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Development of the Algorithm for Definition of Residual Service Life by a Comprehensive Diagnosis of the Electromechanical Drive

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Abstract: The algorithm for determining the residual service life of the stand, which consists of an asynchronous motor, clutch and worm gear, is developed. As a comprehensive approach the analysis of mechanical and electrical drive diagnostic parameters is considered. The change in vibration speed and spectral coefficients of the wavelet analysis of the stator electric current is investigated under load in the presence and absence of defects. The equation is received to determine the residual service life.

Keywords: Diagnostics, electromechanical drive, worm gear, vibration, electric current, wavelet analysis.

1. Introduction

With increasing of automation in modern production requirements for reliability are rising up. To avoid emergency stop of automated processing equipment, it is necessary to carry out the diagnosis and to predict the unit accidents, which may occur during operation. Thus, an equipment diagnosis is becoming the most promising and fastest growing aspect of modern production and the definition of residual life – is the basis for the most cost-effective functioning of components and machines.

In [1–12] questions of diagnostics for electric motors and processing equipment are considered. Also the attention is paid to find a residual service life by means of fuzzy logic [1,3].

In [5-7] mechanical and electric diagnostic parameters for definition of technical condition of the electromechanical drive were investigated. Changes of a range of vibration speed and coefficients of wavelet-transformation of electric current of the stator are revealed at absence and existence of various defects.

2. Experimental Section

Experimental research was conducted at the stand consisting of the asynchronous motor, the coupling and the worm reducer. For definition of a residual service life a number of experiments was carried out. It is revealed that such kind of malfunction as lack of greasing in a gear can lead to emergence of a certain defects of

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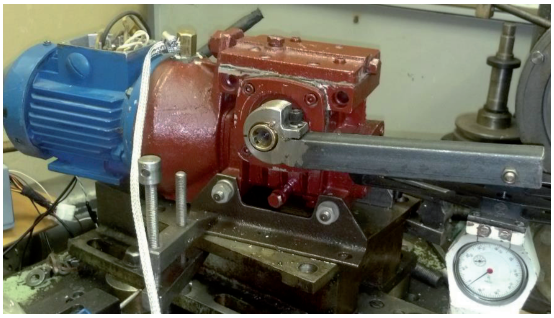

Fig. 1: *The laboratory stand.*

a tooth gearing. Therefore, at the laboratory stand emulation of such type of malfunction was carried out. The photo of the stand is given in fig. 1.

The vibrator inverter AP2019 (fastening on the coupling using a magnet) and current sensors LEM LA-55P (installation on 3 phases of the asynchronous motor's stator) were used.

All data were recorded in a mode with load of worm-and-wheel reduction unit (M = 32 Nm).

Electric motor power P = 0,18 kW. Rotation speed N = 1350 rpm. Worm gear is МЧ-40М-31,5-47,6-51-5-1С-У3. The oscillograph Tektronix TDS3014 was used to record signals and process them in MathCAD and MathLAB software.

Data collection parameters: the number of samples N = 10000, reading data time t = 2 s, the period dt = 0.0002 s, sampling frequency υ = 5000 Hz.

As basic data parameters of the serviceable drive are received. The oscillogram of vibration acceleration and a range of vibration speed of completely serviceable electromechanical drive under loading are given in fig. 2 and 3. The general level of vibration, equal 448,31 mm /c^2 is recorded. The received wavelet transformation coefficients for the first phase of the stator for the serviceable drive are given in fig. 4. In the analysis Daubechies wavelets (db-8) were used. For the analysis of the motor current a table 1 was correspond to the coefficients of the wavelet transform bands of the spectrum of the motor current.

Further the grease was removed from a reducer and measurements were repeated in every 3 hours. The results of measurements after 24 hours of stand functioning are given in fig. 5-7. The general level of vibration, equal 1144 mm/s^2 is recorded. The increase in average mean-square deviation of wavelet-coefficient of d5 from 0,11 up to 0,13 is traced.

Table 1: *Frequency Bands of the stator current with wavelet transform.*

Value dt (s)	Specification	Sub-band (Hz)
0,0002	D1	2500…5000
	D2	1250…2500
	D3	625…1250
	D4	312,5…625
	D5	156,3…312,5
	D6	78,1…156,3
	D7	39…78,1
	D8	19,5…39

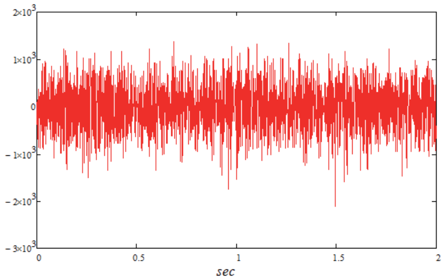

Fig. 2: *The oscillogram of vibration acceleration (mm/s^2) for serviceable stand.*

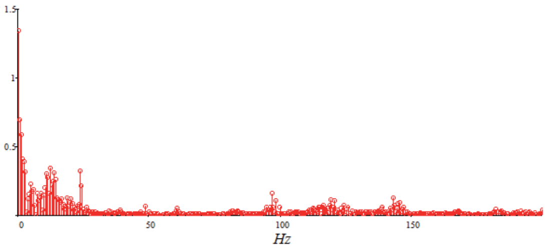

Fig. 3: *The spectrum of vibration speed (mm/s) for serviceable stand.*

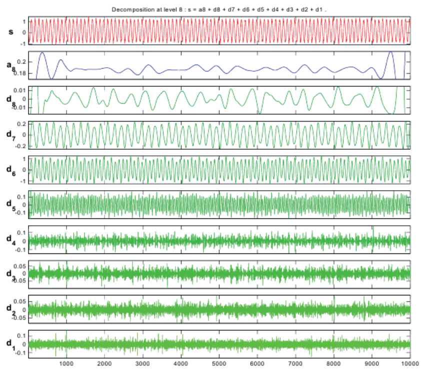

Fig. 4: *The electric current of the first phase of the serviceable motor stator and its wavelet transform.*

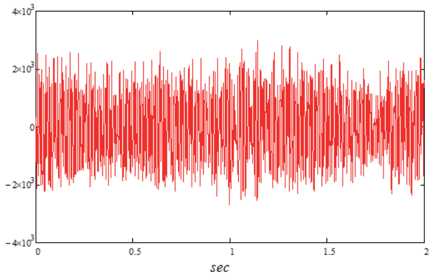

Fig. 5: *The oscillogram of vibration acceleration (mm/s²) after 24 hours.*

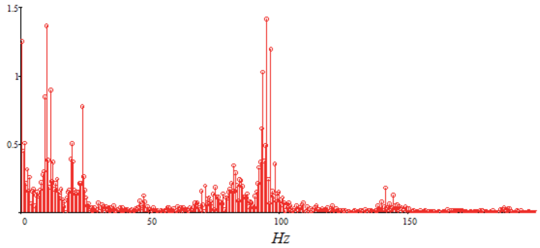

Fig. 6: *The spectrum of vibration speed (mm/s) after 24 hours.*

On the spectrum of vibration speed the rise of amplitude at a tooth frequency of a reducer (90 Hz) up to 1,5 mm/s and also emergence of a set of side harmonicas are observed. This fact shows the obvious presence of defect of a tooth gearing.

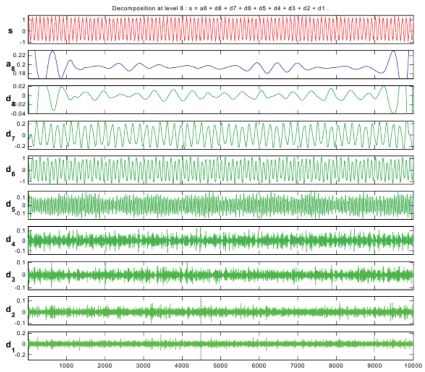

Fig. 7: *The electric current of the first phase of the motor stator and its wavelet transform after 24 hours.*

Further experiments for determination of the maximum value of the general level of vibration and coefficient d_5 were made (since it was more sensitive to such kind of defect). The received results: v_{max} = 2430 mm/s; d_{5max} = 0,18.

By linear approximation the diagram of change for the general level of vibration during an operation of the stand (the trend) in the conditions of grease lack in a reducer (fig. 8) is received.

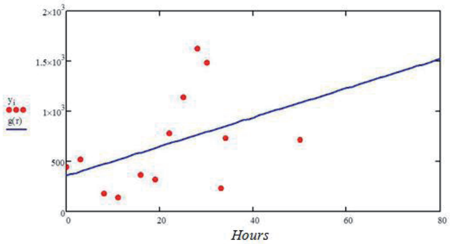

Fig. 8: *The trend of vibration of the stand (mm/s²) with grease lack in a reducer within 50 hours.*

The diagram of change for the wavelet-coefficient d_5 (fig. 9) is similarly received.

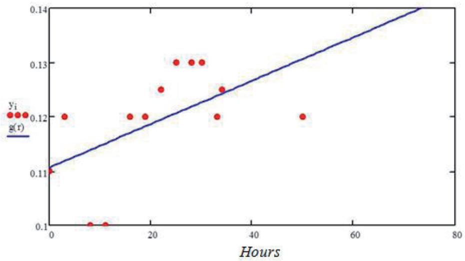

Fig. 9: *The trend of wavelet-coefficient d_5 with grease lack in a reducer within 50 hours.*

Further, the equations for approximation of experimental data were received:

$$v = 14,57t + 356,543; \quad d_5 = 0,0004t + 0,111 \qquad (1)$$

Now, by substituting in expression (1) of maximum values v_{max} and d_{5max}, it is possible to define a residual life for operation of the stand in the current mode (2).

$$t = \frac{v - d_5 - 356,432}{14,57} \qquad (2)$$

At continuous monitoring of the equipment it is necessary to recalculate the received values and plot the graphs with a certain period. It will lead to the greatest accuracy in determination of a residual life.

At real operation of the equipment where various modes of loading take place, use of criterion of Bailey is quite possible.

3. Conclusions

In this work the algorithm for definition of residual service life is developed. Mechanical and electric diagnostic parameters of the electromechanical drive were considered. It is shown that change of a spectrum of vibration speed and coefficients of the wavelet-analysis of electric current of the stator is directly connected with existence or lack of defects.

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5. References and Notes

[1] Abramov, I., Nikitin, Y., Zorina, O., Božek, P., Stepanov, P., Stollmann, V. (2014). Monitoring of technical condition of motors and bearings of woodworking equipment. Acta Facultatis Xylologiae, vol. 56(2), pp. 97-104.

[2] Abramov, I., Nikitin, Yu., Abramov, A., Sosnovich, E., Božek, P., Stollmann, V. (2014). Diagnosis of rolling mill line gearmotors. Proc. of International Conference on Innovative Technologies, IN-TECH 2014. Leiria, Portugal, pp. 155-158, Sep. 10-13.

[3] Abramov, I. V., Nikitin, Yu. R., Abramov, A. I., Sosnovich, E. V., Božek, P. (2014). Control and diagnostic model of brushless DC motor. Journal of Electrical Engineering, vol. 65, no. 5, pp. 277- 282.

[4] Hammer, M., Šimková, M., Ministr, M. (2010). Artificial Intelligence in Diagnostics of Electric Machines. In Recent Advances in Mechatronics, Springer, Berlin Heidelberg, pp. 139-144.

[5] Stepanov P., Nikitin Yu. (2014). Diagnostics of Mechatronic Systems on the Basis of Neural Networks with High-Performance Data Collection. Mechatronics 2013: Recent Technological and Scientific Advances, pp. 433-440. Brno, Czech Republic, Springer Intrenational Publishing Switzerland.

[6] Stepanov P., Lagutkin S. (2014). Research of Electric and Mechanical Diagnostic Parameters of Drive Equipment. Applied Mechanics and Materials, vol. 683, pp. 177-281. Trans Tech Publications, Switzerland.

[7] Stepanov P., Lagutkin S., Božek P., Nikitin Yu. (2014). Comprehensive approach to technical conditions of electromechanical units in mechatronic systems. American Journal of Mechanical Engineering, vol. 2, No. 7, pp. 278-281.

[8] Cowan, R.S., Winer, W.O. (2013). Handbook of Technical Diagnostics: Fundamentals and Application to Structures and Systems. Machinery Diagnostics, pp. 387–410. Springer Berlin Heidelberg.

[9] Dovban', S.N., Veselov, O.V. (2012). Technical diagnostics of electromechanical systems based on the analysis of distorted output signal. Automation and Remote Control, vol. 73, Issue 11, pp. 1902–1909. November 2012.

[10] Hetmanczyk, M.P., Swider, J.A. (2014). Selected vibrational symptoms in transient states of AC drives. International Journal of Dynamics and Control, Feb. 2014. [Online] Available: http://link.springer.com/article/10.1007/s40435-014-0062-0/fulltext.html [Accessed Dec. 2, 2014].

[11] Virgala, I., Frankovský, P., Kenderová, M. (2013). Friction Effect Analysis of a DC Motor. In: American Journal of Mechanical Engineering. Vol. 1, no. 1 (2013), p. 1-5. ISSN 2328-4102.

[12] Lee, Y.S., Kim, Y.W. (2007). Condition monitoring of induction motors for vertical pumps with the current and vibration signature analysis. Experimental analysis of nano and engineering materials and structures, pp. 419-420. Springer, Dordrecht.

[13] Virgala, I., Frankovský, P., Kenderova, M. (2013). Friction Effect Analysis of a DC Motor. In: American Journal of Mechanical Engineering, 1(1), 1-5.

[14] Živčak, J., Kelemenová, T., Kelemen, M., Maxim, V.: Model-based approach to development of engineering. In: Acta Mechanica Slovaca. Roč. 17, č. 3 (2013), s. 56-62. - ISSN 1335-2393

[15] Kuryło P.: The study of residual stresses in the surface layer. In: Acta Mechanica Slovaca. 2013, Vol. 17, no. 4, s. 6-15

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