inside datum	108	Location.....	87
Inspection	13	Location error	25
Inspection process.....	173	Location tolerance	87
Inspection process capability	173	Lower tolerance limit.....	47
Inspection-oriented datum	63, 73	Low-pass filter.....	157
Intensity	166	LSCI	146
Invocation principle	142	LSCO.....	146
ISA	21	LSCY	146
ISO	21	LSPL	146
ISO 1	29	Maximum inscribed circle.....	145
ISO 10579.....	73	Maximum inscribed cylinder	48, 145
ISO 1101	37	Maximum inscribed element	88
ISO 13920.....	141	Maximum material condition...107, 119	
ISO 14253.....	171	Maximum permissible error	88, 173
ISO 14405.....	47	Maximum permissible measuring error	173
ISO 16610.....	167, 168	MCCI	145
ISO 22432.....	12	MCCY	145
ISO 2692.....	119		

Measurement system analysis	177	Precision dial gage.....	116
Measurement system capability	173	Primary datum.....	66
Measurement uncertainty.....	171	Principle of independency.....	53
MICI	145	Probing error.....	175
MICY	145	Production	12
Minimum circumscribed circle.....	145	Production deviations.....	26
Minimum circumscribed cylinder.....	145	Profile tolerance	98
Minimum circumscribed element	88	Profile-of-a-line tolerance	39
Modifiers	48	Profile-of-a-surface tolerance.....	44
Morphological filter	167	Projected tolerance zone	137
MPE	173	Projection method.....	30
Multiple-stylus probing system.....	175	Radial runout tolerancing	117
Multiwave standard	153	Rank-order size.....	50
N.....	145	Real geometry	22
NC	64	Real-time spectral analysis	155
Nominal geometry.....	22	Reciprocity requirement.....	128
Nominal size.....	47	Reference temperature.....	29
Non-convex.....	64	Regardless of Feature Size	132
Ø.....	35	Repeatability range.....	175
Off-line inspection	53	Restricted datum area	135
Offset Zone	100	Restricted tolerance zone	133
Operation sequence-related datum...	63	Reversal measurement.....	82
Orientation.....	75	RFS.....	132
Orientation error	25	Robust Gaussian filter.....	167
Orientation indicator	80	Rotary table.....	175
Orientation only	109	Rotational degree of freedom.....	66
Orientation tolerance.....	75	Roughness	25
OTPL	145	Roughness inspection.....	164
Outer shell.....	54	Roughnesses	153
Outer tangential element.....	72	Roundness	31
Outer tangential plane.....	88, 145	Roundness error.....	25
Ovality	152	RPR	128
OZ.....	100	RPS system	72
Parallelism tolerance.....	75	Runout error	25
Peak	154	Runout tolerance.....	115
Peak-to-valley height	166	Runout tolerancing.....	115
Perpendicularity tolerance.....	75	SØ	93
Point cloud	22	Scales.....	25
Position error.....	25	Scanning probing error.....	175
Position of an axis.....	91	Scanning time	175
Position tolerance	75, 87		

SCS	51	Three-lobed circle.....	152
Secondary datum	66	Three-plane datum reference frame ..	69
Separate zone	36	Tolerance indicator.....	31
Size tolerancing	47	Tolerance symbol	31
SØ.....	45	Tolerance value	31
Spectral analysis	148	Tolerance zone orientation indicator ..	80
Spectrum	148	Tolerances.....	12
Spherical Diameter	45	Tolerance-zone restriction	134
Spherical tolerance zone.....	93	Tolerancing of form	25
Spiral line	116	Total axial runout tolerancing	115
Spiral staircase form	118	Total radial runout tolerancing	117
Spline filter	167	Total runout tolerancing.....	115
Spline Filter	147	Translational degree of freedom.....	66
Straight line of holes.....	107	Transverse profile	164
Straight-edge	34	Two-point size	48
Straightness error	25	UF.....	100
Straightness tolerance of a plane.....	33	Undulations per revolution	147, 151
Straightness tolerance of an axis.....	35	United Feature	100
Straightness tolerance of an edge.....	35	Unsymmetrical Zone.....	92, 99
Straightness tolerance of surface lines	37	Upper tolerance limit.....	47
Striations.....	25, 153	UPR.....	147, 151, 158
Suitability of measurement systems	171	UZ.....	92, 99
Superposition of waves	149	Variable tolerance zone.....	134
Surface inspection	164	VDA 5	179
Surface line	35, 38, 82	VDI/VDE 2601	25
Symmetry tolerancing.....	93	W/U (UPR).....	158
SZ	36, 109	Wavelength	149, 166
T	145	Waviness.....	25, 153
Tangential element.....	72	Without form	81, 92, 94, 97
TED	51	Workpiece surface	148
Tertiary datum.....	66	X.....	145
Theoretically Exact Dimension.....	51	λ	149
Third angle projection	29		