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Guideline DKD-R 3-3

Calibration of force measuring devices

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Deutscher Kalibrierdienst (DKD) – German Calibration Service

Since its foundation in 1977, the German Calibration Service has brought together calibration laboratories of industrial enterprises, research institutes, technical authorities, inspection and testing institutes. On 3rd May 2011, the German Calibration Service was reestablished as a *technical body* of PTB and accredited laboratories.

This body is known as *Deutscher Kalibrierdienst* (DKD for short) and is under the direction of PTB. The guidelines and guides developed by DKD represent the state of the art in the respective areas of technical expertise and can be used by the *Deutsche Akkreditierungsstelle GmbH* (the German accreditation body – DAkkS) for the accreditation of calibration laboratories.

The accredited calibration laboratories are now accredited and supervised by DAkkS as legal successor to the DKD. They carry out calibrations of measuring instruments and measuring standards for the measurands and measuring ranges defined during accreditation. The calibration certificates issued by these laboratories prove the traceability to national standards as required by the family of standards DIN EN ISO 9000 and DIN EN ISO/IEC 17025.

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Foreword

DKD guidelines are application documents that meet the requirements of DIN EN ISO/IEC 17025. The guidelines contain a description of technical, process-related, and organizational procedures used by accredited calibration laboratories as a model for defining internal processes and regulations. DKD guidelines may become an essential component of the quality management manuals of calibration laboratories. The implementation of the guidelines promotes equal treatment of the equipment to be calibrated in the various calibration laboratories and improves the continuity and verifiability of the work of the calibration laboratories. In addition, the implementation of the guidelines allows the state of the art in the respective field to be incorporated into laboratory practice.

The DKD guidelines should not impede the further development of calibration procedures and processes. Deviations from guidelines as well as new procedures are permitted in agreement with the accreditation body if there are technical reasons to support this action.

Calibrations by accredited laboratories provide the user with the security of reliable measuring results, increase the confidence of customers, enhance competitiveness in the national and international markets, and serve as metrological basis for the inspection of measuring and test equipment within the framework of quality assurance measures.

The present guideline has been drawn up by the DKD Technical Committee *Force, Acceleration and Acoustics* and approved by the Board of the DKD.

This edition replaces all previous editions of DKD-R 3-3. Compared to the previous edition, it contains mainly the following changes:

- adaptation to the current edition of DIN EN ISO 376
- new Appendix C regarding the procedure for determining a priori knowledge
- bibliography update
- editorial modifications for clarification and better comprehensibility

Table of contents

1 Scope and application

This guideline applies to static loading processes. In addition to the usual calibration sequences with three mounting positions, it does also describes simplified sequences which from a metrological point of view reduce the efforts to an acceptable minimum and thus help to reduce costs. For this purpose, certain prerequisites – such as the requirements of international rules for determining the measurement uncertainty – must be met. The user may go beyond the efforts described in this guideline but must not go below it. This guideline allows the realisation of practical calibration sequences and evaluations.

In principle, simplified calibration sequences cannot lead to smaller measurement uncertainties than corresponding calibrations of the same calibration item according to more complex procedures (e.g. DIN EN ISO 376).

When using reduced calibration sequences, it should be noted that in the case of high-quality force measuring devices it may not be possible to reach conformity with (manufacturer) specifications due to the increased measurement uncertainty.

This guideline does no longer contain descriptions of classifications.

This guideline applies to all force measuring devices determining force through elastic deformation of a body. It can also be used for force transducers alone.

This guideline may only be used for force measuring devices that can be calibrated with increasing and decreasing loads, and with at least 3 force steps in each direction.

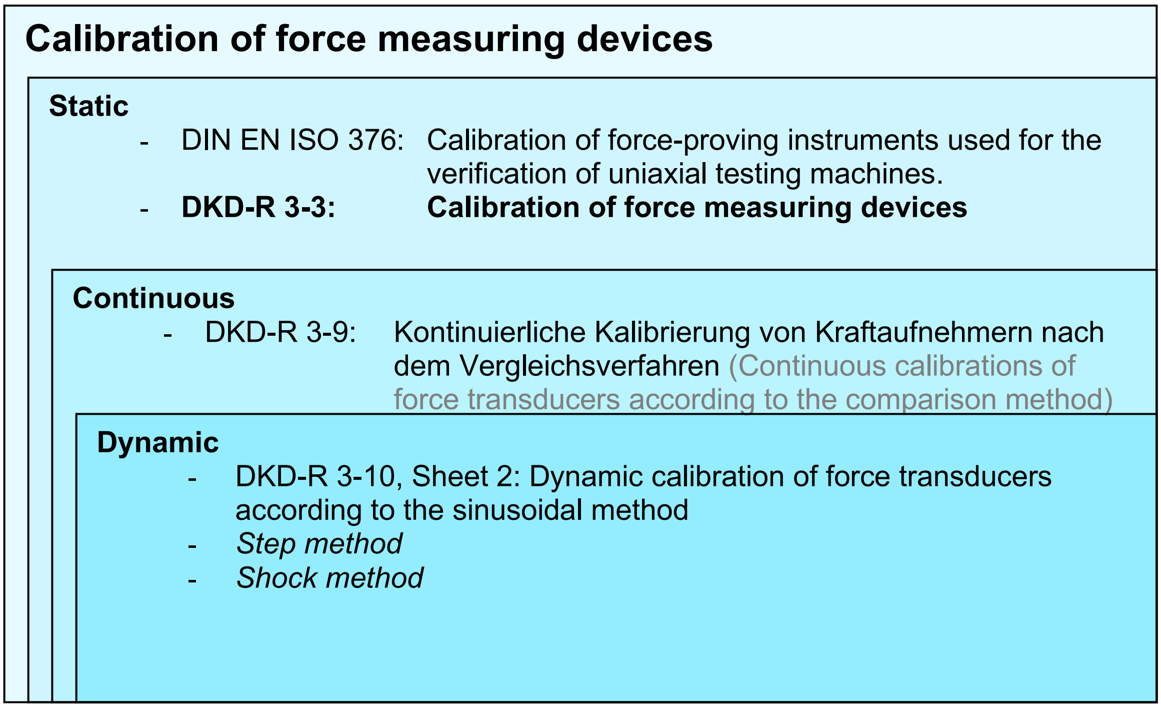


Figure 1: Categorisation of DKD-R 3-3 in the context of existing regulations for force calibration. Corresponding regulations for the applications shown in italics still have to be developed.

2 Symbols

The symbols and designations used in this guideline comply with the requirements of the guidelines DIN EN ISO 376 and VDI/VDE/DKD 2638. Additional symbols and designations are listed below. The symbols used for the first time in Section 7 (Measurement uncertainty) are listed separately there.

Symbols

Symbols	Unit	Explanation
F	N	Force
$\Delta\vartheta$	K	Temperature difference
f_c	%	Relative regression deviation for increasing load
f_c'	%	Relative regression deviation for decreasing load
f_0	%	Relative zero error (relative zero-point deviation)
	AE	AE = Indication unit of the output signal (e.g. N, mV/V, V, LSB)
b	AE	Reproducibility (with increasing load)
b_ab	AE	Reproducibility (with decreasing load)
b^*	AE	Reproducibility (with increasing and decreasing load)
b'	AE	Repeatability (with increasing load)
b_ab'	AE	Repeatability (with decreasing load, sequence B)
b'^*	AE	Repeatability (with increasing and decreasing load, sequence B)
v	AE	Hysteresis
X_A	AE	Value of the regression function
X_i	AE	Measured value with increasing force at step i
X_i'	AE	Measured value with decreasing force at step i
W	%	Relative expanded measurement uncertainty
W'	%	Relative deviation margin
E	AE/N	Transmission coefficient (sensitivity) of a force transducer
E_app	AE	(Measurement) error of the coefficient
$\overline{X_\mathrm{r}}$	AE	Mean value of the measured deformation value for different mounting positions (with increasing load, sequence A)

$\overline{X_{\mathrm{wr}}}$	AE	Mean value of the measured deformation value for different mounting positions (with increasing load, sequences A and B)
$\overline{X'_{\mathrm{r}}}$	AE	Mean value of the measured deformation value for different mounting positions (with decreasing load, sequence A)
$\overline{X'_{\mathrm{wr}}}$	AE	Mean value of the measured deformation value for identical mounting position (with increasing load, sequence A)
$\overline{X^{*}_{\mathrm{r}}}$	AE	Mean value of the measured deformation value for different mounting positions (with increasing and decreasing load, sequence A)
$\overline{X^{*}_{\mathrm{wr}}}$	AE	Mean value of the measured deformation value for identical mounting position (for sequences B and C from increasing and decreasing load; for sequence D from the two increasing load measurement series)

Abbreviations

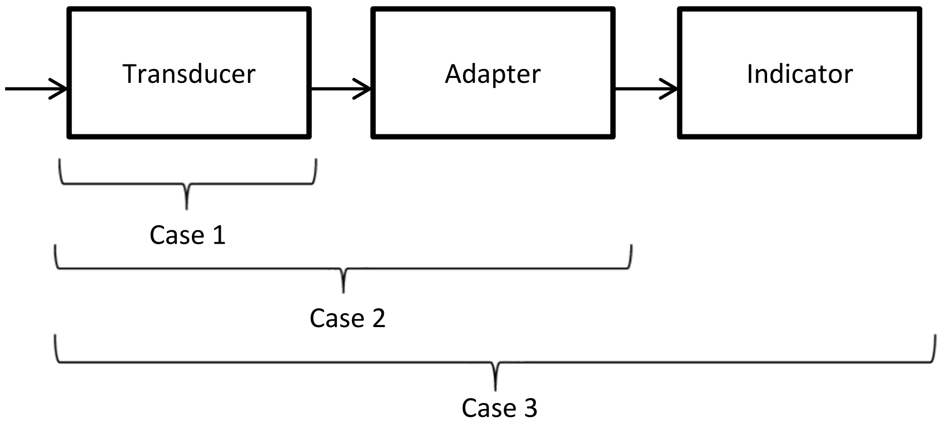
Abbreviations	**Explanation**
a.v.	Actual value
DAkkS	Deutsche Akkreditierungsstelle GmbH (National Accreditation Body, Germany)
DKD	Deutscher Kalibrierdienst (German Calibration Service, DKD)
f.s.	Full scale, final value
K-BNME	Force calibration machine (reference measuring equipment)
MU	Measurement uncertainty

3 Calibration item

3.1 Components of the force measuring device

The force measuring device consists of a force transducer, an adapter (e.g. amplifier) and an output device (e.g. indicating device). For force measuring devices with digital output, the measured value can also be transferred via a standardised interface to a data terminal device – printer, recording device or computer – instead of the indicating device. Indication of the measured values during calibration is recommended. It must be ensured that the read-in data are clearly interpreted and processed.

In case that the calibration item does only consist of the force transducer, a measuring chain consisting of traceably calibrated components of the force calibration machine must be assembled. Among other things, this leads to differences in the measurement uncertainty analysis.



Case 1: The calibration item does only consist of a transducer.
Case 2: The calibration item consists of a transducer with integrated amplifier (converter) or of a transducer with separate adapter/amplifier (measuring chain).
Case 3: The calibration item consists of a transducer, an adapter/amplifier, and a data acquisition/indicating unit (complete measuring device).

Figure 2: Differentiation calibration item

3.2 Calibration capability

The processing of a calibration order requires the calibration capability (suitability) of the calibration item, i.e. the current condition of the calibration item should correspond to the generally acknowledged rules of technology.

Before starting the calibration, quality inspections and functional tests must be carried out to ensure that an undisturbed calibration procedure is guaranteed.

Quality inspections comprise, for example:

- visual inspections for damage
- visual inspection regarding labelling/legibility of the nameplate
- check whether the documents required for calibration (technical data, operating instructions) are available

Functional tests comprise, for example:

- electrical functioning
- direction of the measuring signal
- insulation resistance
- zero signal

3.3 Clamping and mounting parts

The mounting parts are to be regarded as components of the calibration item. Provision of the mounting parts must be agreed between customer and calibration laboratory. Preferably, the design of the mounting parts has to be in accordance with DIN EN ISO 376 – Annex A. If the application of mounting parts according to standard should not be possible, they should at least simulate the conditions in practical use. Here, it must be noted that when coupling the calibration item to the reference force transducer inadmissible disturbing components have to be avoided (prevention of bending moments, tensioning, or deformations).

Note:

Dimensioning of the clamping parts must such that the calibration device is not damaged by a breakage of the clamping parts. The dimensional tolerances for clamping parts should be adjusted to the tolerances of the technical drawings of the force transducer.

3.4 Signal-carrying components in the force calibration machine

The signal-carrying components are the measuring amplifiers and the indicators in the measuring channel for the calibration item (see Figure 2, Case 1).

The calibration laboratory is responsible for selecting and setting the signal-carrying components (consultation with the customer, if necessary). The transmission behaviour of the components must be known and taken into account in the measurement uncertainty budget.

Detectable systematic deviations can be taken into account in the calibration result by way of correction.

4 Environmental conditions

The relevant environmental conditions (ambient temperature, air pressure, relative humidity) should be monitored and documented in the calibration certificate; if necessary, they are to be considered in the measurement uncertainty budget. During calibration, the measurement setup must be in thermal equilibrium. Calibration must be carried out at a stable temperature (± 1 K) within the range of 18 °C to 28 °C in accordance with DIN EN ISO 376 [1]. In Germany, a reference temperature between 19 °C and 23 °C and a maximum fluctuation range of 1 K at the location of the calibration item during calibration is recommended.

5 Calibration process

Before calibrating the force transducer or the force measuring device, thermal equilibrium with the environment must be established; possible heating of the transducer due to the supply voltage is to be considered. In the case of force transducers, e.g. with strain gauges, the complete measuring chain must be electrically activated before calibration until reaching stabilisation of the measuring device. The zero signal must then be measured as output signal of the unloaded force transducer without mounting parts in a defined position (in relation to the earth's gravitational field). This has to be stated in the calibration certificate. Comparison of the currently measured zero signal with previous measurements can provide information about changes in the force transducer, for example due to overloading.

If the force transducer is calibrated using an indicating device from the calibration laboratory, this must be stated in the calibration certificate. Interchangeability is generally limited to devices of the same type.

Note:

In case the customer does not send his indicating device for calibration, the customer must ensure the interchangeability of the indicating device himself (for example by means of an external calibration).

If the force transducer is to be calibrated in the direction of tensile and compressive force, separate calibrations and analyses must be carried out successively in the directions of force.

After each mounting or each reversal of the force direction, the force transducer must be preloaded with the maximum force. In each case, the maximum force must correspond to the final value of the calibration range. If the calibration item is designed for loading in the direction of tensile and compressive force, it must be preloaded three times before calibration. In case the design of the calibration item is only suitable for loading in one direction (tensile or compressive force) or if the customer can specify the direction of the last usage-related load, two preloads before calibration will be sufficient. For each new mounting position, an additional preloading is required.

Time for preloading should be at least 1 minute. Reading of the zero point is carried out approx. 30 seconds after the force transducer has been fully unloaded. The force steps should be distributed as evenly as possible over the calibration range. Each measurement series contains the same force steps. The time between two successive load steps must be identical and must last at least 30 seconds. The reading is to be taken no earlier than 30 seconds after the start of the force change.

For each series of measurements, the measurement signal of the unloaded force transducer (including force introduction parts) must be recorded before and after loading.

The minimum number of calibration steps for each measurement series consists of 3 measuring points (excluding the zero point).

If a 3rd degree regression equation is to be specified, at least 5 measuring points per measurement series must be realised; these must be evenly distributed over the calibration range, i.e. at 20 %, 40 %, 60 %, 80 % and 100 %. In case of more measuring points, the measurement series can be extended by an additional measuring point at 10 %, for example.

This guideline describes four calibration sequences (A to D), graded according to effort. The characteristic quantities (reproducibility, repeatability, hysteresis), which can no longer be determined from the measured values, must be added from a priori knowledge. This knowledge can be obtained from statistical methods (see [7] and Appendix C), calibration certificates from previous calibrations (e.g. in accordance with DIN EN ISO 376) or from data sheets.

Note 1:

In the following illustrations of calibration sequences A to D, symbols and designations are used in accordance with DIN EN ISO 376.

Note 2:

Data sheet information in accordance with VDI/VDE/DKD 2638 supports the use of reduced sequences since defined terms and definitions are used. Records regarding the data sources and values used are to be kept in the calibration laboratory.

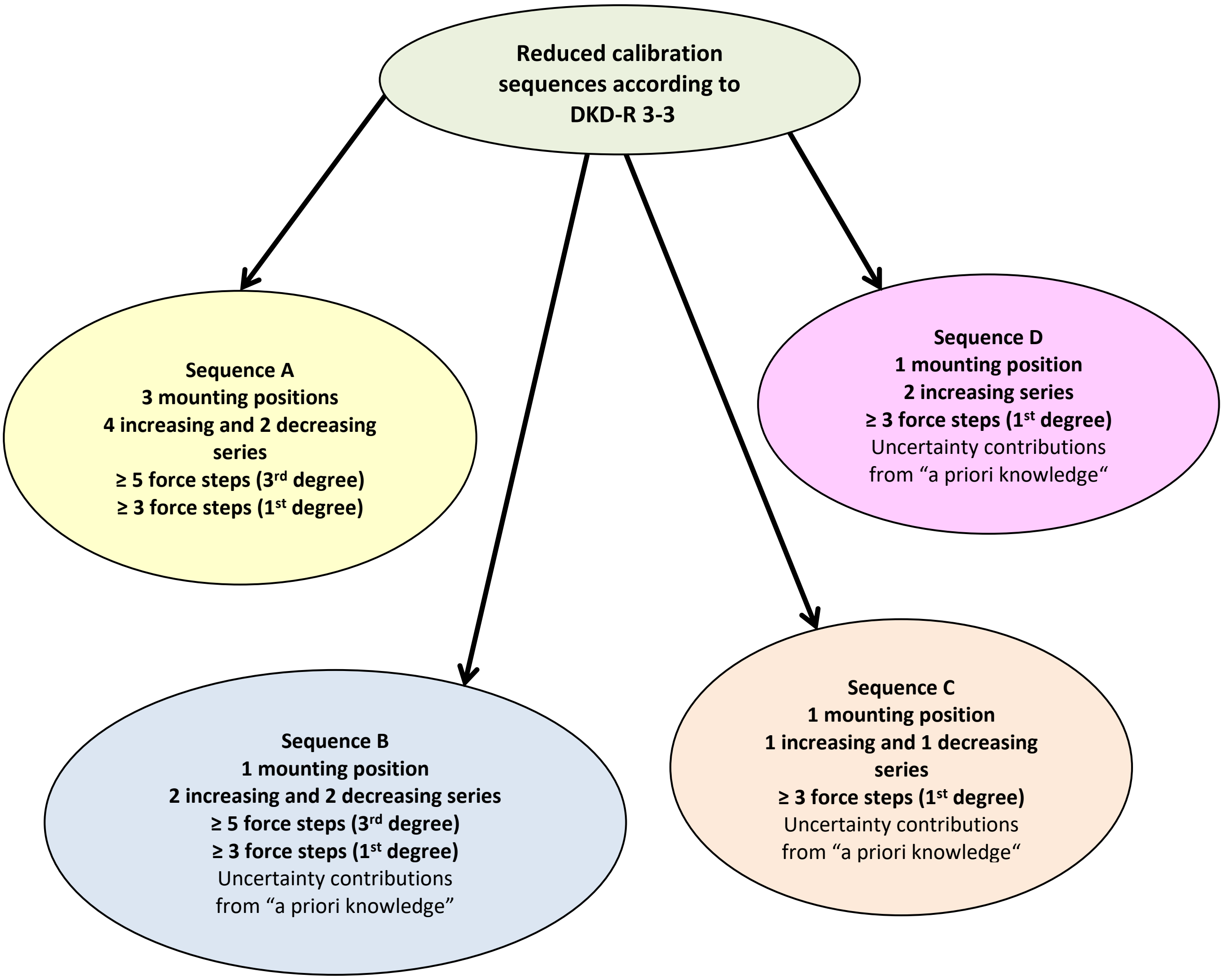


Figure 3: Calibration sequences of DKD-R 3-3 including indication of the number of mounting positions, force steps and the usual degree of the regression function

Table 1: Parameters of the calibration sequences

Calibration sequence	**Number of preloads**	**Number of mounting positions**	**Number of measurement series**		**Minimum number of measuring points for a regression function** without zero, increasing and decreasing load respectively		**Force steps** (in % of the final value of the calibration range)
			in-creasing	de-creasing	1st degree	3rd degree	e. g.
A	2 … 3	3	4	2	≥ 3	≥ 5	20, 40, 60, 80, 100 or 20, 60, 100
B	2 … 3	1	2	2	≥ 3	≥ 5	
C	2 … 3	1	1	1	≥ 3	≥ 5	
D	2 … 3	1	2	0	≥ 3	≥ 5	

5.1 Sequence A:

Based on the calibration procedure DIN EN ISO 376, calibration sequence A (see Figure 4) only involves reducing the number of force levels. All characteristic quantities required to determine the measurement uncertainty (reproducibility, repeatability, hysteresis, zero error) can be determined from the measured values.

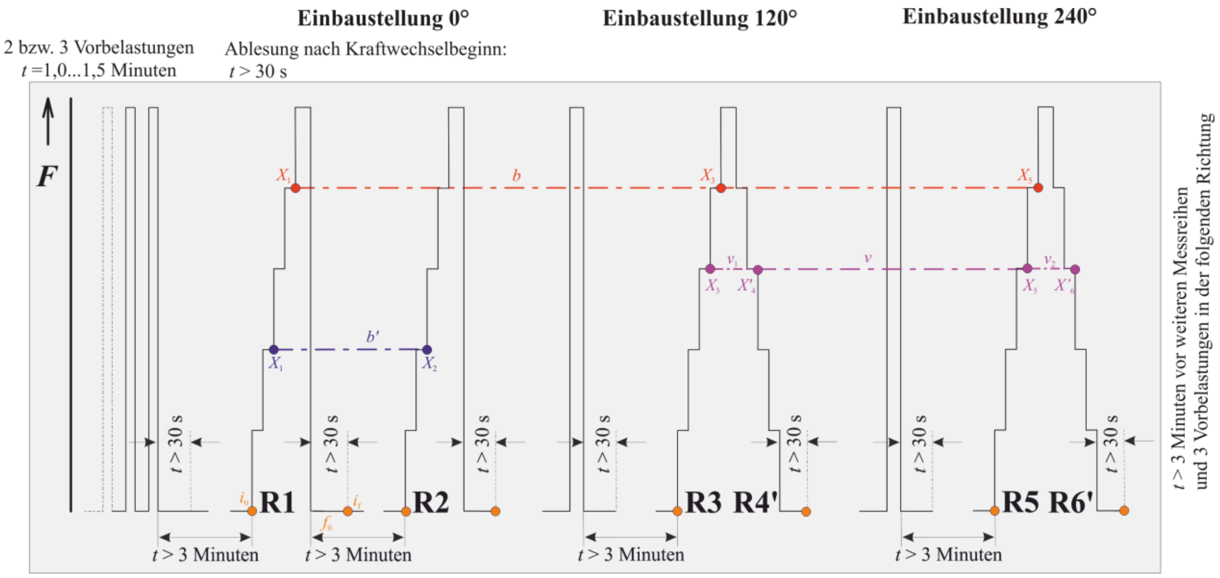


Figure 4: Example calibration sequence A; three mounting positions, five force steps
(Mounting positions at 0°, 120° and 240°, 2 or 3 preloads, reading after start of force change; more than 3 minutes before further measurement series and 3 preloads in the following direction)

5.2 Sequence B:

In sequence B, calibration is carried out in only one mounting position in two series of measurements with increasing and decreasing loads (see Figure 5). The reproducibility can only come from a priori knowledge.

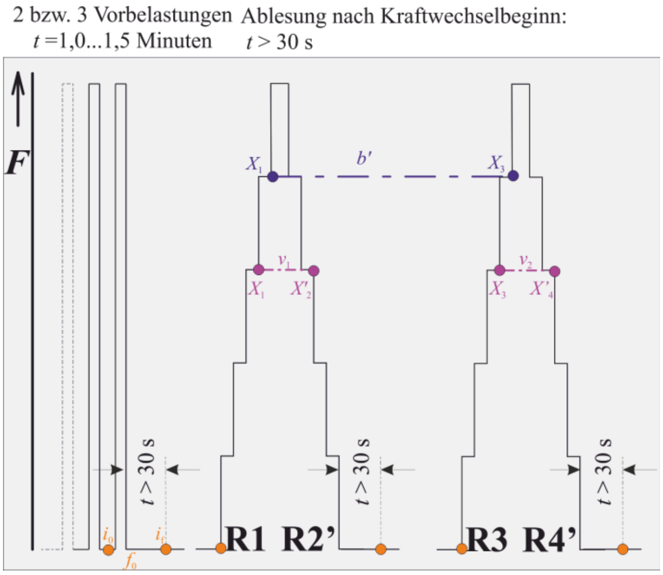


Figure 5: Example calibration sequence B; one mounting position, five force steps
(2 or 3 preloads, reading after start of force change)

5.3 Sequence C:

In sequence C, calibration is carried out in only one mounting position in one series of measurements with increasing and decreasing load (see Figure 6). The repeatability and reproducibility can only come from a priori knowledge.

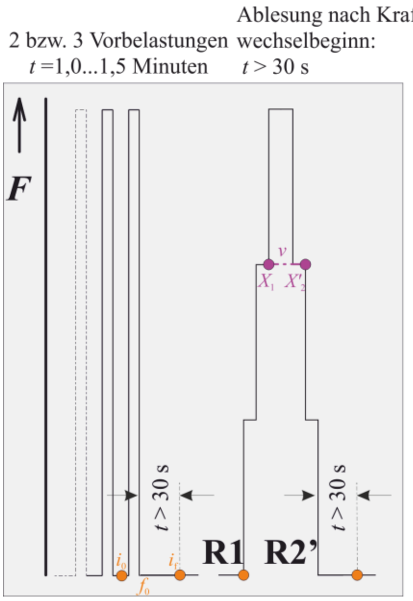


Figure 6: Example calibration sequence C; one mounting position, one measuring series, increasing and decreasing load, three force steps
(2 or 3 preloads, reading after start of force change)

5.4 Sequence D:

In sequence D, calibration is carried out in only one mounting position in two series of measurements with increasing load (see Figure 7). The reproducibility and hysteresis can only come from a priori knowledge.

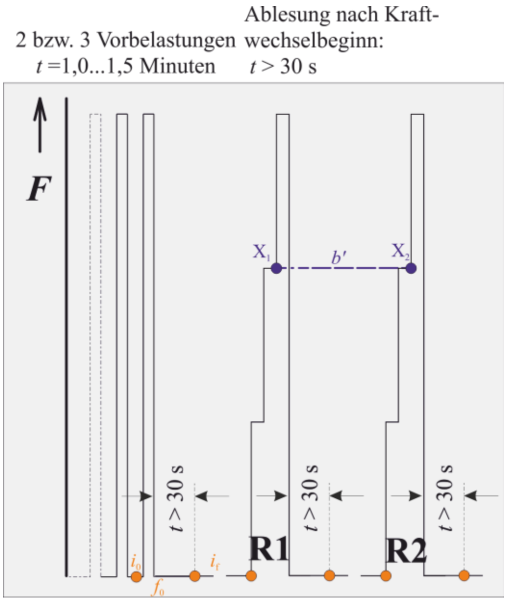


Figure 7: Example calibration sequence D; one mounting position, two measurement series, two increasing loadings, three force steps
(2 or 3 preloads, reading after start of force change)

6 Evaluation

The evaluation must provide the information required for calibration certificates, such as the value set on the standard and the value indicated by the calibration item including the associated measurement uncertainty. In case of recording several measurement series, mean values and fitted polynomials are usually formed and imparted.

Existing regulations only consider the measured values with increasing load when calculating mean values and regression functions (see for example DIN EN ISO 376). In addition, and depending on the application and customer requirements, the measured values for decreasing load or the mean values from increasing and decreasing loading can also be used (see Figure 8).

For example, a joint evaluation of increasing and decreasing series (evaluation by the mean values) should be selected in case of pulsating load.

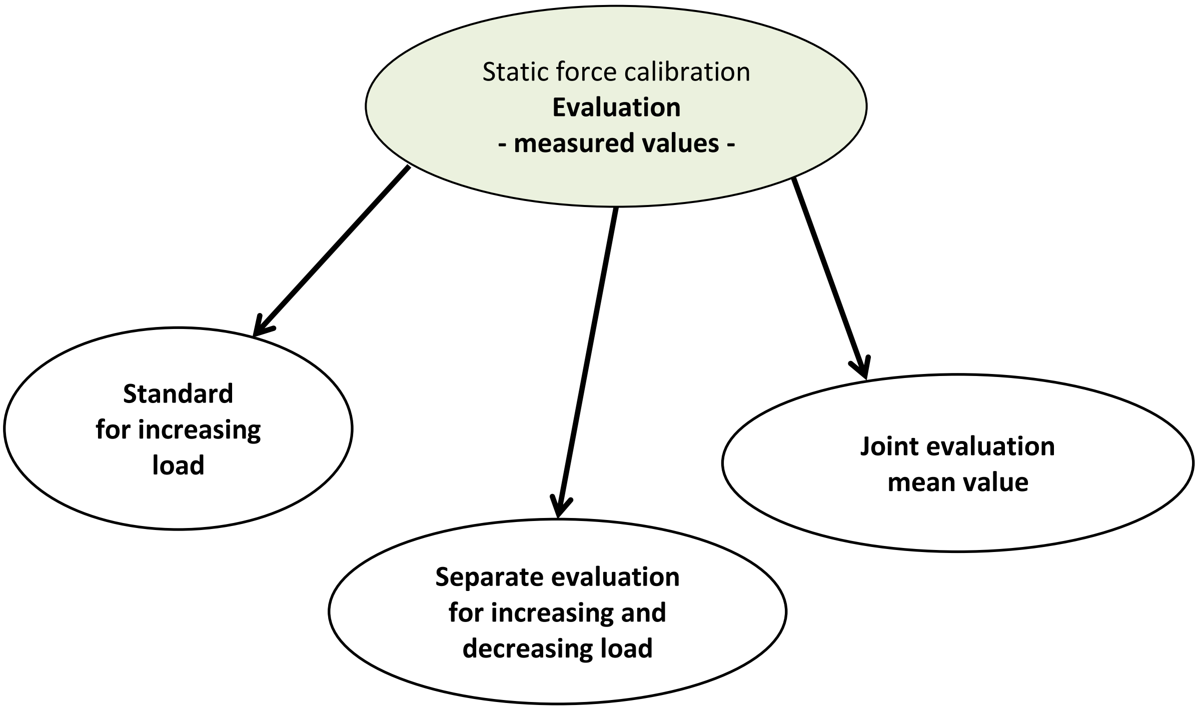


Figure 8: Possible types of evaluation

The regression analysis should be carried out in such a way that the sum of the squares of the absolute errors yields a minimum and without constant element in the fitted polynomial. As regression function, a 3rd or 1st degree polynomial is recommended (see Table 1).

Information regarding the determination of the best estimates and the measurement uncertainty contributions can be found in Appendix B.

7 Measurement uncertainty

The determination of the measurement uncertainty does not replace the qualification and experience of the measurement technician, for example when

- selecting the appropriate measurement method
- planning/designing the measurement set-up
- carrying out the measurements
- evaluating the measurements.

Table 2: Sources of measurement errors and measurement uncertainties

Source	Cause
Measuring devices	– internal and external alignment – resolution – noise – drift – protective screening – long-term instability
Environmental conditions	– ambient temperature – air pressure – relative humidity – vibration – shocks – surrounding medium
Circuit / test design	– impedances – electrical lines – thermoelectric voltages – supply voltages – mechanical adaptations – installation sites – mounting positions – mass – gravitational acceleration
Measurement technician	– writing error – reading error – presence of the measurement technician
Programming	– incorrect file accesses – wrong constants – incorrect parameter transfer

A measurement uncertainty is always assigned to a measured value. It must first be ensured that all systematic deviations are recognised, and corrections are applied. The remaining unknown measurement errors must be considered in the measurement uncertainty budget in the form of estimated measurement uncertainty contributions.

To set up the evaluation model, it is recommended that the influence quantities are listed and graphically represented. A suitable method for this is the fishbone diagram (Ishikawa diagram).

Depending on the type of calibration item (see Figure 2), the calibration provides different output quantities, i.e. different models of evaluation with different measurement uncertainty contributions are used.

In the following, you will find examples of the model and the measurement uncertainty budget for

- the calibration of indicating force measuring devices of the type “indication error” in the unit N, see Figure 2, Case 3
- the calibration of force transducers of the type “transmission coefficient” in the unit (mV/V)/N, see Figure 2, Case 1

The examples include influence quantities from Figure 9 and Figure 10 without claiming to be exhaustive.

The measurement uncertainty components are determined from the measured values according to DIN EN ISO 376 [1]. Should this not be possible (for example, in the case of reduced sequences), the measurement uncertainty components are estimated from a priori knowledge.

It is to be noted that models and budgets only apply to individual measured values. If range specifications are required, this can be done as described in chapter 7.6.

7.1 Measurement uncertainty for the “error of indication” model

As output quantity, the calibration of indicating force measuring devices yields an deviation (error of indication). It is the difference between the indicated value and the value represented/set by the standard, i.e. the force calibration machine.

7.1.1 Influence quantities

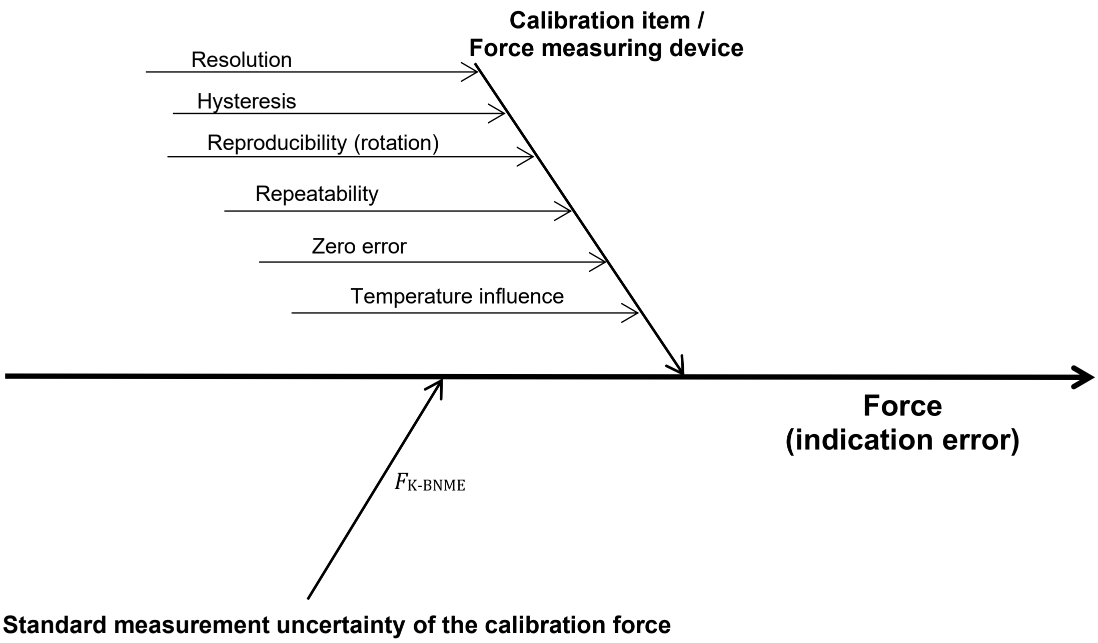


Figure 9: Influence quantities in the determination of the measurement uncertainties associated with the measured values of an indicating measuring device

7.1.2 Model of evaluation (using the example of an indicating force measuring device)

The model of evaluation is formulated as a sum/difference model using measurement uncertainties in the unit of the measurand.

In general terms, the following applies to the measurement function:

Quantities:

$$Y = \sum_{i=1}^{N} p_i X_i \,;\;\; p_i \coloneqq \{+1, -1\} \tag{1}$$

Estimated values:

$$y = \sum_{i=1}^{N} p_i x_i ;\;\; p_i \coloneqq \{+1, -1\} \tag{2}$$

In detailed representation – conditional equation of the error of indication of a force measuring device for individual force values with best estimates – this becomes:

$$\Delta F_j = \bar{F}_j - F_{\text{K-BNME},j} + \sum_{i=1}^{N} \delta F_{i,j} \tag{3}$$

with $\overline{F}_j$ as mean value of the zero-corrected indicated values of the measuring device for each force step j and k as index for the different measurement series:

$$\bar{F}_j = \bar{F}_{\text{MG},j} = \frac{1}{n} \sum_{k=1}^{n} (F_{\text{ind},j,k} - F_{\text{ind},0,k}) \tag{4}$$

and

$$\sum_{i=1}^{5} \delta F_{i,j} = \delta F_{\text{zer}} + \delta F_{\text{rep},j} + \delta F_{\text{rot},j} + \delta F_{\text{tmp},j} + \delta F_{\text{rev},j} \tag{5}$$

with i : index of the measurement errors.

Index “MG” in $\bar{F}_{\text{MG},j}$ is used to show that the complete measuring device is being considered here – consisting of transducer, adapter and indicator (including supply, if necessary).

For greater clarity, the running index j for the load step will be omitted in the rest of the document.

Table 3: Measurement errors in the determination of the measurement uncertainties attributed to the measured values of an indicating force measuring device

ΔF	Output quantity; error of indication of the force measuring device		1	
F_{ind}; $F_{\text{ind,0}}$	Indication of the force measuring device at load step and before loading		2	4
$F_{\text{K-BNME}}$	Force value set by the force calibration machine			
δF_{zer}	Systematic measurement error due to the	zero error	3	
δF_{rep}	Systematic measurement error due to the	repeatability		
δF_{rot}	Systematic measurement error due to the	reproducibility		
δF_{tmp}	Systematic measurement error due to the	temperature influence		
δF_{rev}	Systematic measurement error due to the	hysteresis		

δF_i Measurement error(s)

$E[\delta F_i] = 0$ Expected value

7.1.3 Uncertainty analysis

Due to the linear sum/difference model with the factors $p_i \coloneqq \{+1, -1\}$, the sensitivity coefficients are always equal to 1 ($c_i = \pm 1$).

This means that the contributions $u_i(y)$ to the uncertainty of the output quantity correspond to the uncertainties of the input quantities $u(x_i)$. For the standard measurement uncertainty attributed to the result, this means that

$$u(\Delta F) = \sqrt{u_{\text{ind}}^2(\Delta F) + u_{\text{ind,0}}^2(\Delta F) + u_{\text{K-BNME}}^2(\Delta F) + u_{\text{zer}}^2(\Delta F) + u_{\text{rep}}^2(\Delta F) + u_{\text{rot}}^2(\Delta F) + u_{\text{tmp}}^2(\Delta F) + u_{\text{rev}}^2(\Delta F)} \tag{6}$$

and for the expanded measurement uncertainty:

$$U(\Delta F) = k \cdot u(\Delta F). \tag{7}$$

The expanded measurement uncertainty is calculated from the standard measurement uncertainty multiplied by the coverage factor $k = 2$, so that the coverage probability is approx. 95 %.

The resolution or half the fluctuation range is used as the uncertainty for determining ("reading") the indicated values. As described in DIN EN ISO 376, the last numerical step is used as resolution r (i.e. the full width $2\,a_{\text{res}} = r$). If the display fluctuates, half the fluctuation range is used instead of the resolution. As the indicated forces are always difference values (see Eq. (4)), the resolution (rectangularly distributed) is taken into account twice[4].

The zero error is calculated using the zero signals measured before and after each series of measurements. Their difference, divided by the measured value (indicated value) at maximum calibration force, yields the zero error according to DIN EN ISO 376. For the simplified

1 Output quantity (VIM 2.51: output quantity)
2 N' Input quantities for determining the output quantity $N' < N$ (VIM 2.50: input quantity)
3 N Quantities for determining the measurement uncertainty $N = N' + N''$
4 As a result, r is taken into account with the divisor root (6) in DIN EN ISO 376 [1]

sequences B, C and D, the zero error of the last preload must also be taken into account. The maximum determined zero error is to be used.

For calibration sequence A, the repeatability and reproducibility as well as the hysteresis can be determined directly from the measured values, as described in DIN EN ISO 376. For the calibration sequences B, C and D, one or two of these characteristic quantities must be derived from a priori knowledge.

Recommendation: When calibrating a measuring device according to DKD-R 3-3, a regression through the increasing values should always be carried out; the measurement uncertainty should be calculated taking into account the **full hysteresis** (Case 1 in Table 4). A transducer calibrated in this way can be universally used – both for increasing and decreasing forces.

Upon request by the customer and in consultation with the customer, the hysteresis can also be taken into account in a different way when calculating the measurement uncertainty. In this case, it should be noted that the measuring device may then only be usable to a limited extent (cases 3 and 4). This must be stated in the calibration certificate.

Depending on the subsequent use of the measuring device and the evaluation method, the uncertainty component for the hysteresis is calculated as follows:

Table 4: Uncertainty component depending on application and evaluation method

	Application of the measuring device	Evaluation method	Uncertainty component (rev)
1	Used for increasing and decreasing forces	Regression by increasing values (standard)	Full hysteresis (standard)
2	Used for increasing and decreasing forces	Regression by mean values	1/2 of the hysteresis
3	Used **only** for increasing force	Regression by increasing values	1/3 of the hysteresis
4	Used **only** for decreasing force	Regression by decreasing values	1/3 of the hysteresis

Performing a creep test does not form part of the present guideline DKD-R 3-3. For Case 3 "Regression by increasing values" and "Use only for increasing forces" (accordingly also for Case 4), the uncertainty component for creep is assumed to be 1/3 of the hysteresis in accordance with DIN EN ISO 376 and taken into account by the uncertainty component for the hysteresis δF_{rev}.

The temperature influence can be neglected when adhering to the temperature limits and the temperature stability recommended for Germany in section 4 (environmental conditions); otherwise, it has to be considered as described in DIN EN ISO 376 or EURAMET cg-4.

Table 5: Uncertainty analysis for the "error of indication" model

No.	Quan-tity X_i	Best estimate x_i	Half-width of distribution a	Divi-sor	Standard measurement uncertainty $u(x_i)$	Sensitivity coefficient c_i	Uncer-tainty contri-bution $u_i(y)$	Variance $u_i^2(y)$
1	F_{ind}	x_1 N	$a_{res} = {}^{r}/_{2}$	$\sqrt{3}$	$u(F_{\text{ind}})$	1	$u_{\text{ind}}(\Delta F)$	$u_{\text{ind}}^2(\Delta F)$
2	$F_{\text{ind,0}}$	$x_{1,0}$ N	$a_{\text{res}} = {}^{r}/_{2}$	$\sqrt{3}$	$u(F_{\text{ind,0}})$	1	$u_{\text{ind,0}}(\Delta F)$	$u_{\text{ind,0}}^2(\Delta F)$
3	$F_{\text{K-BNME}}$	x_2 N	$U(F_{\text{K-BNME}})$	2	$u(F_{\text{K-BNME}})$	-1	$u_{\text{K-BNME}}(\Delta F)$	$u_{\text{K-BNME}}^2(\Delta F)$
4	δF_{zer}	0 N	$a_{\text{zer}} = f_0 \cdot F_{\text{K-BNME}}$	$\sqrt{3}$	$u(\delta F_{\text{zer}})$	1	$u_{\text{zer}}(\Delta F)$	$u_{\text{zer}}^2(\Delta F)$
5	δF_{rep}	0 N	$a_{\text{rep}} = b' \cdot F_{\text{K-BNME}}$	$\sqrt{3}$	$u(\delta F_{\text{rep}})$	1	$u_{\text{rep}}(\Delta F)$	$u_{\text{rep}}^2(\Delta F)$
6	δF_{rot}	0 N	$u(\delta F_{\text{rot}}) = \sqrt{\frac{1}{6} \cdot \sum_{k=1,3,5} (F_k - \overline{F})^2}$	1	$u(\delta F_{\text{rot}})$	1	$u_{\text{rot}}(\Delta F)$	$u_{\text{rot}}^2(\Delta F)$
7	δF_{tmp}	0 N	a_{tmp}	$\sqrt{3}$	$u(\delta F_{\text{tmp}})$	1	$u_{\text{tmp}}(\Delta F)$	$u_{\text{tmp}}^2(\Delta F)$
8	δF_{rev}	0 N	$a_{\text{rev}} = \nu \cdot F_{\text{K-BNME}}$ or $a_{\text{rev}} = \frac{\nu \cdot F_{\text{K-BNME}}}{2}$ or $a_{\text{rev}} = \frac{\nu \cdot F_{\text{K-BNME}}}{3}$	$\sqrt{3}$	$u(\delta F_{\text{rev}})$	1	$u_{\text{rev}}(\Delta F)$	$u_{\text{rev}}^2(\Delta F)$
	ΔF	y N	Standard measurement uncertainty u			$u(\Delta F) = \sqrt{\sum_{i=1}^{N} u_i^2(\Delta F)}$		
	ΔF	y N	Expanded measurement uncertainty U			$U(\Delta F) = k \cdot u(\Delta F)$		
Indication of the complete measurement result						$\Delta F = y \pm U(\Delta F)$		

7.1.4 Measurement uncertainty budget

The measurement uncertainty must be determined for each calibration value, i.e. for each specified load level. A clear overview is provided by the following measurement uncertainty budget (Table 6).

Table 6: Measurement uncertainty budget for the “error of indication” model (all load levels within the range)

Force	Indication error	Standard measurement uncertainty $u_i(y)$ (measurement uncertainty contributions attributed to the result due to influence quantities)						
		Indica-tion resolu-tion	Expanded MU of the calibra-tion force	Zero error	Repeat-ability	Repro-ducibility	Hyste-resis	Tempera-ture
N	N	N						
F_{min}								
...								
F_{max}								

Force	Indication error	Standard measurement uncertainty $u(y)$	Expanded measurement uncertainty $U(y)$ $(k=2)$	
N	N	N		
F_{min}				
...				
F_{max}				

7.2 Measurement uncertainty for the “transmission coefficient” model

When solely calibrating the force transducers, the output quantity obtained is the transmission coefficient as quotient of output quantity (mV/V) and input quantity (force value in N set by the force calibration machine).

7.2.1 Influence quantities

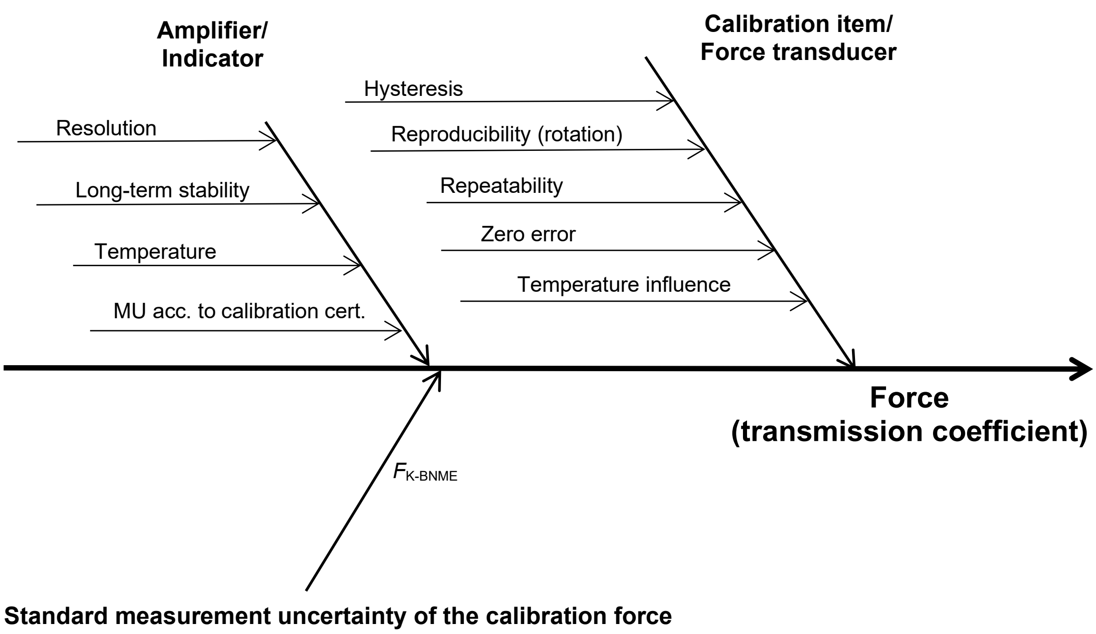


Figure 10: Influence quantities in the determination of the measurement uncertainties attributed to the transmission coefficients of a force transducer

7.2.2 Evaluation model (using the example of a force transducer)

The model for the evaluation of force transducer calibrations is formulated as a linear product/quotient model using relative measurement uncertainties.

In general, the following applies to the measurement function:

Quantities:

$$Y = q \cdot \prod_{i=1}^{N} X_i^{p_i}\,;\; p_i \coloneqq \{+1, -1\} \qquad \textbf{(8)}$$

Estimated values:

$$y = q \cdot \prod_{i=1}^{N} x_i^{p_i};\; p_i \coloneqq \{+1, -1\} \qquad \textbf{(9)}$$

In a detailed representation – conditional equation of the transmission coefficient of a force transducer for individual force values with best estimates – this results in:

$$E_j \overset{\text{hier}}{\longrightarrow} E_{\text{KA},j} = \frac{\bar{S}_{\text{KA},j}}{F_{\text{K-BNME},j}} \cdot \prod_{i=1}^{N} K_{i,j} = \frac{\bar{S}_{\text{MG},j}}{F_{\text{K-BNME},j} \cdot R_{\text{KG}} \cdot G_{\text{KG}}} \cdot \prod_{i=1}^{N} K_{i,j} \quad \textbf{(10)}$$

with $\bar{S}_{\text{MG},j}$ as the mean value of the zero-corrected indicated values of the measuring device at each force step j and k as the index for the different measurement series:

$$\bar{S}_{\text{MG},j} = \frac{1}{n} \sum_{k=1}^{n} \left(S_{\text{ind},j,k} - S_{\text{ind},0,k} \right) \quad \textbf{(11)}$$

and

$$\prod_{i=1}^{6} K_{i,j} = K_{\text{zer}} \cdot K_{\text{rep},j} \cdot K_{\text{rot},j} \cdot K_{\text{tmp}} \cdot K_{\text{rev},j} \quad \textbf{(12)}$$

with i : index of the correction factors.

The index “MG” in $\bar{S}_{\text{MG},j}$ is used to illustrate that the complete measuring device is being considered here – consisting of the transducer with corresponding adapter and indicator provided by the customer (including supply, if necessary).

For reasons of clarity, the running index j for the load step will be omitted in the following.

Table 7: Influence quantities in the determination of the measurement uncertainties attributed to the transmission coefficients of a force transducer

E	Output quantity; transmission coefficient (sensitivity) of the force transducer	5	
$S_{\text{ind}}; S_{\text{ind},0}$	Output signal of the force measuring device or the indicator at loading step and prior to loading	6	
$F_{\text{K-BNME}}$	Force value set by the force calibration machine		
R_{KG}	Transmission coefficient of the indicator		
G_{KG}	Transmission coefficient of the adapter		
K_{zer}	Correction factor relative zero error		7
K_{rep}	Correction factor relative repeatability		
K_{rot}	Correction factor relative reproducibility		
K_{tmp}	Correction factor relative temperature deviation		
K_{rev}	Correction factor relative hysteresis		

Correction factors:

$$K_i = \left(1 + \frac{\delta x_i}{|x_i|} \right) \quad \textbf{(13)}$$

with

δx_i measurement errors and

$E[\delta x_i] = 0\,; E[K_i] = 1$ expected value

[5] Output quantity (VIM 2.51: output quantity)
[6] N' Input quantities for determining the output quantity $N' < N$ (VIM 2.50: input quantity)
[7] N Quantities for determining the measurement uncertainty $N = N' + N''$

7.2.3 Uncertainty analysis

Due to the selected linear product/quotient model and the application of relative measurement uncertainties, the sensitivity coefficients [8] are always equal to 1 ($c_i^* = \pm 1$).

Thus, the contributions $w_i(y)$ to the uncertainty of the output quantity correspond to the uncertainties of the input quantities $w(x_i)$. Consequently, the result's associated relative standard measurement uncertainty is:

$$w(E) = \sqrt{w_{S_\mathrm{ind}}^2(E) + w_{S_\mathrm{ind,0}}^2(E) + w_\mathrm{K-BNME}^2(E) + w_\mathrm{R}^2(E) + w_\mathrm{G}^2(E) + w_\mathrm{zer}^2(E) + w_\mathrm{rep}^2(E) + w_\mathrm{rot}^2(E) + w_\mathrm{tmp}^2(E) + w_\mathrm{rev}^2(E)} \qquad \textbf{(14)}$$

And for the relative expanded measurement uncertainty it follows that:

$$W(E) = k \cdot w(E) \qquad \textbf{(15)}$$

The notes given in section 7.1.3 also apply to the various uncertainty components.

If it is only the force transducer that is to be calibrated, then the calibration laboratory must provide an indicator and/or adapter. Corresponding measurement uncertainty components must be taken into account for the transmission behaviour of these measuring chain elements. These uncertainty components can be determined by means of sub-budgets which include, for example, the measurement uncertainty according to the calibration certificate, the long-term instability, a possible temperature influence and other acting influences.

There are different ways for taking into account the regression deviation. Particularly when calibrating force measuring devices of poorer quality with increased regression deviations, it makes sense to include the regression deviation in a specification limit determined during calibration through determination of a deviation margin (see section 7.5). Increased regression deviation means that it is significantly greater than the combined measurement uncertainty determined from the other acting influences.

Under normal circumstances, this guideline (also sequence A) is not intended for the calibration of transfer and reference force measuring devices. In case that force measuring devices of a higher quality are to be calibrated according to this guideline, the measurement uncertainty must be determined in accordance with DIN EN ISO 376, Annex C [1]. In this case, higher-quality force measuring devices means that the regression deviation is in the same order of magnitude as the combined measurement uncertainty determined from the other acting influences.
If a 3rd degree polynomial is used in the evaluation, the regression deviation is regarded as a random deviation and taken into account as a measurement uncertainty component. If a 1st degree polynomial is used in the evaluation, the regression deviation is regarded as a systematic deviation and, if it is not corrected, can be included in a specification limit determined as part of the calibration.

[8] The sensitivity coefficient c_i^* is the factor by which the relative uncertainty $w(x_i)$ is converted into the relative uncertainty contribution $w_i(y)$. It is related to the sensitivity coefficient c_i as follows: $c_i^* = \frac{x_i}{y} \cdot c_i$

Table 8: Uncertainty analysis for the “transmission coefficient” model

No.	**Quantity** X_i	**Best estimate** x_i	**Half-width of the distribution** a	**Divisor**	**Standard measurement uncertainty** $w(x_i)$	**Sensitivity coefficient** c_i^*	**Uncertainty contribution** $w_i(y)$	**Variance** $w_i^2(y)$
1	S_{ind}	x_1 LSB	$a_{\mathrm{res}} = {}^{r}/_{2}$	$\sqrt{3}$	$w(S_{\mathrm{ind}})$	1	$w_{S_{\mathrm{ind}}}(E)$	$w^2_{S_{\mathrm{ind}}}(E)$
2	$S_{\mathrm{ind,0}}$	$x_{1,0}$ LSB	$a_{\mathrm{res}} = {}^{r}/_{2}$	$\sqrt{3}$	$w(S_{\mathrm{ind,0}})$	1	$w_{S_{\mathrm{ind,0}}}(E)$	$w^2_{S_{\mathrm{ind,0}}}(E)$
3	$F_{\mathrm{K-BNME}}$	x_2 N	$W(F_{\mathrm{K-BNME}})$	2	$w(F_{\mathrm{K-BNME}})$	-1	$w_{\mathrm{K-BNME}}(E)$	$w^2_{\mathrm{K-BNME}}(E)$
4	R_{KG}	x_3 LSB/V	$W(R_{\mathrm{KG}})$	2	$w(R_{\mathrm{KG}})$	-1	$w_{\mathrm{R}}(E)$	$w^2_{\mathrm{R}}(E)$
5	G_{KG}	x_4 V/(mV/V)	$W(G_{\mathrm{KG}})$	2	$w(G_{\mathrm{KG}})$	-1	$w_{\mathrm{G}}(E)$	$w^2_{\mathrm{G}}(E)$
6	K_{zer}	1	$a_{\mathrm{zer}} = f_0$	$\sqrt{3}$	$w(K_{\mathrm{zer}})$	1	$w_{\mathrm{zer}}(E)$	$w^2_{\mathrm{zer}}(E)$
7	K_{rep}	1	$a_{\mathrm{rep}} = b'$	$\sqrt{3}$	$w(K_{\mathrm{rep}})$	1	$w_{\mathrm{rep}}(E)$	$w^2_{\mathrm{rep}}(E)$
8	K_{rot}	1	$w(K_{\mathrm{rot}}) = \frac{1}{\bar{S}} \sqrt{\frac{1}{6} \cdot \sum_{k=1,3,5} (S_k - \bar{S})^2}$	1	$w(K_{\mathrm{rot}})$	1	$w_{\mathrm{rot}}(E)$	$w^2_{\mathrm{rot}}(E)$
9	K_{tmp}	1	a_{tmp}	$\sqrt{3}$	$w(K_{\mathrm{tmp}})$	1	$w_{\mathrm{tmp}}(E)$	$w^2_{\mathrm{tmp}}(E)$
10	K_{rev}	1	$a_{\mathrm{rev}} = v$ oder $a_{\mathrm{rev}} = \frac{v}{2}$ oder $a_{\mathrm{rev}} = \frac{v}{3}$	$\sqrt{3}$	$w(K_{\mathrm{rev}})$	1	$w_{\mathrm{rev}}(E)$	$w^2_{\mathrm{rev}}(E)$
	E	$y \, \frac{\mathrm{mV}/V}{\mathrm{N}}$	Relative standard measurement uncertainty w			$w(E) = \sqrt{\sum_{i=1}^{N} w_i^2(E)}$		
	E	$y \, \frac{\mathrm{mV}/V}{\mathrm{N}}$	Relative expanded measurement uncertainty W			$W(E) = k \cdot w(E)$		
	Indication of the complete measurement result					$E = y(1 \pm W(E)) \frac{\mathrm{mV}/V}{\mathrm{N}}$		

7.2.4 Measurement uncertainty budget

However, the measurement uncertainty must be determined for each calibration value, i.e. for each specified load level. The following measurement uncertainty budget (Table 9) provides a clear overview.

Table 9: Measurement uncertainty budget for the transmission coefficient model (all force steps within the range)

Force	**Transmission coefficient**	**Relative standard uncertainty** $w(y)$	**Relative expanded uncertainty** $W(y)$ $(k = 2)$	**Relative uncertainty interval** $W'(y)$ (for sequences B, C and D)
N	(mV/V)/N	%		
F_{min}				
…				
F_{max}				

Force	**Transmission coefficient**	**Relative standard measurement uncertainty** $w_i(y)$ (measurement uncertainty contributions attributed to the result due to influence quantities)						
		Output signal	**Expanded MU of the calibration force**	**Transmission coefficient indicator / adapter**	**Zero error**	**Repeatability**	**Reproducibility**	**Hysteresis + Column Temperature**
N	(mV/V)/N	%						
F_{min}								
…								
F_{max}								

7.3 Measurement uncertainty contributions with reduced calibration sequences

For the complete calibration sequence A, all relevant measurement uncertainty contributions can be determined in accordance with the document DIN EN ISO 376 [1]. For the reduced calibration sequences B, C and D, this information must be obtained in increasing numbers by other means. The following sources may be considered:

- statistical determination of a priori knowledge
- previously performed complete calibration of the calibration item
- data sheet specification

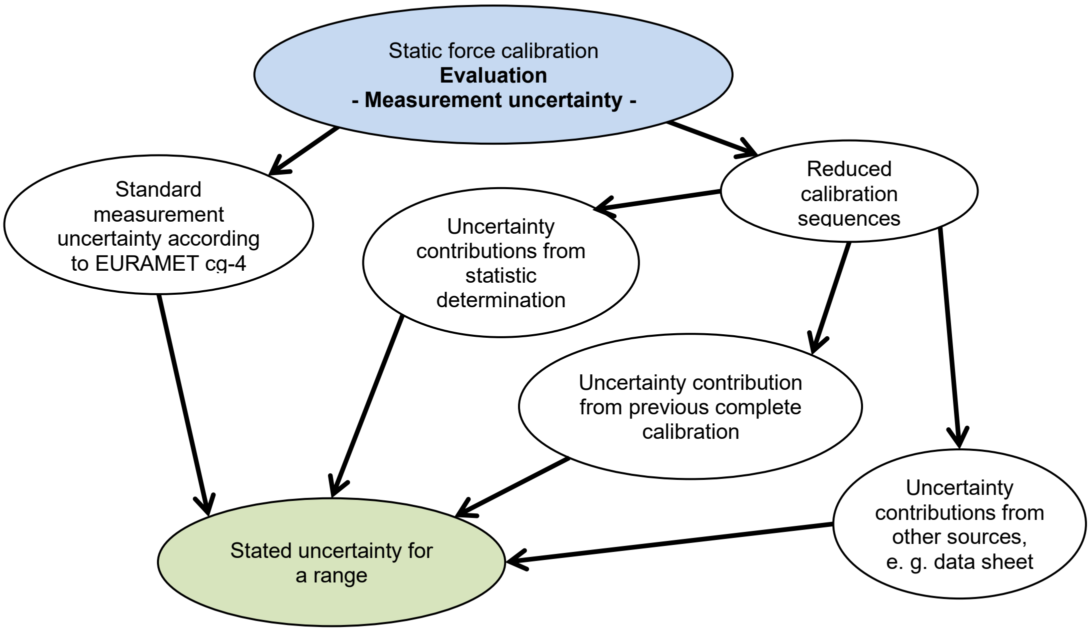


Figure 11: Stated measurement uncertainties

The thus determined values of the measurement uncertainty contributions must be multiplied by a factor before use. In addition, further characteristics of the force transducer as for example the zero signal and the sensitivity from previous calibrations (inspection of test and measuring equipment, history) must be evaluated to validate this procedure.

The size of the factor may depend on the origin or trustworthiness of the information.

Table 10: Factors for measurement uncertainty contributions from different sources

I.	Calibration of force measuring devices of the same type carried out in your own force calibration machine (determination from a priori knowledge, see [7])	t factor[9] 2 … 4,3
II.	Previous calibration of the same calibration item according to DIN EN ISO 376 or sequence A in your own or comparable force calibration machine [10]	Factor 2
III.	Values to be added as measured value-related data sheet specifications (as upper limits) according to the definitions of VDI/VDE/DKD 2638	Factor 2
IV.	Other measured value-related data sheet specifications (as upper limits)	Factor 3
V.	Other measured value-related data sheet information (as typical information)	Factor 5

Note 1:
Data relating to final values must be converted to data relating to measured values.

Note 2:
If smaller factors are used, the procedure for determining the factors must be documented within the quality management system.

Note 3:
In this version of DKD-R 3-3, the measurement uncertainty component for the reproducibility is determined in accordance with DIN EN ISO 376 [1] and therefore different from the 2007 version. It is now slightly smaller. For this reason, it is possible to continue using the already existing data for the a priori values of the reproducibility and the measurement uncertainty components for the reproducibility determined from these values in accordance with the previous version of DKD-R 3-3 (divisor $\sqrt{2}$).
The basic procedure for determining the measurement uncertainty for reduced calibration sequences is shown in the diagram in Appendix A.

Appendix C provides a detailed example of the procedure according to Case I.

[9] Factor depending on the number of specimens analysed; Student's distribution is used. This means that the factor lies between the value **2** for > 50 specimens and the value **4,3** for 3 specimens (for a coverage probability of 95 %)
[10] If a priori knowledge is to be derived from the calibration on another force calibration machine, the corresponding MU contribution may be estimated too small if the other force calibration machine is significantly better than the own one.

7.4 Visualisation of the measurement uncertainty budget

When visualising the uncertainty contributions (variances) in a bar chart, sorting the contributions in descending order, one can clearly see for which influence quantities measures have to be taken in order to reduce the measurement uncertainty.

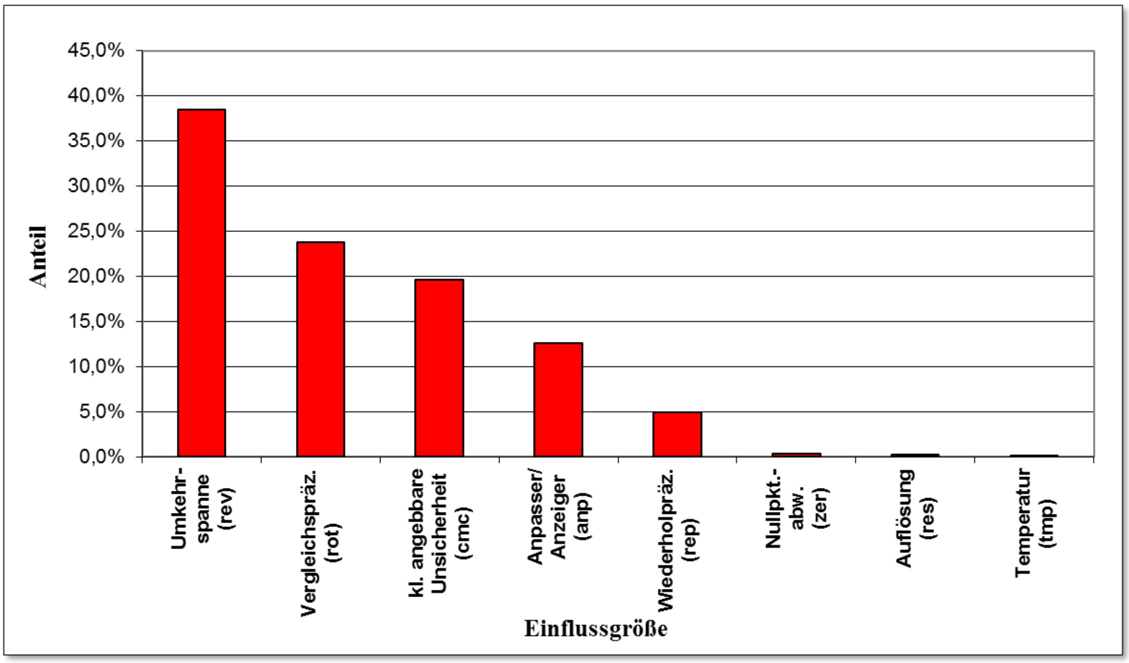


Figure 12: Example for visualising the variance components (square of the uncertainty contributions) of the total variance (square of the standard measurement uncertainty) in descending order
Explanation of the legend:
Share (in percent) of the influence quantities in descending order from left to right: hysteresis, reproducibility, smallest measurement uncertainty, adapter/indicator, zero-point deviation, resolution, temperature)

7.5 Deviation margin

According to the *Guide to the Expression of Uncertainty in Measurement* (GUM), systematic deviations must be corrected, and the combined standard measurement uncertainty has to be determined by the root of the sum of the squared individual standard uncertainty contributions. In some applications, however, it is not possible to correct the (systematic) measurement deviation. If the measurement error is dominant compared to the other influences, it makes sense to specify a specification limit determined from the calibration results on the basis of the so-called deviation margin.

The relative deviation margin W' is formed by addition of the systematic measurement deviation and the relative expanded measurement uncertainty ($k = 2$). Due to the systematic component, a rectangular distribution is assumed as probability distribution for the deviation margin. For the transmission coefficient model, the regression deviation for the 1st degree regression function is such a systematic measurement deviation (see single-figure indication):

$$W' = \left|\frac{\Delta E_{\mathrm{app}}}{E}\right| + W \qquad \textbf{(16)}$$

7.6 Single-figure indication as calibration result

Each measurement uncertainty is assigned one measured value. For calibrations with different and usually equidistantly distributed values within a range, result tables are obtained (for example, Table 9). The user of the calibration item, on the other hand, often only works with one value for the entire validity range of the calibration, the so-called single-figure indication. This single-figure indication is, for example, the transmission coefficient (sensitivity) of a transducer for the measuring range. However, it is difficult to specify a measurement uncertainty for this single-figure indication in accordance with the rules of the GUM; it can therefore be replaced by a statement of conformity.

This requires the determination of specification limits, taking into account the systematic measurement deviation (of the individual values from the single-figure indication) and the expanded measurement uncertainty (associated with the individual values) (deviation margin).

The upper and lower specification limits are approximated to the largest deviation margin (sum of systematic measurement deviation and expanded measurement uncertainty); preferably with a small safety margin so that smooth numerical values are obtained. The thus determined specification limits are to be taken into account as measurement uncertainty contribution in the measurement uncertainty budget of the application. Due to the systematic component in the deviation margin, a rectangular distribution is assumed.

The transmission coefficients and the associated expanded measurement uncertainties are shown by comparing them with the specification limits as stated by the manufacturer or with the specification limits determined during calibration.

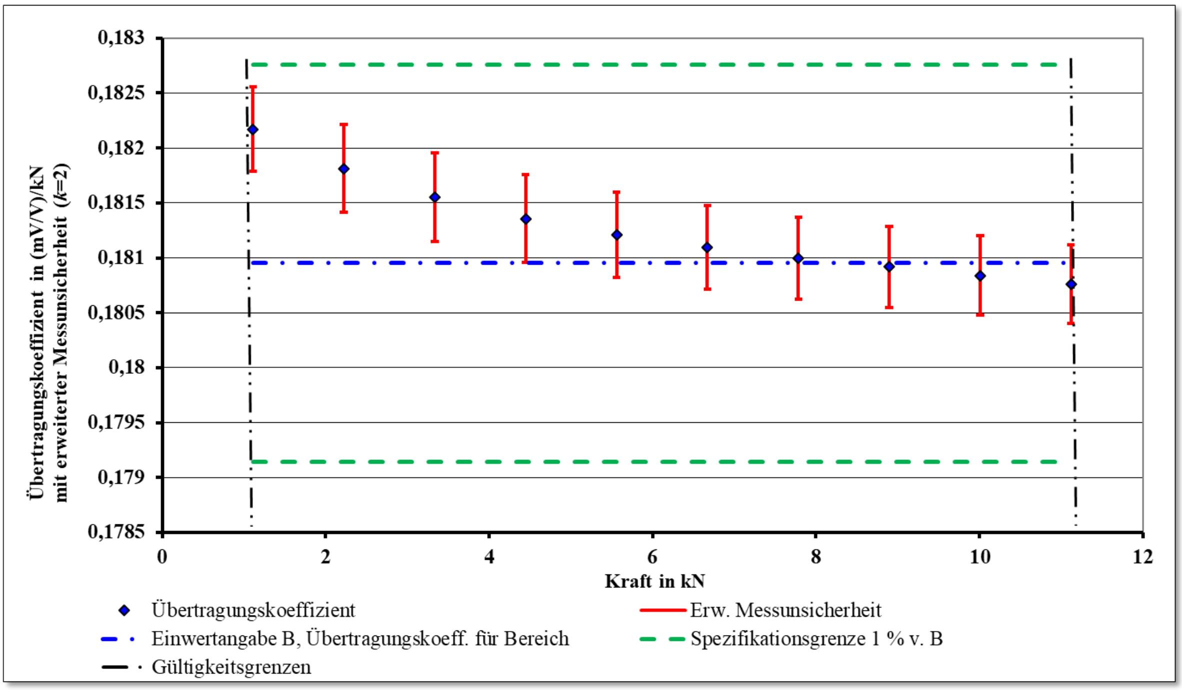


Figure 13: Transmission coefficients with expanded measurement uncertainty, single-figure indication (transmission coefficient for the range) and specification limit

Translation of the German words in Figures 13 - 16:

Übertragungskoeffizient in	Transmission coefficient in
mit erweiterter Messunsicherheit	with expanded measurement uncertainty
Kraft in kN	Force in kN
Einwertangabe B, Übertragungskoeff. für Bereich	Single-figure indication B, transmission coefficient for the range
Gültigkeitsgrenzen	Validity limits
Erw. Messunsicherheit	Expanded measurement uncertainty
Spezifikationsgrenze 1 % v.B.	Specification limit 1 % of the range
Unsicherheitsintervall	Uncertainty interval

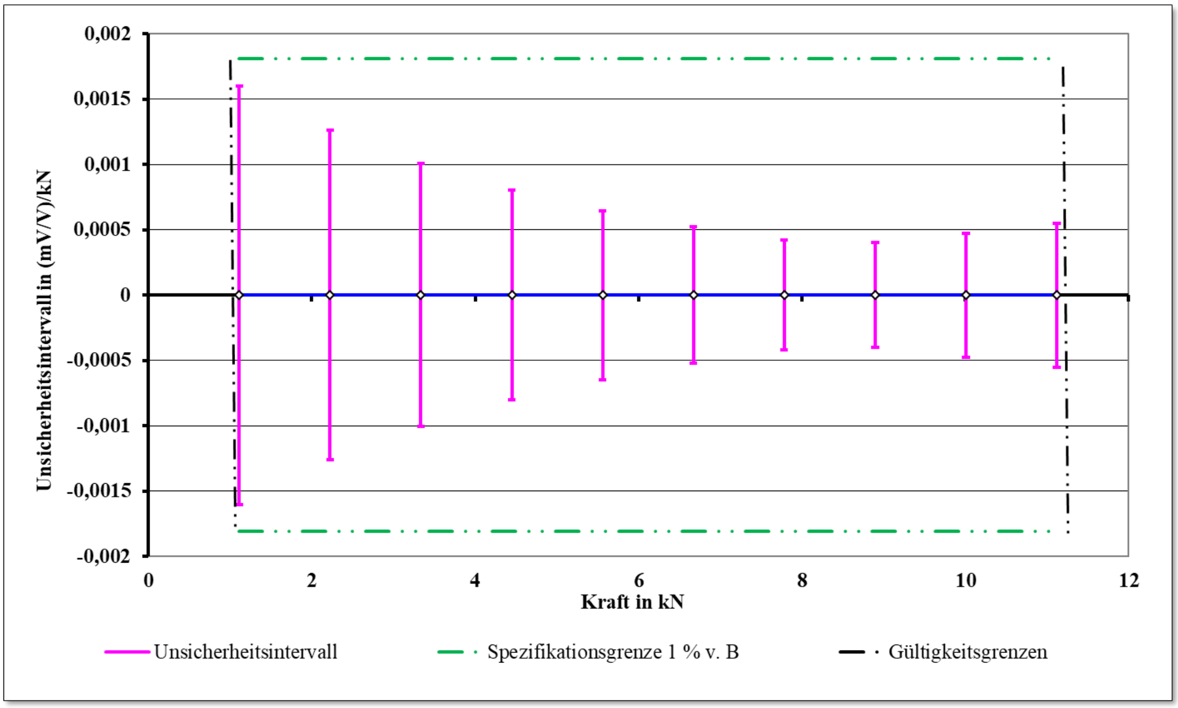


Figure 14: Deviation margin and specification limit

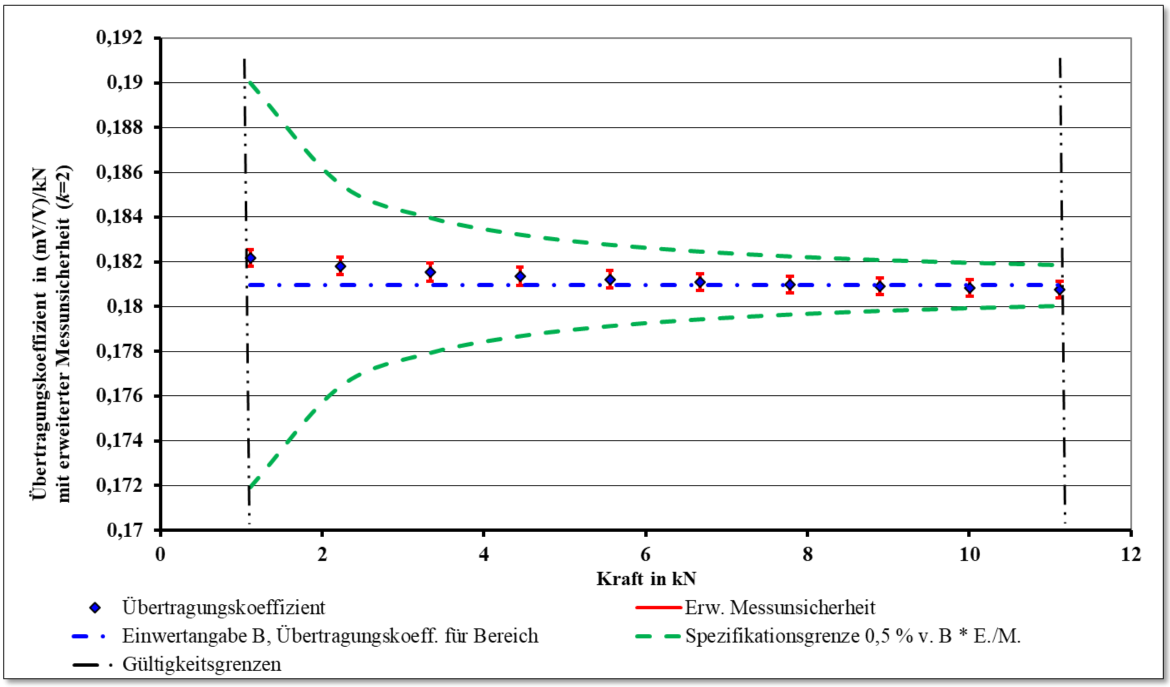


Figure 15: as in Figure 13, but with hyperbolic specification limit (B = single-figure indication; E. = calibration range end value; M. = set value)

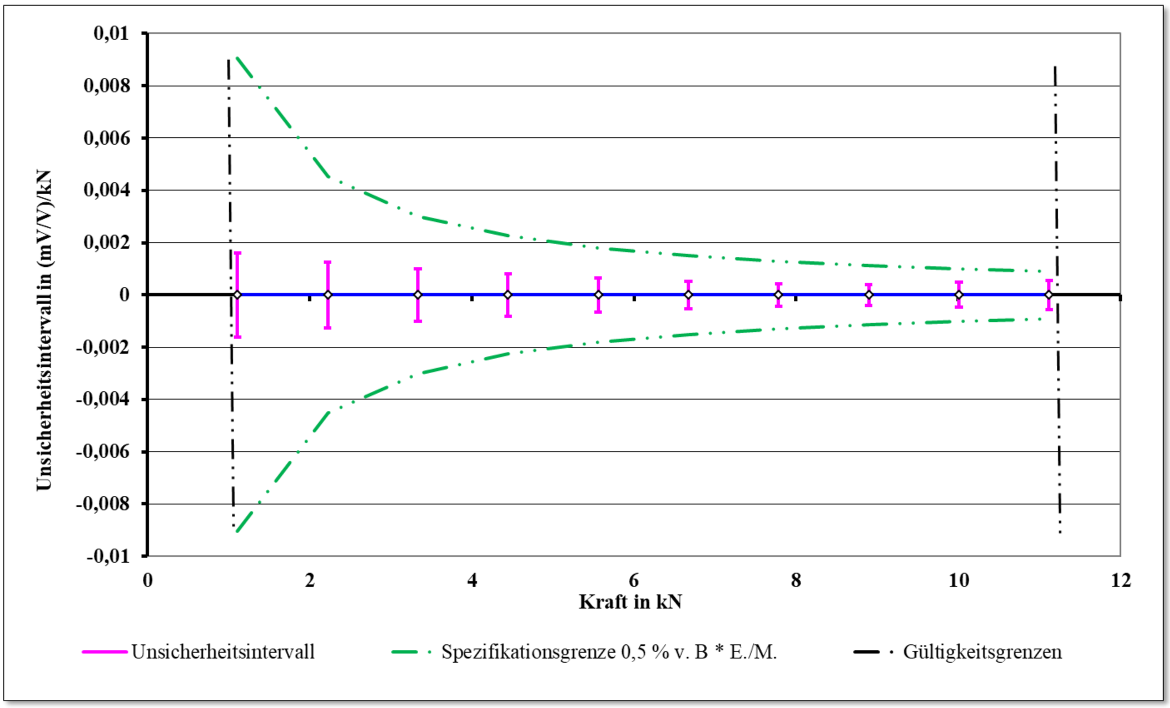


Figure 16: as in Figure 14, but with hyperbolic specification limit

8 Information provided in the calibration certificate

Basically, the requirements of DIN EN ISO/IEC 17025 regarding the subjects “General requirements for reports” and “Special requirements for calibration certificates” [6] apply:

- Identity of the force transducer or force measuring chain
- Calibration procedure (with sequence used and origin of those measurement uncertainty contributions that cannot be determined from the measured values, i.e. from the determination of a priori knowledge, from a previous calibration or from data sheet information)
- Designation and traceable measurement uncertainty of the force calibration machine used
- Calibration conditions
    - ambient temperature and, if applicable, temperature of the force transducer
    - air pressure and relative humidity, if required
- Description of the force introduction parts used
- Indication of the direction of force
- Information regarding supply voltage, connection technology used (4- or 6-wire), cable length
- Measured values
- Calculated values depending on the calibration sequence and evaluation method according to Appendix A
- Zero signal of the unloaded force transducer without mounting parts
- The calibration result (including the associated measurement uncertainty) is
    - the error of indication

    or

    - the transmission coefficient as gradient of a regression line through the origin of the coordinates (single-figure indication)

      Note 1:

      The origin of the measured values on which the regression calculation is based must be specified (e.g. measured values in the direction of increasing load or mean values from measured values with increasing/decreasing load)

      Note 2:

      The calculation method must be specified, see chapter 7.1.3.

      and, if applicable

    - the specification limits and associated validity limits determined during calibration

      Note 1: The user of the calibration item can take into account the specification limit determined during calibration as input quantity in his measurement uncertainty budget under assumption of a rectangular distribution.

      Note 2: Visualisation of the results is recommended, as described in chapter 7.1.3.
    - Coefficients of the regression function

- Information regarding the measuring amplifier
  - carrier frequency or DC voltage
  - filter and filter characteristic

  Note:
  If the calibration item is a force transducer that has been calibrated without the associated measuring amplifier, it must be noted that the information from the calibration certificate may only be used directly if identical measuring amplifiers are used.

- On customer request: Contributions (and their origin) to the measurement uncertainty, if reduced calibration sequences are used - as compared to DIN EN ISO 376 or sequence A.
- In the case of conformity statements, it is necessary to indicate the rule used and the origin of the limits.

9 Records kept in the calibration laboratory

The calibration laboratory must keep and retain records of the calibration set-up along with the corresponding order, for example:

- Software version for computerised operation
- Description of the mounting position of the calibration item, for example by the direction of the cable outlet
- Slots of the measuring amplifiers in multi-channel systems, if these have an influence on the measurement results
- Contributions (and their origin) to the measurement uncertainty if there are reduced calibration sequences as opposed to DIN EN ISO 376 or sequence A (and these are not listed in the calibration certificate)

10 Conformity

If a conformity assessment is carried out, a decision rule according to ILAC-G8 [5] can be applied. The selected decision rule and the origin of the specification limits must be indicated in the calibration certificate, for example manufacturer-specific information according to the data sheet or customer requirements. If the specification limits are determined from the current calibration data, this must be indicated.

11 Calibration mark

A calibration mark is fixed to the device in accordance with the specifications of the accreditation body. In the case of calibration items consisting of several separable components, each component is given an identical mark. If the calibration item is stored in a box or container for protection, this receptacle can also be identified by an identical mark to make it easier to locate the item.

12 Bibliography

[1] DIN EN ISO 376:2011, Metallische Werkstoffe – Kalibrierung der Kraftmessgeräte für die Prüfung von Prüfmaschinen mit einachsiger Beanspruchung (Calibration of force-proving instruments used for the verification of uniaxial testing machines)

[2] EURAMET cg-4:2022, Uncertainty of Force Measurements – Calibration Guide, EURAMET e.V., 3rd edition February 2022

[3] EA-4/02 M: 2022, Evaluation of the Uncertainty of Measurement in calibration, European Accreditation, rev.03, 04. Apr 2022;
EA-4/02 M: 2022, Ermittlung der Messunsicherheit bei Kalibrierungen (German translation as of 31.08.2022), DAkkS

[4] Burghart Brinkmann: Internationales Wörterbuch der Metrologie: Grundlegende und allgemeine Begriffe und zugeordnete Benennungen (VIM); Deutsch-englische Fassung ISO/IEC-Leitfaden 99:2007, Beuth-Verlag Berlin, 2012. ISBN 978-3-410-22473-0 (International Vocabulary of Metrology (VIM))

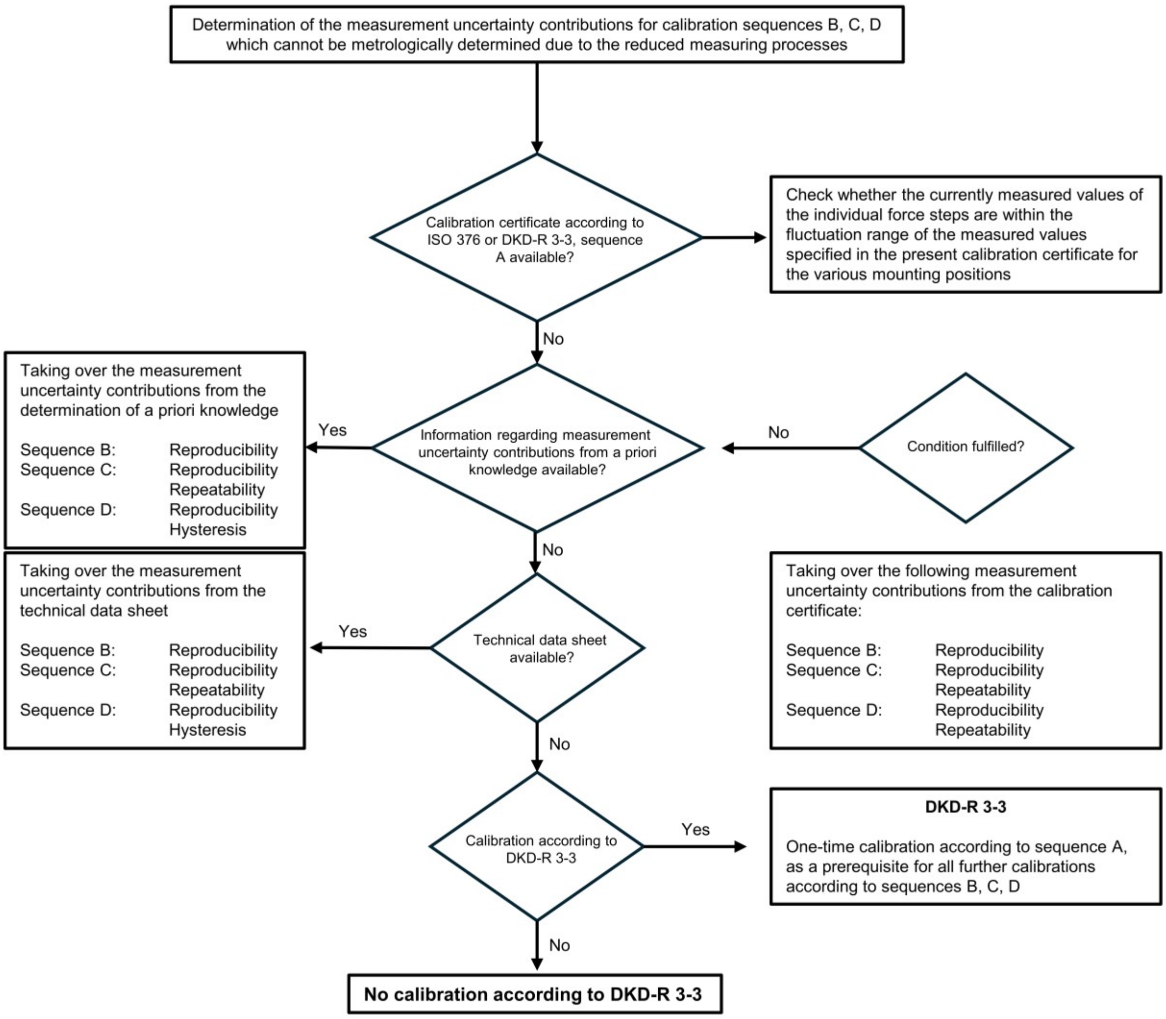
[5] ILAC-G8:09/2019, Guidelines on Decision Rules and Statements of Conformity, ILAC, September 2019.
ILAC-G8:09/2019, Leitlinien zu Entscheidungsregeln und Konformitätsaussagen (German translation as of 19.02.2021), DAkkS

[6] DIN EN ISO/EC 17025:2018-03 Allgemeine Anforderung an die-Kompetenz von Prüf- und Kalibrierlaboratorien; Beuth-Verlag Berlin, März 2018
(General requirements for the competence of testing and calibration laboratories)

[7] L. Stenner: Messunsicherheit bei vereinfachten Kalibrierabläufen der Messgrößen Kraft und Drehmoment unter Anwendung statistischer Verfahren; VDI-Berichte 2365 Messunsicherheit 2019, VDI-Verlag Düsseldorf, Seite 207 - 216.
DOI: https://doi.org/10.51202/9783181023655-207
(Measurement uncertainty for simplified calibration procedures of the measurands force and torque using statistical methods; VDI report)

Appendix A: Flow chart for determining the measurement uncertainty

Flow chart for determining the measurement uncertainties for reduced calibration sequences



Appendix B: Measurement uncertainty contributions (estimated values and characteristic quantities)

<table>
<tr><th rowspan="2">Sequence</th><th rowspan="2">Evaluation</th><th rowspan="2">Best estimate</th><th colspan="10">Characteristics for determining the measurement uncertainty contributions [11]</th></tr>
<tr><th colspan="2">Relative zero error[12]</th><th colspan="2">Relative repeatability</th><th colspan="2">Relative reproducibility[13]</th><th colspan="2">Relative hysteresis[14]</th><th colspan="2">Relative regression deviation[15]</th></tr>
<tr><td rowspan="3">A</td><td>Standard (as in DIN EN ISO 376)</td><td>$\overline{X_{wr}} = \frac{X_1 + X_2}{2}$
$\overline{X_r} = \frac{X_1 + X_3 + X_5}{3}$</td><td>$f_0 = \frac{i_f - i_0}{X_N}$</td><td>☺</td><td>$b' = \left|\frac{X_2 - X_1}{\overline{X_{wr}}}\right|$</td><td>☺</td><td>$b = \left|\frac{X_{max} - X_{min}}{\overline{X_r}}\right|$</td><td>☺</td><td rowspan="3">$v_1 = \left|\frac{X'_4 - X_3}{X_3}\right|$
$v_2 = \left|\frac{X'_6 - X_5}{X_5}\right|$
$v = \frac{v_1 + v_2}{2}$</td><td rowspan="3">☺</td><td>$f_c = \frac{\overline{X_r} - X_a}{X_a}$</td><td>☺
☺</td></tr>
<tr><td>Increasing or decreasing load</td><td>$\overline{X_{wr}} = \frac{X_1 + X_2}{2}$
$\overline{X_r} = \frac{X_1 + X_3 + X_5}{3}$
$\overline{X'_r} = \frac{X'_4 + X'_6}{2}$</td><td>$f_0 = \frac{i_f - i_0}{X_N}$</td><td>☺</td><td>$b' = \left|\frac{X_2 - X_1}{\overline{X_{wr}}}\right|$</td><td>☺</td><td>$b = \left|\frac{X_{max} - X_{min}}{\overline{X_r}}\right|$</td><td>☺</td><td>$f_c = \frac{\overline{X_r} - X_a}{X_a}$
$f'_c = \frac{\overline{X'_r} - X_a}{X_a}$</td><td>☺</td></tr>
<tr><td>Mean value</td><td>$\overline{X^*_r} = \frac{\overline{X_r} + \overline{X'_r}}{2}$</td><td>$f_0 = \frac{i_f - i_0}{X_N}$</td><td>☺</td><td>$b' = \left|\frac{X_2 - X_1}{\overline{X_{wr}}}\right|$</td><td>☺</td><td></td><td>☺</td><td>$f_c = \frac{\overline{X^*_r} - X_a}{X_a}$</td><td>☺</td></tr>
</table>

[11] ☺ means that the characteristic quantities can be determined from the measured values, ☹ means that the values are derived from a priori knowledge.
[12] The respective maximum zero-point deviation is used in the uncertainty budget.
[13] The measurement uncertainty contribution for the reproducibility is determined via the standard deviation from the 3 values of the increasing series.
[14] To take into account the hysteresis when calculating the measurement uncertainty, see chapter 7.1.3. In a standard evaluation, the full hysteresis is to be taken into account in the measurement uncertainty budget. If only increasing (only decreasing) forces are to be measured with the transducer in later use, 1/3 of the hysteresis is to be taken into account as half-width; when carrying out the evaluation using the mean values, half the hysteresis is taken into account as half-width.
[15] If a 3rd degree polynomial is used in the evaluation, the regression deviation is regarded as a random deviation and taken into account as a measurement uncertainty component. If a 1st degree polynomial is used in the evaluation, the regression deviation is regarded as a systematic deviation and, if it is not corrected, can be included in a specification limit determined as part of the calibration.

Sequence	Evaluation	Best estimate	Characteristics for determining the measurement uncertainty contributions									
			Relative zero error		Relative repeatability		Relative reproducibility		Relative hysteresis [16]		Relative regression deviation	
B	Increasing or decreasing load	$\overline{X_{wr}} = \frac{X_1 + X_3}{2}$ $\overline{X'_{wr}} = \frac{X'_2 + X'_4}{2}$	$f_0 = \frac{i_f - i_0}{X_N}$	☺	$b' = \left\lvert\frac{X_3 - X_1}{\overline{X_{wr}}}\right\rvert$ $b'_{ab} = \left\lvert\frac{X'_4 - X'_2}{\overline{X'_{wr}}}\right\rvert$	☺	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹	$v_1 = \left\lvert\frac{X'_2 - X_1}{X_2}\right\rvert$ $v_2 = \left\lvert\frac{X'_4 - X_3}{X_3}\right\rvert$ $v = \frac{v_1 + v_2}{2}$	☺	$f_c = \frac{\overline{X_{wr}} - X_a}{X_a}$ $f'_c = \frac{\overline{X'_{wr}} - X_a}{X_a}$	☺
	Mean value	$\overline{X^*_{wr}} = \frac{\overline{X_{wr}} + \overline{X'_{wr}}}{2}$	$f_0 = \frac{i_f - i_0}{X_N}$	☺	$b'^* = \frac{b' + b'_{ab}}{2}$	☺	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹			$f_c = \frac{\overline{X^*_{wr}} - X_a}{X_a}$	☺

[16] To take into account the hysteresis margin when calculating the measurement uncertainty, see chapter 7.1.3.

Sequence	**Evalua-tion**	**Best estimate**	**Characteristics for determining the measurement uncertainty contributions**									
			Relative zero error		Relative repeatability		Relative reproducibility		Relative hysteresis [17]		Relative regression deviation	
C	**Increasing or decreasing load**	$X_1; X_2'$	$f_0 = \frac{i_f - i_0}{X_N}$	☺	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹	$v = \left\| \frac{X_2' - X_1}{X_1} \right\|$	☺	$f_c = \frac{X_1 - X_a}{X_a}$ $f_c' = \frac{X_2' - X_a}{X_a}$	☺
	Mean value	$\overline{X_{wr}^*} = \frac{X_1 + X_2'}{2}$	$f_0 = \frac{i_f - i_0}{X_N}$	☺	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹			$f_c = \frac{\overline{X_{wr}^*} - X_a}{X_a}$	☺
D	**Increasing load**	$\overline{X_{wr}^*} = \frac{X_1 + X_2}{2}$	$f_0 = \frac{i_f - i_0}{X_N}$	☺	$b' = \left\| \frac{X_2 - X_1}{\overline{X_{wr}^*}} \right\|$	☺	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹	Factor Case I:2…4,3 Case II: 2 Case III: 2 Case IV: 3 Case V: 5	☹	$f_c = \frac{\overline{X_{wr}^*} - X_a}{X_a}$	☺

[17] To take into account the hysteresis margin when calculating the measurement uncertainty, see chapter 7.1.3.
For sequence D, it is assumed that the force measuring device is only used with increasing load; therefore, 1/3 of the hysteresis is taken into account as half-width in the uncertainty budget.

Appendix C: Procedure for determining a priori knowledge

This appendix shows a possible procedure for implementing the method described in [7]. The result is a value that is scaled to the calibration steps. This example is only a simple realisation of the procedure described in [7]; more efficient solutions are possible if a database is used.

This procedure is a systematic method which can be used to determine a representative value for a measurement uncertainty contribution for a certain type of transducer. Since this determination is carried out on a sample of transducers of the same type, it is possible to draw conclusions about the behaviour of all the transducers of the same type when taking into account the Student factor (*t* factor). When selecting the sample, care should be taken to ensure that the specimens come from different batches. As a general rule, the transducers should exhibit similar behaviour (free of outliers).

To determine a correct and significant measurement uncertainty, the following criteria must also be taken into account when selecting the data for the type test:

- type designation by the manufacturer may contain different designs of the measuring element for different nominal forces; these must be considered separately.
- calibration on identical force calibration machine
- matching of the load direction (evaluate tension and compression calibrations separately)
- identical load steps: ideally, each calibration step is analysed separately (for the best possible measurement uncertainty)
- Separate evaluation of partial range calibrations
- sufficient resolution

The term “a priori” makes it clear that this measurement uncertainty contribution is not obtained from the measured values of the current calibration but comes from “prior knowledge”.

Procedure 1:

Table 11 shows an example for calculating a representative measurement uncertainty contribution for the reproducibility of a certain type of transducer. Input data are the measurement uncertainty contributions for the reproducibility determined in calibrations according to DKD-R 3-3, sequence A or DIN EN ISO 376 [1]. These have to be calculated according to equation C8 of DIN EN ISO 376 [1].

$$w_{\mathrm{rot}} = \frac{1}{|\bar{X}_r|} \cdot \frac{\sqrt{\frac{1}{2} \cdot \sum_{i=1,3,5} (X_i - \bar{X}_r)}}{\sqrt{3}} \; ; \quad i\text{: running index of the measurement series} \qquad \textbf{(17)}$$

The MU contribution (a priori) to be used in the reduced sequences results from the maximum of the MU contributions across all force levels, multiplied by the *t* factor of the Student distribution valid for the number of measured specimens according to equation (18).

$$w_{\mathrm{rot}} = \max(w_{\mathrm{rot},i,j}) \cdot t \qquad \textbf{(18)}$$

with i : running index for different specimen
and j : running index for the different force steps

Designation: Force transducer
Manufacturer: Company *xyz*
Type: Type *xyz*
Measurement direction: tensile force

Table 11: Calculation of the measurement uncertainty contribution for the reproducibility

Force F kN	**Relative standard uncertainty (reproducibility)** X_1, X_3, X_5 0°, 120°, 240° w_{rot} Serial number 10356	10357	10358	10359	10365	02054	**Max** of the measured value	***t* factor for:** $n = 6$ $f = 5$ 2-sided 95 %	**Upper limit** (in relation to measured value) of the measured value
0	-	-	-	-	-	-	0,860 %	2,571	2,211 %
5	0,16%	0,79%	0,65%	0,73%	0,21%	0,22%			
10	0,14%	0,86%	0,54%	0,66%	0,18%	0,20%			
20	0,05%	0,51%	0,34%	0,53%	0,13%	0,17%			
30	0,02%	0,29%	0,20%	0,39%	0,10%	0,15%			
40	0,03%	0,20%	0,13%	0,60%	0,08%	0,14%			
50	0,05%	0,23%	0,11%	0,31%	0,07%	0,14%			

Uncertainty contribution	Relative standard uncertainty w_{rot} (a priori)	**2,21**	%	(of the measured value)

The numerical values listed in the table are randomly chosen and are only intended to illustrate how the system works.

Table 12: *t* factor

Number degrees of freedom f	P for two-sided confidence range 0,95 P for one-sided confidence range 0,975
5	2,571
6	2,447
7	2,365
8	2,306
9	2,262
10	2,228

When determining the a priori knowledge, it is deliberately **not** the mean value that is multiplied by the *t* factor but the maximum! This procedure creates an increased safety margin and is due to the small number of samples and the limited knowledge of the behaviour of the individual specimens.

The thus determined measurement uncertainty contribution can be used for the entire calibration range. In a measured value-related diagram, this measurement uncertainty contribution then appears as a constant line.

Procedure 2:

Alternatively, a measurement uncertainty contribution with reference to the final value can be calculated from the measured value-related data. To do this, it is useful to first convert the relative, measured value-related input values into values in units of the standard. The measurement uncertainty contribution (a priori) results from the maximum of the measurement uncertainty contributions across all force levels, multiplied by the *t* factor of the Student distribution valid for the number of measured specimens. The example in Table 13 shows this procedure. Table 14 shows the calculation of the measurement uncertainty contribution with final value reference from a table with measured value-related input data.

Again, this procedure only determines one value, which is representative of a specific type of transducer. The different values of the "upper limit" result from the scaling to the respective force step. Figure 17 shows the resulting limits.

Table 13: Calculation of the measurement uncertainty contribution for the reproducibility (final value-related)

Force F kN	**Relative standard uncertainty (reproducibility)** X_1, X_3, X_5 0°, 120°, 240° u_{rot} kN Serial number 10356	10357	10358	10359	10365	02054	**Max** kN	***t* factor for:** $n = 6$ $f = 5$ 2-sided 95 %	**Upper limit** of the final value	**Upper limit** (in relation to final value) of the measured value
0	-	-	-	-	-	-	0,240	2,571	0,617 kN corresponds to 1,234% of the final value	-
5	0,0081	0,0395	0,0325	0,0365	0,0103	0,0110				12,34%
10	0,0135	0,0860	0,0540	0,0660	0,0176	0,0197				6,17%
20	0,0106	0,1012	0,0680	0,1065	0,0258	0,0343				3,09%
30	0,0057	0,0883	0,0600	0,1174	0,0298	0,0459				2,06%
40	0,0138	0,0806	0,0520	0,2400	0,0316	0,0567				1,54%
50	0,0246	0,1131	0,0550	0,1554	0,0340	0,0687				1,23%

MU contribution	Standard uncertainty u_{rot} (a priori)	**0,62**	kN	
MU contribution	Relative standard uncertainty w_{rot} (a priori)	**1,23**	%	(of the final value)

Table 14: Calculation of the measurement uncertainty contribution for the reproducibility (final value-related) from measured value-related input data

	A	B	C…G	H	I	J	K	L
	Force F kN	**Rel. Standard.** X_1, X_3, X_5 0°, 120°, 240° w_{rot}		**Max** (of the step)	**Max** (of the step)	**Max**	***t* factor for:** $n = 6$ $f = 5$	**Upper limit** (in relation to final value)
		Serial number						
		10356	…	of the measured value	of the measured value	of the measured value	2-sided 95 %	of the measured value
1	0	-	-	-	-			-
2	5	0,16%	…	=Max(B2:G2)	=H2*(A2/A7)			=J1*K1*(A7/A2)
3	10	0,14%	…	=Max(B3:G3)	=H3*(A3/A7)			=J1*K1*(A7/A3)
4	20	0,05%	…	0,53%	0,213%	=Max(I2:I7)	2,571	3,1%
5	30	0,02%	…	0,39%	0,235%	=0,480%		2,1%
6	40	0,03%	…	0,60%	0,480%			1,5%
7	50	0,05%	…	0,31%	0,311%			1,2%

MU contribution	Relative standard uncertainty w_{rot} (a priori)	=J1*K1	%	(of the final value)
MU contribution	Standard uncertainty u_{rot} (a priori)	=J1*K1*A7	kN	

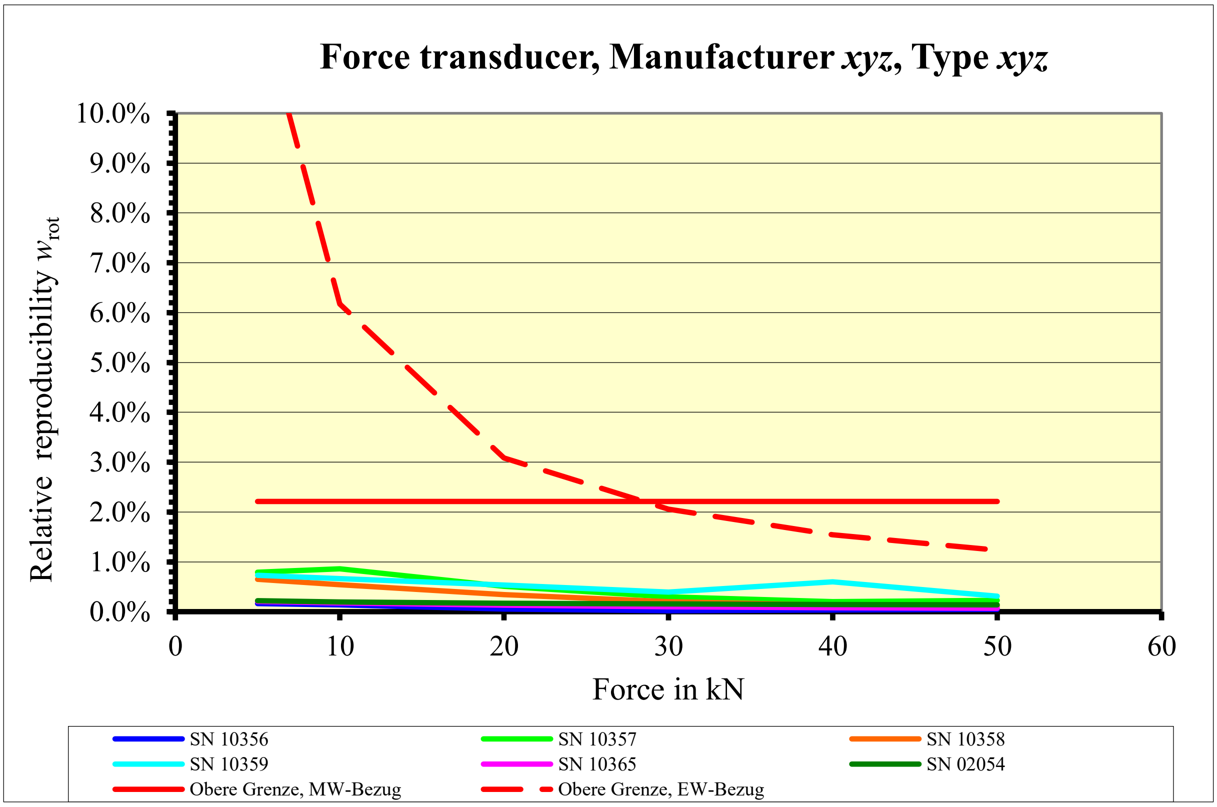


Figure 17: Visualisation of the measurement uncertainty contribution of the reproducibility

Obere Grenze, MW-Bezug	Upper limit, in relation to measured value
Obere Grenze, EW-Bezug	Upper Limit, in relation to final value

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