Wireless Monitoring and Health Assessment Technology Integrating Ultrasonic Energy Supply and Data Transmission

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Abstract Long-term online health monitoring during storage of hermetically sealed special-purpose equipment is essential for evaluating material life and equipment efficiency. To address the requirements of efficient power supply, high reliability data transmission, and high integration of long-term online health monitoring for special sealing equipment, a non-destructive, wireless, in-chamber condition monitoring and health-assessment technology that integrates ultrasonic wireless power transfer (UWPT) and wireless data transmission is proposed. An electro-acoustic synergistic impedance matching model is developed using α-Al_2O_3 and epoxy, which enables efficient coupling between acoustic energy transfer and communication functions and realizes the integrated operation of UWPT and data transmission. The results show that the proposed impedance matching approach increases the ultrasonic power transfer efficiency from 29.35% to 68.71%. The reliability of the proposed system in power supply and data feedback to sensors inside the sealing device is verified by applying it to high-temperature accelerated aging experiments on a specific component material. The proposed technology demonstrates an efficient non-destructive, wireless monitoring method for the internal status of sealed equipment, offering an engineering-oriented solution for long-term online health monitoring and assessment of special materials in hermetically sealed storage environments.

Keywords ultrasonic power transfer; wireless data transmission; impedance matching; high-temperature accelerated aging; online health monitoring

Bearing Fault Diagnosis Based on Multi-modal Data Fusion and Improved CNN

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Abstract Single sensor data in complex engineering systems are limited in their ability to capture equipment health information and are highly susceptible to operating conditions. To address these limitations, a convolutional neural network (CNN) based multi-modal data fusion method for rolling bearing fault diagnosis is proposed in this study. First, a wavelet filter bank is constructed to adaptively select time frequency representations scale intervals for vibration and acoustic emission signals, performing continuous wavelet transforms to generate time frequency pattern samples. Then, a deep learning diagnostic model is built, incorporating multi-scale module and dense coupling module to extract fault features from each modality, while a similarity constraint is employed to enhance joint feature learning. Finally, a softmax classifier achieves precise classification of fault location and severity. Experimental results on a laboratory multi-modal dataset demonstrate that, when testing on previously unseen rotational speeds, the proposed multi-scale feature dense coupled CNN achieves 99.21% average accuracy. It outperforms classical deep learning models, ablation variants, and single modality methods in the aspects of classification accuracy, diagnostic stability, and generalization ability.

Keywords data fusion; fault diagnosis; convolutional neural network; multi-modal; rolling bearing

Gear Fault Diagnosis Based on MWPE and DBO-SVM

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Abstract To improve the accuracy and efficiency of recognition in gear fault diagnosis, a fault recognition method that integrates multiscale weighted permutation entropy (MWPE), dung beetle optimizer (DBO), and support vector machine (SVM) is proposed. First, given the difficulty in determining the embedding dimension of MWPE, which has a substantial impact on diagnostic performance, the coefficient of variation is introduced through MWPE entropy analysis to determine the embedding dimension. Then, a fault feature set is constructed. Finally, the DBO-SVM classifier is utilized for fault recognition. The results show that MWPE achieves superior extraction performance for gear fault compared with algorithms such as multiscale permutation entropy, multiscale entropy, and multiscale fuzzy entropy. The DBO-SVM classifier outperforms conventional optimization classifiers in terms of recognition accuracy and efficiency, achieving a recognition accuracy of 99.13% on the gear feature test set and 94.10% under noisy conditions, thereby demonstrating the superior noise robustness of MWPE.

Keywords gear fault diagnosis; multiscale weighted permutation entropy; support vector machine; dung beetle optimizer; coefficient of variation; noise robustness

Nonlinear Ultrasonic Detection and Signal Processing of Coating Quality of Magnesium Alloy

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Abstract In view of the difficulty encountered by conventional methods in detecting defects in magnesium alloy coatings, the nonlinear ultrasonic detection technology is proposed to detect the samples of polylactic acid coating of magnesium alloy with different degree of microdefects. Meanwhile, due to the small size of the magnesium alloy coating specimen and the small number of sinusoidal pulse cycles that can be accommodated, the calculation of the ultrasonic nonlinear coefficient β is highly susceptible to noise interference and frequency shift, resulting in significant errors. To process the detection signals of the coating specimen, 4 signal processing methods, including truncation least square method are proposed, and simulation experiments are conducted. The results show that the error in calculating β using truncation least square method is within 5%, and the method demonstrates higher noise robustness and greater accuracy in processing signals with fewer cycles compared with the other 3 methods. Through the analysis of the measured signals, the results show that the trend change of β is more obvious than that of the discrete Fourier transform, and the β can be calculated more effectively.

Keywords magnesium alloy; nonlinear ultrasonic detection; polylactic acid coating; least square method; signal processing

Broadband Noise Reduction Structure Based on Coplanar Coiled Cavity

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Abstract To address the problem of noise suppression in a continuous wide frequency range, a broadband noise reduction structure featuring coplanar coiled cavity is proposed based on the concept of coiled space. First, the cavity is partitioned to form a zigzag continuous cavity, replacing the traditional straight-through cavity, which significantly extended the actual propagation path of sound waves in the cavity; Second, the transmission loss (TL) of the initial coiled cavity muffler is calculated using the transfer matrix method, and local resonant units together with perforated plate structures are introduced to eliminate the inherent attenuation zeros; Then, numerical simulation is employed to optimize the structural parameters, enabling the optimized muffler to achieve a minimum TL of 20 dB within the continuous frequency range above 150 Hz. Finally, the TL of the coiled cavity muffler is determined by experiments. The results indicate that, compared with the traditional straight cavity muffler, the expansion ratio of the coiled cavity muffler is only 5 and the thickness is only 24 mm, which exhibits better noise reduction performance and a more compact structure. The experimental results are in good agreement with the simulation, verifying the effectiveness of the designed structure.

Keywords noise reduction structure; coiled cavity; local resonance units; perforated plate; broadband continuous noise reduction

Extraction of Weak Fault Features of Rolling Bearings Based on CP Decomposition

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Abstract To address the limitations that single sensor information acquisition has in characterizing bearing fault and susceptible interference from background noise, a method for extracting weak fault features in rolling bearings based on tensor canonical polyadic (CP) decomposition is proposed in this study. First, based on the cyclostationary characteristics of bearing fault pulse signals under stable operating conditions, the spectral correlation (SC) analysis method is used to transform the multi-channel measurement signals into the SC domain. Subsequently, the multi-channel SC matrices are organized into a tensor indexed by frequency, cyclic frequency, and channel. CP decomposition is then utilized to extract the fault information tensor, and the resulting fault feature tensor is averaged along the channel dimension to obtain an SC matrix that more effectively characterizes the fault features. Finally, a designed filter and the enhanced envelope spectrum are used to further enhance the fault feature SC matrix, the effectiveness of the proposed method is verified through simulations and experiments. The results demonstrate that the proposed method can accurately and effectively extract weak fault features from bearing fault signals under strong background noise interference.

Keywords tensor; feature extraction; bearing fault; spectral correlation; CP decomposition; enhanced envelope spectrum

Rolling Bearing Fault Diagnosis Based on Data Layer Feature Fusion

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Abstract To address the limitations of feature matrices constructed using traditional time domain and frequency domain statistical indicators in handling complex nonlinear data, a bearing fault diagnosis method combining data layer feature fusion and convolutional neural network (CNN) is proposed. First, the collected signals are processed using variational mode decomposition, and components with kurtosis values exceeding a predefined threshold are selected for reconstruction. Second, a multi-dimensional composite feature matrix of the reconstructed signals is calculated and constructed from the aspects of time domain, frequency domain, energy, and stability, integrating data features. Then, the feature matrix undergoes kernel principal component analysis for dimensionality reduction to remove redundant information. Finally, the obtained low-dimensional matrix is input into a CNN model optimized by batch normalization layers for fault identification and classification. Data validation is conducted using experimental data from the intelligent maintenance systems of the University of Cincinnati and the rotating machinery vibration analysis and fault diagnosis experimental platform. The results indicate that the proposed method achieves high classification and stability in bearing fault classification.

Keywords rolling bearing; characteristic matrix; dimensionality reduction; convolutional neural network

Cross-domain Fault Diagnosis of Rolling Bearings Based on Auxiliary Classifiers

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Abstract To address the limited generalization performance of rolling bearing fault diagnosis models under varying operating conditions, a cross-domain fault diagnosis model with semi-supervised convolutional neural network based on auxiliary classifiers is proposed. First, to enhance the reliability of pseudo-labels for target domain samples during training, the model introduces a nearest neighbor center classifier that generates pseudo-labels according to the cosine distance between class centers and sample embedding features, which effectively improves the reliability of the pseudo-labels. Second, the classification loss is computed using a cross-entropy function that includes a label-smoothing component, which mitigates the adverse effects of pseudo-labels noise on semi-supervised learning and strengthens the generalization capability of the model. Finally, experimental analyses on 2 different datasets were conducted to validate the proposed method. The results indicate that the proposed model effectively aligns the embedding features of vibration signals under different operating conditions, and shows the significant advantages in cross-domain fault diagnosis of rolling bearings.

Keywords deep learning; semi-supervised learning; cross-domain fault diagnosis; auxiliary classifiers

Safety Evaluation of a Steel Truss Using Bayesian Decision Network

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Abstract Existing safety evaluation methods for civil structures suffer from poor timeliness, strong subjectivity, and difficulty in quantification. Current arificial neural network has been criticized for lacking interpretability and physical meaning, as well as weak graphical visualization capabilities. To address these issues, a safety evaluation method for truss structure is proposed using Bayesian decision network (BDN), which rely on Bayesian reasoning and utility calculation. First, based on an analysis of the load transfer mechanisms, the truss system is divided into several substructures, each is defined as a chance node. Meanwhile, decision nodes and utility nodes are added into the network, and all the nodes are connected with directed edges to define the BDN topology. Second, the nodal conditional probability tables are subsequently computed without assuming specific load distributions, and the tables are used to determine the probability and state parameters of the nodal variables. Then, the utility function is established on the influence factors and the utility values, which are the independent and dependent variables for the function, respectively. Finally, the state score curve is generated to support decision-making and assess the current condition of the structure. The results show that BDN can describe the state variation of the steel truss under a given load combination. The critical load of a specific state is identified at the intersection point of the safety score curve and the failure score curve. Based on reasoning and decision, the inferred state probability of the truss system is consistent with the experimental observations. Thus, the proposed method provides a reference for safety evaluation of similar structures.

Keywords safety evaluation; Bayesian decision network; truss structure; decision nodes; utility function

Study on Low-frequency Lateral Swaying Characteristics of Metro Vehicles Under Service Conditions

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Abstract Lateral low-frequency swaying has frequently occured in the service of domestic metro vehicles, which seriously affects the riding comfort of passengers. To understand the lateral low-frequency swaying characteristics of the metro in service, first, the wheel wear of a metro line in Shanghai is investigated, and a lateral dynamics model of the metro vehicles considering track irregularity input is established to simulate the lateral low-frequency swaying phenomenon of the metro. Then, the effect of equivalent conicity on lateral riding comfort under service conditions is studied, and the variation of the main modes of vehicle systems with speed is analyzed. Finally, the parameters of the anti-yaw damper are selected and the necessity of its application is discussed. The results show that the lateral low-frequency swaying phenomenon is caused by the exchange between the wheelset hunting mode and the body shaking mode, and the abrupt change of damping ratio under the low equivalent conicity. With the increase of equivalent conicity, the damping ratio of hunting motion is too low, so the lateral vibration energy cannot be attenuated in time, and the problem of vehicle swaying will occur directly at a lower speed without lateral swaying, which deteriorates the vehicle running quality. By installing anti-yaw damper, the problem of the low-frequency lateral swaying of metro vehicles can be effectively suppressed. This study provides theoretical support for the solution of the vehicle swaying bottleneck problem faced by the service metro vehicles for further speeding up.

Keywords metro vehicles; lateral stability; vehicle swaying; equivalent conicity; modal analysis; anti-yaw damper

A Dimensionality Reduction Algorithm of Rotor Fault Dataset Based on LFPCDA

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Abstract To address the difficulty of fault classification caused by redundant feature attributes in high-dimensional fault dataset of rotating machinery, a local Fisher principal component discriminant analysis (LFPCDA) method for dimensionality reduction of fault data sets is proposed. First, the Laplacian score algorithm is used for filtering the redundant features in the high-dimensional fault feature set, and principal component calculation is integrated into the local Fisher discriminant analysis. The principal components that best reflect the fault nature are adaptively selected to form the projection matrix, so as to obtain the low-dimensional feature subset. Second, the low-dimensional feature subset is fed into the K-nearest neighbor for fault mode identification. Finally, the rotor fault data set simulated by a double-span rotor test bench is used for verifying the proposed algorithm and compare it with other typical dimensionality reduction algorithms. The results show that the proposed algorithm has the function of eliminating redundant information in high-dimensional fault data sets and retaining the main components of features, thereby making the differences between fault categories more prominent. Thus, the accuracy of fault pattern recognition can be improved. This algorithm can provide theoretical reference for data dimensionality reduction processing of intelligent decision-making technology of rotor fault.

Keywords fault diagnosis; local Fisher discriminant analysis; principal component calculation; dimensionality reduction

A Bearing Fault Diagnosis Method Based on Empirical Undecimated Wavelet

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Abstract The morphological undecimated wavelet has been applied to fault diagnosis in rotating machinery. However, the selection of morphological operators, the setting of structural elements, and the setting of decomposition levels, rely heavily on prior knowledge, reducing the adaptability of the method. To overcome these limitations, a new empirical morphological undecimated wavelet (EMUDW) for fault diagnosis of rolling bearings is proposed. First, the geometric characteristics and frequency response characteristics of existing morphological operators are analyzed to select the operator with better filtering effect. Sencond, waveform trends are introduced to eliminate the interference caused by random shocks. Then, regarding the settings of structural elements and the number of decomposition layers, a new adaptive selection strategy is proposed, which uses the impact interval of signals to determine the size of structural elements, and determines whether to stop decomposition based on the difference of Gini index. Finally, the superiority of the proposed method is demonstrated through simulation and experimental verifications. The results show that EMUDW exhibits excellent noise immunity and effectively elinates random shocks interferences. Compared with other methods, the proposed method preserves signal details more effectively and achieves higher computational efficiency.

Keywords rolling bearings; morphological wavelet; Gini index; fault diagnosis

Bearing Fault Diagnosis Based on Adaptive Optimal-scale Morphological Filtering

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Abstract Morphological filtering (MF) is a typical fault feature extraction technology, wherein the length of structural element (SE) shows an important influence on feature extraction and noise removal. To better match and extract fault pulse features under strong interference in bearing fault diagnosis, and improve computational efficiency, a method for extracting transient features of bearing is proposed. First, to adaptively determine the SE length, an improved SE (ISE) selection strategy is proposed. In this strategy, the SE length range is determined by the extreme points of the vibration signal auto-correlation, and the adjusted diagnostic feature (ADF) is used for selecting the optimal SE length by evaluating the fault feature information in the filtered signals. Second, to suppress the broadband noise pollution, the auto-correlation envelop spectrum (AES) is developed to the filtered signals to further eliminate fault unrelated components. Then, a bearing fault diagnosis method based on ISE and AES, namely MF-AES, is proposed. Finally, the proposed method is validated and compared using simulated signals and bench test signals. The results show that the proposed method can effectively enhance the fault-related impulse features and diagnose bearing faults.

Keywords morphological filtering; structural element; auto-correlation envelop spectrum; bearing fault diagnosis

Study on Mechanical Characteristics and Application of Steel Spring Vibration Isolators for Urban Express Rail Transit

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Abstract To study the feasibility of applying steel spring floating slab track to a 160 km/h urban express rail transit, first, indoor tests are used to determine the stiffness and damping ratio of the steel spring vibration isolators and the shared vibration isolators suitable for urban express rail transit. Then, a finite element model of a high-speed steel spring floating slab track (HSFST) is established based on these parameters. Through harmonic response analysis, its performance is compared with the steel spring floating slab track and ordinary track. The conclusions are as follows: The floating slab track exhibits lower transmission force and foundation reaction force than the ordinary track. It can transmit deformation and force more effectively in the longitudinal direction. The natural frequency and amplification frequency range of HSFST are lower than that of steel spring floating slab track, and the frequency band outside the vibration amplification area possesses a higher vibration isolation rate. The application of shared vibration isolators can effectively improve the connection strength and force transmission efficiency between slabs. While increasing the foundation reaction force at the location of the shared vibration isolators, it can also significantly reduce the foundation reaction force at other locations. In summary, HSFST is of lower deformation, transmission force, foundation reaction force, and higher vibration isolation rate, making it well-suited for urban express rail transit.

Keywords urban express rail transit; high-speed steel spring floating slab track; steel spring vibration isolators; indoor tests; harmonic response analysis; vibration isolation rate

Seismic Fragility Analysis of High-rise Building Frame-Shear Wall Structures with Thick Slab Transfer Floors

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Abstract Taking a typical high-rise frame-shear wall structure with thick plate transfer as the research object, the seismic fragility analysis is conducted based on the incremental dynamic analysis (IDA) method, and the seismic fragility curves and fragility matrices are obtained above and below the transfer floor under different limit states. The analysis results show that: 1) under the same peak ground accelaration (PGA), the maximum inter-story displacement angle above the transfer floor is less than that below the transfer floor. 2) When PGA$<0.2g$, the exceedance probability of the slight failure state of the frame part below the transfer floor is significantly greater than that of the frame-shear wall part above the transfer floor; When PGA$>0.4g$, the probability of exceeding the severe failure state of the frame part begins to increase rapidly, indicating that the risk of collapse increases rapidly. 3) Under the rare earthquake of intensity 7 or lower, the overall structure has a high probability of being slightly damaged. 4) During a rare intensity-7 earthquake, moderate damage tends to occur below the structural conversion layer, while the structure above the transfer floor is still in the slight damage state. The probability of collapse below and above the transfer floor is 0.91% and 0.38%, respectively. The damage and collapse risk of the structure is caused by the frame part below the transfer floor. The structure can meet the seismic requirements of "no collapse under strong earthquake and giant earthquake", demonstrating well seismic performance.

Keywords high-rise building; thick plate transfer; frame-shear wall structure; IDA method; seismic fragility analysis

Quantitative Diagnosis of Rotor System Imbalance Fault Based on MUII-CK Method

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Abstract Regarding the problems of insufficient fault data and the difficult construction of accurate simulation modal for traditional rotor system imbalance fault diagnosis, a quantitative diagnosis method based on maximize uncertainty improvement infill and co-kriging (MUII-CK) is proposed. First, low- and high-fidelity kriging surrogate models are built using simulation data and experimental data. Second, points in the regions with low high-fidelity data density are estimated and added, the vibration response is predicted by fusing data and model with co-kriging. Finally, a parameter identification inverse problem model is built by many fault samples from the prediction model, thereby achieving accurate quantitative diagnosis of imbalance fault. The results show that the proposed method can effectively predict the vibration response and identify the fault parameters under the conditions of insufficient experimental data and large simulation model deviation, and can directly use the vibration response signal for real-time fault diagnosis after the model is built, showing broad engineering application prospects.

Keywords rotor imbalance fault; co-kriging; surrogate model; uncertainty; inverse problem

Research on Intelligent Fault Diagnosis of Agricultural Machinery Based on Acoustic Signals

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Abstract The stable operation of agricultural machinery directly impacts agricultural production efficiency, research on condition monitoring and fault diagnosis for agricultural equipment has not yet achieved widespread adoption and application. In this study, the fault diagnosis of agricultural machinery under strong background noise is carried out using a wheat harvester as an example. First, a method based on a combination of complete ensemble empirical modal decomposition with adaptive noise (CEEMDAN) and wavelet thresholding (WT) is designed to perform the corresponding denoising pre-processing of the acoustic signals collected from the wheat harvester. Second, the features of 15 relevant parameters characterization signals of the wheat harvester are extracted as the input of the diagnostic model to improve the diagnostic accuracy. Finally, a diagnostic model combined convolutional neural networks (CNN) with regularized extreme learning machine (RELM) is constructed, namely CNN-RELM, realizing the acoustic signals fault diagnosis of wheat harvester.

Experimental results show that the CNN-RELM model is of better diagnostic performance compared with the single CNN model and the extreme learning machine model, and the combination of CEEMDAN-WT and CNN-RELM can effectively achieve the fault identification of wheat harvester under strong background noise.

Keywords acoustic signals; agricultural machinery; fault diagnosis; complete ensemble empirical modal decomposition with adaptive noise; regularized extreme learning machine

Design and Performance Research of a Small Vibrating Direct Drive Crawling Robot

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Abstract In order to solve the problems of complex structure or rope actuation of exploration robot in narrow spaces, a small three-legged crawling robot without transmission system is proposed in this study. First, the forward or rotational motion of the robot is driven by the periodic change of the centrifugal force when the vibration motor rotates. Second, the theoretical model of small crawling robot is established, and its trajectory is drawn by numerical calculation. Then, a prototype with size of 38 mm×36 mm×33 mm and mass of 17.70 g is developed. Finally, the circuit drive control system of the robot is developed to realize onboard power supply and independent control. The experimental results show that the small crawling robot can control the linear speed, steering radius, speed, and load on the rubber and polyvinyl chloride (PVC) surface by adjusting the voltage duty cycle. At driving voltage of 3.3 V, the small crawling robot can reach a maximum speed of 81 mm/s and the maximum load of 35.00 g on the rubber surface. The robot shows the advantages of lightweight, small size, simple structure, controllable movement, and onboard power.

Keywords vibration drive; small robot; onboard power; crawling

Experimental Study on Flow Induced Vibration Transmission Path Model of Pipeline Crossing Dike

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Abstract To solve the problems of pipeline damage and dike leakage caused by vibration during long-term operation of pipeline crossing dike, the vibration transmission path in the pipeline and soil is analyzed, and vibration reduction tests are conducted. First, a pipeline crossing dike project in Guangdong Province is taken as the prototype, the similarity ratio of the model test is determined using the dimensional analysis method. The design dimensions of each structure of the pipeline crossing dike, the materials of the pipeline and soil are also obtained, and the model dike is laid. Second, the vibration transmission path along the pipeline passing through the dike and the dike soil is investigated by applying the theory of transfer entropy and information transfer rate.

Finally, the vibration reduction effects of coarse sand, polyvingl chloride plastic, and rubber materials on the pipeline structure passing through the dike are analyzed. The results show that the vibration occurs in the reverse flow direction at the center of the pipeline and the outlet of the dike. In the horizontal direction of the dike, vibration is transmitted from both sides to the middle. In the vertical direction of the dike, vibration is transmitted from the pipe body upwards and downwards through the dike. The main frequencies of pipeline vibration are 9.89 Hz, 12.29 Hz, 17.53 Hz, and 21.18 Hz. The 3 reduction materials have a weakening effect on the vibration peak, mean square deviation, and main frequency energy. The main frequencies of 9.89 Hz and 17.53 Hz do not appear after vibration reduction with coarse sand and rubber materials, indicating that coarse sand and rubber materials can effectively change the main frequency of vibration and avoid resonance with the pipeline.

Keywords vibration; model test; pipeline crossing dike; transmission path; transfer entropy; vibration reduction

Non-stationary Torsional Vibration Signal Frequency Estimation Algorithm Based on ASA-LSF

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Abstract The problems of speed fluctuations in rotating machinery during service are addressed in this study. These fluctuations result in non-stationary torsional vibration signals measured via pulsed laser sequences reflected from zebra tapes, accompanied by real-time changes in sampling frequency. Additionally, the manual pasting of zebra tapes can introduce indexing angle errors due to stretching deformation or poor end-to-end connection, which severely affects the accuracy of torsional vibration frequency estimation. To solve these problems, a frequency estimation algorithm for non-stationary torsional vibration signals is proposed by combining angle-domain synchronous average (ASA) and least squares fit (LSF), namely ASA-LSF. First, the angle-domain synchronous averaging technique is applied to eliminate the time-varying sampling frequency problem caused by speed fluctuations, and the non-stationary signals are transformed into the equivalent stationary angle-domain signals. Second, the least squares method is used to effectively fit the angle-domain synchronous averaged data, eliminating the indexing angle errors at the junctions of the zebra tapes. Finally, the effectiveness of the proposed algorithm is verified through experiments designed under different voltages and currents. The results show that the proposed algorithm provides a new solution for the accurate identification of torsional vibration frequency in practical engineering applications, thereby avoiding resonance when the torsional vibration frequency is close to the natural frequency of the unit.

Keywords torsional vibration; angle-domain synchronous average; least squares method; frequency estimation

Positioning Performance of Redundant Inertial Measurement Units for Underground Mobile Equipment

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Abstract To improve the positioning accuracy of underground mobile equipment in coal mines, a data fusion and calculation method based on the redundant inertial measurement units (IMU) is proposed. First, 6 layout configurations for the redundant IMU are designed, and the fusion equations and calculation models for specific force and angular velocity for different layout configurations are established. Second, the motion trajectory of the underground mobile equipment is simulated, and a comparative analysis of the different redundant IMU layouts is conducted. Then, a wheeled trolley experiment platform is constructed. Motion pose detection is performed following a designed Z-shaped trajectory to verify the pose calculation accuracy of the regular pyramid IMU layout under both static and dynamic conditions. Finally, to further test the practicality of the redundant IMU layout, a motion experiment involving a crawler drilling robot moving along a "straight-ramp" trajectory is carried out. The results indicate that the regular pyramid layout yields smaller errors in both position and attitude calculation, outperforming other redundant layout configurations. The mean absolute errors for pitch angle, heading, and roll angles calculated using this layout are 0.479 4°, 0.210 8°, and 0.214 3°, respectively. The mean absolute errors for displacement in the east, north, and upward (sky) directions are 0.113 3 m, 0.075 2 m, and 0.166 9 m, respectively. The results demonstrate that the regular pyramid layout can more effectively suppress error accumulation.

Keywords underground mobile equipment; inertial measurement units; redundant configurations; precise positioning

Failure Analysis and Experimental Study on Fracture of Metro Cowcatcher Bracket

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Abstract The fracture failure of a cowcatcher bracket on metro vehicles during operation is investigated in this study. The fracture bracket is examined through several methods, including fractographic analysis, strength simulation, dynamic stress testing, and vibration characteristic analysis, to reveal the combined causes of its failure. The results show that structural fatigue in the bracket is induced by long-term high-frequency alternating load, while its fatigue life is further reduced by improper surface machining. Under current wheel-rail conditions, excessive swing is exhibited by the cowcatcher, leading to high dynamic stress. Furthermore, the natural frequency of the bracket's lateral bending mode is close to the excitation frequency associated with the track bed structure along the line. This resonance phenomenon increases vibrational energy, resulting in fatigue fracture due to long-term operational vibration. To prevent bracket fracture, the materials with better vibration and fatigue resistance is recommended, along with improvements to the swinging stability of the cowcatcher and optimization of the bracket structure to lower its resonance frequency.

Keywords metro vehicles; fatigue fracture; dynamic stress; line test

Optimization of Drilling Parameters for Measuring Residual Stress in Steel Tubes by Incremental Hole-Drilling Method

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Abstract To investigate the influences of drilling depth and hole diameter on the measurement accuracy of residual stress, first, a three-dimensional finite element model is constructed using ANSYS software. By varying the hole diameter and drilling depth, the strain release coefficient matrix for type B strain gauges with a central circle diameter of 9.6 mm is calibrated. Subsequently, a known non-uniform initial stress field is applied in the depth direction of the model. The theoretical stress values are calculated using the measured strain values and the calibrated release coefficient matrix, and are then compared with the initial stress field to optimize the hole diameter and depth. The results indicate that the calculation errors of the incremental hole-drilling method increase with the drilling depth. When the drilling depth is set at the recommended value and the hole diameter is $0.4D$, the maximum error between the calculated theoretical stress and the initial stress is within 10%. For measurements within the limit depth of $0.45D$, all stress errors below 12%. Beyond this limiting depth, the errors increase rapidly. This study provides a reference for selecting the drilling depth and hole diameter when using other types of strain gauges to measure residual stress.

Keywords incremental hole-drilling method; finite element analysis; non-uniform residual stress; strain release coefficient matrix

Optimized LSSVM and Its Application in Motor Fault Diagnosis

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Abstract To enable the rapid and accurate diagnosis of fault types in asynchronous motors during operation, an optimized intelligent fault diagnosis model based on the least squares support vector machine (LSSVM) is constructed. First, by replacing inequality constraints with equality constraints, LSSVM achieves a faster convergence speed. Second, an improved particle swarm optimization algorithm is proposed, which incorporates a particle mutation process during iteration. This process allows randomly placed particles to guide the population in escaping local optima and locating the global optimum. Finally, the intelligent diagnosis model is applied to diagnose both bearing data from Case Western Reserve University and experimental data from 7 types of faults in asynchronous motors. The results show that the diagnosis time of LSSVM is less than 30% of that required by traditional support vector machine (SVM), the diagnostic accuracy for bearings and asynchronous motors reaches 100%, and 94.3% respectively. Compared with the traditional SVM, LSSVM demonstrates faster convergence speed and higher diagnostic accuracy.

Keywords asynchronous motors; least squares support vector machine; particle swarm optimization algorithm; fault diagnosis

Study on Ultrasonic Echo Measurement of Icing Thickness Growth

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Abstract To address the measurement of icing thickness growth on aircraft surfaces, a dynamic measurement method based on ultrasonic pulse echo thickness measurement technology is proposed. First, a conformal ice-detection structure consisting of a transducer, an aluminum layer, and an ice layer is established. Theoretical analysis and simulation of the transducer are conducted, taking into account the detection sensitivity and attenuation characteristics of ultrasound in ice at different frequencies. Subsequently, an ultrasonic transducer is fabricated based on the design parameters, and ice-detection experiments are carried out in an icing wind tunnel. Finally, the sound velocity in ice at different temperatures is calibrated to obtain accurate values, thereby improving the measurement accuracy of icing thickness obtained via ultrasonic detection. The results demonstrate that it is feasible to measure the growth of icing thickness using ultrasonic pulse echo, showing high sensitivity and accuracy. The accuracy of icing thickness measurement is significantly improved through sound velocity correction.

Keywords ultrasonic detection; icing growth; ultrasonic transducer; pulse echo; sound velocity correction

Analytical Modeling and Parameter Identification of Tire Based on Ring Model Considering Damping Effects

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Abstract The flexible ring model based on tire structure is an important direction for tire dynamic modeling. To address the difficulty in measuring structural parameters such as damping required for modeling, a method integrating experimental modal analysis via hammer impact, dynamic modeling and parameter identification is proposed, with consideration of structural damping. First, an in-plane vibration modal test of a tire with a fixed hub is conducted to obtain the first 10 natural frequencies, damping ratios, and frequency response function (FRF) in the 0—320 Hz frequency range. Second, based on the classical two-dimensional flexible ring theory and considering the prestress induced by inflation pressure and the material loss factor, an improved dynamic equation for the ring model is established. Analytical expressions for the natural frequencies, damping ratios, and FRF of the tire's radial vibration are derived. Finally, taking mean squared error between the experimental modal results and the modal's analytical solutions as the optimized objective, unknown parameters are identified with the aid of a genetic algorithm, and the accuracy of the computational results is evaluated. The results show that the proposed theoretical model can effectively reflect the relationship among tire modal parameters, the structure, and damping parameters of the model. The proposed method enhances the identification accuracy of the tire structural model.

Keywords tire flexible ring model; experimental modal analysis; parameter identification; structural damping effect; genetic algorithm

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