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Measuring Uncertainty

A New Software Function for Dynamic Display of the Uncertainty of Measurement in Cubis® II Balances

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Abstract

The QApp "Measuring Uncertainty" is a new software function available in the QApp Pharma Package of Sartorius's Cubis® II premium balances. This QApp function provides a dynamic display of the uncertainty of measurement, based on the EURAMET Calibration Guide No. 18 "Guidelines on the Calibration of Non-Automatic Weighing Instruments"[1-3] (denoted as "EURAMET cg-18" in the following).

The attachment to Sartorius's calibration certificate according to EURAMET cg-18 also shows a determination of weighing uncertainty when the balance is in use. This global expanded software function "measuring uncertainty" is given in the form of a straight-line equation, containing both a constant contribution and a contribution proportional to the reading. In most cases, this represents a sufficiently good estimation of the uncertainty of weighing results of the balance in use.

For the benefit of the user, the software function allows entering the parameters (as shown in the calibration certificate according to EURAMET cg-18) of the straight-line equation directly into the device. Thus the software function always directly specifies the uncertainty for each measured value, as shown in the appendix to the calibration certificate.

Find out more: www.sartorius.com/cubis-ii

Why is Measurement of Uncertainty Important?

Today's high-performance laboratory balances support users in every respect, with impressive practical and regulatory functionality. Nonetheless, high-performance laboratory balances are complex and highly sensitive measuring devices. Therefore, depending on the device, many different influences, such as the installation location and the expertise of the user, can influence the displayed results.

Even if a balance is properly leveled, adjusted, and calibrated, one question for the user remains: How large is the uncertainty of the displayed weight value?

A new dynamic function displays the uncertainty for each measured value in the complete weighing range, from zero to the maximum capacity. This particularly benefits customers working in regulated environments, for whom documentation of weighing values is of critical importance; the function allows printing of each weighing value with its corresponding uncertainty.

The required parameters can be set easily by Sartorius Service. Values are taken from the calibration certificate, considering multiple parameters contributing to the uncertainty.

All influencing parameters are defined and described in detail in the EURAMET cg-18.

The EURAMET (European Association of National Metrology Institutes) is a collaborative alliance of national metrological organizations from member states of the European Union (EU) and of the European Free Trade Association (EFTA). EURAMET coordinates metrological activity at a European level, liaising with the International Organization of Legal Metrology (OIML) and the International Bureau of Weights and Measures (BIPM), where appropriate.

The software function's calculation for measuring uncertainty of weighing results includes uncertainty contributions for many aspects, for instance, rounding at zero and under load, repeatability, deviation from eccentric loading, possible changes to the balance, and buoyancy effects of temperature changes at the place of use. Moreover, the error of indication, and its interpolation determined during calibration.

Theoretical Background

The EURAMET cg-18 describes the complete metrological theory and background of the measuring uncertainty of weighing. In the following, we attempt to summarize this very comprehensive theory in its basic statements and try to clarify the essential relationships.

A general description of the possible influences on the weighing result W can be shown by the following equation, which takes various corrections into account:

$$W = W^* + \delta R_{\mathrm{instr}} + \delta R_{\mathrm{proc}}$$

In this general equation, W^* is the indicated weight value directly after the calibration of the balance. The term δR_{instr} represents a correction due to environmental influence when using the instrument after calibration. The term δR_{proc} includes all corrections due to the operation of the instrument.

To distinguish from the indications obtained during calibration and the weighing results obtained when weighing a load *L* after calibration on the instrument, the parameters R_0 and R_{L} must be taken into account.

R_0 = the reading without load on the calibrated instrument obtained after the calibration.

R_{L} = the reading when weighing a load *L* on the calibrated instrument obtained after the calibration.

The indicated weight value directly after the calibration, can then be expressed by the following equation

$$W^* = R_{\mathrm{L}} + \delta R_{\mathrm{digL}} + \delta R_{\mathrm{rep}} + \delta R_{\mathrm{ecc}} - \left(R_0 + \delta R_{\mathrm{dig0}}\right) - E$$

The following error contributions of the reading in use are taken into account:

δR_{dig0} = the rounding error at zero reading

δR_{digL} = the rounding error at load reading

δR_{rep} = the repeatability of the instrument

δR_{ecc} = the error due to eccentric positioning of a load

E = the error of indication for a reading, which is reported in the calibration certificate

Generally, users of an instrument should be aware that, in normal use, the weight is different from that at calibration, in some or, very often, all aspects.

The following term describes the errors regarding the individual environmental influences during weighing, after calibration of the instrument.

$\delta R_{\text{instr}} = \delta R_{\text{temp}} + \delta R_{\text{buoy}} + \delta R_{\text{adj}}$

Including these contributions

δR_{temp} = the possible change in the characteristic of the instrument caused by a change in ambient temperature

δR_{buoy} = the possible change in the buoyancy due to a variation of the air density

δR_{adj} = the possible change in the characteristics of the instrument since the time of calibration due to drift, or wear and tear (not taken into account in the calibration certificate)

The contributing terms for the errors resulting from the particular operation of the instrument are

$\delta R_{\text{proc}} = \delta R_{\text{Tare}} + \delta R_{\text{time}} + \delta R_{\text{ecc}}$

with

δR_{Tare} = the possible change due to a tare balancing operation

δR_{time} = possible effects of creep and hysteresis (not taken into account in the calibration certificate)

δR_{ecc} = the possible error due to eccentric positioning of a load.

Finally, the expanded global measurement of uncertainty $U_{gl}(W)$ can be calculated using the following equation which includes all the above described parameters

$$U_{\text{gl}}(W) = 2 \cdot \big[u^2(R) + a_1^2 \cdot R^2 + a_1^2 \cdot u^2(R) + R^2 \cdot u^2(a_1) + u^2(\delta R_{\text{temp}}) + u^2(\delta R_{\text{buoy}}) + u^2(\delta R_{\text{adj}}) + u^2(\delta R_{\text{Tare}}) + u^2(\delta R_{\text{time}}) + u^2(\delta R_{\text{ecc}})\big]^{0.5}$$

This includes an additional coefficient a_1 and its uncertainty $u(a_1)$, resulting from a linear regression of the error of the result obtained during calibration.

Since all contributions are either constant or proportional to R, $U_{\text{gl}}(W)$, uncertainty can be approximated by a straight-line equation. According to the EURAMET cg-18, the contributions to the global expanded uncertainty equation can be grouped into the terms α_{gl}, which includes all constant uncertainties, and β_{gl}, which includes all proportional uncertainties. This can then be expressed in the simplified linear equation

$$U_{\text{gl}}(W) \approx \alpha_{\text{gl}} + \beta_{\text{gl}} \cdot R$$

with the interception $\alpha_{\text{gl}} = U_{\text{gl}}(W = 0)$, the slope $\beta_{\text{gl}} = \frac{U_{\text{gl}}(W=Max) - U_{\text{gl}}(W=0)}{Max}$ and the displayed weighing value R.

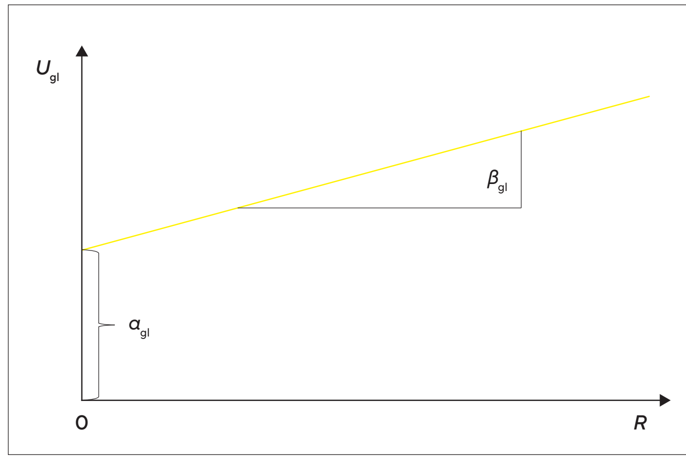

Figure 1: Graphical representation of the absolute measurement uncertainty as a straight line with interception α_{gl} and slope β_{gl}

How to Enter Values and to Configure the QApp

Sartorius Service can create a calibration certificate based on the guidelines of the EURAMET cg-18 using the Sartorius calibration software Verical®. From the calibration certificate, the summand α_{gl} and the factor β_{gl} can be taken and entered in the QApp "Measuring Uncertainty" function to indicate the uncertainty of any load placed on the pan of the balance.

Since the factor β_{gl} usually is on the order of some millionth, it is given in scientific notation, i.e., $1.23 \cdot 10^{-6}$ as a better manageable notation than 0.00000123. For convenience, the value in the front (the so-called "mantissa" – "1.23" in this example) and the exponent must be entered separately. Since the latter is always negative, one need only enter the absolute value, i.e., "6" instead of "-6" in this example.

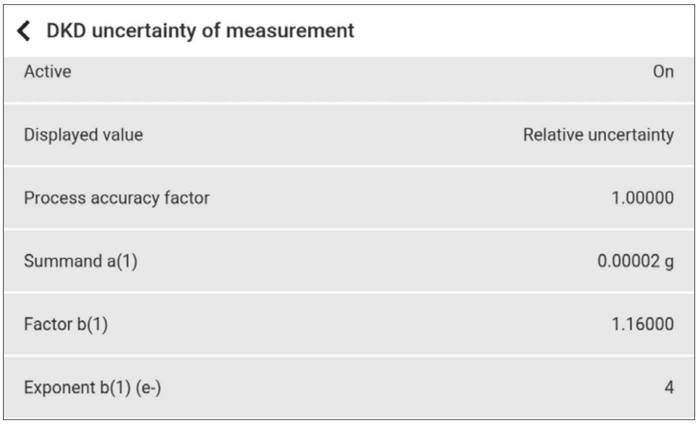

Figure 2: Menu of the QApp with the possibility to enter summand, factor and exponent from a straight line equation

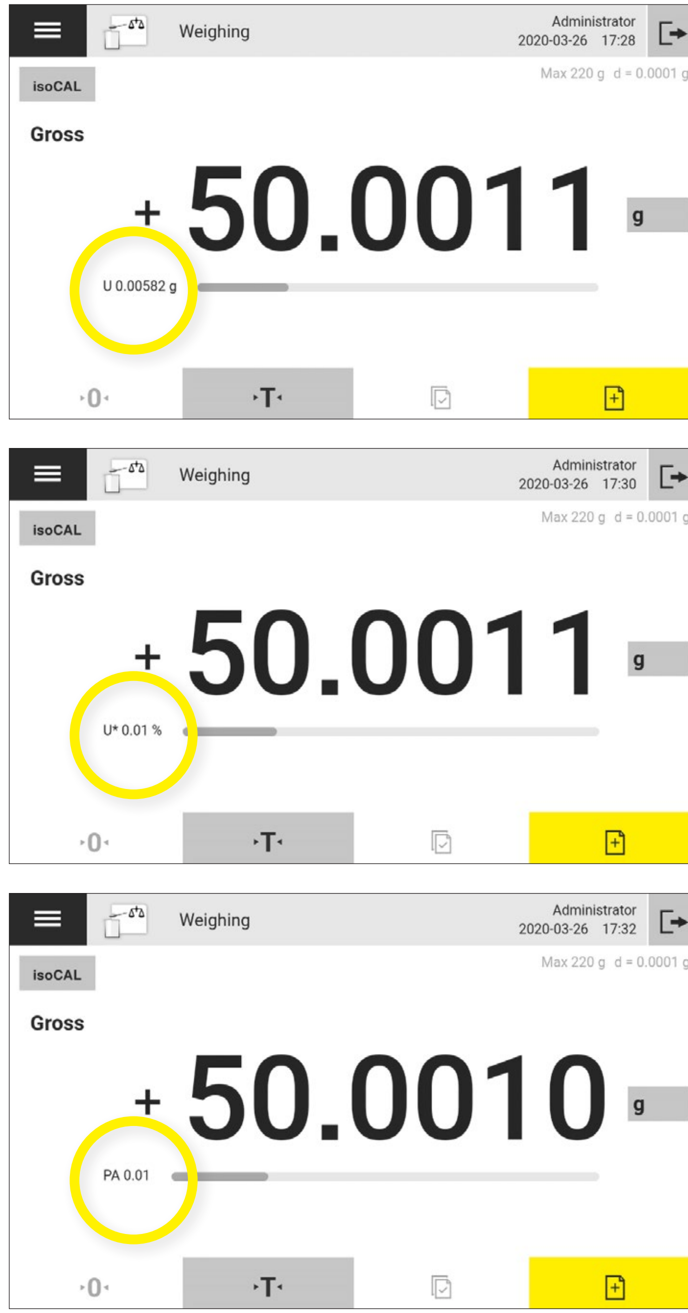

Figure 3: The indication of the measurement uncertainty can be given as an absolute value (top), a relative value (middle) or as a process accuracy (bottom).

For multi-interval balances (denoted with a "P" in the model name of the Cubis® II series, i.e., MCA225P), a separate equation is given on respective calibration certificates for each calibrated partial weighing range. Accordingly, these models feature the possibility of entering one set of parameters for each partial weighing range.

The settings of the QApp further allow setting the status Active on or off, i.e., to indicate the uncertainty or not.

Furthermore, the user can adjust whether the uncertainty shall be indicated as an absolute value, a relative value, or as a process accuracy.

Accordingly, the QApp automatically calculates the corresponding absolute uncertainty of measurement $U = a + b \cdot W$ (in the chosen unit, i.e., "g" or "mg") or the relative uncertainty of measurement $U^* = U/W \cdot 100\ \%$ (in %) for every indicated weight W. For process accuracy, the relative measurement uncertainty is multiplied with a safety factor | process accuracy factor that can be entered by the user: $PA = k_S \cdot U^*$.

This factor can be used to account for influences on the accuracy of a user's process that could not be considered during calibration and | or to increase the confidence interval of the stated uncertainty. For some advice on how to reasonably choose this factor, read our relevant Whitepaper [4].

How to Understand the Indicated Measurement Uncertainty Values

The determined measurement uncertainty according to EURAMET cg-18 is an expanded uncertainty—that means that for any reading *R*, the true value is within the interval [*R-U* ... *R+U*] with a probability of 95.45%. For the example in Figure 2, this would correspond to a probability of 95.45% for the interval [50.0011 g – 0.00582 g ... 50.0011 g + 0.00582 g] = [49.99528 g ... 50.00692 g].

Furthermore, the user can monitor for any weighing result, whether the process accuracy requirements are fulfilled. For example, let the user's requirement be a process accuracy of 0.1% for a sample preparation before a subsequent analytical method. The user will weigh-in 10 mg of sample in a weighing boat on a Cubis® II MCA semi-micro balance, with a maximum capacity of 220 g and a scale interval of *d* = 0.01 mg. This user will monitor this process permanently, and he is able to see when to increase the sample amount, so that the required process accuracy will not exceed 0.1%.

With regard to state-of-the-art good documentation practice, it is furthermore possible to choose in the printing settings whether the uncertainty shall be printed on print-outs. Furthermore, it is possible to enter additional information like the calibration certificate number, from which the values were taken, as well as the calibration date and whether the calibration was conducted by an accredited calibration laboratory. With GLP print settings it is possible to decide, if (and which of) the parameters and settings of the app shall be printed.

Gross	G	+637.86	g
Absolute uncertainty	U	0.083	g
Relative uncertainty	U*	0.01	%
Process accuracy	PA	0.01	
Gross	G	+739.76	g
Absolute uncertainty	U	0.096	g
Relative uncertainty	U*	0.01	%
Process accuracy	PA	0.01	
Gross	G	+930.19	g
Absolute uncertainty	U	0.121	g
Relative uncertainty	U*	0.01	%
Process accuracy	PA	0.01	

Figure 4: Example print-out of some weighing values and their respective absolute and relative uncertainties as well as their process accuracies.

Conclusion

With this new function available in the Cubis® II balance, Sartorius makes it much easier for users to determine the uncertainty of a measurement or the process accuracy of an initial sample weight, without needing to calculate it from a diagram of the calibration certificate. A calibration certificate is, thus, an important document containing relevant information to support the demands of monitoring testing and measuring equipment.

References

1. EURAMET Calibration Guide No. 18, Version 4.0. **Guidelines on the Calibration of Non-Automatic Weighing Instruments.** (2015)

2. **Sartorius White Paper: Calibration certificates according to EURAMET cg-18 (Understanding calibration certificates and practical application of the results)**. 2020 (planned)

3. **Sartorius White Paper: Calibration guide EURAMET cg-18 for electronic non-automatic weighing instruments (Specifications, options and implementation of the guideline by Sartorius).** (2020) (planned)

4. **Sartorius White Paper: Minimum net weight values according to USP <41>, OIML R76 and EURAMET cg-18 (What is the minimum weight of a sample to get reliable weighing results?).** (2020)

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