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Two-point calibration of coating thickness gauges: what needs to be considered to improve measurement accuracy

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Abstract. It is shown that, unlike other means of measuring linear dimensions, coating thickness gauges do not have a regulatory framework governing their accuracy (error). It is noted that a number of external factors influence the reliability of the results of coating thickness measurements. Using the example of coating thickness gauges, the difference in the measurement results for two-point and zero calibration is shown.

One of the main indicators of coating thickness gauge quality is their accuracy and reliability. The lack of a proper regulatory framework for coating thickness gauges leads to vagueness of these quality indicators. The accuracy of the measuring instrument is estimated by the accuracy class, which regulates the measurement error of this device. For example, for micrometers, the error is normalized according to GOST 6507-90 [1], depending on the accuracy class, for indicator inside measuring device - GOST 868-82 [2], for contact profilographs, GOST 19300-86 [3] normalizes the error, depending on the degree of accuracy and so on.

Depending on the class (or degree) of accuracy, tolerances for other parameters of the instruments are also established. For example, for a micrometer, the tolerance of parallelism and the flatness toclerance of working surfaces, the tolerance for the length of the installation measures, etc. are normalized. Developing a standard for technical conditions for coating thickness gauges will not only streamline instruments by accuracy, normalizing the magnitude of error by accuracy classes, but also bring some benefit to manufacturers: on the one hand, a thickness gauge of first-class coatings will cost more than a similar second-class device, on the other hand - the classification of the device will provide appropriate hidden advertising, which contributes to better commercialization of goods. The consumer will have more accurate information in terms of accuracy indicators thickness gauges.

As for the second indicator of the quality of coating thickness gauges - the accuracy of the measurement results. Reliability of measurement is the most important characteristic of measurement quality, characterizing confidence in the measurement results. In this case, the reliability of measurement results used in research, testing and quality control of products will be understood largely by the correctness of the decisions made when measuring coating thickness [6].

Modern magnetic and eddy-current thickness gauges for measuring coatings are quite sensitive to factors affecting the measurement accuracy. So GOST 31993-2013 [4] gives eleven such factors for magnetic thickness gauges and ten for eddy current meters. Each of these factors in one way or another influences the final result, but the manufacturers of thickness gauges in their operational documentation, which the consumer uses, do not always reflect and not all factors are reflected. Studies of operational

documentation conducted earlier [5] showed that only one factor (coating thickness that can be measured with this device) is given for all thickness gauges under study. Factors, such as, the edge effect take into account only 40% of the thickness gauges under study, the thickness of the base (the thickness of the measured surface without coating) and the curvature of the measured surface are given in the documentation of 78% of the thickness gauges, etc. In addition, it was revealed during the analysis that some of the indicated factors in the operational documentation are represented by numerical values (for example, the minimum base thickness of 0.5 mm), and some of the factors are indicated by a verbal description, for example, "the curvature of the test object has some influence on the measurements, which obviously increases with decreasing radius of curvature". Such a description of the factor carries limited information and does not give recommendations to the consumer to reduce measurement errors.

To increase the accuracy and reliability of measurements, some thickness gauges provide not only zero calibration, but also two-point calibration.

With zero calibration, the thickness gauge is applied to the attached base and is set to zero. Then the thickness of the coating is measured.

With two-point calibration, zero calibration is first performed. Then a measure of thickness is established on the base, the value of which is close to the thickness of the coating being tested. The value on the display of the thickness gauge is adjusted to the value of the measure of the coating thickness. The device is ready to measure.

For further research, a coating thickness gauge of the TM-20MG4 model was used (figure 1), which includes an induction transducer 1 and an electronic unit 2.

Figure 1. General view of the thickness gauge.

Metrological characteristics of the thickness gauge model TM-20MG4:

- measuring limits - 200 microns;
- permissible measurement error -$\pm (0.03 \ h + 1)$ μm, where h the thickness of the coating is being measured;
- -which includes an induction transducer 1 and an electronic unit 2
- the minimum thickness of the ferromagnetic base is not less than 0.4 mm;
- the distance from the center of the transducer to the edge of the ferromagnetic base is not less than 24.5 mm;
- the radius of curvature of the test surface is not less than 40 mm.

The principle of operation of the thickness gauge under investigation is based on the magnetic method of non-destructive testing, i.e. capable of measuring the thickness of any non-magnetic coatings on a ferromagnetic base. Sectoral purpose of this thickness gauge is: engineering, automotive, construction, chemical industry, scientific research, etc.

The set of the device includes a base with a thickness of 13 mm and a diameter of 50 mm. On this basis, both the zero calibration of the device before the start of measurements, and the two-point calibration is carried out. Based on the metrological characteristics, the device can be used to measure the thickness of the coating, the base thickness of which does not exceed 0.4 mm.

The error of the thickness gauge in two cases of its use was investigated in this work:

- in the first case, the instrument was calibrated on the enclosed basis. The error estimate for zero calibration and two-point calibration for various thickness gauges was determined for objects which thickness is equal to the thickness of the calibration base. To exclude experimental errors associated with the difference in the magnetic properties of the base, its roughness and other factors affecting the error, the error estimation was determined on the same basis;
- in the second case, the instrument was calibrated both with zero and two-point calibrations on the same attached base, and the instrument's error was estimated on a similar basis 1 mm thick (the instrument's metrological characteristics allow a minimum thickness of the base to 0.4 mm without exceeding the permissible error device specified in the operational documentation of the device).

For further research, the following method for estimating the error in measuring the coating thickness was used:

1. Five measurements of the thickness h_i of the coating on each standard of thickness are carried out and the arithmetic average value h_c is found by the formula:

$$h_c = \frac{1}{n} \sum_{i=1}^{n} h_i.$$

2. The systematic error Δ_c of measurement as $\Delta_c = h_c - h_{\text{н}}$, is determined, where h_n is the nominal value of the standard of the coating thickness.

3. The random error is determined Δ_o by the formula:

$$\Delta_o = t \sqrt{\frac{\sum_{i=1}^{n}(h_i - h_c)^2}{n(n-1)}}$$

where t is the student coefficient. With a confidence level of $P = 0.95$ and the number of observations (measurements) $n = 5$, the Student t coefficient is $t = 2.78$.

4. The main error of the thickness gauge is determined $\Delta = \Delta_c \pm \Delta_o$. under test.

When assessing the error of the gauge model TM-20MG4 used coating thickness standards are of the following sizes: 18; 48.6; 101.6; 250.3; 352; 497; 598; 998; 1555 and 1876 microns.

The research results are shown in figures 2 and 3. For more informativeness and clarity, the figures show the absolute value of the basic error. In this case, the gray color shows the permissible value of the basic error specified in the operational documentation of the device and calculated for the nominal value of each thickness standard. The black color represents the instrument error, determined with a zero gauge of the thickness gauge, and the light background indicates the instrument error, determined with a two-point calibration.
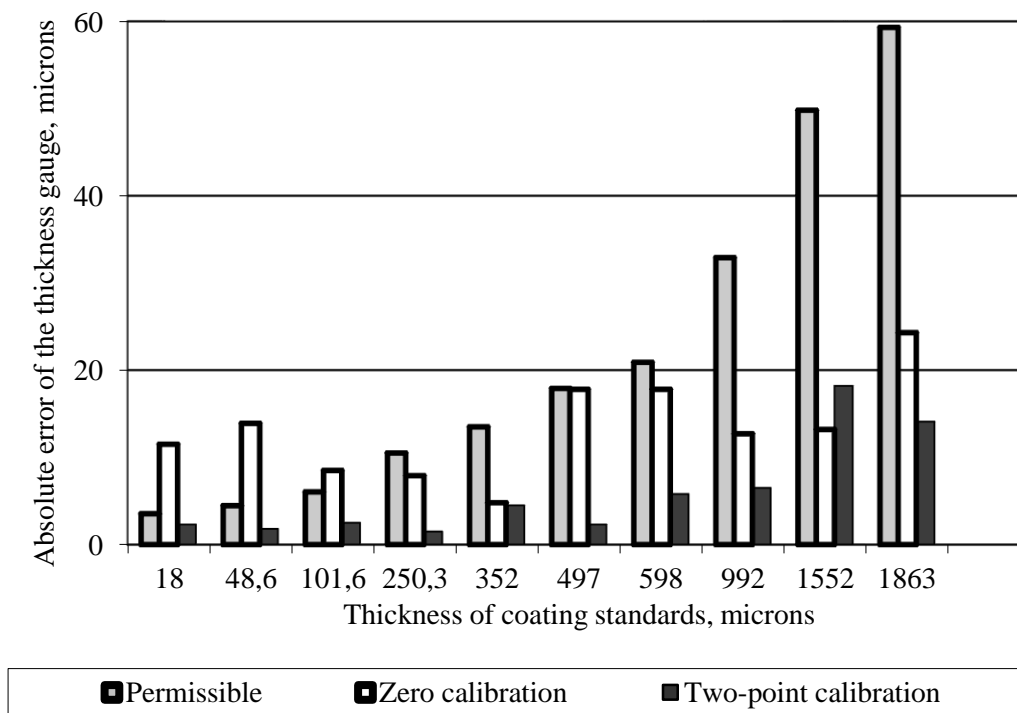
Figure 2. The error of the thickness gauge is shown, estimated by the thickness standards, installed on the 13 mm thick base attached to the instrument. Calibration of the instrument (zero and two-point) was carried out on the same basis.
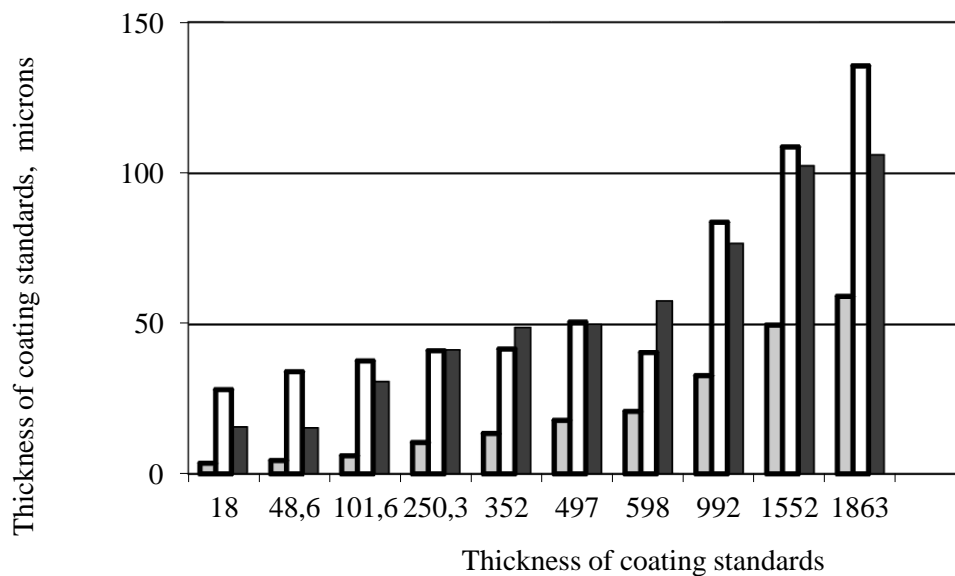

Figure 3. Error thickness gauge model TM-20MG4 when calibrating at a base thickness of 13 mm and measuring the thickness of the standards on the basis of 1 mm thickness.

It can be seen from the diagram that with zero calibration on the first three standards of thickness, the error of the device exceeds the allowable values. Two-point calibration significantly reduces the error in the entire range of coating thickness measurements. It is for this purpose provided by the design of the device. However, the thickness of the bases of many products may differ many times from the thickness of the base applied for calibration in the instrument set. Therefore, the thickness of the cases of household appliances, cars, building materials, etc. is presented within one millimeter. In this case, the two-point calibration is powerless (see figure 3). If the calibration is carried out on the attached base with a thickness of 13 mm, and the measurement is carried out on a base of 1 mm, then the error of the instrument over the entire measurement range, both with zero calibration and two-point one, will greatly exceed the allowable value. Hence the logical conclusion is: in order to preserve the principle of non-destructive testing, designers and manufacturers of coating thickness gauges need to provide a set of bases of various thickness, as it is done with thickness standards.

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