Abstract

The subject of this doctoral thesis was the development of an innovative comparator with a resolution of 10 ng, higher than previously achieved in mass metrology. The comparator is to be used for determination of mass standards below 1 mg with lower measurement uncertainty than that offered by devices currently available on the market.

This comparator is able to calibrate mass standards in the range of 0.05 mg − 500 mg, but the main focus of the researches was on masses below 1 mg. A higher resolution of the device was achieved through to the appropriate modification of the comparator actuator coil and its sealing in order to reduce moisture sorption, as well as the use of an innovative magnetic circuit made of ARMCO material. This allowed for the reduction of mass measurement errors, and thus a significant increase in the comparator accuracy, as well as the automation of the measurement process.

In the introductory part of the thesis, the main aspects related to the calibration of mass standards were discussed. The factors that influence the accuracy of the calibration (components of the uncertainty budget) were also analyzed. Various types of mass comparators are also presented, their structure, the advantages of automation, as well as the fundamentals of the entire SI unit system, and, in particular, recent redefinition of the kilogram unit.

The main part of the dissertation presents the design and tests of the innovative NANO.AK-4/500 mass comparator, which is the first in the world to enable mass measurement with a resolution of 10 ng. The advantages of the mechanism modifications, which significantly reduced measurement errors related to moisture sorption and the improvement of the electromagnetic actuator structure, as well as the mass, and hence inertia of the mechanical system, including the coil, were discussed.

Further, the deviation of measurement results for various mass standards was analyzed. It was demonstrated that the comparator achieved standard deviations from 6 ABBA cycles below 50 ng (5 reading divisions). The determined standard deviations were compared with the measurement uncertainties of another commercial comparator device (UMA-5, RADWAG) considered to be one of the best comparators in the range of small masses. The tests proved that in all cases the measurement uncertainties of the NANO.AK-4/500 device were lower by about 75% as compared to the UMA-5 comparator for all tested masses. The

UMA-5 comparator was selected for comparisons since so far 0.05 mg – 500 mg standards have been calibrated to candles using such or similar devices.

Next, the repeatability was also calculated according to commonly used procedures. The calculated value of the *EV* (equipment variation) for the NANO.AK-4/500 comparator was *EV* = 0.115 μg, which was very close to the uncertainty obtained for the standard deviation from a single run of 6 ABBA comparison cycles. Compared to the UMA-5 comparator, the repeatability was better by about 65%.

The results of the difference in masses between the reference standard and the test standard were also compared with the comparator of the highest resolution of 0.1 μg. The study revealed overlapping dispersion ranges for the tested masses, with a much lower measurement uncertainty of NANO.AK-4/500.

The stability of the novel NANO.AK-4/500 device was also checked with a standard procedure. Repetitions were made within 7 months from April to November 2020 at intervals of 14 days. The dispersion of the results obtained during the test did not exceed the assumed maximal uncertainty 50 ng for the innovative comparator. Within the doctoral dissertation, a scientific thesis was proven that appropriate modification of the comparator actuator coil and its sealing for the reduction of moisture sorption, as well as the use of an innovative magnetic circuit made of ARMCO material, can reduce errors in mass measurement, and thus significantly increase the accuracy of the comparator. Moreover, further development directions were indicated.

The test results of the NANO.AK-4/500 comparator with a resolution of 10 ng were so satisfactory that the comparator was included in the commercial offer of RADWAG Wagi Elektroniczne.

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