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Guideline DKD-R 3-13

Calibration of angular velocity measuring devices

Sheet 1

Quasi-static calibration

Edition 03/2024

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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.

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1 Scope and application

Guideline DKD-R 3-13 deals with calibration methods that can be used to calibrate angular velocity measuring devices (with analogue and digital output signals). The present document (Sheet 1) refers to static or quasi-static calibration methods. By using static calibration methods, it is possible to provide information regarding the quality of the linearity of the angular velocity measuring device; however, these methods do not offer the possibility to make a statement about the dynamic transmission behaviour of the measuring devices.

The determination of other characteristics such as temperature influence, cross-sensitivities, etc. are not dealt with in this guideline.

2 Terms and definitions

Abbreviation	Explanation
ADU	A/D converter
MG	Measuring device
BN	Reference standard
KE	Calibration device
KG	Calibration item
RLV	Rotation laser vibrometer

3 Symbols

For the application of this DKD guideline, the symbols listed in the following table apply.

Symbol	Typical unit	Explanation
Ω	rad/s	Angular velocity; another possible unit: °/s
U_{Ref}	mV	Output signal of an angular velocity reference transducer
$U_{\mathrm{Ref,0}}$	mV	Zero signal (offset signal) of the reference
$S_{u\Omega,\mathrm{Ref}}$	mV/(rad/s)	Transmission coefficient of an angular velocity reference transducer
j		Running index for different angular velocities
Φ_{Mittel}	rad	Mean angular resolution of an (incremental) angular reference transducer
f_{Osz}	Hz	Oscillator frequency (of an oscillating quartz crystal for time determination)
n		Number of quartz oscillations during the passage of one grating period of the angle reference transducer
$S_{u\Omega}$	mV/(rad/s)	Transmission coefficient; other possible units: mV/(°/s), LSB/(rad/s), LSB/(°/s)
U_{A}	mV	Measured value of the output signal of the calibration item, e.g. in mV or LSB
$U_{\mathrm{A,0}}$	mV	Zero signal (offset signal) of the calibration item
K_{IA}		Influencing factor; instability over time
K_{Vgl}		Influencing factor; reproducibility incl. mounting
K_{Q}		Influencing factor; cross-sensitivity
K_{TK}		Influencing factor; dependence on temperature
K_{L}		Influencing factor; linearity deviation
K_{R}		Influencing factor; residual influences

4 Aim of the calibration

The aim of calibration is to determine the transmission behaviour of an angular velocity measuring device.
In static methods, a transmission coefficient is determined by relating the output signal of the calibration item (KG) to a set, constant angular velocity. As a rule, this is carried out at different angular velocities so that a statement can be made about the linearity of the calibration item.

5 Requirements regarding calibration capability

Requirements regarding the calibration capability of accelerometers are described in detail in DKD R 3-1, Sheet 1. They equally apply to the calibration of angular velocity measuring devices.

6 Ambient conditions

The relevant ambient conditions must be adapted to the calibration task, traceably monitored and documented.
The influences of the ambient conditions must be taken into account in the respective uncertainty budget.
During calibration, the measurement set-up must be in thermal equilibrium. The warm-up times specified by the manufacturer must be observed.
The calibration should be carried out at an ambient temperature of (23 ± 3) °C.
The relative humidity should not exceed 75 %.

7 Reference transducers

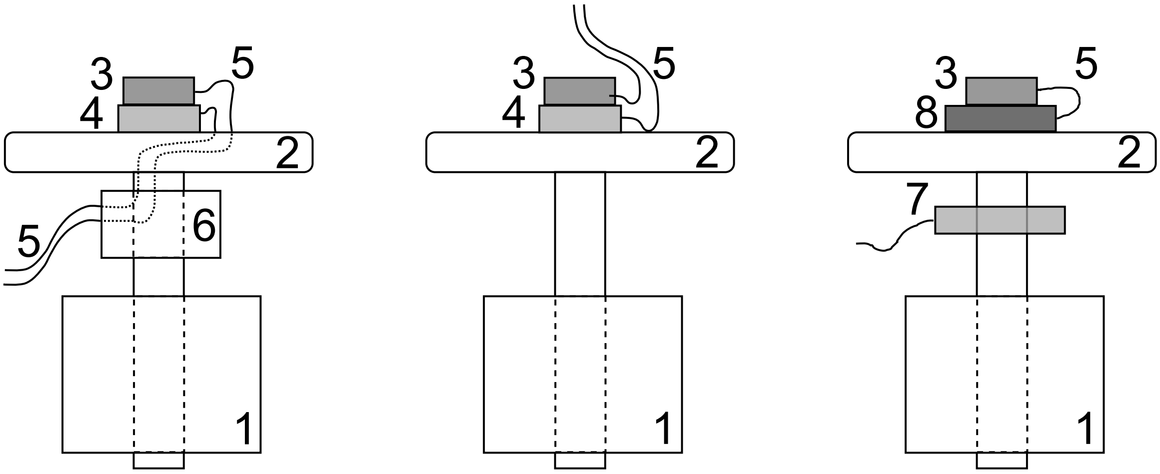
There are different ways to determine the set angular velocity. When using an (incremental) angle reference transducer, the measured angles must be brought into relation with time in order to calculate the resulting angular velocity.
When using an angular velocity reference transducer, it must be ensured that it can measure constant angular velocities, i.e. it does not exhibit any high-pass behaviour. Its measurement result can also serve as direct reference.
The use of angular accelerometers as a reference for the (quasi-) static angular velocity must be ruled out due to common integration errors.
In any case, the reference measurands must be measured in a metrologically traceable form.

8 Calibration device and signal transmission

Figure 1 shows the basic set-up of a calibration device. The calibration device consists of a drive that generates the rotation of a flat mounting surface at right angles to the shaft via a dumb-bell shaft. The rotation of the mounting surface is recorded by a reference transducer. If the reference transducer supplies an angular quantity as output signal, this must be converted into the angular velocity via traceable time measurement.
The calibration system continuously analyses the reference angular velocity. As soon as certain stability criteria are met, the output signal of the calibration item is measured.
The calibration device may have a vertically or horizontally orientated axis of rotation.

Usually, manufacturers of angular velocity transducers specify the direction of rotation with a positive output signal on the transducer housing and/or in the data sheet. This definition of direction by the calibration item is adopted for defining the positive angular velocity of the calibration device for the purpose of calibration. When rotating the calibration item in a positive direction it should generate a positive output signal, thus resulting in a positive transmission coefficient according to Eq. 3. If the output signal of the calibration item is negative despite the positive direction of rotation, a negative transmission coefficient results accordingly.

If the calibration item (without decoupling) is connected directly to a stationary data acquisition system, the number of rotations around its own axis is limited by the calibration system (centre illustration). The direction of rotation must then be reversed regularly. Due to the corotating connecting cable, the cable routing must be carefully selected with an appropriate loop. Possible damage to the connecting cable limits the maximum possible angular speed as well as the number of rotations. The desired angular velocity cannot be maintained at a constant level for any length of time.
If the number of rotations exceeds the flexibility of the sensor's connecting cable and if the cable must therefore be decoupled from the rotary movement, decoupling can be achieved using a slip ring assembly (illustration on the left) or a telemetry system. Alternatively, a data acquisition system that rotates with the sensor (illustration on the right) can be used. The data is read out after measurement.



1 Drive
2 Rotary table
3 Calibration item
4 Reference transducer
5 Connecting cable of the transducer
6 Slip ring assembly
7 Reference angle transducer
8 Data acquisition system

Figure 1: Illustration of set-ups and signal transmission of an angular velocity calibration device; on the left via a slip ring assembly, in the centre via a flexible connection cable, on the right via a corotating data acquisition system.

The lower limit of the angular velocity to be realised depends on the signal/noise or resolution ratio and, if applicable, the stability of the zero signal (offset) of the reference.
The maximum adjustable angular velocity level at the calibration device strongly depends on the exciter and the mechanical components. The rotating mass, unbalance, and the rotation of the connecting cable can limit the maximum achievable angular velocity.
At present, the upper limit for calibration devices without slip ring assembly in known systems is 4800 °/s maximum.
Commercially available systems with slip ring assembly can currently realise maximum angular velocities of up to 50,000 °/s.

9 Calibration method

9.1 Alternating step-by-step procedure

The exciter rotates alternately in one direction and then in the other. This is repeated at different angular velocities. As a rule, this method is used if the calibration device only allows a limited number of non-destructive rotations due to a lack of decoupling of the sensor connection cable.

Figure 2 shows a typical signal curve for the alternating step-by-step procedure. Here, the exciter first rotates at the lowest negative angular velocity, then rotates back at the lowest positive angular velocity; this continues with the desired number of angular velocity levels up to the highest angular velocity of the calibration. As the data is recorded here at a constant sampling frequency over a specific angle (e.g. one revolution), the number of measured values per angular velocity level decreases as the angular velocity increases.

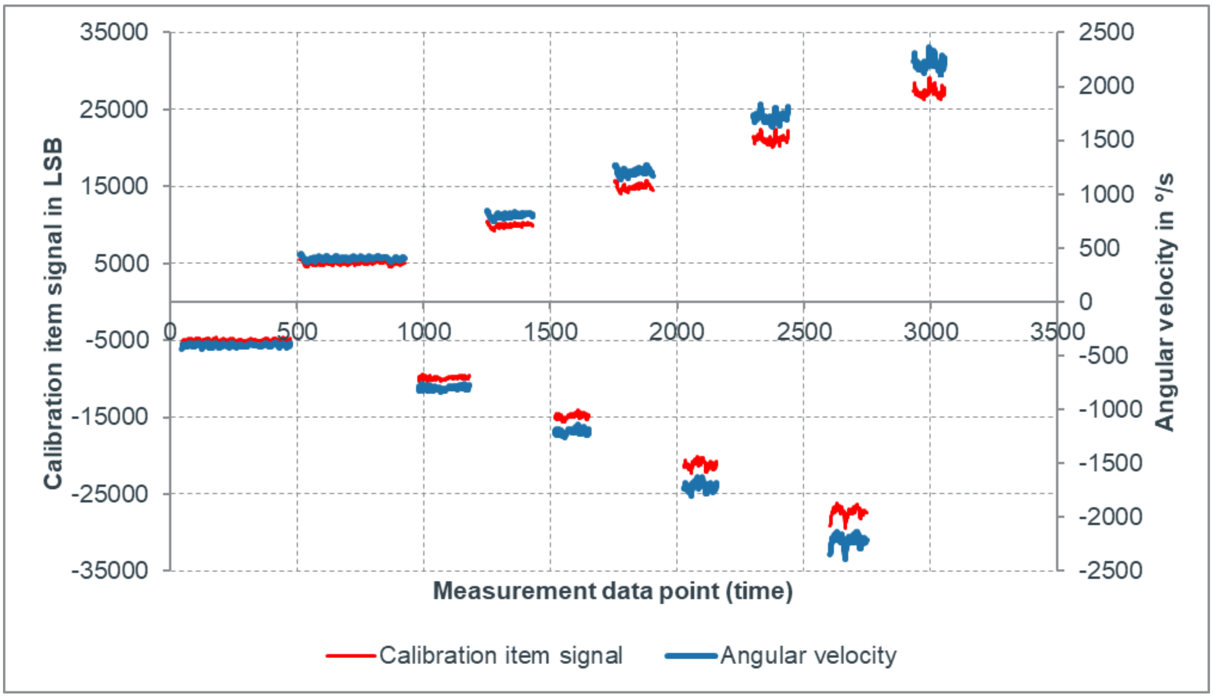


Figure 2: Signal curve of calibration item and standard in the step-by-step procedure without slip ring transmission.

9.2 Monotonic step-by-step procedure

When using the monotonic step-by-step procedure, the rotary disc is brought to a constant angular velocity by the exciter. This velocity can be kept constant over any number of revolutions to obtain the desired mean value.
Once the measurement is completed, a new level of angular velocity is selected to successively cover the entire calibration range. Figure 3 shows a possible sequence.

This procedure is usually adopted in cases where connecting cable of the sensor is decoupled via a slip ring assembly, a telemetry system or a corotating data acquisition system.

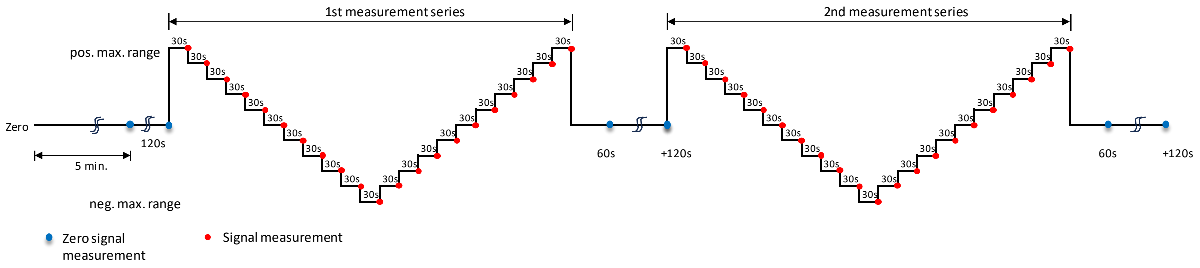


Figure 3: Signal curve of calibration item and standard when using the monotone step-by-step procedure

10 Signal acquisition

For communication and signal adaptation, both methods require various electronic components to amplify the signals, convert them to analogue/digital and/or transmit them to a computer as desired. To ensure sufficient modulation of the A/D converter, the settings should be selected accordingly.
In the case of multi-channel transducers, the cross-sensitivities can be determined by parallel measurement of the respective orthogonal directions.
To obtain a statement regarding the transducer behaviour over the entire calibration range, the indication values of the calibration item should be determined at a minimum of ± 5 (≙ 10) approximately equidistantly distributed, positive and negative angular velocities.

Before calibration, the zero signal of the calibration item should be determined and documented. Significant changes in the zero signal, compared to the zero signal determined during the previous calibration, allow conclusions to be drawn about a change in the behaviour of the calibration item since its last calibration.

Due to temperature drift, the measured values of a calibration item (e.g. MEMS gyroscopes) may vary significantly depending on the ambient conditions when the calibration item is in a rest position. The manufacturers of such measuring devices therefore recommend taring of the measuring device before measurement in order to eliminate deviations in the measured values due to temperature differences or temperature drift. Such cases also require a taring of the calibration item before calibration. This must be noted in the calibration certificate.

11 Evaluation

The transmission coefficient of the measuring device is obtained after data acquisition by relating the output signal of the calibration item to the angular velocity determined by the reference transducer.
When starting the measurement, the zero signals (offset voltages) of the reference and the calibration item must be recorded $(U_{\mathrm{Ref},0};\ U_{\mathrm{A},0})$. For this purpose, both transducers must be stored in a resting position and the zero signals must be determined over a sufficiently long period of time. These must be recorded and used for further calculation of the angular velocity Ω_j and the transmission coefficient $S_{u\Omega}(\Omega_j)$. If the zero signals are not included in the calculation, an additional contribution must be taken into account in the uncertainty budget.
By taking into account the zero signal $U_{\mathrm{Ref},0}$, the provided angular velocity Ω_j can be calculated as follows if the reference transducer is an angular velocity transducer:

$$\Omega_j = \frac{U_{\mathrm{Ref},j} - U_{\mathrm{Ref},0}}{S_{u\Omega,\mathrm{Ref}}} \tag{1}$$

If the reference transducer is an incremental angle transducer, the following results:

$$\Omega_j = \frac{\Phi_{\mathrm{Mittel,Ref}} \cdot f_{\mathrm{Osz,Ref}}}{n_j} \tag{2}$$

The angular velocity must be specified in the SI-compliant units rad/s or °/s; other customer-specific specifications are also possible, e.g. deg/s.
The output quantities of the reference and the calibration item are usually electrical voltages. If other output quantities are available (e.g. digital values in LSB for digital sensors), the voltages in the equations listed must be replaced by these quantities.
In the case of indicating devices or a digital value as output signal, there is no need for the laboratory to provide an adapter/indicator. Therefore, the corresponding measurement uncertainty of the adapter/indicator with which the voltages $U_{\mathrm{A},j}$and $U_{\mathrm{A},0}$ are determined is omitted. In this case, it is of particular importance to take into account a measurement uncertainty component due to the resolution / fluctuation range of the output signal.

As transmission coefficient of the calibration item for the angular velocity Ω_j we get:

$$S_{u\Omega}(\Omega_j) = \frac{U_{\mathrm{A},j} - U_{\mathrm{A},0}}{\Omega_j} \tag{3}$$

By determining the output signals of the calibration item at different levels of angular velocity, a regression calculation can be used to determine a single value for the transmission behaviour in the angular velocity range under consideration (single-number value). The various methods are described in DKD-R 3-1, Sheet 2, Section 6 *Evaluation*.
To ensure comparability of the calibration results, the method used to determine the single-number value must be stated in the calibration certificate.

Here it is preferable to determine a straight-line equation with indication of the ordinate intercept (tolerance band method).

If $\Delta U_{A,j} = U_{A,j} - U_{A,0}$ are the output values of the calibration item corrected by the zero signal at the corresponding angular velocities Ω_j (determined by means of the reference), then the least squares method is used for the required slope $\tilde{S}_\Omega$ of the straight line from $\Delta U_{A,j}$via Ω_j:

$$\tilde{S}_\Omega = \frac{n \sum \Omega_j \cdot \Delta U_{A,j} - \sum \Omega_j \cdot \sum \Delta U_{A,j}}{n \sum {\Omega_j}^2 - \left(\sum \Omega_j\right)^2} \tag{4}$$

The ordinate intercept is calculated as follows:

$$\Delta U_{A,0} = \frac{\sum {\Omega_j}^2 \cdot \sum \Delta U_{A,j} - \sum \Omega_j \cdot \sum \Omega_j \cdot \Delta U_{A,j}}{n \sum {\Omega_j}^2 - \left(\sum \Omega_j\right)^2} \tag{5}$$

Should the output values have already been corrected by the zero signal in advance, the ordinate intercept should only be small.

If a straight-line equation through the origin is to be determined during evaluation (on customer request, for example), the straight-line gradient is calculated as follows:

$$\tilde{S}_{\Omega} = \frac{\sum \Omega_j \cdot \Delta U_{A,j}}{\sum {\Omega_j}^2} \tag{6}$$

For the sake of simplicity, the same measurement uncertainties were assumed for the input measurands (otherwise, a corresponding weighting would be necessary).

12 Measurement uncertainty

A product model can be used as mathematical model to determine the transmission coefficient of an angular velocity measuring device. When using an angular velocity reference transducer, the following results:

$$S_{u\Omega} = \frac{U_{\mathrm{A},j} - U_{\mathrm{A,0}}}{\Omega_j} \cdot \prod_{i=1}^{N} K_{i,j} = \frac{\left(U_{\mathrm{A},j} - U_{\mathrm{A,0}}\right) \cdot S_{u\Omega,\mathrm{Ref}}}{\left(U_{\mathrm{Ref},j} - U_{\mathrm{Ref,0}}\right)} \cdot \prod_{i=1}^{8} K_{i,j} \tag{7}$$

When using an incremental angle reference transducer to determine the angular velocity, the model would read as follows:

$$S_{u\Omega} = \frac{U_{\mathrm{A},j} - U_{\mathrm{A,0}}}{\Omega_j} \cdot \prod_{i=1}^{N} K_{i,j} = \frac{\left(U_{\mathrm{A},j} - U_{\mathrm{A,0}}\right) \cdot n_j}{\Phi_{\mathrm{Mittel}} \cdot f_{\mathrm{Osz}}} \cdot \prod_{i=1}^{8} K_{i,j} \tag{8}$$

with

$$\prod_{i=1}^{8} K_{i,j} = K_{\mathrm{IA},j} \cdot K_{\mathrm{Vgl},j} \cdot K_{Q,j} \cdot K_{\mathrm{Vib},j} \cdot K_{\mathrm{TK},j} \cdot K_{\mathrm{L},j} \cdot K_{\mathrm{Geo},j} \cdot K_{\mathrm{R},j} \tag{9}$$

Output quantity:

$S_{u\Omega}$	Result, transmission coefficient of the calibration item

Input / fundamental quantities:

Ω	Angular velocity (generated by the calibration device)
$U_{\mathrm{A,Ref}}$	(Mean) output signal of the angular velocity reference transducer
$U_{\mathrm{Ref,0}}$	Zero signal (offset signal) of the reference transducer
$S_{u\Omega,\mathrm{Ref}}$	Transmission coefficient of the angular velocity reference transducer
Φ_{Mittel}	Mean angle resolution (of an incremental) angle reference transducer
f_{Osz}	Oscillator frequency (of an oscillating quartz crystal for time determination)
U_{A}	Measured value of the output signal of the calibration item
$U_{\mathrm{A,0}}$	Zero signal (offset signal) of the calibration item

Influence quantities:

K_{IA}	Correction factor; instability over time
K_{Vgl}	Correction factor; reproducibility including mounting
K_{Q}	Correction factor; cross-sensitivities (e.g. to centripetal acceleration)
K_{Vib}	Correction factor; sensitivity to parasitic vibrations (e.g. fluctuations in the synchronisation of the drive or unbalances)
K_{TK}	Correction factor; dependence on temperature
K_{L}	Correction factor; linearity deviation
K_{Geo}	Correction factor; influence of the earth's rotation (e.g. for sensors with high sensitivity)
K_{R}	Correction factor; residual influences

Note regarding the cross-sensitivity to centripetal acceleration:
Due to their design, some calibration items exhibit disturbances when subjected to centripetal acceleration. Such calibration items must be mounted in such a way that the seismic element of the calibration item is positioned as close as possible to or directly on the central axis of rotation of the exciter. In the case of off-centre mounting, a centripetal acceleration a_{Z} becomes effective the magnitude of which is the product of the distance (radius r) to the central axis of rotation and the square of the angular velocity. This centripetal acceleration will act as lateral acceleration in the direction of the central axis of rotation; its influence must be estimated within the measurement uncertainty budget and included as contribution.

Depending on the design of the device, the type of sensor or individual ambient conditions, further significant measurement uncertainty components may occur. These are not included in the above list. It is the responsibility of the laboratory to appropriately integrate these components into the uncertainty budget.

The single-number value as calibration result from the regression calculation is used in the application to determine a transmission coefficient for rotational speeds for which no explicit calibration result is available. Several simplifications and restrictions must be observed as part of the regression.

1. The regression equations in the previous section assume that all output values have been determined with the same measurement uncertainty (unweighted regression).
2. When using a weighted, simple linear regression (not described here), only measurement uncertainties of the measured output values are taken into account but not the measurement uncertainties of the measured input or reference values which are still present.
3. The information found in the literature on determination coefficients or quality criteria of the fit (such as „r^2“) are generally unsuitable here, as they only take into account the quality of the fit to the measured values, but not the uncertainty of the measured values.

Considering that in the case of an angular velocity with calibration result the measurement uncertainty would be taken from the discrete results of the individual measuring points, it seems obvious taking the information from the discrete calibration results for the estimated measurement uncertainty of any other given point on the regression line.

If the angular velocity lies in the interval $\Omega_i < \Omega < \Omega_{i+1}$ – with discrete calibration results available for Ω_i and Ω_{i+1} – the measurement uncertainty of $S(\Omega)$ is to be taken as the maximum of the measurement uncertainties of $S(\Omega_i)$ and $S(\Omega_{i+1})$.

13 Calibration certificate

The calibration certificates should comply with the requirements of the currently valid DIN EN ISO/IEC 17025.

It is recommended to present the results – including the measurement uncertainty – in tabular and graphical form.

All conditions having a significant influence on the calibration result must be indicated. Examples:

- electrical supply
- auxiliary measuring devices used, including settings
- design-related measurement conditions, e.g. cable length, type of mounting of the calibration item; interfaces used for digital sensors
- torque during mounting
- design-related characteristic quantities, e.g. zero signal
- characteristic quantities and characteristic of filters
- if applicable, single-number value including range of validity, evaluation algorithm
- performed taring

14 Bibliography

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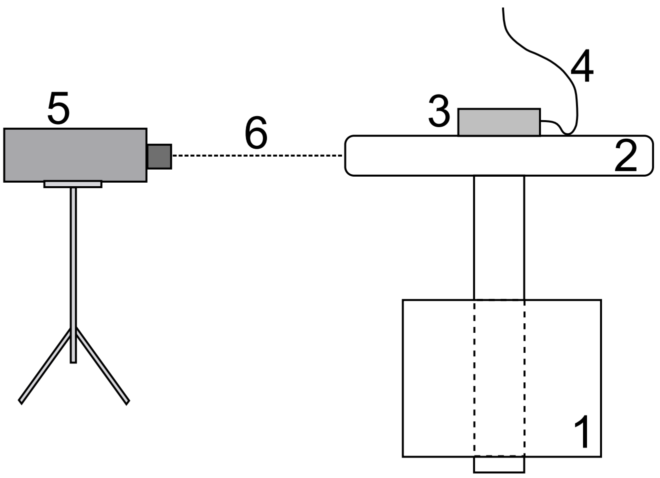
Appendix A: Rotation laser vibrometers

As an alternative to electro-mechanical angular velocity transducers, it is also possible to use rotation laser vibrometers (RLV) as calibration item or reference.



1 Drive
2 Rotary table
3 Calibration item
4 Connecting cable of the transducer
5 Rotation laser vibrometer
6 Laser beams (two consecutive)

Figure 4: Basic set-up, here for the use of an RLV as reference on a calibration device.

Fundamental differences arise due to the fact that an RLV records the measurand without contact. In contrast to other transducers, the RLV is not moved and therefore does not generate a mass load on the calibration device. However, movements relative to the measuring device must be thoroughly observed.
There are no mechanical restrictions due to the connecting cable of the sensor when using the vibrometer as calibration item. Otherwise, the instructions in section 8 apply.

Operating principle

The optical measuring principle for the RLV is based on laser interferometry. Its use is not limited to cylindrical parts. By using a special differential method with two measuring beams only the rotational motion component is recorded, regardless of the shape of the measured object, while translational vibrations are suppressed to a large extent, see also *Measuring method – basic principles*.

Surface

Due to the optical measuring principle, certain minimum requirements apply with regard to the reflectivity of the surface scanned by the laser beams. In some cases, the surface to be used must therefore be prepared accordingly. For example, a retro-reflective film can be used for this purpose.
Corresponding instructions can usually be found in the device manual. With the help of the device's signal intensity display, a good optical level for the calibration measurement can be ensured.
In general, a better reflection behaviour produces a higher signal-to-noise ratio of the measurement. As this ratio is not very high in rotational measurements due to the speckles of

the backscattered light, it is advisable in most cases to prepare the measurement object as carefully as possible.

Alignment

For rotation measurements, the sensor must always be mounted in such a way that the plane of the two laser beams is orthogonal to the axis of rotation of the measurement object.
The measurement result is independent of the position of the laser beams as long as the plane of the laser beams is orthogonal to the axis of rotation.

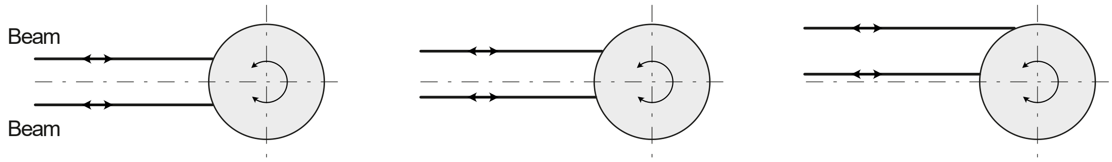


Figure 5: Permissible positions of the laser beams orthogonal to the axis of rotation when using an RLV for measurement

The angle of incidence of the laser beam to the object surface is important given that it is always the component of movement in the direction of the laser beam that is recorded. So, if the laser beam is not orthogonal to the rotating surface, the amplitude values are usually too small.

Measuring method – basic principles

A tangential velocity v_t, which depends on the radius of rotation R, can be assigned to each point on the circumference of a body rotating at the angular velocity ω.
This translational velocity can be broken down into two arbitrarily orientated, but perpendicular, translational velocity components. The following figure shows the vector representation of such a velocity decomposition for two points on the circumference of a rotating body of any shape, where one of the velocity components has been placed in the direction of incidence of the laser beam.

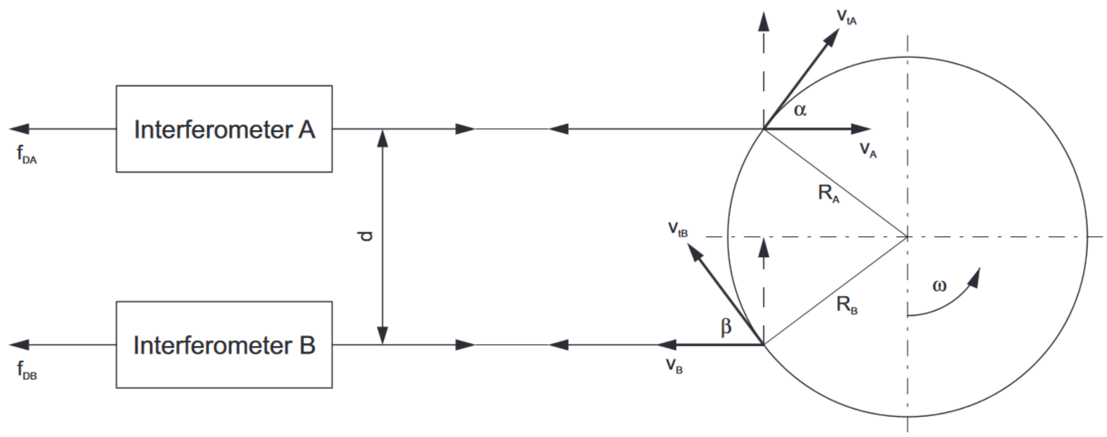


Figure 6: Geometry of the measurement and decomposition of the tangential velocities.

As shown below, it is possible to calculate the angular velocity ω by measuring two parallel translational velocity components. A measuring arrangement consisting of two interferometers with two parallel laser beams arranged at a distance d records the velocity components v_A and v_B. Due to the vectorial decomposition, the following two relationships apply:

$$v_{\mathrm{A}} = v_{tA} \cdot \cos\alpha = \omega \cdot R_{\mathrm{A}} \cdot \cos\alpha$$
$$v_{\mathrm{B}} = v_{tB} \cdot \cos\beta = \omega \cdot R_{\mathrm{B}} \cdot \cos\beta \quad (10)$$

The velocity components v_{A} and v_{B} acting in the direction of the laser beams generate the Doppler frequency shifts f_{DA} and f_{DB} in the backscattered laser beams. Here, the following relationships apply:

$$f_{DA} = \frac{2v_{\mathrm{A}}}{\lambda} = \frac{2(\omega \cdot R_{\mathrm{A}} \cdot \cos\alpha)}{\lambda}$$
$$f_{DB} = \frac{2v_{\mathrm{B}}}{\lambda} = \frac{2(\omega \cdot R_{\mathrm{B}} \cdot \cos\beta)}{\lambda} \quad (11)$$

The geometric relationship between the distance d of the laser beams and the angles α and β with the given radii R_{A} and R_{B} can be described by the following equation:

$$d = R_{\mathrm{A}} \cdot \cos\alpha + R_{\mathrm{B}} \cdot \cos\beta \quad (12)$$

From this relationship, the sum of the Doppler frequency shifts is obtained:

$$f_D = f_{DA} + f_{DB} = \frac{2d \cdot \omega}{\lambda} \quad (13)$$

Thus, the resulting Doppler frequency shift only depends on the system constants d and λ and the angular velocity ω. The angular velocity determined from the Doppler frequency shift and, if applicable, the rotational speed are indicated by the RLV either as an analogue voltage or digitally.
Taking into account the signs of the angle functions and the velocity components, it is easy to show that an additional translational motion component in the direction of the laser beams has no influence on the magnitude of the resulting Doppler frequency shift as it would be superimposed on the two velocities v_{A} and v_{B} in the same direction.
Likewise, a translational component acting perpendicularly would have no influence since a movement directed perpendicular to the laser beam of an interferometer does not generate a Doppler shift.
Given that each translational movement of the body to be measured is represented by a component in the direction of the laser beams and one perpendicular to it, the method is in principle insensitive to translational movements.

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