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ESTIMATION OF UNCERTAINTY MEASUREMENT OF PARAMETERS OF THE EXTERNAL MAGNETIC FIELD OF TECHNICAL MEANS

A methodology for estimating the uncertainty of indirect measurements of the magnitude of the magnetic moment created by an external magnetic field of a technical device is proposed. Previously, to estimate the measured value, direct, multiple measurements of the useful signal were performed. The measurements were performed at eight points with different coordinates. An induction type sensor was used for the measurements. Direct measurements were also made of the distance from the geometric center of the magnetic field source under investigation to the sensor. Model equation is completed. The specification of measurements is made. An uncertainty budget for measuring the magnetic moment has been compiled. Found the total uncertainty of measuring the magnetic moment. Extended uncertainty found.

Keywords: *measurement uncertainty, indirect measurement, magnetic moment, induction sensor, uncertainty budget.*

Introduction

Problem statement. Magnetic measurements are widely used in many branches of engineering and science. The scope of their application is constantly expanding. An important place among magnetic measurements is taken by measuring the magnetic moment of a technical device – the source of a magnetic field. According to regulatory documents, the parameters that are subject to control for sources of an external magnetic field are the magnitudes of their magnetic moments. The magnetic moment ($\mathrm{M}, \mathrm{A} \cdot \mathrm{m}^2$) is a cumulative characteristic of the external magnetic field of a technical object. Through this parameter, you can determine the field strength at any point in space, the structure and spatial configuration of the magnetic field of a technical tool [1]. Magnetic moment measurements are in demand in the field of electric power industry, design, development and operation of electrical machines and apparatus, space research, navigation, military affairs, electromagnetic compatibility, etc. To solve a number of tasks in these areas of technology, there is a need to improve metrological assurance magnetic measurement. This includes analytical modeling of the field, development of more accuracy measurement methods, processing of results and their presentation through uncertainty parameters in accordance with international requirements.

The analysis of recent researches and publications. Works [2–3] give general recommendations for the estimation of uncertainty of indirect measurements, but there is no complete scientific methodology for estimating the uncertainty of the measurement of the magnetic moment.

In the work [4] it was shown that the application of point methods, which use inductive sensors as primary measuring transducers, greatly simplifies the implementation of measuring systems. This gives them the property of mobility, which allows the use of such devices for monitoring the level of the magnetic field in industrial conditions and on stationary magnetometric stands. The methodical errors are defined in the work, but there is no definition of uncertainty of measurements.

In [5–6], the character of the distribution of a magnetic field is studied. The necessity of improvement of metrological characteristics, applied measuring instruments is established. In [7], it was shown that the development of measurement systems of magnetic parameters is important for increasing the accuracy of the measurement. Alternative methods for measuring magnetic moment are proposed in [8], but there are certain limitations of the application of these methods for magnetic field sources of various sizes and non-rendered data on uncertainty of measurements.

The disadvantage of the model of the measuring system proposed in [9], on the basis of which the means of measuring magnetic quantities are developed, is the lack of estimation of uncertainty of measurements. In [10], the methodology for estimating the uncertainty of measurements of type A and type B is not detailed.

Thus, it is necessary to solve interconnected tasks for the creation of high-precision methods for measuring magnetic quantities, as well as developing a methodology for estimating the uncertainty of these measurements.

Purpose of the article. The purpose of the article is the development and improvement of metrological assurance of magnetic measurements. This includes developing:

– more accuracy methods for measuring the magnetic moment;

– development of a methodology for estimating the uncertainty of point measurement methods.

This will facilitate the comparison of measurement results and harmonization of regulations in the field of magnetic measurements at the international level.

Exposition of basic material

Method of measuring magnetic moment. The magnetic field of the source in the space, where the current density is zero and $\mathrm{rot}\overline{H} = 0$, can be described by scalar magnetic potential U. In this case, the vector of the intensity of the magnetic field $\overline{H} = -\mathrm{grad}\, U$. Magnetic potential U is the solution of the Laplace equation $\nabla^2 U = 0$ [4]. The components of the magnetic field strength are determined by differentiating the magnetic potential by the current coordinates. The magnetic potential of the field source can be described by a spherical harmonic Gaussian series (1) in the form of the sum of multipoles of the spatial harmonics of a dipole, quadrupole, octupole, etc. constituents:

$$U = \frac{1}{4\pi}\sum_{n=1}^{\infty}\frac{1}{R^{n+1}}\sum_{m=0}^{n}\left(g_{nm}\cos m\varphi + h_{nm}\sin m\varphi\right)\cdot$$

$$\cdot P_n^m(\cos\theta)\,, \qquad (1)$$

where R, φ, θ – spherical coordinates of the observation point;

g_{nm}, h_{nm} – coefficients of a series that determine the magnitudes of zonal, axial and sectoral harmonics of multipole magnetic moments, $[\mathrm{A}\cdot \mathrm{m}^{n+1}]$;

n – the ordinal number of the spatial harmonic of the magnetic field of the Gaussian series;

m – the ordinal number of the n-th harmonic elementary multipole;

$P_n^m(\cos\theta)$ – attached Legendre functions.

The components of the magnetic field strength are differentiated by the potential from the expression (1) by coordinates R, ϕ, θ. For example, the axial component:

$$H_\theta = -\frac{1}{R}\frac{\partial U}{\partial\theta} = -\frac{1}{4\pi}\sum_{n=1}^{\infty}\frac{1}{R^{n+2}}\cdot$$

$$\cdot\sum_{m=0}^{n}\left(g_{nm}\cos m\varphi + h_{nm}\sin m\varphi\right)\frac{\partial P_n^m(\cos\theta)}{\partial\theta}. \qquad (2)$$

The essence of the proposed method is as follows. It is proposed by the induction sensor at the points of the equatorial plane $\theta = 90^\circ$ with the value of the angular coordinates $\varphi_i = (2i-1)45^\circ$, $\varphi_k = (2k-9)45^\circ$, $i = 1...4,\ k = 5...8$ to measure of the useful signal E_i, mV, which induced by the magnetic field intensity (2). The resulting signal is equal to

$$E_z = \frac{8}{k_f R^3}g_{10} - \frac{4}{k_f}\sum_{n=5}^{\infty}\frac{1-(-1)^n}{R^{n+2}}\frac{(R_2/R_1)^{3-n}-1}{(R_2^2/R_1^2)-1}\cdot$$

$$\cdot\sum_{m=1}^{n} g_{nm}\cos m45^\circ \sin^3 m90^\circ \frac{\partial P_n^m(\theta = 90^\circ)}{\partial\theta}. \qquad (3)$$

From expression (3) it turns out that the measurable useful signal corresponding to the axial magnetic moment is determined by the expression:

$$E_z \approx E_{z1} = \frac{8 g_{10}}{k_f R^3}. \qquad (4)$$

From expression (4) it turns out that the axial magnetic moment of the source of the magnetic field is equal

$$M = g_{10} = \frac{E_z k_f R^3}{8}. \qquad (5)$$

Expression (5) is an equation for measuring the axial magnetic moment, that is, the model equation.

The estimation method of uncertainty of dots-methods of measurements of magnetic momentum. We define the standard and extended uncertainty of measuring the axial dipole magnetic moment. We will do this for the developed method – the method of eight points [4]. Preliminarily performed direct multiple measurements of the useful signal (U, mV) (tabl. 1) and distances (R, m) from the geometric center of the source of the external magnetic field to the primary transducer (tabl. 2).

Table 1

Results of direct repeated observations of the useful signal, mV

20,23	20,23	20,21	20,23	20,22	20,23	20,21	20,20
20,24	20,22	20,23	20,22	20,23	20,23	20,22	20,22
20,20	20,23	20,22	20,21	20,23	20,22	20,23	20,23

Table 2

Results of direct multiple observations of the distance
(the geometric center of the source of the external magnetic field to the primary measuring transducer), mm

250	249	250	250	251	250	250	250
250	250	250	250	250	250	250	250
249	251	250	250	250	250	250	250

Coarse errors and errors were excluded from the number of observations and corrections were made for known systematic effects.

1. We make the specification of measurements [2; 11]:

a) measurement conditions: normal laboratory;

b) analysis of technical characteristics.

A «UT 632» digital voltmeter is used to measure the useful signal.

To measure the distance (transducer), a 1000 mm measuring line is used (ДСТУ ГОСТ 427: 2009).

The primary measuring transducer is an inductive transducer (conversion factor $k_f = 6 \pm 10^{-3}$ A/mV);

c) make a model equation

$$M = 0.125 \cdot k_f \cdot R_{ind}^3 \cdot U_{ind} \,. \tag{6}$$

d) correlation: none of the input values is considered correlated with the others to any significant degree.

2. We define the arithmetic average of the results of repeated observations of the useful signal by the formula

$$\bar{U}_{ind} = \frac{1}{24}\sum_{i=1}^{24} \hat{U}_{ind\ i} = 20.22 \text{ mV}.$$

Determine the standard deviation of observations of the useful signal by the formula

$$s\left(\hat{U}_{ind}\right) = 0.01 \text{mV}$$

and standard uncertainty of evaluation of the measurement result of the useful signal by the formula

$$s(\bar{U}_{ind}) = \frac{0,01}{\sqrt{24}} = 0.002 \text{ mV}.$$

3. We define the arithmetic average of the results of repeated observations of the distance from the geometric center of the source of the external magnetic field to the primary measuring transducer

$$\bar{R}_{ind} = \frac{1}{24}\sum_{i=1}^{24} \hat{R}_{ind\ i} = 250 \text{mm}.$$

Determine the standard deviation of observations of the distance from the geometric center of the source of the external magnetic field to the primary measuring transducer

$$s(\hat{R}_{ind}) = 0.29 \text{ mm}$$

and standard uncertainty of measurement of the distance from the geometric center of the source of the external magnetic field to the primary measuring transducer

$$s(\bar{R}_{ind}) = \frac{0.29}{\sqrt{24}} = 0.059 \text{ mm}.$$

4. Find the standard uncertainties of the other estimates of the input values for type B.

Assuming that within the limits of error, the errors are uniform distributed, we find

$$u(k_f) = \frac{0,001}{\sqrt{3}} = 6 \cdot 10^{-4} \frac{A}{m \cdot V}.$$

5. We define the values of the sensitivity coefficients as partial derivatives of the model equation (6) with respect to the input values in accordance with the expression (7)

$$c_i = \frac{\partial f}{\partial x_i} = \left.\frac{\partial f}{\partial X_i}\right|_{x_1, x_2, \ldots x_m}; \tag{7}$$

$$c(\bar{U}_{ind}) = 0.125 \hat{k}_f \bar{R}^3 = 0.012 \frac{Am^2}{V};$$

$$c(\bar{R}_{ind}) = 0.375 \hat{k}_f \bar{U} \bar{R}^2 = 0.003 \text{Am};$$

$$c(\hat{k}_f) = \frac{1}{8}\bar{R}^3 \bar{V} = 3.9 \cdot 10^{-5} \text{ Vm}^3.$$

We draw up a budget of uncertainty (tabl. 3).

Table 3

The budget of the uncertainty of measuring the magnetic moment

Input value	Estimated input value	Standard uncertainty	Number of degrees of freedom	Distribution of the probability of the input value	Sensitivity coefficient	Contribution of uncertainty, $A \cdot m^2$
U_{ind}	20.22 mV	0,002 mV	23	Normal distribution	$0,012 \ \frac{Am^2}{V}$	$2,4 \cdot 10^{-7}$
R_{ind}	500 mm	0,18 mm	23	Normal distribution	0.003 Am	$5,4 \cdot 10^{-7}$
k_f	$6 \ \frac{A}{mV}$	$6 \cdot 10^{-4} \frac{A}{mV}$	∞	uniform distribution	$0.3 \cdot 10^{-4}$ Vm^3	$0.18 \cdot 10^{-7}$
M	$2.3 \cdot 10^{-4}$ $A \cdot m^2$	$1.97 \cdot 10^{-7}$ Am^2	–	–	–	–

6. Find the total uncertainty estimates of the axial magnetic moment. In view of the nonlinearity of the model, the total uncertainty is found taking into account the higher members of the Taylor series by the formula

$$u_c(M_z) = \left(\left(\sum_{i=1}^{3} c_i^2 u^2(x_i) + \sum_{i,j=1}^{3} \left(\frac{1}{2} \left(\frac{\partial^2 f}{\partial x_i \partial x_j} \right)^2 + \right. \right. \right.$$

$$\left. \left. \left. + \frac{\partial f}{\partial x_i} \frac{\partial^3 f}{\partial x_i \partial x_j^2} \right) u^2(x_i) u^2(x_j) \right)^2 \right)^{1/2} =$$

$$= \Big[c^2(\bar{V}_{ind}) u^2(\bar{V}_{ind}) + c^2(\bar{R}_{ind}) u^2(\bar{R}_{ind}) +$$

$$+ c^2(\hat{k}_f) u^2(\hat{k}_f) +$$

$$+ \frac{1}{2} \left(\left(\frac{\partial^2 M_z}{\partial V^2} \right)^2 + \left(\frac{\partial^2 M_z}{\partial R^2} \right)^2 + \left(\frac{\partial^2 M_z}{\partial k_f^2} \right)^2 + \ldots \right) \Big]^{1/2} =$$

$$= 1.97 \cdot 10^{-7}\ \mathrm{Am}^2.$$

7. Find an estimate of the measured value.

In view of the non-linearity of the model, the assessment of the measured value is made by the formula (8):

$$\bar{M} = \frac{1}{n} \sum_{k=1}^{n} f(U_{1,k}, R_{1,k}) =$$

$$= \frac{1}{24} \sum_{k=1}^{24} f(U_{1,k}, R_{1,k}) = 2.3 \cdot 10^{-4}\ \mathrm{A} \cdot \mathrm{m}^2. \qquad (8)$$

8. Calculate the coverage ratio as follows [12]:

$$k = t_{0,95}(\nu_{eff}).$$

Effective number of degrees of freedom

$$\nu_{eff} = \frac{u_c^4}{\sum_{i=1}^{m} \frac{u^4 (y_i)^4}{\nu_i}} =$$

$$= \frac{u_c^4}{\left(\frac{\left(u(\bar{U}) c(\bar{U})\right)^4}{\nu_i} + \frac{\left(u(\bar{R}) c(\bar{R})\right)^4}{\nu_i} \right) + \frac{\left(u(\hat{k}_f) c(\hat{k}_f)\right)^4}{\infty}} =$$

$$= \frac{\left(1,97 \cdot 10^{-7}\right)^4}{\left(u(\bar{U}) c(\bar{U})\right)^4 + \left(u(\bar{R}) c(\bar{R})\right)^4} \approx 23.$$

9. Find extended uncertainty

$$U = k\, u_c(\hat{M}) = t_{0,95}(23) \cdot 1.97 \cdot 10^{-7} =$$

$$= 2.07 \cdot 1.97 \cdot 10^{-7} = 4 \cdot 10^{-7}\ \mathrm{Am}^2.$$

10. Write the measurement result in the form

$$M = (0.230 \pm 0.001)\, \mathrm{mA} \cdot \mathrm{m}^2, \ p = 0.95.$$

Conclusion

1. A methodology for estimating the uncertainty of the eight-point method for measuring the axial dipole magnetic moment is proposed. The proposed approach can be applied in estimating the uncertainty of the existing and developed point methods for measuring the dipole magnetic moment.

2. The results obtained facilitate the comparison of measurement results and the harmonization of regulatory documents in the field of magnetic measurements at the international level.

3. The results of the work contribute to the introduction of the concept of uncertainty in the domestic metrological practice.

Список літератури

1. Лупиков В.С. Магнитный момент как функция параметров источника магнитного поля для различных видов электрооборудования [Текст] / В.С. Лупиков [и др.] // Вестник Нац. техн. ун-та "ХПИ": сб. науч. тр. Темат. вып.: Проблемы совершенствования электрических машин и аппаратов. – Харьков: НТУ "ХПИ", 2008. – № 25. – С. 67-80.

2. Захаров И.П. Оценивание неопределенности измерений: основные подходы, модели и алгоритмы [Текст] / И.П. Захаров, С.В. Водотыка // Системи обробки інформації. – 2009. – № 5(79). – С. 9-14.

3. Захаров И.П. Сравнительный анализ методов обработки экспериментальных данных при косвенных некоррелированных измерениях [Текст] / И.П. Захаров, С.Г. Рабинович // Системи обробки інформації. – 2011. – № 1(91). – С. 33-37.

4. Alrawashdeh R. Development of a method for measurements of the parameters of the external magnetic field of technical means [Text] / R. Alrawashdeh, O. Degtiarov // Technology audit and production reserves. – 2017. – No. 6/1 (38). – P. 59-65. https://doi.org/10.15587/2312-8372.2017.119330.

5. Distribution of magnetic field strength inside exciting coil of single sheet tester [Text] / R. Matsubara, Y. Takahashi, K. Fujiwara, Y. Ishihara, D. Azuma // AIP Advances. – 2018. – Vol. 8, No. 4. – P. 47209. https://doi.org/10.1063/1.4993997.

6. Research of the axial strong magnetic field applied at the initial period of inertial stretching stage of the shaped charge jet [Text] / B. Ma, Z. Huang, Z. Guan, X. Zu, X. Jia, Q. Xiao // International Journal of Impact Engineering. – 2018. – Vol. 113. – P. 54-60. https://doi.org/10.1016/j.ijimpeng.2017.11.002.

7. Charubin T. Measurement System for Magnetic Field Sensors Testing with Earth's Magnetic Field Compensation [Text] / T. Charubin, M. Nowicki, R. Szewczyk // Advances in Intelligent Systems and Computing. – Springer International Publishing, 2017. – P. 613-618. https://doi.org/10.1007/978-3-319-65960-2_76.

8. Amrani D. Determination of Magnetic Dipole Moment of Permanent Disc Magnet with Two Different Methods [Text] / D. Amrani // Physics Education. – 2015. – Vol. 31, No. 1. – P. 1-6.

9. Крюков М.А. Модель эксплуатации измерительной информационной системы с цифровой обработкой сигналов [Текст] / М.А. Крюков, И.В. Руженцев, А.В. Дегтярев // Радіоелектронні і комп'ютерні системи. – 2011. – № 1. – С. 97-102.

10. Бережной Д.А. Неопределенность метрологических характеристик измерительных каналов [Текст] / Д.А. Бережной, Н.К. Маловик, А.Н. Мирошниченко // Системи обробки інформації. – 2014. – № 3 (119). – С. 127-130.

11. Шайняк И.Р. Объединение информации при формировании оценки неопределенности измерений [Текст] / И.Р. Шайняк // Системи обробки інформації. – 2014. – № 3 (119). – С. 28-31.

12. Юров Л.В. Определение оптимального коэффициента охвата расширенной неопределенности при поверке средств измерений [Текст] / Л.В. Юров // Системи обробки інформації. – 2014. – № 3 (119). – С. 41-130.

References

1. Lupikov, V.S. (2008), "Magnitnyy moment kak funktsiya parametrov istochnika magnitnogo polya dlya razlichnykh vidov elektrooborudovaniya" [Magnetic moment as a function of the parameters of the source of the magnetic field for various types of electrical equipment], *Scientific Works of National Technical University "Kharkiv Polytechnic Institute"*, No. 25, pp. 67-80.

2. Zakharov, I.P. and Vodotyka, S.V. (2009), "Otsenivaniye neopredelennosti izmereniy: osnovnyye podkhody, modeli i algoritmy" [Estimation of measurement uncertainty: basic approaches, models and algorithms], *Information Processing Systems,* No. 5(79), pp. 9-14.

3. Zakharov, I.P. and Rabinovich, S.G. (2011), "Sravnitel'nyy analiz metodov obrabotki eksperimental'nykh dannykh pri kosvennykh nekorrelirovannykh izmereniyakh" [Comparative analysis of experimental data processing methods for indirect uncorrelated measurements], *Information Processing Systems,* No. 1(91), pp. 33-37.

4. Alrawashdeh, R. and Degtiarov, O. (2017), Development of a method for measurements of the parameters of the external magnetic field of technical means, *Technology audit and production reserves*, No. 6/1(38), pp. 59-65, https://doi.org/10.15587/2312-8372.2017.119330.

5. Matsubara, R., Takahashi, Y., Fujiwara, K., Ishihara, D. and Azuma, D. (2018), Distribution of magnetic field strength inside exciting coil of single sheet tester, *AIP Advances,* No. 4, Vol. 8, 47209 p. https://doi.org/10.1063/1.4993997.

6. Ma, B., Huang, Z., Guan, Z., Zu, X., Jia, X. and Xiao, Q. (2018), Research of the axial strong magnetic field applied at the initial period of inertial stretching stage of the shaped charge jet, *International Journal of Impact Engineering*, Vol. 113, pp. 54-60, https://doi.org/10.1016/j.ijimpeng.2017.11.002.

7. Charubin, T., Nowicki, M. and Szewczyk, R. (2017), Measurement System for Magnetic Field Sensors Testing with Earth's Magnetic Field Compensation, *Advances in Intelligent Systems and Computing*, Springer International Publishing, pp. 613-618, https://doi.org/10.1007/978-3-319-65960-2_76.

8. Amrani, D. (2015), Determination of Magnetic Dipole Moment of Permanent Disc Magnet with Two Different Methods, *Physics Education*, No. 1, Vol. 31, pp. 1-6.

9. Kryukov, M.A., Ruzhentsev, Y.V. and Dehtyarev, A.V. (2011), "Model ekspluatatsyy yzmerytelnoy ynformatsyonnoy systemy s tsyfrovoy obrabotkoy syhnalov" [Operating model of measuring information system with digital signal processing], *Radio electronic and computer systems*, No. 25, pp. 97-102.

10. Berezhnoy, D.A., Malovik, N.K. and Miroshnichenko, A.N. (2014), "Neopredelennost metrologicheskikh kharakteristik izmeritel'nykh kanalov" [Uncertainty of metrological characteristics of measuring channels], *Information Processing Systems*, No. 3(119), pp. 127-130.

11. Shaynyak, I.R. (2014), "Obyedineniye informatsii pri formirovanii otsenki neopredelennosti izmereniy" [Combining information in the formation of an assessment of measurement uncertainty], *Information Processing Systems*, No. 3(119), pp. 28-31.

12. Yurov, L.V. (2014), "Opredeleniye optimal'nogo koeffitsiyenta okhvata rasshirennoy neopredelennosti pri poverke sredstv izmereniy" [Determination of the optimal coverage ratio of the expanded uncertainty when calibrating measuring instruments], *Information Processing Systems*, No. 3(119), pp. 127-130.

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ОЦІНКА НЕВИЗНАЧЕНОСТІ ВИМІРЮВАНЬ ПАРАМЕТРІВ ЗОВНІШНЬОГО МАГНІТНОГО ПОЛЯ ТЕХНІЧНИХ ЗАСОБІВ

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Мета роботи – розвиток і вдосконалення метрологічного забезпечення магнітних вимірювань. Це включає в себе створення більш точних методів вимірювання магнітного моменту, створеного зовнішнім магнітним полем технічного засобу і розробку методології оцінювання невизначеності точкових методів вимірювань магнітного моменту. Запропоновано методологію оцінки невизначеності опосередкованих вимірювань величини магнітного моменту, створеного зовнішнім магнітним полем технічного засобу. Оцінка стандартної і розширеної невизначеності виконувалася для точкового методу вимірювання дипольного магнітного моменту, створеного зовнішнім магнітним полем технічного засобу. Даний метод вимірювання припускає використання в якості первинних вимірювальних перетворювачів індукційних датчиків. Датчик розташовується в восьми контрольних точках з заданими координатами. Попередньо, для оцінки вимірюваної величини були виконані прямі, багаторазові вимірювання корисного сигналу. Також були виконані прямі вимірювання відстані від геометричного центру досліджуваного джерела магнітного поля до датчика. З числа спостережень були виключені грубі похибки і промахи і внесені поправки на відомі систематичні ефекти. Складено модельне рівняння. Кореляція: жодна їх вхідних величин не розглядається корелятивною з іншими в який-небудь значній мірі. Складено бюджет невизначеності вимірювання магнітного моменту. Знайдено сумарну невизначеність оцінки магнітного моменту. З причини нелінійності моделі, сумарну невизначеність визначено з урахуванням вищих членів ряду Тейлора. Знайдено стандартну невизначеність опосередкованих вимірювань. Знайдена розширена невизначеність. Запропонований підхід може бути застосований при оцінці невизначеності існуючих і розроблюваних точкових методів вимірювання дипольного магнітного моменту. Отримані результати сприяють порівнянні результатів вимірювань і гармонізації нормативних документів в області магнітних вимірювань на міжнародному рівні. Результати роботи сприяють впровадженню концепції невизначеності в вітчизняну метрологічну практику.

Ключові слова: *невизначеність вимірювання, непрямі вимірювання, магнітний момент, індукційний датчик, бюджет невизначеності.*

ОЦЕНКА НЕОПРЕДЕЛЕННОСТИ ИЗМЕРЕНИЙ ПАРАМЕТРОВ ВНЕШНЕГО МАГНИТНОГО ПОЛЯ ТЕХНИЧЕСКИХ СРЕДСТВ

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Предложена методология оценки неопределенности косвенных измерений величины магнитного момента, созданного внешним магнитным полем технического средства. Предварительно, для оценки измеряемой величины были выполнены прямые, многократные измерения полезного сигнала. Измерения выполнены в восьми точках с разными координатами. Для измерений использован датчик индукционного типа. Также были выполнены прямые измерения расстояния от геометрического центра исследуемого источника магнитного поля до датчика. Составлено модельное уравнение. Составлена спецификация измерений. Составлен бюджет неопределенности измерения магнитного момента. Найдена суммарная неопределенность измерения магнитного момента. Найдена расширенная неопределенность.

Ключевые слова: *неопределенность измерения, косвенные измерения, магнитный момент, индукционный датчик, бюджет неопределенности.*