32st International Conference
ENGINEERING MECHANICS 2026
Medlov, Czech Republic, May 11 – 13, 2026

MODAL TESTS OF TECHNICAL OBJECTS

Kałaczyński T.[1], Liss M.[2], Łukasiewicz M.[3]

Abstract: *The paper presents the process of identifying the technical condition of objects with large spatial dimensions and large masses using the properties of the exploitation modal analysis method, based on measurements of the response to exploitation excitations. The paper presents the possibility of implementing modal analysis in assessing the selected technical objects technical state. The presented procedure demonstrates the possibilities of classifying objects based on their state of wear.*

Keywords: Modal analysis, Technical object, Vibration diagnostics, Technical state, Exploitation

1. Introduction

Contemporary technical facilities are complex, dynamic systems, both structurally and functionally, often occupying large production spaces. The production and exploitation of such facilities requires significant financial, raw material, and energy expenditures on businesses. The increase in technical requirements for the parameters of machines and devices, while reducing the costs of production and operation, has led to fundamental changes in the methods of designing, controlling production and operating technical facilities. The occurrence of unexpected damage or failure generates economic losses resulting from the cessation of production and results in additional expenditure on repair processes, justifying the need to conduct diagnostic tests, which are the basic source of information about the changing state of technical objects exploitation.

Modal analysis is a method for examining the dynamic properties of structures and can be used to conduct diagnostic tests on complex technical objects. Modal analysis produces a modal model consisting of an ordered set of natural frequencies, corresponding damping coefficients, and natural vibration modes. The idea behind this method is to track changes in modal model parameters resulting from misalignment, wear, damage, or failure, based on current observations of the object. Based on knowledge of the modal model, it is possible to predict the object's response to any disturbance, both in the time and frequency domains (Łukasiewicz M.. et al., 2010). It is implemented as theoretical, experimental, or exploitation modal analysis (often referred to interchangeably as exploitation modal analysis) (Furgal, Sz. et al., 2023).

Exploitation modal analysis is a technique based on measuring the system's response to unknown operational forces resulting from the action of technological process forces or kinematic forces and the destruction process of machine components (Żółtowski B. et al., 2012). During testing, measurement points and reference points—constant throughout the measurements—must be determined. The advantage of this method for identifying the dynamic characteristics of objects is the preservation of boundary conditions and excitations typical of their operation (Crocker, M. J. et al., 2007). The properties and research conducted in the implementation of operational modal analysis in assessing the technical condition of technical objects enable the classification of the condition and the quality of repair procedures (Kałaczyński T. et al., 2025). This allows for the identification of wear and tear of technical object components.

---

[1] Tomasz Kałaczyński, PhD.: Faculty of Mechanical Engineering, Bydgoszcz University of Science and Technology, Al. prof. S. Kaliskiego 7, Bydgoszcz; PL, kalaczynskit@pbs.edu.pl

[2] Michał Liss, PhD.: Faculty of Mechanical Engineering, Bydgoszcz University of Science and Technology, Al. prof. S. Kaliskiego 7, Bydgoszcz; PL, michal.liss@pbs.edu.pl

[3] Marcin Łukasiewicz, PhD.: Faculty of Mechanical Engineering, Bydgoszcz University of Science and Technology, Al. prof. S. Kaliskiego 7, Bydgoszcz; PL, mlukas@pbs.edu.pl

ISSN: 1805-8256, doi: 10.21495/em2026-61

2. Object and research methodology

In this method, modal parameters are estimated based on measured signals at the object's output, as well as signals obtained during measurements at selected reference and measurement points for unknown system excitations. As a result, the system's poles and natural frequencies are identified, and then the mode shapes are estimated based on these values (Żółtowski B. et al., 2012). In exploitation modal analysis, no additional vibration exciters (modal hammers) are used, and measurements are taken for the object during its operation. This approach allows us to obtain measurement data for normal operational excitations (actual object operation) at selected measurement points relative to a reference point. The selection of the number and location of reference points is crucial in this method. The obtained data is further estimated using various computational methods (Łukasiewicz M.. et al., 2019).

The research methodology included the use of the LMS SCADAS Recorder System, which is one of the most modern measurement systems used in diagnostic testing. LMS Test.Lab software was used for data acquisition and analysis of test results. To demonstrate the practical capabilities of the LMS SCADAS measurement system with LMS Test.Lab software for determining the natural frequencies of technical objects, Figure 1 illustrates two impeller blades. One blade was in good working order, while the other was worn after long periods of operation. These blades are shown in Figure 2.

This article presents selected and useful research results and their analysis. The full text of the research is available from the authors. The presented results are part of an ongoing research process focused on the development and exploitation verification of the proprietary MTM Solution repair quality assessment method.

a

Fig. 1: Blade wheels of a projecting rotor (from left): new wheel, worn wheel.

The measurement results were obtained from a total of 16 measurement points, eight on each side of the paddle wheel. The measurements were taken on two paddle wheels in different technical state. The measurement method was based on exploitation modal analysis, The response signal generated was recorded using standard piezoelectric sensors from 16 measurement points on a single wheel in the form of spectral transfer functions (FRFs). Individual spectral transfer functions (FRFs) were then transferred to other software for analysis.

3. Results and conclusions

The results of the modal analysis are individual modal parameters, such as natural frequencies, damping coefficients, and mode shapes. These parameters are estimated based on the generated stabilization diagram, which is presented for a functioning wheel in Figure 3.

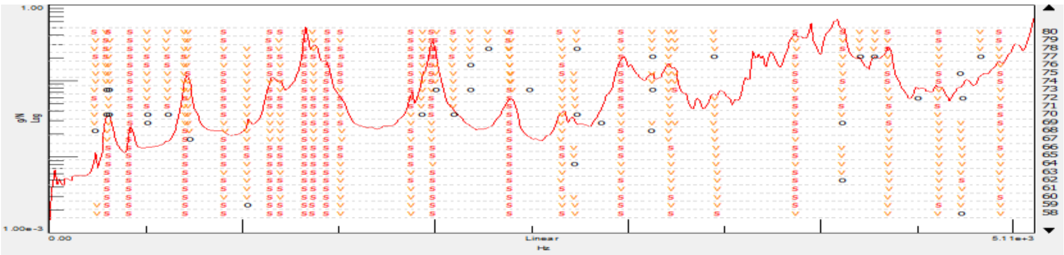


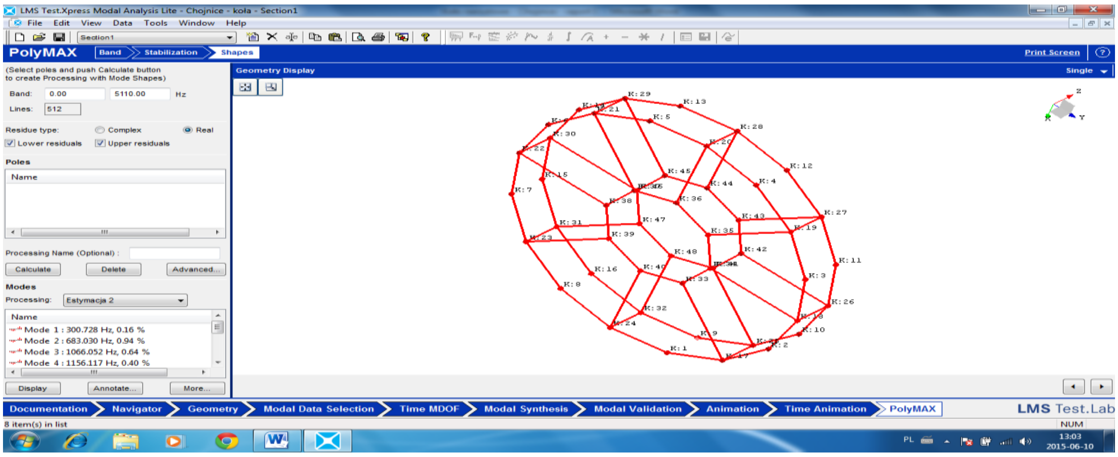
Fig. 2: Stabilization diagram created using the SUM indicator from 16 individual measurements for a new wheel.

Based on the results presented in Table 1, it can be seen that the worn wheel exhibits a second mode of natural vibration around 400 [Hz]. Another characteristic feature clearly illustrating the differences between the two test objects is the damping coefficient, which is generally significantly higher for the worn wheel than for the unworn wheel. Other features include shifts in individual vibration modes on the frequency axis. For a worn paddle wheel, all estimated natural frequencies are lower than for a new paddle wheel.

Tab. 1: Summary of natural frequencies and damping coefficients for both considered paddle wheel cases.

	New wheel		Worn wheel	
Own vibration mode	Frequency	Damping	Frequency	Damping
	[Hz]	[%]	[Hz]	[%]
Mode 1	302,78	3,65	300,73	0,16
Mode 2	415,79	2,36		
Mode 3	709,73	1,46	683,03	0,94
Mode 4	1147,43	1,09	1066,05	0,64
Mode 5	1328,14	0,69	1156,12	0,40
Mode 6	1987,53	0,40	1440,83	0,31
Mode 7	2968,40	0,41	2343,09	0,23

The next step is to estimate the individual vibration modes and visualize their form using a geometric representation. The mode estimation window is shown in Figure 3, along with a geometric representation of the analyzed paddle wheel.



(Select poles and push Calculate button to create Processing with Mode Shapes)

Band: 0.00 5110.00 Hz

Lines: 512

Residue type: ○ Complex ● Real

☑ Lower residuals ☑ Upper residuals

Poles

Name

Processing Name (Optional) :

Modes

Processing: Estymacja 2

Name

Mode 1 : 300.728 Hz, 0.16 %

Mode 2 : 683.030 Hz, 0.94 %

Mode 3 : 1066.052 Hz, 0.64 %

Mode 4 : 1156.117 Hz, 0.40 %

8 item(s) in list

Fig. 3: Mode shape estimation window

The estimated individual own vibration modes can be visualized on the prepared geometric model. A comparison of the individual own vibration modes and their graphical representations is presented in the figures below. Analyzing the individual vibration modes of a worn wheel, numerous similarities can be observed with those of a new wheel. In all cases, these modes are flexural in nature.

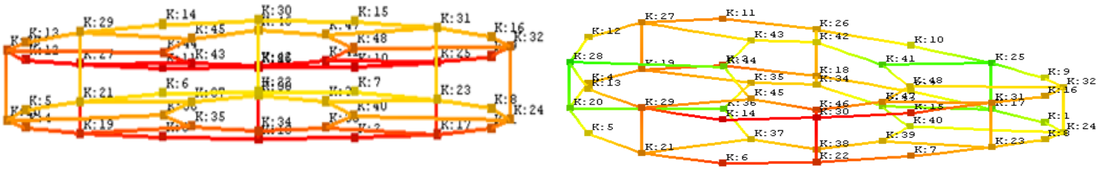


Fig. 4: Comparison of the mode I of the new wheel on the left side (302.775 Hz, 3.65%) with the mode I of the worn wheel on the right side (300.728 Hz, 0.16%)

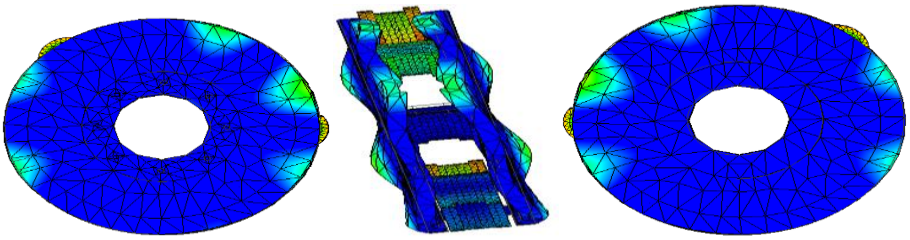


Fig. 5: Mode of Action

The estimated and selected own vibration modes were validated using the AutoMAC method. Validation results are presented in Figure 6.

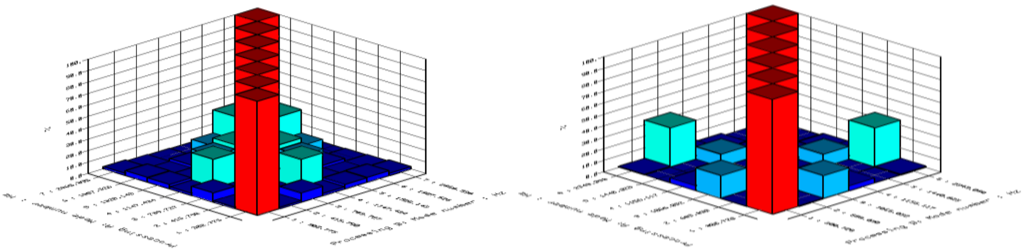


Fig. 6: Summary of AutoMAC validation results: a) (from left) for a new wheel, b) (from right) for a worn wheel

The estimated and selected vibration modes were validated using the AutoMAC method. Validation allowed for verification confirming the feasibility of implementing exploitation modal analysis.

Conclusions:

1) Modal tests of the impeller blade wheel clearly illustrate differences in the results between the individual test object states. This is indicated primarily by shifts in the individual vibration modes on the frequency axis, and even by the complete disappearance of one mode in the case of a worn wheel. In the case of a worn wheel, it can also be observed that the damping coefficient has significantly decreased in some own vibration modes.
2) The advantage of this method is that the tested object can be tested without excluding it from the operational process. Therefore, such tests do not generate additional costs, and the obtained results are based on actual signals generated by the tested object.
3) Modal analysis parameters form the basis for building a model that classifies the degree of wear and tear of technical object components. They are also used in assessing the quality of repair procedures.

References

Crocker, M. J. (2007) *Handbook of Noise and Vibration Control*. Wiley-Interscience. New Jersey.

Furgal, Sz., Kałaczyński, T., Łukasiewicz, M., Martinod, R. (2023) Analysis of the changes impact in the construction of the vehicle exhaust silencer on the noise emission level, *Proc. 21st International Conference Diagnostics of Machines and Vehicles "Hybrid Multimedia Mobile Stage"*, Matec Web of Conferences, Bydgoszcz – Dresden, pp. 1-12.

Kałaczyński T., Łukasiewicz M., Liss M., Mazurkiewicz A. (2025) Vibration diagnostics in the assessment of the vehicles bodywork technical state procedure, ENGINEERING MECHANICS 2024, ISSN 1805-8256 , 30th INTERNATIONAL CONFERENCE May 14 – 16, 2024, Milovy, Czech Republic,pp 109 – 112.

Łukasiewicz M., (2010) Vibration measure as information on machine technical condition, Studies & Procedings of Polish Association for Knowledge Management 35, ISSN 1732-324X, Bydgoszcz.

Łukasiewicz, M., Liss, M., Dluhunovych, N. (2019) Analysis of vibrodiagnostics methods in the technical state study of designed multimedia mobile scenes, *Proc. 18th International Conference Diagnostics of Machines and Vehicles*, Matec Web of Conferences, Bydgoszcz, pp. 1-9.

Żółtowski B., Łukasiewicz M. (2012) *Diagnostyka drganiowa maszyn, Biblioteka Problemów Eksploatacji ITE Radom*, Wydawnictwo Naukowe Instytutu Technologii Eksploatacji - Państwowego Instytutu Badawczego w Radomiu, ISBN 978-83-7789-138-4.

Żółtowski B., Łukasiewicz M., Kałaczyński T. (2012) *Techniki informatyczne w badaniach stanu maszyn*, Wydawnictwa Uczelniane UTP w Bydgoszczy, Bydgoszcz.