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Intelligent testing

Measurement Uncertainty in Mechanical Testing

Dr. Eduard Schenuit

Industry Manager Metal
ZwickRoell GmbH & Co. KG

Agenda

- Why do we need measurement uncertainty?
  - Confidence interval for characteristic values
  - Requirements of ISO/IEC 17025
- How do the standards developing for testing methods?
  - Examples of an approach to measurement uncertainty
  - Status of discussion in international standardization (ISO TC 164)
- How does ZwickRoell support evaluation of measurement uncertainty
  - Calculation of measurement uncertainty based on calibration certificates
  - Tool for calculation and assigning measurement uncertainty to characteristic values

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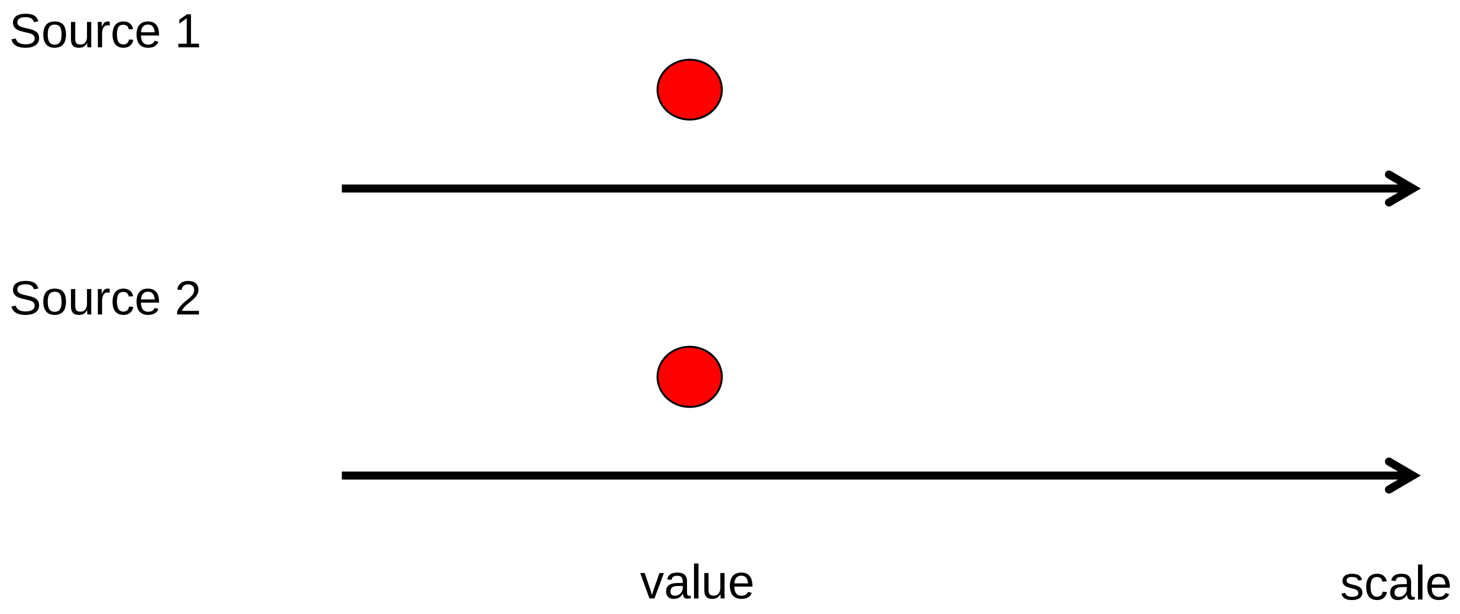
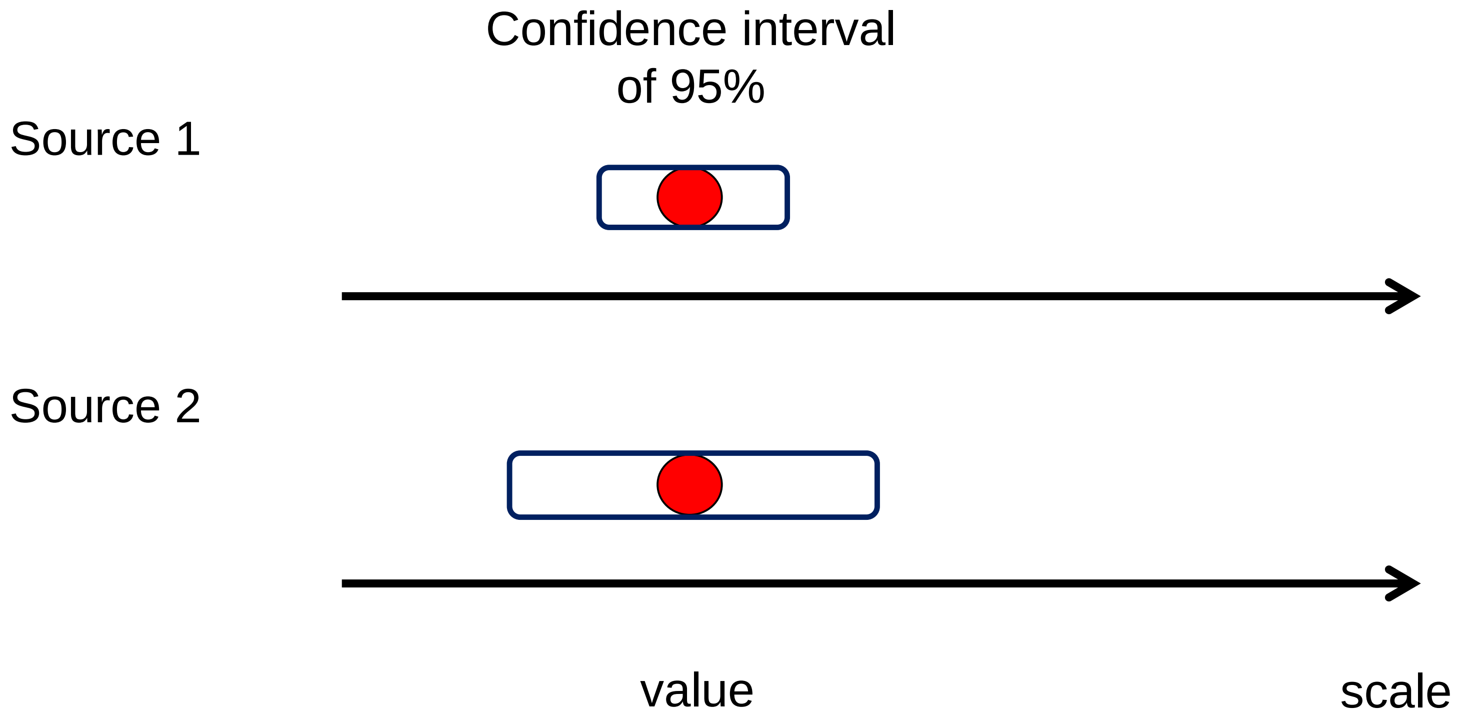
Confidence interval

No characteristic value and no test result is arbitrary exactly.



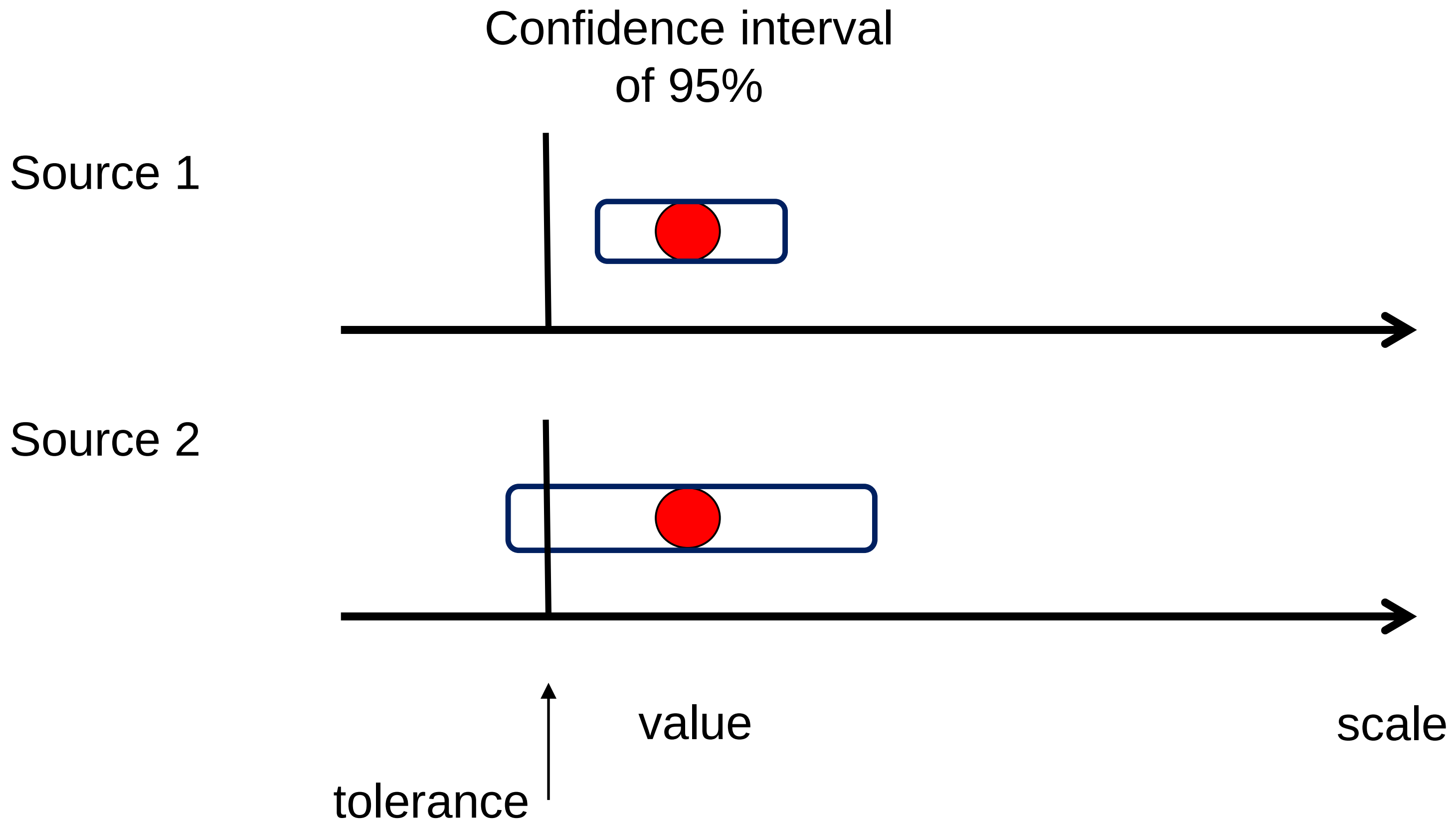
Confidence interval

The knowledge, in which interval the true value or the true test result can be expected with which probability, creates trust in values and results.



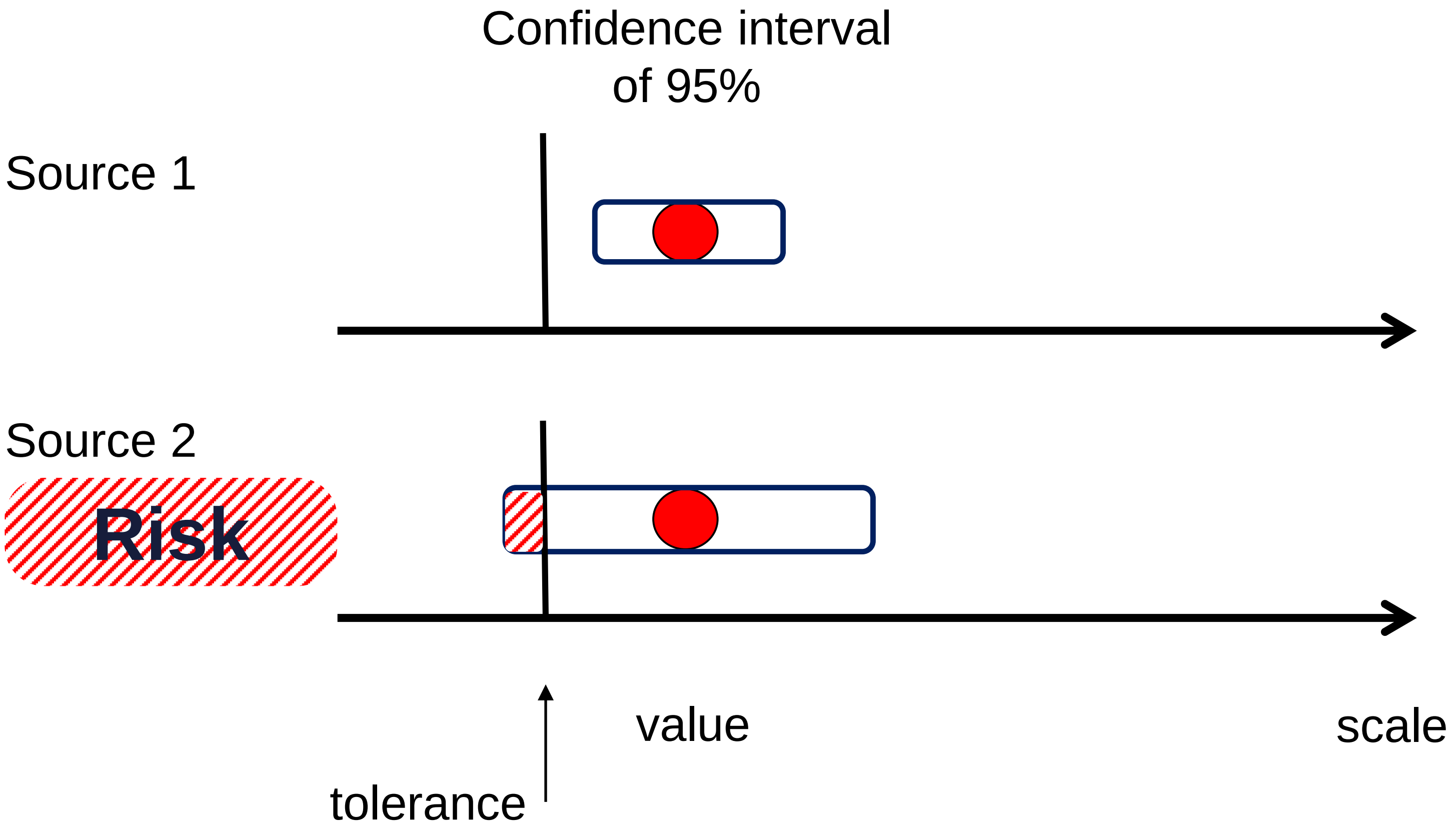
Confidence interval

The size of the confidence interval and the location of the value or result are critical in predicting whether there is a risk in meeting tolerances or not.



Confidence interval

The size of the confidence interval and the location of the value or result are decisive in the statement with which risk tolerances can be kept.



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The international standard EN ISO / IEC 17025 - with unrestricted validity also for the EU - requires the determination of the measurement uncertainty.

Title of the standard:
„General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025:2017)“

7.6.1 Laboratories shall identify the contributions to measurement uncertainty. When evaluating measurement uncertainty, all contributions that are of significance, including those arising from sampling, shall be taken into account using appropriate methods of analysis.

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)“, Beuth Verlag, Berlin

The international standard EN ISO / IEC 17025 - with unrestricted validity also for the EU - requires the determination of the measurement uncertainty.

7.6.3 A laboratory performing testing shall evaluate measurement uncertainty. Where the test method precludes rigorous evaluation of measurement uncertainty, an estimation shall be made based on an understanding of the theoretical principles or practical experience of the performance of the method.

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)", Beuth Verlag, Berlin

The international standard EN ISO / IEC 17025 - with unrestricted validity also for the EU - requires the determination of the measurement uncertainty.

7.7.1 The laboratory shall have a procedure for monitoring the validity of results.

The resulting data shall be recorded in such a way that trends are detectable and, where practicable, statistical techniques shall be applied to review the results.

This monitoring shall be planned and reviewed.

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)“, Beuth Verlag, Berlin

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Testing standards

Assistance to determining the measurement uncertainty in the common testing standards are of very different quality and currently always informative.

- **Example ISO 6892-1**
- Estimated measurement uncertainty shall not be applied in product assessments
- Annex K: Contributions are estimated on a percentages based on requirements for the sensors
- Hints for further contributions are given, but no details or figures are given
- Annex G: two procedures were given with two different results

- **Example ISO 6508-1**
- Complete determination of measurement uncertainty should be done
- Option 1: judgement based on direct calibration
- Option 2: indirect calibration with certified reference blocks. Guideline is given in Annex G
- Annex G: detailed procedure with examples

The estimation of measurement uncertainty in ISO 6892-1 is only informative.

23 Measurement uncertainty

23.1 General

Measurement uncertainty analysis is useful for identifying major sources of inconsistencies of measured results.

Product standards and material property databases based on this part of ISO 6892 and earlier editions of ISO 6892 have an inherent contribution from measurement uncertainty. It is therefore inappropriate to apply further adjustments for measurement uncertainty and thereby risk failing product which is compliant. For this reason, the estimates of uncertainty derived by following this procedure are for information only.

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)“, Beuth Verlag, Berlin

The estimation of the measurement uncertainty may not be applied to the test conditions or the measurement results in the context of a product evaluation.

23.2 Test conditions

The test conditions and limits defined in this part of ISO 6892 shall not be adjusted to take account of uncertainties of measurement.

23.3 Test results

The estimated measurement uncertainties shall not be combined with measured results to assess compliance to product specifications.

For consideration of uncertainty, see Annexes J and K, which provide guidance for the determination of uncertainty related to metrological parameters and values obtained from the interlaboratory tests on a group of steels and aluminum alloys.

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)", Beuth Verlag, Berlin

In Annex K, the percentage influences on the uncertainty in the characteristic values are roughly estimated.

Table K.2 — Examples of uncertainty contributions for different test results, due to the measuring devices

Parameter	Uncertainty contribution[a] %				
	R_{eH}	R_{eL}	R_m	A	Z
Force	1,4	1,4	1,4	—	—
Extension	—	—	—	1,4	—
Gauge length, L_e, L_o	—	—	—	1	—
S_o	1	1	1	—	1
S_u	—	—	—	—	2

[a] Values are given for information only.

$$u(y) = \sqrt{(u(x_1)^2 + u(x_2)^2 + \cdots + u(x_n)^2)}$$

Table K.4 — Examples for a 95 % level of confidence, *k* = 2 (based on Table K.3)

95 % level of confidence, k = 2 for different parameters %				
R_{eH}	R_{eL}	R_m	A	Z
1,82	1,82	1,82	1,82	2,58

The simple percentage estimation of the measurement uncertainty in Annex K is supplemented by references to other influencing factors.

K.4 Parameters depending on the material and/or the test procedure

The precision of the test results from a tensile test is dependent upon factors related to the material being tested, the testing machine, the test procedure and the methods used to calculate the specified material properties. Ideally all the following factors should be considered:

a) test temperature;

b) testing rates;

c) the test piece geometry and machining;

d) the method of gripping the test piece and the axiality of the application of the force;

e) the testing machine characteristics (stiffness, drive and control mode);

f) human and software errors associated with the determination of the tensile properties;

g) extensometer mounting geometry.

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)“, Beuth Verlag, Berlin

The estimation of the measurement uncertainty in the ISO 6508-1 (Rockwell hardness test) is only informative.

G.1 General requirements

The measurement uncertainty analysis is a useful tool that helps to find sources of error and to understand differences in the test results.

This appendix provides a guide to estimating uncertainty, but the procedures contained herein are for information only, unless the customer has specifically stated otherwise. ...

These permissible deviations [in the product specifications] therefore contain a contribution due to the uncertainty of the hardness measurement, and it would be inappropriate to add another component to this uncertainty ...

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)“, Beuth Verlag, Berlin

Annex G describes two methods and examples of calculation.

Table G.2 — Determination of the measurement result according to method M2

Step	Description	Symbols	Formula	Literature/Certificate	Example [..] = HRC
1	Expanded uncertainty derived from maximum permissible error	b_E	b_E = Maximum positive value of permissible bias	Permissible bias b according to ISO 6508-2:2015, Table 2	$b_E = 1{,}50$
2	The standard deviation of repeatability measurements.	s_H	$s_H = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(H_i - \overline{H}\right)^2}$	Five measurements are made by the laboratory on a CRM having a hardness similar to the test sample (see Note)	$s_H = 0{,}17$ HRC
3	Standard uncertainty due to lack of repeatability	u_H	$u_H = t \times s_H$	$t = 1{,}14 \quad n = 5$ (see ISO/IEC Guide 98-3, G.3 and Table G.2)	$u_H = 1{,}14 \times 0{,}17 = 0{,}19$
4	Standard uncertainty due to resolution of the hardness value indicating display	u_{ms}	$u_{ms} = \frac{\delta_{ms}}{2\sqrt{3}}$	$\delta_{ms} = 0{,}1$ HRC	$u_{ms} = \frac{0{,}1}{2\sqrt{3}} = 0{,}03$
5	Determination of the expanded uncertainty	U	$U = k \times \sqrt{u_H^2 + u_{ms}^2} + b_E$	Steps 1, 3, and 4 $k = 2$	$U = 2 \times \sqrt{0{,}19^2 + 0{,}03^2} + 1{,}50$ $U = 1{,}88$ HRC
6	Result of the measurement	X	$X = x \pm U$		$x = 60{,}5$ HRC $X = (60{,}5 \pm 1{,}9)$ HRC

Quelle: Norm „Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien (ISO/IEC 17025:2017)“, Beuth Verlag, Berlin

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The aim of measurement uncertainty discussed in this year's ISO Advisory Group meeting is:

- We do not want to set up new requirements for product assessments
- We do want to support testing laboratories calculating uncertainties when testing specimens *)

*) characterize materials;
not include materials characteristics into MU

Under recent discussion: The shell model structures the uncertainty contributions and establishes common criteria and procedures.

What can be used for the uncertainty determination:

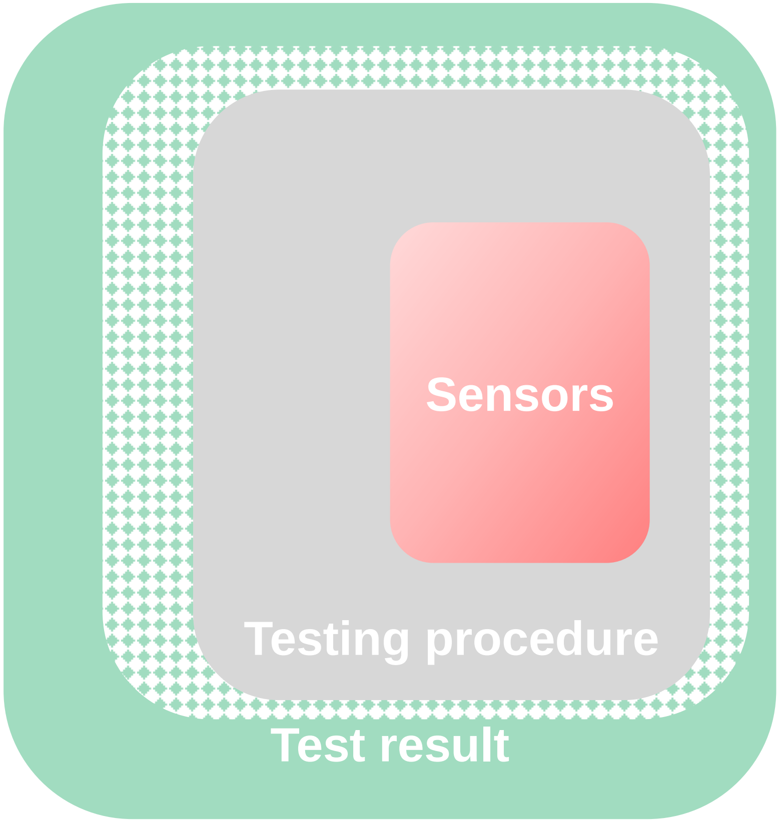
For the measuring system (sensors):
+ Calibration data and CWA 15261-2

For the testing procedure:
+ certified reference material (CRM)

For the test result:
+ Round Robin tests /proficiency tests acc to standards

To be internationally (ISO) agreed:

- Definition of shells (also number)
- Description of the shells (also rules of calculations)



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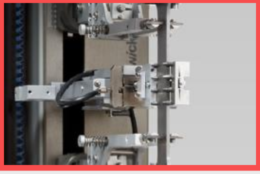
Testing machines are calibrated regularly; the results can be used to determine the measuring system-related measurement uncertainty.

Calibration data for force

Calibration data for cross-sectional area calipers

Calibration data for extensometers

Calibration data for reduction-in-width devices

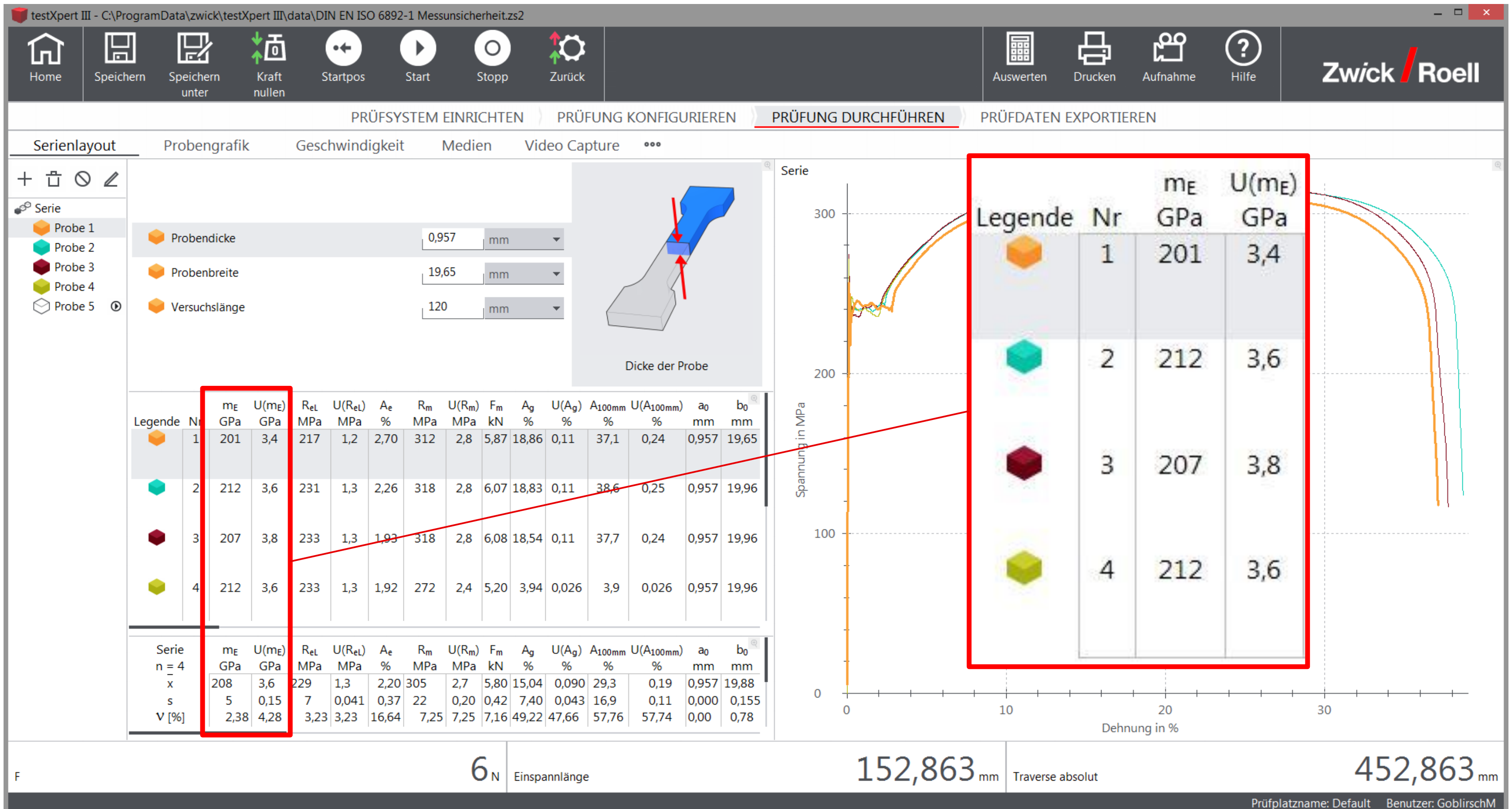


CWA 15261-2:2005 *Measurement uncertainties in mechanical tests on metallic materials — The evaluation of uncertainties in tensile testing* describes the influences of the measuring systems on the characteristic values in the metal tensile test.

- The specifications in the CWA 15261-2 can be used to automatically determine the measurement system-related measurement uncertainties for metal tensile tests for each test.
- The measuring system-related measurement uncertainty cannot be undershot.
- The creation of a total budget for the measurement uncertainty is the responsibility of the laboratories.

Testing machines

Display of measuring system-related measurement uncertainty takes place as an absolute or relative value.



Testing machines

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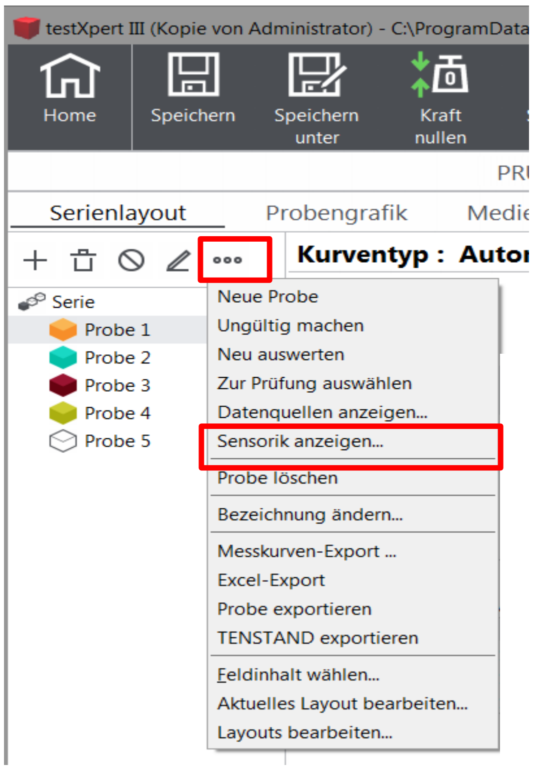
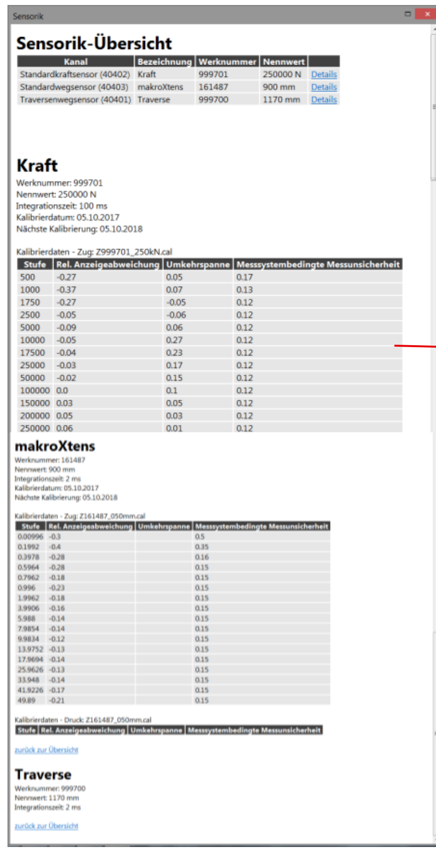
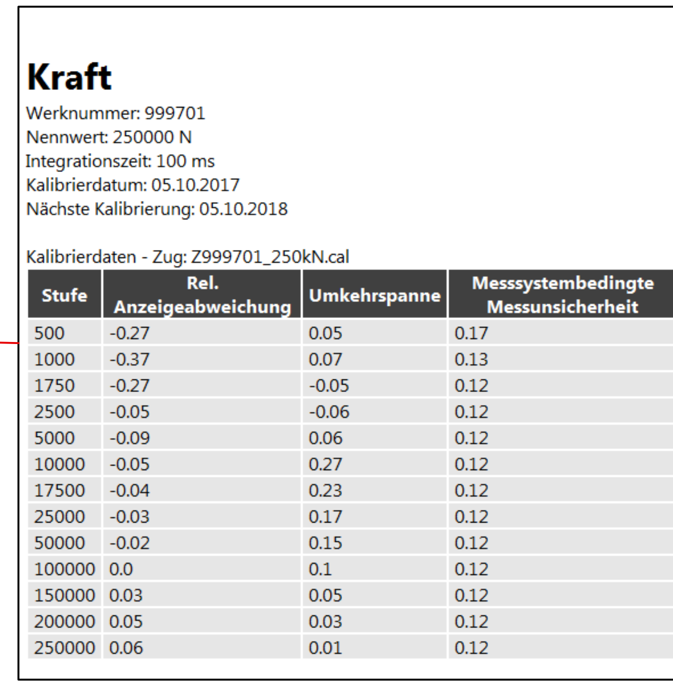
The calibration data used for the calculation of measurement uncertainty are stored specimen-specific and traceable.







Kraft

Werknummer: 999701
Nennwert: 250000 N
Integrationszeit: 100 ms
Kalibrierdatum: 05.10.2017
Nächste Kalibrierung: 05.10.2018

Kalibrierdaten - Zug: Z999701_250kN.cal

Stufe	Rel. Anzeigeabweichung	Umkehrspanne	Messsystembedingte Messunsicherheit
500	-0.27	0.05	0.17
1000	-0.37	0.07	0.13
1750	-0.27	-0.05	0.12
2500	-0.05	-0.06	0.12
5000	-0.09	0.06	0.12
10000	-0.05	0.27	0.12
17500	-0.04	0.23	0.12
25000	-0.03	0.17	0.12
50000	-0.02	0.15	0.12
100000	0.0	0.1	0.12
150000	0.03	0.05	0.12
200000	0.05	0.03	0.12
250000	0.06	0.01	0.12

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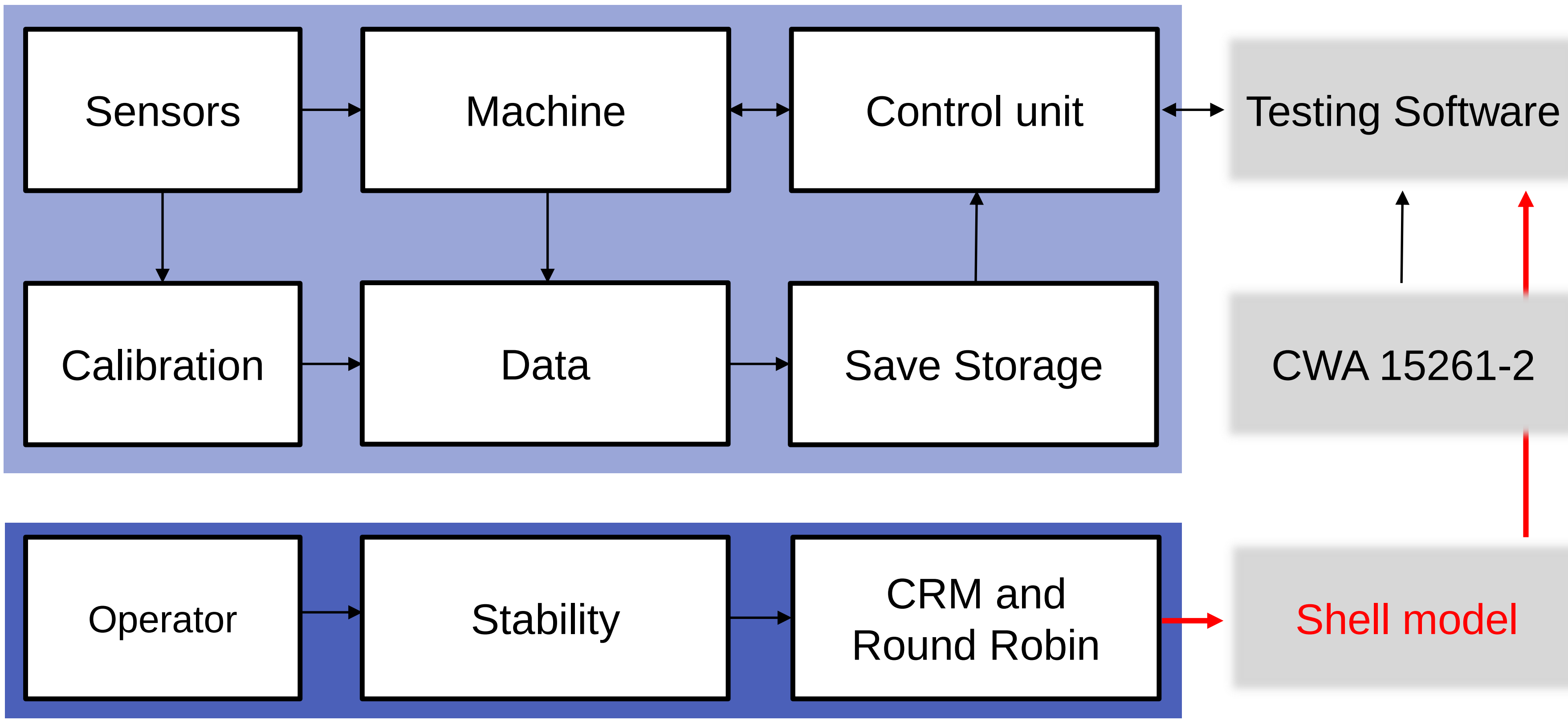
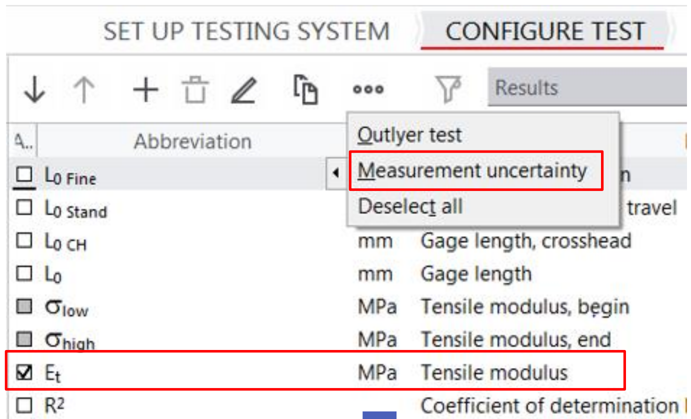
Testing machines

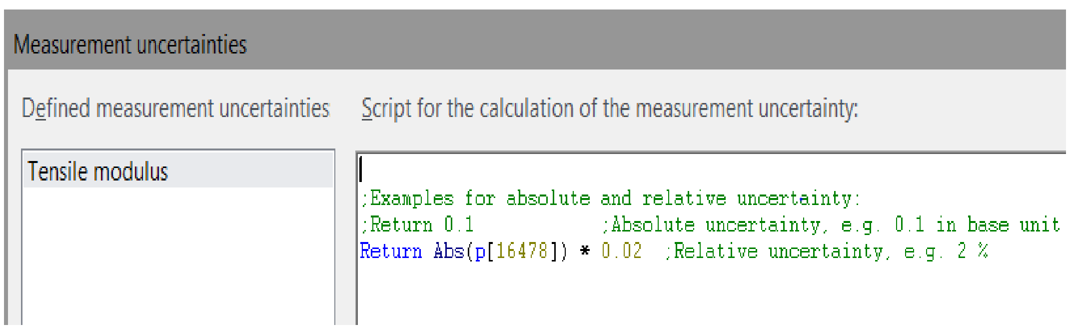
Schematic representation of a structure for determining uncertainties in test results.



The integration of the measurement uncertainty takes place in 3 simple steps.



Example: Tensile modulus



Example: Relative measurement uncertainty of 2%

- In the result dialog, the corresponding measurement uncertainty can be easily stored for each result
- The measurement uncertainty is entered via a ZIMT dialog
- A percentage and absolute measurement uncertainty is generated default
- Ability to enter a complex formula for measurement uncertainty

Testing machines

Test protocols within testXpert integrate specimen- and series-specific measurement uncertainties.

☑	E_t	MPa	Tensile modulus
☑	$U(E_t)$	MPa	U(Tensile modulus) ...
☑	$\%U(E_t)$	%	%U(Tensile modulus) ...

Legend	No.	E_t MPa	$U(E_t)$ MPa	$\%U(E_t)$ %	σ_Y MPa	ε_Y %
	1	3110	62.17	2.00	66.2	7.1
	2	3070	61.35	2.00	65.3	7.4
	3	3080	61.66	2.00	66.0	7.1
	4	3040	60.76	2.00	65.4	-
	5	3050	60.98	2.00	66.0	7.2

Series n = 5	E_t MPa	$U(E_t)$ MPa	$\%U(E_t)$ %	σ_Y MPa	ε_Y %
$\bar{x}$	3070	61.38	2.00	65.8	7.2
s	27.9	0.56	0.00	0.391	0.14
ν [%]	0.91	0.91	0.00	0.60	1.91

- Arrangement of the measurement uncertainties takes place directly under the corresponding result

- In the result table, the measurement uncertainty is displayed in % and "absolute"

→ Measurement uncertainty for each test

- Can be activated /deactivated individually

- The measurement uncertainties can also be used for the statistics table

Summary

- There are no measurements or characteristic values without measurement uncertainty
- Known uncertainties create trust in the measured and characteristic values
- The ISO / IEC 17025 demands the handling of measurement uncertainty
- The method standards are on the way to adopting prescriptions that allow a practical determination of the measurement uncertainty
- Today, testXpert software is able to calculate the measurement system-related uncertainties for many characteristic values (for metal tensile test done)
- Test software testXpert is also able to calculate customer-specific uncertainties and assign them to the characteristic values
- The laboratories remain responsible for determining the uncertainty of results