CALIBRATION OF GAUGE BLOCK SET

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Gauge blocks are materialized dimensions that are used exclusively for the calibration of length gauges. Every measuring workplace where length dimensions are measured should have its own gauge block set for internal calibration and verification of its length gauges. But even these gauge blocks must be calibrated using a suitable methodology. This article attempts a methodology for the internal calibration of such a gauge block set.

KEYWORDS

gauge block, measuring instrument, uncertainty, standard

1 INTRODUCTION

Gage blocks (Fig. 1) are high-precision length standards. They serve as the basic standard for measuring length in mechanical engineering, manufacturing and metrology. They are essential for calibrating measuring instruments, setting up precise measuring systems and verifying manufacturing tolerances. They are mainly used for calibrating micrometers, calipers and dial indicators; for setting up measuring instruments, height gauges, calipers and length sensors; for verifying manufacturing tolerances and geometric accuracy of parts; for setting up CNC machines and workpieces before machining [Bozek 2016, Kelemen 2021, Kelemenova 2021b, Klarak 2021, Machac 2023, Malik 2025, Trojanova 2021, Peterka 2020, Stejskal 2016].

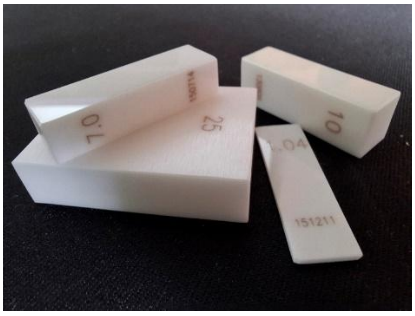

Figure 1. Gauge blocks

They are rectangular prisms (Fig. 1) made of high-quality steel, ceramics, tungsten carbide or other stable materials. Their size is given by the distance between the end surfaces. The measuring surfaces of the gauges are obtained through a complex technological process, have a minimal deviation of flatness and parallelism while maintaining a relatively small surface roughness value. By combining different blocks, thousands of different lengths can be obtained with extreme precision [ISO 3650: 1998, EA-4/02 1999, JCGM 100 2008].

Gauge blocks are sold in sets (Fig. 2), such as 81-piece, 47-piece, or 103-piece sets, which cover the range from a few tenths of a mm to several centimetres. Each set is assembled to allow for the most combinations possible with the minimum number of blocks.

Gauge blocks are manufactured in different accuracy classes according to their intended use [ISO 3650: 1998, EA-4/02 1999, JCGM 100 2008]:

Grade "K" – are blocks with highest class of accuracy. They are the length standards in a calibration laboratory and other calibration values are derived from these gauges (Typical tolerance (±0.05 to ±0.1um);

Grade "0" – are intended for use by measuring technicians in environmentally controlled inspection rooms for example to calibrate measuring equipment because of their high accuracy (Typical tolerance (±0.1 to ±0.2um);

Grade "1" – are used as working standards in inspection rooms within the production to set and calibrate measuring instruments and equipment as well as to inspect tools, fixtures and machines (Typical tolerance (±0.2 to ±0.5um);

Grade "2" – are intended for general workshop use by skilled workers to set up, for example measuring instruments (Typical tolerance (±0.5 to ±1um).

Gauge blocks calibration is the process of accurately determining their actual length and verifying compliance with metrological requirements (e.g. according to ISO 3650 or national standards). The aim is to ensure that gauges provide a reliable and traceable reference dimension for measurements, calibrations and adjustments [ISO 3650:1998].

Calibration methods can be divided into the following groups:

1. Comparative method (Comparative) - Comparison of the tested gauge with a standard gauge using an interference microscope or mechanical comparator. It is used for calibrations of lower accuracy classes (e.g. class 1 or 2).

2. Interferometric method (Optical Interferometry) - The most accurate calibration method, using the principle of optical interference of light. It determines the actual length of the gauge in vacuum (so-called absolute length) with nanometer accuracy. It is used in national metrological institutes (e.g. PTB, NPL, SMU).

3. *Mechanical comparison in air (Comparison in Air)* - Comparison of scale lengths in laboratory conditions under defined laboratory conditions (temperature, pressure, humidity). Suitable for industrial calibration laboratories.

Figure 2. Gauge block set in wooden case (47-pieces)

In order for the calibration results to be accurate and repeatable, strict conditions must be met: Temperature: exactly 20.0 °C ± 0.5 °C, as the coefficient of thermal expansion significantly affects the length. Cleanliness of surfaces: surfaces must be perfectly clean and dry. Air pressure and humidity: correction for the refractive index of air is necessary for optical calibration. Stabilization: both the scales and the instruments must be thermally stabilized for at least 2-4 hours before calibration [JCGM 104 2009, JCGM 200 2012].

The calibration output is a calibration protocol or certificate that contains:

- The actual measured length of each gauge block (e.g. 20.00007 mm). Or it is possible to specify deviation of gage block length (e.g. -0.1 µm).
- The measurement uncertainty (e.g. ±0.05 µm).
- Measurement conditions (temperature, pressure).

- Traceability to the standard.
- Date and signature of the metrologist / responsible person.
- The mark of the calibration laboratory (accredited according to ISO/IEC 17025).

2 MATERIALS, METHODS AND DEVICES

Ceramic gauge block set made of Zirconia ceramics has been subjected to a calibration process (Fig. 2). These gauge blocks are highly durable, corrosion proof and completely stable for long-term use. Hardness is in the range of 88 - 90 HRC. The coefficient of thermal expansion is relatively low with a value of $(9.2\pm1)\cdot10^{-6}$ /°C. The gauge blocks cross-section is 30x9 mm (for gauge blocks with a nominal value in the range of 0.5 - 10 mm) and for larger gauge blocks the cross-section is 35x9 mm (for gauge blocks with a nominal value greater than 10 mm). There are 47 gauge blocks in the set.

A reference gauge block set of grade "0" was used as a reference for comparative measurements during calibration. A calibration certificate is available for this set.

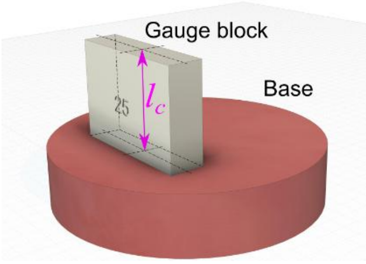

Figure 3. Central length of gauge block

The main parameter of gauge blocks that must be measured is the **length of gauge block**, which can be measured at different points of the gauge block.

According to some standards, it is recommended to measure the length of gauge block at five points (Fig. 4) [ISO 3650:1998].

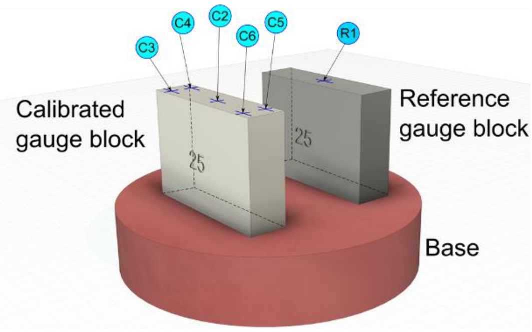

Figure 4. Central length of gauge block

A comparator (Fig. 5) is usable for measurement, which compares the reference gauge block and the calibrated gauge block.

The first option is a **5-point measurement strategy** (Fig. 4). The first contact of the comparator is made at point R1 on the reference gauge block and zero is set on the comparator here (Fig. 4). This is followed by measurement points C2, C3, C4, C5 and C6. Finally, a control measurement at point R1 is recommended (Fig. 4) [ISO 3650:1998].

The second option is a **2-point measurement strategy**, where only the central points R1 and C2 are measured and then a control measurement is made at point R1.

Measurement points R1 and C2 are central points. Points C3, C4, C5 and C6 are 1.5 mm away from the edge of the gauge block (Fig. 4). It is recommended to make at least 10 measurements.

In this article, a 2-point measurement strategy will be implemented at the central points of gauge blocks. In this case it is the **central length of gauge block**, which is measured at the central points of the measuring surfaces. The gauge block is placed on the measuring base during measurement.

The **deviation of the length** from the nominal length is what declares compliance or error with the nominal value. In the case of the central length, the **deviation of the central length** will be assessed.

Variation of length is a controlled parameter and in the case of the central length it is the **variation in central length**.

Deviation from flatness is another important parameter that is assessed and evaluated as the minimum distance between two parallel planes that cover all points of the gauge block surface.

A linear incremental encoder and a measuring device with a position display unit were used as a comparator for the calibration process (Fig. 5).

Figure 5. Linear incremental encoder and position display unit measuring device

The linear encoder contact is moved to the calibrated gauge block by means of a motorized displacement and the length of the gauge block is determined by means of the optical interference principle. The device was used as a comparator in combination with a gauge block set that is already calibrated and has the same or higher grade.

3 RESULTS

The calibrated gauge block set and the reference gauge block set together with the calibration device are placed in a room with a stable temperature (20±0.5)°C. Tweezers and gloves are used to handle the gage blocks. Each gauge block must be cleaned of preservative and dirt.

Visual inspection of the gauge block surface (Fig. 6) was performed using an optical microscope. No significant damage (scratches, cracks, fractures, and dirt deposits) was detected on the gauge blocks.

The flatness of the gauge blocks was checked using a reference ruler. All functional surfaces of the gauge blocks did not have significant flatness deviations. Visual inspection was performed using a microscope (Fig. 7).

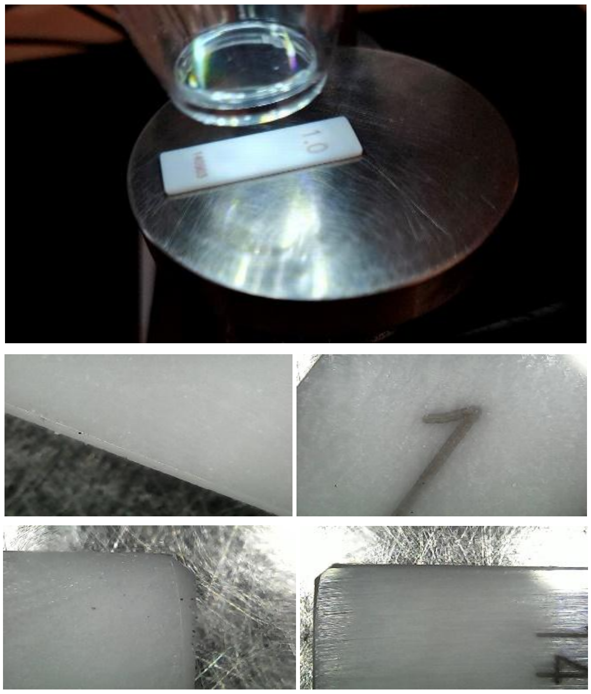

Figure 6. Visual inspection of the surface of gauge blocks

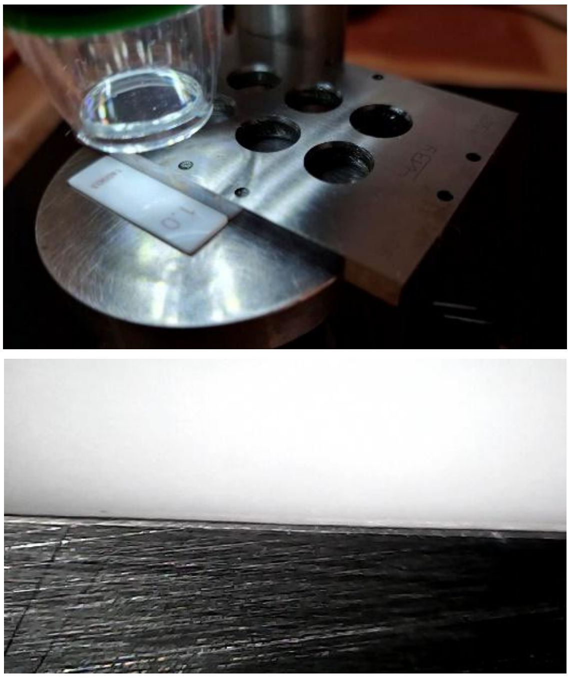

Figure 7. Checking the flatness of gauge blocks.

The chamfers of the gauge blocks were measured (Fig. 8) using a microscope. All chamfers did not exceed the tolerance (0.3 mm) (defined by standard ISO3650:1998).

The result of the comparison measurements are the deviations of the central length of calibrated gauge blocks (Fig. 9). The values are determined by the arithmetic mean of the tenth measurements at the central point of the gauge blocks. In the comparison measurement, a calibrated gauge block and a reference gauge block with the same nominal value were always used. The graph (Fig. 9) also indicates the maximum permissible tolerances for individual gauge blocks of this grade. All detected deviations are within the limits of the maximum permissible tolerance (defined by standard ISO3650:1998).

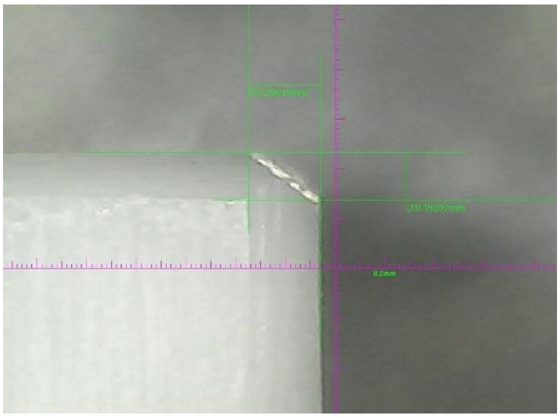

Figure 8. Measuring chamfer of gauge blocks.

When determining the deviation of the central length, the deviations of the reference gage blocks were also taken into account and thus the deviations shown (Fig. 9) are related to the nominal value of the scale [ISO 3650:1998].

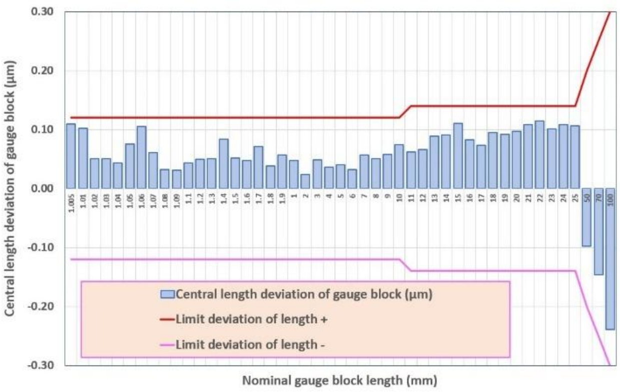

Figure 9. Central length deviations of calibrated gauge blocks.

The central length of gauge block related to the nominal scale value can be determined using the equation:

$$l_c = l_E + \delta l \qquad (1)$$

where:

l_E - nominal value of gauge block length,

δl – deviation of gauge block length.

From the determined deviations of the central length of the gauge blocks, the variations of the deviations were also determined (Fig. 10) as the difference between the maximum and minimum deviations. The maximum permissible values of the variation are indicated in the graph and it follows that all the determined values of the variations are within the permissible tolerance limits (Fig. 10) (defined by standard ISO3650:1998).

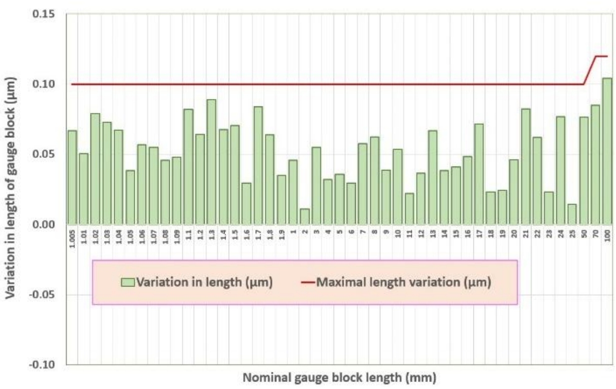

Figure 10. Variations in length of calibrated gauge blocks.

The combined uncertainty of the gauge block length determination is defined by:

$$u_c = \sqrt{u_A^2 + u_{BC}^2 + u_{BE}^2} \quad (2)$$

where

u_A – standard uncertainty determined by method A,

u_{BC} – standard uncertainty of comparator determined by method B from calibration certificate,

u_{BE} – standard uncertainty of reference gauge block determined by method B from calibration certificate.

When determining the standard uncertainty by method A, the relationship for the standard deviation is taken as a basis and it is recommended to make at least 10 measurements of the central length of the gage block (see Fig. 11). If the number of measurements is less than 10, then the standard uncertainty determined by method A must be multiplied by the correction factor defined in the standard [ISO3650:1998].

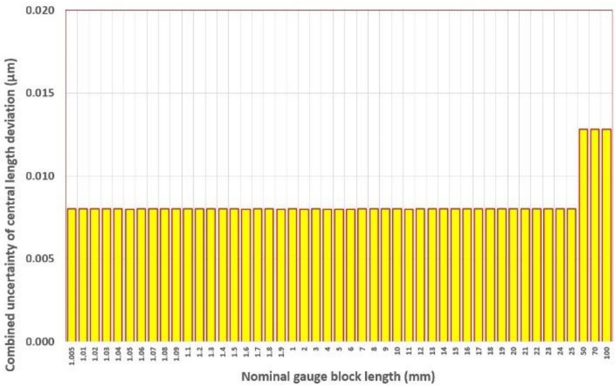

Figure 11. Combined uncertainty of calibrated gauge blocks.

4 CONCLUSIONS

Gauge blocks are length standards that are used to calibrate other length measuring instruments. It is therefore crucial that gauge blocks are calibrated in relation to a superior reference set of gauge blocks. In this article, we have addressed internal calibration according to our reference gauge block set. According to the result of the internal calibration process, the gauge block set is suitable for use and meets the conditions according to ISO3650:1998 [ISO 3650:1998, EA-4/02 1999, JCGM 100 2008].

These gauge block sets are also widely used in other measurements, where distances are determined using sensors, cameras and other measuring systems [Blatnicky 2020, Brada 2023, Bratan 2023, Duhancik 2024, Duplak 2023, Hortobagyi 2021, Hroncova 2023, Klichova 2025, Koniar 2014, Kuric 2021, Mascenik 2020, Mikova 2022, Pavlasek 2018, Pivarciova 2021, Romancik 2024, Semjon 2024, Vagas 2024 & 2025].

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REFERENCES

[Blatnicky 2020] Blatnicky, M., et al. Design of a Mechanical Part of an Automated Platform for Oblique Manipulation. Applied Sciences, 2020, Vol. 10, No. 23, Art. No. 8467. DOI: 10.3390/app10238467.

[Bozek 2016] Bozek, P., Lozkin, A., Gorbushin, A. Geometrical Method for Increasing Precision of Machine Building Parts. Procedia Engineering, 2016, Vol. 149, pp. 576-580. https://doi.org/10.1016/j.proeng.2016.06.708.

[Brada 2023] Brada, L., et al. Conducting an Examination of the Trajectory and Workspace of the Manipulator within the Matlab Environment. AD Alta-Journal of Interdisciplinary Research, 2023, Vol. 13, Issue 2, pp. 353-356. www.doi.org/10.33543/1302.

[Bratan 2023] Bratan, S., Sagova, Z., Saga, M., Yakimovich, B., Kuric, I. New Calculation Methodology of the Operations Number of Cold Rolling Rolls Fine Grinding. Applied Sciences, 2023, Vol. 13, No. 6. DOI: 10.3390/app13063484.

[Duhancik 2024] Duhancik, M., Krenicky, T., Coranic, T. Design and Testing of a Measurement Device for High-Speed Bearing Evaluation. Applied Sciences, 2024, Vol. 14, 508. https://doi.org/10.3390/app14020508.

[Duplak 2023] Duplak, J., Duplakova, D., Zajac, J. Research on Roughness and Microhardness of C45 Material Using High-Speed Machining. Appl. Sci., 2023, Vol. 13, 7851. https://doi.org/10.3390/app13137851.

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

[Hortobagyi 2021] Hortobagyi, A., et al. Holographic Interferometry for Measuring the Effect of Thermal Modification on Wood Thermal Properties. Applied Sciences, 2021, Vol. 11, No. 6. DOI: 10.3390/app11062516.

[Hroncova 2023] Hroncova, D., et al. Inverse and Forward Kinematics and Dynamics of a Two Link Robot Arm. MM Science Journal, 2023, No. December, pp. 7085-7092. DOI: 10.17973/MMSJ.2023_12_2023067.

[ISO 3650: 1998] ISO 3650:1998, Geometrical Product Specifications (GPS) — Length standards — Gauge blocks. Technical Committee: ISO/TC 213. Edition 2, 1998.

[JCGM 100 2008] JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3). 1st edition, 2008. Available from: www.iso.org/sites/JCGM/GUM-JCGM100.htm.

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

[JCGM 200 2012] JCGM 200—International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM). JCGM, 2012. Available from: www.iso.org/sites/JCGM/VIM-JCGM200.htm.

[Kelemen 2021] Kelemen, M., et al. Head on Hall Effect Sensor Arrangement for Displacement Measurement. MM Science Journal, 2021, No. October, pp. 4757-4763. DOI: 10.17973/MMSJ.2021_10_2021026.

[Kelemenova 2021b] Kelemenova, T., et al. Verification of the Torque Gauges. MM Science Journal, 2022, No. March, pp. 5533-5538. DOI: 10.17973/MMSJ.2022_03_2022014.

[Klarak 2021] Klarak, J., et al. Analysis of Laser Sensors and Camera Vision in the Shoe Position Inspection System. Sensors, 2021, Vol. 21, No. 22. DOI: 10.3390/s21227531.

[Klichova 2025] Klichova, D., et al. Transformation of Metrology Procedures for Surface Quality Evaluation Using Profile Parameters. MM Science Journal, 2025, No. June, pp. 8374-8378. DOI: 10.17973/MMSJ.2025_06_2025047.

[Koniar 2014] Koniar, D., et al. Virtual Instrumentation for Visual Inspection in Mechatronic Applications. Procedia Engineering, 2014, Vol. 96, pp. 227-234. DOI: 10.1016/j.proeng.2014.12.148.

[Kuric 2021] Kuric, I., et al. Analysis of Diagnostic Methods and Energy of Production Systems Drives. Processes, 2021, Vol. 9, 843. doi.org/10.3390/pr9050843.

[Machac 2023] Machac, T., et al. Aditive Manufacturing of M300 Steel Cutting Tools by Selective Laser Melting. MM Science Journal, 2023, No. October, pp. 6735-6739. DOI: 10.17973/MMSJ.2023_10_2023055.

[Malik 2025] Malik, M., et al. Optimization of a Robotic Cell in the Roboguide Environment. MM Science Journal, 2025, No. June, pp. 8276-8281. DOI: 10.17973/MMSJ.2025_06_2025021.

[Mascenik 2020] Mascenik, J., Pavlenko, S. Controlled testing of belt transmissions at different loads. MM Science Journal, 2021, No. December, pp. 5497-5501.

[Mikova 2022] Mikova, L. et al. Upgrade of Biaxial Mechatronic Testing Machine for Cruciform Specimens and Verification by FEM Analysis. Machines, 2022, Vol. 10, No. 10. DOI: https://doi.org/10.3390/machines10100916.

[Pavlasek 2018] Pavlasek, P., et al. Flexible Education Environment: Learning Style Insights to Increase Engineering Students Key Competences. In: EDULEARN18 Proceedings - 10th Int. Conf. on Education and New Learning Technol., 2-4 July 2018, Palma, Spain, pp. 10156-10165, 2018. ISBN: 978-84-09-02709-5. DOI: 10.21125/edulearn.2018.2468.

[Peterka 2020] Peterka, J., et al. Diagnostics of Automated Technological Devices. MM Science Journal, Vol. 2020, No. October, pp. 4027-4034. DOI: 10.17973/MMSJ.2020_10_2020051.

[Pivarciova 2021] Pivarciova, E., et al. Interferometric Measurement of Heat Transfer above New Generation Foam Concrete. Measurement Science Review, 2019, Vol. 19, No. 4, pp. 153-160. DOI: 10.2478/msr-2019-0021.

[Romancik 2024] Romancik, J., et al. Design, Implementation, And Testing of a 3D printed Gripper Actuated by Nitinol Springs. MM Sci. J., 2024, No. June, pp. 7352-7356. DOI: 10.17973/MMSJ.2024_06_2024009.

[Semjon 2024] Semjon, J., et al. Verification of the Properties of an Industrial Robot for the Nuclear Industry. MM Science Journal, 2024, No. November, pp. 7788-7794. DOI: 10.17973/MMSJ.2024_11_2024056.

[Stejskal 2016] Stejskal, T., et al. Information Contents of a Signal at Repeated Positioning Measurements of the Coordinate Measuring Machine (CMM) by Laser Interferometer. Measurement Science Review, 2016, Vol. 16, No. 5, pp. 273-279. DOI: https://doi.org/10.1515/msr-2016-0034.

[Trojanova 2021] Trojanova, M., Cakurda, T., Hosovsky, A., Krenicky, T. Estimation of Grey-Box Dynamic Model of 2-DOF Pneumatic Actuator Robotic Arm Using Gravity Tests. Applied Sciences, 2021, Vol. 11, No. 10, Art. No. 4490.

[Vagas 2024] Vagas, M., et al. Implementation of IO-Link Technology into the Handling and Sorting Sub-Station of the Festo FMS 500 Automated Line. MM Science J., 2024, No. June, pp. 7348-7351. DOI: 10.17973/MMSJ.2024_06_2024008.

[Vagas 2025] Vagas, M., et al. Data Processing Approach Based on OPC UA Architecture Implementation and Bluebird Platform. IEEE Access, 2025, Vol. 13, pp. 51069-51084. DOI: 10.1109/ACCESS.2025.3552976.

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