VERIFICATION OF THE TORQUE GAUGES

TATIANA KELEMENOVA, MICHAL KELEMEN, IVAN VIRGALA, LUBICA MIKOVA, ERIK PRADA, MARTIN VARGA, JAN SEMJON, MAREK SUKOP, RUDOLF JANOS, PETER TULEJA, PETER MARCINKO

Technical University of Kosice, Faculty of Mechanical Engineering, Kosice, Slovakia

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michal.kelemen@tuke.sk

The article deals with the methodology of verification of mechanical and electronic torque gauges. Legislative metrological requirements are set for these gauges and the verification process for these types of gauges is also set. The working standard is used to verify two selected torque gauges and then the suitability of these gauges is assessed. Measurement uncertainties are identified to determine the reliability of the measurement process.

KEYWORDS

Torque, gauges, etalon, uncertainty, torque wrench

1 INTRODUCTION

Measurement as a process makes it possible to identify unknown values of a quantity using a suitable type of gauge. Uncertainty reporting is also an inseparable measurement process. Several works and standards are available for measurement, sensors, data acquisition and reporting uncertainties [JCGM 100 2008, JCGM 104 2009, EA-4/02 1999, Murcinkova 2013, Kelemen 2021, Kelemenova 2021, Lumnitzer 2016, Oscadal 2020].

The moment of force represents the force that tries to cause rotation. It is defined by multiplying the applied force by the distance between the pivot point and the force. The moment of force causes the angular acceleration of the bodies resp. angular rotation, or their deformation and with the help of these effects it is also possible to measure it. Common applications where it is necessary to determine the amount of torque include e.g., identification of engine power, where it is necessary to determine the amount of engine torque. Torque must also be measured in various applications in robotics and automation [Hajduk 2009 and Hajduk 2018, Kelemen 2012 and Kelemen 2014, Liptak 2018, Olejarova 2016, Semjon 2016, Bozek 2021, Virgala 2021]. A frequent application is also the assembly of screw connections, which must be tightened with a defined torque [Saga 2020]. Otherwise, the screw connection may come loose and not function. If the defined value of the tightening torque is exceeded, we risk damaging the threaded part of the screw connection. These are mainly screw connections on the flanges of pressure equipment, screw connections on internal combustion engine blocks, but also screw connections on wheel discs, which are probably most often assembled and disassembled.

2 VERIFIED GAUGES

The verified gauges are a torque wrenches (Fig. 1) that are used to tighten bolted joints. The first is a mechanical gauge that mechanically blocks further tightening of the screw connection when tightening. The torque wrench has a square with a size of ½ "and an arm with a length of 460 mm and the tightening torque can be set in the range of 28-210 Nm. The adjustment is made by turning the handle according to the scale.

Figure 1. Verified gauge – setting torque wrench and electronic torque wrench

Another verified torque wrench is a digital electronic torque wrench (Fig. 1) designed for tightening bolted joints. It has a measuring range of 40 – 200 Nm and the manufacturer defines the maximum relative error of the *RMPE* ± 2%. It is terminated with an inner and outer square ½" for connection to tightening wrench.

3 LEGAL MEASURING INSTRUMENTS

The types of legal measuring instruments, the areas of their use, details on the method of their metrological control or conformity assessment and the validity period of verification of individual types of legal measuring instruments are specified in [DECREE 161/2019, DIRECTIVE 2009/34/EC, ACT 157/2018, DIRECTIVE 2014/32/EU, ISO 6789-1 2017, ISO 6789-2 2017]. According to this reference, the torque wrench belongs to the legal measuring instruments gauges, in group 2. Mechanical quantities in the category "Torque wrenches", these gauges being intended for mandatory metrological control or conformity assessment. Legal measuring instruments may not be placed on the market without a metrological check or conformity assessment. The validity period of the torque wrench verification is 1 year.

Metrological control during the use of legal measuring instruments is an ex-post verification of legal measuring instruments (hereinafter referred to as "ex-post verification"). Metrological control is performed by the institute and, to a limited extent, by an organization designated by the Office (hereinafter referred to as the "designated organization") and entrepreneurs or other legal entities authorized by the Office's decision pursuant to [DECREE 161/2019, DIRECTIVE 2009/34/EC, ACT 157/2018, DIRECTIVE 2014/32/EU, ISO 6789-1 2017, ISO 6789-2 2017] (hereinafter the "authorized person").

The verification of a legal measuring instrument consists of testing the measuring instrument and confirming its conformity with the approved type and with the technical requirements and metrological requirements for the given type of measuring instrument. Torque wrenches designed to check the tightening of threaded joints, which are used as legal measuring instruments according to [DECREE 161/2019, DIRECTIVE 2009/34/EC, ISO 6789-1 2017, ISO 6789-2 2017], are divided into torque wrenches into:

a) <u>Type I: Indicating torque tools</u> - is a torque wrench with a mechanical or electronic measuring system and indicating device (scale, dial indicator or display). Type I torque tools are divided into classes:

- Class A: wrench, torsion or flexion bar
- Class B: wrench, rigid housing, with scale or dial or display
- Class C: wrench, rigid housing and electronic measurement
- Class D: screwdriver, with scale or dial or display
- Class E: screwdriver, with electronic measurement

b) <u>Type II: Setting torque tools</u> - is an adjustable torque wrench that acoustically, optically or mechanically indicates that the set torque is reached. Type II torque tools are divided into classes:

- Class A: wrench, adjustable, graduated or with display
- Class B: wrench, fixed adjustment
- Class C: wrench, adjustable, non-graduated

- Class D: screwdriver, adjustable, graduated or with display
- Class E: screwdriver, fixed adjustment
- Class F: screwdriver, adjustable, non-graduated
- Class G: wrench, flexion bar, adjustable, graduated

Torque wrenches are subject to subsequent verification during their use as specified gauges. The procedure for subsequent verification is the same as for the initial verification. Torque wrenches that meet the specified requirements during verification shall be marked with a verification mark and a proof of verification shall be issued. Metrological requirements, technical requirements, technical test methods for type approval and test methods for torque wrench verification are described in [DECREE 161/2019, DIRECTIVE 2009/34/EC, ISO 6789-1 2017, ISO 6789-2 2017].

The Indicating torque wrench error is the difference between the torque wrench reading and the conventionally actual torque value. The setting torque wrench error is the difference between the set torque value and the conventionally actual torque value [DECREE 161/2019, DIRECTIVE 2009/34/EC, ISO6789-1 2017, ISO 6789-2 2017]. The maximum permissible relative errors of the *RMPE* indicator torque wrenches (type I and II) are given in tab. 1 and tab. 2.

Type I: Indicating torque tools	Maximum permissible relative errors of indicating torque wrenches *RMPE*	
	<10 Nm	>10Nm
Class A: wrench, torsion or flexion bar	<6%	<6%
Class D: screwdriver, with scale or dial or display	<6%	<6%
Class B: wrench, rigid housing, with scale or dial or display	<6%	<4%
Class C: wrench, rigid housing and electronic measurement	<6%	<4%
Class E: screwdriver, with electronic measurement	<6%	<4%

Table 1. **Maximum permissible relative errors of indicating torque wrenches**

Type II: Setting torque tools	Maximum permissible relative errors of indicating torque wrenches *RMPE*	
	<10 Nm	>10Nm
Class A: wrench, adjustable, graduated or with display	<6%	<4%
Class B: wrench, fixed adjustment	<6%	<4%
Class C: wrench, adjustable, non-graduated	<6%	<4%
Class D: screwdriver, adjustable, graduated or with display	<6%	<6%
Class E: screwdriver, fixed adjustment	<6%	<6%
Class F: screwdriver, adjustable, non-graduated	<6%	<6%
Class G: wrench, flexion bar, adjustable, graduated	<6%	<6%

Table 2. **Maximum permissible relative errors of setting torque wrenches**

The indicating torque wrench indicates values from zero. The scale interval of the indicating device must not exceed 5% of the upper limit of the measuring range. The torque wrenches return to the zero position when completely unloaded. Torque wrenches are designed to be rigid enough for a given measuring range. At the highest load, no part of the torque wrench is permanently deformed.

4 WORKING ETALON GAUGE

The etalon gauge (Fig. 2) is designed for verification of torque gauges, the so-called torque wrenches. The etalon gauge must be attached to a solid base and can then be used to verify torque wrenches. When verifying measuring instruments, it is necessary to insert this verified measuring instrument into the connection point with a square form connection with dimension ½ ". This working etalon gauge can be considered as a working etalon, while the manufacturer sets its maximum allowable relative error ± 1%. This etalon gauge can be used for internal verification of torque gauges.

Figure 2. Electronic working etalon torque gauge for verification of torque wrench and electronic torque gauge

5 TORQUE GAUGE VERIFICATION METHODOLOGY

The initial and subsequent torque wrench verification tests consist of an external inspection and an accuracy test. During the external inspection of the torque wrench, it is visually inspected whether its design corresponds to the approved type, whether its design meets the requirements of the relevant technical standard [ISO6789-1 2017] [ISO6789-2 2017], whether the torque wrench is not mechanically damaged, deformed or otherwise defective and the legibility, accuracy and completeness of prescribed inscriptions.

During the torque wrench verification process, the expanded measurement uncertainty by the standard equipment during the technical type-approval tests shall not exceed ± 1% of the measured torque value. The technical type-approval tests shall be performed at a temperature of (23±5)°C and a relative humidity of up to 90%. During these tests, the temperature must not change by more than 2°C. At the time of type-approval, at least three repetitive tests shall be performed to determine the torque wrench error in accordance with the procedure of the initial and subsequent verification tests.

5.1 *Relative torque wrench reversal error*

The relative torque wrench reverse error is checked and calculated according to the relationship:

$$\Delta_{BRMk} = \frac{M_U - M_Z}{M_{Mk}} \cdot 100\% \qquad (1)$$

Where:

M_U - conventionally the actual value of the moment of force during unloading read from the scale of the etalon gauge,

M_Z - conventionally the actual value of the moment under load read from the scale of the etalon gauge,

M_{Mk} - force torque value read from the torque wrench scale.

However, this relationship is inapplicable even if it is not possible to determine the load and unloading torque values. For some types of torque wrenches, only load torque values can be specified.

5.2 *Torque wrench relative error span*

The r_{MK} torque wrench relative error span is checked and determined according to the relationship:

$$r_{MK} = \frac{M_{MAX} - M_{MIN}}{M_{MK}} \cdot 100\% \qquad (2)$$

Where:

M_{MAX} - the largest conventionally actual value of the moment of force from three series of measurements read from the scale of the etalon gauge,

M_{MIN} - the smallest conventional actual value of the moment of force from three series of measurements read from the scale of the etalon gauge,

M_{MK} - force torque value read from the torque wrench scale.

The relative range of the r_{MK} error is tested at least three values, approximately 20%, 60% and 100% of the measuring range. The r_{MK} relative error range shall not exceed 0.6 times the absolute value of the maximum permissible error *RMPE* for the type and class given in tab. 1 and tab. 2.

The expanded measurement uncertainty during the initial and subsequent verification should be less than or equal to 1/2 of the maximum permissible error *MPE* of the gauge.

Before starting the test, the torque wrench shall be pre-loaded three times to the largest value of the measuring range and relieved back to the zero position. Torque wrenches are tested at the values of the measuring range specified at the type of approval of the instrument. If the torque wrench has both right and left load directions, a test is performed for both load directions. At each value and in each direction of torque, at least five consecutive measurements shall be made.

5.3 *Relative torque wrench error*

The relative error of the torque wrench Δ_{RMK} is checked and calculated according to the relation:

$$\Delta_{RMK} = \frac{M_{Mki} - M_{MKe}}{M_{MKe}} \cdot 100\% \qquad (3)$$

Where:

M_{Mki} - force torque value read from the torque wrench scale,

M_{MKe} - conventionally the actual value of the moment of force read from the scale of the etalon gauge.

The detected relative error Δ_{RMKi} of the torque wrench calculated according to the previous relation must not exceed in any measurement the Maximum permissible error *RMPE* for the given type and class given in tab. 1 and tab. 2. Torque wrenches that have complied with the established requirements pursuant to [DECREE 161/2019 2019] [DIRECTIVE 2009/34/EC 2009] during verification shall be marked with a verification mark and a verification document shall be issued.

6 EXPERIMENTAL VERIFICATION OF THE SETTING TORQUE WRENCH

The torque wrench verification process was carried out in such a way that, for each of the set values on the torque wrench, a control tightening was performed on an electronic etalon gauge. The measurement was performed 10 times under the same unchanged conditions. All values of the main torque wrench scale (14 values) were selected for verification (Fig. 3).

Torque deviations (Fig. 4) indicate that the torque wrench does not reach the set torque at almost all setpoints. By using such a wrench, the screw connections will not be tightened to the required torque. We can find out whether these absolute deviations (Fig. 4) are within the required limits by comparing the relative deviations with the maximum relative errors of the *RMPE*.

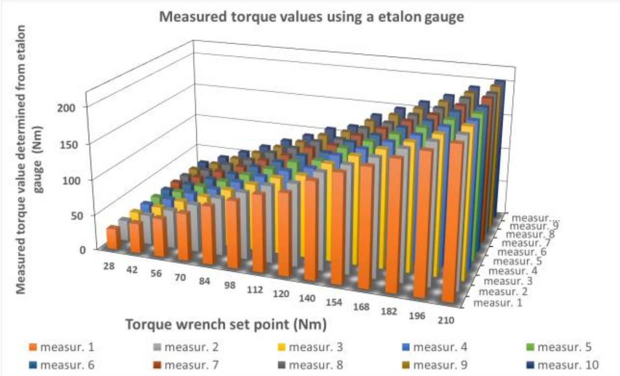

Figure 3. Measured torque values for different torque wrench settings and torque deviations

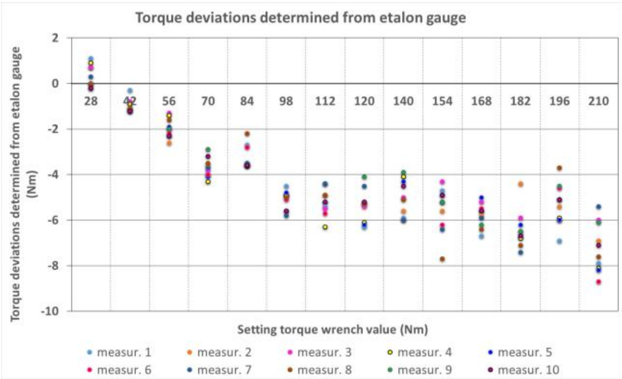

Figure 4. Torque wrench torque deviations

For each set of measurements, a span of relative errors of the verified torque was processed, which according to [DECREE 161/2019 2019] [DIRECTIVE 2009/34/EC 2009] must be less than 0.6 times the *RMPE*. However, one of the values did not meet the condition, does not meet this condition and is outside this marked interval (Fig. 5). The torque wrench is therefore unsuitable for further use.

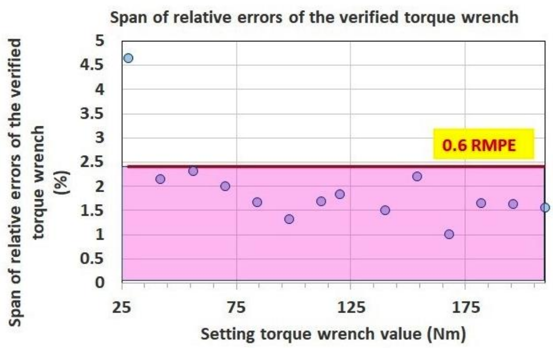

Figure 5. Range of relative errors of the verified instrument

The relative error of the torque wrench Δ_{RMK} is evaluated and shown on fig. 6. The verified torque wrench has relative errors that exceed the Maximum allowable *RMPE* error in several values. The verified torque wrench therefore does not meet the metrological requirements [DECREE 161/2019, DIRECTIVE 2009/34/EC 2009].

The standard uncertainty determined by method B for the torque values set on the torque wrench is not available and will not be considered in this evaluation process. It is also not possible to determine the standard uncertainty of the A method for the torque values set on the torque wrench.

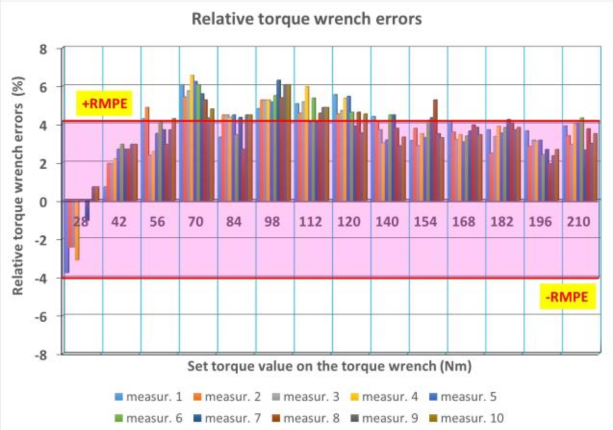

Figure 6. Relative errors of the verified torque wrench

Method A standard uncertainty for torque values determined by a standard gauge:

$$u_{AMKe} = \bar{s}_{MKe} = \sqrt{\frac{\sum_{i=1}^{n}(\bar{M}_{Ke} - M_{Kei})^2}{n(n-1)}} \quad (4)$$

The verification process is specific in that each torque wrench load is a new measurement that cannot be performed under exactly the same measurement conditions. Thus, in terms of [EA-4/02 1999, JCGM 100 2008], it is not possible to determine even the standard uncertainty by Method A.

For the etalon gauge, the maximum permissible error ε_R = 1% of the measured value by this gauge is stated in the catalogue datasheet. The etalon gauge is a digital electronic instrument, for which it is customary to consider a uniform law of distribution of random values, so we will consider the coverage factor with the value $k_{MKe} = \sqrt{3}$. Then the standard uncertainty by method B for the torque values determined by the etalon gauge:

$$u_{BMKe} = \frac{\varepsilon_R \cdot M_{Kei}}{k_{MKe}} = \frac{0.01 \cdot M_{Kei}}{k_{MKe}} \quad (5)$$

The combined uncertainty of the torque deviation determination will be determined by combining all known standard measurement uncertainties [JCGM 100 2008]:

$$u_{CMK} = \sqrt{(u_{AMKe}^2 + u_{BMKe}^2)} \quad (6)$$

Since the standard uncertainty of the etalon gauge is the only identifiable source of measurement uncertainty, then the combined measurement uncertainty is equal to the standard uncertainty determined by Method B for the etalon gauge.

Subsequently, it is possible to determine the expanded measurement uncertainty (Fig. 7) where the coverage factor will be considered with the value $k_{MK} = \sqrt{3}$, then the expanded measurement uncertainty is determined only from the maximum allowed relative error of the etalon gauge:

$$U_{MK} = 0.01 \cdot M_{Kei} \quad (7)$$

The expanded uncertainties of the average deviations mean that the actual values of the deviations can lie anywhere in the plotted interval with a probability of 95%. In considering this probability, it is therefore assumed that this torque wrench no longer complies with the maximum permissible error specified by the gauge manufacturer and standards.

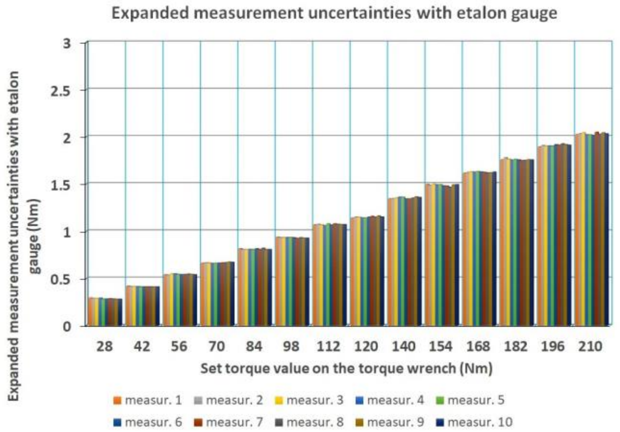

Figure 7. Expanded uncertainties of the average deviations of the verified torque wrench

7 EXPERIMENTAL VERIFICATION OF ELECTRONIC TORQUE WRENCH

The verification of the electronic torque meter was performed by gradual loading up to the tightening point of the screw connection. This load was constantly at a higher tightening torque value. The values on the electronic torque wrench were visible only for a short time and it was problematic to read the indication from both indication devices (from the verified torque wrench and from the etalon gauge). Both devices do not have electronic data output, so it was not possible to perform synchronized data acquisition from both devices. For this reason, the use of time-lapse video, which was created during the load and unload verification cycles, was chosen. The measured values were thus taken from the recorded time-lapse video (Fig. 8).

Figure 8. Time-lapse video from electronic torque wrench verification

The obtained measured values of the verified electronic torque wrench were compared with the values on the etalon gauge and the absolute measurement errors were determined (Figure 9). However, to assess the verification of the electronic torque wrench, it is necessary to evaluate the relative measurement errors and compare them with the maximum relative measurement error for the electronic torque wrench *RMPE* = 2% (Fig. 10).

The values of relative errors for all performed measurements were smaller than the limit values defined by the maximum relative measurement error for the electronic torque wrench. The electronic torque wrench is therefore suitable for further use for tightening screw connections and its measuring errors are less than the maximum measuring error defined by the manufacturer of the electronic torque wrench.

Expanded measurement uncertainties (Fig. 11) similar to the previous scale, in this case only the uncertainty of the etalon gauge determined by method B will be included in the combined uncertainty and thus the expanded uncertainty can be determined directly from the maximum relative measurement error. The values of the expanded measurement uncertainty for the individual verified values of the etalon gauge are less than ± 1.7 Nm. The span of relative errors could not be realized because the measurement principle does not allow us to obtain values under the same load case with the same value.

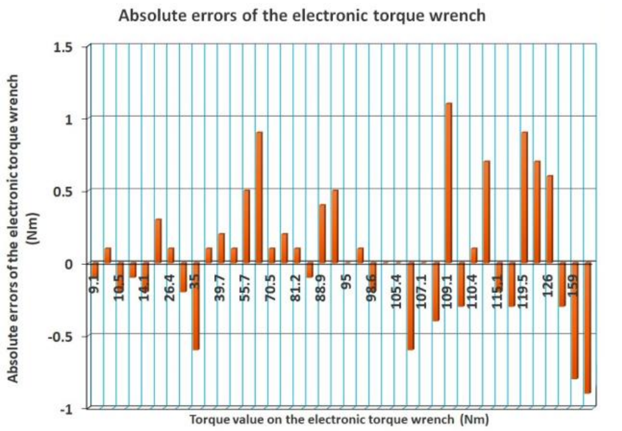

Figure 9. Absolute measurement errors of the electronic torque wrench

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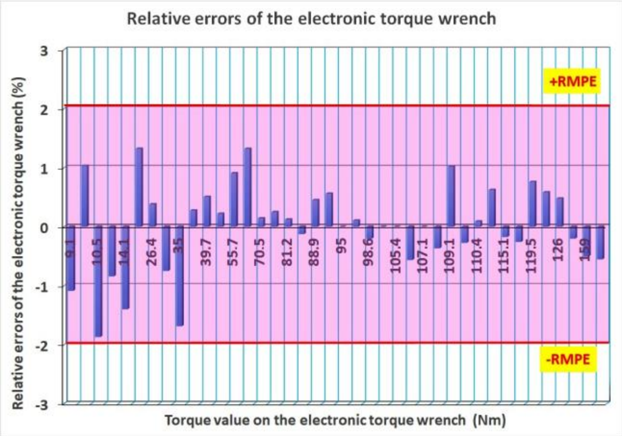

Figure 10. Relative errors of electronic torque wrench measurement

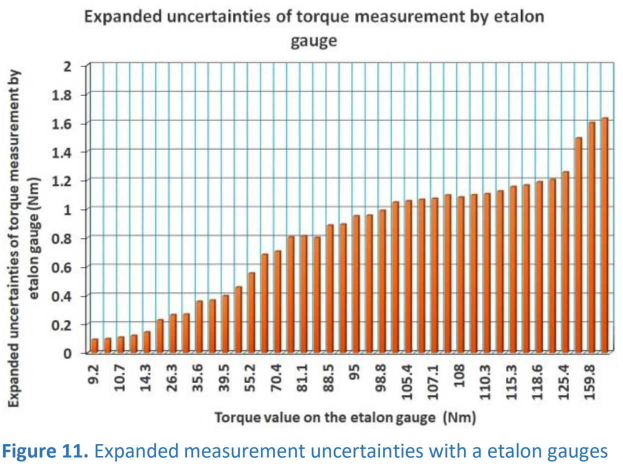

Figure 11. Expanded measurement uncertainties with a etalon gauges

8 CONCLUSIONS

The article presents the internal verification of torque wrenches, which belong to the legal measuring instruments subject to inspection by an authorized person. To increase the quality of work performed by these means for tightening screw joints, it is necessary to carry out such verification of these torque wrenches at periodic intervals or even in case of damage or suspicion of damage to these devices.

The setting torque wrench does not meet the specified conditions in the verification process, so this torque wrench may no longer be used in accordance with the applicable legislation [ACT 157/2018, DIRECTIVE 2014/32/EU]. The verification process of the electronic torque wrench shows that this instrument meets the specified conditions of the verification process and can thus continue to be used for tightening screw connections. The weakness of this method is that for the successful implementation of the verification of the gauge it is necessary to pay great attention to the method of loading and the practice of the operator is also very important. To improve this process, an automated stand is planned.

Analogous, it is possible to implement verification of other sensing systems used in industry or in other areas such as medicine, food industry, services, etc [Pinosova 2018, Pastor 2020, Saga 2020]. The importance of verifying measuring instruments and reporting measurement uncertainties is also of serious economic and legal importance in almost all areas of science, technology, but also other areas of everyday life [Lumnitzer 2015].

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REFERENCES

[ACT 157/2018] ACT 157/2018 of the Slovak Republic of 15 May 2018 on metrology and on the amendment of certain laws, 2018.

[Bozek 2021] Bozek, P., Nikitin, Y., Krenicky, T. Methods, Models, Algorithms for Diagnostics of Mechatronic Systems. Studies in Systems, Decision and Control, 2021, Vol. 345, pp. 17-26.

[DECREE 161/2019] DECREE 161/2019 of the Office for Standardization, Metrology and Testing of the Slovak Republic of 27 May 2014 on measuring instruments and metrological control, 2019.

[DIRECTIVE 2009/34/EC] Directive 2009/34/EC of The European Parliament And Of The Council of 23 April 2009 relating to common provisions for both measuring instruments and methods of metrological control, 2009.

[DIRECTIVE 2014/32/EU] Directive 2014/32/EU of The European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments (recast), 2014.

[EA-4/02 1999] Expression of the Uncertainty of Measurement in Calibration. European Co-operation Accreditation Publication Reference, 1999.

[Hajduk 2009] Hajduk, M. et al. Multiagents system with dynamic box change for MiroSot. In*:* Progress in Robotics: Communications in Computer and Information Science 44. Berlin: Springer-Verlag, 2009, pp. 287-292, ISBN 978-3-642-03985-0. DOI: 10.1007/978-3-642-03986-7_34.

[Hajduk 2018] Hajduk, M. et al. Principles of Formation of Flexible Manufacturing Systems. Tehnicki Vjesnik - Technical Gazette, 2018, Vol. 25, Issue 3, pp. 649-654, ISSN 1330-3651. DOI: 10.17559/TV-20161012132937.

[ISO6789-1 2017] ISO 6789-1:2017 - Assembly tools for screws and nuts — Hand torque tools — Part 1: Requirements and methods for design conformance testing and quality conformance testing: minimum requirements for declaration of conformance, 2017.

[ISO6789-2 2017] ISO 6789-2:2017 - Assembly tools for screws and nuts — Hand torque tools — Part 2: Requirements for calibration and determination of measurement uncertainty, 2017.

[JCGM 100 2008] JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3), 2008. Available online: http://www.iso.org/sites/JCGM/GUM-JCGM100.htm

[JCGM 104 2009] Evaluation of measurement data – An introduction to the Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-1), 2009. Available online: http://www.bipm.org/en/publications/guides/gum_print.html

[Kelemen 2012] Kelemen, M. et al. Design and Development of Lift Didactic Model within Subjects of Mechatronics. Procedia Engineering, 2012, Vol. 48, pp. 280-286. ISSN 1877-7058. DOI: 10.1016/J.PROENG.2012.09.515.

[Kelemen 2014] Kelemen, M. et al. Rapid Control Prototyping of Embedded Systems Based on Microcontroller. Procedia Engineering, 2014, Vol. 96, Issue 11, pp. 215-220. ISSN 1877-7058, doi.org/10.1016/j.proeng.2014.12.146.

[Kelemen 2021] Kelemen, M. et al. Head on Hall Effect Sensor Arrangement for Displacement Measurement. MM Science Journal, 2021, Issue 11, pp. 4757-4763. ISSN 1803-1269. DOI: 10.17973/MMSJ.2021_10_2021026.

[Kelemenova 2021] Kelemenova, T. et al. Verification of Force Transducer for Direct and Indirect Measurements. MM Science Journal, 2021, Vol. October, pp. 4736-4742. ISSN 1803-1269. DOI: 10.17973/MMSJ.2021_10_2021021.

[Liptak 2018] Liptak, T. et al. Modeling and control of two-link snake. International Journal of Advanced Robotic Systems, 2018, Vol. 15, Issue 2, pp. 1-13, ISSN 1729-8814. DOI: 10.1177/1729881418760638.

[Lumnitzer 2015] Lumnitzer, E. et al. Environmental and economic impacts of the relocation of automobile production. SGEM International Multidisciplinary Scientific GeoConference EXPO Proceedings. STEF92 Technology, 2015, pp. 647-653. ISBN 978-619-7105-40-7. doi.org/10.5593/sgem2015/b52/s23.086.

[Lumnitzer 2016] Lumnitzer, E. et al. Verification of the impact of the used type of excitation noise in determining the acoustic properties of separating constructions. Measurement, 2016, Vol. 78, pp. 83–89. doi.org/10.1016/j.measurement.2015.09.030.

[Mascenik 2016] Mascenik, J. and Pavlenko, S. Controlled testing of belt transmissions at different loads. MM Science Journal, 2021, pp. 5497–5501. DOI: 10.17973/MMSJ.2021_12_2021045.

[Murcinkova 2013] Murcinkova, Z., Krenicky, T. Implementation of virtual instrumentation for multiparametric technical system monitoring. In: SGEM 2013: 13th Int. Multidisciplinary Sci. Geoconf., Vol. 1; 16-22 June, 2013, Albena, Bulgaria. Sofia: STEF92 Technology, 2013, pp. 139-144. ISBN 978-954-91818-9-0.

[Olejarova 2016] Olejarova, S. and Krenicky, T. Monitoring the Condition of the Spindle of the Milling Machine Using Vibration. MM Science Journal, 2016, No. November, pp. 1227-1231, ISSN 1803-1269. DOI:10.17973/MMSJ.2016_11_201653.

[Oscadal 2020] Oscadal, P. et al. Improved Pose Estimation of Aruco Tags Using a Novel 3D Placement Strategy. Sensors, Vol. 20, Issue 17, pp. 1-16, ISSN 1424-3210. DOI: 10.3390/S20174825.

[Pastor 2020] Pastor, M. et al. Application of advanced measuring methods for identification of stresses and deformations of automotive structures. Applied Sciences, Vol. 10, No. 21, 7510. https://doi.org/10.3390/app10217510.

[Pavlenko 2020] Pavlenko, I. et al. Parameter identification of cutting forces in crankshaft grinding using artificial neural networks. Materials, 2020, Vol. 13, No. 23, 5357, 12 p. doi.org/10.3390/ma13235357.

[Pinosova 2018] Pinosova, M. et al. Objective and subjective evaluation of the risk physical factors near to conveyor system. Advances in Science and Technology Research Journal, Vol. 12, No. 3, pp. 188–196. doi.org/10.12913/22998624/94964.

[Saga 2020] Saga, M. et al. Case study: Performance analysis and development of robotized screwing application with integrated vision sensing system for automotive industry. International Journal of Advanced Robotic Systems, Vol. 17, No. 3, 23 p. doi.org/10.1177/1729881420923997.

[Semjon 2016] Semjon, J. et al. Testing of parameters of proposed robotic wrist based on the precision modules. International Journal of Advanced Robotic Systems, 2016, Vol. 13, 7 p., ISSN 1729-8814. DOI: 10.1177/1729881416662772.

[Virgala 2021] Virgala, I. et al. A snake robot for locomotion in a pipe using trapezium-like travelling wave. Mechanism and Machine Theory, tmm, design theory and methodology, haptics and human-machine-interfaces. Elsevier Science, April 2021, Vol. 158, 21 p., ISSN 0094-114X. DOI: 10.1016/J.MECHMACHTHEORY.2020.104221.

CONTACTS:

Michal Kelemen, prof. Ing. PhD.
Technical University of Kosice, Faculty of Mechanical Engineering,
Institute of Automation, Mechatronics, Robotics and Production Techniques,
Letna 9, 04200 Kosice, Slovak Republic
michal.kelemen@tuke.sk