SICK AG WHITEPAPER

DATA SHEET ACCURACY VALUES OF ENCODERS AND MOTOR-FEEDBACK-SYSTEMS

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CONTENT

Introduction

For encoders and motor-feedback-systems a plurality of parameters is given in the datasheets as a summary of the relevant physical properties and features of these products. Among them, there are angular accuracy values describing the quality of the basic function of the angular measurement. A distinction can be made between systematic and random error values, which both describe the potential maximum angular position output deviation from the mechanical shaft angle that is measured.

The measurement of these values is performed according to the DIN 1319-1 [1] standard as well as to GUM [2, 3]. Namely, the systematic angular measurement error and the repeatability standard deviation are calculated from the measured data to ensure the product quality in terms of angular accuracy.

This white paper illustrates the details in regard to the definition, measurement, and analysis of these accuracy parameters. Additionally, the interrelation with some old-established but obsolete parameters is shown. For a common understanding of the technical terms used in this white paper a glossary is attached.

Data sheet values and relation to standard

Data sheet values	Relation to standard
Error limit/system accuracy • Systematic angular measurement error • Given as plus-minus-value assuming a symmetrical deviation from the real angle • Given in arcseconds* (″) or angular degrees (°)	Error limit (DIN 1319-1) • The measured systematic deviation from the real mechanical angle is the systematic angular measurement error, which has to be within the error limit
Repeatability/noise • Random angular measurement error • Given as 1-σ-value • Given in arcseconds* (″) or angular degrees (°)	Repeatability standard deviation (DIN 1319-1) • The measured statistical deviation from the real mechanical angle is the random angular measurement error, which has to be within the given 1-σ repeatability standard deviation
INL (obsolete) • Integral non-linearity (systematic)	• The integral non-linearity is part of the systematic angular measurement error
DNL (obsolete) • Differential non-linearity (systematic)	• The differential non-linearity is part of the systematic angular measurement error

Table 1: Data sheet values and relation to standard

Test conditions

Every encoder and motor-feedback-system is calibrated before shipping. This is done by mounting the respective device onto a test system with a high accuracy and calibrated reference encoder and by recording the angle output of both for one turn of the shaft (Fig. 1: Real mechanical angle and measured angle). The deviation of the angular value of the device from the angular value of the test system‘s reference is considered to be the deviation from the real mechanical angle and therewith the angular measurement error which contains systematic and random errors (Fig. 2: Angular measurement error and error limits).

For the calculation of the systematic angular measurement error, the random angular measurement error is ignored by applying a low-pass filter. Depending on the type of product, the systematic angular measurement error is adjusted. For the calibration, an adjusted mechanical setup is used to avoid mechanical influences of the mounting while measuring to achieve the optimum accuracy and therewith the maximum tolerance range. A measuring system analysis is done for the test system to determine the measurement uncertainty and to set the error limit for the testing accordingly.

The randon angular measurement error, which is also referred to as noise, is measured separately from the systematic angular measurement error for a number of different angular positions at standstill. Since the random angular measurement error is unpredictable, it cannot be described by an error limit but by the value for the statistical 1-σ repeatability standard deviation assuming a normal distribution (Fig. 4: Statistical noise).

Please note:
The angular measurement error examples in the following graphs are for demonstration purposes only, to illustrate the variety of effects that may occur and are not to scale in regard to any product.

* 1° (1 degree) = 60‘ (60 arcminutes) = 3600“ (3600 arcseconds)

Deviation from the real mechanical angle

The measured angular values of the device under test and those of the reference encoder are recorded for one turn of the shaft in order to calculate the angular measurement error. The reference is considered to represent the real mechanical angle with a known measurement uncertainty, while the encoder or motor-feedback-system suffers some angular measurement error from different mechanical and/or electrical influences as well as some noise.

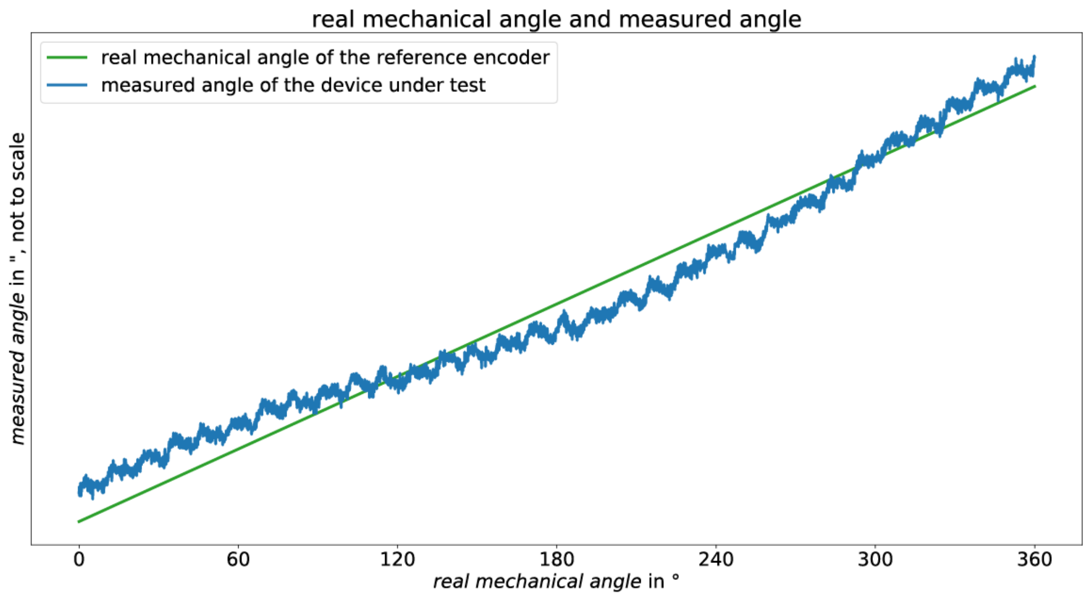

Fig. 1: Real mechanical angle and measured angle

Angular measurement error

In order to calculate the angular measurement error, the measured angular values from one turn of the device under test and the reference encoder of the test system are subtracted from each other. The resulting angular measurement error consists of both systematic and random error components. The example in the graph shows systematic error components of 32 physical periods per turn, a single period error as well as statistical noise. The measured systematic error excluding the noise has to be within the datasheet error limit, which is given as the symmetrical maximum deviation from the real mechanical angle of the reference encoder. This real angle can be understood as an angular position relatively depending on the application's angular zero or commutation, which can be adjusted by applying a position offset.

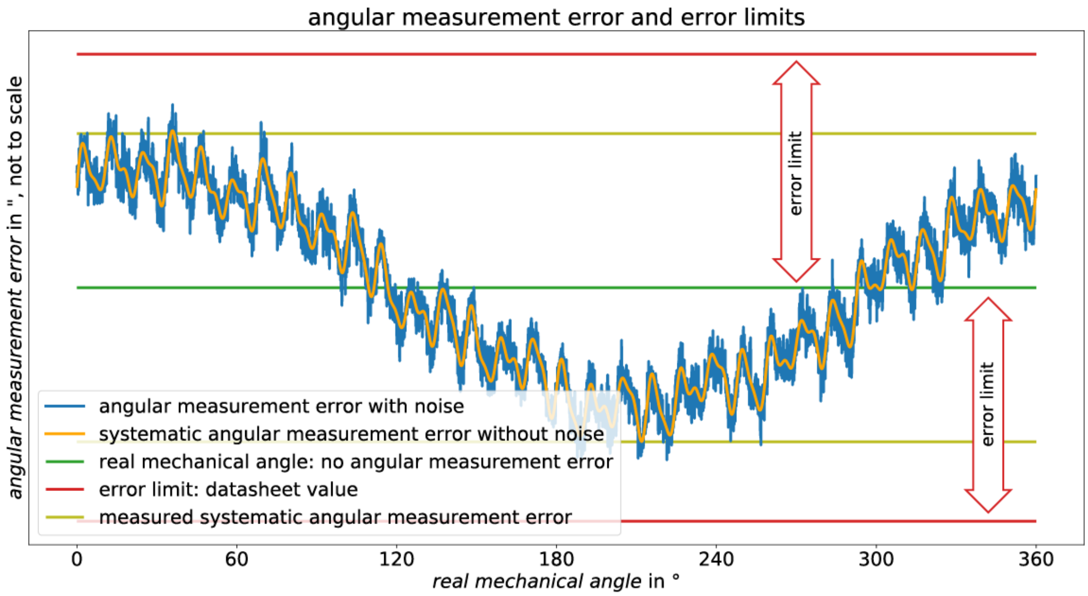

Fig. 2: Angular measurement error and error limits

Frequencies of the angular measurement error

The absolute values of the Fast Fourier Transform (FFT) of the angular measurement error reveal the angular frequencies, namely the occurrence of particular periods per turn. These can be assigned to the systematic angular measurement error values given in the datasheet. As shown in the graph, the occurrence of the 32 physical periods per turn and their harmonics used to be given as the DNL while the single period used to be given as the INL. Since there may be additional frequencies from other mechanical and/or electrical influences, the systematic angular measurement error consists not only of the INL and DNL, but of the sum of all systematic influences. The noise floor in the FFT consists of the random angular measurement error.

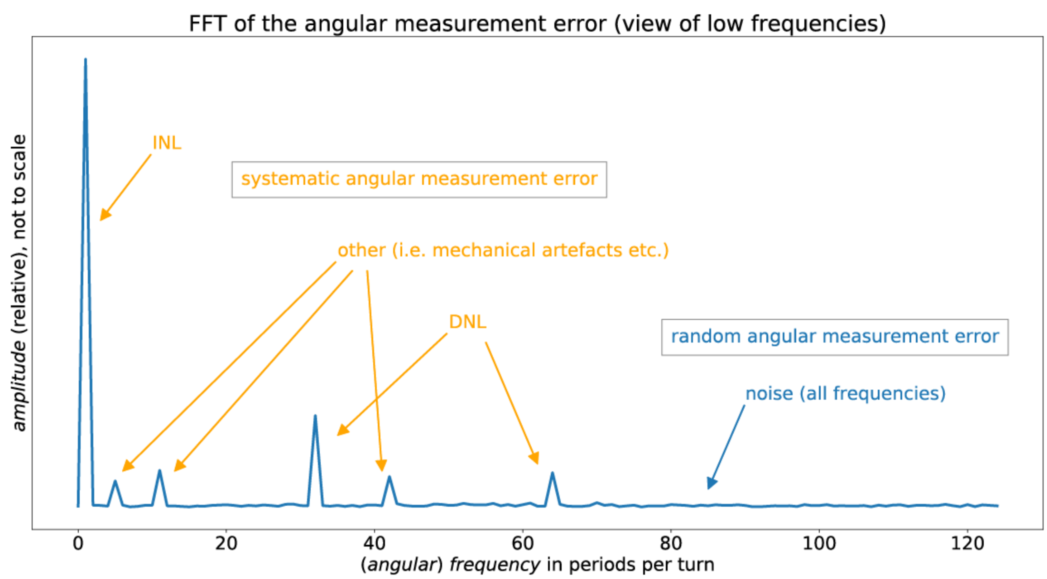

Fig. 3: FFT of the angular measurement error (zoom on the lower frequencies)

Noise

The random components of the angular measurement error can be considered as statistical noise, which is measured for a number of different angular positions at standstill. It is described by the datasheet value for the symmetrical 1-σ repeatability standard deviation assuming a normal distribution.

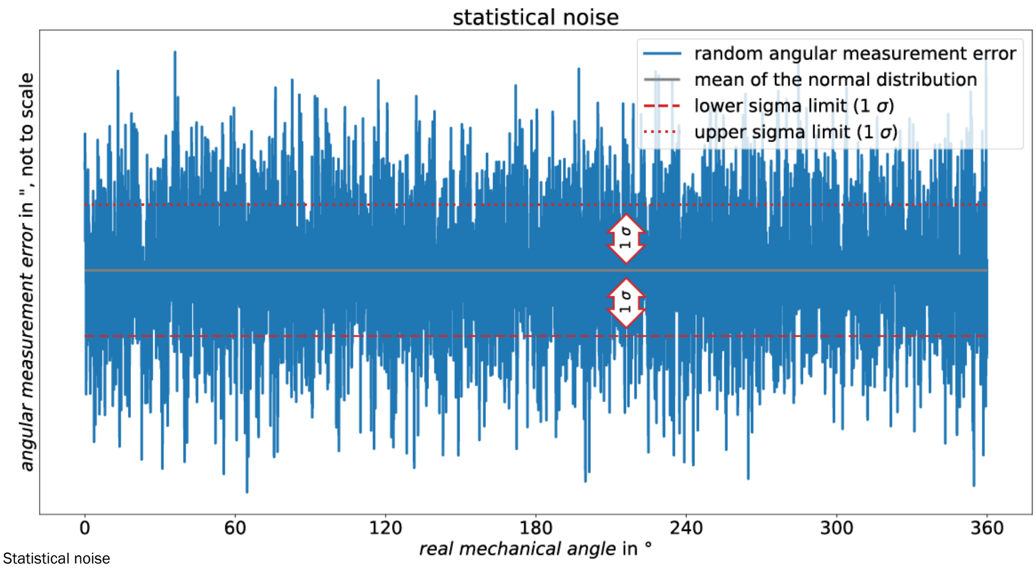

Fig. 4: Statistical noise

Normal distribution and sigma

The histogram of the measured noise illustrates its normal distribution. From this normal distribution, the 1-σ repeatability standard deviation can be calculated. A minimum of 68.3 % of all measured samples has to be within this value.

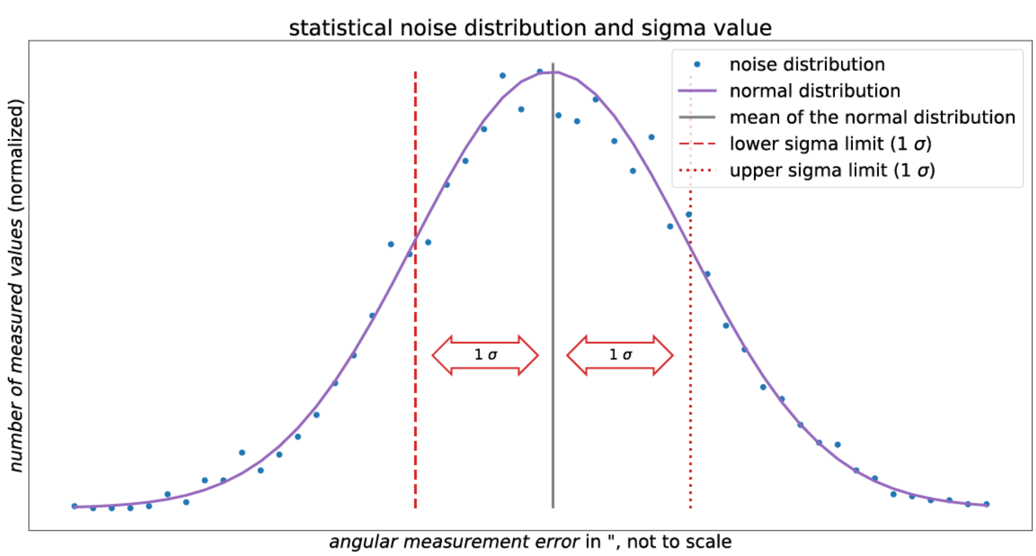

Fig. 5: Statistical noise distribution and one-sigma value

Glossary

Term	Definition
Adjustment	Adjustment is the setting or alignment of the device under test, so that the angular measurement errors are minimized and do not exceed the error limits. An adjustment of the device under test can only be performed on the systematic angular measurement errors.
Calibration	Calibration is the comparison of measured values with reference values of known accuracy, taking into account the measurement uncertainty.
DNL	The differential non-linearity (DNL) is part of the systematic angular measurement error, defined as periodic systematic angular measurement error related to the physical signal generation, which in most cases is the number of periods and/or twice the number of periods per turn.
Error limit	The error limit defines the maximum deviation of the systematic angular measurement error from the real mechanical angle.
INL	The integral non-linearity (INL) is part of the systematic angular measurement error, defined as single period systematic angular measurement error per turn, which can occur from modulator eccentricity and/or mechanical mounting tolerances.
Measurement uncertainty	The measurement uncertainty is the expression of the statistical dispersion of the measured angular values. All measurements are subject to uncertainty so that a measurement is only complete if accompanied by the associated uncertainty, which usually is given as the repeatability standard deviation of the dispersion.
Random angular measurement error	The random angular measurement error, which is always present in the form of inherently unpredictable fluctuations in the readings of a measurement, consists of all random deviations from the real mechanical angle. It is described by the statistical 1-σ repeatability standard deviation, assuming a normal distribution. The random angular measurement error cannot be adjusted.
Repeatability standard deviation	The repeatability standard deviation defines the maximum 1-σ-value of the statistical angular measurement error.
Systematic angular measurement error	The systematic angular measurement error consists of all systematic deviations from the real mechanical angle, is predictable, and typically can be identified and adjusted. It mainly occurs from mechanical and/or electrical influences as well as from environmental conditions.

REFERENCES

[1] DIN Deutsches Institut für Normung e.V., DIN 1319-1:1995 Fundamentals of metrology – Part 1: Basic terminology

[2] JCGM Joint Committee for Guides in Metrology, JCGM 100:2008 Evaluation of measurement data – GUM Guide to the expression of uncertainty in measurement

[3] ISO International Organization for Standardization, ISO/IEC GUIDE 98-3:2008 Uncertainty of Measurement – Part 3: Guide to the Expression of Uncertainty in Measurement