PREDICTION OF LIFE CYCLE OF NON-AUTOMATIC WEIGHING INSTRUMENT IN LEGAL METROLOGY

Haris Memić[1], Zijad Džemić[1], Jasmin Kevrić[2], Dejan Jokić[2]

[1] Institute of Metrology of Bosnia and Herzegovina (IMBiH), Sarajevo, Bosnia and Herzegovina, haris.memic@met.gov.ba

[2] International Burch University (IBU), Sarajevo, Bosnia and Herzegovina, jasmin.kevric@ibu.edu.ba

Abstract:
In this paper, the possibilities and important factors that can influence the prediction of the life time (life cycle) of a measuring instrument used in the field of legal metrology, which is found in everyday work and in different working conditions, are considered. Based on the measurement history and a large number of measurement results data, significant factors (history of measurements, different provider of services, measurement uncertainty and environmental conditions) that can influence the judgment of the life cycle of the measuring instrument were analysed. The presented results indicate the further research for development of a more efficient, faster and better system meant for consumer protection from inaccurate measurements.

Keywords: legal metrology, conformity assessment, life cycle, digitalization, verification

1. INTRODUCTION

Legal metrology represents one of the three basic metrology areas, especially dedicated to consumer protection. The task of legal metrology is to ensure measurement results with the necessary accuracy and reliability wherever there is a public interest or a need for consumer protection. In order to have developed legal metrology, it is necessary to develop appropriate methods, measurement standards and ensure metrological traceability in a prescribed manner. In accordance with the stated needs, it is obvious that all categories of metrology are interdependent, and that without the simultaneous development of scientific, legal and industrial metrology, the international metrology system would not be functional. Legal metrology implies the application of legal requirements to measurements and measuring instruments. Measuring instruments used in the field of legal metrology are those measuring instruments that provide measurement results that serve as a basis for economic transactions, for the protection of human and animal health, environmental protection, these are measuring instruments whose measurement results can be the subject of court and administrative proceedings.

Legal metrology with its recognized competences represents a greater part of the activities of each country legislature in relation to other categories of metrology, and the coordination and management of the same is always the subject of state authorities. Measurement data, which are the basis for the analysis of this paper, were provided by the Institute of Metrology of Bosnia and Herzegovina (IMBiH), which is responsible for metrology system in Bosnia and Herzegovina, covering legal, industrial and scientific metrology.

In order to adequately analyse some specific measuring instrument, and for a valid conformity assessment to be made for the same, it is necessary to carry out measurements by competent laboratories. In addition to the analysis related to the subsequent verifications of the measuring instrument, this paper analyses the measurement results obtained on the measuring instrument in laboratory conditions (at different temperatures in accordance with the manufacturer's declaration), and the subsequent comparison of the results related to similar types of measuring instrument that are used in real life conditions.

There are certain standards that indicate ways of life cycle management, as well as analysis of modelling processes of essential steps in determining the life cycle [1], from the clients requests to the manufacturing of a product. However this analysis is based on the results of measuring instrument that have a certain history of use. On hand of these information obtained in the use of the measuring instrument, new information have been obtained indicating the need for further research in development of algorithms for data digitalization and transformation for accurate prediction of life cycle of a measuring instrument.

In addition to the measurement verification procedure that has been conducted, the measurement calibration procedure was also approached on the same test object, in order to determine the contribution of measurement uncertainty of the measurement error and analysis of the impact on the permissible measurement error, as well as the final impact on the consumer protection.

On the basis of the overall analysis, a prerequisite for the algorithm was determined, which will be used for both, prediction of the life cycle of a measuring instrument and for traceable diagnostics in the future operation of the measuring instrument.

2. METHODOLOGY

The two most well-known processes that we encounter in the field of metrology, in addition to testing, are calibration and verification of measuring instruments. Although very similar in performance, these two processes differ from each other. Calibration is usually carried out in order to provide a quantitative report on the correctness of the measurement result of a measuring instrument, and is mostly used in the field of industrial metrology to achieve metrological traceability.

According to the International Vocabulary of Metrology (VIM) [2], calibration represents operation on measuring instrument or measuring system, that under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

Confidence in the results is achieved through ensuring the traceability and determining the uncertainty of the measurement results. Laboratories that carry out calibrations must have a certificate of competence from an independent third party, which is mostly proven by accreditation, i.e. by confirmed implementation of the ISO/IEC 17025 standard [3]. On the other hand, verification is a procedure used to check the compliance of measuring instruments in accordance with the relevant legal regulations. In accordance with the international dictionary (VIML) [4] of legal metrology, verification is conformity assessment procedure (other than type evaluation) which results in the affixing of a verification mark and/or issuing of a verification certificate. Verification represents the provision of objective evidence that a certain item meets certain requirements prescribed according to law on metrology or by-laws on metrological characteristics of measurement instruments under verification. The requirement that must be met by the laboratories that carry out verifications in Bosnia and Herzegovina is the implementation of the ISO/IEC 17020 standard [5], which has to be confirmed by an independent third party.

2.1. Verification of measuring instrument and stability of use in laboratory conditions

The subject of the analysis of this paper in monitored laboratory conditions was a precise non-automatic weighing instruments of the accuracy class II, with a maximum weighing capacity of 6200 g, a minimum weighing capacity of 0.5 g, verification scale interval (e) of 0,1 g, and actual scale interval of 0.01 g (up to 1500 g), 0.02 g (3000 g) and 0.05 g (up to 6200 g). The verification procedure was carried out in laboratory conditions at different temperatures (18°C, 20°C, 25°C) and in different time periods (September 2021 - February 2022) in accordance with the international recommendation of international organization of legal metrology OIML R76 [6]. At each of the temperatures, at least 3 verifications were performed in different time periods and always at the same test loads (10 loads) from the minimum to the maximum capacity (and vice versa) in order to test the linearity of the subjected non-automatic weighing instrument. The verification has been performed with weights of F_1 accuracy class.

2.2. Verification of measuring instruments in working conditions

In order to get a clearer overview of the life cycle of a measuring instrument, an analysis of the stability of measuring instrument with similar metrological characteristics of the same type was carried out (compering to the non-automatic weighing instrument, described in 3.1). The analysis has been done on measuring instrument which has daily use in real working conditions and which is operated by personnel who do not necessarily have the skills of an experienced metrologist. The non-automatic weighing instrument that was taken into analysis was the subject of regular subsequent verifications over the years.

The subjected non-automatic weighing instrument is the same family type as the one analysed in laboratory conditions, from the same manufacturer with a maximum weighing capacity of 6200 g, a minimum capacity of 5 g, verification scale interval of 0.1 g and actual scale interval of 0.01 g. The non-automatic weighing instrument was verified in the period 2012-2018 and at temperatures ranging from 22-25°C.

2.3. Contribution of measurement uncertainty to measurement results in relation to mpe

In accordance with the requirements of the ISO/IEC 17025 standard, which refers to general requirements for testing and calibration laboratories, based on calibration measurement data, obtained in accordance with EURAMET guide cg.18 [7] it is possible to make a decision of the conformity of the measuring instrument with the relevant legal requirements in accordance with the limits of mpe specified in OIML recommendation R76.

The non-automatic weighing instrument, subjected for the analysis in point 3.1. of this paper, was regularly calibrated in laboratory conditions in the period from 2013 till nowadays.

3. RESULTS AND DICUSSION

3.1. Linearity tests in monitored laboratory conditions

As stated earlier in the text, the linearity test was performed at 10 points (different loads), where the maximum permissible error (mpe) in the weighing range up to 500 g is 0.05 g (0.5e), up to 2000 g is 0.1 g (1e) and everything above up to the maximum capacity of 6200 g is 0.15 g (1.5e). In accordance with the prescribed mpe, it is possible to conclude that all measurements at a temperature of ~18°C (when testing linearity by continuous loading) are within the prescribed mpe limits and that they are very stable (although they deviate from each other in different time periods). The largest deviation in relation to the prescribed mpe (-0.06 g), as well as the largest mutual deviation, is found at the point of maximum capacity (6200 g) regardless of the measurement period, which constitutes for 40% of the mpe (Figure 1).

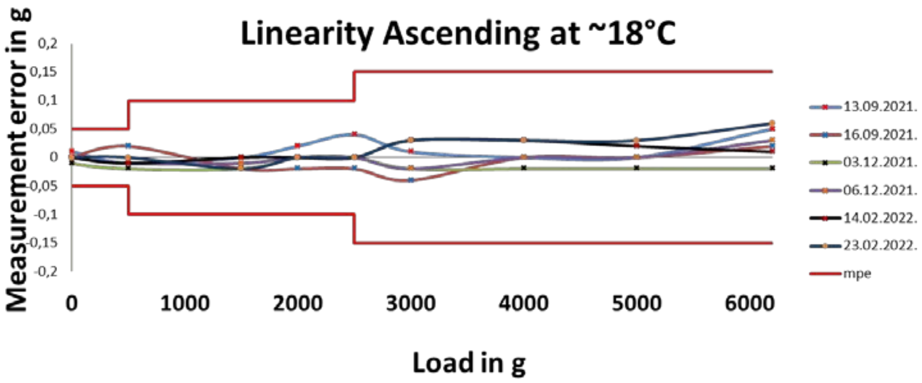

Figure 1. Linearity Ascending at 18°C

As well as at a temperature of ~18°C, the measuring instrument proved to be stable at temperatures of ~20°C. All load points were within the limits of the prescribed mpe, while the largest deviation is again at the point of maximum weighing capacity of 6200 g and constitutes 40% of the mpe (Figure 2).

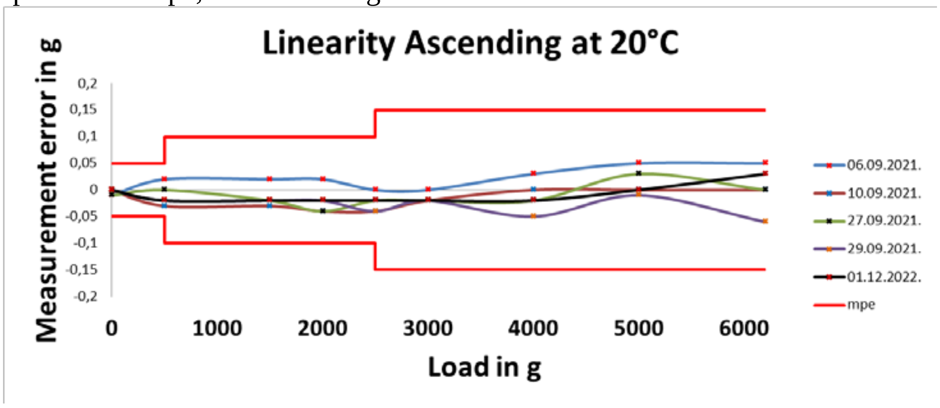

Figure 2. Linearity Ascending at 20°C

The behaviour of the subjected measuring instrument is the same at a temperature of ~25°C as in the previous two cases, and as expected, with a linear increase of the load, the measurement error also increases and at the maximum capacity is the largest. However, the deviations at this temperature comparing to the mpe are the smallest and constitutes to approximately 1/3 of the prescribed mpe.

All measurements at all test points, at different temperatures and time periods showed that the subjected non-automatic weighing instrument is very stable and with very small deviations in relation to the nominal values (approximately 2/3 less than the prescribed mpe).

Comparable results are also obtained by measuring when the non-automatic weighing instrument is tested in descending path (unloading the test standards from the maximum to the minimal capacity) with a very small or negligible influence of hysteresis.

3.2. Linearity tests in working conditions

Analysing the results shown in figure 3. it is possible to conclude that the measurements ware very stable until 2016, with very small deviations from the nominal value, while in 2018, there is a visible deviation in points (load) close to the maximum load of the non-automatic weighing instrument. The reason that can be taken into account is the fact, that measurements in 2018 were made by another metrology laboratory (different personal), using other equipment (traceability) that possibly did not have the same characteristics as the laboratory that performed previous verifications, which, based on the measurement results, is an important factor in predicting the life cycle of the measuring device.

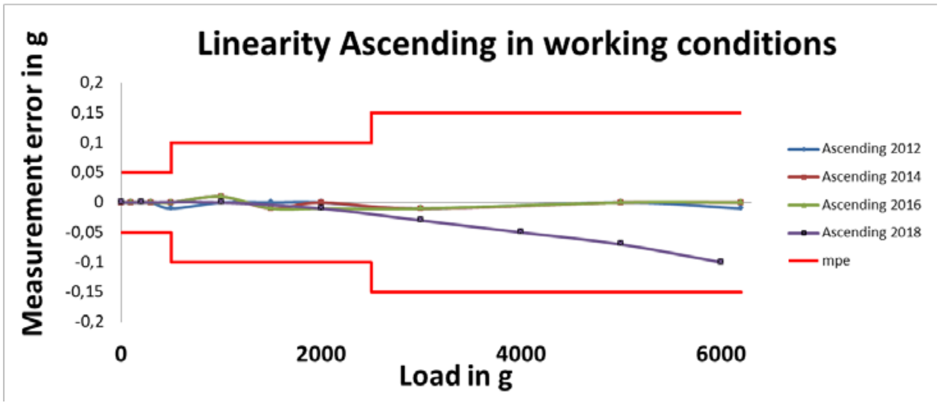

Figure 3. Linearity - working conditions

With a more detailed analysis, it is necessary to determine whether there will be visible changes in other laboratories (nominated laboratories which are part of BiH metrology system) as well, to determine the parameter that is the reason for the obvious changes and isolating the one.

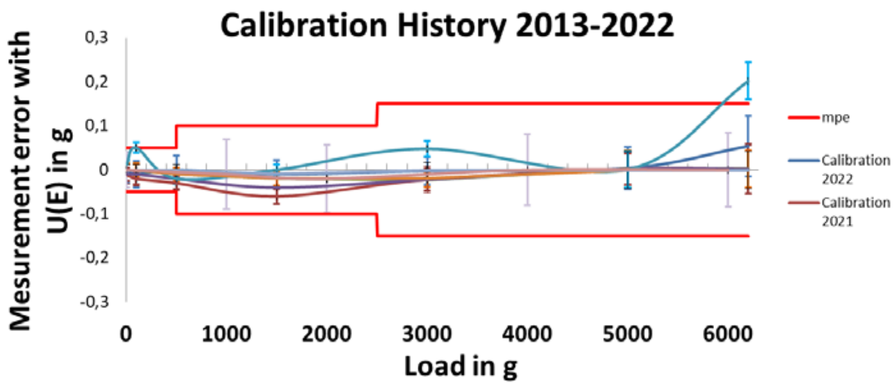

Figure 4. Conformity from calibration results

3.3. Linearity tests based on calibration results

All calibrations have been performed by IMBiH, beside the year 2013 when the calibration has been done by private accredited laboratory. Based on the measurement results, an error was determined, and based on the mpe, a conformity assessment was made (Figure 4).

From the Figure 4., it can be concluded that the non-automatic weighing instrument was within the legally prescribed limits, except for 2016, when the it has showed a significantly larger error compared to previous years. In 2016, the non-automatic weighing instrument was outside the limits of the mpe at the point of load of 100 grams and at the point of maximum capacity.

If the contribution of the expanded measurement uncertainty U(E) (with coverage factor k=2 and coverage probability =95%) is also taken into account (values given in Table 1.), then it can be concluded that the scale deviates approximately 60% above the mpe in the maximum capacity, which clearly indicates that the non-automatic weighing instrument had to be subject to service (internal calibration of the scale) and recalibration. This was the case with the subjected non-automatic weighing instrument, because, after the internal calibration has been done, the results were again within the limits of the mpe over the following years.

Table 1: Calibration history (linearity test) of non-automatic weighing instrument from 2013-2022

Load in g	Measurement error (E) and extended measurement uncertainty U (E) in g							
	2013	2014	2015	2016	2017	2019	2021	2022
0,5		E=0.00 U(E)=0.015	E=0.00 U(E)=0.012	E=0.010 U(E)=0.012	E=-0.010 U(E)=0.022	E=0.000 U(E)=0.0082	E=-0.010 U(E)=0.0150	E=0.000 U(E)=0.0310
100		E=0.00 U(E)=0.015	E=0.00 U(E)=0.012	E=0.050 U(E)=0.012	E=-0.010 U(E)=0.022	E=0.000 U(E)=0.0082	E=-0.020 U(E)=0.0150	E=-0.010 U(E)=0.0310
500		E=0.01 U(E)=0.015	E=0.00 U(E)=0.012	E=-0.020 U(E)=0.012	E=-0.020 U(E)=0.022	E=-0.010 U(E)=0.0087	E=-0.030 U(E)=0.0150	E=0.000 U(E)=0.0320
1000	E=-0.01 U(E)= 0.079							
1500		E=-0.02 U(E)=0.015	E=-0.01 U(E)=0.012	E=0.000 U(E)=0.012	E=-0.040 U(E)=0.023	E=-0.020 U(E)=0.0120	E=-0.060 U(E)=0.0170	E=-0.010 U(E)=0.0320
2000	E=-0.02 U(E)= 0.078							
3000		E=-0.02 U(E)=0.017	E=0.00 U(E)=0.017	E=0.048 U(E)=0.017	E=-0.022 U(E)=0.030	E=-0.022 U(E)=0.0240	E=-0.022 U(E)=0.0250	E=-0.002 U(E)=0.0310
4000	E=0.00 U(E)= 0.081							
5000		E=0.00 U(E)=0.042	E=0.00 U(E)=0.042	E=0.001 U(E)=0.042	E=0.002 U(E)=0.038	E=0.002 U(E)=0.0340	E=0.002 U(E)=0.0350	E=0.004 U(E)=0.0480
6000	E=0.00 U(E)= 0.084							
6200		E=0.00 U(E)=0.042	E=0.00 U(E)=0.042	E=0.202 U(E)=0.042	E=0.002 U(E)=0.058	E=0.002 U(E)=0.0550	E=0.002 U(E)=0.0560	E=0.054 U(E)=0.0690

Although the contribution of measurement uncertainty is not required in the conformity assessment in the field of legal metrology, the measurement errors obtained by the calibration procedure increased by the expanded measurement uncertainty, indicate that the difference in errors can significantly influence the decision-making about the conformity of the measuring instrument compared to cases when measurement uncertainty is not taken into consideration. Measuring instruments that meet the prescribed limits of mpe in the verification process will not necessarily meet the mpe if the expanded measurement uncertainty is added to them, as can be seen from the Figure 4.

3.4. Further analysis

The consumers' health protection is crucial reason for introduction of new concepts, such as digitalization process in legal metrology, which simultaneously increases the amount of data exchange. This is possible by establishing a database with the history of measurements of specific measuring instrument (subject of legal control) and adequate process of those measurement data.

In order to make an adequate assessment of a life cycle of a measuring instrument, in addition to the analyses carried out on the measurements, it is necessary to keep up with the current developments in the field of digitalization. This process will enable easier flow of information and analysis of a large amount of data. For the past few years, developed European metrology institutes have been working on the digitalization of calibration certificates, which could be further processed through digital transformation to the end users and directly integrated into the actual process in which this important metrology data are intended to (the same could be applied to verification).

This process takes place through three concepts from digitization through digitalization to the final digital transformation. To make this complete process clearer, it is necessary to know what these separate concepts of digital technology represent.

The first phase of the transformation is called digitization, which in its simplest sense is the conversion of analog data into digital data (an example of data digitization).

The second phase is digitalization and represents "the process of using digital technology and the impact it has" (for example digitalization of the process) [8]. The third, at the same time the final stage, represents digital transformation, which is the broadest of the three terms and encompasses the work of an entire institution. There are different explanations of what exactly digital transformation represents, however, the German metrology institute (PTB) described this process in the field of metrological services as digital upgradingof the quality infrastructure and of legal metrology, among other things by developing reference architectures, validated statistical procedures for predictive maintenance, an infrastructure for digital calibration certificates and, last but not least, by setting up a "metrology cloud" in the form of a digital quality infrastructure for the harmonization and development of conformity assessment and market surveillance [9].

This process of digital transformation reflects the need for strengthening the protection of the end consumer, respectively, legal metrology. Through EC funds, within the framework of the European metrology organization EURAMET, certain research projects were launched that would contribute to the development of this field [10].

The analysis in this paper indicates which factors are important for a more detailed analysis and prediction of the measuring instrument life cycle, and further research would lead in the direction of mathematical modelling and conversion of these factors into numerical variables and analysis of their mutual correlation which is closely related to digitalization and data processing.

Important factors that could influence the determination of the life cycle of the measuring instrument (among them also those ascertained through the analysis in this work) are:

- The year since the instrument has been in use,
- Reference to the normative document/standard, used for the approval of a measuring instrument,
- Verification performed regularly or not
- Potential measurement uncertainty,
- Environmental conditions data during measurement
- Data on service of measuring instrument (breakdown)
- Feedback from users of the measuring instrument
- Information on the laboratory which performed measurements (the same/or there were changes)
- The period of recalibration of the equipment of a laboratory that performed the measurements
- Information on traceability of the measuring equipment of the laboratory who has performed measurements (National metrology institute/ designated institutes or accredited laboratory)
- Information on manufacturer of the measuring instrument under test.

By determining the mutual correlation and determining the parameters that obviously affect the changes in the measurement results, the prediction of the life cycle of the measuring instrument will be solved, as well as the determination of the time periods of subsequent verifications.

In 2012, IMBiH esatblished a database of all measuring instruments (not only non-automatic weighing instruments) to enhance the measurement system and to solve the way of predicting the life cycle of a measuring instrument. This data base consist of measuring instruments that are in use in Bosnia and Herzegovina, i.e. a database of verified measuring instruments, which have been verified by competent nominated laboratories that are accredited to perform verifications in the subject metrology field. Currently, the database consists of reports from nominated laboratories, which are in different formats; from scanned copies with manual entries, but also electronic reports such as excel tables or word documents. These reports generally have to be re-entered in order to make a detailed analysis by type of measuring instrument and to provide a quality conformity assessment and to predict the lifetime of the measuring instrument on the basis of a large amount of data. In addition to all of the above mentioned, IMBiH initiated digitalization activities that would take place in three steps in accordance with global developments in this field. The first step, which is already taking place, is that all the test reports on the verification of the measuring instruments, which are carried out by the nominated laboratories, are converted into pdf (digitization) so that a measurement history can be made for all the measuring instruments in use. Additionally, from 2021, an online program was launched, through which all nominated laboratories can enter their data on verified measuring instruments, either directly for each separated subject of verification or by uploading an excel table with information on reviewed measuring instruments. However, the measurement results are not entered, but the data base of measuring instruments that are in use and that have met the conformity assessment is established.

The second step, which will be implemented in the next phase, would refer to the creation of unique forms that the nominated laboratories would fill in with the measurement results and send to the unique server of the IMBiH, with a unique database (digitalization) of all measuring instruments. The final third step would be a digital transformation, where through certain algorithms and machine reading, comparisons and analyses of measuring results will be conducted, consequentially predicting the future course of the measuring instrument behaviour and its life cycle.

4. SUMMARY

The non-automatic weighing instrument on which the measurements were made in laboratory conditions has been in regular use since 2013 and already has a certain history of measurements (calibration) behind it. Based on this history it was possible to analyse the stability of the measurement results. Moreover, based on verification results carried out in the period September 2021-February 2022, it was possible to determine the significance of the changes influenced by the environmental conditions. Regardless of whether the verifications are performed in laboratory conditions or in working conditions, the subject of this test showed satisfactory results in accordance with the prescribed mpe limits.

Depending on the amount of data that should made up by the database with all the measuring instruments which are in use in Bosnia and Herzegovina, it is possible to get a clear overview for the other measuring instruments in use, regardless of the accuracy class and the field of application. The overview imposes possible changes in the verification period of measuring instruments, but also the reliability and stability of all measuring instruments in use and the prediction of their life cycle.

The analysis showed that the contribution of measurement uncertainty (if available), if added to the obtained error, would significantly affect the assessment of the conformity of the measuring instrument, which would greatly contribute to the possibility of predicting the life cycle of the measuring instrument. Another important influence that could be taken into account is the fact that the measuring instruments are inspected during their working life by different laboratories, which, although having confirmed competences, may deviate from each other in the performance of the measurement procedure itself, but also in the equipment they use (reproducibility).

The analysis in the paper labels important factors for a more detailed analysis and prediction of the measuring instrument life cycle. These factors include potential numerical and categorical variables, together with possible mutual correlations. Categorical variables can be encoded to numerical in order to apply mathematical modelling for the prediction of a measuring instrument life cycle.

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