Middle East Research Journal of Engineering and Technology
ISSN: 2789-7737 (Print) ISSN: 2958-2059 (Online)
Frequency: Bi-Monthly
DOI: https://doi.org/10.36348/merjet.2026.v06i03.003

KUWAIT SCHOLARS PUBLISHER
Website: http://www.kspublisher.com/
Email: office@kspublisher.com

Determination of Diagnosed Parameters of Electromechanical Systems

Sergey V. Derkachev[1]*, Vladimir A. Sidorov[2]
[1]Ph.D. (Engineering Sciences), Head of the Youth Research Laboratory "Instrument Engineering and Machine Tool Building", Donetsk National Technical University
[2]D.Sc. (Engineering Sciences), Professor, Department of Mechanical Equipment for Ferrous Metallurgy Plants, Donetsk National Technical University

Abstract: Induction motors are widely used as drives for electromechanical systems in metallurgical complexes operating under high load conditions in a continuous technological process. The failure of one of the units often leads to a shutdown of the entire production and is accompanied by significant losses. The most common method for diagnosing the actual condition of such systems is threshold protection based on exceeding specified values of a single parameter, most often vibration velocity. However, practical research shows that developing defects may not affect the vibration level for a long time, and then, within a few hours, lead to sudden failure. An analysis of the literature allows us to conclude that, despite the many existing diagnostic methods based on a single parameter (vibration, stator current, temperature), there is no unified methodology that substantiates a minimally sufficient set of diagnostic parameters with a limited number of sensors and considers the physics of damage development. The purpose of this work is to substantiate the minimum necessary set of monitored diagnostic parameters based on damage development models of electromechanical systems, ensuring defect identification 14 days before complete failure. The practical value of the proposed approach lies in the ability to detect degradation processes early using standard measuring instruments without significantly increasing costs. This goal is achieved based on 5-year monitoring data of an industrial 1000 kW induced draft fan. An additional set of thermodynamic and tribological parameters (bearing heating time constant, Hersey–Stribeck parameter) is proposed, which makes it possible to detect signs of degradation 21 days before failure, whereas using only vibration velocity according to ISO 10816-1 does not provide lead time for coupling defects. Based on this, the 'minimum data sufficiency rule' for diagnostic systems has been formulated, applicable to a wide class of electromechanical equipment.

Keywords: Induction Motor, Electromechanical System, Damage Development Model, Diagnostics, Actual Condition.

Research Paper

***Corresponding Author:**
Sergey V. Derkachev
Ph.D. (Engineering Sciences), Head of the Youth Research Laboratory "Instrument Engineering and Machine Tool Building", Donetsk National Technical University

How to cite this paper:
Sergey V. Derkachev & Vladimir A. Sidorov (2026). Determination of Diagnosed Parameters of Electromechanical Systems. *Middle East Res J. Eng. Technol, 6*(3): 56-63.

Article History:
| Submit: 15.04.2026 |
| Accepted: 18.05.2026 |
| Published: 20.05.2026 |

INTRODUCTION

Induction motors are widely used as drives for electromechanical systems in metallurgical complexes, operating under high load conditions in a continuous technological process. The failure of one of the units often leads to a shutdown of the entire production and is accompanied by significant losses for each day of downtime [1].

The traditional approach to diagnosing the actual condition of such systems is based on non-destructive testing methods, which in most cases are aimed at identifying defects in individual components [2–4], rather than at a comprehensive assessment of the technical condition of the system as a whole. At the same time, threshold protection based on exceeding specified values of a single parameter is widely used. Often, vibration velocity serves as such a parameter [5, 6].

However, practical research shows that developing defects may not affect the vibration level for a long time, and then, within a few hours, lead to sudden failure. Consequently, modern diagnostic methods should not simply signal a defect but should ensure its early identification with prediction of remaining useful life [7, 8].

The literature presents numerous diagnostic methods based on a single monitored diagnostic parameter: vibration level [9–11], stator current analysis [12–16], temperature [17, 18]. However, there is no unified methodology that would justify a minimally sufficient set of diagnostic parameters with a limited number of sensors and consider the physics of damage development.

Thus, the purpose of the article is to substantiate the minimum necessary set of monitored diagnostic parameters, based on damage development models of electromechanical systems, that ensures defect identification 14 days before complete failure, which is sufficient for a planned shutdown and taking the equipment out for repair.

The scientific novelty of the obtained results lies in the fact that, based on 5-year monitoring data of an industrial 1000 kW induced draft fan, it has been experimentally confirmed that using only vibration velocity according to the ISO 10816-1 standard does not provide sufficient lead time for coupling defects. An additional set of thermodynamic and tribological parameters has been proposed, which enables the detection of signs of degradation 21 days before failure. Based on this, the 'minimum data sufficiency rule' for diagnostic systems has been formulated, applicable to a wide class of electromechanical equipment.

MATERIALS AND METHODS

The object of the study was an industrial induced draft fan of the gas cleaning unit in the electric steelmaking shop (Fig. 1), the electric drive of which is a squirrel-cage induction motor with a rated power of 1 MW, a stator voltage of 6 kV, and a rotor speed of 1475 rpm.

Fig. 1: General view of the induced draft fan of the gas cleaning unit in the electric steelmaking shop

Modeling the faults of an electromechanical system requires the use of several calculation models: kinematic model, electrical-to-mechanical energy conversion model, force model, torsional oscillation model, longitudinal vibration oscillation model, thermodynamic model, hydrodynamic model, and damage development models.

The kinematic model, the structural diagram of which is shown in Fig. 2, serves as the basis for constructing the reliability diagram of the electromechanical system. The general structural diagram of reliability is shown in Fig. 3.

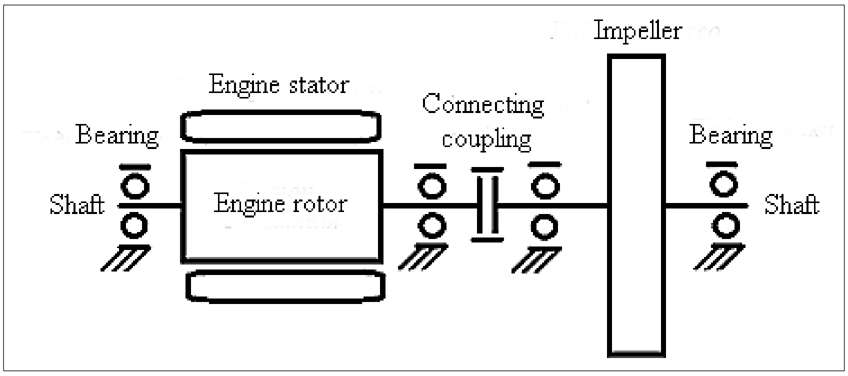

Fig. 2: Kinematic model of the electromechanical system

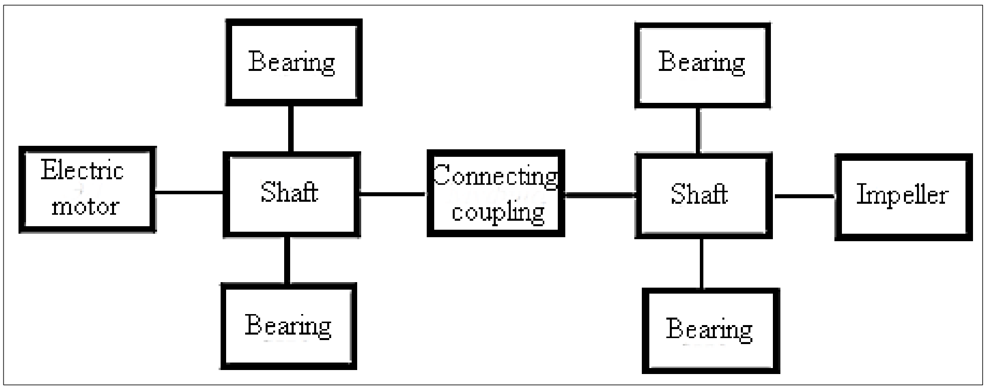

Fig. 3: Structural diagram of reliability

The model of converting electrical energy into mechanical energy is generally based on the laws of electromagnetic induction and electromagnetic forces, and is described by the following formula:

$$P_{EL} = P_{MECH} + \Delta P = U \cdot I = I^2 \cdot r + M \cdot \omega \qquad (1)$$

Where: U – напряжение статора электропривода; I – токи статора электропривода; r – активное сопротивление обмоток электропривода; M - электромагнитный момент электропривода; ω - угловая скорость вращения электропривода.

The force model is intended to determine the acting force based on the axioms of statics, kinematic motion parameters, and the laws of dynamics.

The torsional oscillation model is intended to describe an elastic-viscous mechanical system. The simplest representation is the two-mass calculation diagram shown in Fig. 4.

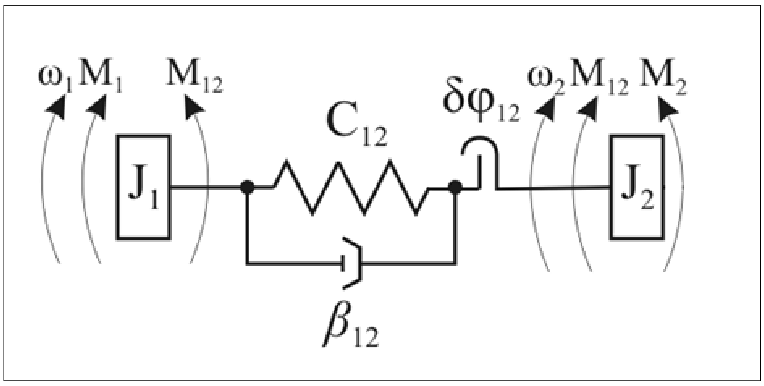

Fig. 4: Calculation diagram of the two-mass model of torsional oscillations

Considering dry friction and clearance, the behavior of the system is described by the following system of equations:

$$\begin{gathered} J_1 \cdot p\omega_1 = M_1 - M_{12} - M_{FRIC1}(\omega_1) \\ J_2 \cdot p\omega_2 = M_{12} - M_2 - M_{FRIC2}(\omega_2) \\ M_Y = C_{12} \cdot \Delta\varphi_{12} \\ M_B = \beta_{12} \cdot \Delta\omega_{12} \\ M_{12} = M_Y + M_B \end{gathered} \qquad (2)$$

Depending on the magnitude of the clearance in the kinematic transmission, the torsion angle is determined by the formula:

$$\Delta\varphi_{12} = \begin{cases} 0, if\ \Delta\omega_{12}/p \le \delta\varphi_{12} \\ \Delta\omega_{12}/p, if\ \Delta\omega_{12}/p > \delta\varphi_{12} \end{cases} \qquad (3)$$

where: p - оператор Лапласа; J_1 и J_2 – моменты инерции первой и второй масс; ω_1 и ω_2 - угловые скорости; M_1 - движущий момент; M_2 – момент сопротивления; M_{FRIC1} и M_{FRIC2} – моменты сухого трения; M_Y – упругая составляющая момента; M_B – вязкая составляющая момента; C_{12} – коэффициент упругости; β_{12} – коэффициент вязкого трения; $\Delta\varphi_{12}$ – угол закручивания; $\Delta\omega_{12}$ – разность угловых скоростей; $\delta\varphi_{12}$ – зазор в кинематической передаче.

Damage to components (e.g., wear of the coupling or loosening of threaded connections) leads to changes in the coefficient of elasticity, the coefficient of viscous friction, and in the kinematic transmission, which is reflected in the vibration spectrum.

The model of longitudinal vibration oscillations is based on the two-mass calculation diagram shown in Fig. 5, with the second mass tending to infinity.

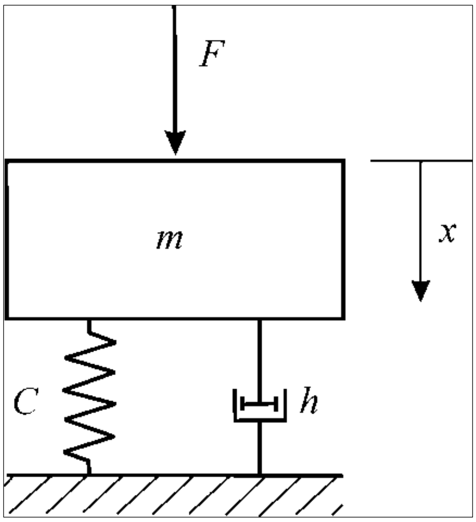

Fig. 5: Calculation diagram of the two-mass model of longitudinal vibration oscillations

The model of longitudinal vibration oscillations is described by the following equation:

$$m \cdot \ddot{x} + h \cdot \dot{x} + c \cdot x = F \qquad (4)$$

Where: m – масса; h - коэффициент демпфирования; c – жесткость.

Oscillations of the system are possible under the influence of a variable force F. The nature of forced oscillations is determined by inertial forces, elastic forces, damping forces, and disturbing influences.

In this model, the system characteristics and responses are considered: mass, stiffness, and damping coefficient. The values of these quantities during vibration measurement are unknown, but they are assumed to remain unchanged. Damage in a mechanical system leads to a change in stiffness due to wear of components or loosening of threaded connections, a change in the damping coefficient due to crack propagation, etc.

The system responses in this case (vibration acceleration, vibration velocity, and vibration displacement) are a function of the forcing excitation force and the system characteristics.

The thermodynamic model is intended to account for heating and cooling processes in order to assess fatigue phenomena. If the electric motor is represented as a homogeneous body, then its thermodynamic model can be described by the expression:

$$\tau = \tau_{Steady\_stay} \cdot \left(1 - e^{-\frac{t}{T}}\right) \qquad (5)$$

where: τ_{Steady_stay} - установившаяся температура перегрева; T – постоянная нагрева.

A change in the steady-state heating temperature and the heating time constant during operation indicates a violation of the stability of the thermodynamic equilibrium values — the appearance of additional friction forces, variable heat transfer values, or heat capacity. In this case, diagnostic parameters can include: the warm-up time of the mechanism to steady-state temperature, the heating rate, the absolute value, and others. The thermodynamic dependence of the warm-up of a fault-free mechanism to steady-state temperature is shown in Fig. 6.

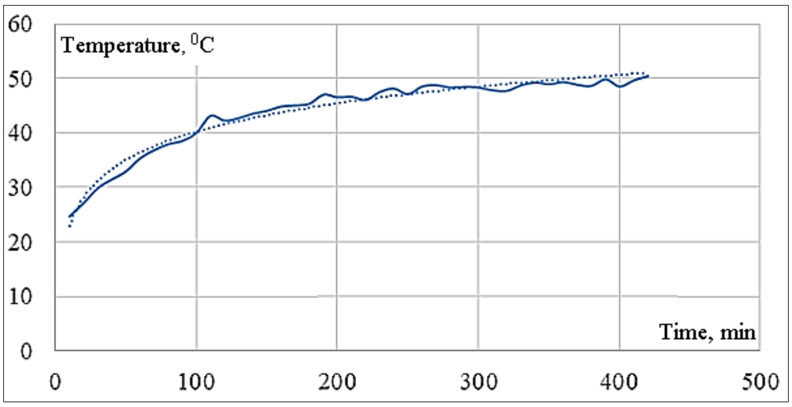

Fig. 6: Thermodynamic dependence of the warm-up of a fault-free mechanism to steady-state temperature

The hydrodynamic model is used to determine the operating mode of bearings based on the dependence of the friction coefficient on the operating characteristic (Fig. 7), the so-called Hersey–Stribeck parameter. Mathematically, this parameter is described by the expression:

$$\lambda = \frac{\mu \cdot \omega}{p} \qquad (6)$$

Where: μ – динамическая вязкость смазочного материала; ω – угловая скорость вращения вала; p – давление в зоне трения.

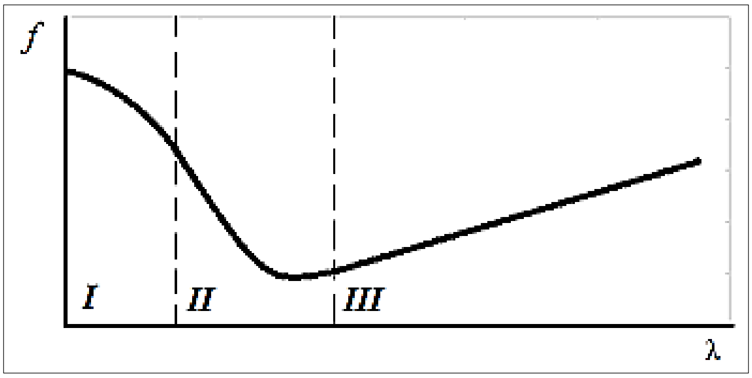

Fig. 7: Hersey–Stribeck diagram

The zones shown in Fig. 7 define the types of friction, namely: I – boundary friction; II – mixed (semi-fluid) friction; III – fluid friction.

The friction force in the bearing can be determined by the formula:

$$F = 2 \cdot \pi \cdot r^2 \cdot l \cdot \mu \cdot \frac{\omega}{\delta} \; (7)$$

where: r - радиус подшипника; l - длина подшипника; μ - вязкость смазочного материала; ω - угловая скорость; δ - зазор.

Damage development models are constructed based on four main types of models: permissible value model, wear model, stepwise transition model, and logical model, which account for the mutual influence of the elements on one another.

During the design phase, the component values of these models are estimated approximately. During operation, under various loading conditions, the following parameters change: external forces, loads on components, operating conditions, oil film characteristics, and the values of elastic-damping properties, among others. Gaps open or close, and the relative positioning of parts changes, which causes a change in the technical condition. Additionally, the asymmetry of characteristics of similar components should be noted. The exact values of model parameters under operating conditions cannot be determined; it is only possible to assess the degree of their influence on the ongoing processes and the rate of change.

Electromechanical systems are recoverable through scheduled and unscheduled maintenance and repairs (both planned and unplanned). Compensating for the degradation processes of system components with timely recovery operations makes it possible to avoid unplanned shutdowns and disruptions to the continuity of the technological process. Errors in technical condition management lead to sudden failures and downtime of the metallurgical machinery complex. For example, the aforementioned induced draft fan of the gas cleaning unit in the electric steelmaking shop operates in a continuous mode, under stable load, with no extreme influences except for environmental effects. A shutdown of this mechanism leads to a shutdown of the entire electric steelmaking production. The downtime duration is determined by the time required to carry out repairs under conditions where the maintenance service is unprepared, and can be very significant.

Results and Discussion

The technical condition assessment of the induced draft fan of the gas cleaning unit was carried out from the moment of startup over a period of 5 years by measuring vibration levels and comparing them with the standard values regulated by GOST R ISO 20816-1-2021 "Vibration. Vibration measurement and evaluation of machine vibration condition. Part 1. General guidelines" and GOST R IEC 60034-14-2008 "Rotating electrical machines. Part 14. Mechanical vibration of certain types of machines with a shaft height of 56 mm and above. Measurement, evaluation, and vibration limits." The vibration velocity values defining the condition boundaries are: up to 2.8 mm/s – operation without time limitations; 2.8…7.1 mm/s – operation for a limited period of time; above 7.1 mm/s – possible damage to the machine.

Vibration measurements were carried out in the vertical, horizontal, and axial directions using a 795M vibration analyzer and a C11 piezoelectric sensor. The sensor was attached using a magnet. Measurements of overall values and the frequency waveform of the vibration signal were performed. The monitored frequency ranges were 10…1000 Hz and 10…5000 Hz.

Vibration measurements of the bearing assemblies of the induced draft fan of the gas cleaning unit were performed at the following reference points: 1 – free bearing of the motor; 2 – fan bearing; 4 – bearing on the idle side of the fan shaft.

Vibration values across the entire measurement range were stable and did not exceed 2.0 mm/s. On November 21, 2013, the recorded condition was satisfactory, but three weeks later – on December 14, 2013 – the vibration velocity values increased by a factor of 4 to 5. Repeated measurements on December 17, 2013, after additional lubrication, confirmed the need for shutdown, which was agreed upon with the technological service of the shop (Table 1). The subsequent disassembly of the coupling revealed wear of the half-coupling and fracture of the connecting spring. The outer ring of the fan bearing on the coupling side shows signs of rotation; the clearance for one row of rollers is 0.05 mm, while for the second row there is no clearance (Fig. 8).

Table 1: Change in vibration velocity values for reference points of the No. 2 induced draft fan motor

Measurement point	Root mean square (RMS) value of vibration velocity (mm/s) for measurement directions, frequency range 10…1000 Hz			Measurement date
	Vertical	Horizontal	Axial	
1	0,7	1,1	0,6	November 21
2	1,1	1,2	0,4	
1	1,5	5,8	1,6	December 14
2	1,8	4,2	1,3	
1	1,3	5,2	1,2	December 17
2	1,7	3,6	1,0	
1	0,9	1,3	0,5	April 3
2	0,9	1,1	0,5	

Starting the motor with the coupling disconnected revealed a satisfactory vibration condition of the motor, with current values corresponding to good condition; temperature values were also within acceptable limits. Timely shutdown and repair of the coupling prevented a production stoppage and allowed the continued operation of the unit.

a b

Fig. 8: Wear of the half-coupling (a) and signs of rotation (b) of the outer ring of the induced draft fan bearing

The foundation of any control system is the availability of information, the efficiency of its processing, and its utilization. For electromechanical systems, data characterizing the mechanical and electrical system components, as well as the parameters of their interaction, should be identified. System faults develop according to different models and at different rates, which necessitates the availability of real-time information (recorded with maximum resolution) and information accumulated over a long period of time. Knowledge of the completed production program and the repairs carried out is also required.

Figure 9 shows examples demonstrating the capabilities of modern monitoring systems for time-domain recording of acting forces, current, and vibration indicators. These data can be incorporated into damage accumulation models or permissible value models for predicting time to failure or immediate shutdown of the mechanism. The array of initial data can be effectively used in expert condition assessment programs.

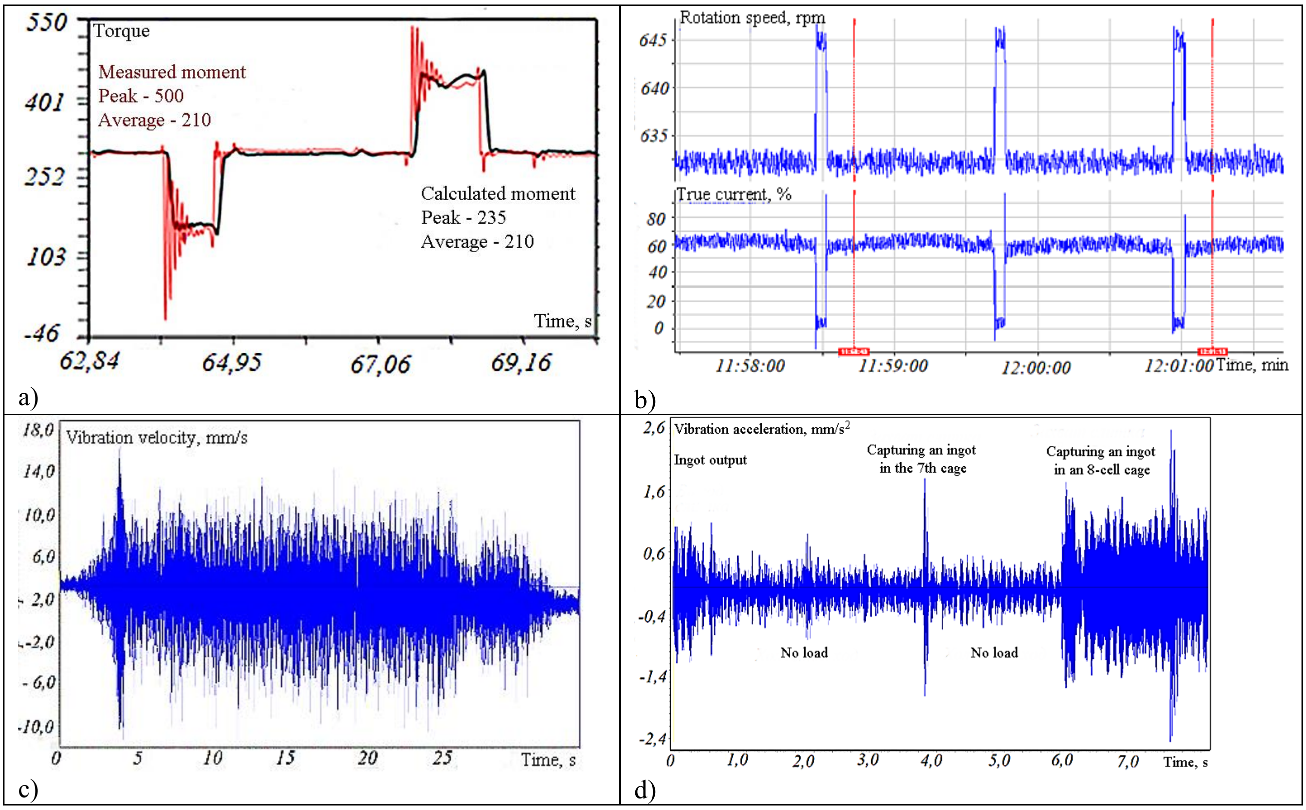

Fig. 9: Time waveforms: (a) acting forces – data from SMS; (b) rotation speed and motor current during rolling on a continuous mill; (c) vibration velocity of the skip hoist bearing assembly; (d) vibration acceleration of the combined gearbox bearing assembly of the rolling stand drive

CONCLUSION

The results obtained in this work allow us to draw the following conclusions:

***Scientific Novelty and Theoretical Significance*:** Based on a critical analysis of existing diagnostic methods, their main limitation has been identified – the lack of lead time in the event of sudden coupling failures. An approach to substantiating a minimally sufficient set of diagnostic variables is proposed, based on the integration of eight calculation models. For the first time, the "minimum data sufficiency rule" is formulated, according to which parameters providing a lead time of at least 14 days are selected.

***Experimental Validation of Method Effectiveness*:** Based on 5-year monitoring data of an industrial exhauster (1000 kW), it has been confirmed that using only vibration velocity according to ISO 10816-1 provides no lead time for coupling defects. The proposed set of thermodynamic and tribological parameters (bearing thermal time constant, Hersey–Stribeck parameter) enables the detection of degradation signs 21 days before failure.

***Practical Significance and Implementation Potential*:** The proposed minimally sufficient parameter set (vibration velocity, bearing temperature, lubrication regime assessment) can be integrated into stationary diagnostic systems without substantial additional cost. Its practical value is demonstrated by preventing a production stoppage during the exhauster coupling failure. The "minimum sufficiency rule" applies to a wide range of electromechanical equipment.

REFERENCES

- Jardine, A. K. S., Lin, D., & Banjevic, D. (2006). A review on machinery diagnostics and prognostics implementing condition-based maintenance. *Mechanical Systems and Signal Processing*, 20(7), 1483–1510.
- Verenev V.V., Bol'shakov V.I., Putnoki A.Yu., Manshilin A.G., Macko S.V. (2007) Diagnostics and

dynamics of rolling mills. *Dnepropetrovsk: IMA-pres., 144*. (Original work published in Russian)

- Sushko A.E. (2011) Methodology for implementing hardware and software tools for monitoring the technical condition and diagnostics of rolling mills using various vibration parameters. *Stal', 5, 60 – 65.* (Original work published in Russian)
- Ishmet'ev E.N., Panov A.N., Romanenko A.V., Vasil'ev E.Yu., Korobejnikov S.M. (2014) Experience in using automated stationary vibration monitoring and diagnostics systems. *Elektrotekhnicheskie Sistemy i Kompleksy, 1(22), 56 – 59* (Original work published in Russian)
- ISO 10816-1:1995. Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts – Part 1: General guidelines.
- GOST 20815-93 (MEK 34-14-82) (2003). Electric rotating machines. Mechanical vibration of certain types of machines with a rotational axis height of 56 mm or more. (Original work published in Russian)
- Lee, Jay; Wu, Fangji; Zhao, Wenyu; Ghaffari, Masoud; Liao, Linxia; Siegel, David (2014). Prognostics and health management design for rotary machinery systems—Reviews, methodology and applications. *Mechanical Systems and Signal Processing*, 42(1-2), 314–334. doi:10.1016/j.ymssp.2013.06.004
- Heng, A., Zhang, S., Tan, A. C., & Mathew, J. (2009). Rotating machinery prognostics: State of the art, challenges and opportunities. *Mechanical Systems and Signal Processing*, 23(3), 724–739.
- Kupriyanov I.S., Luk'yanov A.V. (2023) Mathematical and physical modeling of vibration in asynchronous electric motors with static rotor eccentricity. *System Analysis & Mathematical Modeling*, 5(4), 425–441. (Original work published in Russian)
- Ermolaev A.I., Erofeev V.I., Plekhov A.S., Tishin I.V. (2023) Study of magnetic noise in an asynchronous motor with static rotor eccentricity. *Aktual'nye problemy elektroenergetiki,* 50–64. (Original work published in Russian)
- Alimardani R., Rahideh A., Hedayati Kia S. (2023) Mixed eccentricity fault detection for induction motors based on time synchronous averaging of vibration signals. *IEEE Transactions on Industrial Electronics*, 99, 1–9.
- Biryukov A.E., Sorokin D.G., Lysov N.V., Sitnikov M.S. (2023) Diagnostic algorithm for analyzing the current of asynchronous electric motors based on the methods of evaluating the hodograph and frequency spectrum. *Sovremennye tekhnologii. Sistemnyj analiz. Modelirovanie,* 4(80), 88–101. (Original work published in Russian)
- Kryukov O.V., Kolganov A.R., Gulyaev I.V. (2025) Automation of asynchronous electric motor diagnostics processes at compressor stations. *Vestnik Ivanovskogo gosudarstvennogo energeticheskogo universiteta,* 4, 76–84. (Original work published in Russian)
- Zhang Y., Gao A., Yu Z., Gao T., Feng Z. (2026) Stator current AM-FM model and signature analysis for induction motor eccentricity detection *Mechanical Systems and Signal Processing,* 242, 113630.
- Li H., Zou Z., Sun X., Gu F., Ball A.D. (2021) A numerical study of rotor eccentricity and dynamic load in induction machines for motor current analysis based diagnostics. *Maintenance, Reliability and Condition Monitoring*; 1(2), 71–86.
- Alimardani R., Rahideh A., Hedayati Kia S. (2025) Mixed eccentricity fault detection of induction motors based on variational mode decomposition of current signal. *Machines*, 13(10), 968.
- Stenin V. A., Vishnyakov A. S., Selyanin P. V., Popovskij D. D. (25 June 2024) Thermal diagnostics of an asynchronous motor. *Nauka XXI veka: vyzovy, stanovlenie, razvitie: Sbornik statej XVIII Mezhdunarodnoj nauchno-prakticheskoj konferencii, Petrozavodsk*, 6-10. (Original work published in Russian)
- Valiullin, K. R., Tushev S.I. (2022) Algorithm for recalculating the temperature of an asynchronous motor based on an equivalent thermal circuit. *Energeticheskie sistemy,* 2, 42-48. (Original work published in Russian)