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Application of vibration analysis for medical diagnosis

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Highlights

- The application of vibration analysis in medical diagnosis offers a diverse range of benefits, from non-invasive diagnostics to early detection and continuous monitoring of various health conditions.
- As technology continues to advance, the integration of vibration analysis into medical practices holds promise for enhancing diagnostic accuracy and improving patient outcomes.

Abstract

The ability to interpret vibration signals in the biomedical field offers a promising path toward continuous improvement of medical devices. By examining the revolutions per minute profile, analysts can identify any deviations or anomalies in the vibration patterns at different speeds. This information can help identify potential faults or imbalances within the rotating machinery. With a comprehensive understanding of the revolutions per minute profile, analysts can make informed decisions regarding maintenance and repairs. Besides, the analysis of the order of vibration signals represents an essential pillar of biomedical engineering, bringing an innovative and in-depth perspective to the development of medical devices, and contributing to the continued advancement of medical technology and healthcare. Integrating vibration analysis into preventive maintenance practices can help ensure the reliability of medical equipment, reduce potential risks to patients, and contribute to the advancement of healthcare quality.

Keywords: Vibration analysis, medical devices, biomedical

Introduction

Vibration is a common phenomenon in various mechanical systems and structures, ranging from rotating machinery like motors, pumps, and turbines to bridges, buildings, and vehicles [1-3]. When a mechanical system operates, it generates vibrations because of imbalances, misalignments, wear, resonance, structural weaknesses, or other mechanical faults [4-7].

Vibration analysis is a vital technique used to assess the condition and performance of machinery and structures [8-12]. It involves measurement, analysis, and interpretation of vibration signals to identify potential problems, such as faults, anomalies, or mechanical problems [13-19]. Vibration analysis utilizes specialized sensors, such as accelerometers, to capture the vibrations induced by systems or structures [20-22]. These sensors measure the acceleration, velocity, or displacement of the vibrating component and convert the mechanical vibrations into electrical signals [23-25]. 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 [26-28]. 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 repair [29-31].

The key objectives of vibration analysis include:

- **Fault detection:** Identifying faults or anomalies in machinery or structures. This involves detecting issues like unbalance, misalignment, bearing wear, gear damage, resonance, and mechanical looseness.

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• **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.

• **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.

• **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.

• **Structural health monitoring:** Evaluating the condition and performance of structures, such as bridges, buildings, and wind turbines, to ensure their integrity and safety. Vibration analysis can detect signs of degradation, fatigue, or damage, enabling proactive maintenance and preventing catastrophic failures.

Order analysis stands as a crucial technique in the realm of vibration analysis, particularly in examining the vibrational signals emitted by rotating machinery. This methodology centers around the analysis of the signals in terms of rotational orders, which are harmonics corresponding to the fundamental rotational frequency of a rotating component, be it a gear or a shaft [32-35].

In essence, rotational orders encapsulate the multiples of the basic rotational frequency, unveiling a comprehensive perspective on the dynamic behavior of the machinery. By employing order analysis, engineers and maintenance professionals can gain valuable insights into the condition of the rotating components. This technique is proven to be indispensable for identifying specific fault frequencies, aiding in the accurate diagnosis of potential issues, and facilitating ongoing monitoring efforts [36].

In practical terms, order analysis involves processing vibration data to discern the presence and amplitude of rotational orders [37]. This information is instrumental in pinpointing irregularities, such as misalignments, unbalances, or bearing defects, that may affect the rotating machinery. The ability to isolate and interpret these harmonics provides a powerful diagnostic tool, contributing to proactive maintenance practices and the optimization of machinery reliability [38-40].

Ultimately, order analysis emerges as a vital component of predictive maintenance strategies, offering a nuanced understanding of the vibrational characteristics inherent in rotating machinery. Its applications extend across various industries, playing a pivotal role in ensuring operational efficiency, reducing downtime, and enhancing the overall reliability of critical rotating components [41-43].

Medical diagnosis by vibration analysis

Vibration analysis can be a valuable tool in medical diagnosis, providing insights into the mechanical properties of tissues and aiding in the detection and characterization of various medical conditions. Here are some specific applications of vibration analysis in medical diagnosis:

• **Elastography:** Elastography techniques use controlled vibrations to evaluate the stiffness of tissues. The presence of abnormal stiffness may indicate diseases such as liver fibrosis, breast tumors, and prostate cancer.

• **Ultrasound vibro-acoustography:** Combining ultrasound and vibration analysis, vibro-acoustography can provide detailed images of tissue structures and aid in the diagnosis of breast lesions, thyroid nodules, and other abnormalities.

• **Vibration analysis in orthopedics:** Assessing joint function and bone health by analyzing vibrations during movement can help diagnose conditions such as osteoarthritis and osteoporosis.

• **Vocal cord vibrations:** Analyzing vibrations in the vocal cords can help diagnose voice disorders and assess laryngeal health. This is particularly important in otolaryngology.

• **Cardiovascular vibration analysis:** Assessing the vibrations associated with blood flow dynamics aids in understanding cardiovascular conditions, such as detecting abnormal heart valve function and studying arterial stiffness.

• **Eye biomechanics:** Vibration analysis can be applied to study the biomechanics of the eye, aiding in the diagnosis of glaucoma and evaluating corneal health.

• **Dental diagnostics:** Analyzing vibrations in

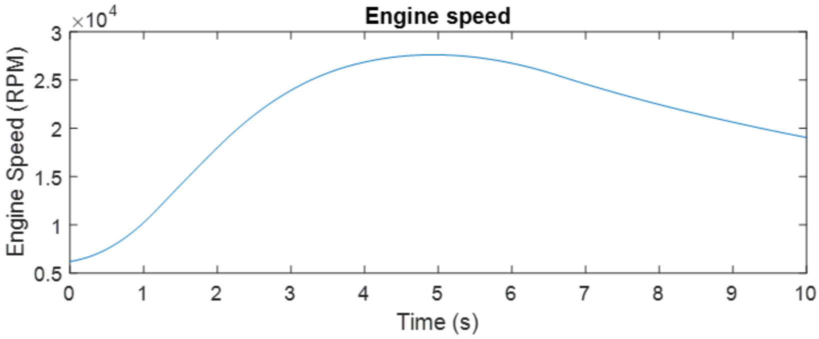

Figure 1. Motor speed as a function of time.

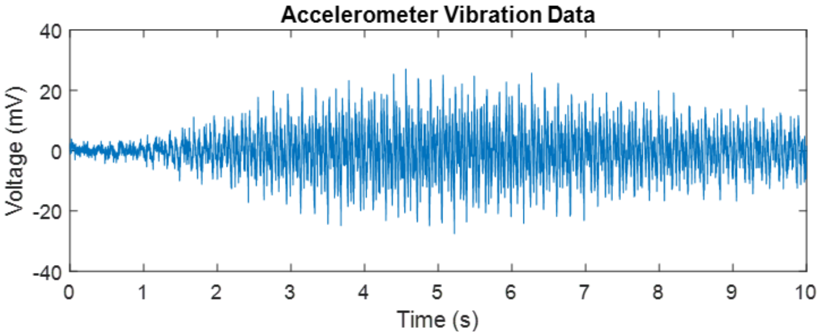

Figure 2. Accelerometer vibration data as a function of time.

teeth and jaws can assist in diagnosing dental conditions, including tooth fractures, bite forces, and temporomandibular joint disorders.

• **Vibration-based diagnostics in neurology:** Vibration analysis can be used to assess peripheral nerve function, helping diagnose carpal tunnel syndrome, diabetic neuropathy, etc.

• **Respiratory system analysis:** Analyzing vibrations associated with breathing patterns can aid in diagnosing respiratory diseases, such as asthma or chronic obstructive pulmonary disease.

• **Detection of abnormalities in organs:** Vibration analysis, when combined with imaging modalities, can help detect abnormalities in organs, such as tumors or cysts, by studying their mechanical properties.

• **Gastrointestinal system assessment:** Vibration analysis can be applied to assess the motility of the gastrointestinal tract, aiding in the diagnosis of irritable bowel syndrome and gastroparesis. etc.

In each of these applications, vibration analysis provides additional diagnostic information that complements traditional imaging techniques, contributing to more accurate and comprehensive medical assessments. The continuous exploration in vibration analysis can contribute to the improvement of diagnostic capabilities in various medical specialties.

Order analysis of a vibration signal in the field of biomedical engineering

Analysis of the order of a vibration signal is of crucial importance in the field of biomedical engineering, especially in the medical devices assisted diagnosis. This approach allows a detailed assessment of the vibration signals emitted by medical devices, providing valuable information on their performance, operational status, and structural integrity. In the biomedical context, where the reliability and safety of devices are paramount, vibration order analysis is emerging as an essential tool to detect possible failures or anomalies.

This methodology can be applied to various medical devices, such as scanners, medical imaging devices, and infusion pumps. By understanding the characteristics of vibrations at specific frequencies, biomedical engineers can assess how well devices are functioning, anticipate potential problems, and implement preventative measures.

Analysis of the order of vibration signals in biomedical engineering also contributes to the development of safer and more effective medical devices. By identifying characteristic frequencies linked to specific phenomena, it is possible to optimize the device design and minimize unwanted vibrations.

A motor speed signal commonly consists of a sequence of tachometer pulses. Tachorpm function can be used to extract revolutions per minute (RPM) 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 in rpm, and hence no conversion is needed. See **Figure 1** and **Figure 2** for the motor speed and vibration data as functions of time.

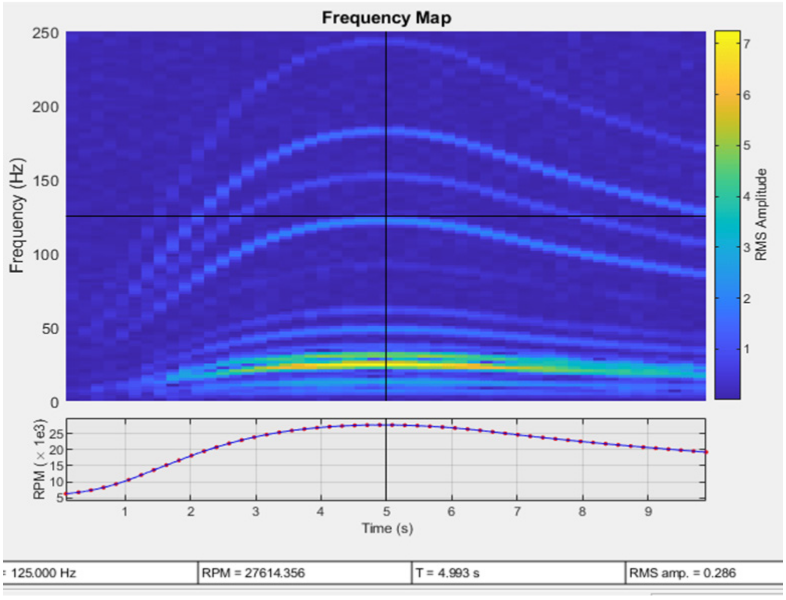

Figure 3. RPM-frequency map for vibration data. RPM: revolutions per minute.

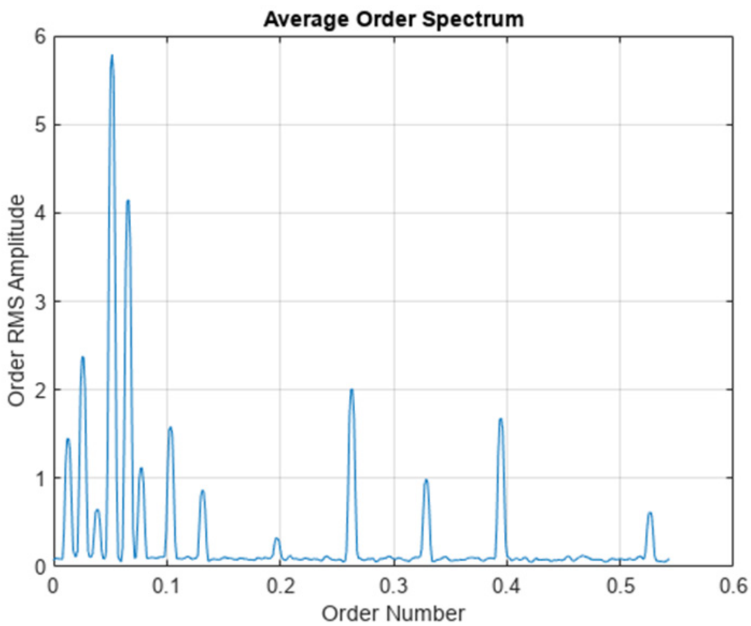

Figure 4. The average spectrum of map.

Figure 1 illustrates the variation in motor speed over time. The x-axis represents time, measured in seconds, depending on the duration of the data collection period. The y-axis represents motor speed, typically measured in RPM. The plot depicts how the motor speed changes throughout the recorded period. The trajectory of the curve provides insights into the motor's performance, behavior, and response to different conditions or stimuli.

Figure 2 illustrates the vibration data captured by an accelerometer over a specific duration of time. The x-axis represents time, typically measured in seconds, depending on the duration of the data collection period. The y-axis represents the accelerometer's vibration data, typically measured in units such as acceleration (m/s^2). The plot visually depicts how the vibration levels change over time, providing valuable insights into the dynamic behavior of the system being monitored. The trajectory of the curve reveals various characteristics of the vibration signal, which can be analyzed to assess the condition, performance, and health of machinery or structures.

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 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 the analysis and interpretation of 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 identifying specific frequencies associated with faults, detecting resonance effects, understanding gear, and bearing behavior, and diagnosing potential issues occurring at specific rotational speeds.

Visualizing data using an RPM-frequency map

The innovative approach to vibration analysis, utilizing an RPM-frequency map, exemplifies the intersection of data science and machinery diagnostics. By providing a visual narrative of the vibrational landscape, this technique enhances the precision and efficiency of maintenance practices, contributing to overall reliability and performance optimization.

Visualizing the vibration data using an RPM-frequency map facilitates the identification of potential dysfunction areas and aids in the diagnosis of rotating machinery. It provides a comprehensive overview of the vibration behavior of machinery across different RPM ranges, facilitating effective decision-making for maintenance, optimization, and ensuring reliable machinery operation (**Figure 3**).

Determining peak orders using an average order spectrum

Vibration analysis is a pivotal tool in predictive maintenance, allowing for the early detection of potential issues in machinery. An advanced technique in this domain involves the determination of peak orders using an average order spectrum, providing a nuanced understanding of the dynamic behavior of rotating equipment.

By determining peak orders using an average order spectrum (**Figure 4**), analysts can identify dominant frequency components associated with specific rotation orders, such as gear meshing frequencies or bearing fault frequencies. This provides essential information for diagnosing faults, assessing the condition of rotating machinery and optimizing operational parameters. Additionally, combining mid-order spectrum with other diagnostic techniques, such as envelope analysis or trend analysis, can improve fault detection and health monitoring capabilities. It involves calculating the average power spectral density or amplitude spectrum from multiple measurements. This averaging helps reduce the impact of random noise and highlights consistent frequency components.

In vibration analysis, maps can be used to show the relationship between different parameters, such as frequency and amplitude, in a spatial arrangement.

Conclusion

In conclusion, the analysis of the order of a vibration signal is emerging as an invaluable method in the field of biomedical engineering, especially in medical devices assisted diagnosis. This approach explores and interpret vibration characteristics in detail, thus providing significant advantages for the maintenance, reliability, and safety of medical devices.

Using order analysis, biomedical engineers can not only detect anomalies and potential failures but also anticipate emerging issues before they compromise device integrity or performance. This methodology provides an in-depth understanding of the specific frequencies associated with different phenomena, thereby facilitating the optimal design of safer and more effective medical devices.

References

[1] Ghemari Z. Progression of the vibratory analysis technique by improving the piezoelectric sensor measurement accuracy. Microw Opt Technol Lett 2018;60:2972-2977.

[2] Ghemari Z, Salah S, Bourenane R. Resonance Effect Decrease and Accuracy Increase of Piezoelectric Accelerometer Measurement by Appropriate Choice of Frequency Range. Shock Vib 2018;2018:5370438.

[3] Zhan C, Ji S, Liu Y, et al. Winding Mechanical Fault Diagnosis Technique of Power Transformer Based on Time-Frequency Vibration Analysis. 2018 Condition Monitoring and Diagnosis (CMD) 2018;1-6.

[4] Noubissi RK, Daosheng L, Boxue D. Study on Harmonic Response Analysis and Vibration Reduction of Amorphous Metal Alloy Transformer. 2023 IEEE 4th International Conference on Electrical Materials and Power Equipment (ICEMPE) 2023;1-4.

[5] Defdaf M, Ghemari Z, Elias Hadjaj A, et al. Improvement of Method Queues by Progress of the Piezoresistive Accelerometer Parameters. J Adv Manuf Syst 2017;16:227-235.

[6] Ghemari Z, Saad S. Parameters improvement and suggestion of new design of capacitive accelerometer. Analog Integr Circuits Signal Process 2017;92:443-451.

[7] Ghemari Z, Salah S. Simulation and Experimental Validation of New Model for the Piezoresistive Accelerometer Displacement. Sens Lett 2017;15:132–136.

[8] Ghemari Z, Belkhiri S, Saad S. Improvement of the Relative Sensitivity for Obtaining a High Performance Piezoelectric Sensor. IEEE Instrum Meas Mag 2023;26:49-56.

[9] Ghemari Z, Belkhiri S, Saad S. A capacitive sensor with high measurement accuracy and low electrical energy consumption. Appl Phys A 2023;129:362.

[10] Ghemari Z, Salah S, Defdaf M. Appropriate Choice of Damping Rate and Frequency Margin for Improvement of the Piezoelectric Sensor Measurement Accuracy. J Adv Manuf Syst 2021;1-12.

[11] Li C, Li J, Fang XL, et al. Application of a Method of Identifiying Instantaneous Shaft Speed from Spectrum in Aeroengine

Vibration Analysis. 2022 Global Reliability and Prognostics and Health Management (PHM-Yantai) 2022;1-7.
[12] Khatri P, Chhatre U, Kadge S. Visual Vibration Analysis of Vibrating Object at Low Frequency. 2021 6th International Conference for Convergence in Technology (I2CT) 2021;1-5.
[13] Belkhiri S, Ghemari Z, Saad S, et al. Improvement of the Vibratory Analysis by Enhancement of Accelerometer Characteristics. Sens Lett 2020;18:39-42.
[14] Ghemari Z, Saad S. Defects Diagnosis by Vibration Analysis and Improvement of Vibration Sensor Measurement Accuracy. Sens Lett 2019;17:608-613.
[15] Ghemari Z, Saad S, Khettab K. Improvement of the Vibratory Diagnostic Method by Evolution of the Piezoelectric Sensor Performances. Int J Precis Eng Manuf 2019;20:1361-1369.
[16] Ghemari Z, Saad S. Enhancement of capacitive accelerometer operation by parameters improvement. Int J Numer Modell: Electron Networks, Devices Fields 2019;32:e2568.
[17] Cao H, Huang T, Lu L, et al. Research on Quasi-zero Stiffness Vibration Isolation Technology of Distribution Transformer. 2021 IEEE 4th International Conference on Automation, Electronics and Electrical Engineering (AUTEEE) 2021;613-617.
[18] Tian Y, An T, Qin F, et al. Stress analysis of automotive IGBT module under vibration load. 2022 23rd International Conference on Electronic Packaging Technology (ICEPT) 2022;1-4.
[19] Coronado LOB, Ballesteros LIM, Geraldo EJT, et al. Finite Element Modal Analysis and Harmonic Response Analysis of a 3D Printed Vibration Sensor Enclosure. 2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM) 2021;1-5.
[20] Ghemari Z, Chouaf F, Saad S. New Formula for the Piezoresistive Accelerometer Motion Acceleration and Experimental Validation. J Adv Manuf Syst 2017;16:57-65.
[21] Balabanov IP, Mogilevets VD, Shabaev AA. Influence of Natural Vibration Frequencies in the Analysis on Vibration Resistance of Steel Supporting Parts of a Car. 2022 International Russian Automation Conference (RusAutoCon) 2022;448-452.
[22] Wang Y, Zhang H, Ji Y, et al. Micro-Vibration Prediction and Evaluation Analysis of the Structural Foundation of a Precision Instrument Plant Across the Reservoir. 2022 8th International Conference on Hydraulic and Civil Engineering: Deep Space Intelligent Development and Utilization Forum (ICHCE) 2022;1287-1291.
[23] Liu T, Cheng YJ, Li CF, et al. Research on correlation between modal and vibration of EMU bogie. 2021 4th International Conference on Electron Device and Mechanical Engineering (ICEDME) 2021;189-195.
[24] Yu Z, Li D, Chen L. Statistical analysis of vibration characteristics of power transformers with different voltage levels. 2018 12th International Conference on the Properties and Applications of Dielectric Materials (ICPADM) 2018;694-699.
[25] Liu D, Cai C, Wei B, et al. Investigation on the AMDT Core Model Vibration by Harmonic Response Analysis and Validation of the Resonance Characteristics by Testing. 2020 8th International Conference on Condition Monitoring and Diagnosis (CMD) 2020;43-46.
[26] Jiang X, Shang X, Jiang Y. Characteristic Analysis and Optimization Strategy of Transformer Vibration Signal. 2022 IEEE International Conference on Power Systems Technology (POWERCON) 2022;1-5.
[27] Wang S, Zhang H, Liu M, et al. Ice-induced vibration and fatigue analysis on monopile foundation of offshore wind turbine. 2022 IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA) 2022;1526-1531.
[28] Chao J, Ruihong J, Wen H, et al. Comparative Experiments of Optical Fiber Sensor and Piezoelectric Sensor based on Vibration Detection. 2020 IEEE 4th International Conference on Frontiers of Sensors Technologies (ICFST) 2020;17-20.
[29] Maga D, Hrad J, Hajek J, et al. FE Analysis of a Vibration Measuring Stand for Energy Harvester. 2020 19th International Conference on Mechatronics - Mechatronika (ME) 2020;1-4.
[30] Yang YN, Wang Q. Analysis of Vibration Noise and Transmission Characteristics of Flow-induced Rudder. 2021 OES China Ocean Acoustics (COA) 2021;456-459.
[31] Lin Y, Zhang J, Huang D. Study on Vibration Reduction Indicator of Metal Bellows Using Finite Element Analysis. 2021 IEEE 12th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT) 2021;91-95.
[32] Song H, Song E, Liu Y, et al. Miniature FBG Vibration Sensor With High Performance and Low Angle Dependence for Two-Dimensional Vibration Measurement. IEEE Trans Instrum Meas 2023;72:1-11.
[33] Zhong L, Gao M, Zhou D, et al. Simulation Analysis of Mechanical Performance of 500kV Transformer Ascending Flanged Base

Under Vibration Excitation. 2023 IEEE 6th International Electrical and Energy Conference (CIEEC) 2023;3061-3065.
[34] Ghemari Z. Decrease of the resonance phenomenon effect and progress of the piezoelectric sensor correctness. 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM) 2018;1-5.
[35] Ghemari Z. Analysis and optimization of vibration sensor. 2018 IEEE International Conference on Smart Materials and Spectroscopy (SMS) 2018;1-5.
[36] Linessio RP, Silva JCCd, Tavares LHdS, et al. Vibration analysis of a cantilever beam with viscoelastic neutralizers using fiber Bragg gratings. 2017 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC) 2017;1-5.
[37] Fang XY, Li XY, Hu KM, et al. Destructive Reliability Analysis of Electromagnetic MEMS Micromirror Under Vibration Environment. IEEE J Sel Top Quantum Electron 2022;28:1-8.
[38] Aswin F, Suzen ZS. Analysis of free vibration measurement by mems accelerometer device on wind turbine blade. 2018 International Conference on Applied Science and Technology (iCAST) 2018;425-431.
[39] Das S, Rahman MW, Roy D, et al. Investigation on the Vibration of a 3-Phase SRM Analysis. 2022 IEEE 1st Industrial Electronics Society Annual On-Line Conference (ONCON) 2022;1-6.
[40] Zhang LF, Jiang BS, Zhang PQ, et al. Random Vibration Fatigue Analysis of Base In Macro-micro Motion Platform. 2021 Global Reliability and Prognostics and Health Management (PHM-Nanjing) 2021;1-6.
[41] Ghemari Z. Improvement of the piezoelectric sensor by the progress of the measurement accuracy. 2018 IEEE International Conference on Smart Materials and Spectroscopy 2018;1-5.
[42] Ghemari Z. Enhancement of the vibratory analysis technique by the accelerometer characteristics evolution. The 7th International Conference on Control Engineering & Information Technology 2019;1-4.
[43] Ghemari Z, Belkhiri S, Morakchi MR. Improvement of the vibration analysis technique by optimizing the parameters of the piezoelectric accelerometer. 2022 IEEE 21st international Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA) 2022;183-186.