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Basic concepts in metrology

Terminology relating to the use of measuring instruments

DIN 1319 Part 2

Grundbegriffe der Messtechnik; Begriffe für die Anwendung von Messgeräten

As it is current practice in standards published by the International Organization for Standardization (ISO), the comma has been used throughout as a decimal marker.

Contents

1 Scope

DIN 1319 Part 1 to Part 3 defines general basic concepts which are important for all sectors of metrology. The present standard deals with the terminology relating to the use of measuring instruments and measuring systems. Questions of detail which are of a specific and more far-reaching nature are reserved for the specialized standards or codes of practice valid in the different fields of application[1]).

2 Measuring instrument, measuring system, measuring chain, measuring installation

A measuring instrument supplies or embodies measured values (see DIN 1319 Part 1), also the combination of two or more independent measured values (e.g. the ratio of measured values).

A measuring system consists of a measuring instrument or two or more related measuring instruments plus additional facilities forming a complete assembly. The additional facilities consist primarily of auxiliary devices which do not directly serve the functions of sensing, transformation or output (e.g. facilities for auxiliary energy, reading magnifier, thermostat), as well as signal and measuring lines.

The principal task of a measuring system is the sensing of the measured value of a physical quantity (measurand) or of a measurement signal representing the wanted measured value, the onward transmission and conversion of the measurement signal and the display of the measured value.

The first element in a measuring system is often termed the sensor; this picks up the measured value of the measurand and delivers a corresponding measurement signal. The final element in a measuring system is termed the readout device; this may be either a direct readout device (visual readout device e.g. an indicating instrument or a recorder) or an indirect readout device (e.g. punched card readout device, magnetic tape readout device, memory).

The transmission elements of any kind existing between the sensor and readout device constitute the transmission path[2]); this comprises measuring amplifiers, measuring transducers and measuring converters (see subclause 3.2). Sensors and readout devices shall not be referred to as measuring transducers; sensors, measuring transducers

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1) See, for example:

DIN 2257 Part 1 and Part 2 Terminology used in dimensional metrology;

DIN 43 745 Electronic measuring systems;

DIN 43 780 Direct-acting indicating measuring instruments and accessories;

VDI/VDE-*Richtlinie* (Code of practice) 2600 *Metrologie (Messtechnik)* (Metrology).

In the course of the work on this standard attention was also paid to the *Vocabulaire de Métrologie Légale; termes fondamentaux* (1969) (Vocabulary of legal metrology; fundamental terms) of the *Organisation Internationale de Métrologie Légale (OIML)* (International Organization of Legal Metrology) (German-French version of the international vocabulary of legal metrology, collection of reprints from *PTB-Mitteilungen* 1967 to 1970).

2) By transmission path is meant here the complete transmission system between sensor and readout device, and not simply the measuring line and other line sections.

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and readout devices are, however, covered by the common term "measuring instrument".

A measuring system in the form of a system composed primarily of sensor, "chainwise" connected transmission elements (measuring transducers) and readout device is also termed a measuring chain.

A measuring installation comprises two or more mutually independent measuring systems which are related to one another in spatial or functional terms.

3 Types of measuring instrument

3.1 Measuring instruments with direct output (visual readout devices)

3.1.1 An indicating measuring instrument is characterized by the fact that the information offered or displayed by it, namely the measured value (see DIN 1319 Part 1), can be read off or taken off directly.

N o t e . The term "indicating measuring instrument" also covers a measuring instrument with null indication (analogue or digital indication) in a measuring system such that the measured value assigned to the zero position is given by a standard of comparison.

3.1.2 A recording measuring instrument marks individual measured values or the variation – usually in terms of time – of measured values (recorder, printer).

3.1.3 A counting measuring instrument displays as the measured value a number (e.g. piece counter, measuring system for counting α particles) or the total of quantifying units (e.g. water meter with measuring chambers, piston type gasmeter with integrating movement), or it belongs to the group of measuring instruments usually also termed "meters" which integrate a measurand with respect to time (e.g. electricity meters, gas-flow integrators).

3.1.4 In the case of measuring instruments with analogue indication an index (e.g. a defined part of a physical pointer or of a luminous spot, a vernier mark, an edge, the meniscus of a liquid column, the designated portion of a window) sets itself, usually continuously, to a position on the scale (graduation) of the instrument or the scale is aligned therewith. It is immaterial whether the moving element is the index or the scale.

N o t e . Certain indicating measuring instruments have two or more scales which may be arranged side by side or one behind the other with respect to the index.

3.1.5 In the case of measuring instruments with digital indication the output quantity is a numerical representation of the measurand in which the smallest increment is a given constant. The measured value appears discontinuously as the sum of quantifying units or as the sum (number) of pulses, e.g. in a digital sequence. Measuring instruments of this kind do not have a continuously readable scale (see DIN 1319 Part 1, November 1971 edition, clause 2).

N o t e . In the case of measuring instruments with numerical indication the sequence of digits may be given decade weighting by an automatic arrangement (indication of powers of ten, automatic point shifting).

3.1.6 Material measures are measuring instruments embodying specific, usually constant individual values, or a sequence of values of a measurand, e.g. a unit, multiples or submultiples of a unit (e.g. slip gauges, graduated flasks, weights, standard resistors; similarly a metre rule and a measuring cylinder are specific examples of material measures).

3.2 Transmitting measuring instruments (measuring instruments with indirect output)

Transmitting, non-indicating measuring instruments (measuring amplifiers, measuring transducers, measuring converters) within a measuring system or measuring chain constitute the principal elements of the transmission path (in telemetering also termed the "transmission channel", see DIN 40 146 Part 1); their function is to process the information concerning the measured value already available as measuring signals into other suitable measuring signals, and to pass them on (transmit them) to the readout (or further processing) device.

During this process the information concerning the measured value shall be preserved intact and unfalsified.

Examples: Measuring transducers (used here in the narrower sense of measuring instruments for transforming analogue input signals into analogue output signals unequivocally related to the input), current transformers and voltage transformers, measuring converters (e.g. analogue-to-digital converters), measuring amplifiers.

4 Output

The output is the information concerning the wanted measured value, delivered in whatever form by the measuring system or the measuring instrument, see DIN 1319 Part 1. The information may be made available either direct as an indication or indirect without indication.

N o t e . The further processing of outputs (e.g. information processing) is not covered by this standard.

4.1 Direct output; indication

The direct output, termed indication, is the output directly perceptible (readable) by the human senses. In the case of indicating measuring instruments it is stated in units of the measurand or as a numerical value, also as a number of scale divisions in the case of measuring instruments with scale indication (see subclause 6.4 and examples in subclause 6.7).

The indication can also be conveyed acoustically (e.g. radio time signals), as a light signal or via recorders or printers.

In the case of material measures (see subclause 3.1.6) the inscription (nominal value of the measurand) corresponds to the indication.

4.2 Indirect output

In the case of indirect output the wanted information regarding the measured value or the variation of the measured value is conveyed without indication or transmitted, in a form not interpretable without special facilities, to receiving devices. Hence, an indirect output constitutes either the onward transmission of the measured value at the output of a measuring transducer by means of measurement signals (e.g. voltage, current, pneumatic pressure, see DIN 40 146 Part 1) or the representation of the measured value, e.g. on punched cards, magnetic tape or other data media.

5 Output range, scale range, measuring range

5.1 Output range

The output range is the range of all values of the measurand which can be made available by a measuring instrument either direct or indirect.

5.2 Scale range

The output range of indicating measuring instruments is termed the scale range. It comprises the range of all values of the measurand observed which can be read off on a measuring instrument. Certain types of measuring instrument, e.g. thermometers with enlargements, may have two or more subranges.

Note 1. When selecting between ranges of a measuring instrument with two or more scale ranges, the scale interval, the scale factor and generally also the sensitivity are altered along with the scale range.

Note 2. The suppressed range is that range of values of the measurand which, by reason of the specific design of the measuring instrument, has to be covered before it starts to indicate.

The interruption range is the subrange of all possible measured values within which the measuring instrument does not indicate (e.g. linked with interruption of the scale).

Example:

In liquid thermometers (including those with zero mark) provided with an enlargement in the capillary the indication is suppressed or interrupted within a particular temperature range.

5.3 Specified measuring range

The specified measuring range is that range of values of the measurand within which specified, agreed or guaranteed limits of error are not exceeded (see DIN 1319 Part 3).

In the case of measuring instruments with two or more specified measuring ranges, different limits of error may apply to the individual ranges (example: multi-range measuring instrument).

The specified measuring range is defined by its limits, namely the minimum value and maximum value. The difference between both values is termed the span.

In the case of indicating measuring instruments the specified measuring range is a part of the scale range. It may cover the entire scale range, but often consists only of one or more parts of the scale range.

Note. The terms 'output range' (scale range) and 'specified measuring range' should be clearly differentiated and the two ranges precisely indicated.

6 Scales and terminology relating thereto

6.1 Types of scale

6.1.1 A line scale consists of an ordered set of scale marks on a scale carrier. Line scales mainly have a scale numbering with regular spacing and are mostly intended for the continuous indication of measured values.

Note. Scales exist as both plane types (with either straight or circular-arc base line) and as curved types. Depending on the arrangement and position of the pointer relative to the scale a distinction is made between horizontal edgewise scales, vertical edgewise scales, quadrant scales, sector scales and circular scales (see DIN 43 802 Scales and pointers for electrical measuring instruments).

6.1.2 A digital scale (e.g. of a meter) comprises a sequence of digits (usually 0 to 9) on a scale or numeral carrier, generally arranged so that only the digit to be read is visible. A multi-place digital scale consists of two or more single-place digital scales arranged side by side with digits which are readable, for example, through windows; the usual practice in such cases is for the individual digital scales to be ranked decimally relative to one another.

A digital scale is intended primarily to give a discontinuous stepwise indication. The difference between the digital scale and the line scale loses its significance (as regards readability or uncertainty of measurement) when the digital increment (see subclause 6.5) is smaller than the uncertainty of indication.

Note. The digit to be read off may be denoted, for example, by illumination (by means of luminous digits, decade counter tubes). Occasionally a digital scale (permitting only discontinuous indication) is combined with a (continuously readable) line scale, e.g. in the roller counters of certain integrating measuring instruments. In such cases the line scale gives the final digit(s) of the indication.

6.2 Scale length

The scale length (total length) of a line scale is the distance between the first and last scale marks, which are often specially emphasized, as measured in length units along the path traversed by the index. In the case of indicating measuring instruments with plane curved scale (circular scale) the scale length shall be measured along the arc passing through the centres of the shortest scale marks; the scale angle can also be specified.

6.3 Scale spacing

The scale spacing of a line scale is the distance, measured in linear or angular units, between two successive scale marks.

Note. Unduly small scale spacing (less than approx. 0,7 mm) should be avoided, since such scales are tiring to read and in particular the estimating of tenths is impossible so that the observation is rendered less certain. The index shall pass over the centres of the shortest scale marks. In the case of instruments with permanently built-in optical magnification the definitive spacing is the apparent scale spacing, i.e. the product of the scale spacing as defined above and the optical magnification or the scale of representation.

6.4 Scale division

The scale division of a line scale is one of the division units in which the indication can be given; the scale spacing is regarded for this purpose as the "scale division" unit of counting for the indication.

Note 1. The following are used as division units: scale division and digital increment (without indication of the unit of the measurand), scale interval (usually in units of the measurand).

N o t e 2. The scale division is implemented (relating to the marking with numerical values) as unity-based division, dual-based division or five-based division (see example in the note concerning subclause 6.7: unity-based division is exemplified by scale patterns A and B and dual-based division by scale pattern C). There are linear scales (in which the scale spacing is of equal value) and non-linear scales (see example in note concerning subclause 6.7: scale pattern D). The scale division of a line scale should be used as a division unit only in the case of linear scale division.

6.5 Digital increment

The digital increment of a digital scale is equal to the jump between two successive numerals of the last digit.

6.6 Scale interval

In the case of a measuring instrument with scale indication the scale interval is equal to that change in the value of the measurand which corresponds on a line scale to a displacement of the index through one scale division. In the case of a measuring instrument with digital indication the scale interval is equal to that change in the value of the measurand which corresponds on the digital scale to the digital increment. The scale interval shall always be specified in the unit which has been chosen for the measurand. The scale interval is used as the characteristic quantity, for example, in the case of the following indicating measuring instruments: liquid thermometers, areometers, length measuring instruments, volume measuring instruments with scale.

N o t e. If the last digit of a multi-place digital scale is read off on a line scale, the scale interval shall be related to a scale spacing of the line scale.

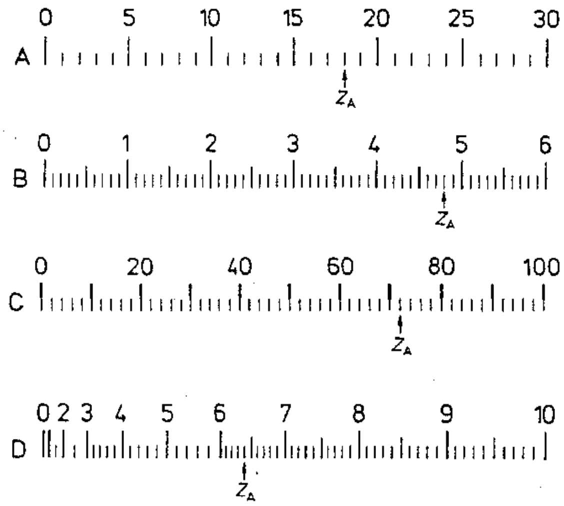
6.7 Scale constant, instrument constant

The scale constant of measuring instruments with scale indication without a directly stated unit (e.g. in the case of multi-range measuring instruments) is that quantity k with which the numerical value of the indication z_A (corresponding to the position of the index relative to the scale numbering) is to be multiplied in order to obtain the wanted measured value x, hence

$$x = k\, z_A \text{ and } k = x/z_A$$

The scale constant, which is also briefly referred to as the constant, is used mainly in connection with electrical measuring instruments. The scale constant k is also often referred to as the "instrument constant", particularly in the case of instruments without scale (e.g. capillary viscometers), and in certain fields the term "calibration constant" is also used.

N o t e. The difference between the term "scale interval" and "scale constant" may be illustrated by the following four scale patterns with the index positioned at the point marked z_A in each case.



In the case of scale pattern A the scale divisions are counted continuously; the numbering denotes the number of scale divisions. In this case, assuming a uniformly divided scale, the scale interval agrees with the scale constant.

In the case of scale pattern B groups of 10 scale divisions are counted continuously and numbered. Therefore, in this case the scale interval differs from the scale constant. The measured value x is obtained from x = 4,8 · 1,0 mA = 48 · 0,1 mA = 4,8 mA.

In the case of scale pattern C with dual-based division groups of 10 scale divisions are counted continuously and numbered according to the dual-based division. Hence the scale interval 0,4 mA *is twice the size of the scale constant* 0,2 mA. *The measured value x is obtained from x = 72 · 0,2 mA = 36 · 0,4 mA = 14,4 mA.*

In the case of scale pattern D with non-linear (in this case square) division, the subdividing of the scale between the long, numbered scale marks shall be coarser at the start than at the finish. The scale intervals in this case would be 0,1 A; 0,05 A; 0,02 A *and* 0,01 A *in the corresponding indication ranges:* 0 *to* 1; 1 *to* 3; 3 *to* 6 *and*

Scale	*Indication z_A*		*Measuring range e.g.*	*Scale constant k*	*Scale interval*	*Measured value x at indication z_A*
	Numerical value	*Number of scale divisions*				
A	18,0	18	0 *to* 6 mA	0,2 mA	0,2 mA	3,6 mA
B	4,8	48	0 *to* 6 mA	1,0 mA	0,1 mA	4,8 mA
C	72	36	0 *to* 20 mA	0,2 mA	0,4 mA	14,4 mA
D	6,4	–	0,3 *to* 1 A	0,1 A	–	0,64 A

6 to 10. *Hence in such cases only the scale constant can be used, which is always independent of the way the scale is divided.*

6.8 Multi-range measuring instruments

In the case of multi-range measuring instruments the scale interval or the scale constant relating to each range shall be stated.

It is often regarded as sufficient, however, to state the measured value for the maximum scale value which, in the case of electrical measuring instruments, usually corresponds with the maximum value of the measuring range.

7 Sensitivity

7.1 Definition

The sensitivity of a measuring instrument (in certain circumstances at a definite point) is expressed by the quotient of an observed change of the output signal (or of the indication) and the (sufficiently small) change of the input signal (or of the measurand) causing it. The concept of sensitivity is used mainly in connection with indicating measuring instruments.

7.2 Method of stating sensitivity when the latter varies

If the sensitivity is not constant along the scale it is necessary to specify the indication to which it applies each time, or the corresponding value of the measurand. In particular, a distinction may be made between the start-of-range sensitivity and the end-of-range sensitivity.

Note 1. It should always be borne in mind that the change in the effect is to occupy the numerator of every sensitivity quotient, whereas the change in the cause is to occupy the denominator. It is only meaningful to speak of sensitivity when there is no possibility of doubt as to which quantity is to be regarded as the cause and which as the effect.

Note 2. It is contrary to the definition to name as the sensitivity the reciprocal of the quotient defined for this purpose. For example, the current sensitivity of a galvanometer with a scale in length units is not 10^{-8} A/mm, *but* 100 mm/µA *(more readily visualized than* 10^8 mm/A*).*

Note 3. It should be noted that the sensitivity is referred to the change of the measurand and not to the deflection angle.

Note 4. In the physics of optical radiation and lighting practice (see DIN 5031 Part 2) the preferred term, apart from the sensitivity as differentially defined in subclause 7.1, is the "total sensitivity s" being the quotient of the output quantity Y (effect) and the input quantity X (cause), hence $s = \frac{Y}{X}$.

Note 5. In the field of radiation technology a concept analogous to that of the total sensitivity s in optics is the responsivity. In radiation technology, and more especially in dosimetry, the "responsivity" (or the "detection probability") used for classifying measuring instruments, and particularly radiation detectors, is defined as the ratio of the indication observed on the measuring instrument to the value of the measurand causing it.

7.3 Method of stating sensitivity in the case of scale indication

In the case of measuring instruments with scale indication the sensitivity E is equal to the quotient obtained by dividing the change ΔL in the indication by the change ΔM in the measurand causing it, hence sensitivity $E = \frac{\Delta L}{\Delta M}$.

Note. If the scale spacing of a linear line scale is designated as A, the scale interval as S and the sensitivity as E, *then* $E = \Delta L/\Delta M \approx A/S$. *Hence the sensitivity is also approximately equal to the quotient obtained by dividing the scale spacing by the scale interval and thus is independent of the nature of the scale division.*

7.4 Method of stating sensitivity in the case of digital indication

In the case of measuring instruments with digital indication the sensitivity E is equal to the quotient obtained by dividing the number ΔZ of the digital increments, by which the indication changes as a result of a change ΔM in the measurand, by the change ΔM causing it, hence $E = \Delta Z/\Delta M$.

7.5 Sensitivity of length measuring instruments

In the case of length measuring instruments the sensitivity is equal to the ratio of the travel of the index, e.g. the pointer, to the travel of the measuring element, e.g. the contact stylus (output travel to input travel).

Example:

> A precision indicating gauge with a ratio of 1000 : 1 (transfer factor 1000) has a sensitivity of 1 mm/0,001 mm, because a change of 0,001 mm in the measurand causes the indication to change by 1 mm.

8 Reversal error

The reversal error of a measuring instrument at a given value x_e of the measurand (input quantity) is equal to the difference of the indications $(x_a' - x_a)$ (output values) obtained when the specified measured value x_e is slowly set either continuously or incrementally by approaching it first from smaller values – increasing (indication x_a) and, second, from larger values – decreasing (indication x_a'). The relative reversal error is then $(x_a' - x_a)/x_a$. For the fixed measured value x_e either values in the vicinity of the limits of the measuring range (approx. 0,1 and 0,9 of the scale range), the maximum value or the mean value within the measuring range are chosen.

When quantitative information regarding the reversal error is given, the measuring method shall be stated. In general the reversal error is to be determined in a closed cycle between zero and the maximum value of the measuring range; for this purpose it is normally measured at several points throughout the range in graduated steps.

Note 1. Causes of reversal error are, for example, friction, lost motion, elastic effects, remanence, hysteresis.

N o t e 2. The reversal error is not always constant (e.g. due to variability of friction). It is often simply stated as being below a certain limit.

9 Discrimination threshold, discrimination value, starting value

The discrimination threshold is that value of a small change in the measurand which is necessary to produce for the first time a perceptible change in the response of a measuring instrument (first visible change in a pointer deflection, for example).

The discrimination threshold at the zero point is also termed the discrimination value.

In the case of integrating measuring instruments the discrimination value is termed the starting value. It is that value of the measurand above which integration with respect to time is performed (e.g. current or power in the case of electricity meters, or volumetric flow through a gas-flow integrator) at which the first clearcut indication is perceptible, i.e. at which the meter starts positively.

Example:

> A class 1,0 electricity meter must start and continue running at 0,4 % of the rated current under rated conditions. A check has to be made that the rotor definitely makes a full revolution (see IEC Publication 521).

N o t e 1. Discrimination threshold, discrimination value and starting value are not always constant (e.g. owing to the variability of friction). They are often simply stated as being below a certain limit.

N o t e 2. In some areas of metrology the term "resolution" is used. This is understood to mean the small change in the value of the measurand which is necessary to produce a perceptible (often specified) small change in the response (in the case of measuring instruments with scale indication, for example, 1/5 of the scale interval). In the case of measuring instruments with digital indication the resolution is equal to the digital increment.

In optics the resolution (resolving power) of a measuring system is the smallest separation between two points of an object or of two adjacent magnitudes which can be registered by the measuring system as being definitely separated (distinctly distinguishable). Example: In the case of a microscope the resolution is the smallest separation of two points which appear in the image as still separated.

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