JJMIE

Volume 18, Number 1, March. 2024
ISSN 1995-6665
Pages 219- 226
https://doi.org/10.59038/jjmie/180117
Editor-in-Chief: Prof. Ali M. Jawarneh

Jordan Journal of Mechanical and Industrial Engineering

Towards Condition Monitoring: Fabrication and Finite Element Analysis of A Helical Gear Transmission Rig for Fault Simulation

Ahmed Salman Hammood

Assistant Lecturer, University of Technology- Iraq, Training and Workshops Center, Iraq

Received 8 Oct 2023 *Accepted 21 Jan 2024*

Abstract

Mechanical systems are mainly considered in heavy transmissions, and helix-angled gears are being mostly used in such fields of interest. As these mechanical components operate, they are heavily subjected to potential faults of operation. To avoid experimental faults, simulation-based analysis and test apparatus are now used for diagnosing purposes and hence, improving the dependability while enhancing their performance. For that, this paper presents an integrated approach of simulation analysis and the fabrication of a test rig specifically designed for fault inducing and seeding in helical gear transmissions. Computer-aided design and engineering techniques are both used to conduct vibration-based analysis. Six mode shapes are called out for in the modal simulation workbench where they were discussed accordingly. Bearing-mounted accelerometers were used to capture vibration signals of three operating axis in order to study the potentiality of utilizing them for condition monitoring. The current approach has demonstrated advancements in fault diagnosis methodologies and provided valuable insights in enhancing reliability and dependability of such applications.

Keywords: Finite Element Analysis, Helical Gears, Fault Simulation, Vibration Signals, Frequency Domain.

1. Introduction

Helical gears are widespread across diverse applications due to their increased benefits and dependable functionality. Numerous industries, including automotives, aerospace, power generation, and heavy machinery, are all extensively utilizing gear system transmissions and connections [1], [2]. Due to the growing demand in helical connections, it has applicably demonstrated great significance in use and hence, the parallel increase in necessity for efficient methodologies of fault diagnosis [3]–[5]. It is vital, important, and safe to detect and prevent unanticipated faults and failures in such transmissions to guarantee efficient operation. This can only be achieved by means of fault detection techniques and defect diagnosis methods.

The performance of helical gear transmissions may be significantly affected over time due to various types of faults. Crack propagation [6] and teeth wear [7] are two prevalent fault types frequently observed in gear transmissions that are helix-angled. These faults demonstrate an increasingly significant impact as they progress. Gear components are heavily subjected to crack propagation, and these crack advancements may result from material fatigue, extreme applied loads, or manufacturer neglection of imperfections. The increasing advancement of these cracks might lead to a heavy reduction overall structural performance of the gear pairs, which thereby increases the possibility of sudden unwanted breakdowns or failures. These cracks are to be detected and the condition needs to be diagnosed if the operating representative seeks healthy operation procedures. In addition to the presence of cracks as common faults, it is commonly known that teeth wear is also one of the major failure causes in such heavy machinery that utilize helical gears. Extended exposure to highly excessive loads, insufficient maintenance and lubrication, and abrasive agents are all reasons of gradual degradation of dental surfaces that lead to mechanical wear. The gradual reduction in gear tooth profile accuracy due to the over-time teeth wear would lead to compromised gear meshing represented in elevated noise and decreased transmission efficiency. Therefore, it is essential to implement effective condition monitoring and diagnostic techniques to ensure the dependability and effective functioning of industrial transmissions that implement gears of helix angles.

The methodology of Finite element analysis (FEA) is commonly recognized as the most highly effective tool for the analysis and optimization of variant mechanical engineering procedures [8]–[11]. The helical-geared usage in heavy machinery is considered to be part of these mechanical systems. FEA can be utilized in the prospect of mechanical engineering to accurately forecast and analyse the gear system behaviour while being subjected to diverse operating and boundary conditions. This mathematical-modelling technique enables a detailed examining of

* Corresponding author e-mail: ahmed.s.hammood@uotechnology.edu.iq.

different workbenches of interest within different mechanical components. Valuable insights would be brought to analysers and users when conducting the mentioned methodology in order to understand the reliability of a specific system. The fabrication of experimental test apparatus in any geared system requires the inclusion of FEA to understand the transmission behaviour and to analyse the mechanical components in variant approaches. The test rig's distinctive design and configuration necessitate a comprehensive understanding of the structural integrity and response of the components when exposed to dynamic loading. FEA can assist in the evaluation of the mechanical behaviour of the test rig which by turn allows to assess the impacts of various operating conditions and fault schemes in any failure type.

In the work of [12], the implementation of FEA was utilized within a fully automated framework. The proposed approach had lead to a proficient and reliable achievement of an optimal lightweight gear design. The study showcased the proposed methodology by demonstrating the creation of a software architecture that combines pre-existing commercial solutions with tailored procedures. The practicality and credibility of the proposed methodology are both evaluated by means of a fully-detailed assessment. This analysis has considered the multiobjective optimization of a transmission system that consists of a set of helical transmission mechanical gears.

In addition to FEA, vibration analysis has been widely adopted by mechanical engineering divisions in the fabrication of test rigs for fault simulations in heavy machinery transmissions. Several studies have highlighted the significance of vibration analysis as a complementary technique to evaluate the dynamic behaviour and performance of mechanical-geared systems [13]. For instance, in [14], the helix angle of the helical gears is measured to be 30.5 degrees. An algorithm for calculating mesh stiffness is derived. A mathematical model is developed to represent the dynamic behaviour of a Two-Stage helical gear transmission system in an electric vehicle operating at a consistent velocity. A bench test is conducted in order to validate the model. A friction model is utilized. The analysis of the dynamic characteristics is conducted subsequent to the careful consideration of both the friction and axial stiffness components. Similarly, in [15] a proposal is put forth to develop an innovative virtual prototype model of a gear pair for a vibrating screen exciter, with the aim of effectively demonstrating the unique characteristics of gear transmissions in this context. These studies demonstrate the importance of integrating vibration analysis alongside other analytical methods, such as finite element analysis, to enhance the accuracy and effectiveness of fault simulations in helical gear transmissions, among many other studies [16], [17].

Despite the considerable progress achieved in prior research on fault simulations in helical gear transmissions, there are still certain limitations and gaps that need to be addressed. A significant portion of the current research endeavours have primarily concentrated on discrete examination of either finite element analysis or vibration analysis, with a restricted level of integration between these two methodologies. The aforementioned segregation impedes the attainment of an in-depth understanding regarding the behaviour of gear systems in the presence of faults. Furthermore, it is worth noting that certain studies have made efforts to create test rigs for the purpose of simulating faults. However, these studies often fall short in terms of adopting a comprehensive approach that integrates advanced analysis techniques with innovative design methodologies. As a result, it is imperative to develop a new research methodology that combines the triangles of FEA, vibration analysis, and advanced design principles in order to construct a test rig that can effectively replicate faults in gears that are utilized for mechanical transmissions. The objective of this study is to address the aforementioned gaps by introducing a comprehensive methodology that integrates various analytical techniques with an innovative test rig design. This integration facilitates more precise fault simulations, thereby contributing to the advancement of gear fault diagnosis and analysis in the field.

Regarding the organization of this paper, the first section introduces the subject to be discussed as well as presents a survey of related research. In Section 2, computer-aided design and engineering employing FEA are described. The fabrication of the experimental test rig is illustrated in the section 3. In Section 4, the results of the vibration analysis and the adopted FEA method in terms of modal simulation are both discussed. Finally, the paper concludes with section 5 by an overview of the design and capabilities of the test apparatus.

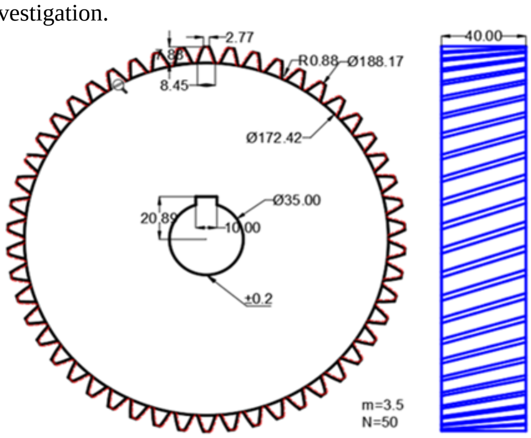
2. Computer Aided Design and Engineering

2.1. Geometrical Approach

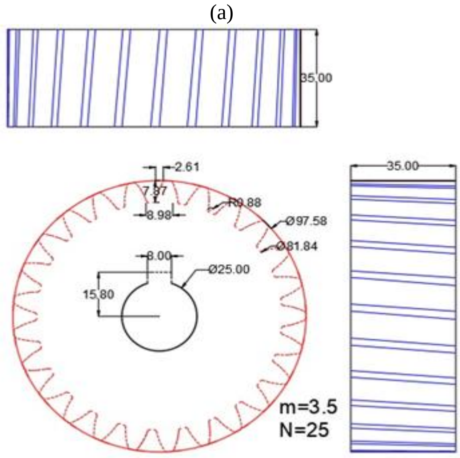
To design and optimize mechanical systems of interest, the use of Computer-Aided Design (CAD) is usually a door introductory to furnish the robust tools for simulation analysis [18]-[20]. CAD software empowers its users to generate precise and comprehensive 3D models in addition to components and assemblies which enables to facilitate rich visualization and analysis of their geometric attributes. The tools of CAD commonly known to expedite the exploration of diverse design iterations to enable rapid prototyping and efficient assessment of alternative design options. Moreover, CAD systems seamlessly integrate with other engineering analysis tools, such as the previously mentioned FEA to derive the evaluation of structural integrity and performance of the designed components to be assembled. To enhance the product performance and to minimize the design process timings, the CAD tools are leveraged. Not to mention the highly effective cost savings and economic friendly nature of such simulation-based analysis.

During the experimental procedure of test rig fabrication, the utilization of CAD assumes a central role in ensuring the precision and dependability of the overall setup. CAD software encompasses specialized functionalities tailored to gear design of which enabling the users to generate accurate gear models that incorporate intricate tooth profiles and realistic meshing characteristics from real experimental procedures. Furthermore, the use of CAD SolidWorks has enabled to optimize the test rig parts assembly. Regardless if the parts are bearing supports, helical gears, shafts, stand, and fixations. These parts are to be assembled in an integrated manner that ensures vibration analysis procedures to be conducted smoothly. The relationship between each of the assembled parts would be revealed and studied depending on different workbench methodologies, which in turn leads to studying fault diagnosis and condition monitoring techniques. Collectively, CAD in test apparatus manufacturing for heavy machinery power transition presents a robust toolkit for designing and refining experimental setups which thereby enabling accurate fault simulations and advances gear behaviour studies across diverse operating conditions. Fig. 1 elaborates the dimensions of the helical gear in the transmission system adopted in the proposed methodology.

Figure 2 depicts the test rig utilized in the experimental setup proposed, where N is the number of teeth and m is the module of the gears. Furthermore, the SolidWorks software was utilized to create and assemble all the components of the system. Figure 3 illustrates the complete design and fabrication of the test rig in a three-dimensional view. The motor is linked to a receiving pulley through a belt-drive mechanism to initiate motion. Subsequently, the transmission of torque and speed from the input shaft to the output shaft is facilitated by the utilization of a helical gear functioning as a pinion on the receiving shaft. This pinion gear transfers the aforementioned torque and speed to a helical gear receiver, which in turn interfaces with a load. The velocity is variable, contingent upon the rotational speed of the motor input. The panel of the test rig is equipped with two bearings that secure each shaft. Additional information will be elaborated upon in the experimental section of this investigation.



(a)



(b)

Figure 1. Gear model for the rotational system: (a) Helical gear dimensions; (b) Key and module

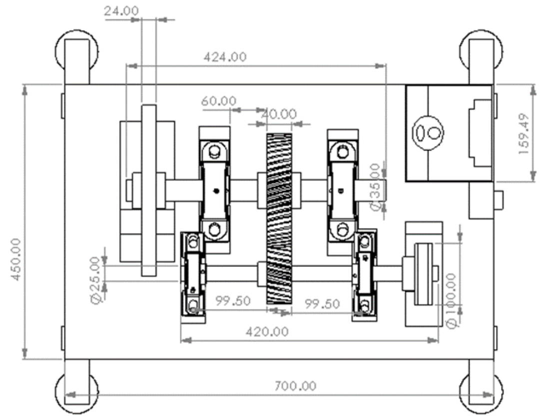


Figure 2. Test rig sketch and dimensions

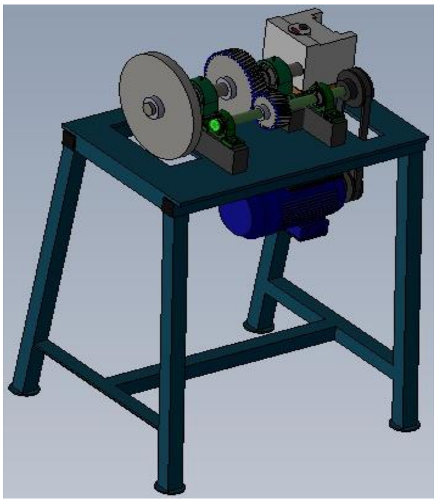


Figure 3. 3D view of the test rig design

2.2. Finite Element Analysis

Computer-aided engineering (CAE), particularly finite element analysis (FEA), has brought about a transformative shift in the realm of engineering by enabling meticulous analysis of intricate mechanical systems [21]-[23]. FEA leverages numerical techniques to discretize complex geometries into smaller finite elements, enabling precise modelling of material properties, boundary conditions, and loading scenarios. CAE, in conjunction with FEA, empowers engineers to simulate and evaluate the structural response of components and assemblies, facilitating an in-depth understanding of critical aspects such as stress distribution, deformation, and performance across a spectrum of operational conditions. Finite element approaches are currently delivering good applicability in terms of component behavior analysis where it identifies critical zones of potential failure. It is also noted that FEA is usually combined with CAD for analyzing the geometrical model. This approach would minimize the reliance on physical modelling or real-life machines experiments. The adoption of FEA within the proposed approach in this study will obtain good results in terms of analysing the experimental part which will guarantee safety procedures in addition to optimum performance.

In the presented work, the modal simulation workbench is utilized for accurate presentation of the solution. This workbench is specialized in acquiring the vibrational patterns in terms of mode shapes that correspond to the operating natural frequency possibility. Such assessments will reveal good identification of vulnerable regions susceptible to failure, subsequently informing the optimization of the test rig's design to ensure the structure's integrity and accurate fault simulations. The contact patterns with the dynamic responses will all be studied and presented through the simulations within specified parameters that reflect the actual experimental apparatus. Consequently, it contributes to the development of reliable and efficient test rigs, enabling advanced analyses and augmenting the understanding of gear behaviour under faulty conditions. Figure 4 displays the ANSYS-based geometry imported as a Parasolid file from the SolidWorks program.

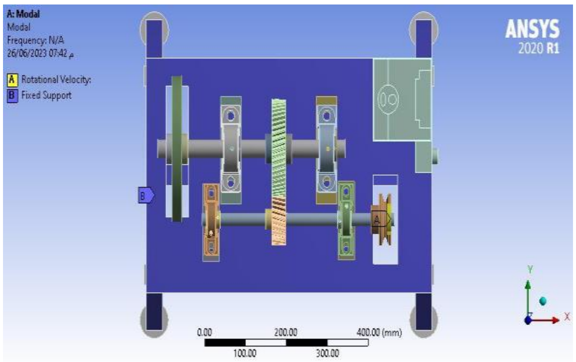


Figure 4. Top view of the test rig design

3. Experimental Work

3.1. Test Rig Fabrication

It is crucial to note that the production of helical gears involved the utilization of computer-aided manufacturing tools integrated within the SolidWorks software, enabling the generation of G-code instructions for CNC machine operation [24-27]. The test rig that has been artificially constructed is depicted in Figure 5 below. The rotational velocity from the motor is transmitted to the input pulley through a belt-drive mechanism, resulting in the first shaft rotating at the same velocity as the motor. It is crucial to highlight that the first rotating shaft is equipped with both a pair of bearings and a helical pinion featuring a helix angle. The gear acquires the rotational velocity by means of the teeth engagement with the pinion. The second shaft begins to rotate, exhibiting a torque ratio of 2, thereby resulting in a doubling of the input torque. The second rotating shaft, which carries a flywheel load as an output, is supported by two bearings.

The present test rig has the capability to effectively simulate faults through deliberate introduction of cracks in the helical gears or intentional wear in the operating teeth of said gears, among various other fault-inducing mechanisms. The acquisition of vibration signals can be achieved by utilizing vibration accelerometers that are installed on the bearings. These accelerometers enable the acquisition of time-domain or frequency-domain signals, which can then be used to assess and compare the operational state of the system. This comparison allows for the differentiation between healthy and faulty operating conditions.

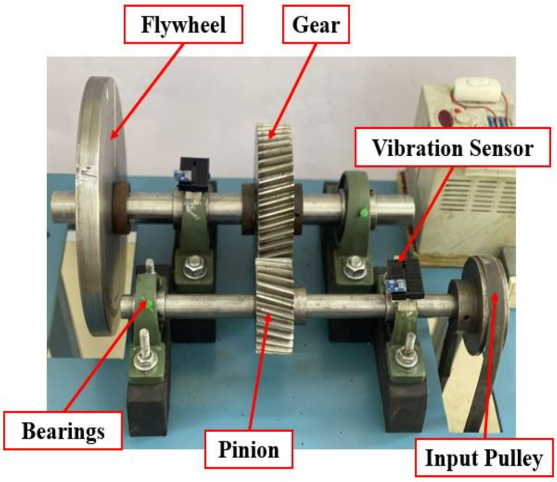


Figure 5. Experimental test apparatus

3.2. Methodology

Vibration signals are widely utilized across a diverse range of applications for the purpose of fault diagnosis and other [28-34]. Different methodologies in acquiring these vibration signals were discussed and presented for defect detection [35-38]. In this study, the ADXL335 accelerometer was selected based on its exceptional capabilities in detecting faults caused by vibration signals [39,40]. Any software designed for signal processing would functional to obtain the vibrational patterns. This methodology employs the use of LabVIEW program to acquire time-domain healthy signals and simulate the amplitude differences in comparison to faulty operating conditions in order to open the doorway for condition monitoring in machine learning.

4. Results and Discussion

4.1. Finite Element Analysis Results

As stated earlier, the FEA was employed to investigate the dynamic behaviour of the test apparatus designed for fault simulating as the experimental section of this paper elaborated. The mode shapes obtained from FEA provide insights into the structural response and deformation patterns of the system, shedding light on its vibration characteristics. Figure 6 presents a visual representation of the mode shapes which illustrates the corresponding deformation values in millimetres.

When analysing the mode shapes, it was revealed that distinct deformation patterns and associated natural frequencies are appearing. The first three mode shapes exhibited maximum deformation in the flywheel which indicates the influence of its geometry and material properties on the system's vibrational response. The first mode shape displayed a maximum deformation of 10.31 mm, with a natural frequency of 143.35 Hz. On the other hand, mode shapes 2 and 3 are exhibiting a deformation value of 10.206 mm and 13.431, respectively. While their corresponding natural frequencies are 181.5 Hz and 193.46

Hz, simultaneously. These values give an indication to the significance of the flywheel in the dynamic behaviour of the testing apparatus. In contrast, the fourth, fifth, and sixth mode shapes exhibited maximum deformation in the input pulley that emphasizes its role in the transmission's vibration statistics. The fourth mode shape showcased a significant deformation of 30.036 mm, accompanied by a natural frequency of 436.78 Hz. Likewise, the fifth and sixth mode shapes demonstrated deformations of 30.462 mm and 19.369 mm, correspondingly. These mode shapes had similarly corresponded to natural frequencies of 482.3 Hz and 578.42 Hz. It is concluded that the input pulley has a substantial influence on the system's dynamic response, potentially affecting gear meshing behaviour and overall system performance.

The identified mode shapes and their associated natural frequencies contribute to the understanding of the system's vibration behaviour and aid in determining appropriate sampling frequencies for acquiring vibration signals during experimental testing. By incorporating this knowledge, the test rig can be further optimized to enhance its performance and reliability in introducing the desired induced defects to study the vibrational pattern and assess it accordingly.

The natural frequency values are displayed in Table 1 in terms of Hertz units. In addition to that, Table 2 lists the maximum deformation of the mode shapes discussed previously.

Table 1. Natural frequencies values

Mode shape	Natural frequency (Hz)
1	143.35
2	181.5
3	193.46
4	436.78
5	482.3
6	578.42

Table 2. Maximum deformation values

Mode shape	Natural frequency (mm)
1	26
2	26.3336
3	27.215
4	29.3369
5	33.222
6	39.21

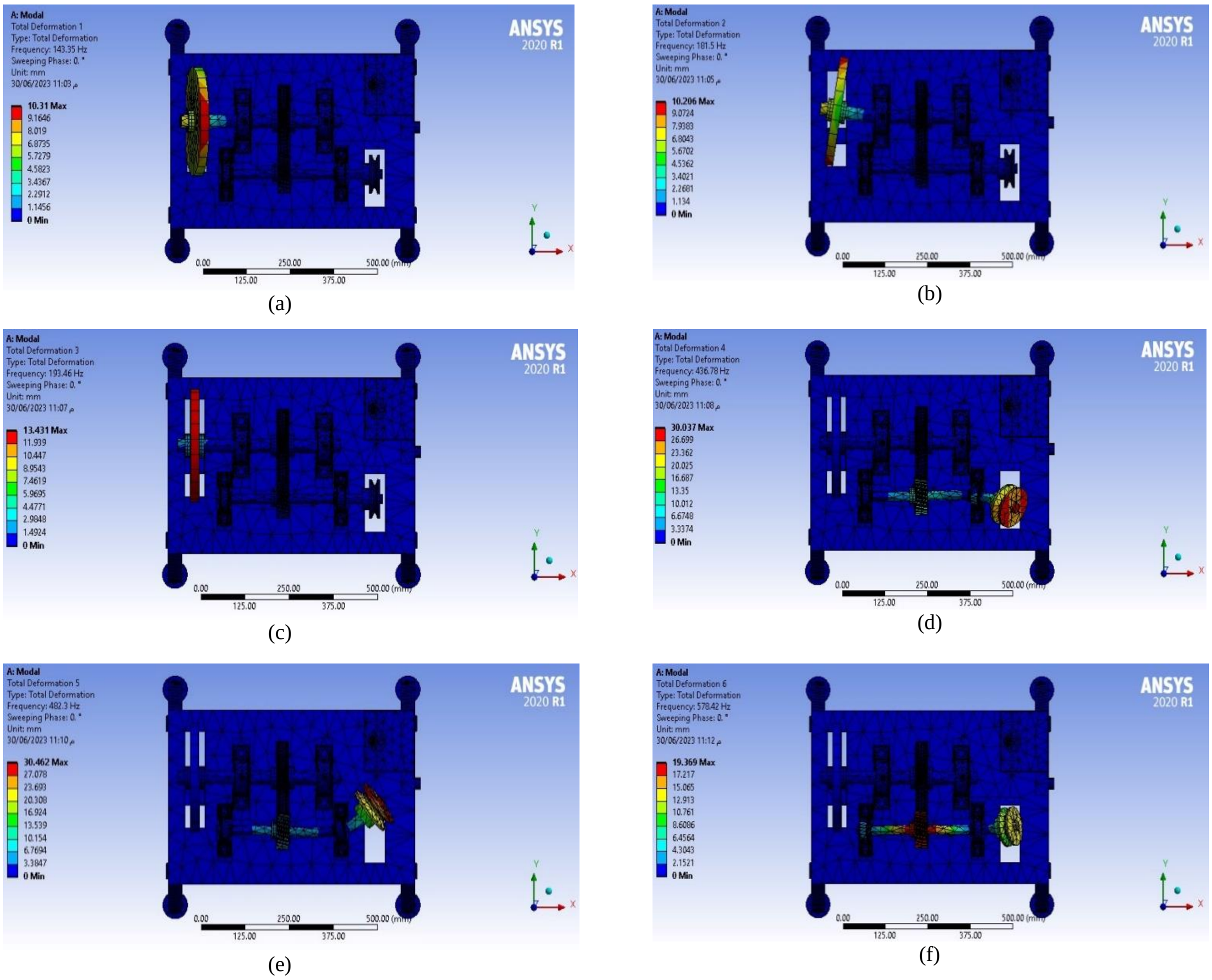


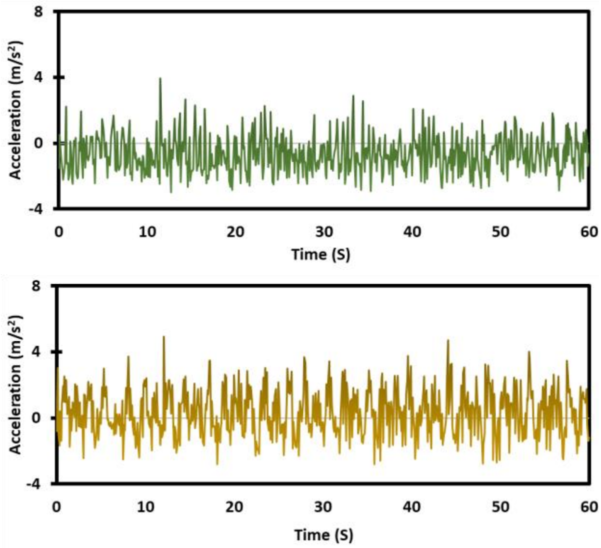
Figure 6. Acquired natural frequencies and mode shapes' deformation: (a) First mode shape; (b) Second mode shape; (c) Third mode shape; (d) Fourth mode shape; (e) Fifth mode shape; (f) Sixth mode shape

4.2. Vibration signals-based Fault Diagnosis

Vibration signals, which manifest as oscillatory disturbances, play a pivotal role in serving as a highly valuable and indispensable source of intricate and nuanced information for the purpose of meticulously diagnosing and discerning faults, anomalies, and irregularities that may arise within the complex and intricate realm of helical gear transmissions. Within this particular subsection, the primary goal lies in the meticulous examination and profound comprehension of the vibration signals that have been meticulously obtained from the experimental apparatus. The visual representation of the vibration signals in the time domain, which facilitates the identification and analysis of faults, is presented through two distinct figures, namely Figure 7 and Figure 8.

Figure 7 presents the vibration signals captured during the test rig's operation at a constant speed for one minute under healthy conditions. The x-axis represents time in seconds, while the y-axis represents the acceleration values in m/s2. Comparing the healthy vibration signals across the x, y, and z dimensions, it can be observed that the acceleration values remain relatively low and consistent throughout the entire time period. This indicates normal behaviour and the absence of significant faults in the system.

Conversely, Figure 8 illustrates the vibration signals acquired under identical operating parameters, albeit in a defective state, specifically simulating misalignment between the pinion and gear. The x-axis in Figure 7 represents time in seconds, while the y-axis represents acceleration values in meters per second squared (m/s2). It is worth mentioning that the vibration signals in the defective state demonstrate markedly greater amplitude values in all dimensions (x, y, and z) in comparison to the state of normal functioning. The observed rise in vibration amplitude can be directly attributed to the induced misalignment, indicating the existence of a fault within the gear transmission system.



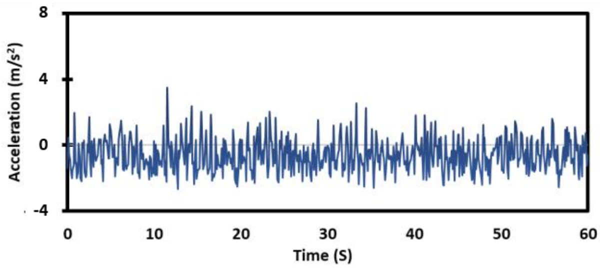


Figure 7. Healthy vibration readings in X, Y and Z

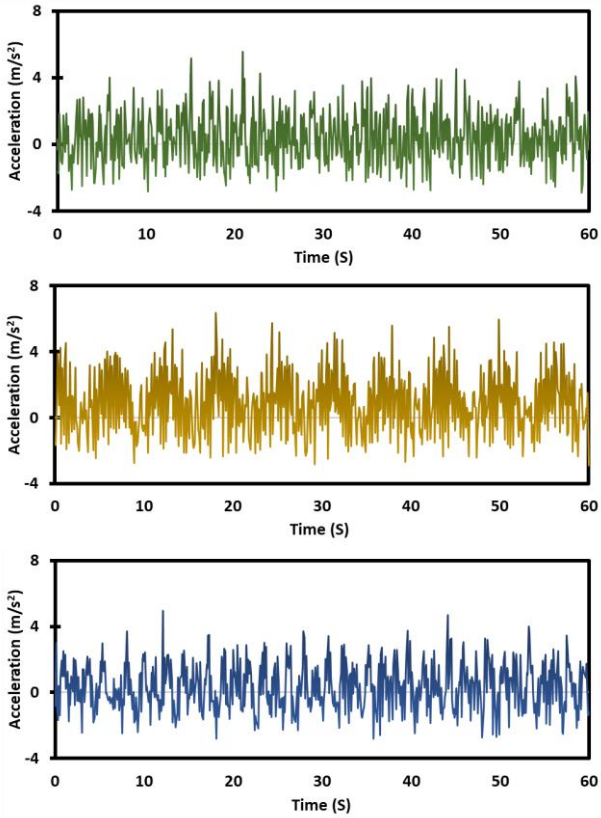


Figure 8. Faulty vibration readings in X, Y and Z

The distinct disparity between the vibration signals of the healthy and faulty conditions demonstrates the effectiveness of vibration signals in fault diagnosis. By comparing the vibration signatures of known healthy states with those of faulty conditions, deviations in amplitude, frequency content, and vibration patterns can be identified. Such variations serve as indicators of potential gear faults, including tooth wear, pitting, or misalignment. The analysis and interpretation of vibration signals, as exemplified by previous figures, provide a foundation for developing automated fault diagnosis algorithms and techniques, enhancing the ability to detect and mitigate faults in helical gear transmissions.

In terms of comparing the outcomes with prior research, the study conducted in [41] has constructed a testing apparatus specifically designed for simulating gearbox faults. The presented methodology has successfully demonstrated a fault diagnosis approach for an open system consisting of helical gears. Simulating faults in a gearbox is relatively straightforward due to the inherent vibrations of the entire system. The analysis of both the healthy and faulty vibration readings provide a comprehensive understanding of the subject matter. In addition, In the study presented by authors of [14], the dynamics of a Motor Two-Stage helical gear transmission system in electric vehicles with a helix angle of 30.5 degrees is explored. Emphasis is placed on sliding friction as a primary excitation and its subsequent effects on the vibration dynamics in different orientations. Although valuable insights into the dynamics of helical gears in electric vehicles are provided, particularly concerning the influence of friction and axial stiffness, the research presented in this study offers a broader scope. Valuable insights into different faulty conditions of crack, wear, or misalignment in helix-angled mechanical components were provided by means of fabricating and analysing the experimental test apparatus. A fully assessment of the entire system's dynamics was achieved by means of integrating FEA along with experimental procedures. Moreover, while the work in [14] focuses on the role of friction and axial stiffness components, multi-dimensional vibration signals were captured and analysed which has furnished a richer diagnostic perspective. Consequently, the current approach presents a more overview-based framework for fault diagnosis in the mechanical transmission that utilize helix-angled gears, with implications for enhancing the reliability and efficiency across diverse integrated systems.

5. Conclusion

In summary, this study presented the fabrication and finite element analysis of a testing rig for defect inducing in the helical-geared power transitions. The study had also integrated the use of CAD and CAE that allowed for the design of an optimal lightweight gear-train power transmission system which was efficient reliable in diagnostics. The experimental approach had involved the construction of the test apparatus in addition to the acquisition of vibration signals for induced and unwanted fault diagnosis. Valuable insights into the dynamic behaviour and fault conditions of the system were provided through the analysis of these time-domain signals. The capability of the experimental design to accurately simulate such defections was demonstrated as evidenced by the distinct differences observed in the vibration signals between healthy and faulty conditions. The developed methodology contributes to the field of condition monitoring and machine learning in helical-geared connections and offers opportunities for enhanced system design and maintenance. Generally speaking, a deeper understanding of the mentioned applications has been achieved through this research and a it also established a foundation for future advancements in unbalance detection and reliability analysis in similar mechanical systems.

Acknowledgment

The aid and help received from Mr Aws, at the Mechanical Engineering Department of the University of Technology- Iraq, is highly appreciated.

Abbreviations

CAD	Computer Aided Design
CAE	Computer Aided Engineering
FEA	Finite Element Analysis

References

[1] V. Pourmostaghimi, F. Heidari, S. Khalilpourazary, and M. R. C. Qazani, "Application of Evolutionary Optimization Techniques in Reverse Engineering of Helical Gears: An Applied Study," Axioms, vol. 12, no. 3, 2023, doi: 10.3390/axioms12030252.

[2] J. Du, L. Hu, J. Mao, and Y. Zhang, "Optimal Vibration Suppression Modification Method for High-Speed Helical Gear Transmission of Battery Electric Vehicles under Full Working Conditions," Machines, vol. 9, no. 10, 2021, doi: 10.3390/machines9100226.

[3] X. Tang et al., "Intelligent fault diagnosis of helical gearboxes with compressive sensing based non-contact measurements," ISA Trans, vol. 133, pp. 559–574, 2023, doi: https://doi.org/10.1016/j.isatra.2022.07.020.

[4] P. Wang and C.-M. Lee, "Fault Diagnosis of a Helical Gearbox Based on an Adaptive Empirical Wavelet Transform in Combination with a Spectral Subtraction Method," Applied Sciences, vol. 9, no. 8, 2019, doi: 10.3390/app9081696.

[5] S. A. M. Alshammari, M. M. Makrahy, and N. M. Ghazaly, "Fault Diagnosis of Helical Gear through Various Vibration Techniques in Automotive Gearbox," Journal of Mechanical Design and Vibration, vol. 7, no. 1, pp. 21–26, 2019, doi: 10.12691/jmdv-7-1-3.

[6] S. A. Mohammed, N. M. Ghazaly, and J. Abdo, "Fault Diagnosis of Crack on Gearbox Using Vibration-Based Approaches," Symmetry (Basel), vol. 14, no. 2, 2022, doi: 10.3390/sym14020417.

[7] V. Atanasiu, C. Oprişan, and D. Leohchi, "The Effect of Tooth Wear on the Dynamic Transmission Error of Helical Gears with Smaller Number of Pinion Teeth," in Engineering Solutions and Technologies in Manufacturing, in Applied Mechanics and Materials, vol. 657. Trans Tech Publications Ltd, Jun. 2014, pp. 649–653. doi: 10.4028/www.scientific.net/AMM.657.649.

[8] L. A. Al-Haddad and A. A. Jaber, "Influence of Operationally Consumed Propellers on Multirotor UAVs Airworthiness: Finite Element and Experimental Approach," IEEE Sens J, p. 1, 2023, doi: 10.1109/JSEN.2023.3267043.

[9] E. H. Flaieh, F. O. Hamdoon, and A. A. Jaber, "Estimation the natural frequencies of a cracked shaft based on finite element modeling and artificial neural network," Int J Adv Sci Eng Inf Technol, vol. 10, no. 4, pp. 1410–1416, 2020.

[10] A. F. Ogaili, M. N. Hamzah, and A. A. Jaber, "Integration of Machine Learning (ML) and Finite Element Analysis (FEA) for Predicting the Failure Modes of a Small Horizontal Composite Blade," International Journal of Renewable Energy Research (IJRER), vol. 12, no. 4, pp. 2168–2179, 2022.

[11] H. and B. L. Ghermoul Oussama and Benguesmia, "Finite element modeling for electric field and voltage distribution along the cap and pin insulators under pollution," Diagnostyka, vol. 24, no. 2, pp. 1–9, 2023, doi: 10.29354/diag/159517.

[12] F. Cosco, R. Adduci, L. Muzzi, A. Rezayat, and D. Mundo, "Multiobjective Design Optimization of Lightweight Gears," Machines, vol. 10, no. 9, 2022, doi: 10.3390/machines10090779.

[13] Y. and K. D. Bouaouiche Karim and Menasria, "Detection of defects in a bearing by analysis of vibration signals," Diagnostyka, vol. 24, no. 2, pp. 1–7, 2023, doi: 10.29354/diag/162230.

[14] Y. Li, S. Yuan, W. Wu, X. Song, K. Liu, and C. Lian, "Dynamic Analysis of the Helical Gear Transmission System

in Electric Vehicles with a Large Helix Angle," Machines, vol. 11, no. 7, 2023, doi: 10.3390/machines11070696.

[15] X. Cheng, Z. Li, C. Cao, Y. Wang, N. Ding, and G. Wu, "Dynamic Analysis and Fault Diagnosis for Gear Transmission of a Vibration Exciter of a Mine-Used Vibrating Screen under Different Conditions," Applied Sciences, vol. 12, no. 24, 2022, doi: 10.3390/app122412970.

[16] Y. Li, S. Yuan, W. Wu, K. Liu, C. Lian, and X. Song, "Vibration Analysis of Two-Stage Helical Gear Transmission with Cracked Fault Based on an Improved Mesh Stiffness Model," Machines, vol. 10, no. 11, 2022, doi: 10.3390/machines10111052.

[17] Y. Yang, Y. Wu, Y. Li, and X. Liu, "Effects of Tooth Modification in the Involute Helical Gear Form-Grinding Process on Loaded Transmission Character with Consideration of Tooth Axial Inclination Error," Machines, vol. 11, no. 2, 2023, doi: 10.3390/machines11020305.

[18] Top, N., Gökçe, H. & Şahin, I. Additive Manufacturing of Bio-Inspired Microstructures for Bone Tissue Engineering. Exp Tech (2023). doi:10.1007/s40799-023-00630-8.

[19] Keene, L.T., Lum, J.S., Busby, E. et al. Laser Speckle Pattern Stability in Hypersonic Regimes for Experimental Mechanics and Metrological Studies. Exp Tech (2023). doi:10.1007/s40799-023-00648-y.

[20] Moharana, S., Gottumukkala, S. Scour Monitoring at the Downstream of Hydraulic Structure Using Piezoelectric Transducer. Exp Tech (2023). doi:10.1007/s40799-023-00647-z.

[21] Dass, S., Siddiqui, J.A. & Mulaveesala, R. Applicability of Nanoparticle Coating in Bone Density Evaluation Using Gaussian-Weighted Linear Frequency-Modulated Thermal Wave Imaging. Russ J Nondestruct Test 59, 228–239 (2023). doi:10.1134/S106183092260109X.

[22] Hosseini, S.H., Honarvar, F. A Numerical Model for Ultrasonic Time-of-Flight Diffraction (TOFD) Testing of Austenitic Welds. Russ J Nondestruct Test 59, 182–203 (2023). doi:10.1134/S106183092360003X.

[23] Krishna, K.R.A., Karaseeri, A.G. & Karmakar, D. Oblique wave propagation through composite permeable porous structures. Mar Syst Ocean Technol 17, 164–187 (2023). doi:10.1007/s40868-022-00122-1.

[24] J. Yu, Z. Zhu, T. Wang, Y. Yao, and J. Ding, "A New Method to Analyze CNC Lathe Faults Based on Gutenberg–Richter Curve," Jordan Journal of Mechanical and Industrial Engineering (JJMIE), vol. 15, no. 1, 2021

[25] T. Kristyadi, M. Marsono, and S. Sayuti, "Axial Flux BLDC Motor Liquid Cooling System: Modelling and Experimental Analysis," Jordan Journal of Mechanical and Industrial Engineering (JJMIE), vol. 16, no. 4, 2022

[26] M. Tomov, B. Prangoski, and P. Karolczak, "Mathematical Modelling and Correlation Between the Primary Waviness and Roughness Profiles During Hard Turning.," Jordan Journal of Mechanical and Industrial Engineering, vol. 15, no. 3, 2021

[27] J. Yu, Z. Zhu, T. Wang, Y. Yao, and J. Ding, "A New Method to Analyze CNC Lathe Faults Based on Gutenberg–Richter Curve," Jordan Journal of Mechanical and Industrial Engineering (JJMIE), vol. 15, no. 1, 2021

[28] V. Dave, H. Thakker, and V. Vakharia, "Fault Identification of Ball Bearings using Fast Walsh Hadamard Transform, LASSO Feature Selection, and Random Forest Classifier," FME Transactions, vol. 50, no. 1, pp. 202–210, 2022.

[29] S. K. Sar and R. Kumar, "Hasty Fault Diagnosis of a Rotating Machinery Hinge on Stalwart Trippy Classifier with Robust Harmonized Swan Machine.," Jordan Journal of Mechanical and Industrial Engineering, vol. 14, no. 2, 2020

[30] Q. Pan and J. Zhang, "Electromechanical Coupling Model of AC Asynchronous Motor Drive System Based on Multiscale Method.," Jordan Journal of Mechanical and Industrial Engineering, vol. 15, no. 1, 2021

[31] M. Rahman and M. A. Rahman, "Application of Potential Energy Method for Driver Seat Suspension System Using Quasi-Zero Stiffness: A Numerical and Experimental Study.," Jordan Journal of Mechanical and Industrial Engineering, vol. 15, no. 5, 2021

[32] A. Ahmed and M. M. S. Mulapeer, "Torsional vibration of a Rod Composed of Two Dissimilar Frictionally Welded Parts with and without Crack in a Thermal Environment.," Jordan Journal of Mechanical and Industrial Engineering, vol. 16, no. 3, 2022

[33] Z. Yu, H. Jia, and X. Huang, "Design of the Lower Control Arm of an Electric SUV Front Suspension Based on Multi-Disciplinary Optimization Technology.," Jordan Journal of Mechanical and Industrial Engineering, vol. 15, no. 1, 2021

[34] S. K. Sar and R. Kumar, "Hasty Fault Diagnosis of a Rotating Machinery Hinge on Stalwart Trippy Classifier with Robust Harmonized Swan Machine.," Jordan Journal of Mechanical and Industrial Engineering, vol. 14, no. 2, 2020

[35] L. A. Al-Haddad and A. A. Jaber, "Improved UAV blade unbalance prediction based on machine learning and ReliefF supreme feature ranking method," Journal of the Brazilian Society of Mechanical Sciences and Engineering, vol. 45, no. 9, p. 463, 2023, doi: 10.1007/s40430-023-04386-5

[36] L. A. Al-Haddad, A. A. Jaber, M. N. Hamzah, and M. A. Fayad, "Vibration-current data fusion and gradient boosting classifier for enhanced stator fault diagnosis in three-phase permanent magnet synchronous motors," Electrical Engineering, 2023, doi: 10.1007/s00202-023-02148-z

[37] L. A. Al-Haddad, W. Giernacki, A. A. Shandookh, A. A. Jaber, and R. Puchalski, "Vibration Signal Processing for Multirotor UAVs Fault Diagnosis: Filtering or Multiresolution Analysis?," Eksploatacja i Niezawodność – Maintenance and Reliability, 2023, doi: 10.17531/ein/176318

[38] L. A. Al-Haddad, A. A. Jaber, S. A. Al-Haddad, and Y. M. Al-Muslim, "Fault diagnosis of actuator damage in UAVs using embedded recorded data and stacked machine learning models," J Supercomput, 2023, doi: 10.1007/s11227-023-05584-7

[39] J. S. Mohammed and J. A. Abdulhady, "Rolling bearing fault detection based on vibration signal analysis and cumulative sum control chart," FME Transactions, vol. 49, no. 3, pp. 684–695, 2021.

[40] L. A. Al-Haddad and A. A. Jaber, "An Intelligent Quadcopter Unbalance Classification Method Based on Stochastic Gradient Descent Logistic Regression," in 2022 3rd Information Technology To Enhance e-learning and Other Application (IT-ELA), 2022, pp. 152–156. doi: 10.1109/IT-ELA57378.2022.10107922.

[41] A. Dubaish Asaad Abdulhussein and Jaber, "Fabrication of a test rig for gearbox fault simulation and diagnosis," Diagnostyka, vol. 24, no. 2, pp. 1–8, 2023, doi: 10.29354/diag/162541.