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CONSIDERATION OF THE UNCERTAINTY OF MEASUREMENT DURING THE CALIBRATION OF HARDNESS TEST MACHINES

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Abstract – The uncertainty of measurement is always characteristic of the test set-up and the test procedure. Only at the end of the calibration the uncertainty of measurement is transferred to the measured object concerning the exactness of the scale design. The problems with the inclusion of the uncertainty of measurement in the conformity according to ISO 17025 at the calibration of material test machines is often founded in the too little number of single measurements, as e.g. at the calibration of the test force on hardness test machines according to ISO 6508. The number of single measurements in the calibration specifications of the test standards should be increased and variably arranged for the particular calibration requirement.
The consideration of the uncertainty of measurement is condition of any metrological result evaluation.

Keywords Uncertainty of measurement, limit deviation, ISO 17025

1. BASIC INFORMATION

Generally, physical, technical measurement categories are formally defined in a mathematical description. An ideal metrological realization of the formal definition would show the "true value" of the measurand. The best possible physical technological realization according to the definition in a standard or a measurement system occurs on the level of the National metrological institutes. The validation of the measurand occurs using round robbing tests between the National metrological institutes. The mean of this round robbing test is probably the best approach on the "true value" and counts as "right value". Because the invariant description of a measurand at independently realizations in a measuring system is not possible, the average values are justified according to the "right value". Here, the mean is subject to a variation again, except it is based on a very large (theoretically endless) number of single measurements (population). The estimation of the variation of the mean results out of a statistical test evaluation. Over the metrological chain (national metrological institute, calibration laboratories and industrial users) the measurand is passed on.

2. MEASURAND RECORDING FROM STOCHASTIC RESP. STATISTICAL VIEW

From the stochastic view every taken measurement is the result of a random experiment. Intention of metrological measured value collection is the estimation of an expected value. From the statistic way of thinking this corresponds to the mean of the population. For reasons of time and cost efficiency the mean of the population is estimated by a usually limited number of measurements (sample). The task of the statistic test evaluation consists in the estimation of the mean of the population of a sample. Generally thereby the normal distribution is presupposed under the conditions of a purely random caused measured value variation in the repetition attempt. The normal distribution is characterized as the parameter distribution by the mean „μ“ and the standard deviation „σ“ of the population (both are constants). However, the mean „$\bar{x}$“ and the standard deviation "s" of a sample are random variables. The estimation of the parameter of the population from the random variables of a sample occurs as:

- Point estimate: Mean and standard deviation of the sample will be set equal to the mean and the standard deviation of the population. For applying this acceptance exists only a very small probability.
- Interval estimate: Out of the sample an interval for the mean of the population is estimated by a model calculation.

The models for the estimation of sample values are based on the "direct conclusion". Thereby, out of a known population, the error bands of mean and standard deviation with different sample sizes will be estimated by tests or combination calculations. For example, the Student´s distribution (t-distribution) is the result of a calculation, if a great number of samples with changing number „n“ from a well-known population (parameter μ, σ) is taken and the average value and the standard deviation s are determined in each case:

$$t_{f,1-\alpha} = \frac{\bar{x} - \mu}{s} \cdot \sqrt{n} \tag{1}$$

In „the indirect conclusion“ (reverse) the parameters of the population are gathered from the random characteristic values of a sample. From a sample the average value and the standard deviation of the population are unknown. If the sample is to be assigned clearly to a normal distribution, then the average value of the population can be suggested by means of the t-distribution. By the formal conversion an interval dependent on the probability for the average value of the population will be received:

$$\bar{x} - \frac{t_{f,1-\alpha} \cdot s}{\sqrt{n}} \leq \mu \leq \bar{x} + \frac{t_{f,1-\alpha} \cdot s}{\sqrt{n}} \qquad (2)$$

The term $\frac{t_{f,1-\alpha} \cdot s}{\sqrt{n}}$ shows of the average value, with an accepted probability, the borders of the interval for the mean value of the population. In the interval is a quantity of equivalent values for the average value of the population. Information-theoretically the incompleteness of the information by the sample limits the reliability value regarding the position of the mean of population (average value of the series of measurements).

$$U_{\bar{x}} = \frac{t_{f,1-\alpha} \cdot s}{\sqrt{n}} \qquad (3)$$

Converged n $\rightarrow\infty$ this becomes too „0 in such a way “

$$\mu \leq \bar{x} \pm \frac{t_{f,1-\alpha} \cdot s}{\sqrt{n}} = \bar{x}(n \rightarrow \infty) \qquad (4)$$

With n $\rightarrow\infty$ the information is complete and the average value of the sample becomes to the mean value of the population (same is valid for the standard deviation). I.e. the instrumentation transmission of a measured variable on the item under test (normal or measuring instrument) can take place with appropriate calibration expenditure with the uncertainty used normal. With conclusion of the calibration the uncertainty of measurement turns into on the item under test (normal or measuring instrument). The uncertainty of measurement with the following passing on of the measured variable by means of normal or the measuring instrument is again dependent on the number of individual measurings as well as the variance the measuring instrument and the samples which can be examined. A goal of each calibration must be the regulation of mean value and standard deviation of the population.

3. INCLUSION OF THE UNCERTAINTY OF MEASUREMENT IN THE STANDARDS

In the standards the significance of the uncertainty of measurement is defined as follows:

- DIN EN ISO/IEC 17025, 2005-08, Beuth Verlag, Berlin, Chapter 5.10.4.2: At conformity the uncertainty of measurement has to be considered.
- DIN EN ISO 14253, 1999-3, Beutch Verlag, Berlin, Chapter 1-6: The limit of specification has to be reduce at the uncertainty of measurement
- DKD 5, 12-2008, DKD-Braunschweig, Chapter 2.2.3: If the compliance of uncertainty of measurement is attested, the measured values have to be within the uncertainty bounds of the uncertainty of measurement .

While the practice of these specifications is usual in the measuring, they are often unconsidered in the test techniques.

4. DIRECT CALIBRATION OF THE TEST FORCE OF HARDNESS TEST MACHINES

At the calibration of the test force of hardness test machines after [2], the measurement deviation “E” is to be determined. The measurement deviation is determined as the calibration value of the measure embodiment subtracted from the expected value of the realization of the measurand in the testing machine. The expected value (mean of the population) will be determined, if possible, out of a sample of respectively 3 measurements in three different position of the plunger. According to [2] force proving device of class 1 should be applied. The classification according to [3] for the force proving device of class 1 gives a minimum uncertainty of measurement of U_{PM} = 0,12% in the range form 2% to 100% of the calibration force (class 0,5; U_{PM}=0,06% / class 2; U_{PM} =0,24%). After [1] the uncertainty of measurement as additive term to the mean is transferred to the calculated measurement deviation. This becomes now a defined interval. The conformity according to [1] is given, if the interval (interval borders) are within the normative specifications according to the limiting deviation. The model for calculation of the uncertainty of measurement considers:

$$E = (\bar{x} - x_K) \pm U \qquad (5)$$

$$E_{zul} \leq E \quad \text{and/ or} \quad E_{zul} \leq (\bar{x} - x_K) \pm U \qquad (6)$$

U_{PM} → The uncertainty of measurement from the return of the test equipment at the calibration is given and dependent on the accuracy, the reproducibility, the stability and the linearity according to the image of the scale. It can be decreased by a precise transfer standard (e.g. force proving device class 0.5).

U_{ms} → The uncertainty of measurement of the least measuring step (standard deviation of the rectangle distribution is dependent on the resolution of the measure embodiment according to the image of the scale. It can be decreased through a higher resolution.

$U_{\bar{x}}$ → The uncertainty of measurement from the sample character of the calibration. It can be decreased optionally by increasement of the number of single measurements.

U → The uncertainty of measurement of the determined measuring value results from, linear independence required, a quadratic addition of the single parts of the uncertainty:

$$U = \sqrt{U_{PM}^2 + U_{ms}^2 + U_{\bar{x}}^2}$$

and / or

$$U(t,\alpha,s,n,U_{PM},U_{ms}) = \sqrt{U_{PM}^2 + U_{ms}^2 + \left[\frac{t_{f,1-\alpha}\cdot s}{\sqrt{n}}\right]^2} \quad (7)$$

The parts of the uncertainty of the return and the least measuring step are linear dependent on the measurand. Because there is a punctual transfer of scale during the calibration of the test force, these parts are in the concrete case approximately constant (e.g. U_{PM} =0,12%; U_{ms} =0,0012% at a signal of 50000 digital units).

The parts of the uncertainty of the sample character are dependent on the variation of the measured values and the number of measurements. The limiting value of the measuring uncertainty for „n→∞" results out of the quadratic addition of the parts of the un certainty of the calibration des transfer standard and the least measuring step (Fig.1). The requirements of a fixed number of measurements causes a dependence fo the decision with the conformity of the factor of the standard deviations resp. the coefficient of variation. At a evaluation based on only 3 single measurements (normatively allowed) would be the test force conform.

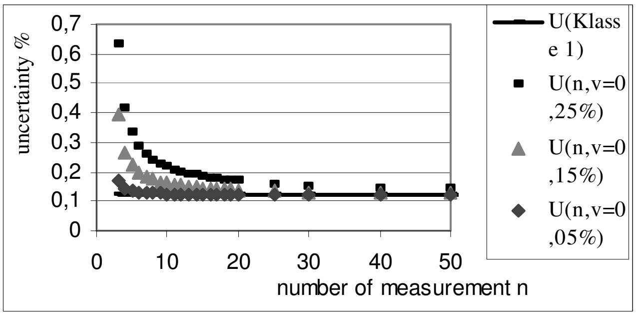

Fig. 1. Uncertainty of measurement „U "as a function of the number „n "and the coefficient of variation „v "

E.g. with 3 test machines on basis of in each case 9 measurements a deviation of the test force of E=0.8% with coefficient of variations of v=0,05%, v=0.15% and v=0.25% is determined. Then becomes confirm with v= 0.05% and v= 0.15% the conformity and with v=0,25% nonconformity of the test force. In the case of an evaluation based on only 3 individual measurings (normative permitted) only the test force would be conformal with v=0,05%. The effect of the uncertainty of measurement on the statements to the conformity at the measurements deviation makes clear, if you reduce the allowed limiting deviation "E_{zul}" by the uncertainty of measurement. The calculated measurement deviation has to be smaller than the reduced measurement deviation „E_{red}". The reduced measurement deviation is dependent on the variance of the measuring values, the number of single measurements and the uncertainty of the transfer standard (Fig.2).

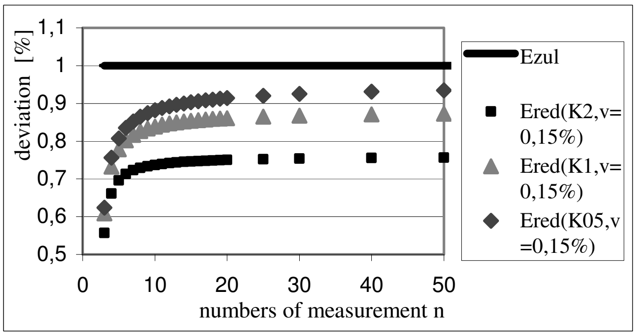

Fig. 2. deviation „Ered" reduced by the uncertainty of measurement as a function of the number of measurements and the class of the force transfer standard „K0,5 to K2 ".

The dependency of the measuring uncertainty of the class of the force calibration device gets very clearly, because of the measuring uncertainty, which gives the limiting value of the reachable measuring uncertainty. For the calibration are class 1 force transfer standard required, but in the band of 2%-100% of the calibration force as well as in the rangse of test forces under 500mN, the force proving device often don´t achieve these requirements anymore. If the determined measurement deviation samller than the reduced measurement deviation, the conformity would also be achieved with a Force proving device class 2, yet with a considerably greater uncertainty of measurement at the transfer of the measurand. Fig. 2.

6. STATISTICAL ANALYSIS

The advancement of the information base according to the functional capability of the hardness testing machines would be possible by statistical analysis of the measured data. The calibration of the test force with 3 series of measurements to every 3 single measurements is accomplished under repetiliity conditions. Deviations of the normal distribution (e.g. after Epps Pulley test [4]) and/or those affiliation to the same population (analysis of variance „ANOVA ") are on advice of a disturbance of the machine. The permissible repetition precision must be specified normative. Conceivable fixing a coefficient of variations v ≤ 0.1% would e.g. be with the test force. After the admission of the 3 series of measurements the statistic analysis takes place. The possibly necessary number of additional measurements can be measured as follows:

$$n = \frac{(2{,}3 * s)^2}{(E_{zul} - E)^2 - U_{PM}^2 - U_{ms}^2} \quad (8)$$

6. GIVEN MAXIMUM UNCERTAINTY OF MEASUREMENT

With the view of of the uncertainty of measurement at calibration and the evaluation of the testing machine in mind, the requirement of a maximum acceptable uncertainty of measurement would be imaginable. The device dependent coefficients of variations would be equalized over the number of measurements. The evaluation of the testing machines took place on the base of the same uncertainty of measurement and an –after statistical specifications- saved data basis would be given on a if so necessary adjustment of the machine. The number of single measurements in dependence of the coefficients of variation results from the forming from (9). However, it is not defined directly, caused by the reflexive reference to the number of the t-factor.

$$n = \frac{((t_{f,1-\alpha/2}) \cdot s)^2}{(U^2 - U_{PM}^2 - U_{ms}^2)} \quad (9)$$

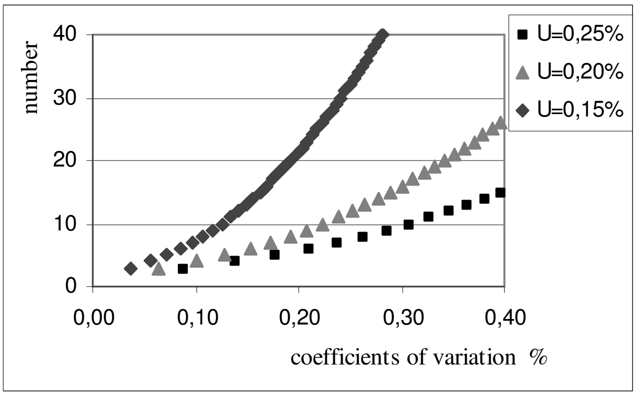

Fig.5 Number of the measurements in dependence of the coefficient of variation; uncertainty of measurement U=0,15 to 0,25%.

By the forming of (9) with the standard deviation as dependent variable and the number as independent variable a table solution is possible. To achieve same measurement uncertainties at increasing coefficient of variation, the number of measurements has to be increased appropriately.

E.g. there is a uncertainty of measurement of U=0,15% for coefficients of variations of v=0,05% at n=5; for v=0,15% at n=19 and for v=0,25% at n=50.
To reduce the calibration effort a determination of a limit value of the modification of the uncertainty of measurement in dependence of the number would be imaginable. (Limit value for the increase of the border). However, the associated modification of the uncertainty of measurement is to keep in mind. The modification of the uncertainty of measurement in dependence of the number of measurements is to define by the quotient of difference. At a quotient of difference of $\Delta U/\Delta n \leq 0{,}0025\%$ there is the result in dependence of coefficients of variations the number of measurements, e.g. at v=0,05%; n=7; U=0,129%; at v=0,15%; n=14; U=0,148%; and at v=0,05%; n=20; U=0,168%.

7. CONCLUSION AND OUTLOOK

The problem, which is described here, with the inclusion of the uncertainty of measurement according to DIN EN ISO 17025 occurs in many categories of the material test machine calibration. Often it is based in a too little number of single measurements as base for the conformity. The revision of the standards should take place according to the number of measurements at the calibration. The consideration of the uncertainty of measurement of a measurand is the requirement of any metrological reasonable evaluation of results.

REFERENCES

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