Measuring with the Electronic-Scale

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MEASURING WITH THE ELECTRONIC SCALE *(abbr: ES)*

Measurement results can be affected by the most diverse influences. Thus, for accurate measuring, on the one hand certain technical requirements must be met and on the other sufficient skills of all contexts be available so that the results obtained can also be correctly interpreted.

Influencing factors:

- Precision and physical properties of the rule/measuring device
- Measuring area (imprecision increases with the size of the area, as a rule not linearly but (somewhat) exponentially).
- Measurement setup (planarity of the measurement support, parallax errors, Abbe's comparator principle etc.)
- Thermal environmen:
    - o Temperature (ambient temperature, radiant heat from the lighting, body temperature of the operator when touching, ...)
    - o humidity (e.g. in paper or plastic foil)
    - o acclimatisation period / -degree
- Physical properties of the part to be tested (coefficients of contraction and expansion, etc.)
- Edge definition of the measuring object
- Tester/user (skills, experience and (visual) susceptibility)

1. Precision of measuring instruments with digital display

With measuring instruments with digital displays it should be noted that as a rule the value displayed does not correspond to the real measurement result. This is because on the one hand the interim values (significance beyond the last displayed digit) are rounded and on the other the display does not take into account either instrument imprecision or any influences caused by the operating personnel.
As a rule, manufacturers give limits of tolerance for instrument imprecision, within which the deviation from the real measurement must lie.

Example for an electronic measuring instrument with guaranteed precision of $\pm$ 0.05 mm:
value shown on the display = 347.12 mm
the actual measurement can be any value between 347.07 mm and 347.17 mm.

"Repeat accuracy" and *"resolution"* are often confused with the actual measuring *"precision"* of an instrument. The three terms have however completely different meanings. *"Repeat accuracy"* states how large the variance if one and the same measurement is measured several times. *"Resolution"* on the other hand is the fineness of the display and states the smallest sub-step shown on the display (e.g. 0.01 mm on the ES; interim values are rounded off).

2. Precision of the ELECTRONIC SCALE

Factors that influence the instrumental accuracy of a rule (e.g. ES) are:

- Construction (rod geometry, coordination of parts, measurement range, consideration of metrological basic principles such as Abbe's comparator principle, parallax, etc.)
- Optical system
- Electronics (as a plotting element) (in the ES: ± 0.01 mm)
- Precision of the capacitor scale (impetus element)

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There are no absolutely accurate measuring devices. Even the ELECTRONIC SCALE has deficiencies. The error margins of these imprecisions are according to the manufacturer:

ES 180	:	0.03 mm
ES 300	:	0.03 mm
ES 500	:	0.03 mm
ES 800	:	0.04 mm
ES 1000	:	0.05 mm
ES 1300	:	0.08 mm
ES 1500	:	0.10 mm

This information should not be understood as plus/minus indications, but correspond respectively to the total "error margins". E.g. in the ES 800 all imprecisions must lie within a margin of 0.04 mm max. In practice this means for the ES 800 example that all deviations found when testing must fall within a range

	from	-0.04 mm	to	0.00 mm (lower extreme case)
or	from	-0.03 mm	to	+0.01 mm
or	from	-0.02 mm	to	+0.02 mm
or	from	-0.01 mm	to	+0.03 mm
or	from	0.00 mm	to	+0.04 mm (upper extreme case)

So that the user knows in which tolerance range his instruments works, each ES comes with a test certificate. However at the same time it must be remembered that the given measurement values only show the tendency and cannot be used as absolute correction values, as absolute zero can be set arbitrarily on the ES.

3. Measurement setup

Measurement inaccuracies arise if the test sample and/or test device bend. A good base is necessary to obtain precise measurement results. Whether layout table or other measurement plate, it must not be allowed to bend! Planarity directly affects the result.

4. Temperature

The effect of temperature (as well as that of humidity", dealt with under Paragraph 5) is in practice hardly or never considered. The characteristic of different materials to expand considerably to various degrees when temperature alters then leads to erroneous interpretations of the measurement results.

The following example will illustrate this problem:

Measuring object/test sample:	Mylar® film
Measuring instrument:	ES 1000 (made of Cr/Ni steel)
Temperature of the measuring objec:	30 °C (layout table!)
Temperature of the rule:	20 °C
Section to be measured:	1000 mm

The following formula applies to thermal expansion:

$\Delta L = L \times AK_T \times \Delta T$ where

ΔL:	elongation
L:	length
AK_T:	coefficient of thermal expansion α
ΔT:	temperature difference

The coefficient of thermal expansion α of polyester is: 27×10^{-6} / °C

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Therefore the following elongation results for the film (at 1,000 mm at 10 °C temperature difference):

$$\Delta L = L \times AK_T \times \Delta T = 1000\ \text{mm} \times 27 \times 10^{-6} / {}^\circ\text{C} \times 10^\circ\text{C} = 0.27\ \text{mm}$$

The error is reduced if the rule has the same temperature as the film (thermal expansion of Cr/Ni steel: $11.5 \times 10^{-6} / {}^\circ\text{C}$). The increase in length of the ES in our example is:

$$\Delta L = L \times AK_T \times \Delta T = 1000\ \text{mm} \times 11.5 \times 10^{-6} / {}^\circ\text{C} \times 10^\circ\text{C} = 0.115\ \text{mm}$$

Since a rule that is too long measures too short, the above determined value for the polyester film is corrected by 0.115 mm.

The resulting measurement error is thus: 0.27 mm – 0.115 mm = 0.155 mm.

This example clearly shows the effect of temperature and how important it is to know the actual temperatures but also the physical properties of the test sample and of the measuring equipment. If the test sample and rule are laid on a warm layout table, then the film (test sample) quickly absorbs the heat, while the heat absorption of the steel rule (the measuring equipment) takes somewhat longer. During this adaptation time as a rule no exact temperatures are known and it is not really known how far test sample and measuring equipment have already adapted. No precise measurements are possible in this period! (see also *acclimatisation*)

Numerical examples of expansion in relation to material, temperature and length:

a) Expansion of Cr/Ni steel: (thermal coefficient of expansion $AK_T = 11.5 \times 10^{-6} / {}^\circ\text{C}$)

Temperature difference	Measuring length / elongation length (all measurements in mm)					
	100	200	300	400	500	1000
1 °C	0.00115	0.00230	0.00345	0.00460	0.00575	0.01150
2 °C	0.00230	0.00460	0.00690	0.00920	0.01150	0.02300
3 °C	0.00345	0.00690	0.01380	0.01840	0.02300	0.03450
4 °C	0.00460	0.00920	0.01380	0.01840	0.02300	0.04600
5 °C	0.00575	0.01150	0.01725	0.02300	0.02875	0.05750

b) Expansion of glass: (thermal coefficient of expansion $AK_T = 9.0 \times 10^{-6} / {}^\circ\text{C}$)

Temperature difference	Measuring length / elongation length (all measurements in mm)					
	100	200	300	400	500	1000
1 °C	0.00090	0.00180	0.00270	0.00360	0.00450	0.00900
2 °C	0.00180	0.00360	0.00540	0.00720	0.00900	0.01800
3 °C	0.00270	0.00540	0.00810	0.01080	0.01350	0.02700
4 °C	0.00360	0.00720	0.01080	0.01440	0.01800	0.03600
5 °C	0.00450	0.00900	0.01350	0.01800	0.02250	0.04500

c) Expansion difference between Cr/Ni steel and glass

Temperature difference	Measuring length / elongation length (all measurements in mm)					
	100	200	300	400	500	1000
1 °C	0.00025	0.00050	0.00075	0.00100	0.00125	0.00250
2 °C	0.00050	0.00100	0.00150	0.00200	0.00250	0.00500
3 °C	0.00075	0.00150	0.00225	0.00300	0.00375	0.00750
4 °C	0.00100	0.00200	0.00300	0.00400	0.00500	0.01000
5 °C	0.00125	0.00250	0.00375	0.00500	0.00625	0.01250

NB: the expansion coefficients shown are examples and are not valid for all types!

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5. Humidity

Humidity does not cause any alteration of length in the ELECTRONIC SCALE. It can however have an effect on the measuring object, as e.g. on the test sample from the previous example (polyester film).

The following formula applies for expansion through absorption of humidity:

$\Delta L = L \times AK_F \times \Delta T$ where
ΔL: elongation
L: length
AK_F: expansion coefficient for humidity
ΔT: temperature difference

The expansion coefficient for humidity for polyester is: 12×10^{-6} / %RF (relative humidity).

For the film this results in an alteration of length (to 1,000 mm with a modification of 10% RF):

$$\Delta L = L \times AK_F \times \Delta T = 1000 \text{ mm} \times 12 \times 10^{-6} / \%RF \times 10 \%RF = 0.12 \text{ mm}$$

Attention: water absorption and -delivery are protracted processes depending on the properties of the object and can often take several days!

Acclimatisation:

As temperature and humidity have such a major influence on precision, it is extremely important to give the test material and measuring equipment sufficient time to adapt to prevailing conditions. If acclimatisation is fully complete, the effects of temperature and humidity (provided that the corresponding coefficients are known) can be purely arithmetically compensated for or calculated against relatively easily with the above formulae. If however acclimatisation is still in progress (e.g. with plastic film after just 24- or 48 hours), then it is not known exactly how far this has progressed, or how much the test sample is still being modified. And consequently arithmetic compensation or safe measurement is not possible.

Numerical examples of measurement deviation of a polyester film in relation to temperature and length and relative humidity and length:

A) Measurement deviation with temperature change: (thermal coefficient of expansion $AK_T = 27 \times 10^{-6}$ / °C)

Temperature difference	Measuring length / elongation length (all measurements in mm)					
	100	200	300	400	500	1000
1 °C	0.0027	0.0054	0.0081	0.0108	0.0135	0.0270
2 °C	0.0054	0.0108	0.0162	0.0216	0.0270	0.0540
3 °C	0.0081	0.0162	0.0243	0.0324	0.0405	0.0810
4 °C	0.0108	0.0216	0.0324	0.0432	0.0540	0.1080
5 °C	0.0135	0.0270	0.0405	0.0540	0.0675	0.1350
6 °C	0.0132	0.0324	0.0486	0.0648	0.0810	0.1620
7 °C	0.0189	0.0378	0.0567	0.0756	0.0945	0.1890
8 °C	0.0216	0.0432	0.0648	0.0864	0.1080	0.2160
9 °C	0.0243	0.0486	0.0729	0.0972	0.1215	0.2430
10 °C	0.0270	0.0540	0.0810	0.1080	0.1350	0.2700

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B) Measurement deviation with humidity change: (thermal coefficient of expansion $AK_F = 12 \times 10^{-6}$ / °C)

Difference % RF	Measuring length / elongation length (all measurements in mm)					
	100	200	300	400	500	1000
1 °C	0.0012	0.0024	0.0036	0.0048	0.0060	0.0120
2 °C	0.0024	0.0048	0.0072	0.0096	0.0120	0.0240
3 °C	0.0036	0.0072	0.0108	0.0144	0.0180	0.0360
4 °C	0.0048	0.0096	0.0144	0.0192	0.0240	0.0480
5 °C	0.0060	0.0120	0.0180	0.0240	0.0300	0.0600
6 °C	0.0072	0.0144	0.0216	0.0288	0.0360	0.0720
7 °C	0.0084	0.0168	0.0252	0.0336	0.0420	0.0840
8 °C	0.0096	0.0192	0.0288	0.0384	0.0480	0.0960
9 °C	0.0108	0.0216	0.0324	0.0432	0.0540	0.1080
10 °C	0.0120	0.0240	0.0360	0.0480	0.0600	0.1200

NB: the expansion coefficients shown are examples and are not valid for all types!

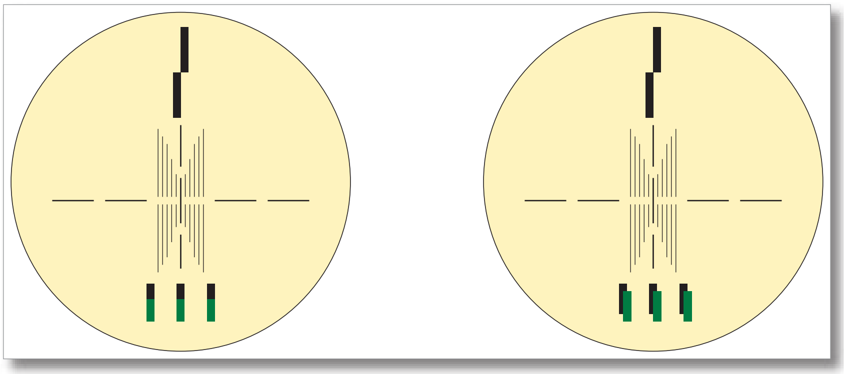
Magnifying lens or microscope?

With ELECTRONIC SCALE different optic aids for locating the measurement lines are available for selection. On the one hand a 10x magnifying lens and on the other a microscope machined specifically for this use with either 25x or 50x magnification.

The precision lens used in the standard model has the advantages of greater field of view and laterally correct image display. Unfortunately it has the great disadvantage of the so-called parallax.

6. Parallax

If there is a gap between the lines on the reticle plate of the measuring equipment and the lines on the measuring object, then a measurement error will occur if the view into the magnifying lens is not exactly vertical.



correct wrong

The measurement error increases with the distance between the measuring mark on the reticle plate and the line to be measured on the test material and with the angular deviation of the viewing axis from the vertical.

The "Parallax check" of the ELECTRONIC SCALE gives the user the ability to check the viewing angle.

Only when the fields lying above one another are optimally aligned does the viewer look vertically at the measurement marks. When used correctly, the ES's sophisticated reticle plate image thus helps to keep the play of individual interpreting low and to reduce measurement uncertainty and measuring results variance of different testers to a minimum.

In optical systems with several lenses such as a microscope, the optic axis is given by the lens system. Thereby the optics cannot be looked through crookedly as with a magnifying lens and no parallax error occurs. This, along with the higher magnification, is the main advantage of a microscope. The disadvantages of a microscope are the smaller view field and the inversion of the image being displayed. What appears at the top is at the bottom; what appears on the left is on the right. When working with a microscope at the beginning this is somewhat confusing. Generally however the user quickly gets used to it.

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7. Visual susceptibility of the tester

Practice makes perfect! - By repeated or regular working the eye becomes more trained and the visual susceptibility of the tester is improved. The user learns to read the picture quicker and better and to interpret more surely.

Factors influencing the measurement results

General influencing factors:

- Precision and physical properties of the rule/measuring device
- Measuring area (imprecision increases with the size of the area, as a rule not linearly but (somewhat) exponentially).
- Measurement setup (planarity of the measurement support, parallax errors, Abbe's comparator principle etc.)
- Thermal environment:
    - Temperature (ambient temperature, radiant heat from the lighting, body temperature of the operator when touching, ...)
    - humidity (e.g. in paper or plastic foil)
    - acclimatisation period / -degree
- Physical properties of the part to be tested (coefficients of contraction and expansion, etc.)
- Edge definition of the measuring object
- Tester/user (skills, experience and (visual) susceptibility)

Factors affecting the precision of an ELECTRONIC SCALE or similar rule:

- Construction (rod geometry, manufacturing precision, coordination of parts, physical properties of the materials being used, measurement range, consideration of metrological basic principles such as Abbe's comparator principle, parallax, etc.)
- Optical system
- Electronics (as a plotting element) (in the ES: +/- 0.01mm)
- Precision of the capacitor scale (impetus element)

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