ISSN: 2976-7466

Journal of Biosensors and Bioelectronics Research

Review Article

Open Access

Order Analysis of a Vibration Signal of a Rotating Machine

Saci Felahi[1]* and Walid Mohamedi[2]

[1]University of Sousse, Tunisia

[2]Cady Ayaed University, Morroco

ABSTRACT
Order analysis is a technique used in vibration analysis to identify the sources of vibration in rotating machinery. It helps to determine the frequencies at which various components within the machinery are experiencing vibration. The RPM profile serves as a key parameter in vibration analysis of rotating machinery, allowing for the examination of vibration amplitude changes as a function of rotational speed. By considering these characteristics, analysts can gain valuable insights into the behavior of rotating systems, identify potential faults, and make informed decisions regarding maintenance and repairs.

***Corresponding author**
Saci Felahi, University of Sousse, Tunisia.

Received: March 02, 2024; **Accepted:** March 12, 2024; **Published:** March 16, 2024

Introduction

Vibration analysis is a vital technique used to assess the condition, performance, and health of machinery and structures. It involves the measurement, analysis, and interpretation of vibration signals to identify potential issues, such as faults, anomalies, or mechanical problems [1-25].

Vibration is a common phenomenon present in various mechanical systems and structures, ranging from rotating machinery like motors, pumps, and turbines to bridges, buildings, and vehicles. When a mechanical system operates, it generates vibrations that can be caused by factors such as imbalances, misalignments, wear, resonance, structural weaknesses, or other mechanical faults [26-38].

Vibration analysis utilizes specialized sensors, such as accelerometers, to capture the vibrations induced by systems or structures. These sensors measure the acceleration, velocity, or displacement of the vibrating component, converting the mechanical vibrations into electrical signals [39-52].

Once the vibration signals are obtained, they are analyzed using various techniques and tools, including time-domain analysis, frequency-domain analysis, statistical analysis, wavelet analysis, and advanced signal processing algorithms [53-85]. The goal of vibration analysis is to extract meaningful information from the vibration signals to understand the behavior, diagnose any faults or anomalies, and make informed decisions regarding maintenance and repairs.

The key objectives of vibration analysis include:

1. **Fault Detection:** Identifying the presence of faults or anomalies in machinery or structures. This can involve detecting issues like unbalance, misalignment, bearing wear, gear damage, resonance, or mechanical looseness.
2. **Fault Diagnosis:** Determining the specific nature, location, and severity of faults. By analyzing the vibrational characteristics, frequency components, and patterns, fault diagnosis aims to pinpoint the source and identify the underlying causes of the problems identified.
3. **Condition Monitoring:** Regularly monitoring the vibration signals to track changes in machinery performance over time. Condition monitoring enables the identification of gradual deterioration, allowing for predictive maintenance and preventing unexpected failures or breakdowns.
4. **Performance Optimization:** Assessing the performance of machinery or structures to maximize efficiency, minimize energy consumption, improve productivity, and extend equipment lifespan. Vibration analysis can reveal opportunities for optimization and suggest improvements to enhance performance.
5. **Structural Health Monitoring:** Evaluating the condition and integrity of structures, such as bridges, buildings, and wind turbines, to ensure they remain safe and operational. Vibration analysis can detect signs of degradation, fatigue, or damage, enabling proactive maintenance and preventing catastrophic failures.

Order analysis is a technique used to analyze the vibration signal of rotating machinery in terms of rotational orders. Rotational orders represent the harmonics of the fundamental rotational frequency of a rotating component (such as a gear or a shaft). Order analysis provides valuable insights into the condition of the rotating components, helps identify specific fault frequencies and aids in fault diagnosis and monitoring.

The first step in order analysis is to measure the vibration signal using an accelerometer or other vibration sensor. This signal is typically recorded over a period of time, during which the machinery is in operation. The signal is then converted from the time domain to the frequency domain using a technique such as the Fast Fourier Transform (FFT).

Next, the frequency spectrum is divided into orders, which represent the harmonics of the rotational speed of the machinery. Each order corresponds to a specific component within the machinery. For example, the first order represents the rotation of the main shaft, while higher orders may represent rotational components such as gears or bearings.

By analyzing the amplitude and phase of each order, it is possible to identify the sources of vibration and determine the severity of the issue. Excessive amplitudes or abnormal phase relationships can indicate problems such as unbalance, misalignment, or bearing faults.

Order analysis can be performed using specialized software or vibration analyzers, which calculate the orders automatically and present the results in a graphical format. This allows maintenance professionals to quickly and accurately diagnose the root cause of the vibration and take appropriate corrective actions.

Order Analysis of a Vibration Signal

Order analysis is a technique used in vibration analysis to understand the sources and characteristics of vibration in rotating machinery. It involves analyzing the frequency content of a vibration signal to identify specific components or phenomena related to the rotational speed of the machinery.

To perform order analysis, the following steps are typically taken:

Data Acquisition: Vibration signals from the machinery are collected using sensors such as accelerometers. The signals are usually collected over a specific time period while the machinery is in operation.

Preprocessing: The collected vibration signal may require preprocessing to remove any noise or unwanted components. This can involve filtering, resampling, or applying mathematical techniques for signal enhancement.

Frequency Analysis: The preprocessed vibration signal is then transformed from the time domain to the frequency domain using techniques like the Fast Fourier Transform (FFT) or wavelet transform. This provides information about the frequency content of the signal.

Order Extraction: In order analysis, the frequency spectrum is then divided into orders. Each order represents a harmonic of the rotational speed of the machinery, with the first order corresponding to the main rotational speed. Higher orders represent harmonics of different components such as gears, belts, or bearings.

Order Tracking: Once the orders are extracted, they can be tracked over time, allowing for the identification of changes or anomalies. This tracking can help pinpoint the specific component or phenomena causing the vibration.

Diagnostic Interpretation: The amplitude and phase characteristics of the orders can provide valuable insights into the condition of the machinery. Excessive amplitudes, changes in phase relationships, or other abnormalities can indicate issues such as unbalance, misalignment, gear wear, or bearing faults.

Reporting and Decision Making: The results of the order analysis are typically presented in graphical or tabular form, allowing maintenance professionals to interpret the data and make informed decisions about necessary corrective actions.

Order analysis is a powerful tool for identifying and diagnosing vibration problems in rotating machinery. By understanding the sources and characteristics of the vibration, maintenance professionals can take appropriate actions to mitigate risks, improve machinery performance, and prevent potential failures.

A motor speed signal commonly consists of a sequence of tachometer pulses. tachorpm can be used to extract an RPM signal from a tachometer pulse signal. tachorpm automatically identifies the pulse locations of a bilevel tachometer waveform and computes the interval between pulses to estimate rotational speed. In this example, the motor speed signal contains the rotational speed, rpm, and hence no conversion is needed.

Plot the motor speed and vibration data as functions of time (see figure 1):

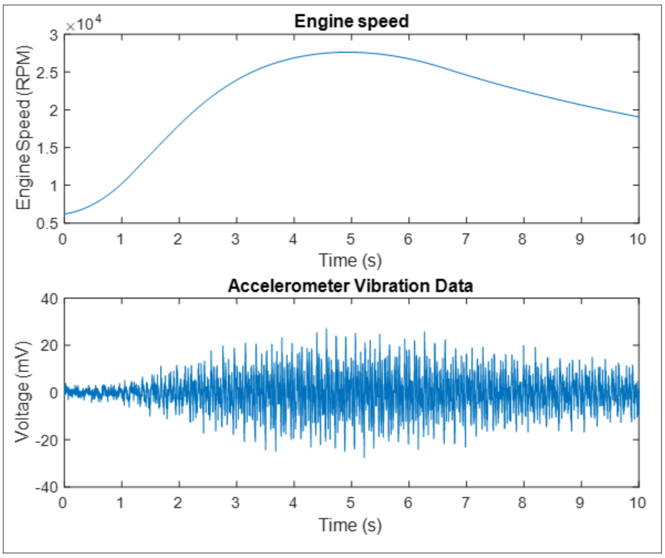


Figure 1: Motor Speed and Vibration Data as Functions of Time

Indeed, when analyzing vibration in rotating machinery, it is common to consider the changes in vibration amplitude as a function of rotational speed. The RPM (Rotations Per Minute) profile, which corresponds to the engine speed during the run-up and coast-down phases, is a crucial parameter in vibration analysis.

Understanding the RPM profile and its influence on vibration amplitudes is crucial in vibration analysis. This knowledge allows analysts to analyze and interpret vibration signals in the context of the machine's operational conditions and speed variations.

By considering the engine speed and its relationship to vibration characteristics, analysts can distinguish between normal operating conditions and potential faults or irregularities. This analysis approach aids in the identification of specific frequencies associated with faults, detection of resonance effects, understanding gear and bearing behavior, and diagnosing potential issues occurring at specific rotational speeds.

Visualizing Data Using An RPM-Frequency Map

An RPM-frequency map, also known as a Campbell diagram, is a graphical representation used to visualize and analyze the relationship between rotational speeds (RPM) and corresponding frequencies in rotating machinery. It helps in identifying critical speeds and potential resonances within the system.

To create an RPM-frequency map, the following steps can be taken:

Data Acquisition: Vibration data is collected from the rotating machinery using sensors such as accelerometers. This data is typically collected over a range of rotational speeds, covering the operational range of the machinery.

Frequency Analysis: The collected vibration data is transformed from the time domain to the frequency domain using techniques like the Fast Fourier Transform (FFT) or wavelet transform. This provides the frequency content of the vibration signal.

RPM Calculation: From the collected data, the rotational speed (RPM) of the machinery at each measurement point is determined. This can be done using a tachometer or by measuring the number of shaft rotations within a specific time interval.

Frequency vs. RPM Plot: The frequency content of the vibration signal is plotted against the corresponding RPM values. Each data point represents a specific frequency at a specific rotational speed.

Mapping and Analysis: The plotted data forms a graphical representation of the RPM-frequency relationship. This map helps in identifying patterns, trends, and specific frequencies that are critical or resonate with the rotational speeds. Resonance occurs when the frequency of vibration matches the natural frequency of a system, leading to a significant increase in vibration amplitude.

Critical Speed Identification: By analyzing the RPM-frequency map, critical speeds can be identified. These are rotational speeds at which the machinery is prone to experience resonances and vibration issues. It is important to avoid operating the machinery at or near these critical speeds to prevent potential failures or excessive vibrations.

Decision Making and Mitigation: The RPM-frequency map provides valuable insights for maintenance professionals to make informed decisions about potential modifications or countermeasures. This might involve adjusting the machinery's speed range, installing damping devices, modifying structural components, or implementing balancing techniques to mitigate or avoid resonances.

An RPM-frequency map is a useful tool for visualizing and analyzing the relationship between rotational speeds and frequencies in rotating machinery. By understanding the critical speeds and potential resonances, maintenance professionals can design and operate machinery more effectively to minimize the risk of vibration-related issues and ensure smooth, reliable operation.

Visualizing the vibration data using an RPM-Frequency map facilitates the identification of potential problem areas and aids in the diagnosis of rotating machinery. It provides a comprehensive overview of the machinery's vibration behavior across different RPM ranges and enables effective decision-making for maintenance, optimization, and ensuring reliable machinery operation (see figure 2).

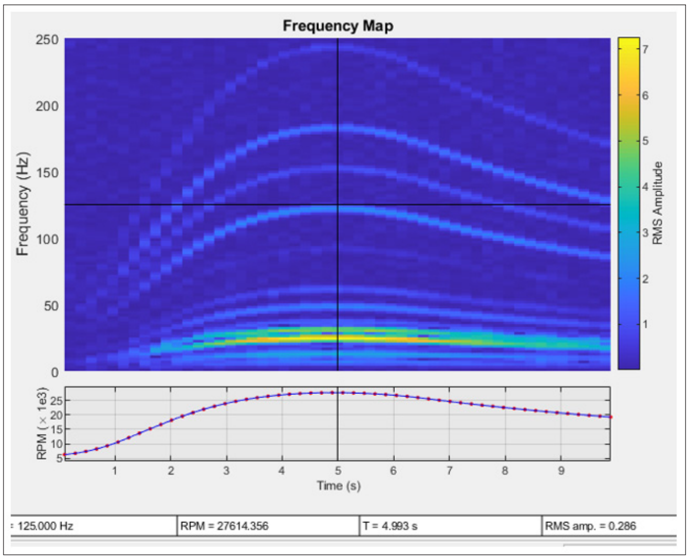
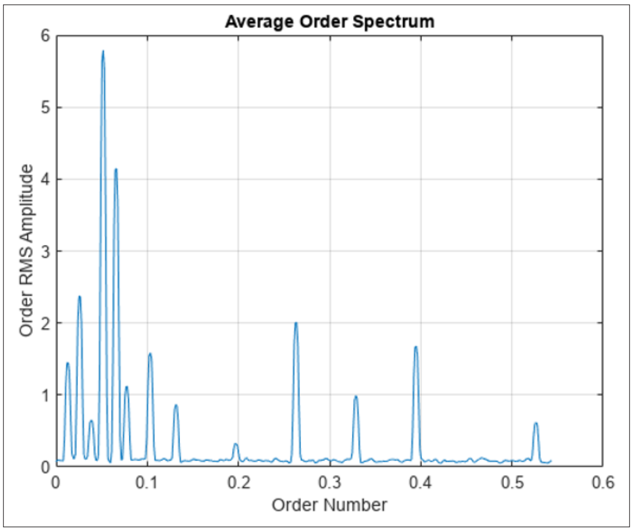


Figure 2: RPM-Frequency Map for the Vibration Data

Determining Peak Orders Using an Average Order Spectrum

Determining peak orders using an average order spectrum is a common technique in rotational machinery vibration analysis. The average order spectrum helps identify dominant frequency components related to specific rotational orders, such as gear meshing frequencies or bearing fault frequencies.

En déterminant les ordres de pointe à l'aide d'un spectre d'ordres moyen, les analystes peuvent identifier les composantes de fréquence dominantes associées à des ordres de rotation spécifiques. Cela fournit des informations essentielles pour diagnostiquer les défauts, évaluer l'état des machines tournantes et optimiser les paramètres opérationnels. De plus, la combinaison du spectre d'ordre moyen avec d'autres techniques de diagnostic, telles que l'analyse d'enveloppe ou l'analyse de tendance, peut améliorer les capacités de détection des défauts et de surveillance de l'état des machines tournantes (see figure 3).



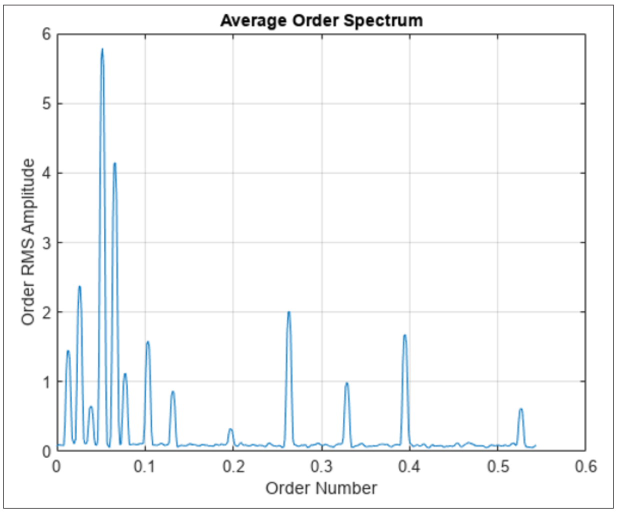


Figure 3: The Average Spectrum of Map

The frequency of data collection and the duration over which you analyze peak orders will depend on your business needs. Regularly reviewing and updating this analysis will help you make informed decisions to optimize your operations (see Figure 4).

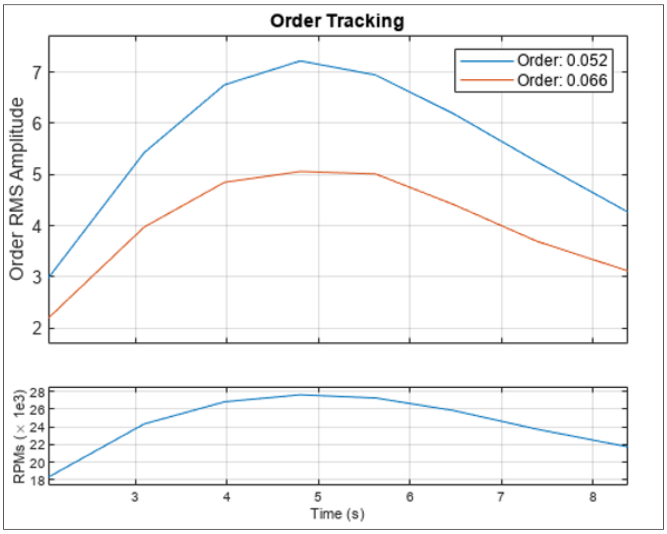


Figure 4: Order RMS Amplitude

That's interesting to note that the amplitude of both orders increases as the rotational speed of the motor increases. It suggests a correlation between the motor speed and the order amplitudes. Regarding the capability of "ordertrack" to separate crossing orders when multiple RPM signals are present, it highlights the usefulness of this function for analyzing complex signals.

By utilizing "ordertrack," you can process and analyze RPM signals, allowing you to separate and identify individual orders even in cases where there are multiple overlapping signals. This can be valuable for understanding the characteristics and behavior of the motor and its components.

To extract time-domain order waveforms for each peak order using "orderwaveform" and compare them to the original vibration signal, you'll need access to a programming language or software that supports the "orderwaveform" function. Below is a general outline of the steps involved:

- If necessary, preprocess the original vibration signal by removing any noise or irrelevant frequencies. This step helps ensure accurate order waveform extraction.
- Determine the two peak orders for which you want to extract order waveforms.
- Utilize the "orderwaveform" function, passing in the original vibration signal, the specified peak orders, and any other necessary parameters. This function will apply the Vold-Kalman filter to extract the order waveforms for the specified orders.
- Once you've extracted the order waveforms, you can compare them to the original signal. Plotting the waveforms separately or overlaying them on the original signal can help visualize any differences or similarities.
- If desired, you can convert the extracted order waveforms into audio files and play them back to audibly experience the individual peak orders.

The following figure illustrates order waveforms for peak order (see Figure 5):

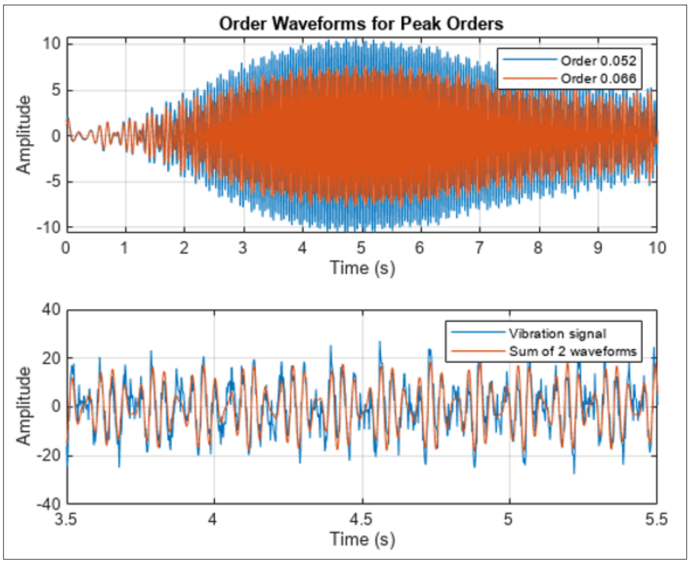


Figure 5: Order Waveforms for Peak Order

Conclusion

Identify the peaks or prominent frequency components in the average order spectrum. These peaks represent the dominant frequency components for different rotational orders. The order with the highest peak amplitude is likely the fundamental rotational order, while other peaks represent harmonics or sidebands related to gear meshing frequencies, bearing faults, or other phenomena.

In conclusion, order analysis is a valuable tool in the field of vibration analysis, as it provides insights into the sources and severity of vibration in rotating machinery. By identifying and addressing these issues promptly, it is possible to prevent further damage, improve machinery performance, and increase overall reliability [86-88].

References

1. C Nawghane, Bart Vandevelde, Riet Labie, Bart Allaert, Ralph Lauwaert, et al. (2018) Vibration fatigue analysis of lead-free CSP assemblies on printed circuit board. 19th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems 1-8.
2. Z Zhao, C Hu, F Yin (2018) Failure Analysis for Vibration

Stress on Ball Grid Array Solder Joints. 19th International Conference on Electronic Packaging Technology 486-490.

3. C Lv, S Zhang, P Gao, F Li, W Li, et al. (2017) Finite element analysis based on sequential coupling method for a glass product under temperature and vibration conditions. Second International Conference on Reliability Systems Engineering 1-7.
4. Zine Ghemari, Salah Belkhiri, Salah Saad (2023) Improvement of the relative sensitivity for obtaining a high-performance piezoelectric sensor. IEEE Instrumentation & Measurement Magazine 26: 49-56.
5. Zine Ghemari, Salah Belkhiri, Salah Saad (2023) A capacitive sensor with high measurement accuracy and low electrical energy consumption. Applied Physics A 129 : 362.
6. Zine Ghemari, Salah Belkhiri (2021) Mechanical resonator sensor characteristics development for precise vibratory analysis. Sensing and Imaging 22: 40.
7. Zine Ghemari, Salah Saad, Mabrouk defdaf (2021) Appropriate Choice of Damping Rate and Frequency Margin for Improvement of the Piezoelectric Sensor Measurement Accuracy. Journal of Advanced Manufacturing Systems 20: 537-548.
8. C Li, J Li, XL Fang, Y Tang, T Deng, et al. (2022) Application of a Method of Identifiying Instantaneous Shaft Speed from Spectrum in Aeroengine Vibration Analysis. Global Reliability and Prognostics and Health Management 1-7.
9. X Chen, X Peng, Z Gu (2021) Optimal Design of Vibration Fixture and Analysis of its Vibration Characteristics. 4th World Conference on Mechanical Engineering and Intelligent Manufacturing 423-426.
10. CL Yeh, WJ Lee, TC Yang (2021) Analysis of Small Bore-Piping Vibration Phenomenon. IEEE 3rd Eurasia Conference on IOT, Communication and Engineering 417-421.
11. T Wenchao, G Hongwei, G Rongcheng (2014) Anti-vibration structure analysis and optimizing on BGA packaging module. 15th International Conference on Electronic Packaging Technology 524-528.
12. Xin Zhang, Ronghui Huang, SenJing Yao, Xu Dong (2016) Finite element analysis and vibration control of the Substation Charged Maintenance Robot. 4th International Conference on Applied Robotics for the Power Industry 1-4.
13. YX Liu, CH Li, WS Chen, XH Ni, JK Liu (2015) Analysis of a novel longitudinal-bending hybrid ultrasonic motor using vibration coupling. Symposium on Piezoelectricity, Acoustic Waves, and Device Applications 45-49.
14. P Khatri, U Chhatre, S Kadge (2021) Visual Vibration Analysis of Vibrating Object at Low Frequency. 6th International Conference for Convergence in Technology 1-5.
15. Salah Belkhiri, Zine Ghemari, Salah Saad, Ghania Boudechiche (2020) Improvement of the Vibratory Analysis by Enhancement of Accelerometer Characteristics. Sensor Letters 18: 39-42.
16. Zine Ghemari, Salah Saad (2019) Defects diagnosis by vibration analysis and improvement of vibration sensor measurement accuracy. Sensor Letters 17: 608-613.
17. Zine Ghemari, Salah Saad, Khatir Khettab (2019) Improvement of the vibratory diagnostic method by evolution of the piezoelectric sensor performances. International Journal of Precision Engineering and Manufacturing 20: 1361-1369.
18. Zine Ghemari, Salah Saad (2019) Enhancement of capacitive accelerometer operation by parameters improvement. International Journal of Numerical Modelling Electronic Networks Devices and Fields 32: e2568.
19. H Cao, T Huang, L Lu, Z Xie (2021) Research on Quasi-zero Stiffness Vibration Isolation Technology of Distribution Transformer. IEEE 4th International Conference on Automation, Electronics and Electrical Engineering 613-617.
20. Tian Lv, Y Zhang (2014) Dynamic stress analysis for vibratory stress relief through the vibration platform. IEEE Workshop on Electronics, Computer and Applications 560-563.
21. Y Tian, T An, F Qin, Y Gong, Y Dai, et al. (2022) Stress analysis of automotive IGBT module under vibration load. 23rd International Conference on Electronic Packaging Technology 1-4.
22. LOB Coronado, Laureen Ida M Ballesteros, Earl John T Geraldo, Alvin M Buison, Ulysses B Ante, et al. (2021) Finite Element Modal Analysis and Harmonic Response Analysis of a 3D Printed Vibration Sensor Enclosure. IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management 1-5.
23. SX Qu, D Xu, R Kang (2013) Analysis of random vibration life of mechanical parts of actuating cylinder based on the finite element. International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering 917-920.
24. J Zhao, H Li, S Wang (2013) Failure causes and countermeasures analysis for a large-scale reciprocating compressor vibration. International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering 1081-1085.
25. Zine Ghemari, Salah Saad (2019) The use of mechanical sensitivity model to enhance capacitive sensor characteristics. Analog Integrated Circuits and Signal Processing 99: 349-357.
26. Salima Khaoula Reguieg, Zine Ghemari, Tarak Benslimane, Salah Saad (2019) Modeling and Enhancement of Piezoelectric Accelerometer Relative Sensitivity. Sensing and Imaging An International Journal 20: 1- 6.
27. Zine Ghemari (2018) Progression of the vibratory analysis technique by improving the piezoelectric sensor measurement accuracy. Microwave and Optical Technology Letters 60: 13-14.
28. Zine Ghemari, Salah Saad (2018) Resonance effect decrease and accuracy increase of piezoelectric accelerometer measurement by appropriate choice of frequency. Journal of shock and vibration 1-8.
29. Zine Ghemari, Salah Saad (2018) Piezoresistive Accelerometer Mathematical Model Development With Experimental Validation. IEEE Sensors Journal 18: 2690-2696.
30. C Zhan, S Ji, Y Liu, L Zhu, Y Shi, et al. (2018) Winding Mechanical Fault Diagnosis Technique of Power Transformer Based on Time-Frequency Vibration Analysis. Condition Monitoring and Diagnosis 1-6.
31. RK Noubissi, L Daosheng, D Boxue (2023) Study on Harmonic Response Analysis and Vibration Reduction of Amorphous Metal Alloy Conference on Electrical Materials and Power Equipment 1-4.
32. HM XU, B WANG (2020) Vibration Analysis of High Pressure Mud Piping Systems and Vibration Reduction Method. 3rd World Conference on Mechanical Engineering and Intelligent Manufacturing 732-737.
33. H Qiu, F Song, H Mo (2015) Vibration analysis of traveling wave tube in working conditions. IEEE International Vacuum Electronics Conference 1-2.
34. AK Ovacikli, P Pääjärvi, JP LeBlanc (2013) Skewness as an objective function for vibration analysis of rolling element bearings. 8th International Symposium on Image and Signal

Processing and Analysis 462-466.
35. Zine Ghemari (2017) Study and analysis of the piezoresistive accelerometer stability and improvement of their performances. International Journal of Systems Assurance Engineering and Management 8: 1520-1526.
36. Mabrouk Defdaf, Zine Ghemari (2017) Improvement of Method Queues by Progress of the Piezoresistive Accelerometer Parameters. Journal of Advanced Manufacturing Systems 16: 227-235.
37. Zine Ghemari, Salah Saad (2017) Parameters improvement and suggestion of new design of capacitive accelerometer. Analog Integrated Circuits and Signal Processing 92: 443-451.
38. Zine Ghemari, Salah Saad (2017) Simulation and Experimental Validation of New Model for the Piezoresistive Accelerometer Displacement. Sensor Letters 15: 132-136.
39. Zine Ghemari (2017) New Formula for the Piezoresistive Accelerometer Motion Acceleration and Experimental Validation. Journal of Advanced Manufacturing Systems 16: 57-65.
40. IP Balabanov, VD Mogilevets, AA Shabaev (2022) Influence of Natural Vibration Frequencies in the Analysis on Vibration Resistance of Steel Supporting Parts of a Car. International Russian Automation Conference 448-452.
41. J Bian, P Wang, Q Mei, M Lei (2014) Fault detection of rolling bearings through vibration analysis via the hybrid CEEMD-EMD approach. Prognostics and System Health Management Conference 245-250.
42. W Dehina, M Boumehraz, F Kratz, J Fantini (2019) Diagnosis and Comparison between Stator Current Analysis and Vibration Analysis of Static Eccentricity Faults in The Induction Motor. 4th International Conference on Power Electronics and their Applications 1-4.
43. Y Chen, Y Li, Y Peng, L Luo (2015) Vibration modal analysis and calculation of a new HVDC converter transformer with inductive filtering method. 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies 1683-1688.
44. M Li, M Wang, X Kan, X Zhang, Q Sun (2020) Random Vibration Analysis in Mechanical Environment of Satellite Laser Communication Terminal Telescope. 2nd International Conference on Artificial Intelligence and Advanced Manufacture 373-376.
45. Y Wang, H Zhang, Y Ji, M Xiong, Z Shen (2022) Micro-Vibration Prediction and Evaluation Analysis of the Structural Foundation of a Precision Instrument Plant Across the Reservoir. 8th International Conference on Hydraulic and Civil Engineering : Deep Space Intelligent Development and Utilization Forum 1287-1291.
46. L Tao, C Yajun, L Chengfu, Z Xianghai, W Qingquan, et al. (2021) Research on correlation between modal and vibration of EMU bogie. 4th International Conference on Electron Device and Mechanical Engineering 189-195.
47. Zine Ghemari, Salah Saad (2014) Reducing the Measurement Error to Optimize the Sensitivity of the Vibration Sensor. IEEE Sensors Journal 14: 5.
48. Zine Ghemari, Salah Saad (2013) Development of measurement precision of sensor vibration. Journal of Vibration and Control 19: 1480-1486.
49. Zine Ghemari, Salah Saad (2013) Modeling and enhancement of mechanical sensitivity of vibration sensor. Journal of Vibration and Control 20: 14.
50. Zine Ghemari, Salah Saad (2012) Development of model and enhancement of measurement precision of sensor vibration. IEEE Sensors Journal 12: 3454-3459.
51. Z Yu, D Li, L Chen (2018) Statistical analysis of vibration characteristics of power transformers with different voltage levels. 12th International Conference on the Properties and Applications of Dielectric Materials 694-699.
52. D Liu, C Cai, B Wei, M Yan (2020) Investigation on the AMDT Core Model Vibration by Harmonic Response Analysis and Validation of the Resonance Characteristics by Testing. 8th International Conference on Condition Monitoring and Diagnosis 43-46.
53. X Jiang, X Shang, Y Jiang (2022) Characteristic Analysis and Optimization Strategy of Transformer Vibration Signal. IEEE International Conference on Power Systems Technology 1-5.
54. F Yang, Y Pan (2020) Vibration Mode Analysis of Casting Flash Cutting Machine. 5th International Conference on Mechanical, Control and Computer Engineering 130-134.
55. S Wang, H Zhang, M Liu, D Zhang, G. Wang (2022) Ice-induced vibration and fatigue analysis on monopile foundation of offshore wind turbine. IEEE International Conference on Advances in Electrical Engineering and Computer Applications 1526-1531.
56. J Chao, J Ruihong, H Wen, H Jiani (2020) Comparative Experiments of Optical Fiber Sensor and Piezoelectric Sensor based on Vibration Detection. IEEE 4th International Conference on Frontiers of Sensors Technologies 17-20.
57. S Wang, J Lu, N Zhao, Z Xu, Y Li (2013) Trasient dyamic analysis of crankshaft torsinal vibration for reciprocating piston compressor. International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering 1910-1916.
58. D Maga, J Hrad, J Hajek, A Boulerie (2020) FE Analysis of a Vibration Measuring Stand for Energy Harvester. 19th International Conference on Mechatronics - Mechatronika 1-4.
59. S Saad, Z Ghemari, L Herous, OE Hadjadj (2007) Transducer (Accelerometer) Modeling and Simulation. Asian J Inform Tech 6: 54-57.
60. Zine Ghemari, Abdelaziz Lakehal (2014) Vibration sensor mechanical sensitivity improvement. International Conference on Electrical Sciences and Technologies 1-4.
61. Zine Ghemari, Salah Saad (2013) Improvement of piezoresistive accelerometer performance. 3rd International Conference on Systems and Control 1-4.
62. Q Rongkai, S Jang, B Luqiang, T Yu (2017) Vibration analysis of transonic wind tunnel air-supply pipeline and vibration attenuation technology research. International Conference on Mechanical, System and Control Engineering 106-110.
63. Y Yunong, W Qing (2021) Analysis of Vibration Noise and Transmission Characteristics of Flow-induced Rudder. OES China Ocean Acoustics 456-459,
64. Y Lin, J Zhang, D Huang (2021) Study on Vibration Reduction Indicator of Metal Bellows Using Finite Element Analysis. IEEE 12th International Conference on Mechanical and Intelligent Manufacturing Technologies 91-95.
65. H Song, E Song, Y Liu, B Wang, Q Wang, et al. (2023) Miniature FBG Vibration Sensor With High Performance and Low Angle Dependence for Two-Dimensional Vibration Measurement. IEEE Transactions on Instrumentation and Measurement 72: 1-11.
66. BK Jun, GT Kim, HK Shin (2018) The Radial Magnetic Force Reduction Design for Vibration and Harmonic Impact Analysis. 21st International Conference on Electrical Machines and Systems 476-479.
67. L. Zhong, Meng Gao, Dan Zhou, Zhiqin Ma, Xian Yang, et

al. (2023) Simulation Analysis of Mechanical Performance of 500kV Transformer Ascending Flanged Base Under Vibration Excitation. IEEE 6th International Electrical and Energy Conference 3061-3065.
68. Zine Ghemari, A Lakehal (2015) Minimisation of resonance phenomena effect of piezoresistive accelerometer. The 4th International Conference on Systems and Control 28-30.
69. Zine Ghemari, A Lakehal (2015) Probabilistic approach for the management of drinking water distribution networks. 3ème Conférence Internationale sur la Maintenance et la Sécurité Industrielle 32-38.
70. Zine Ghemari (2016) Upgrading of piezoresistive accelerometer response. 8th International Conference on Modelling, Identification and Control 1-4.
71. Reguieg Salima Khaoula, Zine Ghemari, Tarak Benslimane (2018) Extraction of the relative sensitivity model and improvement of the piezoelectric accelerometer performances. 4th International Conference on Signal, Image, Vision and their Applications 5-8.
72. Zine Ghemari (2018) Decrease of the resonance phenomenon effect and progress of the piezoelectric sensor correctness. The International Conference on Electrical Sciences and Technologies 60-78.
73. Zine Ghemari (2018) Analysis and optimization of vibration sensor. IEEE International Conference on Smart Materials and Spectroscopy 1-4.
74. RP Linessio, JC Cardozo da Silva, L Henrique dos Santos Tavares, T da Silva, CA Bavastri (2017) Vibration analysis of a cantilever beam with viscoelastic neutralizers using fiber Bragg gratings. SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference 1-5.
75. CC Chen, JY Chang (2013) Vision-Assisted Vibration Analysis of Inhomogeneous Flexible Cables in Hard Disk Drives. IEEE Transactions on Magnetics 49: 2628-2633.
76. XY Fang, XY Li, Km Hu, G Yan, JH Wu, et al. (2022) Destructive Reliability Analysis of Electromagnetic MEMS Micromirror Under Vibration Environment. IEEE Journal of Selected Topics in Quantum Electronics 28: 1-8.
77. F Aswin, ZS Suzen (2018) Analysis of free vibration measurement by mems accelerometer device on wind turbine blade. International Conference on Applied Science and Technology 425-431.
78. S Das, MW Rahman, D Roy, M Sengupta (2022) Investigation on the Vibration of a 3-Phase SRM Analysis. IEEE 1st Industrial Electronics Society Annual On-Line Conference 1-5.
79. LF Zhang, BS Jiang, PQ Zhang, YB Hui (2021) Random Vibration Fatigue Analysis of Base In Macro-micro Motion Platform. Global Reliability and Prognostics and Health Management 1-6.
80. Zine Ghemari (2018) Improvement of the piezoelectric sensor by the progress of the measurement accuracy. IEEE International Conference on Smart Materials and Spectroscopy 5-8.
81. Zine Ghemari (2019) Enhancement of the vibratory analysis technique by the accelerometer characteristics evolution. The 7th International Conference on Control Engineering & Information Technology 24-26.
82. Zine Ghemari (2019) The accelerometer characteristics improvement. The 7th International Conference on Control Engineering & Information Technology 32-36.
83. Zine Ghemari, Salah Belkhiri, MR Morakchi (2022) Improvement of the vibration analysis technique by optimizing the parameters of the piezoelectric accelerometer. IEEE 21st international Ccnference on Sciences and Techniques of Automatic Control and Computer Engineering 183-186.
84. Ghemari Z, Saad S, Amrouche A, Lakehal A (2015) New model of piezoelectric accelerometer relative movement modulus. Transactions of the Institute of Measurement and Control 37: 932-941.
85. Junchao Guo, Qingbo He, Dong Zhen, Fengshou Gu, Andrew D Ball (2023) Multi-sensor data fusion for rotating machinery fault detection using improved cyclic spectral covariance matrix and motor current signal analysis. Reliability Engineering & System Safety 230: 108969.
86. Xinnan Yu, Zhipeng Feng, Dong Zhang (2022) Adaptive high-resolution order spectrum for complex signal analysis of rotating machinery: Principle and applications. Mechanical Systems and Signal Processing 177: 109194.
87. Z Ghemari, Salah Belkhiri, Saad Salah (2024) A piezoelectric sensor with high accuracy and reduced measurement error. Journal of Computational Electronics 1-8.
88. Z Ghemari, Salah Belkhiri, Saad Salah (2023) Appropriate choice of Capacitive sensor bandwidth. Preprint in Research Square 1-8.