Quality Talk

GB

AgieCharmilles

Contents

Foreword

This reference booklet was written by GF AgieCharmilles Milling in order to provide a general overview on the subject of quality and quality assurance, with the focus on acceptance testing on our machining centres. One of our main objectives is the standardisation of the knowledge base on this subject, so that communication within and outside GF AgieCharmilles Milling (especially with clients) can take place on a uniform basis.

The basis for quality and quality assurance is ISO 9001:2000 (Quality) and ISO 14001:2004 (Environmental protection) and OHSAS 18001 : 2007 (Occupational health and safety) certification, in order to confirm a market-driven quality level at GF AgieCharmilles.

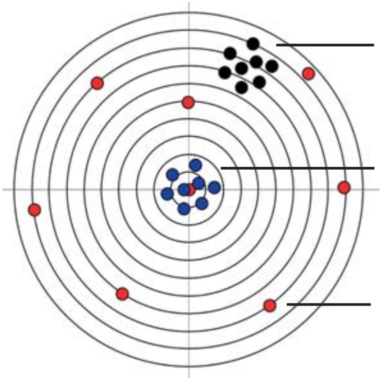
Definition of terms

Quality:
The set of features of a product or of a service with regard to its ability to comply with predefined requirements. In other words, "Actual state relative to requirements"

Accuracy:
Difference between actual measurement and nominal measurement Difference between actual measurement and tolerance centre

Precision:
Reproduction, repetition and control

Error:
An error is an inadmissible variation, for example: **the exceeding of a tolerance** or a failure to comply with agreements



8 results with high **precision** but with low accuracy.
Process is uncontrolled.

8 results with high **accuracy** and with high **precision**.
Process is controlled.

Average value of the 8 individual results with high **accuracy**.
8 results with low precision.
Process is uncontrolled.

Shape and position tolerances (ISO 1101)

General:
A shape and position tolerance of an element (surface, axis, point or midplane) defines the zone within where each point of this element must lie. According to the property to be tolerated and the type of its dimensions, the tolerance zone is one of the following:

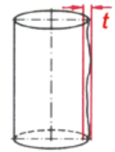
- the surface within a circle
- the surface between two concentric circles
- the surface between two parallel straight lines
- the surface between two equidistant lines
- the space between two parallel planes
- the space between two equidistant surfaces
- the space within a cylinder
- the space between two coaxial cylinders
- the space within a rectangular solid

For position tolerances, it is necessary to specify a reference, which specifies the exact position of the tolerance zone. A reference is a theoretically exact geometric element (for example: an axis, a plane, a straight line, etc.). References can be based on one or more reference elements.

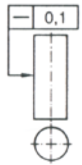
Within the tolerance zone, the tolerated element may have any desired shape, any desired location and any desired orientation, unless additional limiting data are specified.

The tolerance value "t" is determined by the same unit as the dimension of length. Unless otherwise specified, the tolerance applies to the total length or surface of the tolerated element.

— Straightness, DIN ISO 1101



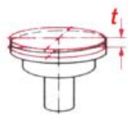
Definition:
The tolerance zone is limited in the measuring plane by two parallel straight lines a distance “t” apart.



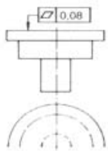
Example:
Any generating line of the toleranced cylindrical surface shall be contained between two parallel straight lines 0.1 apart.

Note: For further straightness tolerances, see DIN ISO 1101

⏥ Flatness, DIN ISO 1101

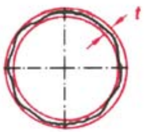


Definition:
The tolerance zone is limited by two parallel planes a.distance “t” apart.

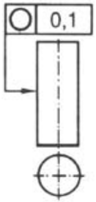


Example:
The toleranced surface shall be contained between two parallel planes 0.08 apart.

Roundness, DIN ISO 1101



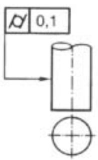
Definition:
The tolerance zone is limited in the measuring plane perpendicular to the axis by two concentric circles a distance “t” apart.



Example:
The circumference of any cross section of the toleranced cylindrical surface shall be contained between two concentric circles 0.1 apart.

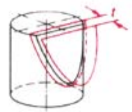
Cylindricity, DIN ISO 1101

Definition:
The tolerance zone is limited by two coaxial cylinders a distance “t” apart.

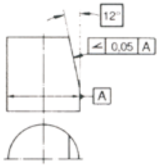


Example:
The toleranced cylindrical surface shall be contained between two coaxial cylinders 0.1 apart.

Angularity, DIN ISO 1101

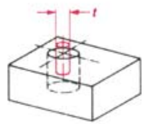


Definition:
The tolerance zone is limited by two parallel planes a distance “t” apart and inclined at the specified angle to the surface.

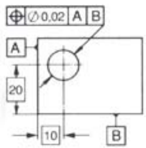


Example:
The tolerance surface shall be contained between two parallel planes 0.05 apart which are inclined at 12° to the datum axis A.

Position, DIN ISO 1101



Definition:
If the tolerance value is preceded by the sign ∅, the tolerance zone is limited by a cylinder of diameter “t”, the axis of which is in the theoretically exact position of the toleranced line.

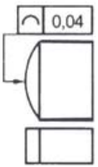


Example:
This axis of the toleranced bore shall be contained within a cylinder of diameter 0.02, the axis of which is in the theoretically exact position with respect to the surface A and B.

Note: For the positional tolerance of a point or a plane, see DIN ISO 1101

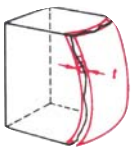
Profile any line, DIN ISO 1101

Definition:
The tolerance zone is limited by two lines enveloping circles of diamter "t", the centres of which are situated on a line having the true geometrical form.

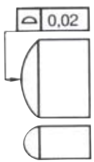


Example:
In each section parallel to the plane of projection, the toleranced profile shall be contained between two lines enveloping circles of diameter 0.04, the centres of which are situated on a line having a true geometrical form.

Profile any surface, DIN ISO 1101

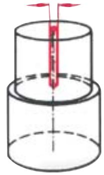


Definition:
The tolerance zone is limited by two surfaces enveloping spheres of diameter "t", the centres of which are situated on a surface having the true geometrical form.

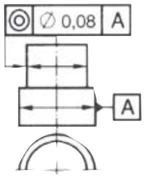


Example:
The considered surface shall be contained between two surfaces enveloping spheres of diameter 0.02 the centres of which are situated on a surface having the true geometrical form.

Concentricity / Coaxiality, DIN ISO 1101



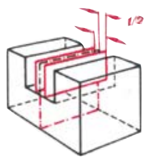
Definition (coaxiality):
The tolerance zone is limited by a cylinder of diameter "t", the axis of which coincides with the datum axis.



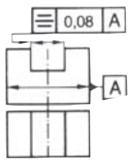
Example (coaxiality):
The axis of the toleranced cylinder shall be contained within a cylinder of diameter 0.08 coaxial with the datum axis A.

Note:
For concentricity tolerance, see DIN ISO 1101

Symmetry, DIN ISO 1101



Definition:
The tolerance zone is limited by two parallel planes a distance "t" apart and symmetrically disposed to the median plane with respect to the datum axis or datum plane.



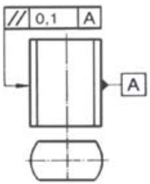
Example:
The median plane of a slot shall be contained between two parallel planes which are 0.08 apart and symmetrically disposed to the median plane with respect to the datum feature A.

Note: For symmetry tolerance of a line or an axis, see DIN ISO 1101

Parallelism, DIN ISO 1101

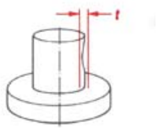
Definition:
The tolerance zone is limited in the measuring plane by two straight lines a distance “t” apart and parallel to the datum.

Example:
Any generating line of the tolerance surface shall be contained between two straight lines 0.1 apart and parallel to the datum surface A.



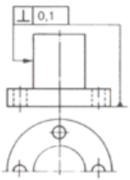
Note: For further parallelism tolerances, see DIN ISO 1101

Perpendicularity, DIN ISO 1101



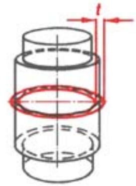
Definition:
The tolerance zone is limited in the measuring plane by two parallel straight lines a distance“t” apart and perpendicular to the datum.

Example:
Any generating line of the tolerance cylindrical surface shall be contained between two straight lines 0.1 apart and perpendicular to the datum surface.



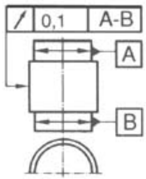
Note:
For further perpendicular tolerances, see DIN ISO 1101

Radial run-out, DIN ISO 1101



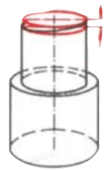
Definition:
The tolerance zone is limited in the measuring plane perpendicular to the axis by two concentric circles a distance “t” apart, the common centre of which lies on the datum axis.

Example:
The circumference of any cross section of the toleranced cylindrical surface shall be contained between concentric circles 0.1 apart, the common centre of which lies on the datum axis formed by A and B.



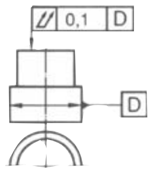
Note: When taking the measurement, the workpiece has to be turned about the datum axis. For axial run-out and run-out tolerances in any or a specified direction, see DIN ISO 1101

Total run-out, DIN ISO 1101



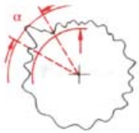
Definition (total axial run-out):
The tolerance zone is limited by two parallel planes a distance “t” apart and perpendicular to the datum axis.

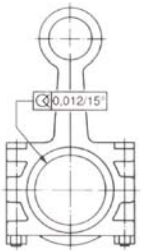
Example (total axial run-out):
The toleranced surface shall be contained between two parallel planes 0.1 apart and perpendicular to the datum axis D.



Note: When taking the measurement, the workpiece has to be turned around the datum axis several times. Workpiece and measuring instrument have to move radially to each other. For total radial run-out, see DIN ISO 1101.

Angular sector roundness, DIN ISO 1101

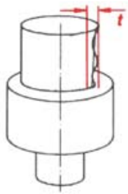


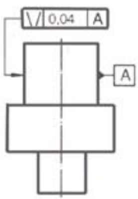


Definition:
The tolerance zone is limited in the measuring plane perpendicular to the axis by two concentric circles a distance apart. The measured circumference shall be contained in any angular sector "t" starting from the profile centre within the tolerance zone.

Example:
The "local" roundness deviation shall be smaller than 0.012 in any angular sector starting from the profile centre and featuring a width of 15°.
(Note**)

Conicity, DIN ISO 1101





Definition:
The tolerance is limited in the measuring plane by two straight lines a distance "t" apart and parallel to the datum.
Not the measured profile, but that section of the reference straight line calculated according to LSS which is restricted to the measuring length shall be contained within the tolerance.

Example:
Each section of a reference straight line calculated according to LSS which is measured in the toleranced cylindrical surface shall be contained between two straight lines 0.04 apart and parallel to the opposite generating line.

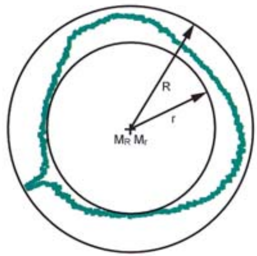
(Note***)

* **Reproduced** with permission of the DIN Deutschland Institut für Normen e. V. The version of reference for the application of the standard is the version thereof with the most recent publication date available at Beuth GmbH, Burggrafstrasse 6, 10787 Berlin. (DIN ISO1101 1985-3)

** **Note (angle sector)**
The out-of- roundness under DIN 1101 may be greater and, if necessary, can be separately tolerated.

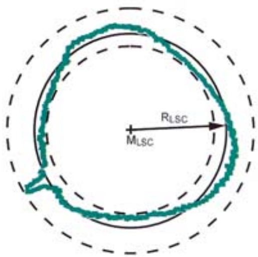
*** **Note (conicity)**
The deflection from the parallel may be greater and, if necessary, can be separately tolerated.

Shape measuring system – Evaluation processes



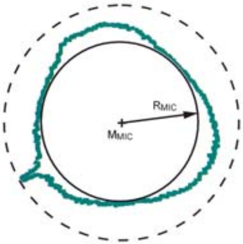
MZC
Minimum Zone Circles

Concentric inner and outer contact circles with minimum radial separation which enclose the roundness profile.



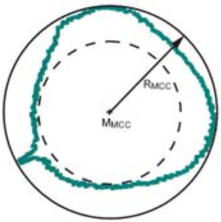
LSC
Least Square Circle

Circle through the roundness profile with the lowest sum of profile deviation squares.
This is the evaluation process generally used by GF AgieCharmilles Milling.



MIC
Maximum Inscribed Circle

Largest circle inscribed within the roundness profile for inner surfaces.



MCC
Minimum circumscribed circle

Smallest circle circumscribed around the roundness profile for outer surfaces.

Surface parameters: DIN EN ISO 4287

Especially in HSC processing, surface quality is of an increasingly greater significance. In most cases, a subjective assessment is performed by observation with the eye or sensing with the fingernail. The disadvantage of this testing process is that different observers can arrive at different results. An objective assessment through the measurement of standardised surface parameters should therefore be preferred. This, however, requires, on one hand, that standardised surface parameters must be provided on the detail drawing, and, on the other hand, that suitable surface-measuring equipment must be available. Only in this way an **objective, independent observer** evaluation is possible.

Breakdown of a surface

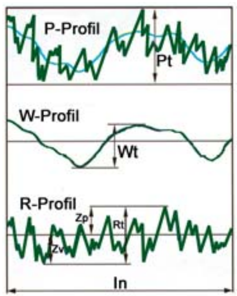
Unfiltered primary profile (P)
A surface is classified according to its actual unfiltered primary profile, consisting of misshapenness, undulation and roughness.

Filtered wave profile (W)
Undulation is separated from roughness in the unfiltered profile by means of a digital low-pass filter.

Filtered roughness profile (R)
Roughness is separated from undulation in the unfiltered profile by means of a digital high-pass filter.

Profile characteristic values Pt, Wt, Rt

The profile values Pt, Wt and Rt according to DIN EN ISO 4287 refer to the measuring section ln.

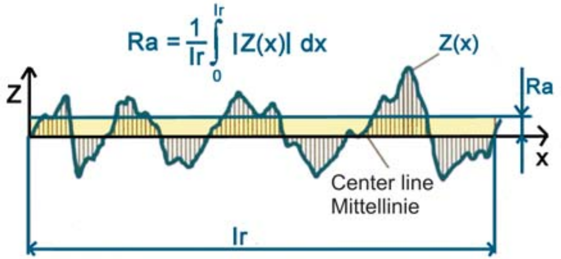


Pt is the maximum profile height of the unfiltered primary profile.

Wt is the maximum profile height of the filtered wave profile.

Rt is the maximum profile height of the filtered roughness profile and is the sum of the height Zp and the depth Zv.

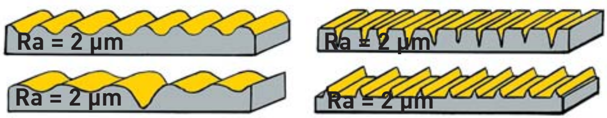
Roughness value Ra (ISO 4287)



Average roughness value Ra (µm): Arithmetical average of the absolute values of the roughness profile ordinates.

- Ra refers to the individual measuring section lr
- The informational value of Ra is very slight
- Individual "maverick" values are not taken into account
- Widely used in USA and Europe
- Historically, the first parameter capable of measurement

Ra alone doesn't count



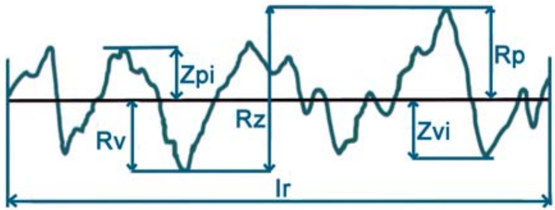
Significance of surface characteristics

The significance of characteristics varies greatly. It would be wrong to adopt any one characteristic as the preferred value in a plant. Rather, the most significant characteristics for a specific function must be determined in order to assess the function of a sample.

Example:

In a sealing surface, a single "maverick" value can give rise to inadmissible leakage. In such a case, the characteristic Ra would not be a logical criteria. In this case, it would be better to determine the characteristic Rt or material proportion Rmr(c).

Average roughness depth Rz (DIN 4768)

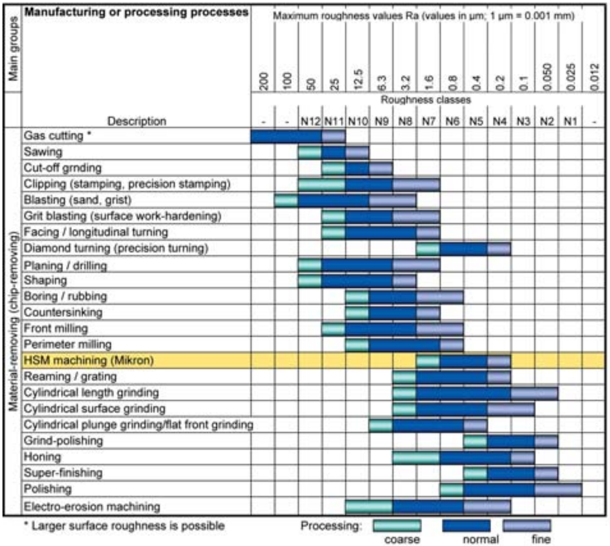


Average roughness depth Rz (µm) is the arithmetical mean of the individual roughness depths of five adjacent measuring sections, $lr=1/5 \times (Z_1+ Z_2 + Z_3 + Z_4 + Z_5)$.

- Rz refers to the individual measuring section lr.
- The average value of 5 individual measuring sections lr corresponds to the Rz value from DIN4768.
- Only one-fifth of the "maverick" value enters into the result.
- Rz can be used, for example, to measure bearing and sliding surfaces and press fit..

Manufacturing processes and their Ra values

The following graphic contains orientation and experience values for the arithmetic average roughness values Ra which can be obtained in various manufacturing processes. It enables the user to determine the manufacturing processes which actually lead to the desired roughness.



normal = roughness attainable in normal workshop conditions.
fine = roughness attainable with special care or with special methods.
coarse = top range of roughness in coarse processing.

QA of MIKRON machines

Test rules for machine tools ISO 230-1:1999

(Extract from DIN ISO 230-1) Section 3.22 Temperature conditions for specific machine parts prior to testing.

The objective is to test the accuracy of the machine tool under conditions which are as close as possible to ordinary environment from the standpoint of lubrication and heating. Before geometry tests and machining tests are carried aut, machine parts, and primarily spindles, which undergo heating and thereby change their shape and position, **must be brought to the temperature which corresponds to working conditions and to the manufacturer's instructions by idling the machine.**

Special conditions may apply to high-precision machines and to certain NC machines, when temperature fluctuations have significant effect on accuracy.

In this regard, the extent to which the machine dimensions change in the transition from ambient temperature to operating temperature must be taken into account.
The preparatory warm-up period and the ambient temperature at which the machine is to be tested should be agreed between the manufacturer and the machine operator.

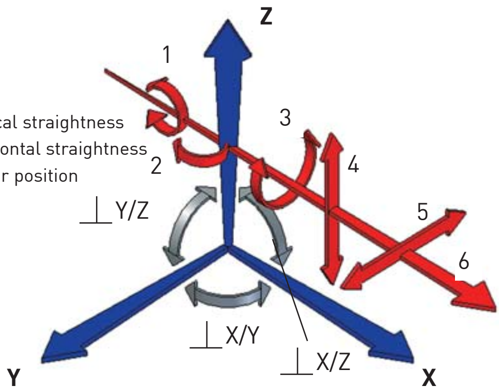
The principal areas in which thermally induced deformations can cause problems are:

a) Structural displacement (including spindles), especially in the main plane and axial plane:
b) Axis drives and positioning control; especially important when the positioning takes place by means of a ballscrew.

Accuracy of geometry ISO 10791-2:2001

In testing the accuracy of geometry and positioning, the co-ordinate system with its six degrees of freedom per axis is of great significance.

1. Pitch
2. Yaw
3. Roll
4. Vertical straightness
5. Horizontal straightness
6. Linear position



6 deviations of components per linear axis
6 deviations of components per rotative axis
Deviations of positions per axis to each other
(22 by machines with 5-axis)

Total 52 geometrical deviations for 5-axis machining centers

According to the test sheet / test report, which is supplied with each machine, we test HSM 600U (for example) 26 geometry characteristics and 25 positioning characteristics.

Positioning accuracy ISO 230-2:1997

We test positioning accuracy according to ISO 230-2:1997. Each machine axis (linear axis, rotative axis, swivel axis) is tested for positioning accuracy by means of a laser interferometer. The measurement values are electronically recorded and evaluated by means of statistical analysis.

The characteristics are:

- Positioning accuracy A
- Positioning error M
- Friction error B
- Repeatability R (R+ and R-)

Standards / Guidelines

ISO 230-2:1997 is an international standard with defined procedure for measuring the positioning accuracy of numerically-controlled axes (linear axis, rotating axes swivelling axes).
VDI/DGQ 3441 is a guideline replaced by ISO 230-2.
ISO 230-2:1997 and VDI/DGQ 3441 are practically identical. The basic differences between them are:

- The repeatability in ISO 230-2:1997 is calculated separately in both axis directions
- It is calculated with ± 2s* compared to ± 3s in VDI/DGQ 3441
- Simplified measurement procedure for axes over 2m travel
- Rotating axes and swivelling axes are specified with measurement positions.

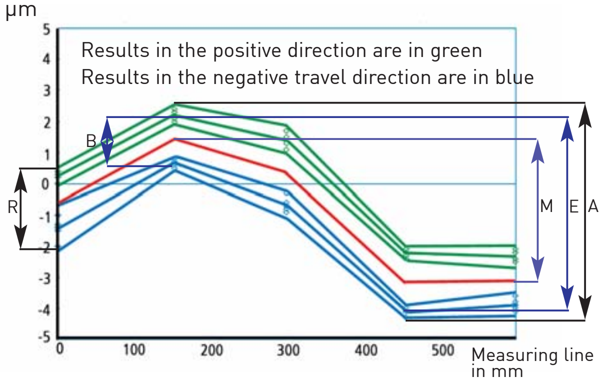
Recording of measurement values

On the entire travel of the axis to be measured, 5 to 8 measurement positions are marked out (positive and negative) at irregular intervals from each other (in order to rule out systematic errors) in the travel direction, 5 times each. (50 measurement results for 5 measuring points per axis).

Statistical evaluation of measurement values

The evaluation of the individual measurement results is performed by statistical methods. The repeatability R is calculated with ± 2s (VDI/DGQ 34441 with ± 3s).
The statistical spread is calculated separately in both travel directions in ISO 230-2:1997. (An average value is taken in VDI/DGQ.)

** Sigma (see Page 27)*



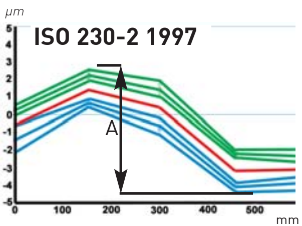
MC: HSM 600 (S/N85.00.009) Date: 29.08.2003 Axis / Tester: X/hob

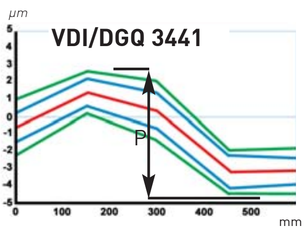
Average two-stage pos. dev. M:	4.610	Reversing error B	2.080
Systematic pos. dev.: E:	6.340	Positioning accuracy A+	5.252
Repeatability R+:	0.912	Positioning accuracy A-	5.207
Repeatability R-:	1.459	Positioning accuracy A:	6.888

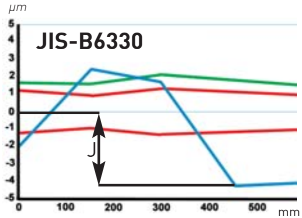
Comparison of standards

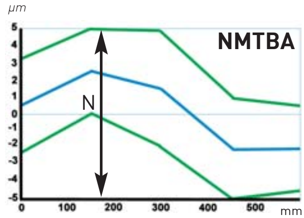
The various measurement processes for determination of positioning accuracy in a machining centre can be compared with each other only in specific circumstances (see Illustration).

Mikron HSM 600 (S/N 85.00.009)









	ISO 230-2	VDI DGQ 3441	JIS-B6330	NMTBA
Accuracy:	A=6.888	P=7.093	J=-4.300	N=±5.06
Average two-stage pos. dev. M:	4.610	4.610	-	-
Reversing play:	B=2.080	U=2.080	2.080	-
Repeatability:	R+ 0.912 R- 1.459	Ps=1.539	1.300	6.704

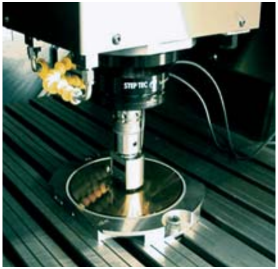
(Values in µm)

Dynamic behaviour/circular test according to ISO 230-4:1994

Measurement processes at GF AgieCharmilles Milling:

- Heidenhain KGM grid encoder; grid, read head and evaluation software
- Ball bar with integrated Quick-Check measuring device by Renishaw evaluation software

Heidenhain KGM Grid Encoder measuring device



(grid and read head)
Roundness test with measurement range ∅ 140mm / ∅ 230mm to ∅ 2μm.
Contactless optical measuring process, track speeds up to 80m/min, system accuracy 2 μm per axis, free form tests for testing any desired contours in two axes.

Ball bar with integrated Renishaw measuring device

(Quick-Check)
Roundness test with radius: 50 (∅ 100); R 100 (∅ 200); R 150 (∅ 300) and R 300 (∅ 600)
Track feeds:
Time per revolution
≥ 1 sec. (up to about 10 m/min)
Geometry testing
This process is especially suitable for rapid testing of a machine tool, for example: on commissioning, simple handling

Areas of application
In principle, there are two basic areas of application for the roundness test:
a) Testing of drives and control (dynamic behaviour)
Measurement of a small circle: ∅ < 10% of the shortest machine axis. GF AgieCharmilles Milling measures dynamic behaviour, generally with a ∅ of 44 mm

b) Testing of machine geometry:
In geometry testing, large circles are measured:
∅ > 2/3 of the shortest machine axis. For an HSM 400 this corresponds to a test diameter of about 230 mm (2/3 of 350mm).
If no large standard circles are available, measurements can be taken with the KGM in various measuring positions.

Standard testing characteristics

G	Out-of-roundness. Evaluation according to LSC (Gauss)
Gcw	Out-of-roundness measured in clockwise direction
Gccw	Out-of-roundness measured counter anti-clockwise direction
H	Circular friction error Greatest difference between Gcw and Gccw
F	Radial deflection Deflection of actual circle relative to nominal circle (Fmax and Fmin)

For further information see ISO 230-4:1996

Machining accuracy ISO 10791-7:1998

Machining accuracy is increasingly significant. At the same time, please note that many **factors which cannot be influenced** by the machine affect the results of operation.

In analysing the results, an excellent knowledge of machine accuracy and precision, processes and methods, tool technology, parts measurement, and so forth is essential.
At GF AgieCharmilles Milling, machining accuracy is proven by machining various test parts. The ISO test parts is a sales position and can be offered with no need for further information.

At our new ZEISS PRISMO measuring machine, we measure, on this test sample, a total of 36 quality characteristics, as follows:

14 form diviations
5 dimensions deviations
17 position deviations

GF AgieCharmilles Milling tests operation accuracy by machining the following test pieces:

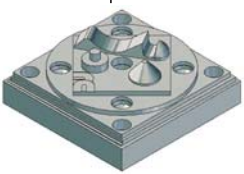
6.1 ISO test piece, (large / small)

6.2 MIKRON test piece with various (large / small) HSC functions

6.3 HSC test piece

6.4 5-axes test piece

6.5 Test component according to the NCG acceptance component



Machine and process capability

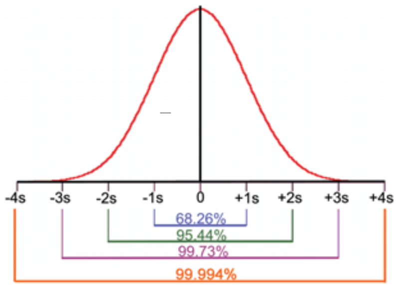
In order to avoid production defects, we need simple statistical tools to enable us to recognise abnormalities as they arise.

The analysis of machine and process capabilities provided proof that a machining centre is capable under specific conditions of manufacturing components within tolerance.

The **machine capability investigation** Cm and Cmk has the character of a **short-term evaluation** (evaluation possibly only of the machine influences) and the **process capability investigation** has the character of a **long-term evaluation** (evaluation of all influences incl.: machine, person, method, material and especially working environment).

When machining several of the same components (e.g. with the parameter under investigation, centre difference of two holes having a nominal measurement of 100mm ±0.01mm), the actual measurement differs from the nominal measurement of 100mm to a greater or lesser degree.

This scatter is influenced by chance deviations. A measurement for this scatter is the standard deviation s.



Machine capability index Cm

The machine capability index Cm - in the following example Cm = 1.56 - shows that at a minimum requirement of, for example, Cm = 1.33, the quality capability is fulfilled. In making this statement we refer only to reproducibility, in other words, to the scatter.

With the requirement that the scatter (±3s) of the machine be less than 60% of the design tolerance, the quality capability is only just fulfilled in the following example (red).
(Tolerance = 0.020, 60% thereof = 0.012, 6s in the example = 0.0127)

Critical machine capability index Cmk

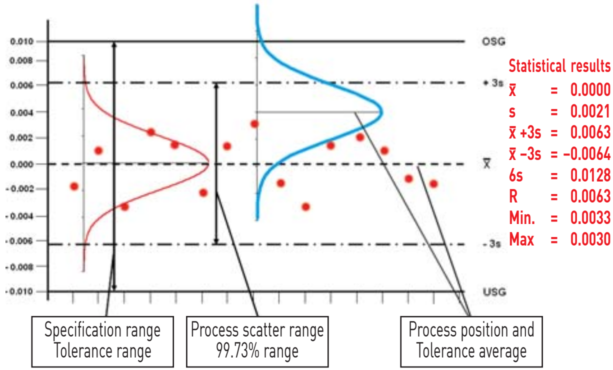
The critical machine capability index Cmk - Cmk = 0.952 or Cmk = 1.269 in the following example - shows that at the same minimum requirement of Cmk = 1.33 the quality capability is not fulfilled. If the mean value of the measurement results is 0.004mm from the tolerance average, then the Cmk value is 0.952. If it is only 0.002mm from the tolerance average, then the Cmk value is 1.269. Although, at this Cmk value of 1.269, the mean value is only 0.002mm from the tolerance average, and there is no measuring result above the tolerance limit, the process is not valid.

A comprehensive statement of the process capability is possible, taking into account the chance (scatter) and systematic (position of the mean value) deviations.

Process capability

The process capability serves as proof that the process (machine, technology and environment) is capable of machining components which are within tolerance over an extended period of time. The process capability indexes Cp and Cpk are determined in a similar way to the machine capability characteristics.

Example with 15 measurement results



The machine capability index Cm and Cmk is calculated, subsequent to a machine capability analysis, using the following formula.
The machine capability index Cm includes the scatter only.

$Cm = \frac{OSG - USG}{6s}$ $Cm = \frac{0.010 - -0.010}{0.0128}$ $Cm = 1.56$

In summary: process is controlled at a minimum requirement of Cm = 1.33.

The index Cmk also takes into account the position of the mean value with respect to the tolerance and specification limits (OSG and USG).
It is calculated according to the following formula:

$Cmk = \frac{Zkrit}{3}$ $Cmk = \frac{2.857}{3}$ $Cmk = 0.952$

Where Zkrit is the critical separation of the mean value for the tolerance limit in s-units.
s-units in the example = 2.857 (0.006/0.0021)

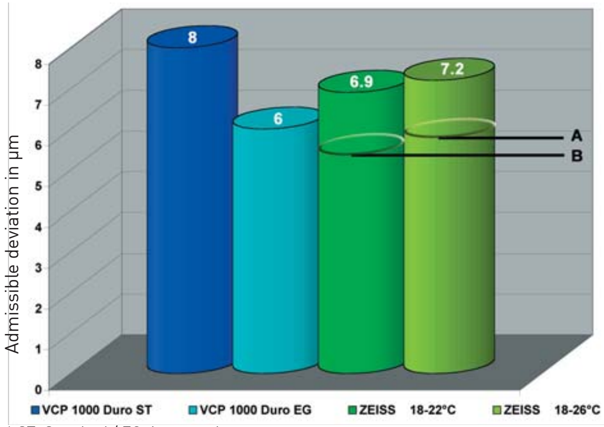
In summary: process is uncontrolled at a minimum requirement of Cmk = 1.33.

Accuracy of positioning

Measurement uncertainty – for example: laser measurement, measurement length 645 mm. Under typical industrial conditions (the machine is not operated in a climate-controlled area and no special attention is paid to the beam orientation), the measurement uncertainty is 0.011mm.
Under improved industrial conditions (climate-controlled environmental conditions and special attention paid to the beam orientation), the measurement uncertainty is 0.0022mm.

Comparison: ZEISS PRISMO - MIKRON VCP 1000 Duro (measurement length 1000 mm)

Please note that our Zeiss Prismo requires a maximum of 50% of the permissible deviations.



* ST: Standard / EG: Increased accuracy
A: EG=5.7 µm (15-30°C) / B: EG=5.3 µm (18-22°C)

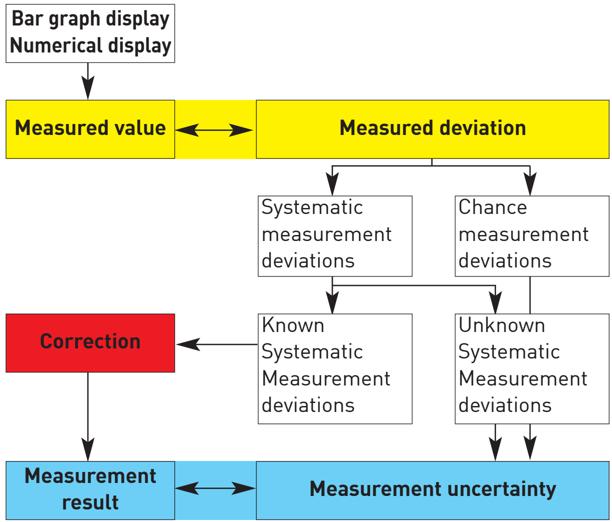
Measurement uncertainty

Test rules for machine tools (DIN ISO 230-1)

Tolerances contain measurement uncertainties inherent to test means and testing processes. Measurement uncertainties must be taken into account, along with tolerances.

Example:
- concentricity tolerance x mm
- measurement uncertainty due to test means y mm
- greatest admissible display difference in testing x-y mm

Graphical representation of the display of the results for the measurement result

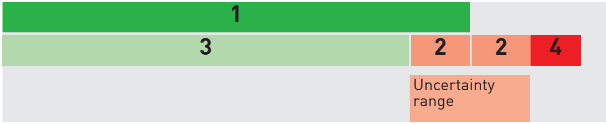


SN EN ISO 14253-1 standard

Measurement uncertainty reduces tolerance!
The "Golden Rule" of measuring technology says that measurement uncertainty must be less than 10% of tolerance.

Compliance achieved:	Tolerance remains unchanged
Compliance not achieved:	Tolerance is reduced by the measurement uncertainty

Figure 1 shows a graphic representation of this rule for a value with uni-directional tolerance, for example: roundness.



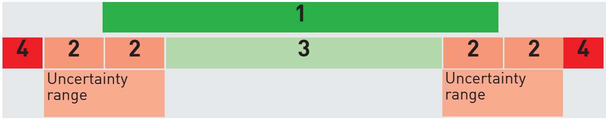
1 = Tolerance range (specification range)	10 µm
2 = Measurement uncertainty	3 µm
3 = Compliance range	< 7 µm
4 = Non-compliance range	> 13 µm

At a roundness tolerance of 0.010mm and a measurement uncertainty of 0.003mm, a corresponding measurement value of less than 0.007mm must be achieved to prove that the tolerance has been met. The available tolerance has thus become substantially smaller.

If, however, it can be shown that the tolerance has not been met, then there will have to be a roundness measurement of greater than 0.013mm. If the measurement value is between 0.007 and 0.013mm, then it cannot be shown that it is “within tolerance” or “not within tolerance”.

This rule for “within tolerance” is applicable to component checking, measurement instrument acceptance, and in accordance with ISO 230-1, geometric checking of machine tools, as well as for machine tool acceptance.

The next figure shows a graphic representation of this rule for a value with bi-directional tolerance, for example: length:



	Drawing specification:	100 ± 0.020mm
1	Tolerance range:	0.040mm
2	Measurement uncertainty:	0.005mm
	Uncertainty range:	99.980 ± 0.005mm
		100.020 ± 0.005mm
3	Compliance range:	0.030mm
		100 ± 0.015mm
4	Non-compliance range (greatest):	100 ± 0.025mm

Proof of compliance with specifications:

Measurement value ≤ tolerance - measurement uncertainty
Example:

Straightness tolerance:	15 µm
Measurement uncertainty:	5 µm
Measurement value:	< 10 µm

Proof of non-compliance with specifications:

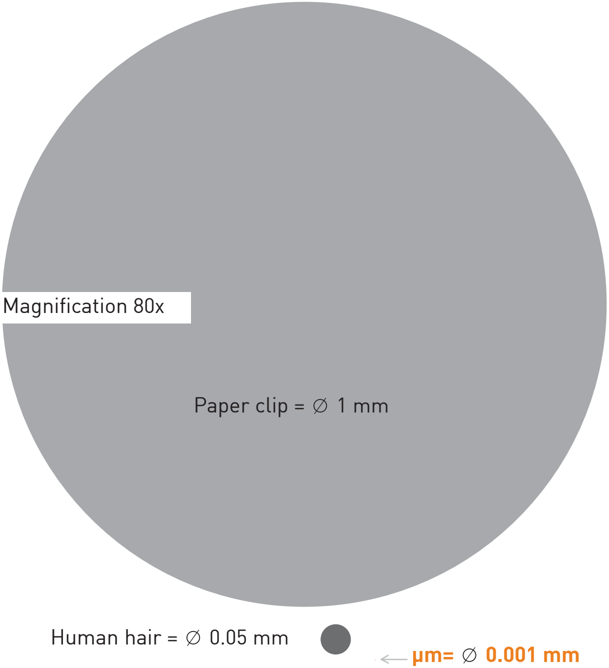
Measurement value ≥ tolerance + measurement uncertainty
Example:

Straightness tolerance:	15 µm
Measurement uncertainty:	5 µm
Measurement value:	> 20µm

Corresponds to ISO 230-1, basic principle for geometric tests of machine tools.

How large is µm?

Everybody is talking about it, but few know how large it is.



Abbe's principle

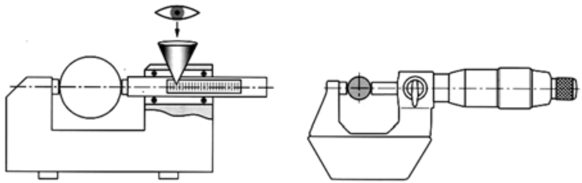
Ernst Abbe, one of the founders of the Zeiss-Werke in Jena, devised the following principle in 1893:

The distance on the test component to be measured and the comparative distance on the measurement body in the measurement direction should be arranged immediately next to each other.

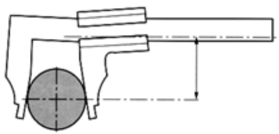
This principle is used in the so-called comparator principle.

Non-compliance with the Abbe Principle when arranging the measurement creates a deviation of the first order in the measurement value.

Comparator Principle according to Ernst Abbe.



Damaged comparator principle.



Decimal multiples and decimal parts of the base unit METRE

Unit	Sign		m	cm	mm	µm	nm
Kilometre	km	1^{3} m	1000 m		1 000 000 mm		
Metre	m	1 m	1 m	100 cm	1 000 mm	1 000 000 µm	
Decimetre	dm	10^{-1} m	0.1 m	10 cm	100 mm	100 000 µm	
Centimetre	cm	10^{-2} m	0.01 m	1 cm	10 mm	10 000 µm	
Millimetre	mm	10^{-3} m	0.001 m	0.1 cm	1 mm	1 000 µm	1 000 000 nm
Tenth of a millimetre		10^{-4} m	0.000 1 m		0.1 mm	100 µm	100 000 nm
Hundredth of a millimetre		10^{-5} m	0.000 01 m		0.01 mm	10 µm	10 000 nm
Micron	µm	10^{-6} m	0.000 001 m		0.001 mm	1 µm	1 000 nm
Tenth of a micron		10^{-7} m	0.000 000 1 m		0.000 1 mm	0.1 µm	100 nm
Hundredth of a micron		10^{-8} m	0.000 000 01 m		0.000 01 mm	0.01 µm	10 nm
Nanometre	nm	10^{-9} m	0.000 000 001 m		0.000 001 mm	0.001 µm	1 nm

Numerical value of ISO-Basic-tolerance IT1 - IT11 (Extract ISO 286-2)

Nominal measurement in mm		Basic tolerance grade										
		IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10	IT11
above	up to	µm Basic tolerance										
-	3	00.8	01.2	02	3	4	6	10	14	25	40	60
3	6	01	01.5	02.5	4	5	8	12	18	30	48	75
6	10	01	01.5	02.5	4	6	9	15	22	36	58	90
10	18	01.2	002	03	5	8	11	18	27	43	70	110
18	30	01.5	02.5	04	6	9	13	21	33	52	84	130
30	50	01.5	02.5	04	7	11	16	25	39	62	100	160
50	80	02	03	05	8	13	19	30	46	74	120	190
80	120	02.5	04	06	10	15	22	35	54	87	140	220
120	180	03.5	05	08	12	18	25	40	63	100	160	250
180	250	04.5	07	10	14	20	29	46	72	115	185	290
250	315	06	08	12	16	23	32	52	81	130	210	320
315	400	07	09	13	18	25	36	57	89	140	230	360
400	500	08	10	15	20	27	40	63	97	155	250	400
500	630	09	11	16	22	32	44	70	110	175	280	440
630	800	10	13	18	25	36	50	80	125	200	320	500
800	1000	11	15	21	28	40	56	90	140	230	360	560
1000	1250	13	18	24	33	47	66	105	165	260	420	660
1250	1600	15	21	29	39	55	78	125	195	310	500	780
1600	2000	18	25	35	46	65	92	150	230	370	600	920
2000	2500	22	30	41	55	78	110	175	280	440	700	1100

Application:

IT1 - IT4	Measurement tool manufacture
IT5 - IT11	General machine and instrument manufacture
IT12 - IT18	Pressed and rolled products

Notes

Standards for machine tool acceptance testing

• Geometric tests:	DIN ISO 230-1:1999 (basic principles)
• Geometric tests:	ISO 10791-2:2001 (machining centre with vertical spindle)
• Accuracy of Positioning:	DIN ISO 230-2:1997
• Thermal effects:	ISO 230-3 ISO/TC 39/ SC 2 N 1432
• Circular tests:	ISO 230-4:1996
• Noise test:	ISO 230-5:2000
• Diagonal displacement tests:	ISO 230-6:2002 (positioning accuracy)
• Machining accuracy:	ISO 10791-7:1998
• Measurement uncertainty:	DIN EN ISO 14253-1:1999
• Vibrations:	ISO/TC 39/SC 2 N 1413 (draft)
• Spindles:	ISO/DIS 230-7 (ISO adaptation)
• Safety of machine tools/ machining centres:	prEN 14070 and SN EN 12417
• Etc.	

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