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SOME ASPECTS OF MEASUREMENT UNCERTAINTY CALCULATION IN GAUGES BLOCK CALIBRATION

Almira Softic, Hazim Basic
University of Sarajevo, Mechanical Engineering Faculty Sarajevo
Sarajevo
Bosnia and Herzegovina

Sinisa Trifunovic
MB FRIGO d.o.o
Sarajevo
Bosnia and Herzegovina

ABSTRACT

Gauge block calibration is one of the oldest high precision calibrations made in dimensional metrology. Measurement Assurance Method determine calibration or measurement uncertainty based on systematic observations of achieved results. All length measurement processes are comparative operation, directly or indirectly. A comparator is device for measuring difference. The unknown length of a block is determined by measuring the difference between it and a reference block of the same nominal size and then calculating the unknown length. Measurement process is continually affected by perturbations from variety of sources. The uncertainty in the result of measurement generally consists of several components which may be grouped in two categories according to the way in which their numerical values are estimated: A-those which are evaluated by statistical methods and B-those which are evaluated by other means.

Keywords: measurement uncertainty, gauge blocks, calibration.

1. INTRODUCTION

A gauge block is a length standard having flat and parallel opposing surfaces. The length of the gauge block is defined at standard reference conditions: temperature 0°C, barometric pressure 101,325 Pa and CO_2 content of air 0,003%. In length measuring by mechanical comparison the length of the test gauge is compared to that of standard gauge and the measured difference in their lengths determines the length of the test gauge. Factors influencing the measurement are: the length calibration of the standard, factors inherent in the comparator equipment used to measure the length difference such as scale linearity and reading capability, gauge geometry with respect to its effect on probing the length difference, the temperature of the environment as it influences the gauge temperatures and etc [1,2].

2. UNCERTAINTY CONTRIBUTORS-WHAT TO LOOK FOR

The process of developing uncertainty budgets requires first to find the causes of measurement uncertainty and quantify them. We must understand the measuring process being evaluated, and a certain amount of experience, to identify and quantify uncertainty contributors. Principle of gauges block calibration using mechanical comparator is given in Figure 1 [1].

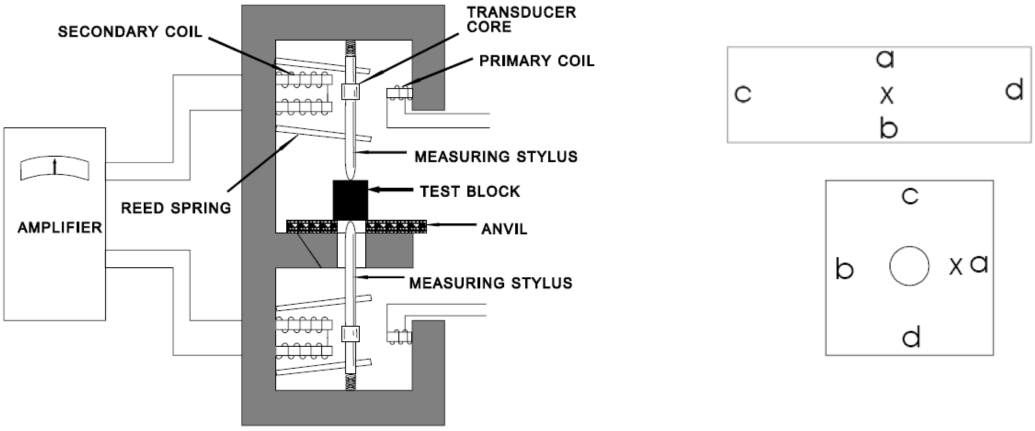

Figure 1. Mechanical gauge block comparator and location of gauging points on gauge blocks for both length (X) and parallelism (a,b,c,d) measurements [1].

When collecting uncertainty contributors, it is important to know the areas where they may be looking. The listed items are not the uncertainty contributors; they are areas in which the uncertainty contributors can be found. These areas can include:

The environment. The uncertainty contributors related to the environment are primarily temperature, humidity, barometric pressure. Before calibration, care is taken to ensure that the gauge blocks assume ambient temperature of the measuring room. The remaining difference in temperature between the standard and the gauge block to be calibrated is estimated to be within ±0,05 K.

The reference element of measuring equipment. In a gage block comparator, the known gage block is the reference element. Looking at the reference element, separately, often gives a clearer picture of where uncertainty originates, than looking at the measuring equipment as one item.

The measuring equipment. It is probe and the base in gauge block comparator.

Measurement setup. It is the plate holding the gage blocks and the vibration isolated base in the gage block comparator.

Software and calculations. Software contributes to the uncertainty, if the equations used are different from what is intended in measurement.

Measuring object. The influences significant, but may be overlooked as contributor to the uncertainty.

Physical constants. The thermal expansion coefficient of steel is used from reference books. However, when using the book value to make compensation, there will be an uncertainty, because the particular batch of steel used to make each gage block has a slightly different expansion coefficient. The variation of the thermal expansion coefficient of gauge block steel with temperature is given in Figure 2.

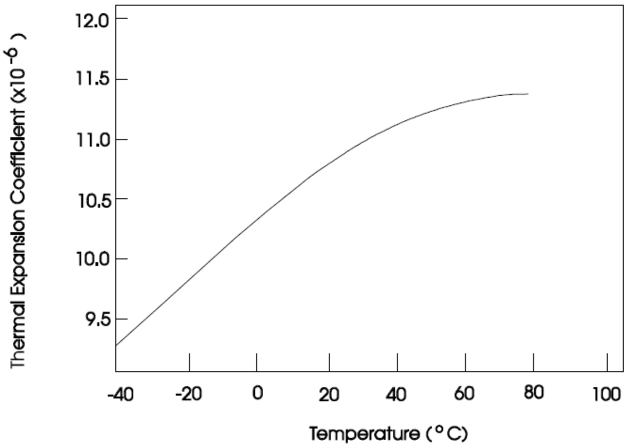

Figure 2. Variation of the thermal expansion coefficient of gauge block steel with temperature [1].

The metrologist. Is there enough light and is it easy to take necessary readings? Does the environment encourage accurate work?

Definition of measurand. The measured is what is to be measured- the length of gauge block.

Measuring procedure. The measuring procedure determines how long the gauge block is allowed to acclimate before it is measured, or how a sequence of repeat measurements are arranged to compensate for drift.

Despite the large thermal expansion coefficient, steel has always been the material of choice for gauge blocks. The reason for this is that most measuring and manufacturing machines are made of steel, and the thermal effects tend to cancel.

Once the contributors have been identified, it is important to quantify how much each adds to the budget. If the uncertainty contributors are incorrectly identified, one will either overestimate or underestimate the uncertainty.

3. UNCERTAINTY OF MEASUREMENT

Like most test, measurement and inspection equipment, gage blocks require regular calibration to maintain accuracy. Scratches, gashes and other damage caused by wear and corrosion can negatively affect the blocks' accuracy. Subjecting the gage blocks to calibration is the best way to verify accuracy. The frequency of calibration depends on the tolerance requirements of the job, the amount of use and conditions under which the gage blocks are used.

Understanding and documenting measurement uncertainty is the key for gauge calibration. The uncertainty of measurement is a parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

The uncertainty in the result of measurement generally consists of several components which may be grouped into two categories according to the way in which their numerical value is estimated:

1. A – Those which are evaluated by statistical methods of series of observations,
2. B – Those which are evaluated by other means than the statistical analysis of series of observations.

There is not always a simple correspondence between the classification into categories A or B and the previously used classification into “random” and “systematic” uncertainties [2,3,4]. The “systematic uncertainty” can be misleading and should be avoided. Any detailed report of the uncertainty should be consisting of complete list of components, specifying for each the method used to obtain its numerical value.

Type A evaluations include an experiment that allows observation of variations caused by the uncertainty contributor. Then the variation is analyzed by statistical means to find the experimental standard deviation for the contributor. The limitation in type A evaluations is that all the variation the contributor causes must be observed. This means the variation must be sampled often enough to capture the slowest variation. The type A evaluation is the standard technique traditionally used for assessing measurement uncertainty. Gage repeatability and study is A study wherein the variation is observed and treated using statistical tools.

The type B evaluation provides freedom to use all the information available, such as prior knowledge, manufacturer’s specifications, and information from calibration certificates, to estimate uncertainty quickly and cost effectively.

Type B evaluations estimate the limits of the variations caused by an uncertainty contributor, assumes a distribution for the variation between these limits, and uses this information to calculate an equivalent standard deviation. The four most commonly used distribution are: normal, triangular, rectangular and U-shaped.

The choice between type A and type B evaluation depends on what information is available. The type A evaluation is attractive if experimental data is available. Otherwise, type B is faster and easier to use, especially in a first draft uncertainty budget where we tries to get a feel for the relative size of the contributors.

The length l_X of the unknown gauge block at the reference temperature (t_0 = 20 °C) is obtained from the relationship [2]:

$$l_x = l_s + \delta l_D + \delta l + \delta l_c - L\left(\bar{\alpha} \cdot \delta t + \delta\alpha \cdot \Delta\bar{t}\right) - \delta l_V \qquad (1)$$

where:

l_{S} - length of the reference gauge block at the reference. The length of the reference gauge block together with the associated expanded uncertainty of measurement is given in the calibration certificate of a set of gauge blocks.

δl_{D} – change of the length of the reference gauge block since its last calibration due to drift. The temporal drift of the length of the reference gauge block is estimated from previous calibrations to be zero with certain limits (for example ±30 nm). General experience with gauge blocks of this type suggests that zero drift is most probable and that a triangular probability distribution can be assumed.

δl – observed difference in length between the unknown and the reference gauge block.

δl_{C} – correction for non-linearity and offset of the comparator. For example, for length differences D up to ±10 µm corrections to the indicated length difference are within the limits ±(30 nm +0,02·$|D|$). Taking into account the tolerances of the grade 0 gauge block to be calibrated and the grade K reference gauge block, the maximum length difference should be within ±1 µm leading to limits of ±32 nm for non-linearity and offset corrections of the comparator used.

L – nominal length of the gauge blocks considered;

$\bar{\alpha} = \left(\alpha_x + \alpha_s\right)/2$ - average of the thermal expansion coefficients of the unknown and reference gauge blocks.

$\delta\bar{t} = t_x - t_s$ - temperature difference between the unknown and reference gauge blocks.

$\delta\bar{\alpha} = \alpha_x + \alpha_s$ - difference in the thermal expansion coefficients between the unknown and the reference gauge blocks.

$\Delta\bar{t} = \left(t_x + t_s\right)/2 - t_0$ - deviation of the average temperature of the unknown and the reference gauge blocks from the reference temperature.

δl_{V} - correction for non-central contacting of the measuring faces of the unknown gauge block. For gauge blocks of grade 0 the variation in length δl_{V} determined from measurements at the centre and the four corners has to be within ±0,12 µm (ISO 3650).

4. CONCLUSIONS

Calibration of gauge blocks by mechanical comparison is widely used for assuring traceability of industrial measurements for the physical quantity “length”. In order to diminish uncertainty of calibration, we shall control all influence parameters very precisely. We must be able to predict intervals of changes of these parameters in short and long term intervals and include those changes in the uncertainty budget. Mathematical model of measurement is used for calculating standard uncertainty of the output value (calibration result) from the uncertainties of the input (influence) quantities. However, this calculation is reliable only if the uncertainties of the influence quantities are evaluated accurately.

Usually, none of the input quantities are considered to be correlated to any significant extent [2]. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor $k = 2$, which for a normal distribution corresponds to a coverage probability of approximately 95 %.

5. REFERENCES

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