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TEST LOAD REFERENCE MASS VALUE FOR AWI CALIBRATION

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Abstract: Calibration of automatic weighing instruments in a dynamic mode of operation can not be performed directly with standard weights. It is necessary to use products or items that are normally weighed on these instruments. Several approaches are presented and discussed in the article for determination of the reference mass value of the test loads used for the calibration of automatic weighing instruments. For each presented approach uncertainty components are identified and evaluated. Finally, the indicative classification of presented methods with regard to their accuracy is carried out.

Keywords: automatic weighing instruments, calibration, test load, uncertainty.

1. INTRODUCTION

While non-automatic weighing instruments (NAWIs) are routinely calibrated according to [1], the calibration of automatic weighing instruments (AWIs) is not as well defined as there is a significant difference between the static measurement mode of operation of NAWIs and the dynamic measurement mode of operation, which is typical for the majority of AWI applications. There is also limited information about the uncertainties achievable using AWIs and little documented guidance available. Therefore, there is a need for calibration methods and measurement uncertainty evaluation models for different groups of AWIs operating in a dynamic measurement mode [2].

Due to the dynamic nature of the operation, AWIs, as a rule, can not be directly calibrated with standard weights, but products or items that that are normally weighed on these instruments need to be used as test loads. To ensure adequate metrological traceability of mass of the test loads, their reference mass value needs to be determined within the calibration process itself.

Accuracy of measurement varies considerably between different AWI groups and classes, so it is necessary to choose an appropriate method of determining the test load reference mass value, taking into account required measurement uncertainty and complexity of the procedure.

In Chapter 2 five methods for determination of the mass of the test load are presented, which are further developed in Chapter 3 taking into account necessary air buoyancy corrections in order to determine the final value of the reference mass value of the test load. Components of measurement uncertainty are evaluated as well.

2. PRINCIPLES OF CALIBRATION OF TEST LOADS

Mass of test loads could be determined in different ways. Some of possible approaches are summarised below:

A. Test load is calibrated prior to calibration of AWI. Its conventional mass is reported together with uncertainty, e.g. in a calibration certificate.

B. Mass of test load is determined by comparison with standard weight at the time and place of calibration of AWI on a weighing instrument, which is used as a mass comparator.

C. Mass of test load is determined by weighing on control weighing instrument at the time and place of calibration of AWI and the control instrument is calibrated at the same time as the calibrated AWI, too.

D. Mass of test load is determined at the time and place of calibration of AWI by weighing on control weighing instrument, which had been calibrated prior to calibration of AWI. Results of calibration the control instrument are reported in the certificate.

E. Mass of test load is determined at the time and place of calibration of AWI by weighing on previously verified weighing instrument.

In order to enable evaluation of reference value of mass and its uncertainty in Section 3, the following subsections provide some information on two possibilities of determination of the conventional mass of the test load.

2.1. Conventional mass of the test load based on comparison with standard weight

When for determination of the test load mass and its uncertainty the control weighing instrument is used as a mass comparator, the conventional mass of the test load m_{cTL} is obtained by its comparison with a reference standard weight with conventional mass m_{cR}:

$$m_{cTL} = m_{cR}(1 + C) + \overline{\Delta m_c} \qquad (1)$$

where C is air buoyancy correction contribution

$$C = (\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_R}\right) \tag{2}$$

$\overline{\Delta m_c}$ is average measured difference between the test load and standard weights, ρ_{aCI} is air density at the time of calibration of the test load on the control instrument, ρ_0 is reference air density, 1,2 kg/m^3, ρ_{TL} is density of the test load, and ρ_R density of standard weights used for calibration of the test load on the control instrument.

2.2. Conventional mass of the test load based on weighing on control instrument

If for determination of the mass and uncertainty of the test load, the load is weighed on the calibrated control instrument the conventional mass of the test load is proportional to the weighing result of the control instrument W_{CI} [1]:

$$m_{cTL} = W_{CI}\left[1 + (\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_{sCI}}\right)\right] \tag{3}$$

where

$$W_{CI} = R_{CI} - E_{CI} \tag{4}$$

$$E_{CI} = I_{CI} - m_{refCI} \tag{5}$$

$$m_{refCI} = m_{cCalCI} + \delta m_{BCI} \tag{6}$$

$$\delta m_{BCI} = -m_{cCalCI}\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right] \tag{7}$$

R_{CI} is reading of the test load on the control instrument corrected for zero reading, E_{CI} is error of the control instrument corrected for zero indication, I_{CI} is indication of the standard weights on the control instrument corrected for zero indication, m_{refCI} and m_{cCalCI} is reference value and conventional mass of mass of standard weights used for calibration of the control instrument, respectively, δm_{BCI} is air buoyancy correction for the standard weights used for calibration of the control instrument, ρ_{aCalCI} is air density at the time of calibration on the control instrument, ρ_{sCI} and ρ_{CalCI} is density of standard weights used for adjustment and for calibration of the control instrument, respectively.

3. TEST LOAD REFERENCE MASS VALUE

The reference value of mass of the test load m_{ref} depends on of the conventional mass of test load m_{cTL} and the air bouyancy correction for test load δm_B

$$m_{ref} = m_{cTL} + \delta m_B \tag{8}$$

where

$$\delta m_B = -m_{cTL}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right] \tag{9}$$

ρ_a is air density at the time of calibration of AWI and ρ_s density of standard weights used for adjustment of AWI.

Based on five possibilities introduced in Section 2 (indents A to E), details of determination of m_{ref} with accompanying uncertainty are given below.

3.1. Case A: Test load with the calibration certificate

If it is justified that the test load is calibrated prior to the calibration of AWI, then it should be accompanied with calibration certificate. The reference value of mass m_{ref}, with sources of variability, is determined by

$$m_{ref} = m_{cTL} + \delta m_B + \delta m_D + \delta m_{conv} \tag{10}$$

m_{cTL} is given in the calibration certificate, together with the uncertainty of calibration U and the coverage factor k. Its standard uncertainty is

$$u(m_{cTL}) = U/k \tag{11}$$

δm_B is determined according to (9) and its relative standard uncertainty $u_{rel}(\delta m_B)$ equals

$$u_{rel}^2(\delta m_B) = u^2(\rho_a)(1/\rho_{TL} - 1/\rho_s)^2 + (\rho_a - \rho_0)^2 u^2(\rho_s)/\rho_s^4 + (\rho_a - \rho_0)^2 u^2(\rho_{TL})/\rho_{TL}^4 \tag{12}$$

Since a difference between densities ρ_{TL} in ρ_s is, in general, significant, δm_B and its uncertainty is not negligible as a rule.

δm_D corresponds to the possible drift of m_{cTL} since the last calibration. It is not advised to apply a correction but to assume rectangular distribution within difference in m_{cTL} evident from consecutive calibration certificates $\pm D$. The standard uncertainty is then

$$u(\delta m_D) = D/\sqrt{3} \tag{13}$$

δm_{conv} corresponds to the convection effects. It is not advised to apply a correction but to assume an rectangular distribution within $\pm\Delta m_{conv}$:

$$u(\delta m_{conv}) = \Delta m_{conv}/\sqrt{3} \tag{14}$$

There are no studies available, which would give a simple elaboration of the convection effects for a general case. In such a case, a suitable temperature equilibrium need to be reached between the test load and surrounding air at location of calibration of AWI.

3.2 Case B: Mass of test load determined by comparison with standard weights

Based on (1) and (2) for the conventional mass of the test load and (9) for the air buoyancy correction, under the condition that $m_{cTL} \cong m_{cR}$, and since the mass of the test load is determined at the same time and place as the calibration of AWI takes place, $\rho_{aCI} = \rho_a$, the reference value of mass as given in (8) is modified, with sources of variability, to

$$m_{ref} = m_{cR} + \delta m_{BTot} + \overline{\Delta m_c} + \delta m_{ba} \qquad (15)$$

If the total contribution of the correction for air buoyancy to m_{ref} in (15) is called δm_{BTot} then

$$\delta m_{BTot} = -m_{cR}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_R} - \frac{1}{\rho_s}\right)\right] \qquad (16)$$

A difference between ρ_R and ρ_s is relatively small, consequently a more elaborate calculation of the correction and its uncertainty component based on actual data may be superfluous. In such a case, no correction is applied, i.e. δm_{BTot}=0. If conformity of the standard weights used for adjustment of the AWI and calibration of the test load to [3] is established and if the AWI is not adjusted before the calibration, the relative uncertainty is evaluated as [1]

$$u_{rel}(\delta m_{BTot}) \approx (0{,}1\,\rho_0/\rho_c + mpe/(4m_N))/\sqrt{3} \qquad (17)$$

The standard uncertainties of the conventional mass of the standard weights $u(m_{cR})$ and difference between the test load and standard weights $u(\overline{\Delta m_c})$ could be evaluated according to Section C.6.2 and C.6.1 of [3], respectively.

δm_{ba} corresponds to the influences of the control instrument used for calibration of the test load. No corrections are apllied and their standard uncertainties $u(\delta m_{ba})$ could be evaluated according to Section C.6.4 of [3].

3.3. Case C: Mass of test load determined by weighing on simultaneously calibrated control instrument

In this case the control instrument needs to be calibrated at the same time as calibration of AWI takes place in calibration points close to nominal masses of the test load. For determination of mass of test load the error of indication of the control instrument is taken into account.

Based on (3) to (7) for the conventional mass of the test load and (9) for the air buoyancy correction, since the mass of the test load is determined at the same time and place as the calibration of control instrument and AWI, $\rho_{aCI} = \rho_{aCalCI} = \rho_a$, under the condition that $m_{cTL} \approx m_{cCalCI}$, and $R_{CI} - I_{CI} - m_{cCalCI}\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right] \ll m_{cCalCI}$, we get the following expression for m_{ref}

$$m_{ref} = R_{CI} - I_{CI} + m_{CalCI} + \delta m_{BTot} \qquad (18)$$

The total contribution of the air buoyancy correction δm_{BTot} to m_{ref} in (18) equals

$$\delta m_{BTot} = -m_{cCalCI}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_s}\right)\right] \qquad (19)$$

The standard uncertainties of reading of the test load on the control instrument $u(R_{CI})$ and indication of the standard weights on the control instrument$u(I_{CI})$ should be evaluated according to Section 7.4.1 and 7.1.1 of [1], respectively.

m_{CalCI} is the reference mass value of standard weights used for calibration of the control instrument, without taking into account the correction term for air buoyancy. Its standard uncertainty $u(m_{CalCI})$ should be evaluated according to Section 7.1.2 of [1], but again without taking into account the standard uncertainty of the air buoyancy correction. The standard uncertainty of the air buoyancy correction is treated separately according the following paragraph.

As in the Case B, the difference between densities ρ_{CalCI} and ρ_s is relatively small. Equation (17) can be used for evaluation of $u_{rel}(\delta m_{BTot})$, if the same conditions are fulfilled as in the Case B.

3.4. Case D: Mass of the test load determined by weighing on previously calibrated control instrument

When the mass of test load is determined by its weighing on the control instrument, which has been calibrated previously, the calibration certificate for the control instrument is on a disposal. However, the same approach could be used also in a case when the instrument is calibrated immediately prior to determination of the mass of test load.

If the conventional mass of test load is close to the calibration point in which the error of control instrument was determined, then the weighing result W_{CI} could be determined based on the reading of the test load R_{CI} corrected for the error of the control instrument E_{CI} as given by (4). The error of the control instrument is reported in its calibration certificate.

If this is not the case, no correction is applied to the reading

$$W_{CI} = R_{CI} \qquad (20)$$

but errors of the control instrument need to be included in an uncertainty (i.e. a “global uncertainty” $U_{gl}(W_{CI})$, which includes the errors of indication such that no corrections have to be applied to the readings in use).

Based on (3) for the conventional mass of the test load and (9) for the air buoyancy correction, under the condition that $m_{cTL} \approx W_{CI}$, and since the mass of the test load is determined at the same time and place as calibration of the AWI, $\rho_{aCI} = \rho_a$, we get the following expression for m_{ref}:

$$m_{ref} = W_{CI} + \delta m_{BTot} \qquad (21)$$

where the total contribution of the air buoyancy correction δm_{BTot} to m_{ref} in (21) equals

$$\delta m_{BTot} = -W_{CI}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{sCI}} - \frac{1}{\rho_s}\right)\right] \quad (22)$$

The standard uncertainty of the weighing result of the control instrument $u(W_{CI})$ should be evaluated according to Sections 7.4.5 or 7.5.2 of [1] for a case when errors of the control instrument are accounted by correction or included in a "global" uncertainty $U_{gl}(W_{CI})$, respectively.

According to [1], standard uncertainty for the weighing result under conditions of the calibration $u(W_{CI}^*)$ could be used instead of $u(W_{CI})$ if the control instrument was calibrated right before its use. Similar can be assumed if the control instrument was adjusted right before its use and uncertainty contributions resulting from the operation of the control instrument are negligible.

The calibration certificate, which have been issued for the control instrument, reports uncertainty of instrument error at calibration. If the certificate reports also uncertainty of the instrument in use, this is non-accredited value. The calibration laboratory needs to independently evaluate uncertainty in use based on actual conditions valid in a period since the last calibration of control instrument.

As in the Case B, the difference between densities ρ_{sCI} and ρ_s is relatively small. Equation (17) can be used for evaluation of $u_{rel}(\delta m_{BTot})$, if the same conditions are fulfilled as in the Case B.

3.5. Case E: Mass of test load determined by previously verified control instrument.

As a precondition for the case, where the mass of test load is determined by its weighing on the control instrument, which has been verified based on requirements of [4], the traceability of the verification needs to be demonstrated and accepted.

As in (20), no correction of the control instruments errors is applied to its reading, but the errors of the verified control instrument need to be included in an uncertainty (i.e. a "global uncertainty" $U_{gl}(W_{CI})$.

Since the mass of the test load is determined at the same time and place as calibration of the AWI, $\rho_{aCI} = \rho_a$, m_{ref} and δm_{BTot} are determined in the same way as given in the case D, i.e. using (21) and (22).

The standard uncertainty of the weighing result of the verified control instrument $u(W_{CI})$ could be evaluated according to Section 7.5.2 of [1] for a case when errors of the control instrument are included in a "global" uncertainty $U_{gl}(W_{CI})$. For the verified instruments it can be assumed that during the verification the errors were smaller or equal to the maximum permissible error of the weighing instrument mpe_{R76}[4] and that they are evenly distributed in the range defined by mpe_{R76}. This is accounted for with the rightmost term in (23)

$$u_{gl}(W_{CI}) = u^2(W_{CI}) + \left(\frac{mpe_{R76}}{\sqrt{3}}\right)^2 \quad (23)$$

In order to evaluate $u(W_{CI})$ in terms of mpe_{R76}, approximations for standard uncertainties of influencing parameters to $u(W_{CI})$ in terms of mpe_{R76} are summarised in Table 1.

Table 1: Standard uncertainty contributions to $u(W_{CI})$ expressed in terms of mpe_{R76}

$u(\delta I_{dig0})$	$mpe_{R76}/(10\sqrt{3}) \cong 0$ for $d \leq e/5$
$u(\delta I_{digL})$	$mpe_{R76}/(10\sqrt{3}) \cong 0$ for $d \leq e/5$
$u(\delta I_{rep})$	$mpe_{R76}/(2\sqrt{3})$
$u(\delta I_{ecc})$	$\cong 0$
$u(\delta m_c)$	$(mpe_{R76}/3)/\sqrt{3}$
$u(\delta m_B)$	$(0{,}000015/\sqrt{3})R$ $+ (mpe_{R76}/3)/(4\sqrt{3}) \leq mpe_{R76}/5$
$u(\delta m_D)$	$(mpe_{R76}/3)/\sqrt{3}$
$u(\delta m_{conv})$	$\cong 0$
$u(\delta R_{dig0})$	$d/(2\sqrt{3}) \leq mpe_{R76}/(4\sqrt{3})$
$u(\delta R_{digL})$	$d/(2\sqrt{3}) \leq mpe_{R76}/(2\sqrt{3})$
$u(\delta R_{rep})$	$mpe_{R76}/(2\sqrt{3})$
$u(\delta R_{ecc})$	$mpe_{R76}/(2\sqrt{3})$
$u(\delta R_{temp})$	$mpe_{R76}/\sqrt{12}$
$u(\delta R_{bouy})$	$(0{,}000015/\sqrt{3})R \leq mpe_{R76}/5$
$u(\delta R_{adj})$	$mpe_{R76}/\sqrt{3}$
$u(\delta R_{Tare})$	0
$u(\delta R_{time})$	0
$u(\delta R_{ecc})$	0, see $u(\delta R_{ecc})$

Taking into account estimates from Table 1, (23) is evaluated in terms of mpe_{R76} as

$$u_{gl}(W_{CI}) = \sqrt{mpe_{R76}{}^2 + \left(\frac{mpe_{R76}}{\sqrt{3}}\right)^2} \cong 1{,}15 mpe_{R76} \quad (24)$$

As in the Case B, the difference between densities ρ_{sCI} and ρ_s is relatively small. Equation (17) can be used for evaluation of $u_{rel}(\delta m_{BTot})$, if the same conditions are fulfilled as in the Case B.

4. CONCUSION

The process of determination of the reference mass value of the test load and its associated measurement uncertainty is one part of the whole process of AWI calibration. An appropriate method of determining the test load reference mass value needs to be selected in a view of required measurement uncertainty and complexity of the method.

Case A could be applicable only in a case when comparable dynamic behaviour of pre-prepared test loads with loads normally weighed on the instruments is achieved. In this case a drift mass of the test load within a time is relevant. A density of the test load needs to be known. Since it is expected that the density considerably from 8000 kg/m^3, air buoyancy correction in not negligible.

In Cases B to E the mass of test loads is determined at the time and place of calibration of AWI. Consequently no significant drift of the test load is expected. A density of the test load does not need to be known. The air buoyancy correction is very small or negligible and does not depend on a density of the test load.

A critical point of Cases D and E is evaluation of uncertainty of the control instrument in use. In Case D the control instrument needs to have calibration certificate. Case E is eligible only if a traceability of the verification is properly demonstrated.

In general, if the same control instrument is used, uncertainty of the reference mass value increases from Case B to Case E.

Practical application of the presented approaches to the determination of the reference mass value of the test load is planned in order to evaluate significance of uncertainty contributions.

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6. REFERENCES

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