XX IMEKO World Congress
Metrology for Green Growth
September 9–14, 2012, Busan, Republic of Korea

MEASURING INSTRUMENTS CALIBRATION NEAR ZERO VALUE

Edi Kulderknup, Argo Pandis

Estonian Accreditation Centre, Estonia, edi@eak.ee
Tepso Laborid Ltd, Estonia, argo@tepso.ee

Anstract: Problem of measuring instruments calibration near zero value exists by accreditation of calibration laboratories. Some calibration laboratories present its calibration capability minimum value as 0 [with measuring unit of quantity *g*] and others with some deviation Δg from 0. Often it is given as $\Delta g \approx U(g)$, where $U(g)$ is the expanded uncertainty. As concrete example can be given air relative humidity measuring instruments calibration, where measuring instrument has in the calibration certificate indication 0,3 % relative humidity with expanded uncertainty U=0,7 % relative humidity, (k=2).

Taking account circumstances that expanded uncertainty U is typically shown with symmetrical distribution, but accordingly to the probability theory the negative probability can't occur, exists disagreement.

Above was the ground for this paper and presents propositions how the calibration scope is useful to present for minimum value taking account users' needs and probability theory

Keywords: Calibration, accreditation, zero value.

1. INTRODUCTION

Problem of the measuring instruments calibration near zero value exists by calibration laboratories accreditation. Some calibration laboratories present its calibration capability minimum value as 0 [with measuring unit of quantity *g*] and others with some deviation value Δg from 0 value.

Value of deviation Δg from 0 has variety. Often it is given as $\Delta g \approx U(g)$, where $U(g)$ is expanded uncertainty. In some cases value Δg is less than U(g), $\Delta g < U$(g). As concrete example can be given air relative humidity measuring instruments calibration, where the measuring instrument has in the calibration certificate indication 0,3 % relative humidity with an expanded uncertainty U=0,7 % relative humidity, k=2 and there are no remark about the probability distribution function type. Calibration laboratories gave as justification for such situation that indication 0,3 % relative humidity can exists practically and client needs indication 0,3 % with some positive uncertainty. Additional variety has measurements in the chemical field where exist terms detection limit, determination limit and decision limit. Taking account probability theory where negative probability can't be exists should be solve above problem taking account needs in practice.

Above was the ground for this paper and presents propositions how calibration scope is useful to present for minimum value taking account users' needs and probability theory. As initial data were used accredited calibration laboratories scopes from various countries. There will be not presented concrete names of laboratories by reason that this can be harmful for the laboratories. Mainly are centred for cases of calibration the measuring instruments of length, electrical parameters and some physical quantities.

2. CALIBRATION SCOPES LOWER LIMIT

For the calibration laboratories is important to give its measurement scope from minimum value up to maximum value and there shall be shown representative quantity of the intermediate values. Each value is given with the uncertainty. As rule, calibration certificate has form where are given measuring instrument indication L, correction K to the indication and expanded uncertainty U with probability value P (or coverage factor k). As usual the measuring instrument scale is produced so that begins from the zero up to the maximum value. Measuring instrument user wants have minimum value as possible nearest to the zero value. But, as rule, near zero value, the measuring instrument has difficulties to achieve needed accuracy level and existed zone where measurements can't be practically carried out.

Additional aspect is associated with adjustment of a measuring system so that it provides a null indication corresponding to a zero value of a quantity to be measured. Often measuring instruments users understand the zero adjustment as correcting the null measurement uncertainty.

In terminology presented in VIM existed next principles for above situation:

- zero error, where the specified measured quantity value is zero, zero error should not be confused with absence of measurement error,
- null measurement uncertainty, measurement uncertainty where the specified measured quantity value is zero. Null measurement uncertainty is

associated with a null or near zero indication and covers an interval where one does not know whether the measurand is too small to be detected or the indication of the measuring instrument is due only to noise. The concept of "null measurement uncertainty" also applies when a difference is obtained between measurement of a sample and a blank.

In chemical measurements above problem is tried to solve giving terms of the detection limit and the determination limit. Detection limit is measured quantity value, obtained by a given measurement procedure, for which the probability of falsely claiming the absence of a component in a material is β, given a probability α of falsely claiming its presence. Determination limit is measured quantity value, obtained by a given measurement procedure, with estimated uncertainty.

Within European Accreditation Cooperation (EA) needed is calibration capability presentation on accreditation scope. The calibration capability is defined as the smallest uncertainty of measurement that a laboratory can achieve within its scope of accreditation, when performing more or less routine calibrations of nearly ideal measurement standards intended to define, realize, conserve or reproduce a unit of that quantity or one or more of its values, or when performing more or less routine calibrations of nearly ideal measuring instruments designed for the measurement of that quantity [1]. So minimum value shall have estimated uncertainty. Requirement is also, that minimal value of the calibration scope shall be given through traceable standards.

As examples for minimum values can be given some widely used fields of measurements. Widely is used the length measuring instrument micrometer which has scale from 0 mm up to 25 mm with scale indication interval 0,005 mm. In some cases on the calibration certificate are given indication values from 0,000 mm up to up to maximum value 25,000 mm with uncertainties.

The roller tester for the vehicles brakes parameters measurement has scale 0 to 6 kN or 0 up to 40 kN with indication interval 10 N. For brakes parameters measurements exist many influence factors and testers producers gives accuracy parameters on the level of 2 % from the maximum value of scale (often is it even not given). Users need measurements of the force beginning from 100 N and in the good conditions is realistic to achieve expanded uncertainty U=100 N, (k=2).

For electrical measuring instruments uncertainty is often given as % from reading plus some minimal scale indication values. For example the digital voltage meter with measurement range 0 V … 20 V has accuracy parameters 0,3 % from reading plus 2 scale divisions.

2. PROBABILITY OF THE MINIMUM VALUE

For the uncertainty estimation mainly are in the practice used for initial data rectangular or triangular probability distribution and for combined uncertainty normal or t-distribution [2]. Rectangular is suitable for cases where is not known exact distribution of data. Normal distribution is ordinary for sum of factors uncertainties and needed is good statistical ground. Both above are symmetrical distributions.

Indication of the calibrated measuring instrument shall be in an interval having a stated level of confidence for both sides from the best estimated value. On the other hand a negative probability P cant exists. So, if result of the calibration is given as $\Delta g<U(g)$, where Δg is deviation from 0 value, the uncertainty of measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand, shall be asymmetric. In normal cases of measuring instruments calibration that is not so.

Asymmetric distribution of possible values can exists, but this is a rare case. There are occasions when all possible values of a quantity lie to one side of a single limiting value. For example, when measuring the fixed vertical height h of a column of liquid in a manometer, the axis of the height-measuring device may deviate from verticality by a small angle [1].

By calibration of measuring instruments shall be strong evidence that the influence factors have possibilities to cause asymmetrical distribution. There will be strong falling of values left from expected value. For uncertainty estimation this situation is problematic and in the practise hard to use (see. Fig 1). On Fig are used next abbreviations for axes - x is the measurement parameter value and P is the expected probability of the value.

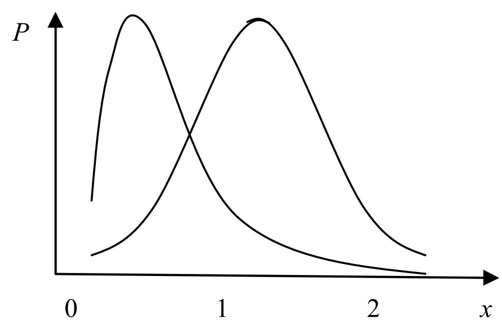


Fig. 1. Probability distribution possibilities by measuring instrument calibration

Presented on Fig 1 left curve is practically one-sided distribution and theoretically can be used for near zero value calibration results. Needed are strong evidences that such distribution has meaning for concrete measuring instrument calibration. If user of the measuring instrument carries out measurement then also the measurement result has strongly one-sided probability distribution. Often user is not metrology specialist, did not have deep probability theory knowledge and so has difficulties to give estimation of uncertainty based on the one-sided distribution.

Right curve is theoretically more assured and understandable for the ordinary user of calibrated measuring instrument.

3. MODELS OF CALIBRATION AND UNCERTAINTY ESTIMATION OF MINIMUM VALUE

According to [1] calibration result must be presented as $y \pm u$ and according to GUM uncertainty is preferable presented as positive value.

It is understood that result of the calibration is the best estimate of the measurand value. All components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion of measurement results.

To analyse possibilities to present of minimum values for measuring instruments calibration should be used models for calibration procedures. Model can be presented, as:

$L=f$ (traceable standard, corrections from influence factors with uncertainties) (1)

For example, the micrometer calibrations with influence factors, can be presented through next model:

$$L=f(E, L_{ind}, K_{st}, K_{read}, K_{mf}, K_{par}, K_{perp}, K_{temp}). \quad (2)$$

where E is a standard value, L_{ind}, is the micrometers indication, $K_{st}=E-L_{ind}$, K_{read} is the correction from the reading rounding, K_{mf} is correction from the measurement force, K_{par} is corrections from the micrometers surfaces parallelism, K_{perp} is correction from the standard location in micrometer and K_{temp} is correction from the variation of temperature. Each correction has its uncertainty.

For the micrometer with indication interval 0,005 mm is realistic to have next minimal value of the standard uncertainties by calibration. In practice can be found the gauge length block as standard with nominal length 0,500 mm with combined standard uncertainty u=0,0002 mm (k=1), reading gives uncertainty $u_{read}=0{,}005/\sqrt{3}=0{,}003$ mm, parallelism and perpendicularity give uncertainty (u_{par}, u_{perp}) =0,001 mm and variation of the temperature influence is minor. Expanded uncertainty on above values is U=0,006 mm (k=2). So correctly calibrated minimal value of micrometer indication is L=0,500 mm with U=0,006 mm (k=2). Doubtful zone is from 0,000 mm up to (0,500–0,006) mm taking account requirement of calibration result traceability.

On Fig. 2 is presented minimum zone with uncertainty for micrometer calibration. If minimal value for standard is 0,500 mm, then one-sided probability did not have meaning and minimal value of traceable calibrated micrometer is 0,500 mm. On Fig L is measurement parameter value and P is expected probability of the value.

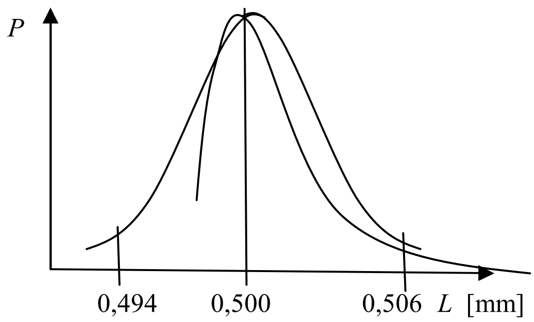


Fig. 2. Probability distribution possibilities for micrometer calibration results with uncertainty

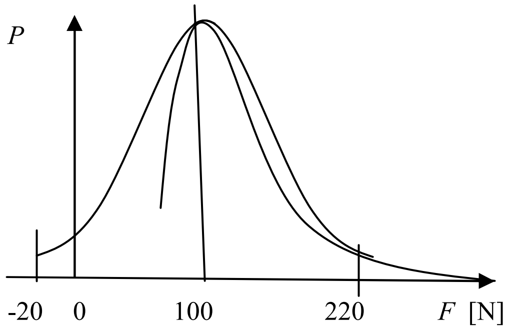
Vehicles brakes roller tester calibration result for force measurement, using as standard special vehicles, can be presented through next model [3]:

$$L=f(E, F_{ind}, K_{sp}, K_{read}, K_{disc}, K_{tir}, K_{rol}, K_{pos}, K_{temp}). \quad (3)$$

where E is a standard value, F_{ind}, is tester indication, $K_{st}=E-F_{ind}$, K_{sp} is correction from speed and stability of the braking force application, K_{disc} is correction from the vehicles braking system and brakes discs working conditions, K_{tir} is correction from the tires conditions, K_{rol} is correction from brake tester rollers surface roughness and dryness, K_{pos} is correction from the vehicles wheels position variation on rollers and K_{temp} is correction from temperature and cleanness of the working environment. Each correction has its uncertainty component.

Using experimental data and results of comparison schemes, expanded uncertainty U value can evaluated to be 120 N, (k=2).

So, the doubtful zone is from 0 N value up to 100 N taking account that corrections and uncertainties.

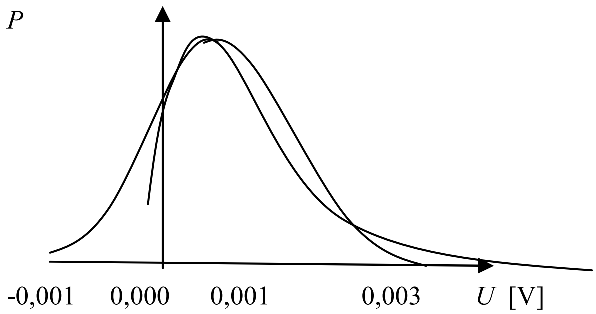


F is measured parameter value

Fig. 3. Probability distribution possibilities for roller tester calibration results with uncertainty

On Fig. 3 is presented minimum zone with uncertainty for roller tester of vehicles braking parameters. In this case use of non-symmetrical distribution is needed.

On Fig. 4 is presented minimum zone with uncertainty for electrical measuring instrument AC voltage meter. Often for this instrument expanded uncertainty is given 0,3 % from reading plus 2 scale divisions. For example, for reading 0,001 V is expanded uncertainty U=0,002 V (k=2).



U is measured parameter value

Fig. 4. Probability distribution possibilities for AC voltage meter calibration with uncertainty

In this case even one-sided distribution is not suitable.

4. PRESENTATION OF CALIBRATION CAPABILITY MINIMUM VALUE

Taking account probability theory basic principles and measuring instruments users needs, the calibration certificate shall exactly show minimum value and its uncertainty. Realistic is to have minimum value over zero value which is bigger than expanded uncertainty U and shall be avoided to use non-symmetrical distribution

There shall be also assured traceability chain and if standards has value considerable over zero, then all interval below standard value is doubtful.

5. CONCLUSIONS

As conclusions can be given next:

- for accredited calibration laboratories is important to give minimum value based on calibration model taking account probability distribution possibilities;
- minimum value shall be over 0 value more than expanded uncertainty,
- doubtful zone near zero shall be excluded clearly from accredited scope.

6. REFERENCES

[1] EA 4/02 „Expression of the uncertainty of measurement in calibration“ EA, 2011.

[2] Dietrich, C.F, “Uncertainty, calibration and probability“, Adam-Hilger (Bristol), 1991.

[3] Kulderknup,E, Riim,J and Levandi,T, “Uncertainty of road traffic safety measurements” in Proc.of XIX IMEKO World Congress, Lisbon,, 2009