Phase noncontact method and procedure for measurement of axial displacement of electric machine's rotor

Hraniak, Valerii , Kukharchuk, Vasyl , Bogachuk, Volodymyr , Vedmitskyi, Yurii , Vishtak, Inna , et al.

Valerii F. Hraniak, Vasyl V. Kukharchuk, Volodymyr V. Bogachuk, Yurii G. Vedmitskyi, Inna V. Vishtak, Piotr Popiel, Gulzada Yerkeldessova, "Phase noncontact method and procedure for measurement of axial displacement of electric machine's rotor," Proc. SPIE 10808, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, 1080866 (1 October 2018); doi: 10.1117/12.2501611

Event: Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, 2018, Wilga, Poland

Phase noncontact method and procedure for measurement of axial displacement of electric machine's rotor

Valerii F. Hraniak*[a], Vasyl V. Kukharchuk[a], Volodymyr V. Bogachuk[a], Yurii G. Vedmitskyi[a], Inna V. Vishtak[a], Piotr Popiel[b], Gulzada Yerkeldessova[c]
[a]Vinnytsya National Technical University, 95 Khmelnytske shose, Vinnytsia, 21021, Ukraine; [b]Lublin University of Technology, Institute of Electronics and Information Technology, Nadbystrzycka 38D, 20-618 Lublin, Poland; [c]Kazakh University Ways of Communications, 050012, Republic of Kazakhstan, Almaty, Shevchenko st., 97

ABSTRACT

Proposed is a new noncontact method for measurement of axial displacement of electric machine's rotor in real-time mode and developed is the structural pattern of measurement procedure to implement this.

Keywords: measurement, axial displacement, electric machine, procedure for measurement, informative wave, phase difference

1. INTRODUCTION

Dynamic analysis of electric power machines' mechanical parameters in the technological process mode is the integral component of the advanced trend for raising the reliability and reducing the operating costs due to construction of up-to-date diagnosing systems. One of the most informative and widespread types of such diagnosing of rotating power machines is the vibration diagnosing [1, 2], the implementation of which in turn requires the availability of measuring transformers of a number of vibration parameters being able to display high-precision measuring information in real-time mode of the unit under test. One of such parameters that is widely used as an input signal is the vibration characteristic of axial displacement of electric machine's rotor, the metrological characteristics of the measurement procedure of which produce a direct impact on the operational efficiency of the entire diagnosing system.

That said, as shown in papers [1], one of the most informative parameters of the vibration signal is specifically the instantaneous vibration displacement, which however can not always be obtained without using the analytical methods of measured information processing. However, when measuring the rotor's axial displacement, attaching additional measuring devices to it is not technically justifiable, since this may cause increasing decentering of the latter. And therefore, the use of methods proposed in papers [2] is not advisable in this case. Hence, taking into account the specificities of the measured unit (MU), one can conclude that development of high-precision methods and noncontact procedures for measurement of instantaneous axial displacement of electric machine's rotor in real-time mode of a technological process is a relevant scientific-application task, the solution of which allows increasing the operational efficiency of the systems for diagnosing the electric power machines.

2. SETTING THE TASK

Eddy-current and capacitance primary measuring transformers became widely applied when measuring the instantaneous axial displacement of electric machine's rotor, such transducers allowing to measure the said parameter in the absence of immediate contact with rotor [3]. Nevertheless, a material weakness of these types of measuring transducers is the fact that they only allow measurements at relatively insignificant (about some millimeters) distances from the MU [3], which requires tight fixation of the sensor to structural elements in the immediate vicinity of the electric machine's moving parts (vibration source). In its turn, this inevitably causes a significant procedure error, since the methods envisaging the use of the said sensors do not take into account their own vibration displacement in relation to the reference point of the coordinate system.

**titanxp2000@ukr.net;*

Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, edited by Ryszard S. Romaniuk, Maciej Linczuk, Proc. of SPIE Vol. 10808, 1080866

doi: 10.1117/12.2501611

Therefore the output of the measurement devices based on the said types of primary measuring transducers is where a composite sound is formed, this being a vector sum of the rotor's axial displacement and the sensor's own vibration displacement, which can not be divided as a result of a random nature and nonstationarity of the vibration signal [2].

Removal of the sensor's fixation point from the vibration source may be an efficient way to reduce this error, since the oscillation amplitude is inversely proportional to the squared distance from the excitation source [1]. Nevertheless, as was mentioned above, such an approach can not be implemented when using eddy-current and capacitance sensors, this restricting their use when solving a stated technical task.

Another promising group of measurement methods, in terms of primary measuring transformation of axial vibration displacement, is represented by optical methods. Nonetheless, despite the theoretical opportunity of noncontact measurement of rotor displacement at quite long distances, the use of optical sensors also has a number of material restrictions associated with availability of noninformative influences on the optical signals on the part of both environment and the MU itself [4 - 7]. Such noninformative excitations may particularly include: change of attenuation coefficient, time-varying absorption coefficient of both ambient environment and the MU itself, MU's own heat radiation etc. [8]. Hence, in view of the foregoing, it is evident that development of new methods for axial displacement measurement, which would ensure the possibility to measure the latter at sufficient distances between the sensor and the MU, and which would be low-sensitive to the influence of noninformative disturbing factors is a relevant task.

3. ANALYSIS OF TASK SOLUTION WAYS

The main problem that requires solution when using optical methods for measurement of axial vibration displacement, as was said before, is the availability of a considerable influence of noninformative influencing values on the informative signal. In view of this, and of the random nature of the disturbing influence, it is evident that the amplitude of the informative signal at the input of the receiver in such a system can not have a stable value. And hence, the use of the latter as an informative parameter in an intermediate measuring transformation is inadvisable. Nevertheless, based on the physical properties of air [9 - 11], which will apparently be present between the radiator, the MU and the receiver, its coefficients of relative dielectric and magnetic permeabilities are only slightly variable in typical conditions of operation of electric power equipment. Hence one can conclude that phase speed of the informative signal in such a system will have quite a high stability. This explains the advisability of using particularly the phase displacement of informative wave as an intermediate informative parameter.

Significant problems to arise when developing the measurement procedure implementing the intermediate measuring transformation of rotor's axial displacement into displacement of the informative signal's phase is the availability of a significant phase-amplitude error determined by instability of signal amplitude at the input of the receiver and a love sensitivity of the device, which is determined by relatively low permissible axial displacements of electric machine's rotor (some hundred micrometers, which corresponds to the length of an electromagnetic wave with the frequency of hundred gigahertz) [2]. Hence, phase noncontact method for measurement of axial displacement of electric machine's rotor must include both the algorithm for phase-amplitude error compensation and the new method for measuring the phase difference to ensure an improved sensitivity at high frequencies of informative signal. Summarizing the foregoing, the algorithm for implementation of phase noncontact method for measurement of axial displacement of electric machine's rotor will be as shown in the flow chart (Fig. 1) [3,12,13].

The problem of phase-amplitude error compensation may be solved by ensuring a variable coefficient of informative signal magnification at the input of the receiver, thus making it possible to ensure its stabilization regardless of external disturbing factors. Given that the reason for occurrence of phase-amplitude error lies in the amplitude difference between the informative and the reference channels, as well as the fact that under certain conditions external disturbances may cause change in the amplitude of the reference signal (albeit within a lower range of values), it is advisable to use the reference signal amplitude as the stabilization criterion. Under such approach, it would be advisable, at the output of the receiver to install a linear amplifier with a regulated magnification coefficient, the value of which to be adjusted in real-time mode on account of the feedback signal being the difference between the amplitude of informative and reference signals [14 - 17].

For the purpose to reduce the strength of the radiated signal, it would be admissible to apply onto a pre-treated surface of the rotor shaft's nose protrusion, the axial displacement of which will correspond to the axial displacement of the entire electric machine's rotor due to a high stiffness of the material, a special coating that improves the reflecting properties of the radiating surface without causing the increasing decentering of the rotor shaft due to an insignificant additional weight of the coating itself. The intermediate transformation of axial displacement into the phase difference with stabilization of the informative wave's amplitude may be implemented using the proposed flow chart shown in fig. 2.

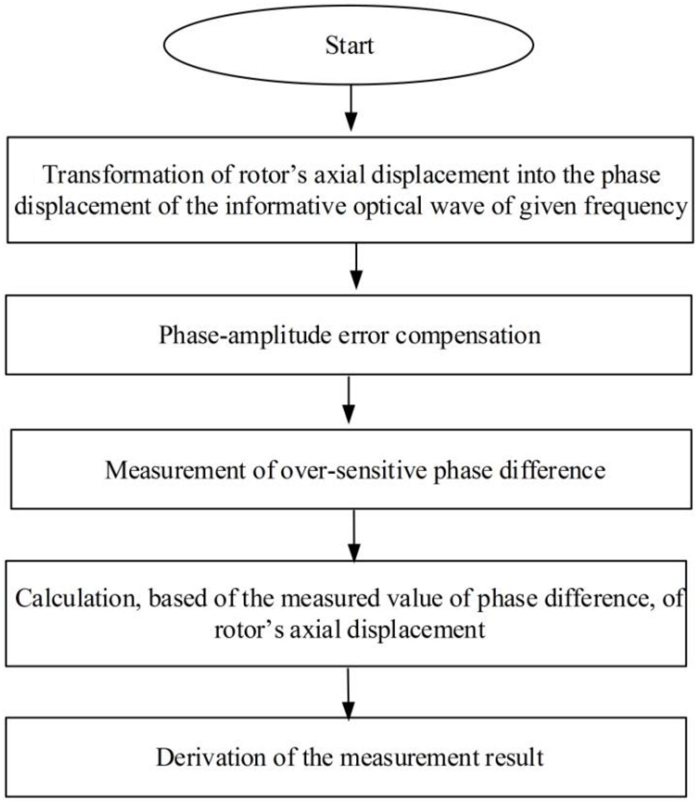

Fig. 1. Flow chart for implementation of phase noncontact method for measurement of axial displacement of electric machine's rotor

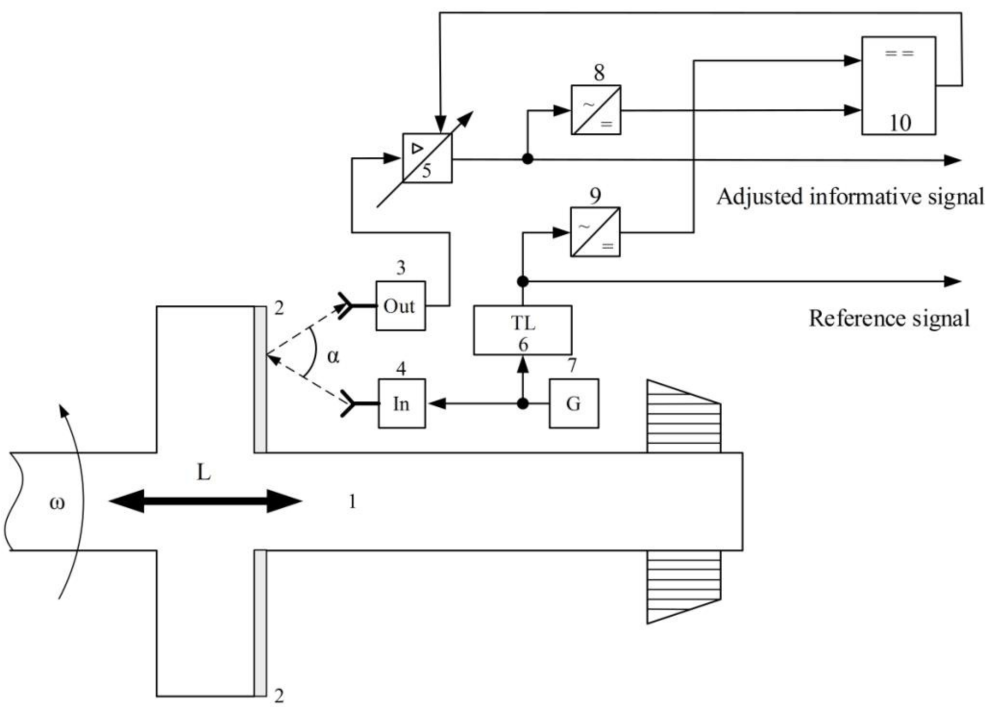

Fig. 2. Flow chart of the system for stabilization of signal amplitude at the output of the receiver

The specificity of operation under the flow chart shown in fig. 2 lies in the fact that the signal of given frequency is sent from generator 7 to the input of radiator 4. At the output of radiator 4, directed radiation is formed from wave generator 7 towards the nose protrusion of rotor 1 shaft, to which the reflecting coating 2 is applied. Having reached the reflecting coating 2, the wave that was radiated by radiator 4 is reflected towards receiver 3 [18 - 21]. Depending on the value and the symbol of axial displacement of the nose protrusion of rotor 1 shaft, the distance between it and radiator 4, and receiver 3 changes. In this case, the fundamental relationship between the increment of the initial phase angle during the electromagnetic wave's spatial movement will be true for the informative signal:

$$\Delta\varphi = \frac{360 \cdot \Delta L}{\lambda}, \tag{1}$$

where $\Delta\varphi$ and ΔL – are, respectively, the increment of the initial phase angle and the increment of the linear coordinate in the direction of wave propagation; λ – the length of the electromagnetic wave that is associated with its frequency in the following interrelation:

$$\lambda = \frac{c}{f}, \tag{2}$$

where f – the informative signal frequency; c – the speed of optical signal propagation in the air (vacuum).

Taking into account (1) and (2), as well as the geometry of wave propagation from radiator 4 to receiver 3, the signal at receiver 3 input will have an additional phase displacement (in degrees), the value of which depends on the axial displacement of the nose protrusion of rotor 1 shaft according to the following transformation equation:

$$\varphi = \frac{2 \cdot 360 \cdot L \cdot f}{c \cdot cos(\frac{\alpha}{2})}, \tag{3}$$

where L – the axial displacement; α – the angle between the incident and the reflected waves, which in case of high-quality pre-treatment of the rotor shaft's nose protrusion remains unchanged.

From receiver 3 output, the accepted signal is transmitted to the input of constant multiplier 5, where stabilization of its amplitude takes place, which is due to comparison of signals from the output of the first 8 and the second 9 rectifiers, which is implemented by the comparator with analog output 10, at which output adjustment signals are formed, which are proportionate to the amplitude difference between signals from outputs of the first 8 and the second 9 rectifiers. The coefficient of proportionality of constant multiplier 5 does functionally depend on the adjustment signal value, due to which the amplitude of signal at its output equalizes with the reference signal amplitude.

The problem of low sensitivity, which restricts the application of phase methods for implementation of task of axial displacement measurement, may be solved by using a special method for phase difference measurement, which, in contrast to the classical approach, does not provide for the intermediate transformation of phase difference into time interval. This allows using the signal of increased frequency as an informative signal without causing any reduction in precision of phase difference channel and thus ensuring the displacement of the informative wave frequency to the area, where the intensity of the MU's own radiation is quite weak.

Taking into account the desired characteristics of phase difference channel, measurement of the latter may be by obtaining the intermediate vector values associated with the informative and the reference signals. When using sinusoidal waves, the reference and the informative signals will be described by a harmonic function, having an equal amplitude at the output of the chart shown in fig. 2. By connecting the time reference system with the reference signal, these can be mathematically shown as follows:

$$\begin{aligned} U_1(t) &= U_m sin(\omega t), \\ U_2(t) &= U_m sin(\omega t + \varphi). \end{aligned} \tag{4}$$

Such being the case, the amplitude of their vector sum will equal to:

$$U_{sum} = 2U_m cos(\frac{\varphi}{2}), \tag{5}$$

with the amplitude of vector difference between the informative and the reference signals equaling to:

$$U_{dif} = 2U_m sin(\frac{\varphi}{2}). \tag{6}$$

Functional dependencies of (5) and (6) ensure transformation of the difference into the associated level of constant voltage, and taking into account the specificity of the sinusoid, the direct measurement of U_{sum} and U_{dif} signals with further calculation of φ will be accompanied by reduction in sensitivity of the measurement procedure with the increase in amplitude of axial displacement, which is unjustified in technical terms. Hence, it would be more advisable to use another value being dependent on phase difference φ as the intermediate signal.

Having divided (6) by (5), we obtain:

$$\frac{U_{dif}}{U_{sum}} = tg(\frac{\varphi}{2}). \qquad (7)$$

In contrast to cos and sin function, tg function is characterized by increasing sensitivity in case of approaching to limit values of the increment range, thus allowing to improve the precision of measurement with the increase in axial displacement, and hence, ensuring, when required, increased precision of axial displacement measurement when approaching to the upper permissible value. Taking into account (7), the transformation equation of phase difference channel when using the proposed approach will be as follows:

$$\varphi = 2arctg(\frac{U_{dif}}{U_{sum}}). \qquad (7a)$$

Based on the foregoing, one can formulate the new method of phase difference measurement, which does not envisage any intermediate transformation of the latter into time interval. The algorithm for implementation of proposed method is shown in fig. 3 in the form of a flow chart.

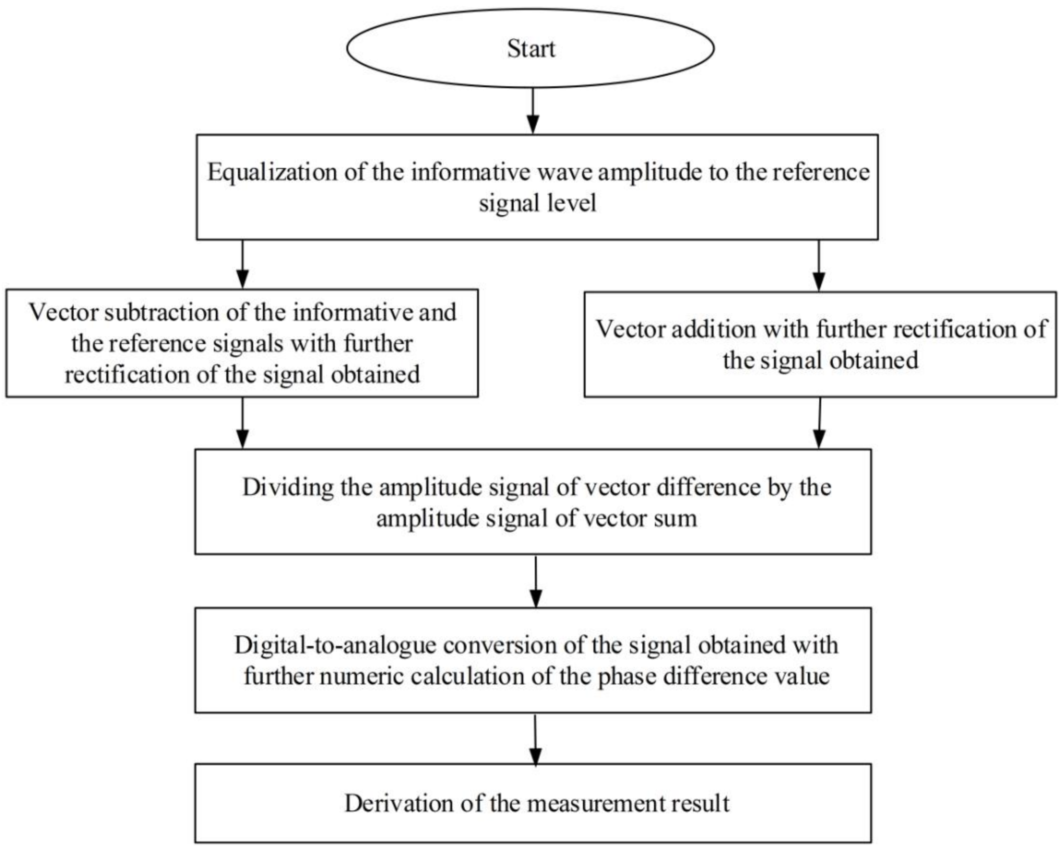

Fig. 3. Flow chart for implementation of proposed method for measurement of phase difference

The flow chart of the measurement procedure, which implements phase noncontact method for measurement of axial displacement of electric machine's rotor may be as shown in fig. 4. In the flow chart shown in fig. 4, one can locate, along with the intermediate transformation of axial displacement and stabilization of the informative signal amplitude, the amplitude of the vector sum and the vector difference between the informative and the reference signals in the blocks of vector subtraction 12 and vector addition 13.

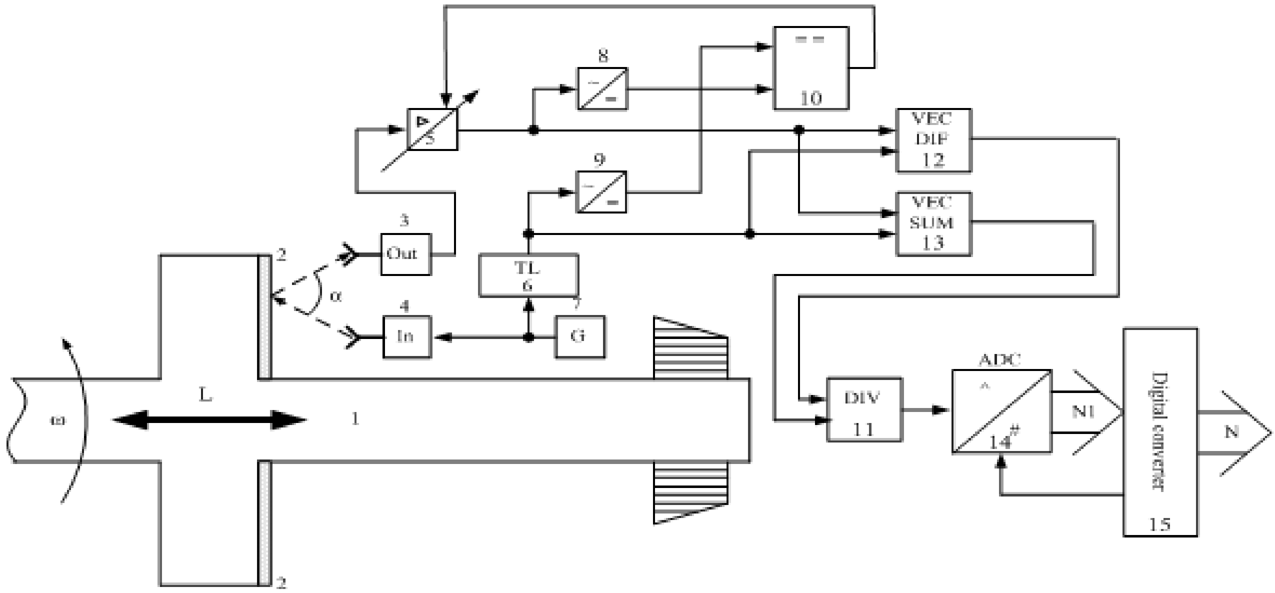

Fig.4. Flow chart of the measurement procedure that implements phase noncontact method for axial displacement of electric machines' rotor

After that, the signals obtained arrive at the division block 11 with the result that its output forms an analogous voltage level proportional to arc tangent of phase difference between the informative and the reference signals. The obtained voltage value will be digitized and arrives at the input of numeric transducer 15, where the final computation of the instantaneous axial displacement of electric machine's rotor takes place according to the transformation equation of proposed measurement procedure:

$$L = \frac{c \cdot cos(\frac{\alpha}{2}) arctg(\frac{U_{dif}}{U_{sum}})}{360 \cdot f}. \tag{8}$$

That said, given that tg function is periodic, with 180-degree period, the frequency of the informative signal, which is advisable to be used in the device proposed in fig. 4, may be calculated using the following interrelation:

$$f \le \frac{c}{2L_{max} + \Delta L}, \tag{9}$$

where L_{max} – the rotor's maximum axial deviation that may be measured by the measurement device; ΔL – the displacement assurance coefficient that renders the transition of the informative wave's phase displacement through the period of tg function within the measurement range impossible.

4. CONCLUSIONS

1. Proposed is the new method for measurement of phase difference of wave-form signals, which due to the absence of intermediate transformation of phase difference into the time interval is characterized by a hypersensitivity in the course of measuring the phase difference of high-frequency signals.
2. Proposed is the new phase noncontact method for measurement of the axial displacement of electric machine's rotor, which due to the use of an optical informative way and the use of the new method for measurement of the phase difference of wave-form signals, which does not envisage any intermediate transformation of the latter into the time interval, allows ensuring a high precision and sensitivity of measurement.
3. Developed is the structural pattern of the new procedure for measurement of the axial displacement of electric machine's rotor, which, due to implementing the phase noncontact method for measurement of the axial displacement of electric machine's rotor, is characterized by noncontact measurement ensuring a higher precision of measurements thanks to reduction of the procedure error conditioned by the sensor's own vibration.

REFERENCES

[1] Shirman, A.R. and Solovyov, A.B., [Practical vibration diagnostics and monitoring of the state of mechanical equipment], Mashinostroenie, Kyiv, (1996).

[2] Lavendel, E.E., [Vibrations in machinery: reference book. In 6 volumes. V. 4. Vibration processes and machines], Mashinostroenie, Moscow (1981).

[3] Babak, V.P., Beregun, V.S., Burova, Z.A. and others, [Hardware and software support for monitoring the facilities of heat power generation, transportation and consumption], Institute of Technical Thermophysics under the NAS of Ukraine, Kyiv, (2016).

[4] Wójcik, W. and Smolarz, A., [Information Technology in Medical Diagnostics], Taylor &Francis Group CRC Press Reference, London, (2017).

[5] Kotyra, A. and Tanaś, J. "Comparison of optical flow algorithms performance on flame image sequences," Proc. SPIE 10445, 1-8 (2017).

[6] Surtel, W., Maciejewski, M. and Cieślar, M., "Model aplikacji na urządzenia mobilne z systemem operacyjnym android do zastosowań w monitoringu środowiskowym pacjenta," Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska 4, 38-40 (2013).

[7] Hotra, O., Boyko, O., Zyska, T., "Improvement of the operation rate of medical temperature measuring devices," Optical Sensors and Electronic Sensors 9291, (2014).

[8] Andreev, A.N., Gavrilov, Ye.V., Ishanin, G.G. and others, [Optical measurements: training aid, Universitetskaya kniga], Moscow, (2012).

[9] Kleschonok, V. V., Luk'yanyk, I.V., Churyumov, K.I. and Ponomarenko, V.A., "Physical parameters of neutral component of coma of comet 103p/Hartley 2, " Kinematics and Physics of Celestial Bodies 31(5), 237-244 (2015).

[10] Poplavko, Yu.M. [Physics of dielectrics], National Academy of Sciences of Ukraine– Kyiv, NTUU "KPI", Kyiv, (2015).

[11] Chepurna, O., Shton, I., Kholin, V., Voytsehovich, V., Popov, V., Pavlov, S., Gamaleia, N., Wójcik, W. and Zhassandykyzy. M., "Photodynamic therapy with laser scanning mode of tumor irradiation, " Proc. SPIE 9816, 1-5 (2015).

[12] Vassilenko, V., Valtchev, S., Teixeira, J.P. and Pavlov, S., "Energy harvesting: an interesting topic for education programs in engineering specialities," Internet, Education, Science 10, 149-156 (2016).

[13] Azarov, O.D., Troianovska, T. I., Savytska, L.A., Savchuk, T., Nykyforova, L.E, Otryshko, V., Suleimenov, B., Gromaszek, K., Kozbekova, A. and Sagymbekova, A., "Quality of content delivery in computer specialists training system, " Proc. SPIE 10445, 1-9 (2017).

[14] Gotra, Z., Golyaka, R., Pavlov, S. and Kulenko, S., "High resolution differential thermometer," Technology and Design in Electronic Apparatuses 6, 19-23 (2009).

[15] Osadchuk, A., Osadchuk, I., Smolarz, A. and Kussambayeva, N., "Pressure transducer of the on the basis of reactive properties of transistor structure with negative resistance, " Proc. SPIE 9816, 1-7 (2015).

[16] Osadchuk, O., Osadchuk, V. and Osadchuk, I., "The generator of superhigh frequencies on the basis silicon germanium heterojunction bipolar transistors," Modern Problems of Radio Engineering. Telecommunications and Computer Science (TCSET) 2, 336 – 338 (2016).

[17] Semenov, A.O., Osadchuk, V., Osadchuk, I., Koval, K. and Prytula, M., "The chaos oscillator with inertial non-linearity based on a transistor structure with negative resistance, " Proceedings of the International Conference Micro/Nanotechnologies and Electron Devices (EDM)7, 178-184 (2016).

[18] Azarov, O.D., Krupelnitskyi, L.V., Komada, P., Ławicki, T., Askarova, N. and Sagymbekova, A., "AD systems for processing of low frequency signals based on self calibrate ADC and DAC with weight redundancy," Przeglad Elektrotechniczny 5(93), 125-128 (2017).

[19] Azarov, O.D., Dudnyk, O., Kaduk, O.V., Smolarz A. and Burlibay, A., "Method of correcting of the tracking ADC with weight redundancy conversion characteristic," Proc. SPIE 9816, 1-8 (2015).

[20] Azarov, O.D., Murashchenko, O.G., Chernyak, O.I., Smolarz, A. and Kashaganova, G., "Method of glitch reduction in DAC with weight redundancy", Proc. SPIE 9816, 98161, 1-9 (2015).

[21] Osadchuk, A.V. and Osadchuk, I.A., "Frequency transducer of the pressure on the basis of reactive properties of transistor structure with negative resistance," Control and Communications (SIBCON) 5, 1-3 (2015).