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Measurement

Wer misst, misst Mist. Damit das nicht passiert, hier noch einmal die wichtigsten Grundlagen auf Englisch.

We measure constantly. When we lift a pen, our senses measure its weight, and when we walk, our body registers *acceleration*, speed and the distance to our *destination*. In engineering we *conduct* tests to optimise our designs or check parameters to verify the quality of our products. But what exactly is a measurement?

When measuring we *quantify* a certain *property* of something, e.g. a body, a substance or a physical phenomenon, by comparing it to a given standard *unit*. The result of the measurement therefore comes in two parts – a unit of measurement according to the property and a number for how many times the standard unit is *contained* in the measured object. Two of many properties of a steel *girder* are its mass and length. According to the Système International d'Unites, or SI units, the unit of the property mass is kilogram (kg) and the unit of the length is metre (m). Compared to the prototype of the kilogram and metre kept in Paris (or their *contemporary* definitions), the girder might be five times a standard metre and 500 times a standard kilogram.

If the measurement is taken by comparing the length of the girder to something with the same property, i.e. the length of a *ruler*, it's called a direct measurement. An indirect measurement, in contrast, looks at a different property, maybe the time sound takes to travel from one end of the girder to the other.

Every Measurement is Inexact

No matter how *elaborate* a test setting might be, or how carefully we take a measurement, there's always a *margin* of doubt. *Inaccuracy* is an integral part of any measurement. Since a measurement is *faulty* by definition, several measurement *attempts* will return different results. The difference between the measured *value* and the true value is called an error. There are many sources of errors.

Most importantly, all *environmental* effects should be *taken into consideration*. Temperature influences the length or volume of an object; other local conditions like air pressure, *elevation* or *humidity* might affect other properties. The measured item should also be stable. A *shifting* frequency or a leaking container are hard to measure. Naturally, the measuring instrument also plays an important role and any faults can easily be multiplied. Electric noise interfering with sensors or a worn out *vernier calliper* are just two of many examples. Equally important as the measuring instrument is the operator and the process he sets up. Reaction times in using a stopwatch vary from person to person and measuring the *circumference* of a cylinder with a *folding rule* is definitely poor practice.

Random or Systematic

All these errors mentioned above can be either random, systematic or in the worst case, both. A systematic error is one which *occurs* with the same value for each of the repeated measurements. The *jaws* of a vernier calliper might be bent resulting in an extra millimetre for each measured length. Or an operator always takes the same tenth of a second reaction time before pressing a button. Because they are constant and happen all the time, systematic errors are very hard to tell. To reduce the risk of systematic effects, measuring instruments regularly have to be checked, i.e. tested against a standard of higher *accuracy*. Such a calibration might be done by comparing the *equipment* to that of a calibration laboratory, which in turn is tested against national standards to *ensure* the *traceability* of the measurement.

Other strategies to avoid systematic errors include using different measuring methods or different set-ups. Naturally, *skilled* operators and a *sophisticated* process are equally important.

Random errors, in contrast, are *unavoidable* but can be *detected* and quantified by repeating the measurement.

Measure *Thrice*, Cut Once

Since, by definition, each measurement is different, a series of tests will result in a *spread* of values representing a *probability distribution*. This distribution can be used to quantify the doubt about the measurement result or the *uncertainty*. A measurement result is only complete when accompanied by a statement of its uncertainty. The *degree* of uncertainty might be important in deciding whether or not a result is adequate for a certain *purpose*. It also allows us to compare results and see if they are *consistent*.

In most cases, the distribution of the values will be a normal or Gaussian distribution with its characteristic bell shape. Statistical methods are then used to calculate the standard deviation. A standard uncertainty is defined as the margin whose size can be thought of as 'plus or minus one standard deviation'. By converting them to the standard uncertainty, all *contributing* uncertainties are expressed at the same *confidence* level and are therefore better to compare and combine. ■

Matthias Meier

(in)accuracy • **äkjərəßi**	*(Un)Genauigkeit*
acceleration	*Beschleunigung*
attempt	*Versuch, Anlauf*
circumference • **ßəkamfərənß**	*Umfang*
conduct, to	*durchführen, vornehmen*
confidence	*Vertrauen*
consistent	*übereinstimmend, vereinbar*
contain, to	*enthalten, beinhalten*
contemporary	*heutig, zeitgemäß*
contribute, to	*beisteuern, beitragen*
conversion table	*Umrechnungstabelle*
degree	*Grad, Maß*
destination	*Ziel*
detect, to	*erfassen*
distribution	*Verteilung*
elaborate	*durchdacht, aufwendig*
elevation	*Höhe, Höhenangabe*
ensure, to	*sicherstellen, garantieren*
environmental	*Umgebungs-*
equipment	*Gerät, Apparatur*
faulty	*fehlerhaft, defekt*
folding rule	*Gliedermaßstab*
girder • **gödə**	*Träger*
humidity	*Feuchtigkeit, Luftfeuchte*
jaw	*Backe*
margin	*Spanne, Spielraum*
measurement	*Messung, Messtechnik*
occur, to • **əkö**	*sich ereignen*
probability	*Wahrscheinlichkeit*
property	*Eigenschaft*
purpose • **pöpəß**	*Zweck, Ziel*
quantify, to	*mengenmäßig bestimmen*
random	*zufällig*
ruler	*Maßstab, Lineal*
shift, to	*verschieben*
skilled	*geschult, qualifiziert*
sophisticated	*ausgeklügelt, hochentwickelt*
spread	*Spanne, Spannweite*
take into consideration, to	*beachten, bedenken*
thrice • **θreiß**	*dreimal*
traceability	*Rückverfolgbarkeit*
unavoidable	*unvermeidbar*
uncertainty	*Unsicherheit*
unit	*Einheit*
value	*Wert*
vernier calliper	*Schublehre, Messschieber*

Conversion Table
Imperial and Metric Units

Before SI units were widely adopted around the world, the British systems of English units and later Imperial units were used in Britain, the Commonwealth and the United States. Unfortunately, Imperial units are still widely in use, not only in literature but also in real life.

Length	
1 inch	2.53 centimetres
0.394 inch	1 centimetre
1 foot = 12 inches	0.305 metre
1 yard = 3 feet	0.914 metre
1.094 yards	1 metre
1 mile = 1760 yards	1.609 kilometres
0.621 mile	1 kilometre

Volume Imperial	
1 fluid ounce (fl oz)	28.413 millilitres
1 pint (pt) = 20 fl oz	0.568 litre
1 gallon = 8 pts	4.546 litres

Volume US	
1 fluid ounce (fl oz)	29.574 millilitre
1 pint (pt) = 16 fl oz	0.473 litre
1 gallon = 8 pts	3.785 litres

Mass	
1 ounce (oz)	28.35 grams
0.035 ounce	1 gram
1 pound (lb) = 16 oz	0.454 kilograms
2.205 pounds	1 kilogram
1 stone = 14 lb	6.35 kilograms