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IDENTIFICATION OF CONDITION OF LINEAR DISPLACEMENT SENSOR

Urgency of the research. *There are several types of displacement sensor available on market. Displacement sensor investigated in this work is based on optical encoder principle. Condition of sensors changes with using of it. Periodically it is necessary to check its condition, if it is within the declared limits.*

Target setting. *Displacement linear sensor is mounted in comparator stand for the verifying of its condition using the set of length gauge blocks. Length gauge blocks allows to set up the etalon of length with various dimension in interval from 0.5mm to 100 mm. The systematic errors of used set of length gauge blocks of grade "0" are very small in comparing with measured dimension and measured deviations.*

Actual scientific researches and issues analysis. *It is necessary to check actual status of sensor. It means that verification process will obtain the information about maximum permissible error and information about reliability.*

Uninvestigated parts of general matters defining. *The main problem was to identify condition of sensor. The question of the probability distribution of measured values and uncertainty balance are uninvestigated, because the next research will be focused to this are.*

The research objective. *The aim is to obtain maximum permissible error of explored sensor. On the base of deviation of measurement made on length gauges could be expressed. The optimal number of measurement is problem to know, because the low number will cause big uncertainty of measurement and large number of measurement will cause the large cost of measurement.*

The statement of basic materials. *Gauge length blocks have been used for verification of investigated sensor. The set of gauge length blocks of grade "0" has been used, which are preferred mainly for calibration or verification purposes. Maximum permissible error has been estimated as math model for next using. Also optimal number of measurement is identified from analysis of standard deviation of measurements made one hundred times on selected dimensions.*

Conclusions. *The investigated sensor meets the maximum permissible error limits set by the manufacturer with a large margin, and so the maximum permissible error limits have been tightened so that the measurement uncertainty is better. The sensor can be used in dimensional measurement applications, even in industrial conditions.*

Keywords: *Displacement sensor; distance; measurement; maximum permissible error; length gauges.*
Fig.: 20. References: 4.

Introduction. This work is focused on the field of engineering metrology of lengths. The main problem in practice is the measurement of lengths with a sufficiently fast reaction time and minimal measurement uncertainty. These are mainly measurements of the dimensions of components in industrial production. For this purpose, different types of gauges are produced based on different physical principles. Measuring systems for measuring dimensions can be divided according to the output quantity into mechanical and electrical gauge. In the case of mechanical gauge, the measured dimension is transformed into a mechanical change in the position of the indicator. For electrical gauge, the measured dimension is transformed into an electrical signal displayed on electrical instruments and display units.

Mechanical gauges are often used, but their accuracy is limited by the inaccuracy of mechanical components and various parasitic phenomena such as friction, backlash and hysteresis. Their service life is limited due to their gradual wear and require maintenance. The measurement uncertainty with these types of meters is unstable over time and tends to deteriorate over time, precisely due to mechanical parasitic phenomena.

For these reasons, it is therefore an attempt to replace mechanical gauge with electrical gauge, where some physical principle is used to transform the measured dimension into an electrical quantity (e.g. electrical voltage, electric current, frequency, pulse width or digital coded signal).

Electric dimensional gauge most often use the resistance principle, optical principle, capacitive principle, ultrasonic principle, inductance principle, Hall Effect, etc. Each of these principles has its advantages and limitations, according to which it is necessary to choose a suitable principle for the application [1].

In this article, the condition of the Linear displacement sensor (fig.1), which uses a photoelectric linear encoder consisting of a transmitter - LED diode and a receiver - photodiode, will be investigated experimentally. By moving the measuring ruler with permeable and impermeable places with a spacing of 20 micrometers, with which it is possible to determine the position of the ruler and thus the measured object. The output of the sensor is a rectangular course of electrical voltage. The sensor can be used in any position. The measuring range of the sensor is 100 mm with a resolution of 0.1μm. The maximum inaccuracy of the sensor is declared at the level (2 + L / 100) μm, where L - is the measured length in millimeters. The sensor is enclosed in a housing with dust and water resistance at the level IP54 of degree of protection. This allows this sensor to be used in industrial operation as well. Spindle is droved with helical spring and contact point is standard 3 mm ball contact point, which is changeable with another contact point. The sensor is connected to digital counter with LED display with possibilities to execute several math functions (fig. 2).

Fig. 1. Verified displacement sensor

Fig. 2. Displacement sensor in comparator stand with digital counter

1. Experimental verification of the sensor. Experimental verification of sensor has been executed via using the length gauge blocks of grade "0" (fig. 3). Verification process has been done using the comparator stand and set of length gauge blocks [2, 3, 4]. The sensor is fixed in comparator stand and length gauge blocks as etalon were placed between the comparator table and spindle contact point (fig. 4). Three pieces of the sensor have been available. The aim is to select the best of them and verify it for achievable accuracy of measurement.

Fig. 3. Set of length gauge blocks (grade 0)

Fig. 4. Verification process of sensor

All three sensors are verified using the set of length gauges as etalon. In the range from 0 to 100 mm, a standard was set from a set of length gauge blocks to verify all sensors. Systematic errors of used length gauge blocks are evaluated as algebraic sum of systematic errors of used individual length gauges (fig. 5). Each millimetre was measured 3 times and the mean values of these measurements are shown in fig. 6. As it is visible, the systematic errors of the scales are much smaller than the values measured by the sensor, so these errors can be neglected and it is not necessary to correct the measured values with these systematic errors of the scales.

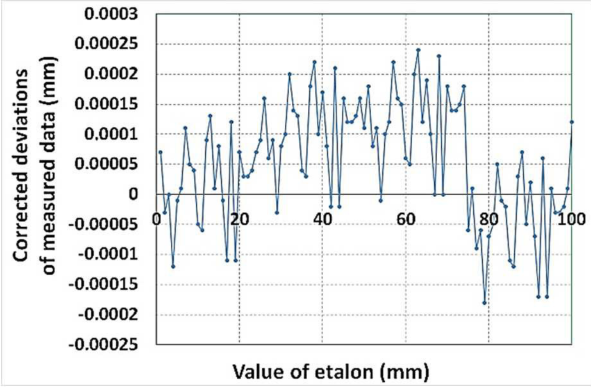

Fig. 5. Systematic errors of length gauge blocks – etalons for every verified dimension

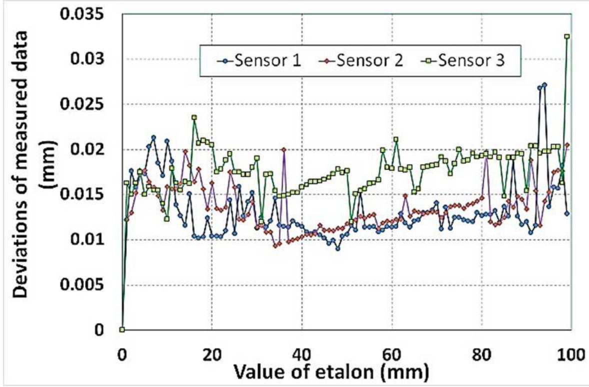

Fig. 6. Deviations of measured data from three available sensors

From fig. 6 it is visible, that the sensor 2 is the best in terms of the measurement accuracy achieved. Therefore, the condition of this sensor will be further investigated. If this sensor is in good condition, it will be used for digital measurement in a length measuring machine for the purpose of modernizing this machine.

Fig. 7 shows the course of deviations of the measured data from the values of the standards. All values are shifted to positive values and the course shows that it could be a systematic error of some part of the measuring chain. The average value of the deviations could be used to correct the measured values to improve the accuracy of the measurement. However, even after this correction, several values would show a relatively large measurement error (fig. 7). The values of deviations show a slightly fluctuating tendency, so it is possible to try to approximate their polynomial function, but if it were used to correct the measured values in this case, some values would show a large measurement error (fig. 8).

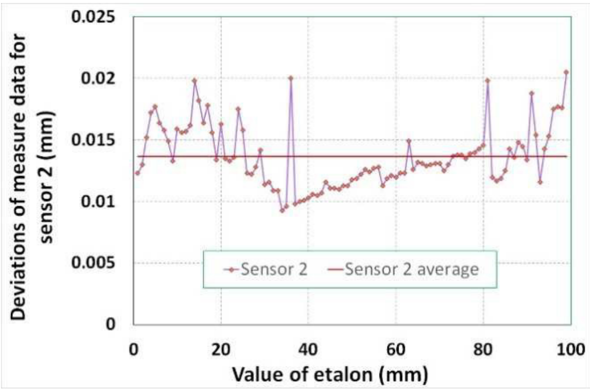

Fig. 7. Deviations of measured data from sensor 2 with approximation with average

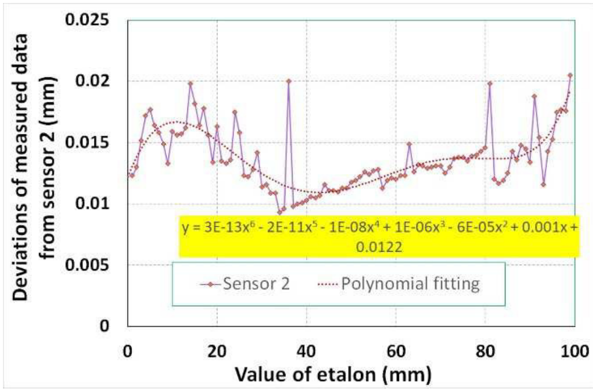

Fig. 8. Deviations of measured data from sensor 2 with approximation with polynomial function

Fig. 9 shows the correction by means of the average value of deviations, and for comparison, a correction was also performed by means of half the value of the variation range (Fig. 10), and in this case the situation is more favourable in terms of measurement errors.

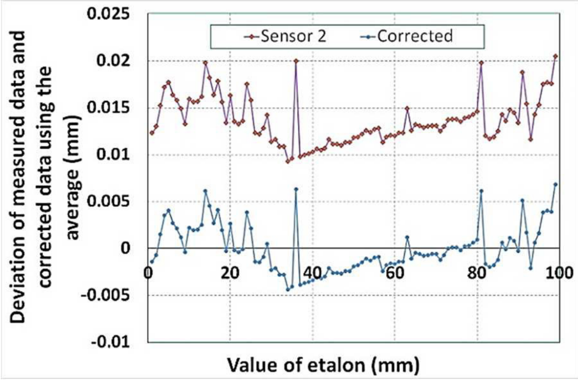

Fig. 9. Deviations of measured data from sensor 2 and deviations corrected using the average value

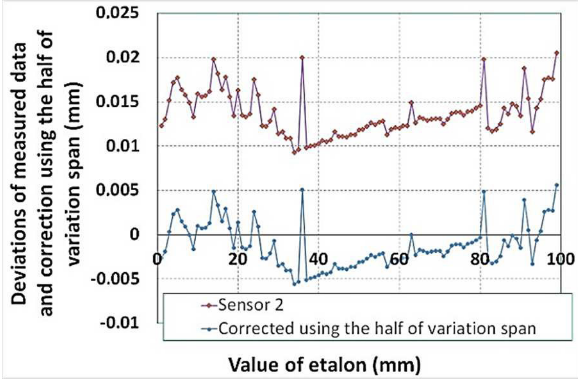

Fig. 10. Deviations of measured data from sensor 2 and deviations corrected using the half of variation span

Next, a correction using half the variation range of the measurement deviations will be considered (Fig. 11). It is then possible to set the maximum deviation limits to ±6 µm. These thresholds could further be used to estimate the measurement uncertainty of the measurement chain, usable for balancing measurement uncertainties that are not known. Based on the experience of measuring with this sensing system, this is the uncertainty determined by method B (fig. 11).

ISO 10360 standard stated as a limit value of the so-called maximum permissible error - *MPE*. It is given in the form of a linear mathematical model $MPE = A + L / B$, which can be more easily processed in the case of use in the processing of measured values. The sensor manufacturer states the maximum permissible error value for this examined sensor in the form $MPE = + - (2 + L / 100)$ in micrometers, where L is the measured value in millimeters.

By plotting this value in the graph of measurement deviations, it is possible to determine whether this sensor complies with the maximum permissible error defined by the manufacturer (fig. 12). The graph (fig. 12) shows that the values are within the defined area bounded by the maximum permissible error values, which means that the sensor complies with the maximum permissible error values specified by the manufacturer.

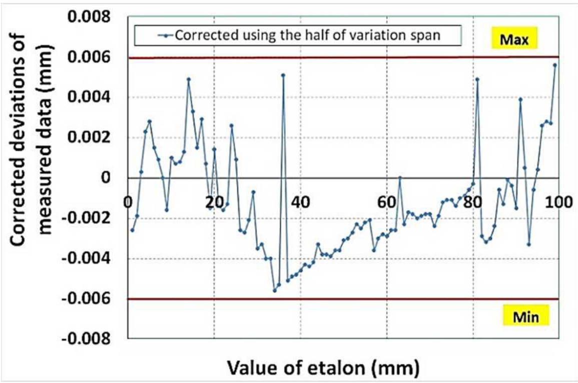

Fig. 11. Deviations corrected using the half of variation span with limits

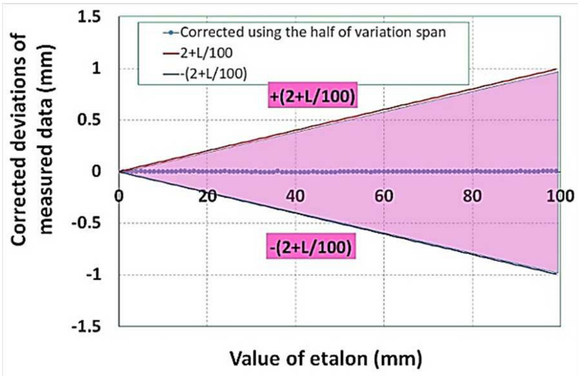

Fig. 12. Comparison of measurement deviations with limits defined by producer

Fig. 12 shows that the sensor with a large margin meets this criterion set by the manufacturer. In Fig. 12, however, it is not possible to see whether the range of values near the zero value meets this criterion due to the display scale. This can be assessed in detail (fig. 13), which shows the situation in the interval near the zero value. This graph (fig. 13) also confirmed that the sensor is in excellent condition.

Since the sensor with a large margin meets the maximum permissible error set by the manufacturer, then the current new maximum permissible error limits can be determined to characterize the current condition (fig. 14). The new maximum permissible error can therefore be approximated by the mathematical model $\pm(2 + L / 400)$ (fig. 14). This border area (fig. 14). It is possible to use later it for a more accurate assessment of the current measurement condition of this measurement system.

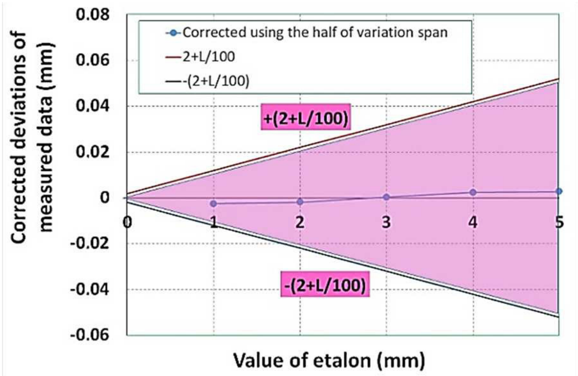

Fig. 13. Comparison of measurement deviations with limits defined by producer – detail near the zero

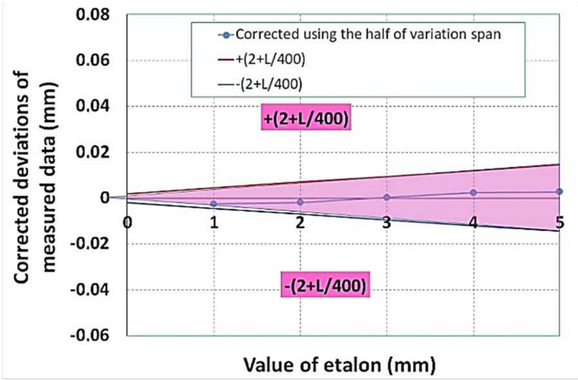

Fig. 14. Comparison of measurement deviations with reduced limits – detail near the zero

2. Repeatability. Another important evaluation criterion of the measuring system is the repeatability of the measurement. Measurement repeatability expresses the ability of the measurement process on the measuring system to show approximately the same value of the measured quantity under the same measurement conditions. If the measured values are very scattered during repeated measurements, it means that the measurement process is unstable and the repeatability of the measurement is unsatisfactory. Five dimensions (0 mm; 5 mm; 25 mm; 50 mm; 70 mm) were selected for the repeatability assessment, in which 100 measurements were performed under the same conditions (Fig. 15, Fig. 16, Fig. 17, Fig. 18, Fig. 19). For a qualitative assessment, fig. 20 shows the cumulative standard deviations. This means that out of a series of 100 measured measurements, the reference values are gradually evaluated with increasing measured values. Therefore, they are called cumulative standard deviations.

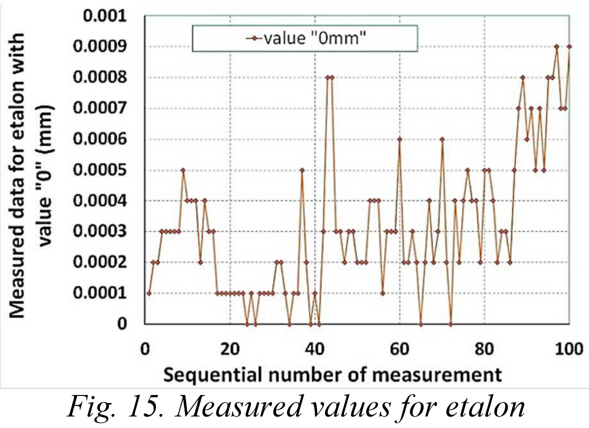

Fig. 15. Measured values for etalon with value "0 mm"

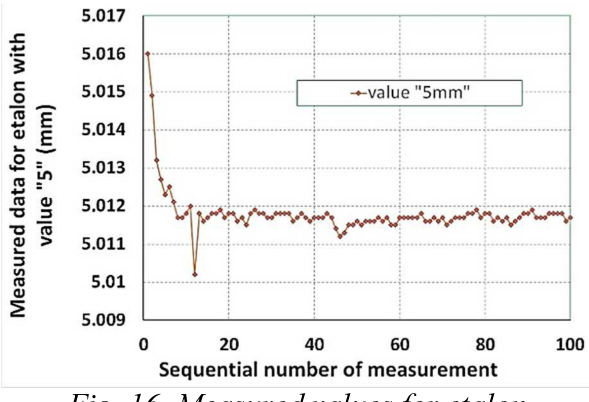

Fig. 16. Measured values for etalon with value "5 mm"

Cumulative standard deviations provide information on how many measurements the measurement process stabilizes. The standard deviation is also used to determine the standard uncertainty by method A. As can be seen from fig. 20, after exceeding the number of measurements 40, there is no further significant reduction in the value of the standard deviation and thus no reduction in the standard uncertainty determined by method A. It is therefore unnecessary to measure more than 40 times, since the measurement process is already stabilized.

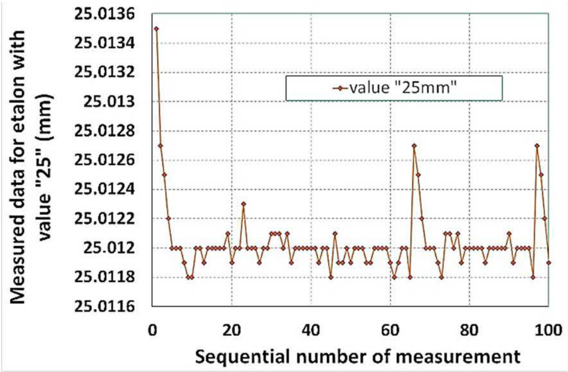

Fig. 17. Measured values for etalon with value "25 mm"

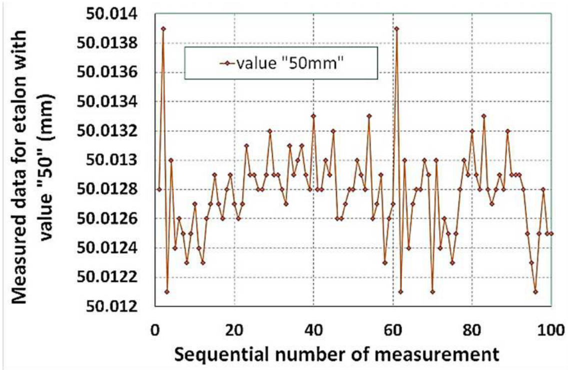

Fig. 18. Measured values for etalon with value "50 mm"

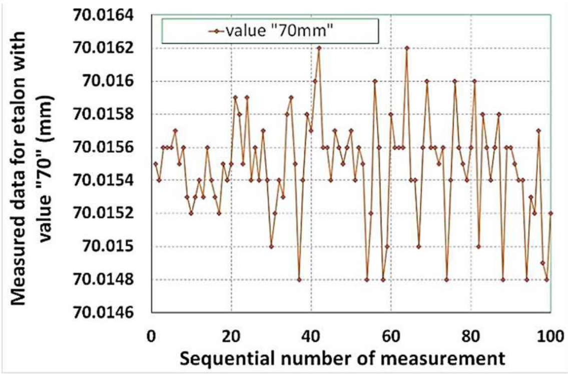

Fig. 19. Measured values for etalon with value "70 mm"

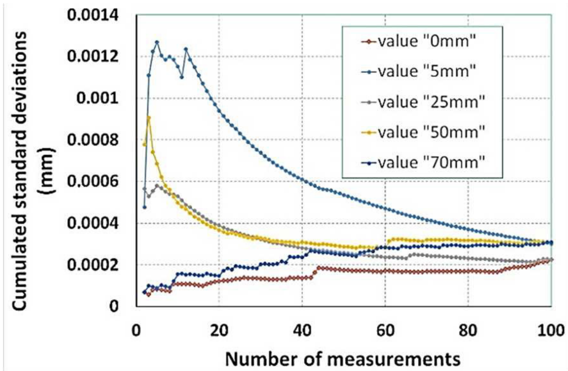

Fig. 20. Cumulative standard deviations for one hundred measurements for selected dimensions

Based on fig. 20, it is thus possible to determine what uncertainty can be obtained by the method A with a specific number of measurements. The question of the required number of measurement repetitions can therefore be determined in this way.

Conclusion. The displacement is one of the most frequently measured quantities in the industry. The sensor investigated in this work is made for use in industrial conditions. After using this sensor, it is necessary to check its condition after a certain time, whether it meets the specified conditions. Using a set of length gauge blocks, measurement inaccuracies were detected, which, however, were within the range delimited by the maximum permissible error values. It is even possible to narrow these limits in order to show a better value of maximum inaccuracy and hence the value of standard uncertainty by method B. Examination of measurement repeatability answered the question of what is the optimal number of measurements to achieve a specific standard deviation that can be considered standard uncertainty determined by method A. Further research will focus on determining the mathematical statistical model of the distribution of measured values, which is needed to determine the coefficient of expansion to determine the expanded measurement uncertainty for the investigated sensor.

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ІДЕНТИФІКАЦІЯ СТАНУ ДАТЧИКА ЛІНІЙНОГО ЗМІЩЕННЯ

Актуальність теми дослідження. *На ринку доступно кілька типів датчиків переміщення. Датчик переміщення, досліджений у цій роботі, базується на принципі оптичного кодера. Стан датчиків змінюється при його використанні. Періодично необхідно перевіряти чи він знаходиться в заявлених межах.*

Постановка проблеми. *Вимірювальний лінійний датчик встановлений у стенді компаратора для перевірки його стану за допомогою набору вимірювальних блоків довжини. Блоки для вимірювання довжини дозволяють встановити еталон довжини з різними розмірами в інтервалі від 0,5 до 100 мм. Систематичні похибки використовуваного набору блоків калібрувальної довжини класу «0» дуже малі в порівнянні з виміряними розмірами та виміряними відхиленнями.*

Аналіз останніх досліджень і публікацій. *Необхідно перевірити фактичний стан датчика. Це означає, що в процесі перевірки буде отримана інформація про максимально допустиму похибку та інформація про його надійність.*

Виділення недосліджених частин загальної проблеми. *Основною проблемою було виявлення стану датчика. Питання розподілу ймовірностей виміряних значень та балансу невизначеності не досліджені, тому наступне дослідження буде зосереджене саме на цьому.*

Постановка завдання. *Мета полягає в тому, щоб отримати гранично допустиму похибку, яку можна виміряти, досліджуваним датчиком на основі відхилення вимірювання, виконаного під час вимірювання довжини. Визначити оптимальну кількість вимірювань складно, тому що мала кількість викличне велику неточність вимірювання, а велика кількість вимірювань призведе до високих витрат на вимірювання.*

Виклад основного матеріалу. *Для перевірки досліджуваного датчика використовувалися блоки вимірювальної довжини. Був використаний набір блоків вимірювальної довжини класу «0», які використовуються в основному для цілей калібрування чи перевірки. Максимально допустима похибка розрахована як математична модель для наступного використання. Також оптимальна кількість вимірювань визначається з аналізу стандартного відхилення 100-кратного вимірювання обраних розмірів.*

Висновки відповідно до статті. *Досліджуваний датчик відповідає гранично допустимим похибкам, встановленим виробником, з великим запасом, і тому гранично допустимі показники похибки були відібрані жорсткіше, щоб похибка вимірювання була точнішою. Датчик можна використовувати для вимірювання розмірів, навіть у промислових умовах.*

Ключові слова: *датчик переміщення; відстань; вимірювання; гранично допустима похибка; датчики довжини.*

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