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DISPLACEMENT MEASUREMENT USING THE HALL EFFECT SENSORS

Urgency of the research. *There are several types of measurement principles for displacement measurement. Hall effect sensor is one of them. Hall sensor has several advantages and there is a need for identification of suitable application principles.*

Target setting. *The selected Hall effect displacement sensors are a low-cost part, which are useful for many various applications. The aim is to identify principles and behaviours of using of these sensors in various modes.*

Actual scientific researches and issues analysis. *The Hall effect sensors working on effect, where magnetic array influences the output voltage on these sensors. There is a problem with definition of suitable configuration of arrangement of these sensors. It depends on polarity of magnetic array and intensity of magnetic array. Also, placement of the sensor is important for this sensing application.*

Uninvestigated parts of general matters defining. *The main problem is expressing of transformation characteristic, which depends on used permanent magnet as source of magnetic array. There is no regulations and recommendation for using these sensors as a displacement sensor. The question is also about the reliability of these sensors and minimum number of measurements for minimized uncertainty of measurement and stability of measured data. Long distance sensing measurements are uninvestigated, therefore the next research will be focused on this area.*

The research objective. *The aim is to obtain any useful experience and recommendations about the using of these sensors. Several sensors also have the hysteresis effect, which is as problem and it is parasitic effect for measurement.*

The statement of basic materials. *The Hall effect with ratiometric voltage output have been explored. So, it is analogue sensors with voltage reaction to changed displacement.*

Conclusions. *The selected explored sensors have perfect properties for displacement measurement. They are potentially applicable for very sensitive and precise measurement of displacement.*

Keywords: *Hall effect; displacement; measurement; magnetic array; gauges.*

Fig.: 10. References: 9.

Introduction. The paper is focused on area of displacement measurement. There are many ways of measurement methods and principles as resistive sensors, capacitive sensors, inductive sensors, optical sensors etc. Hall effect sensor is another way of displacement measurement. The Hall effect is based on material sensitivity towards magnetic array. Sensor SS495A and SS49E are tested for displacement measurement. Both sensors are ratiometric linear sensor suitable for displacement measurement. Magnetic field from permanent magnet or electromagnet can be detected. In our case, the permanent magnet NdFeB (diameter 10mm, length 10 mm) will be used with axial anisotropic polarisation with remanence 1.25T and coercive force 907 kA/m. Four configurations of magnet and sensor (fig. 1) have been tested using the length gauge blocks (fig. 2). Length gauge blocks are used as etalon of displacement [1-7].

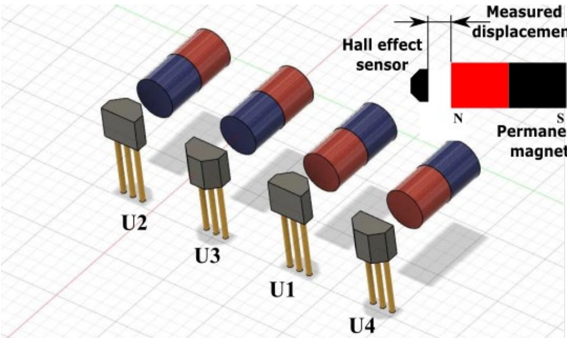


Fig. 1. Configuration U1, U2, U3, U4 of hall effect sensor with permanent magnet for displacement measurement

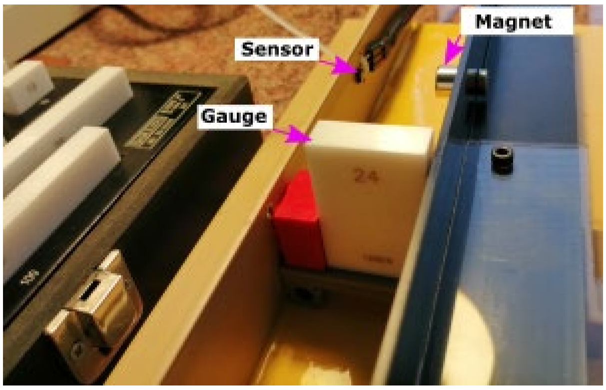


Fig. 2. Displacement sensor in test stand with gauge length block

1. Experimental verification of the sensor. Experimental verification of sensor has been executed using the length gauge blocks Fig. 2 for every millimetre of measured range. Every position has been tested ten times and average number of these measurements are shown on figure 3 and figure 4. They show results for all measurement configuration U1, U2, U3, U4 for both explored sensors SS495A and SS49E. All measurements have been measured for approaching of magnet to the sensor and for moving away of magnet from sensor. This strategy has been used for identifying hysteresis or other parasitic effects unwanted for measurement process. Both sensors have similar characteristics (fig. 3, 4), but some configurations also have hysteresis, what is unwanted effect for measurement purposes. Hysteresis is visible on enlarged graphs on figure 5 and figure 6, where configuration U4 has the minimum hysteresis effect.

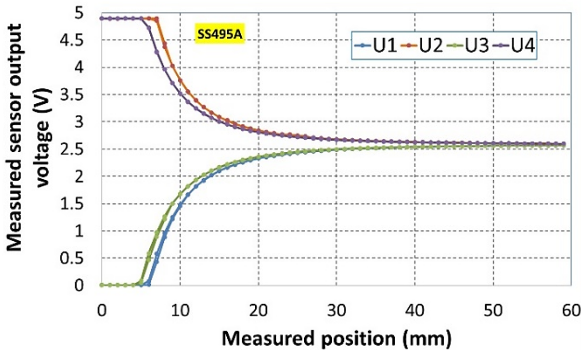


Fig. 3. Measured result from displacement measurement using the sensor SS495A for all measurement configuration U1, U2, U3 and U4

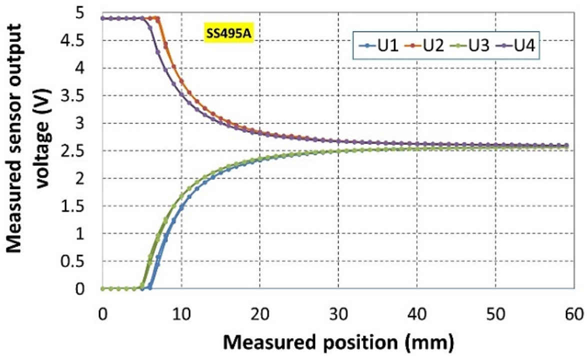


Fig. 4. Measured result from displacement measurement using the sensor SS49E for all measurement configuration U1, U2, U3 and U4

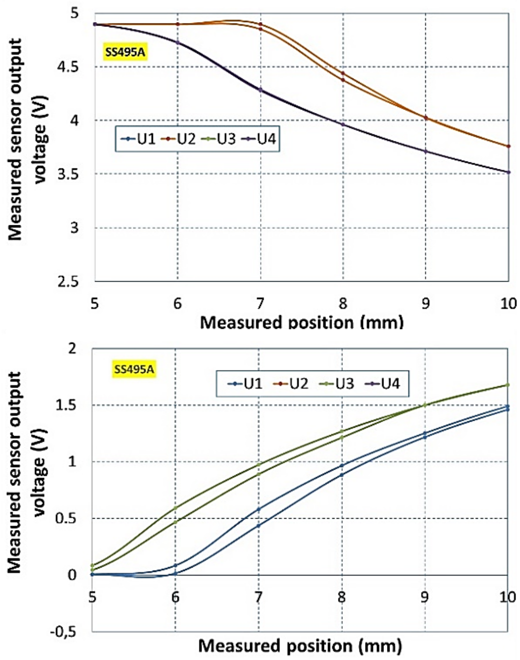


Fig. 5. Hysteresis analysis for displacement measurement using the sensor SS495A for all measurement configuration U1, U2, U3 and U4

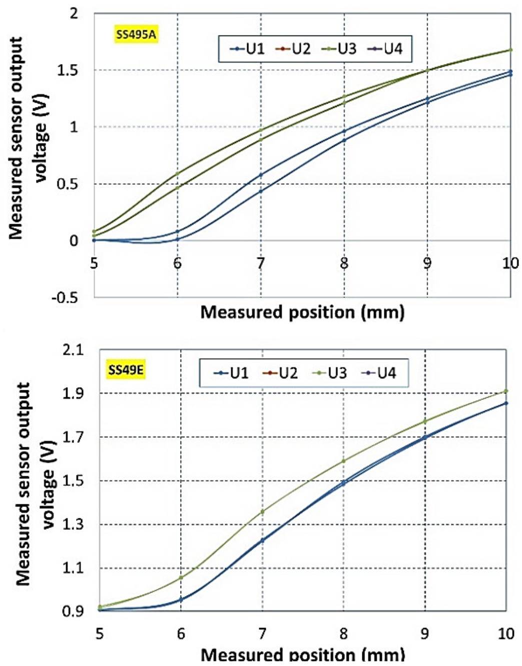


Fig. 6. Hysteresis analysis for displacement measurement using the sensor SS49E for all measurement configuration U1, U2, U3 and U4

Consequently, configuration U4 is the best from the viewpoint of hysteresis. It means that configuration U4 should be used for practical application for both sensor type. Both statics characteristics of U4 configuration are converted to transform characteristics as dependence of measured position on measured sensor voltage output. Math model of these transform characteristic can be used for calculation of searched displacement from measured sensor output voltage. Fitting of these experimental data using the regression analysis using the least square methods is shown on figure 7 and 8. Various types of approximation function have been tested for these characteristics and polynomial function looks like the best approximation (fig. 7, 8). But also, approximation by polynomial function was also a problem, because of atypical shape of characteristic. For this reason, the usable measurement range had to be decreased for further displacements from sensor. Consequently, for reduced measurement range both characteristics were successfully fitted using the polynomial functions (fig. 9 and 10).

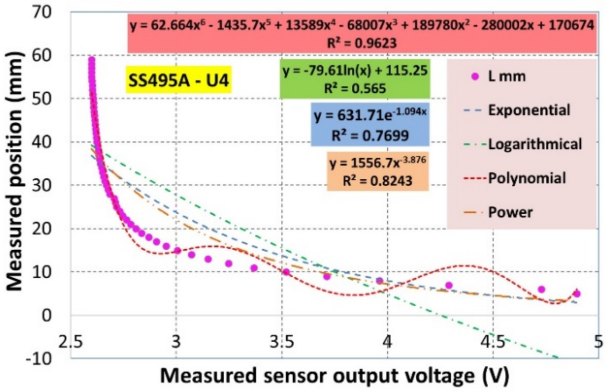


Fig. 7. Regression analysis for displacement measurement using the sensor SS495A for measurement configuration U4

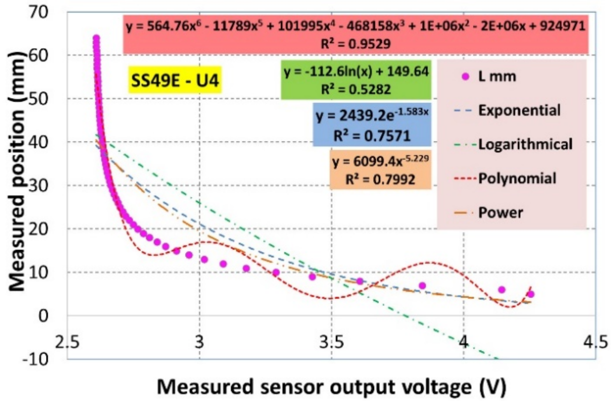


Fig. 8. Regression analysis for displacement measurement using the sensor SS49E for measurement configuration U4

Measurement range for sensor SS495A is defined in interval from 5mm to 25mm and for sensor SS49E the interval is defined from 5mm to 30mm. Therefore, the sensor SS49E has a bit larger measurement range (fig. 7 and 8).

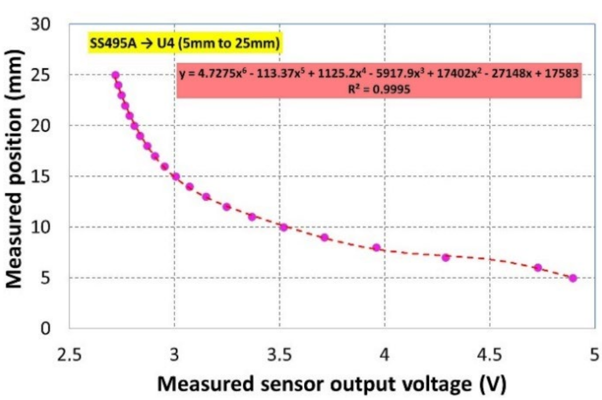


Fig. 9. Polynomial fitting for displacement measurement using the sensor SS495A for measurement configuration U4

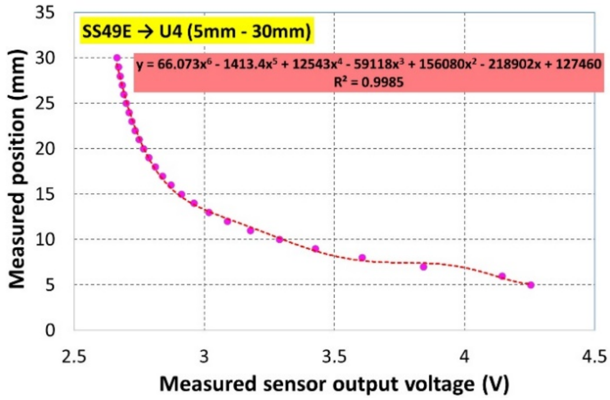


Fig. 10. Polynomial fitting for displacement measurement using the sensor SS49E for measurement configuration U4

2. Reliability of measurement on explored sensors. Reliability gives information about consistency of measurement results for multiply repeated measurements of any quantity. Reliability describes the stability of process of finding the measurement of measurement quantity. For this purpose, a hundred measurements have been executed for 6 selected values of both sensors (fig. 11 and 12).

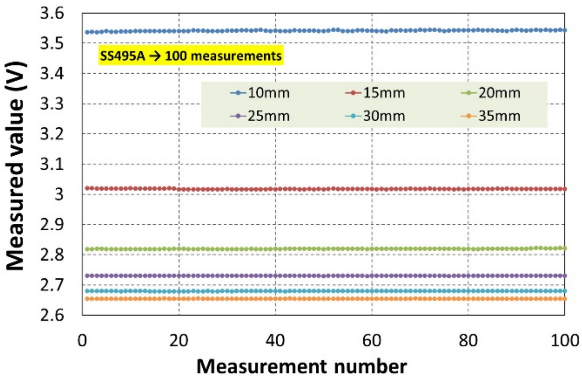


Fig. 11. Hundred measurement for sensor SS495A for measurement configuration U4

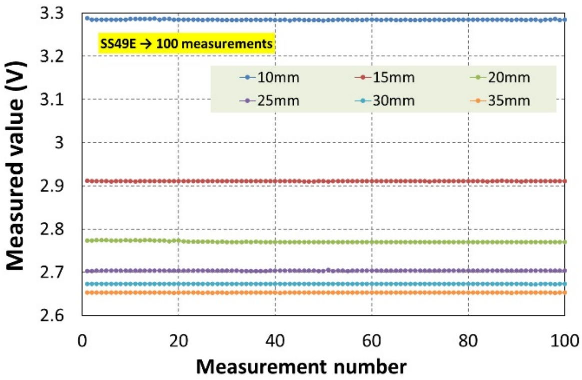


Fig. 12. Hundred measurement for sensor SS49E for measurement configuration U4

The measured data have been captured with one second sampling time. Measured values (fig. 11 and 12) show the perfect time stability of measurement signal. Both graphs are between similar limits so, from this viewpoint, both sensors are comparable. From this data the cumulated standard deviations have been made (fig. 13 and 14).

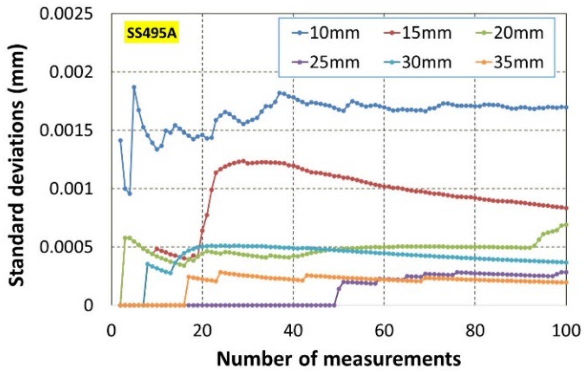


Fig. 13. Cumulated standard deviations for sensor SS495A for measurement configuration U4

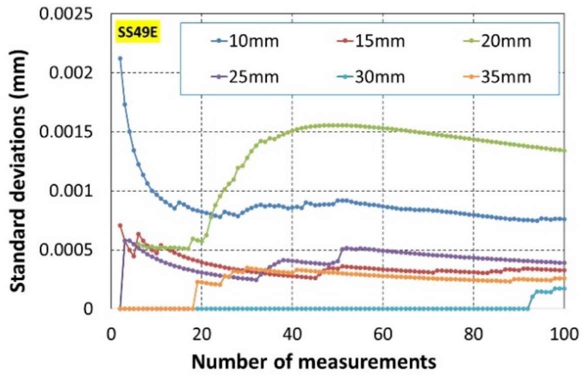


Fig. 14. Cumulated standard deviations for sensor SS49E for measurement configuration U4

Measured data shown on figure 11 and 12 also can be interpreted in different forms. It is possible to make average number for all cases, and maximum error index from the average. For evaluation, it is better to express relative error for both sensors and for all measured values (fig. 15). This graph shows that both sensors are comparable approximately on one level of accuracy. Both sensors have relative error less than 0.25%. It means that these sensors are also perfect from the viewpoint of accuracy of measurement. In addition, it is necessary to say, that these errors also include the error of multimeter (not only for sensor). The error is larger for smaller displacements. The best error index is for displacement of 30 mm and 35 mm. For these values, the error is less than 0.05%. This value means that both these sensors are very accurate (fig. 15). This error can be reported into overall uncertainty of measurement.

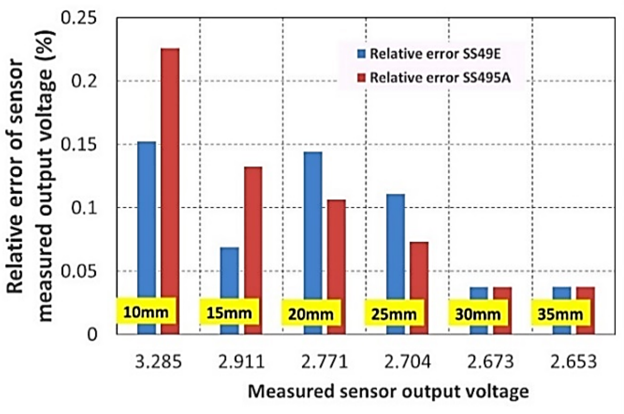
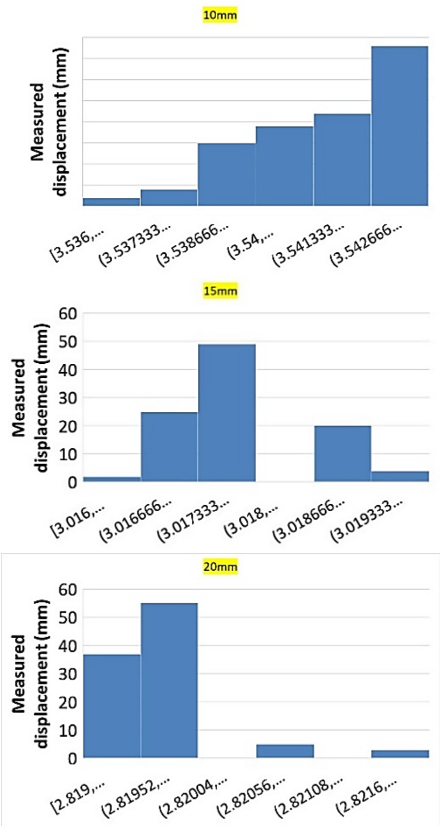
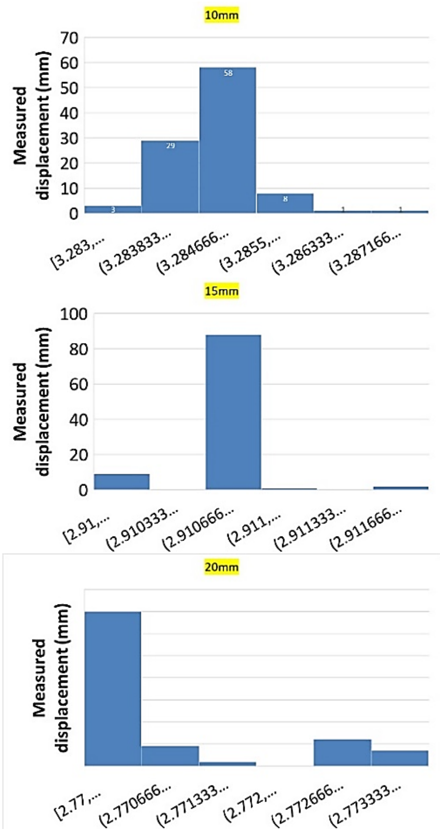


Fig. 15. Relative error for sensor SS495A and SS49E for measurement configuration U4.

Data obtained from the measurement made for reliability exploring, can be used also for evaluation of probability distribution. Figure 16 and 17 shows the histograms for selected nominal values. The histograms confirmed that it is not possible to express them using the gauss normal distribution function. In this case, it is better to use uniform distribution, because the probability of all values in measured range is equal. The knowledge of probability distribution is necessary for expressing of expanded uncertainty, where it is necessary to use the coverage factor, which depends on probability distribution of measured data. In addition, these histograms include influence of used multimeter. The used multimeter has datasheet with declared maximum error with value 0.5 % of measured value and it means that sensors have probably much better accuracy than our exploring shows.





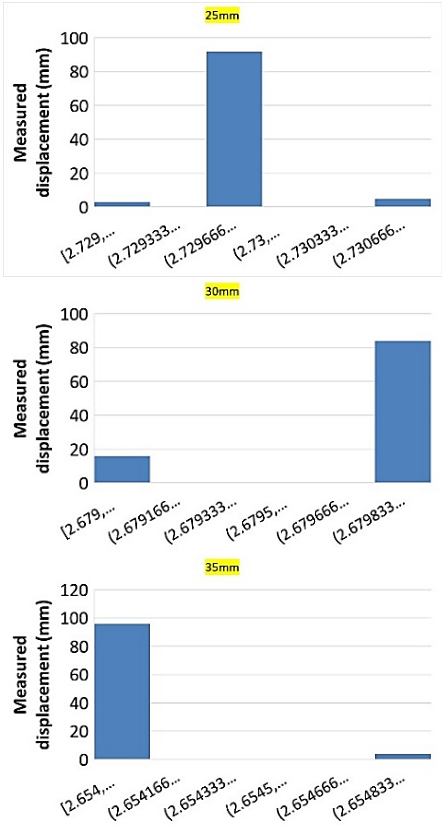


Fig. 16. Histograms for sensor SS495A for measurement configuration U4.

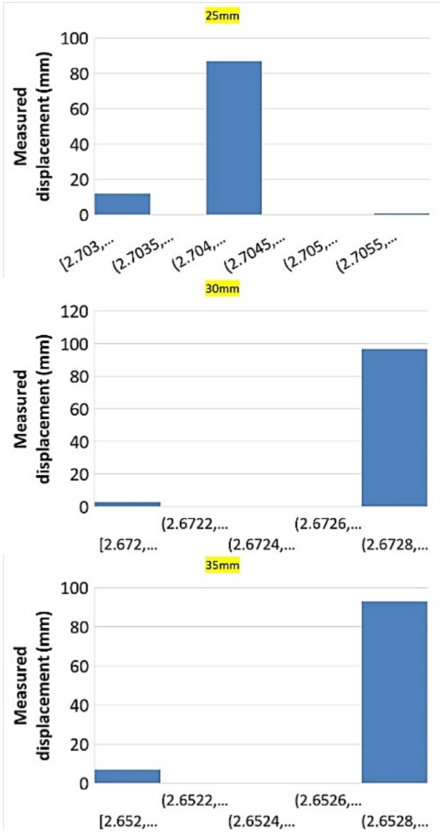


Fig. 17. Histograms for sensor SS49E for measurement configuration U4.

Conclusion. Thanks to mass production, the hall effect sensors are economically perfect selection for realisation of displacement measurement. The experiments show that configuration U4 (North pole of magnet oriented to larger area of sensor) is the best for measurement purposes for both explored sensors. It is possible to make transformation characteristics for implementation to controller program to recalculate voltage to displacement information. Next experiments confirm the perfect time stability of output signal and relative error of both sensors are less than 0.25% of measured value. Histograms show that standard distribution probabilities cannot be used for description of these sensors, so uniform probability distribution is recommended to use for expressing of measurement uncertainties.

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References

1. EA-4/02 M:2013 Evaluation of the Uncertainty of Measurement In Calibration. Publication Reference. European Accreditation Laboratory Committee. September 2013 rev 01. cited August, 8th, 2019. Available online: https://european-accreditation.org/wp-content/uploads/2018/10/ea-4-02-m-rev01-september-2013.pdf. EA-4/02 is a mandatory document belongs to Category: Application documents and Technical Advisory documents for Conformity Assessment Bodies.

2. National translation MSA-L/12 Expression of the Uncertainty of Measurement in Calibration (EA-4/02 M:2013).

3. ISO 3650:1998(E) International Standard, "Length standards – Gauge Blocks," International Organization for Standardization, Geneva, Switzerland.

4. ISO 10360-7:2011 Geometrical product specifications (GPS) -- Acceptance and reverification tests for coordinate measuring machines (CMM) -- Part 7: CMMs equipped with imaging probing systems.

5. KELEMEN, M. (2019) Experimental identification of sensitivity of tilt sensor. In: Technical Sciences and Technologies. Chernihiv National University of Technology, Vol. 18, No. 4 (2019), ISSN 2411-5363. p. 115-121.

6. CHUDÝ, V., PALENČÁR, R., KUREKOVÁ, E., HALAJ, M. (1999). Measurement of technical quantities (in Slovak). Edition of STU, 1st. ed., 1999. ISBN 80-227-1275-2

7. JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3). First edition September 2008. Available online: http://www.iso.org/sites/JCGM/GUM-JCGM100.htm; http://www.bipm.org/en/publications/guides/gum_print.html

8. WIMMER, G., PALENČÁR, R., WITKOVSKÝ, V. (2001). Stochastic models of measurement. (In Slovak) Graphic Studio Ing. Peter Juriga, L. Fullu 13, 841 05 Bratislava. 1st. ed., 2001. ISBN 80-968449-2-X.

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ВИМІРЮВАННЯ ЗМІЩЕННЯ З ВИКОРИСТАННЯМ ДАТЧИКІВ ХОЛЛА

Актуальність теми дослідження. *Існує кілька принципів вимірювання зміщення. Датчик на основі ефекту Холла є одним із них. Датчик Холла має кілька переваг і існує необхідність визначити відповідні принципи застосування.*

Постановка проблеми*. Вибрані датчики переміщення на основі ефекту Холла є недорогими, що є корисним для різних застосувань. Мета полягає у визначенні принципів та поведінки при використанні цих датчиків у різних режимах.*

Аналіз останніх досліджень і публікацій. *Датчики Холла працюють на ефекті, коли магнітна матриця впливає на вихідну напругу цих датчиків. Виникає проблема з визначенням відповідної конфігурації розташування цих датчиків. Це залежить від полярності й інтенсивності магнітного масиву. Крім того, важливим для цього застосування є розміщення датчика.*

Виділення недосліджених частин загальної проблеми. *Основна проблема полягає у вираженні характеристики перетворення, яка залежить від постійного магніту, використаного в якості джерела для магнітної матриці. Немає ніяких правил і рекомендацій із використання цих датчиків як датчика зміщення. Питання також у надійності цих датчиків і мінімальній кількості вимірювань для забезпечення мінімальної неточності вимірювань і стабільності вимірюваних даних. Вимірювання цими датчиками на великих відстанях не досліджені, тому наступне дослідження буде зосереджене на цих питаннях.*

Постановка завдання. *Метою є отримання корисного досвіду та рекомендацій щодо використання цих датчиків. Кілька датчиків також мають ефект гістерезису, що також є проблемою, і це паразитний ефект при вимірюваннях.*

Виклад основного матеріалу. *Досліджено ефект Холла за коефіцієнтом вихідної напруги. Отже, це аналогові датчики з реакцією напруги на зміщення.*

Висновки. *Вибрані досліджені датчики мають відмінні властивості для вимірювання зміщення. Вони потенційно підходять для дуже чутливого і точного вимірювання зміщення.*

Ключові слова: *ефект Холла; зміщення; вимірювання; магнітна решітка; датчики.*

Fig.: 10. References: 8.

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