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Guideline DKD-R 10-5

Static calibration of torque measuring devices with alternating torque

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Deutscher Kalibrierdienst (DKD) – German Calibration Service

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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.

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 monitoring of measuring and test equipment within the framework of quality assurance measures.

The present guideline has been drawn up by the DKD Technical Committee *Torque* and approved by the Board of the DKD. It is based on the guideline DKD-R 3-5 issued in 1998 and has been amended particularly with respect to following points to improve consistency with DIN 51309 which was newly published in 2005:

- the span b_w is referred to as reproducibility
- the span b'_w is referred to as repeatability
- the spans b_w and b'_w as well as the hysteresis h_w are now defined as absolute quantities and have the new designations b_at and b'_at and h_at ("at" – alternating torque)
- the interpolation deviation is now called regression deviation (although not consistent with DIN 51309:2005-12, but still useful)
- the uncertainty contribution of the span b_w (now reproducibility b_at) is now calculated using a rectangular distribution instead of a U-shaped distribution
- the result variable previously indicated by X is now assigned the symbol Y
- the term "characteristic value" for the experimentally determined parameters has been replaced by the term "characteristic quantity" (although not consistent with DIN 51309:2005-12, but still useful)
- the bibliography has been revised and adjusted.

In the current version (Revision 1), a sentence has been added on page 15 to explain Figure 5b.

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1 Scope of application

This guideline supplements DIN 51309 [1] by adding the calibration of torque measuring instruments with alternating torque.

2 Symbols and designations

See DIN 51309 [1] and Table 1.

Table 1: Additional symbols, units and designation

Symbol	Designation	Unit
	DU = Display unit of the output signal (e.g. N·m, mV/V, V, Hz)	
b_{at}	Reproducibility with alternating torque	DU
b'_{at}	Repeatability with alternating torque	DU
t	Mechanical remanence (see Annex A)	DU
Y_{at}	Calibration result with alternating torque	DU
Y'	Display value for a torque with decreasing load	DU
$\bar{Y}$	Average of the display values for a torque from increasing and decreasing series	DU
h_{at}	Hysteresis with alternating torque	DU

3 Calibration of the torque measuring devices

In the following, a distinction is made between a separate calibration for alternating torque (section 3.3) and an additional calibration with previous calibration with clockwise and anti-clockwise torque (section 3.4).

3.1 Preparation for calibration

See DIN 51309 [1].

3.2 Initial value of the measuring range

Taking into account the resolution r for reading the instrument's display, the minimum torque applied to a torque measuring device (initial value of the measuring range M_{A}) must comply with the following two conditions:

a) The initial value of the measuring range M_{A} must correspond to the values given in Table 3, DIN 51309.

b) The initial value of the measuring range M_{A} should be greater than or equal to $0{,}2\ M_{\mathrm{nom}}$.

3.3 Calibration scope and procedure for stand-alone calibrations with alternating torque

3.3.1 Preloading

After the torque transducer has been installed in the calibration device, it must be preloaded three times, once after each change of the mounting position up to the final value of the measuring range M_{E} to be calibrated using the following sequence $0 \rightarrow +M_{\mathrm{E}} \rightarrow 0 \rightarrow -M_{\mathrm{E}} \rightarrow 0$.

3.3.2 Mounting position

The torque transducer should preferably be calibrated in three different mounting positions, rotating the transducer by 120° around the measuring axis. However, four mounting positions (useful for square mounting) would be metrologically reasonable. With only two mounting positions (classes 1, 2 and 5), these must differ by 90° or 120°.

3.3.3 Performing the calibration

According to Table 2, the number of measurement series results from the required class of the torque measuring device; this means the required scope of calibration is determined by the class (see also Annex C).

Table 2: Number of required measurement series

Class	Number of measurement series	
	in unchanged mounting position	per different mounting position
0.2 and 0.5	2	1
1, 2 and 5	1	

The minimum number of torque levels – in addition to the step with zero torque – must be set for increasing and decreasing torque as follows:

- classes ≤ 0.5: 10 (e.g. in % of M_E: 20, 40, 60, 80, 100, –20, –40, –60, –80 and –100)
- classes > 0.5: 6 (e.g. in % of M_E: 20, 60, 100, –20, –60 and –100).

The initial value of the measuring range M_A must form part of the calibration values. A torque measuring device can be calibrated separately for several alternating torque measuring ranges.

3.4 Calibration scope and procedure after previous calibration for clockwise and anti-clockwise torque according to DIN 51309

The additional measurements are used for the experimental determination of the mechanical remanence. It is determined from three preloadings according to section 3.3.1. A further series of control measurements in the same mounting position is used for experimental verification of the calibration result for alternating torque **calculated** from the mechanical remanence. As regards the minimum number of torque steps, the series of control measurements shall meet the requirements specified in section 3.3.3.

4 Evaluation for calibrations according to 3.3

4.1 Calibration result Y_{at} and mechanical remanence t

The calibration result of a torque step is calculated according to equation (1) as mean value of the display values from the increasing and decreasing series of all mounting positions (without repeated series in the same mounting position), reduced by half the remanence value.

$$Y_{at} = \frac{1}{n}\sum_{j=1}^{n}\left(\bar{Y}_j\right) - \frac{t}{2} \qquad \text{with} \quad \bar{Y} = \frac{1}{2}(I + I') - I_0 \qquad (1)$$

$$t = \frac{2}{n}\sum_{j=1}^{n}\bar{Y}_{0,j} \qquad (2)$$

In this case, n is the number of measurement series for different mounting positions.

The repeated measurements for the determination of b'_{at} (class 0.2 and 0.5) carried out in mounting position "0°" are not used for calculating Y_{at} .

4.2 Reproducibility b_{at} and repeatability b'_{at}

The reproducibility b_{at} – as span in different mounting positions – and the repeatability b'_{at} – as span in the same mounting position – are calculated for each torque step i from the mean values of the ascending and descending measurements according to equations (3) and (4).

$$b_{\mathrm{at}} = \left|\overline{Y}_{\mathrm{max}} - \overline{Y}_{\mathrm{min}}\right| \tag{3}$$

$\overline{Y}_{\mathrm{max}}$ and $\overline{Y}_{\mathrm{min}}$ are the extreme values of the mean values from the ascending and descending series measured in different mounting positions.

$$b'_{\mathrm{at}} = \left|\overline{Y}_{\mathrm{max}} - \overline{Y}_{\mathrm{min}}\right| \tag{4}$$

Here, $\overline{Y}_{\mathrm{max}}$ and $\overline{Y}_{\mathrm{min}}$ are the extreme values measured in the same mounting position.

The second ascending series of the 0° position (class 0.2 to 0.5) is not included in the calculation of b_{at}.

In the case of classes 1 to 5, the value for b'_{at} equals the calculated value for b_{at}, (4) is not applicable in this case.

4.3 Zero point deviation f_0

The zero indication is recorded before and after each measurement series. The zero reading is to be carried out approximately 30 s after complete unloading. The zero deviation is calculated according to equation (5) for each mounting position.

$$f_0 = \max\left|I_{\mathrm{f}} - I_0\right| \tag{5}$$

4.4 Hysteresis in case of alternating torque h_{at}

The hysteresis h_{at} is determined according to equation (6) as mean value of the absolute values of the differences between the displays of the increasing and decreasing series for each torque step i:

$$h_{\mathrm{at}} = \frac{1}{n}\sum_{j=1}^{n}\left|I_j - I'_j\right| . \tag{6}$$

Here, n is the number of comparable measurement series with different mounting positions. In the zero point, this value corresponds to the value of mechanical remanence ($h_{\mathrm{at,0}} = t$).

4.5 Regression deviation f_{a}

The regression deviation (regression error) is determined for each torque step i by means of a first-degree equation without intercept for the display value as a function of torque. The equation used must be stated in the calibration certificate.

The mathematical determination of the regression equation must be performed in such a way that the sum of the squares of the absolute deviations in the calibrated measuring range yields a minimum.

The regression deviation is calculated from equation (7)

$$f_{\mathrm{a}} = Y_{\mathrm{at}} - Y_{\mathrm{a}} . \tag{7}$$

5 Evaluation for calibrations according to 3.4, calculation of the additional parameters

The value of the mechanical remanence t is determined from the zero readouts of the second and third preloading with alternating torque according to equation (8)

$$t = \frac{1}{2}\sum_{j=2}^{3}\left(I'_{0,j} - I_{0,j}\right) \tag{8}$$

I_0 Indication before the start of the alternating torque cycle (starting with clockwise torque) and

I'_0 indication at zero torque after relief from clockwise torque.

The calibration result Y_{at} of a torque step for alternating torque is calculated according to equation (9) from the mean value of the indicated values from the increasing and decreasing series of the rotated mounting positions during **calibration with clockwise and anti-clockwise torque** and the value of the mechanical remanence t according to equation (8).

$$Y_{\mathrm{at}} = \frac{t}{2}\cdot\frac{M_{\mathrm{K}}}{M_{\mathrm{E}}} + \frac{1}{n}\sum_{j=1}^{n}\left[\frac{1}{2}\left(I_j + I'_j\right) - I_{0,j}\right] \tag{9}$$

6 Classification

6.1 Classification in case of stand-alone calibrations for alternating torque

The classification for alternating torque is based on Table 3, DIN 51309. Instead of using the values b, b' and h determined for clockwise or anti-clockwise torque, the values for b_{at}, b'_{at} and h_{at} determined for alternating torque are used for classification.

6.2 Classification after previous calibration for clockwise and anti-clockwise torque according to DIN 51309

The classification for alternating torque is based on Table 3, DIN 51309. Instead of using the values determined for h with clockwise or anti-clockwise torque, the determined value of the mechanical remanence t is used for classification.

7 Documentation of the calibration results

The calibration laboratory issues a calibration certificate according to section 6.3, DIN 51309 [1] which contains the result of the calibration with alternating torque.

Bibliography

[1] DIN 51309: **Kalibrierung von Drehmomentmessgeräten für statische Drehmomente**, Ausgabe 2005-12 (English title: Materials testing machines - Calibration of static torque measuring devices. Edition: 2005-12)

Annex A Application of calibrated torque measuring devices for alternating torque

Summary:
Torque transducers intended for quasi-static applications with alternating torque load are also calibrated quasi-statically with alternating torque. Suggestions on how to efficiently derive the alternating torque calibration curve from the curves for simple clockwise or anti-clockwise torque calibration are discussed. The hysteresis in the zero point, called mechanical remanence, provides information about the measurement uncertainty when exposed to alternating torque and thus about the suitability of a transducer for this kind of application. Usually, investigations as to the position of the zero point (to which the measurement results refer) are not carried out when using such type of transducer. As a consequence, twice the value of the hysteresis determined during the alternating torque calibration is to be anticipated.
Keywords: torque calibration, alternating torque, mechanical remanence

A.1 Introduction

In simple clockwise or anti-clockwise torque calibrations, the transducer is calibrated separately for each direction. Here too, compensating curves - or calibration values in case of linear regression - are calculated. This value can be specified individually for clockwise or anti-clockwise torque, or jointly for both directions. Since the calculation must be performed with tared values in order to eliminate a transducer zero signal which is different from zero or the influence of the clamping of the transducer on this signal, the information regarding the zero signal is lost in the calibration value before or after loading with clockwise or anti-clockwise torque. The characteristic quantity "return to zero" describes the reproducibility of the zero signal for loads with torques in only one direction or creep influences. However, tests on various transducers have shown that the zero signal of a transducer - depending, among other things, on the materials of the transducer and the strain gauges as well as the application - can vary greatly when the transducer is subjected to an alternating torque cycle. In case of an alternating load, this results in large differences of the displayed signal with identical torque and strong deviations from the characteristics determined for one-sided calibration with regard to the hysteresis span or the return to zero.

A.2 Calibration with alternating torque

In the following it is assumed that the transducers under consideration exhibit only a very small creep, which means that its influence on the calibration result can be neglected. In a simple calibration - during preloading, as well as after the measuring series - the zero signal of the transducer will take on a value that will be maintained within the scope of the uncertainty of the reproducibility. This value can differ considerably for clockwise (I0+) or anti-clockwise torque (I0-). The difference t = I0+ - I0- between these two values is a typical characteristic of the transducer and referred to as mechanical remanence. However, the position of the zero signals on the measuring signal axis depends on the mounting conditions, the preloading, the temperature and other factors, i.e. both values can be greater or smaller by the same amount. The values of the measurement series of a clockwise torque calibration are tared with respect to I0+, those for an anti-clockwise torque calibration in relation to I0-. Since the regression deviations can be plotted in one and the same diagram (Figure 1a), it seems that both curves run through the same zero point. In fact, both branches of the curve must be imagined to be offset by the difference of the zero points (Figure 1b).
From this we directly get to the diagram for an alternating torque calibration: the end points of the curves with maximum clockwise or anti-clockwise torque are connected to the zero points of the opposite curves by means of curved lines (Figure 2a).

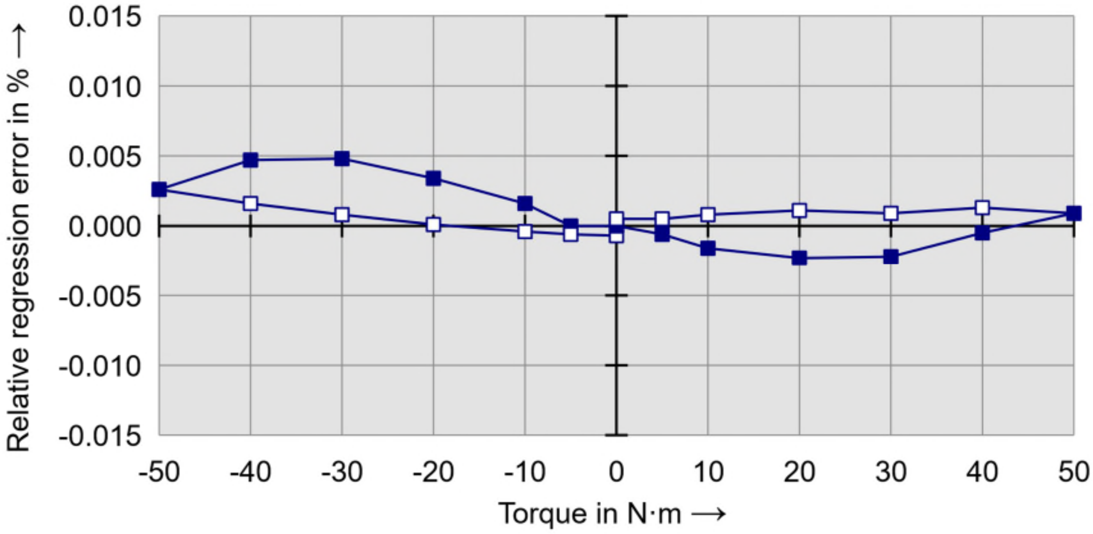

Figure 1a: Calibration curves for clockwise and anti-clockwise torque in relation to the respective zero points (full symbols: increasing torque value, empty symbols: decreasing torque value)

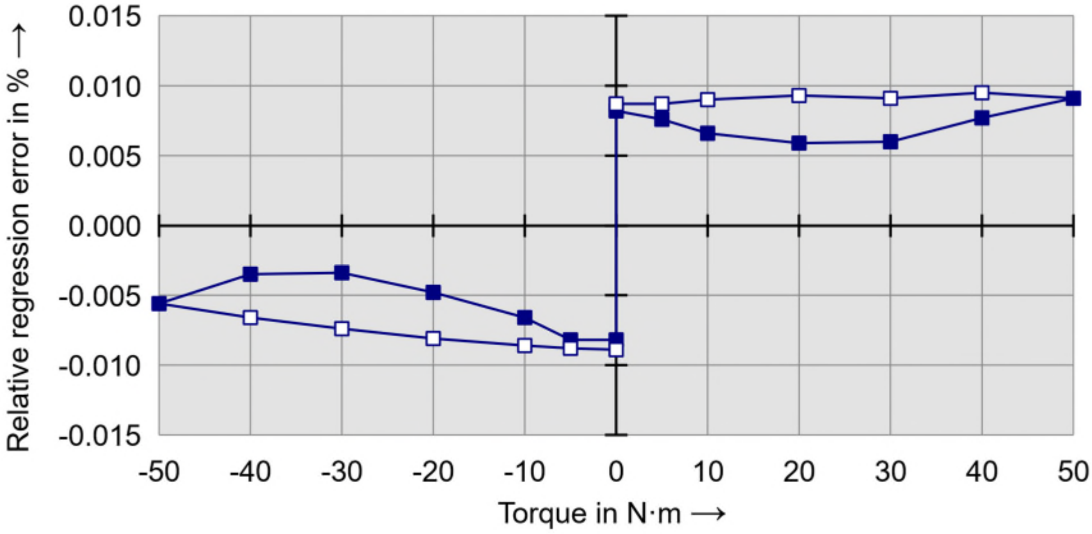

Figure 1b: Calibration curves for clockwise and anti-clockwise torque in relation to the mean value of the corresponding zero points

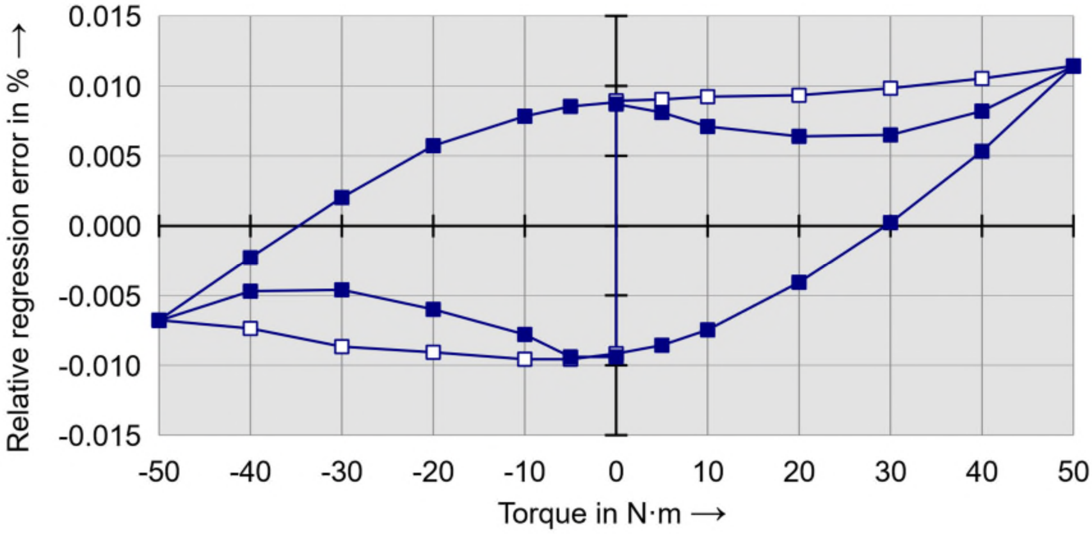

Figure 2a: Example of a torque transducer with a high value of mechanical remanence, compared to the value of the hysteresis for clockwise or anti-clockwise torque

Figure 2a shows the curve of a transducer with a high value of mechanical remanence, Figure 2b shows the example of a small value of mechanical remanence. As can be seen, in the first case the additional uncertainty components are several times higher – due to the alternating torque load – than the hysteresis which was determined by a purely clockwise or anti-clockwise torque calibration.

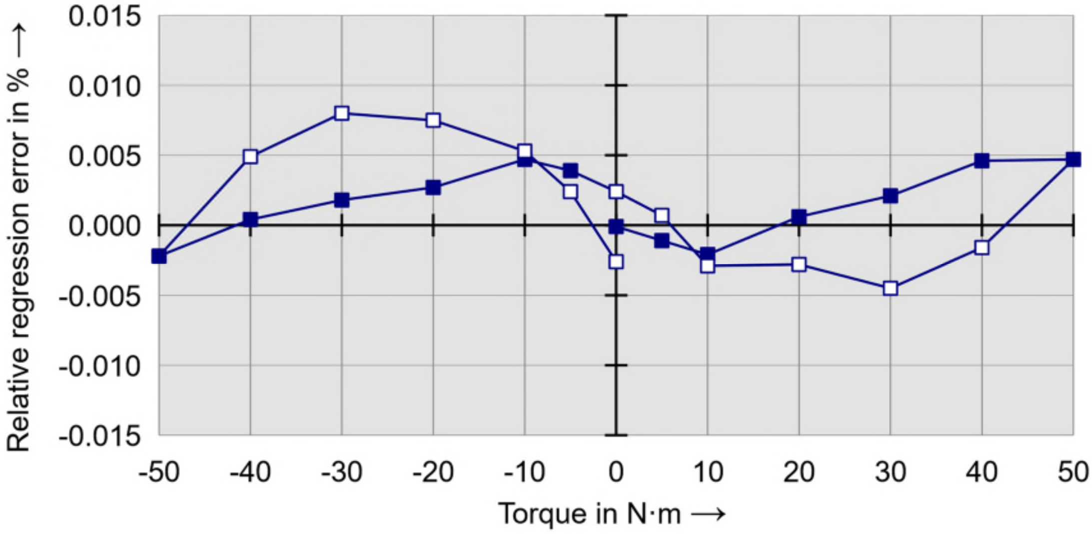

Figure 2b: Example of a torque transducer with a small value for the mechanical remanence, compared to the value of the hysteresis for clockwise or anti-clockwise torque - but with greater creeping

A.3 Recommendation on how to define a characteristic parameter for alternating torque

Investigations on several torque transducers have shown that in case of a transducer calibrated for clockwise and anti-clockwise torque a complete alternating torque calibration is not necessarily required. Within the scope of reproducibility, it is possible to calculate the alternating torque curve and the alternating torque parameters with acceptable accuracy from simple clockwise and anti-clockwise torque calibrations as well as from preloadings in the corresponding directions and from the determination of the zero signals I_{0+} and I_{0-} .

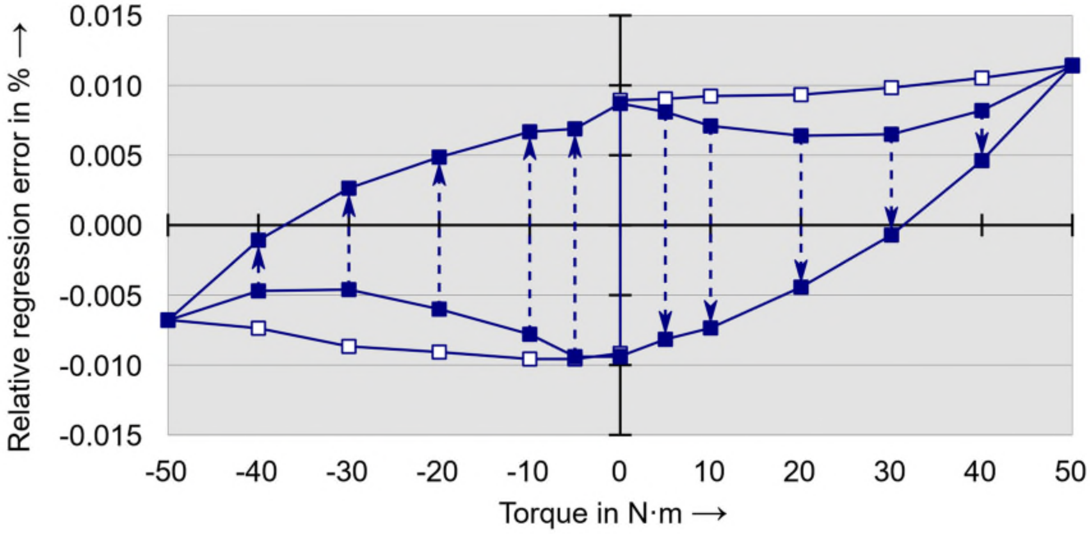

Figure 3: Calculation of the calibration result for alternating torque based on the results of the calibration for clockwise and anti-clockwise torque

The alternating torque curve results from the following curve branches: the partial curves for decreasing torque (from $+M_E$ to 0 N·m and from $-M_E$ to 0 N·m) correspond to the partial curves for clockwise torque (from $+M_E$ to 0 N·m) and anti-clockwise torque (from $-M_E$ to 0 N·m), with the curves being offset by the remanence value at the zero point. The connection between the zero point of the clockwise torque curve and the end point of the anti-clockwise torque curve is obtained by pointwise subtraction of $(1 - M / M_E)$ times the remanence value t from the corresponding curve branch for increasing torque (Figure 3, right). Similarly, for anti-clockwise torque, the connection between the zero point of the anti-clockwise torque curve and the end point of the clockwise torque curve is obtained by pointwise addition of $(1 - |M| / |M_E|)$ times the remanence value t to the corresponding curve branch for increasing torque (Figure 3, left). In case of a negative remanence value, the subtraction in the first case becomes an addition, in the second case the addition is turned into a subtraction.

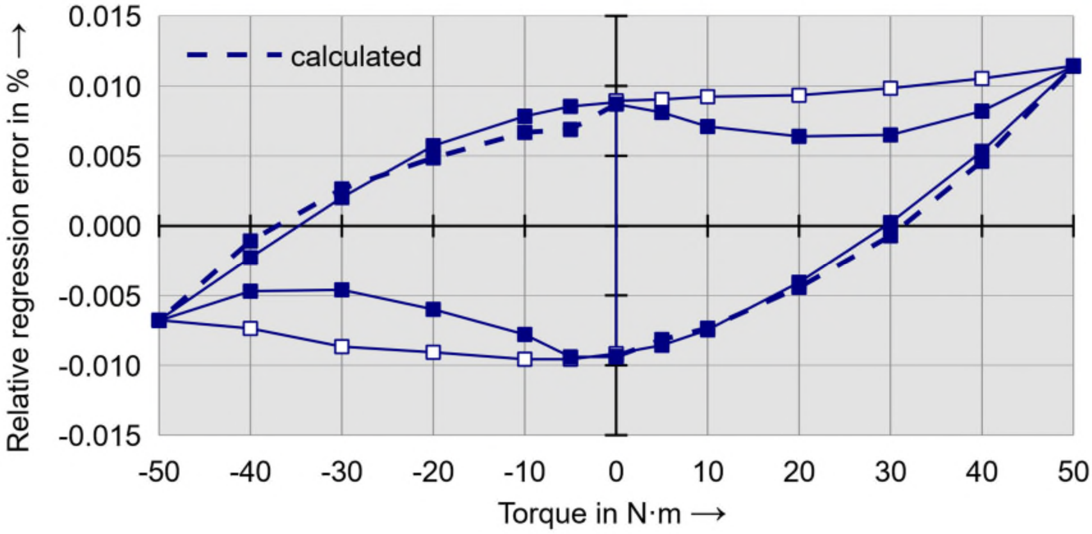

Figure 4a: Calibration curve with calculated curve branches (see text for explanations) - 1 loop

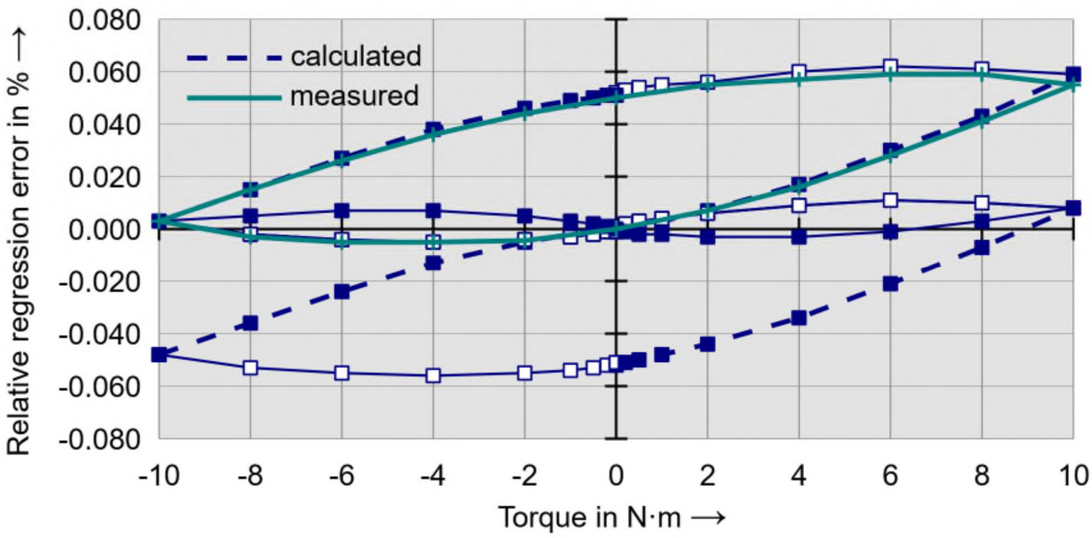

Figure 4b: Calibration curve with calculated curve branches (see text for explanations) - 2 loops adapted to the diagram in the calibration certificate

In most cases. the differences between the calculated and the measured alternating torque curve determined in experiments are less than $1 \cdot 10^{-4}$ (Figures 4a and 4b).

A.4 Application of torque measuring devices for alternating torque

If a torque transducer has been calibrated with alternating torque and the resulting measurement uncertainties have been determined, additional error influences may occur when using this transducer. With the transducer being installed, taring of the indication is generally triggered. As it is very rare that loads are applied beforehand to determine the position of the zero point within the range given by the remanence value, in other words, the history of the transducer is not known, it must be assumed that the zero point found could have been greater or smaller by the remanence value.

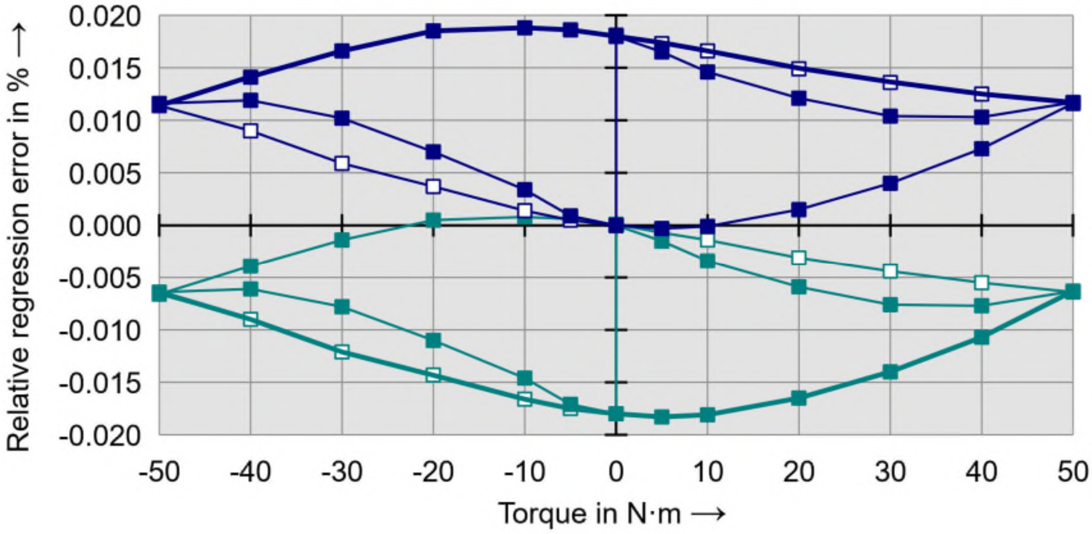

Figure 5a: Range of regression deviation (bold lines) for an alternating torque transducer with unknown history

The curve in Figure 2a could thus have the extreme positions shown in Figure 5a with respect to the arbitrarily found zero point. This implies that the regression deviations could even reach twice the value found in the alternating torque calibration! While in calibration the end value-related measurement uncertainties near the maximum torque values approach zero, the full remanence value needs to be employed for application. In terms of measured values, however, the deviations in case of small torque values play the dominant role. Knowing the previous history, we obtain the range for the possible regression deviations shown in Figure 5b.

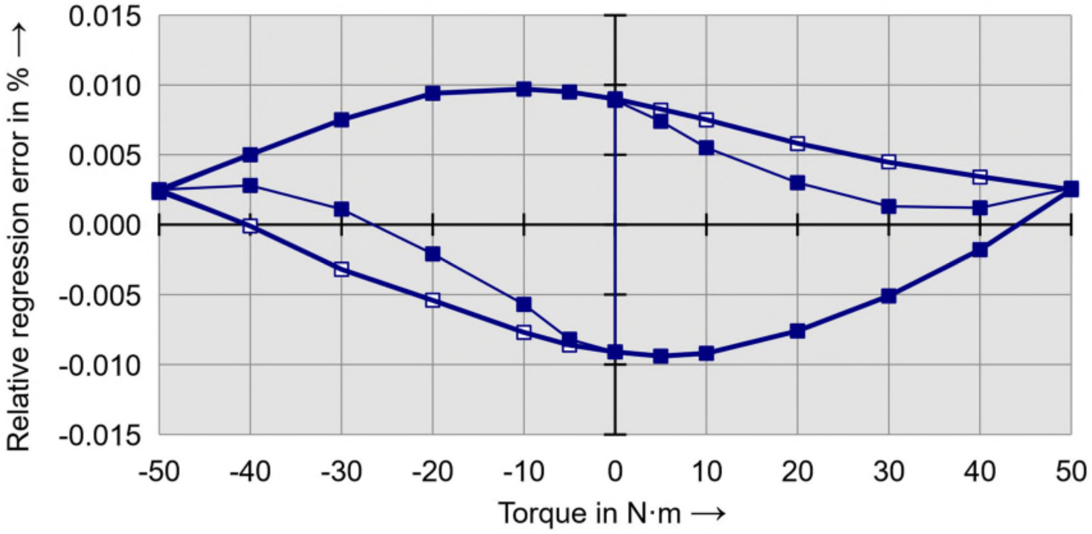

Figure 5b: Range of regression deviation (bold lines) for an alternating torque transducer with known history

Figure 6a shows the example of a large clockwise torque and, after return, small oscillations around zero or, respectively, the opposite case - small oscillations around zero after a large anti-clockwise torque and return to zero. The absolute deviations have the same magnitude as the remanence value and can reach values of several percent in terms of measured values.

Especially with the much more interesting measurements in the partial load range (small torques in different directions) the deviations can become very large depending on the history.

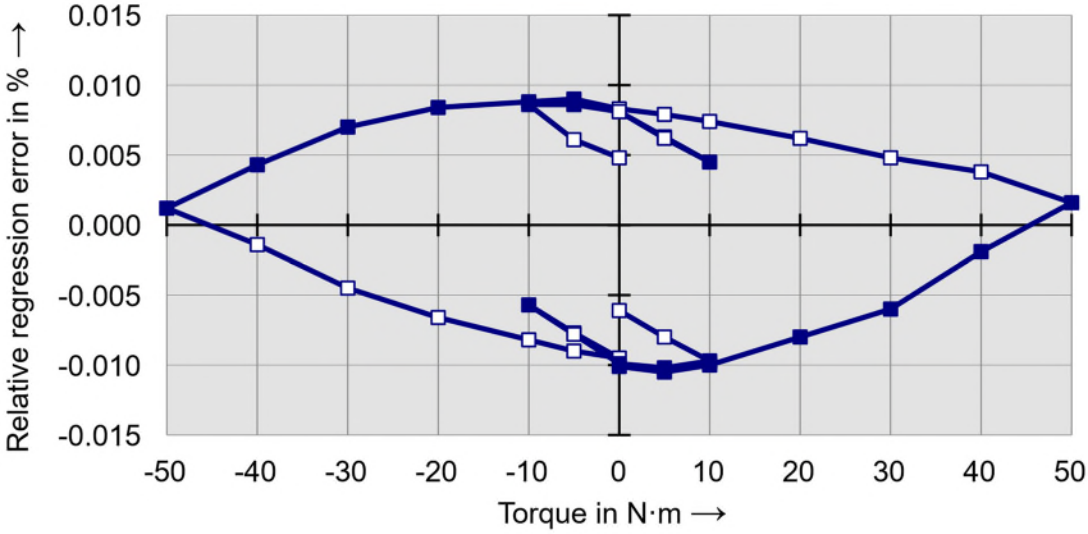

Figure 6a: Alternating torque cycles with low amplitude for different types of history

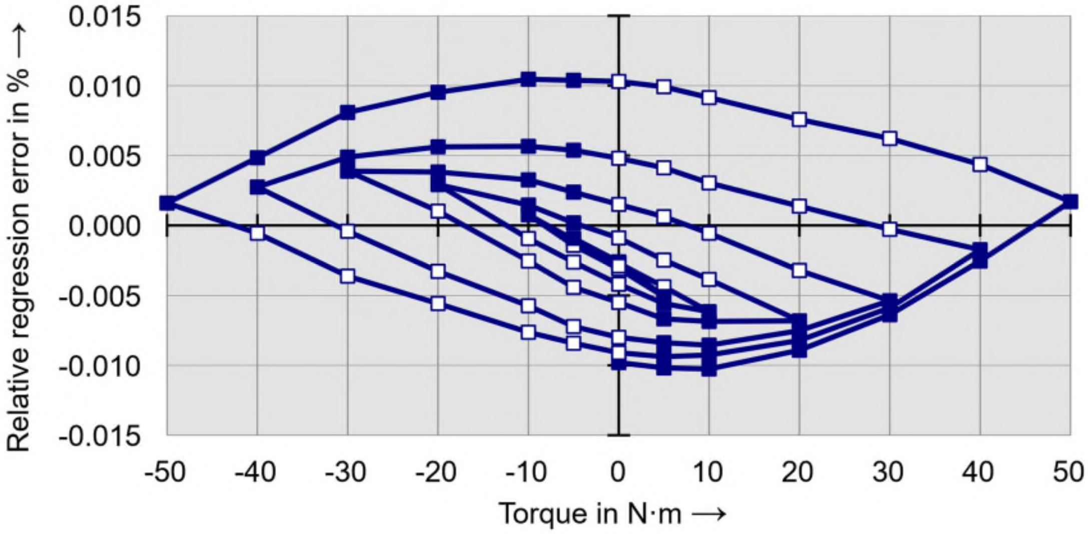

Figure 6b: Alternating torque cycles with decreasing torque amplitude

Figure 6b shows the case of repeatedly alternating load cycles between $-M_E$ and $+M_E$, with the amount of M_E decreasing with each cycle. As can be seen, each point within the alternating torque curve can be reached. Moreover, the difference between successive zero crossings becomes smaller as the span of the measuring range decreases and, for example, amounts to only 5 % of the remanence value for a cycle between –20 % and +20 %.

Annex B Determination of the relative expanded uncertainty W for the calibration of torque measuring devices with alternating torque

The relative expanded uncertainty W of an alternating torque calibration is calculated according to equation (B.1) from the relative deviation margin of the torque measuring device, assuming a known history of the load direction (see Annex A, point 4)

$$W_{\mathrm{MG},i} = \left|\frac{t}{Y_{\mathrm{at},i}}\right| + k \cdot w_{\mathrm{MG},i} \text{ with } k = 2 \qquad \text{(B.1)}$$

and from the accredited (or self-determined by the calibration laboratory) relative expanded uncertainty of the calibration device W_{KE} according to equation (B.2)

$$W = \sqrt{W_{\mathrm{MG}}^2 + W_{\mathrm{KE}}^2}\,. \qquad \text{(B.2)}$$

The relative standard uncertainty of the measuring device w_{MG} is calculated from the uncertainty contributions resulting from the calculated characteristic quantities according to DIN 51309, section 5.4.7. As for the uncertainty contributions, the distribution functions and values of the standard measurement uncertainties according to Table B.1 are used.

The relative uncertainty is calculated for each calibration step i.[1]

$$w_{\mathrm{MG},i}^2 = \frac{1}{12}\left(\frac{f_0}{Y_E}\right)^2 + \frac{1}{12}\left(\frac{b'_{\mathrm{at}}}{Y_{\mathrm{at}}}\right)^2 + \frac{1}{8}\left(\frac{b_{\mathrm{at}}}{Y_{\mathrm{at}}}\right)^2 + \frac{1}{24}\left(\frac{f_{\mathrm{a},i}}{Y_{\mathrm{a}}}\right)^2 + \frac{1}{12}\left(\frac{r}{M_{\mathrm{K},i}}\right)^2 . \qquad \text{(B.3)}$$

In case of a target-oriented calibration in classes 1 to 5, the calibration procedure does not comprise a repetition of the measurement in the same mounting position. For calculation, the reproducibility should therefore also be used for the non-determined repeatability value. Thus the result of the calculation will be more reliable, which seems to make sense for devices of this class. Hence, for classes 1 to 5:

$$w_{\mathrm{MG},i}^2 = \frac{1}{12}\left(\frac{f_0}{Y_E}\right)^2 + \frac{1}{4}\left(\frac{b_{\mathrm{at}}}{Y_{\mathrm{at}}}\right)^2 + \frac{1}{24}\left(\frac{f_{\mathrm{a},i}}{Y_{\mathrm{a}}}\right)^2 + \frac{1}{12}\left(\frac{r}{M_{\mathrm{K},i}}\right)^2 . \qquad \text{(B.4)}$$

The individual criteria determine the compliance with a class, independent of a potentially better result of all other characteristic quantities. By contrast, when calculating the measurement uncertainty, the uncertainty value is determined from all the characteristic quantities. Depending on the use of the measuring instrument to be calibrated, the calculated value of the measurement uncertainty or the determined class may take priority.

[1] For information regarding the evaluation model, see [1]

Table B.1: Distribution functions for calculating the variances of the characteristic quantities calculated from the experimentally determined spans

Characteristic quantity	Distribution function	Relative variance w^2
Zero pont deviation f_0	Rectangular distribution	$w_0^2 = \frac{1}{3}\left(\frac{f_0}{2 \cdot Y_\mathrm{E}}\right)^2$
Reproducibility b_at	Rectangular distribution	$w_\mathrm{b}^2 = \frac{1}{3}\left(\frac{b_\mathrm{at}}{2 \cdot Y_\mathrm{at}}\right)^2$
Repeatability b'_at	Rectangular distribution	$w_\mathrm{b'}^2 = \frac{1}{3}\left(\frac{b'_\mathrm{at}}{2 \cdot Y_\mathrm{at}}\right)^2$
Regression deviation f_a	Triangular distribution	$w_\mathrm{a}^2 = \frac{1}{6}\left(\frac{f_\mathrm{a}}{2 \cdot Y_a}\right)^2$
Resolution r	Rectangular distribution	$w_\mathrm{r}^2 = \frac{1}{3}\left(\frac{r}{2 \cdot M_{\mathrm{K},i}}\right)^2$

Annex C Calibration sequence

The following illustrations show variants of the calibration sequence for a separate alternating torque calibration as specified in section 3.3 and a variant with additional examination as specified in section 3.4 as supplement to the calibration according to DIN 51309 [1] for clockwise and anti-clockwise torque.

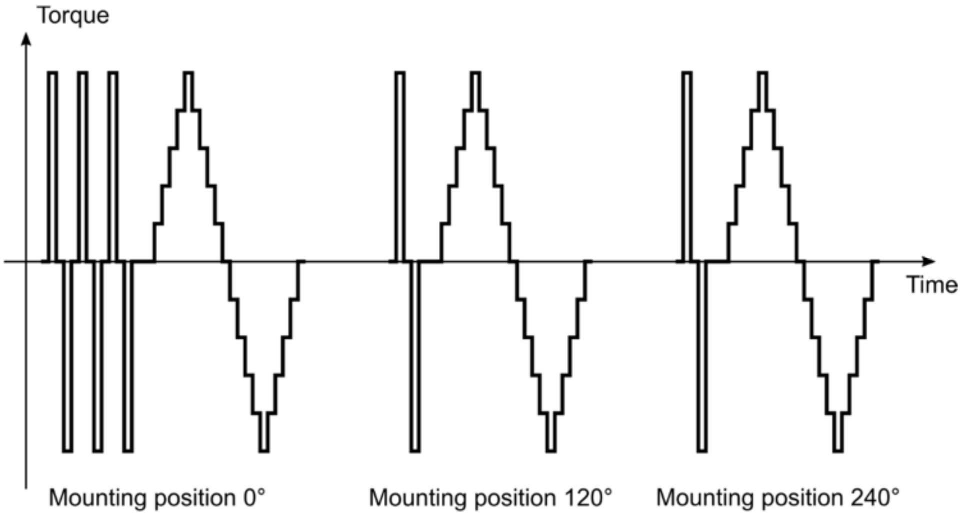

Figure C.1: Example of preloads and measurement series for classes 0.2 and 0.5 for a calibration according to 3.3

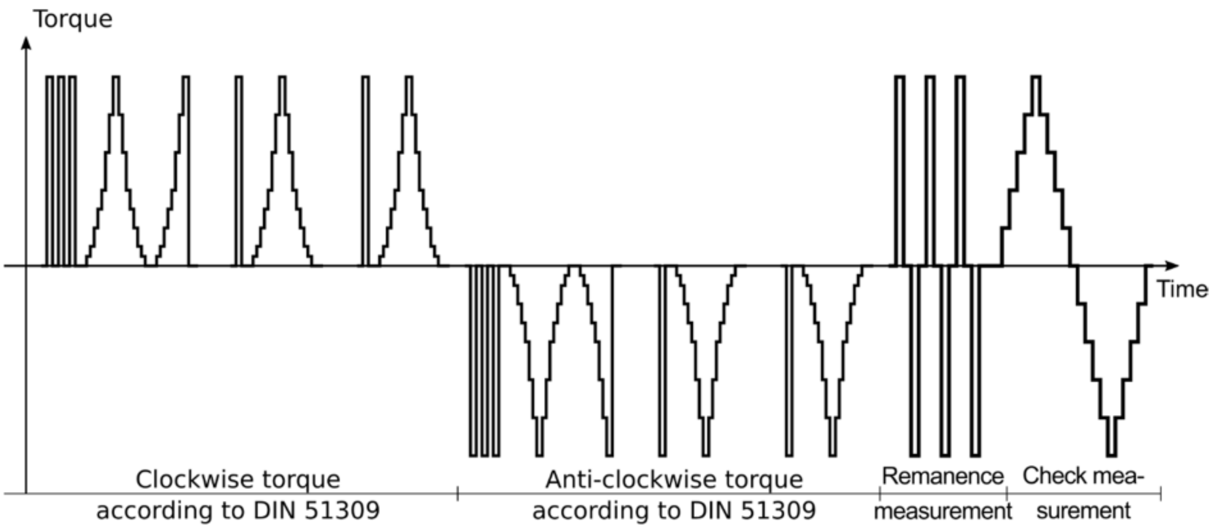

Figure C.2: Example of preloads and measurement series for alternating torque calibration as additional calibration according to 3.4 for a clockwise and anti-clockwise torque calibration according to DIN 51309

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