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Expert Report DKD-E 7-1

Application of the substitution procedure for the calibration of non-automatic weighing instruments

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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 expert reports aim to provide background information and references in connection with other DKD documents as, for example, the DKD guidelines. In some cases, they may even go far beyond these documents. They do not replace the original DKD documents but do provide a lot of supplementary information worth knowing. The expert reports do not necessarily reflect the views of the DKD's Management Board or Technical Committees in all details.

The DKD expert reports are intended to present significant aspects from the field of calibration and to be made accessible to the large community of national and international calibration laboratories through publication within the framework of the DKD.

The present DKD expert report has been approved by the Board of the DKD.

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1 Preamble

The expert report is based on the calibration guideline DKD-R 7-2, Edition 01/2018 [translation of the EURAMET Calibration Guide No.18 Version 4.0 (11/2015)]. The guideline DKD-R 7-2, Edition 01/2018 will hereafter be referred to as DKD-R 7-2.

The expert report contains additional requirements regarding the practical implementation of the substitution procedure, thus supporting the high competence required of an accredited calibration laboratory.

The substitution procedure is described in chapter 4.3.3 of DKD-R 7-2. By using the substitution procedure, the measurement uncertainty contribution of the load used increases with each substitution step and thus the measurement uncertainty of the weighing instrument to be stated in the calibration certificate.

The substitution procedure is used to determine the indication error during calibration. The determination of repeatability and deviation due to eccentric loading is not subject of this expert report.

In case reference is made to the expert report in the calibration certificate, any deviations from this expert report, for example to the design of the weighing instrument, must be indicated there.

The range of services offered by the laboratory should indicate the substitution procedure as a separate procedure in accordance with DIN EN ISO/IEC 17025:2018, par. 5.3.

2 Terminology

All terms basically refer to DKD-R 7-2. Symbols and abbreviations used are shown in DKD-R 7-2, Appendix D.

3 Requirements regarding the application of the substitution procedure

In addition to the basic principles described in DKD-R 7-2, chapter 4.3.3, the following requirements apply.

3.1 Requirements concerning the weighing instruments to be calibrated

3.1.1 Number of scale intervals n

The substitution procedure shall only be used for weighing instruments with a maximum of 10 000 scale intervals (n = Max / $d \leq 10\,000$, scale interval d of the weighing instrument in use).
For multiple range and multi-interval instruments which are calibrated continuously, the number of scale intervals n refers to the scale interval at maximum load of the instrument.

This limitation ensures that the determined measurement uncertainty of the calibration is not dominated by the measurement uncertainty contribution of the applied load.

3.1.2 Weighing range of the weighing instrument

The substitution procedure shall only be used if the weighing range is ≥ 4000 kg.

For multiple range and multi-interval instruments which are calibrated continuously, the weighing range refers to the maximum load.

For multiple range instruments for which each range is calibrated separately, the requirements of the expert report shall be applied separately for each range.

The calibration range as part of the weighing range (see DKD-R 7-2, chapter 4.1.1) may also be specified by the customer as < 4000 kg.

By this specification it is ensured that – when using the substitution procedure – the smallest possible scale interval is d = 500 g and thus the determined measurement uncertainty of the calibration is not dominated by the measurement uncertainty of the applied load.

3.2 Requirements regarding the reference load

In total, the reference load shall consist of metrologically traceable weights ≥ 1000 kg. Depending on the number n of scale intervals, it is recommended to use the following accuracy classes according to OIML R111-1:2004:

$n \leq 3000$: Class M_2 or better
$n > 3000$: Class M_1 or better

3.3 Requirements regarding the substitution load

In addition to the points mentioned in DKD-R 7-2, chapter 4.3.2, the following requirements must be observed:

The value of mass of the substitution load must not change during calibration, e.g. due to:
- evaporation of liquid substitution loads
- non-stationary substitution loads

Magnetic properties of the substitution loads, electrostatic effects as well as effects of the ambient conditions (such as wind, rain) must not influence the indication of the weighing instrument.

3.4 Number of substitution load steps

The number of substitution load steps shall be ≤ 3.
Example:
Reference load + Substitution load 1 + Substitution load 2 + Substitution load 3 = Max

Limiting the number of substitution load steps ensures that the measurement uncertainty of the weighing instrument stated in the calibration certificate usually does not turn out to be more than twice the uncertainty when using continuous reference loads.

4 Influencing factors

The influence of the air buoyancy when using substitution loads is negligible – always provided that the requirements according to chapter 3 are adhered to.

There are no special requirements regarding the material density of the substitution load – always provided that the requirements according to chapter 3 are adhered to.

5 Methods

5.1 Measurement procedure

The substitution procedure is carried out according to DKD-R 7-2, chapter 4.3.3.

Notes:
- When using multiple range and multi-interval weighing instruments, loads at the limits of the range or sub-range should be avoided.
- Automatic zero tracking must not be active during the entire measurement process (switched off or loaded with minimum load).
- In addition, the indication at zero or with minimum load is documented at the end of the measurement.
- The minimum load is a load that is only marginally greater than the effective range of the zero tracking of the weighing instrument.
- If a minimum load is used to switch off the automatic zero tracking, it must be identical at the beginning and end of the measurement and remain on the weighing instrument when completely unloaded to prevent zeroing.

5.2 Load application

The centre of gravity of the applied loads should be centric. If this is not possible, the centre of gravity of the substitution load should be in the same position as the centre of gravity of the reference load when being adjusted.

5.3 Adjustment of the substitution load

Adjustment of the substitution load should be carried out with a maximum difference of ± 10 scale intervals d to the indicated value of the previous load. As a result, the influence of the non-linearity of the weighing instrument's characteristic curve on the substitution procedure can be neglected in practice.

In case of multiple range and multi-scale weighing instruments, the scale interval of the respective range is used.

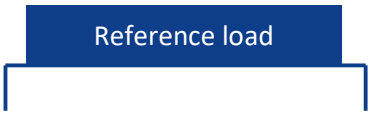
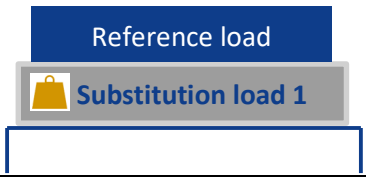
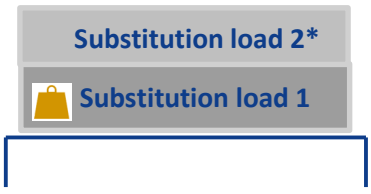
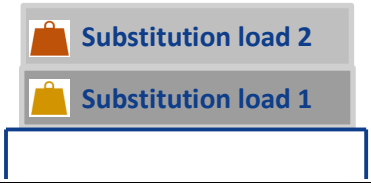
It is possible to replace only parts of the applied reference load with a substitution load.
Example:
Weighing instrument with weighing range 4 t
Reference load: 3 · 1 t
Substitution load: 1 t

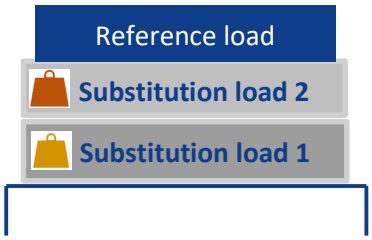
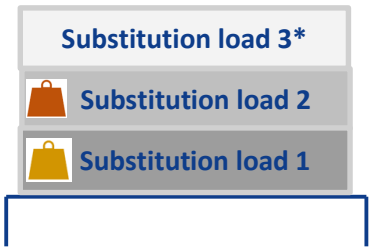
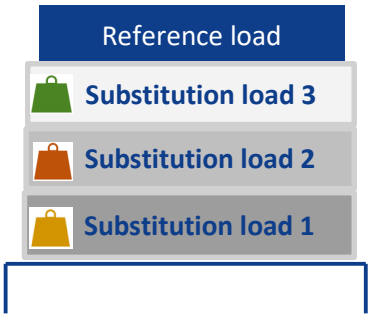
5.4 Hysteresis and creep

Appropriate consideration of hysteresis and creep should form part of the calibration.

5.5 Example of the measurement procedure

For simplification, the substitution loads in the example have been exactly adjusted to the reference loads.

	Activity	Indication	Indication error
	No-load or minimum load (0 kg)	0 kg	0 kg
	Applying reference load (1000 kg)	1005 kg	5 kg
	Removal of reference load		
	Applying substitution load 1*	998 kg	5 kg
	**Adjustment:** substitution load 1 (993 kg + **7 kg**)	1005 kg	5 kg
	Applying substitution load 1 + reference load (2000 kg)	2008 kg	8 kg
	Removal of reference load		
	Applying substitution load 1 + substitution load 2*	2003 kg	8 kg
	**Adjustment:** substitution load 1 + substitution load 2 (1000 kg + 995 kg + **5 kg**)	2008 kg	8 kg

	Activity	Indication	Indication error
	Applying substitution load 1 + substitution load 2 + reference load (3000 kg)	3014 kg	14 kg
	Removal of the reference load		
	Applying substitution load 1 + substitution load 2 + substitution load 3*	3005 kg	14 kg
	**Adjusting** substitution load 1 + substitution load 2 + substitution load 3 (1000 kg + 1000 kg + 991 kg + **9 kg**)	3014 kg	14 kg
	Applying substitution load 1 + substitution load 2 + substitution load 3 + reference load (4000 kg)	4019 kg	19 kg

	Activity	Indication	Indication error
	Unloading of the Weighing instrument		
	No-load or minimum load (0 kg)	4 kg	4 kg

6 Measurement uncertainty

6.1 General

During calibration, the measurement uncertainty is determined according to DKD-R 7-2, chapter 7.1.2.6.

The substitution procedure significantly increases the measurement uncertainty during calibration.

According to DKD-R 7-2, chapters 7.4 and 7.5, the substitution procedure does not influence the calculation method of the measurement uncertainty during use; nevertheless, the uncertainty during use does increase due to the fact that the measurement uncertainty during calibration has increased.

6.2 Representation of the measurement uncertainty in the calibration of a weighing instrument with typical capacity

Figure 1, for example, shows the comparison of the expanded measurement uncertainty during calibration when applying the substitution procedure with three substitution load steps and when using reference loads over the entire measurement range.
The coverage factor k is determined according to DKD-R 7-2 in such a way that the expanded measurement uncertainty corresponds to a coverage probability of 95.45 % according to EA 4-02 M:2013.

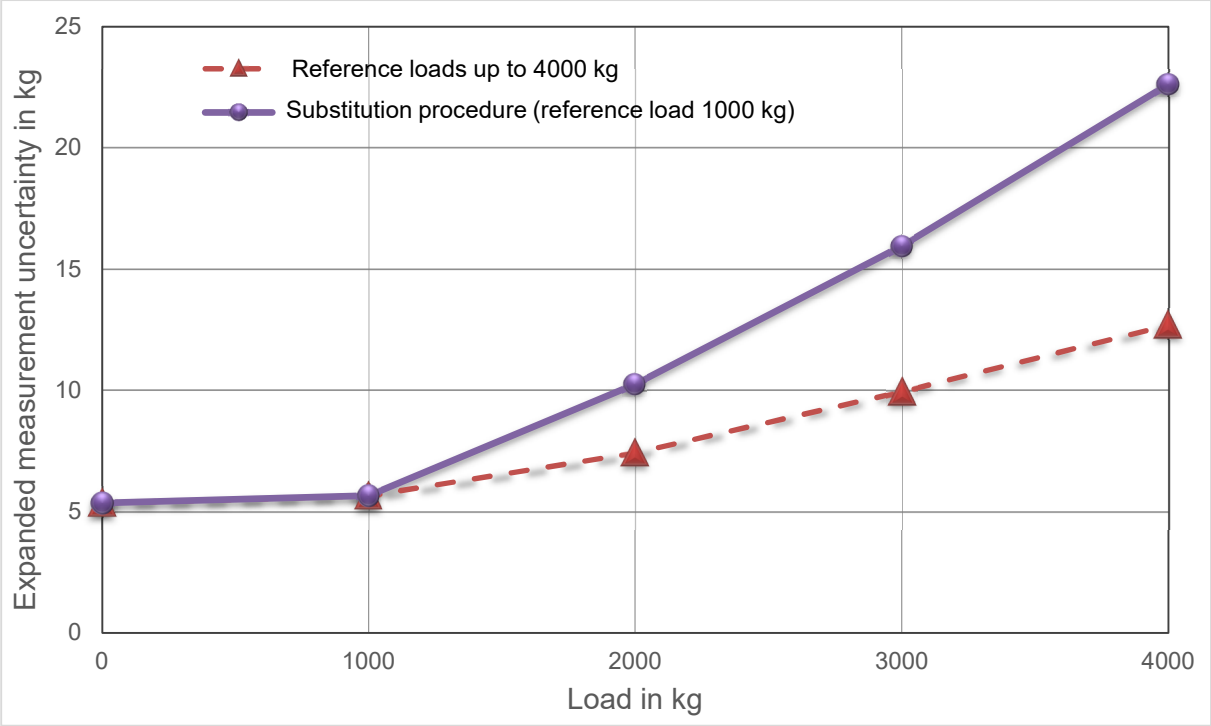


Figure 1: Example illustrating the measurement uncertainty in calibration with and without substitution procedure

7 Result presentation

The use of the substitution procedure shall be indicated in the calibration certificate. The following additional information shall also be included:

- Information about the calibration procedure (for example, calibration guideline EURAMET cg-18 and expert report DKD-E 7-1)
- Indication of the maximum reference load used
- Indication of the number of substitution load steps
- Type of substitution load (for example, water, grain, oil, sand, parts made of steel, liquid, …)

8 Summary

In many cases there are not enough reference weights available for calibrations of non-automatic electronic weighing instruments. Moreover, placing the reference weights on the weighing instrument may prove to be difficult if the load receptor lacks sufficient space. Therefore, the substitution procedure is an appropriate option for calibrating high-capacity scales.

The expert report contains additional requirements regarding the practical implementation of the substitution procedure, thus supporting the high competence required of an accredited calibration laboratory.

The process of the substitution procedure is clearly illustrated by means of a specific example.

The expert report helps to standardise the substitution procedure in the calibration of non-automatic weighing instruments.

It should be noted that the measurement uncertainty during calibration and during use is significantly increased by the substitution procedure.

The requirements regarding the use of the substitution procedure aim to ensure the practicality and comparability of the calculation of the uncertainty of measurement during calibration and when using the weighing instrument.

9 Bibliography

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(General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025:2017); German and English version EN ISO/IEC 17025:2017, DIN, March 2018)

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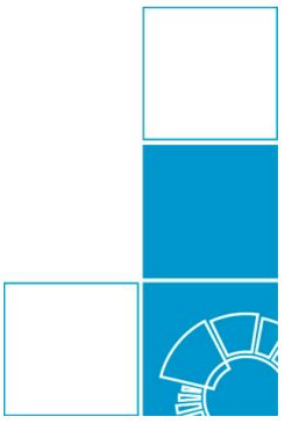
[4] EA-4/02 M: 2013 Ermittlung der Messunsicherheit bei Kalibrierungen (Deutsche Übersetzung), DAkkS, Übersetzung vom 01.08.2019
(Determination of the measurement uncertainty in calibration (German translation), DAkkS, translation as of 01.08.2019)

[5] 71 SD 0 025 Revision 1.1: Darstellung von Kalibrierergebnissen und die Verwendung der DAkkS-Kalibriermarke, DAkkS, September 2019
(Representation of calibration results and the use of the DAkkS calibration mark)



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