SCIENCE SET
OPEN ACCESS PUBLISHERS

ISSN: 3066-7194
Review Article

Novel Journal of Applied Sciences Research

Navigating Fatigue Analysis with Rain flow Counting: A Practical Overview

Zine Ghemari

Mohamed Boudiaf University of M'sila, Algeria

***Corresponding author:** Zine Ghemari, Mohamed Boudiaf University of M'sila, Algeria

Submitted: 04 January 2024 **Accepted:** 11 January 2024 **Published:** 22 January 2024

https://doi.org/10.63620/MKNJASR.2024.1001

Citation: *Ghemari, Z. (2024). Navigating Fatigue Analysis with Rain flow Counting: A Practical Overview. Nov Joun of Appl Sci Res, 1(1), 01-06.*

Abstract

Fatigue analysis is a critical aspect of structural engineering and material design, focused on understanding the progressive weakening of materials and structures subjected to repetitive loading and unloading. Despite stresses below the material's yield strength, fatigue failures can occur over time, necessitating sophisticated methods for accurate fatigue life assessment. Rainflow counting, a widely employed technique, simplifies the task of processing and analyzing fatigue data. This article briefly introduces fatigue analysis using Rainflow counting, delving into its principles, applications, and advantages.

Introduction

Rainflow counting is a widely used technique in fatigue analysis that allows for the quantification of stress cycles in a loading history. It is especially applicable to irregular, non-periodic loading conditions commonly encountered in real-world applications. The method involves identifying and counting the turning points (peaks and valleys) in a stress or strain signal and then grouping these turning points into ranges. These ranges, or cycles, are then used to construct a fatigue damage histogram, providing insights into the distribution of loadings and aiding in the prediction of fatigue life.

Vibration analysis is another integral component of fatigue analysis, particularly in dynamic systems. It involves studying the vibrational behavior of components under various loading conditions to identify potential sources of fatigue-inducing stress. Vibration analysis utilizes techniques such as Fast Fourier Transform (FFT) to analyze the frequency content of signals, helping engineers identify resonant frequencies and potential areas of concern. By understanding the vibrational characteristics of a system, engineers can make informed decisions to mitigate fatigue-related issues [1-7].

Vibration analysis allows engineers to pinpoint potential areas of concern within a system. Whether it's a structural component, a rotating machine, or an entire building, understanding the vibrational characteristics helps identify locations where fatigue-related issues may arise. This targeted insight is instrumental in devising preventive measures.

Armed with a comprehensive understanding of the vibrational characteristics and potential fatigue-inducing factors, engineers can make informed decisions. This may involve adjusting operational parameters, implementing damping mechanisms, altering structural designs, or scheduling maintenance activities to proactively address fatigue-related concerns.

Ultimately, the goal of vibration analysis in the context of fatigue is to facilitate proactive measures for mitigating potential issues. By addressing resonant frequencies and understanding the dynamic behavior of a system, engineers can implement modifications or improvements to enhance the system's resilience and extend its fatigue life.

Fatigue Phenomenon: Unraveling Structural Deterioration

Fatigue is characterized by the degradation of a material's structural properties due to damage induced by cyclic or fluctuating stresses. A key feature of fatigue lies in the progressive damage and strength loss caused by cyclic stresses, each stress individually insufficient to fracture the material [8-13]. The American Society for Testing and Materials (ASTM) provides a formal definition, stating:
"The process of progressive localized permanent structural change occurring in a material subject to conditions that produce fluctuating stresses and strains at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations" [14-21].

The fatigue process unfolds gradually over time, often culminating in sudden failure without apparent warning. Importantly, the mechanisms triggering fatigue may have been in motion since the initial use of the component or structure. Unlike affecting the entire structure uniformly, fatigue operates at localized areas, characterized by elevated stresses and strains. External load transfer, abrupt geometry changes, temperature differentials, residual stresses, or material imperfections contribute to these localized stress concentrations.

The fatigue process involves cyclic stresses and strains, requiring more than sustained loads. However, for the fatigue process to become critical, the magnitude and amplitude of fluctuating stresses and strains must surpass specific material limits. At the heart of all fatigue failures lies a crack that extends to a point where the material can no longer withstand the stress, resulting in abrupt fracture. The final stage, known as ultimate failure or fracture, manifests when the component or structure breaks into two or more parts [21-27].

Vibration Analysis: Decoding Structural Behavior

Vibration analysis delves into the study of mechanical vibrations and oscillations within structures. It involves the measurement and analysis of vibrations to understand structural behavior, detect faults, and optimize performance (see Figure 1)

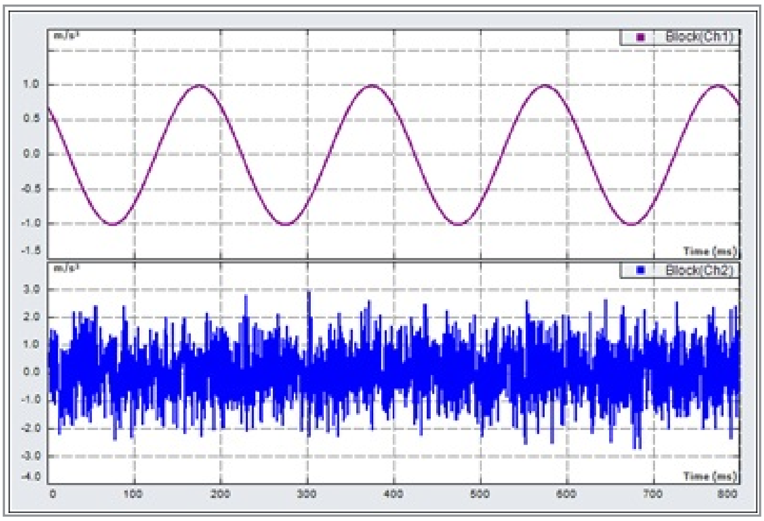

Figure 1: Spectrum of vibration analysis

Key aspects include:

- Dynamic Response Analysis: Studying how structures respond to dynamic loads and identifying natural frequencies and mode shapes.
- Fault detection and diagnostics: Detecting irregularities or faults in machinery and structures by analyzing changes in vibration patterns.
- Modal Analysis: Determining the modes of vibration and associated frequencies, aiding in structural design and modification.

Understanding Stress and Strain: Foundations of Mechanical Analysis

Stress, symbolized by σ, serves as a metric for external force, denoted as F, exerted across the cross-sectional area, A, of an object [3, 4]. Stress is quantified in units of force per area, with the standard International System of Units (SI) using pascals (Pa), where 1 Pa equals 1 N/m^2. In the United States, an alternative unit is pounds per square inch (psi), with 1 psi equaling 1 lb/in^2 [28-36].

The stress experienced can either be constant or variable in amplitude. In the scenario presented, a variable amplitude stress profile is applied to a mechanical component constructed from steel UNS G41300. Subsequently, the damage induced by this stress profile is calculated for analysis (see figure 2).

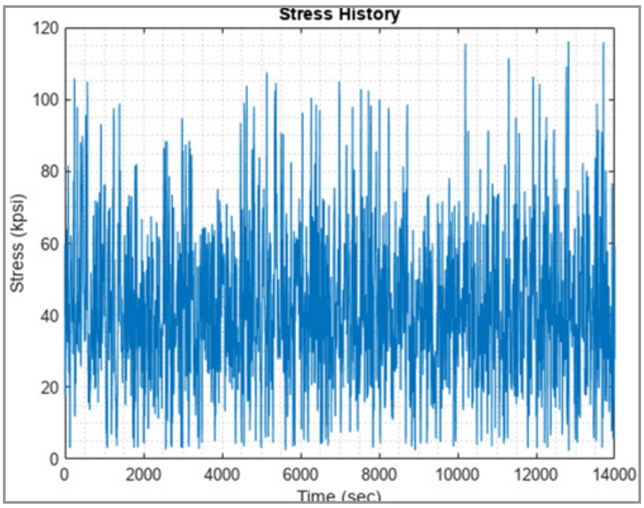

Figure 2: Stress history

Stress, a crucial measure in material analysis, is often described through key parameters that elucidate its behavior and impact on materials. These parameters play a crucial role in understanding the stress profile's characteristics and their implications on materials. The figure below illustrates these stress parameters, providing a visual representation of their significance in stress (see Figure 3) [37-41].

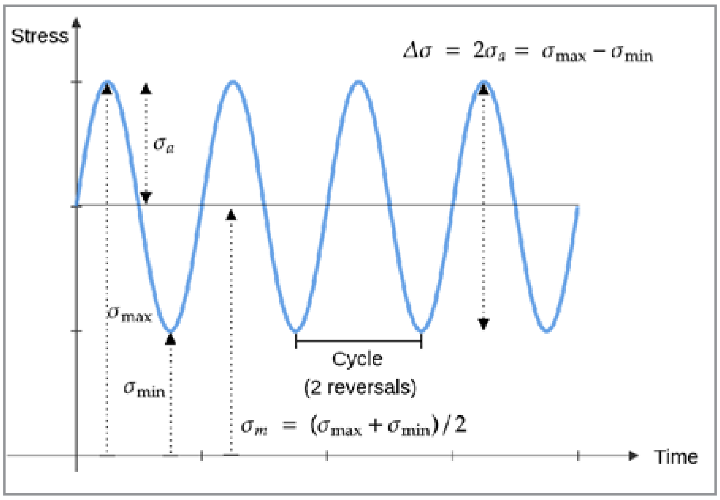

Figure 3: Stress parameters

In stress analysis, a half cycle denotes a pair of consecutive extrema in the stress signal, encompassing the transition from a minimum to a maximum or vice versa. In the context of a variable-amplitude stress history, defining a single cycle becomes ambiguous, leading to the adoption of the concept of a reversal. In this context, two consecutive half cycles or reversals collectively form a complete cycle, providing a clearer framework for understanding stress fluctuations and their impact on materials [41-45].

Understanding the Relationship Between Stress and Strain: Hooke's Law and Elasticity
A constitutive law governs the connection between stress and strain as tensile stress is applied to an object, the extent of deformation increases. In scenarios involving small values of strain, the relationship between stress (σ) and strain (ϵ) is linear, expressed as $\sigma \propto \epsilon$. This linear correlation is encapsulated in Hooke's Law, where the proportionality factor, often denoted as E, represents Young's elastic modulus [46-49].

The range where Hooke's Law holds is termed the elastic region. Within this domain, stress and strain exhibit a linear relationship, allowing for predictable deformations. However, as stress values escalate, the stress-strain relation becomes nonlinear, transitioning into the plastic region. The figure below illustrates a typical stress-strain plot for a ductile metal like steel, showcasing the distinct characteristics of the elastic and plastic regions (see figure 4) [50-53].

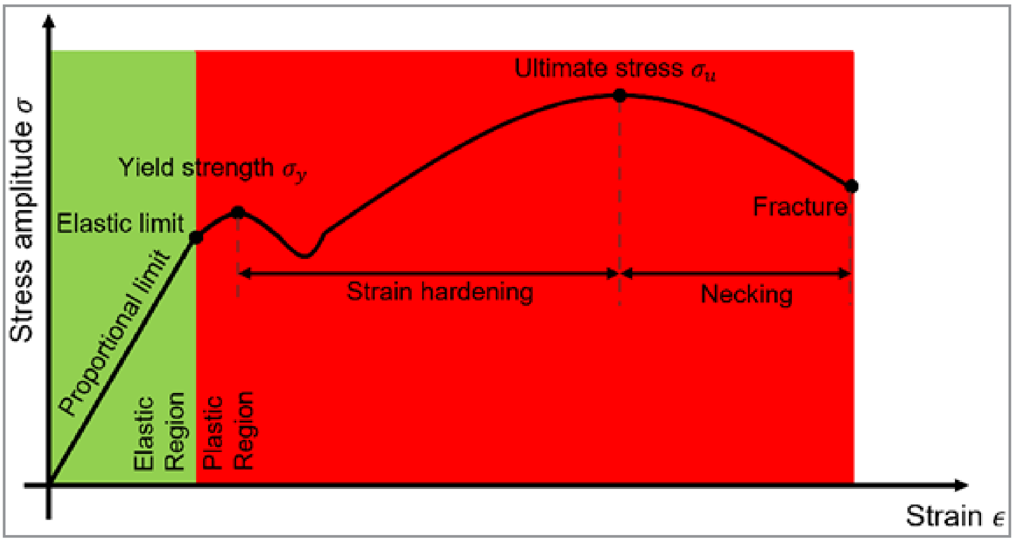

Figure 4: Showcases the distinct characteristics of the elastic and plastic regions

Visualizing these points on the stress-strain curve offers valuable insights into the material's elastic and plastic behaviors, ultimate strength, and the critical juncture leading to failure.

Decoding Fatigue Life and Damage in Mechanical Components
The fatigue life (NF) of a mechanical component represents the number of stress cycles necessary for fracture occurrence. This parameter is influenced by various factors, encompassing stress level, stress state, cyclic waveform, fatigue environment, and the metallurgical state of the material. Crack initiation testing, a common method for measuring fatigue life, involves subjecting mechanical components to stress cycles until a fatigue crack initiates and subsequently grows large enough to induce fracture [5]. Laboratory fatigue testing typically utilizes axial loading, generating tensile and compressive stresses. The stress is cycled between maximum and minimum tensile stresses or between maximum tensile and compressive stresses [54-61].

Results from fatigue crack initiation tests are often depicted as stress amplitude against the number of cycles needed for ultimate failure. Stress can be plotted on either a linear or logarithmic scale, while the number of cycles is typically presented on a logarithmic scale. This graphical representation is commonly known as a Wohler curve or an S-N curve. The figure below illustrates a typical Wohler curve for a mechanical component. The number of stress cycles a metal can withstand before failure increases as stress decreases. Notably, for certain materials like titanium, the Wohler curve levels off at a specific stress limit, often tered the endurance limit. Below this threshold, the component can endure an infinite number of cycles without experiencing failure (see figure 5) [61-64].

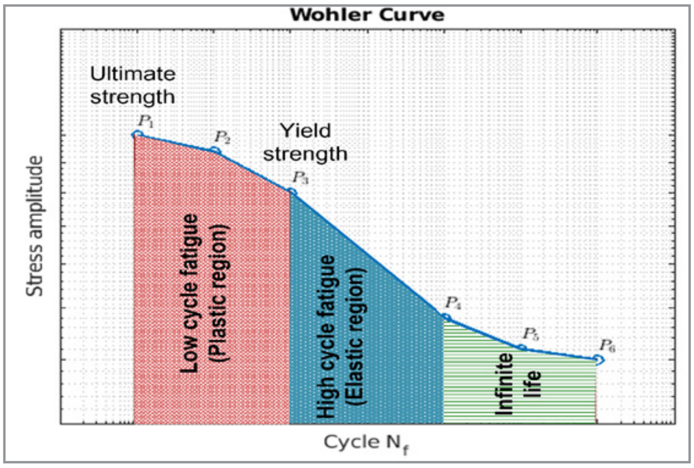

Figure 5: Wohler curve

In practical scenarios, conducting fatigue tests for all potential stress amplitudes proves impractical due to time and cost constraints. To streamline the process and enhance efficiency, models are often employed to fit the S-N (stress-number of cycles to failure) data points. For numerous materials, a piecewise linear model is adept at representing S-N data when expressed in the log-log domain [65-67].

Conclusion

In conclusion, the fusion of Rainflow counting and vibration analysis provides a holistic approach to understanding and ensuring the health of structures and components. The synergy between fatigue analysis and dynamic response evaluation offers a comprehensive toolkit for engineers seeking to optimize performance, prevent failures, and extend the life of critical assets. As industries continue to evolve, this integrated approach remains pivotal in the pursuit of structural safety and reliability.

References

1. Song, Y., Yin, H., Wang, X., Sun, C., Maet, Y., et al. (2022). Design of a Wireless Distributed Real-time Muscle Fatigue Detection System. IEEE Biomedical Circuits and Systems Conference (BioCAS), 709-713.
2. Bin, F., Shuo, X., & Xiaofeng, F. (2019). A Fatigue Driving Detection Method Based on Multi Facial Features Fusion. 2019 11th ICMTMA, 225-229.
3. Xu, L., Chen, X., Cao, S., Zhang, X., & Chen, X. (2018). A Fatigue Involved Modification Framework for Force Estimation in Fatiguing Contraction. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 26, 2153-2164.
4. Ghemari, Z., Saad, S., & Khettab, K. (2019). Improvement of the vibratory diagnostic method by evolution of the piezoelectric sensor performances. International Journal of Precision Engineering and Manufacturing, 20, 1361-1369.
5. Reguieg, S. K., Ghemari, Z., Benslimane, T., & Saad, S. (2019). Modeling and Enhancement of Piezoelectric Accelerometer Relative Sensitivity'' Sensing and Imaging an International Journal, 20, 1.
6. Ghemari, Z., & Saad, S. (2018). Piezoresistive Accelerometer Mathematical Model Development with Experimental Validation. IEEE Sensors Journal, 18, 2690-2696.
7. Ghemari, Z., Saad, S., & Bourenane, R. (2018). Resonance effect decrease and accuracy increase of piezoelectric accelerometer measurement by appropriate choice of frequency range. Shock and Vibration.
8. Ghemari, Z. (2018). Progression of the vibratory analysis technique by improving the piezoelectric sensor measurement accuracy. Microwave and Optical Technology Letters, 60, 2972-2977.
9. Ghemari, Z. (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.

10. Niu, H., Zhu, L., Cheng, T., Zhong, X., Li, J., et al. (2022). EMG-based Assessment of Shank Muscle Fatigue During Dynamic Exercise. 2022 12th International Conference on CYBER Technology in Automation, Control, and Intelligent Systems (CYBER), 307-312.
11. Okuno, J., Yonai, T., Kunihiro, T., Konishi, K., Materano, M., et al. (2022). Demonstration of Fatigue and Recovery Phenomena in Hf0.5Zr0.5O2-based 1T1C FeRAM Memory Arrays. 2022 6th IEEE Electron Devices Technology & Manufacturing Conference (EDTM), 64-66.
12. Su, S., Akkara, F. J., Abueed, M., Jian, M., Hamasha, S., et al. (2018). Fatigue Properties of Lead-free Doped Solder Joints. 2018 17th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 1243-1248.
13. Ghemari, Z., & Belkhiri, S. (2021). Mechanical resonator sensor characteristics development for precise vibratory analysis. Sensing and Imaging, 22, 40.
14. Belkhiri, S., Ghemari, Z., Saad, S., & Boudechiche, G. (2020). Improvement of the Vibratory Analysis by Enhancement of Accelerometer Characteristics. Sensor Letters, 18, 39-42.
15. Ghemari, Z., & Saad, S. (2013). Development of measurement precision of sensor vibration. Journal of Vibration and Control, 19, 1480-1486.
16. Reguieg, S. K., Ghemari, Z., & Benslimane, T. (2018). Extraction of the relative sensitivity model and improvement of the piezoelectric accelerometer performances. 2018 International Conference on Signal, Image, Vision and their Applications (SIVA).
17. Defdaf, M., & Ghemari, Z. (2017). Improvement of Method Queues by Progress of the Piezoresistive Accelerometer Parameters'' Journal of Advanced Manufacturing Systems, 16, 227-235.
18. Ghemari, Z., & Saad, S. (2012). Development of model and enhancement of measurement precision of sensor vibration. IEEE Sensors Journal, 12, 3454-3459.
19. Ghemari, Z. (2018). Improvement of the piezoelectric sensor by the progress of the measurement accuracy. IEEE International Conference on Smart Materials and Spectroscopy (SMS'2018).
20. Ghemari, Z., & Saad, S. (2019). The use of mechanical sensitivity model to enhance capacitive sensor characteristics'' Analog Integrated Circuits and Signal Processing, 99, 349-357.
21. Ghemari, Z., & Saad, S. (2019). Enhancement of capacitive accelerometer operation by parameters improvement. International Journal of Numerical Modelling Electronic Networks Devices and Fields, 32, e2568.
22. Ghemari, Z., Saad, S., & Defdaf, M. (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.
23. L, Y., L, Z., Y, Z., L, H., & S, Y. (2020). Research Progress of Work Fatigue Detection Technology. 2020 IEEE 2nd International Conference on Civil Aviation Safety and Information Technology (ICCASIT), 558-560.
24. Deshpande, A., Jiang, Q., Dasgupta, A., & Becker, U. (2019). Fatigue Life of Joint-Scale SAC305 Solder Specimens in Tensile and Shear Mode. 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 1026-1029.
25. Abueed, M., Athamenh, R., Hamasha, S., Suhling, J., & Lall, P. (2020). Effect of Fatigue on Individual SAC305 Solder Joints Reliability at Elevated Temperature. 2020 19th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 1043-1050.
26. Zanella, S., Etangs-Levallois, A. L. D., Charkaluk, E., Filho, W. C. M., & Constantinescu, A. (2018). Importance of Creep Fatigue Interaction in Reliability of Solder Joints. 2018 7th Electronic System-Integration Technology Conference (ESTC), 1-5.
27. Ghemari, Z., & Saad, S. (2017). Parameters improvement and suggestion of new design of capacitive accelerometer. Analog Integrated Circuits and Signal Processing, 92, 443-451.
28. 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.
29. Ghemari, Z., & Saad, S. (2013). Modeling and enhancement of mechanical sensitivity of vibration sensor. Journal of Vibration and Control, 20, 2234-2240.
30. Ghemari, Z., Chouaf, F., & Saad, S. (2017). New Formula for the Piezoresistive Accelerometer Motion Acceleration and Experimental Validation'' Journal of Advanced Manufacturing Systems, 16, 57-65.
31. Ghemari, Z., Lakehal, A., & Saad, S. (2015). Minimisation of resonance phenomena effect of piezoresistive accelerometer. 2015 4th International Conference on Systems and Control (ICSC), 243-246.
32. Ghemari, Z., & Saad, S. (2021). Improvement of piezoresistive accelerometer performance. 3rd International Conference on Systems and Control, 759-762.
33. Halkiadakis, Y., Alzakerin, H. M., & Morgan, K. D. (2021). Classification Model for Discriminating Trunk Fatigue During Running. 2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), 4546-4549.
34. Makaram, N. K., & Swaminathan, R. (2018). Analysis of Muscle's Electrical Activity During Dynamic Fatiguing Exercise Using Visibility Graph and Degree Statistics. 2018 IEEE Life Sciences Conference (LSC), 267-270.
35. Sankar D, S. V., & Ko, L. (2020). Evaluation of Fatigue and Attention Levels in Multi-target Scenario using CNN. 2020 International Computer Symposium (ICS), 247-251.
36. Li, G., Wang, J., Xu, W., Wu, K., Liu, Y., et al. (2023). Self-Regulation Phenomenon Emerged During Prolonged Fatigue Driving: An EEG Connectivity Study. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 31, 4895-4906.
37. Ghemari, Z. (2018). Analysis and optimization of vibration sensor. IEEE International Conference on Smart Materials and Spectroscopy (SMS'2018).
38. Ghemari, Z. (2016). Upgrading of piezoresistive accelerometer response. 2016 8th International Conference on Modelling, Identification and Control (ICMIC).
39. Ghemari, Z., & Saad, S. (2014). Reducing the Measurement Error to Optimize the Sensitivity of the Vibration Sensor. IEEE Sensors Journal, 14, 1527-1532.
40. Ghemari, Z. (20190). Defects diagnosis by vibration analysis and improvement of vibration sensor measurement accuracy. Sensor Letters, 17, 608-613.

41. Ghemari, Z. (2018). Decrease of the resonance phenomenon effect and progress of the piezoelectric sensor correctness. 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM).
42. Ghemari, Z., & Saad, S. (2015). Simulation and Experimental Validation of New Model for the Piezoresistive Accelerometer Displacement. Sensor Letters, 15, 132-136(5).
43. Lakehal, A., & Ghemari, Z. (2016). Suggestion for a new design of the piezoresistive accelerometer'' Ferroelectrics, 493, 93-102.
44. Salah, S., Ghemari, Z., Herous, L., & Hadjadj, O. E. (2007). Transducer (Accelerometer) Modeling and Simulation. Asian Journal of Information Technology, 6, 54-57.
45. Qi, P., Gao, L., Meng, J., Thakor, N., Bezerianos, A., et al. (2020). Effects of Rest-Break on Mental Fatigue Recovery Determined by a Novel Temporal Brain Network Analysis of Dynamic Functional Connectivity. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 28, 62-71.
46. Chatain, C., Gruet, M., Vallier, J. M., & Ramdani, S. (2020). Effects of Nonstationarity on Muscle Force Signals Regularity During a Fatiguing Motor Task. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 28, 228-237.
47. Franco, R. R., de Souza, G. F. M., & da Silva, C. H. (2018). Experimental Uncertainty Analysis of Gear Fatigue Life Theoretical Prediction. 2018 Annual Reliability and Maintainability Symposium (RAMS), 1-7.
48. Ghemari, Z., & Lakehal, A. (2014). Vibration sensor mechanical sensitivity improvement. International Conference on Electrical Sciences and Technologies in Maghreb.
49. Ghemari, Z. (2013). Modélisation, simulation et analyse expérimentale du capteur de vibration (accéléromètre). Thèse de doctorat, Université de M'sila.
50. Ghemari, Z., Belkhiri, S., & Saad, S. (2022). Improvement of the relative sensitivity for obtaining a high 0performance piezoelectric sensor. IEEE Instrumentation & Measurement Magazine, 26, 49-56.
51. Ghemari, Z. (2006). Modélisation et simulation d'un capteur de vibration (Accéléromètre)'' Mémoire Magister, Université Badji Mokhtar.
52. Lakeha, A., & Ghemari, Z. (2015). Proposition d'une nouvelle formule d'accélération du mouvement pour l'accéléromètre. 3ème Conférence Internationale sur la Maintenance et la Sécurité Industrielle.
53. Song, A., Niu, C., Ding, X., Xu, X., & Song, Z. (2019). Mental Fatigue Prediction Model Based on Multimodal Fusion. IEEE Access, 7, 177056-177062.
54. Lall, P., & Choudhury, P. (2022). Evolution of Fatigue Reliability of UF-Substrate Interfaces under High Temperature Exposure. 2022 21st IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (iTherm), 1-8.
55. Ghemari, Z., & Belkhiri, S. (2021). Capacitive Sensor Accuracy Optimisation by the Frequency Range Appropriate Choice. Preprint: doi.org/10.21203/rs.3.rs-863179/v1.
56. Ghemari, Z. (2019). Enhancement of the vibratory analysis technique by the accelerometer characteristics evolution. The 7th International Conference on Control Engineering & Information Technology.
57. Ghemari, Z., Belkhiri, S., & Saad, S. (2023). A capacitive sensor with high measurement accuracy and low electrical energy consumption. Applied Physics A, 129, 362.
58. Ghemari, Z., Belkhiri, S., & Morakchi, M. R. (2022). Improvement of the vibration analysis technique by optimizing the parameters of the piezoelectric accelerometer. 2022 IEEE 21st international Ccnference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), 183-186.
59. Ghemari, Z., Belkhiri, S., & Saad, S. (2023). A piezoelectric sensor with high accuracy and reduced measurement error" Preprint in Research Square DOI:10.21203/rs.3.rs-3554152/v1.
60. Ghemari, Z., Belkhir, S., & Saad, S. (2023). Appropriate choice of Capacitive sensor bandwidth" Preprint in Research Square https://doi.org/10.21203/rs.3.rs-3515258/v1.
61. Belkhiri, S., Ghemari, Z., & Saad, S. (2022). Reduction of measurement error of the piezoelectric sensor'' Séminaire International en Génie Industriel et Mathématiques Appliquées (SIGIMA'2022).
62. Aissaoui, L., & Ghemari, Z. (2022). Mathematical modeling and simulation of the piezoelectric accelerometer. 3rd International Conference on Applied Engineering and Natural Sciences.
63. Morakchi, M. R., GHEMARI, Z., DEFDAF, M., merwane, k., selman, d., et al. (2022). Different MEMS-based accelerometers types. 3rd International Conference on Applied Engineering and Natural Sciences.
64. Ghemari, Z. (2019). The accelerometer characteristics improvement'' The 7th International Conference on Control Engineering & Information Technology.
65. Morakchi, M. R., GHEMARI, Z., DEFDAF, M., Guezi, A., Selman, d., et al. MEMS accelerometer and gyroscope in navigation technology'' 3rd International Conference on Applied Engineering and Natural Sciences.
66. Morakchi, M. R., & Ghemari, Z. (2022). The best choice of the capacitive accelerometer damping rate for reduction of the measurement error. La 1ere conférence internationale d'Electrotechnique et Technologies Modernes CIETM'22.
67. Morakchi, R., Ghemari, Z., & Defdaf, M. (2022). The optimal accelerometer parameter integrated into the mathematical model for avoiding detection errors. 1st International Conference on Engineering and Applied Natural Sciences.