Advances in Design Methods for Quasi-zero Stiffness Vibration Isolation

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Abstract Quasi-zero stiffness (QZS) vibration isolation, by introducing stiffness nonlinearity, effectively addresses the inherent contradiction between load-bearing capacity and isolation bandwidth in conventional linear isolators. As a result, it exhibits superior low-frequency isolation performance. The core challenge in realizing QZS isolation lies in designing mechanical structures whose force-displacement curves simultaneously demonstrate high static stiffness and low dynamic stiffness. Focusing on QZS isolation design methodologies, this paper first outlines the fundamental principles of QZS isolation and categorizes the traditional approaches according to the means of stiffness nonlinearization into four groups: geometric motion nonlinearity, geometric deformation nonlinearity, magnetic nonlinearity, and stress-strain nonlinearity. Subsequently, it introduces emerging design strategies based on nonlinear positive-stiffness structures, including hardening and softening types, and compares them with conventional approaches, with particular attention to their differences in static and dynamic behavior. Finally, the paper summarizes and discusses future directions from the perspectives of negative-stiffness structure design, QZS characteristic tuning, and potential applications, aiming to provide a comprehensive overview of the latest research progress and to offer insights into future development trends of QZS isolation systems.

Keywords quasi-zero stiffness; low-frequency isolation; stiffness nonlinearity; nonlinear positive stiffness

Dynamic Characteristics for Three-Dimensional Tip Clearance of Rotor System with Blade Cracks

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Abstract To investigate the fault mechanism of blade cracks and to analyze the effects of blade crack on the three-dimensional (3D) tip clearance of the rotor system, while comprehensively considering blade radial deformation, flap-wise bending, and chordwise bending, this paper develops a novel dynamic model of the rotor system based on continuum theory. With the blade breathing crack model under the three-dimensional stress state, a 3D tip clearance dynamic response model of rotor system with blade cracks is further established. The accuracy of the dynamic model is validated by comparing it with the finite element model and experiments. On this basis, the effect of blade crack depth and location on the 3D tip clearance in rotor system is further analyzed. The results show that the amplitudes of the high frequency doubling component of the 3D tip clearance increase with crack depth, while both the fundamental frequency and the high frequency doubling component of the 3D tip clearance show a non-monootonic trend as the relative crack location increases. The research results provide theoretical guidance for research on monitoring and diagnosis method of aero-engine blade crack based on 3D tip clearance.

Keywords dynamic model; blade crack; 3D tip clearance; rotor system; fault mechanism

Collision Characteristics of Hard Spherical Particles-Elastoplastic Polyurethane Plane

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Abstract The theoretical framework of Hertzian contact model for soft sphere collisions is well-established; however limited research has been done on the collision between rigid particles and elastoplastic materials. In this study, a novel damping form is introduced by incorporating the elastoplastic half-space contact constitutive relationship, and a viscoelastoplastic collision model between hard spherical particles and polyurethane surfaces is established. The nonlinear dynamic equations for particle and elastoplastic surface collision are derived. Furthermore, by conducting experiments to measure the coefficient of restitution for coal pellets colliding with polyurethane, the Meyer's index of the polyurethane material and the damping coefficient in the dynamic equations are determined. Additionally, the correctness of the damping model proposed in this study is validated by considering different damping forms in the equations. The changes in contact force at different stages are analyzed under various damping coefficients. The variations of displacement, velocity, and contact force during the collision process between particles and elastoplastic polyurethane are investigated. The results reveal that with an increase in the initial collision velocity, the irreversible plastic deformation of polyurethane increases from 1.636×10^{-4} m to 5.657×10^{-4} m, the coefficient of restitution decreases from 0.583 2 to 0.501 2, the collision time decreases from 6.963×10^{-4} s to 4.737×10^{-4} s, and the proportion of plastic compression stage decreases from 59.81% to 59.04%. The model established in this paper can be used in scenarios where particles collide with softer planes, such as the separation of metal ores and particle dampers. This paper provides theoretical support for the transportation, collision, impact, and separation of particle systems.

Keywords nonlinear contact; coefficient of restitution; particles collision; visco-elastoplastic model

Flutter Monitoring of Screw Milling Based on RF-LSSVM

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Abstract Aiming at the chatter problem in the process of milling screw rotors, a chatter monitoring method based on RelifF algorithm to the least square support vector machine (RF-LSSVM) is proposed. Firstly, the vibration signals in the milling process of the screw rotor are decomposed, and feature extraction and selection are performed using the variational modal (VMD) and the RelifF algorithm. Secondly, the penalty factor, kernel parameter, the number of near neighbor samples of RelifF algorithm and the length of dimension reduction feature of LSSVM are iteratively optimized using the enhanced whale optimization algorithm (E-WOA). Finally, a flutter identification model is established by inputting the reduced-dimensional flutter eigenvector matrix and outputting the flutter occurrence state. The experimental results show that the proposed VMD-RF-LSSVM model has a higher recognition accuracy than the unoptimized variational modal decomposition-support vector machine (VMD-SVM) model, reaching 99.5% accuracy. The proposed method can effectively monitor the chatter problem in the screw milling process, provides a thought for the optimization of the screw milling processing.

Keywords variational modal decomposition; least square support vector machine; machining chatter; feature dimension reduction

Design and Application of a Dynamic Performance Monitoring System for Maglev Train Shoegear and Conductor Rail System

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Abstract In view of the current situation that the detection indices of maglev train boot rail system both domestically and internationally are relatively limited, and there is a lack of detection data within the 100—140 km/h speed range, a comprehensive detection framework for high-speed maglev train boot rail system is proposed. Firstly, in accordance with relevant standards and specifications of pantograph and conductor rail system testing, a detection method is developed, which includes conductor rail contact force, vibration acceleration, electric shoe current, arc combustion and transverse geometric parameters of the conductor rail. Secondly, a real-time side conductor rail monitoring system that combines video surveillance and data statistical analysis is proposed, and a supporting program for extraction, processing and analysis of original detection data is developed. Finally, a medium- and low-speed maglev line is taken as the test object, and the data measured at different speed levels of the maglev train are analyzed. The results show that the dynamic performance of the pantograph differs during the upward and downward runs of the maglev train; The contact force and vibration degree at the expansion joint are larger than those in the middle section, indicating poorer dynamic performance of the conductor rail. Toe vibration mainly comes from vertical vibration. Relevant studies reveal the characteristics and issues of the maglev train boot rail system under different working conditions, providing theoretical support and practical basis for the further optimization of the maglev train boot rail system.

Keywords side boot track; monitoring system; magnetic levitation train; data analysis

A Thickness Imaging Method for Pipeline Corrosion Damage Using Ultrasonic Guided Waves

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Abstract In response to the challenge of quantitatively diagnosing corrosion damage thickness within pipelines, a quantitative imaging method for pipeline corrosion damage using ultrasonic guided waves is proposed. Firstly, based on the frequency domain finite difference method, a numerical model for multi-path helical propagation of guided waves in pipes is established, enabling rapid calculation of guided wave reception signals when thickness map is known. Secondly, by calculating the received signals in the presence of randomly distributed damage, a database comprising 3 500 samples of damage signals is generated through iteratively running the numerical model. Subsequently, a one-dimensional convolutional neural network imaging model is constructed. The model is trained using the generated database to establish a mapping relationship between thickness maps and reception signals, and inputting the reception signals into the imaging model yields corresponding thickness maps. Finally, the feasibility of the proposed method is experimentally validated. The mean square error between experimental imaging results and actual values is 8.6048×10^{-4}, the correlation coefficient is 0.711 6, and the imaging model runtime is 0.538 5 seconds. The results indicate that the proposed method can achieve quantitative imaging of corrosion damage thickness within pipelines with high imaging efficiency.

Keywords ultrasonic guided wave; pipeline structure; damage imaging; finite difference method; convolutional neural network

Reliability Analysis of Hypersonic Vehicle Based on Kriging Model

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Abstract In order to analyze the reliablility of hypersonic flight vehicles, the longitudinal model of the vehicle is simplified as a cantilever beam structure, and a limit state function is formulated. To address the uncertainty of variable parameters within the limit state function, a hybrid reliability analysis method based on a two-stage Kriging model is proposed. For the first stage, initial sample points are selected to construct an initial Kriging model centered on potential failure points meeting specified accuracy requirements, ensuring the model satisfies this accuracy criterion. For the second stage, a hybrid reliability analysis of the flight vehicle is performed using the initial Kriging model and the first-order reliability method. The Kriging model is adaptively updated by incorporating learning functions, thereby enhancing the efficiency and accuracy of reliability calculations. Comparing the results with existing methods under different parameters of ultimate strength, cantilever beam height, and width, it is demonstrated that the proposed method can meet the requirements for real-time and accurate reliability analysis of the hypersonic vehicle.

Keywords hypersonic vehicle; equivalent cantilever beam; hybrid reliability analysis; Kriging model

Experimental Study on Nonlinear Structure Dynamics Based on Response-Controlled

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Abstract Nonlinear structures exhibit multiple responses under steady-state excitation, making it challenging to directly obtain their dynamic characteristics using traditional vibration test methods. To address this issue, a constant-force dynamic characteristics testing method based on acceleration-response-controlled step-sine frequency sweep test technology is proposed. First, the acceleration response at the excitation point is selected as the control signal, and a step-sine frequency sweep experiment is performed by maintaining a constant response amplitude. Secondly, the resulting simple harmonic excitation spectrum and acceleration response spectrum are obtained through experiments under various acceleration amplitude conditions, and a smooth simple harmonic force surface is constructed using linear interpolation. Then, by extracting the contour lines corresponding to constant force amplitude from this surface, the frequency response curve of the nonlinear structure under constant-force conditions is derived. Finally, the dynamic characteristics of a typical bolted nonlinear structure are investigated. The results show that the proposed approach can accurately capture the frequency response characteristics of bolted nonlinear structures, revealing the pronounced nonlinear dependence on force amplitude. Furthermore, bolt preload and structural reassembly are found to significantly influence the dynamic characteristics of the connection structure.

Keywords nonlinear structure ; response-controlled; dynamics characteristic; harmonic force surface; experimental technology

Mechanical Fault Diagnosis of In-wheel Motor Based on Weibull Kernel Function and MCSVDD

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Abstract In order to monitor the operation state of each wheel motor in distributed drive electric vehicle and ensure the safety of the vehicle, a fault diagnosis method of in-wheel motor based on improved multi-class support vector data description (MCSVDD) is proposed. The method incorporates two major improvements. First, a classification judgment rule based on the minimum distance to the cluster center within the class is proposed using the affinity propagation (AP) clustering algorithm to enhance MCSVDD. Second, a Weibull kernel function is constructed from the Weibull distribution to optimize data description model. Meanwhile, a dimensionality reduction method based on minimum-distance propagation discriminant projection (MPDP) is proposed for the multi-dimensional feature set of in-wheel motor operating state, which improves the separability of in-wheel motor fault states under different working conditions. Finally, in-wheel motors with typical bearing faults are customized respectively to collect vibration signals under 7 rotating speeds for verifying the effectiveness of the proposed method. The results show that the reduced dimension data's separability of observed samples of in-wheel motor operating state based on MPDP is better than that of linear discriminant analysis (LDA), minimum-distance discriminant projection (MDP) and locality preserving projection (LPP), and the recognition accuracy of MCSVDD's state recognition system based on Weibull kernel function is higher than that of polynomial and Gaussian kernel function.

Keywords in-wheel motor; vibration signal; fault diagnosis; minimum-distance propagation discrimination projection; multi-class support vector data description; Weibull kernel function

Design and Parameter Optimization of LLCC Resonant Network for Linear Ultrasonic Motors

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Abstract Aiming to address the operation stability affected by the parameter time-variation of the ultrasonic motor and the harmonic effect of the drive voltage, this paper focuses on the design and optimization of LLCC resonant network topology as well as total harmonic distortion (THD) of the output voltage for driving linear ultrasonic motors (LUMs). Such method can effectively overcome the issue on the variations of the driving voltages caused by the parameter time-variation to improve their operation stability. Firstly, the calculation method for the LLCC matching parameters is derived by using a contact-based equivalent circuit of LUMs considering the stator/mover contact boundary conditions, and a compensation capacitor is added to improve the elasticity margin and the stability of impedance matching. Furthermore, the filtering characteristics of the LLCC resonant network near the resonant frequency is discussed in depth, and the mathematical relationships are derived between the THD of the output voltage and the parameters of the LLCC resonant network are derived. Furthermore, the influence of the parasitic parameters of the transformer on the LLCC resonant network is also analyzed. On this basis, the design optimization methodology for the LLCC resonant network is proposed while acting the THD of the sinusoidal output voltage as the main target. Finally, a LLCC resonant driver is designed for a V-shape LUM, and the corresponding experiments are conducted. The results indicated that the gain and the THD of the output voltage as well as the peak amplitude of the series capacitor voltage itself are determined by the ratio of the series capacitor and the parallel capacitor in the resonant network. The series inductor is the dominating factor for the soft switching characteristics. The THD of the output voltage is controlled below 3%, which is improved more than 70% compared to the unoptimized LLCC resonant driver.

Keywords linear ultrasonic motor; LLCC resonant network; impedance matching; harmonic suppression

Research on Characteristics of Typical Gas Path Fault Components in Aircraft Engines

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Abstract In response to unclear mechanisms in compressor fault diagnosis research, this article aims to reveal the variation law of component characteristic changes caused by blade wear, numerical simulation analysis method is used for studying the changes in component characteristics of blades under different degrees of wear. The results show that the degree of compressor performance degradation caused by blade surface wear is more significant than that caused by blade tip wear. With the increased speed, the degree of performance degradation becomes greater. The efficiency decay value caused by the increase of blade tip clearance shows a pattern of first decreasing and then increasing with the increase of pressure ratio. Near the working line of the compressor, the efficiency decay value is relatively stable with the change of pressure ratio, while the flow decay value increases with the increase of pressure ratio. After the increase of blade surface roughness, the decay values of efficiency and flow rate both increase with the increase of pressure ratio. Moreover, there is a decreasing trend in the decay values near stall pressure ratio. Near the working line, varying degrees of blade wear have a greater impact on flow rate than on efficiency. The results can provide a theoretical reference for the research of fault diagnosis methods for aviation engine gas paths.

Keywords air circuit wear failure; tip clearance; blade surface roughness; performance degradation

Prediction Models of Airflow Resistivity of Kapok Felt Having Two Fiber Cross-Sectional Shapes

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Abstract To address the inadequacy of existing models for predicting the flow resistivity of kapok felt, the airflow resistivity of kapok felt with different bulk densities is tested. Initially, the airflow resistivity of kapok felt is calculated using empirical and theoretical models commonly used in fibrous materials. Subsequently, a new empirical model suitable for predicting the flow resistivity of kapok felt is developed by fitting the experimental data. Finally, considering the cross-sectional geometries and arrangement of kapok fibers at different bulk densities, theoretical models for the flow resistivity of kapok felt are derived by determining the average velocity and frictional force within micro-units, for both circular and flattened fiber cross-sections, based on the Tarnow model and the Hagen-Poiseuille flow assumption. The models are further modified using a flattening ratio parameter. Results demonstrate that compared to the measured values, the prediction accuracy of existing models for kapok felt flow resistivity is low. The modified model is applicable to transitional states between the two cross-sectional geometries. Within the bulk density range of 20 to 180 kg/m^3, the modified model exhibits high prediction accuracy.

Keywords kapok felt; fiber cross-sectional shape; theoretical models; modified model; airflow resistivity prediction

Influence of Wheel Polygon on Low-Frequency Vibration of Subway Vehicle Body

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Abstract To study the influence of subway wheel polygons on low-frequency vibration of the car body, the polygon wear of wheels of a subway line is investigated, on the basis of grasping the distribution characteristics of wheel polygons of subway lines. A vertical dynamic model of elastic car body considering wheel polygons is established, by the time-domain integral solution method. The relationship between wheel polygon excitation frequency and low frequency vibration of vehicle body is studied. By comparing the low-frequency vibration of wheel polygons of different orders, the effect of changes in the operating speed of metro vehicles under service conditions and changes in the radius of wheel wear on the polygonal action of the wheel body is discussed separately. It is shown that a wheel polygon of order 1—3 at common operating speeds generate a low-frequency excitation frequency of 0—20 Hz, and when the excitation frequency is close to the first-order droop frequency of 10.2 Hz resonance will occur. At the beginning of service, the influence of the second order wheel polygon becomes severe on the low frequency vibration of the car body. With the wear of the wheel radius during service, the influence of the first three order wheel polygon changes on the vibration law of the car body. This paper provides a good reference value for service subway operation and wheel maintenance.

Keywords wheel polygon; radial runout; low-frequency vibration; wheel wear; co-frequency resonance

Detection of Planetary Gearbox Weak Fault Based on Sparsity-Guided IEWT-MOMEDA

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Abstract When early failures occur in planetary gearboxes, the weak fault features are difficult to extract and identify due to the interference of background noise in industrial environments and the attenuation of fault impacts in complex transmission paths. To address this issue, a sparse-guided improved empirical wavelet transform (IEWT) is proposed combined with multipoint optimal minimum entropy deconvolution adjusted (MOMEDA) method for weak fault feature extraction. Firstly, a new fault composite index (FCI) is introduced, and the original signal is adaptively decomposed into a set of IEWT components based on the amplitude envelope of the signal spectrum. Secondly, the sensitive components, selected through the sparse-guided method, are used as the sparse representation of the original weak fault signal. Finally, the MOMEDA technique is applied to the sensitive component signals to reduce signal noise and extract the weak fault feature frequencies for identification. The effectiveness of the proposed method is validated through simulations and experiments, successfully extracting and identifying the weak fault features of planetary gearboxes. This demonstrates that the method has good diagnostic performance for noisy, non-stationary, and non-linear fault signals in planetary gearboxes, providing a new approach for the diagnosis and identification of weak faults in engineering practice.

Keywords planetary gearbox; empirical wavelet transform; multipoint optimal minimum entropy deconvolution adjusted; sparse-guided; weak fault diagnosis

Study on Transient Vibration Suppression Method of Vertical Axis Washing Machine

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Abstract The transient vibration of a vertical axis washing machine is strong in the dehydration process, so a new planar variable damping structure is proposed to reduce the transient vibration. Firstly, the kinetic energy and potential energy of various rigid bodies of the washer are deduced, the generalized forces of the suspension structure are described, the force of the liquid balancer is analyzed, and the vibration model of the vertical axis washing machine is established using Lagrange's equation. The working principle of the planar damping structure is explored, its damping force is described and its suppression effect on transient vibration of the washer is verified. Secondly, the influence of the planar damping structure on dynamic characteristics of the washer is evaluated, the bifurcation theory is employed to analyze stability of the system. Furthermore, the distributions of the stable regions of the system is analyzed, and the appropriate disengaging speed range of the damping structure is obtained. Finally, the effect of the damping structure for suppressing transient suppression of the washer is validated though experiments, and the appropriate disengaging speed of the structure is analyzed. The results show that the planar damping structure can suppress transient vibrations effectively with little influence on other dynamic characteristics of the washer.

Keywords washing machine; transient vibration; vibration suppression; variable damping structure; stability analysis

Research on Noise Reduction of Inertial Navigation Heterogeneous Signals Based on Noise-Sensitive Prior and Improved VMD

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Abstract Aiming at the multi-source noise of inertial navigation in the attitude estimation of coal mine bolting jumbo, a noise reduction method of inertial navigation heterogeneous signal is proposed based on noise sensitive prior and improved variational mode decomposition (VMD), which avoids the over-decomposition and under-decomposition problems caused by the parameter fixation. Firstly, the noise sensitivity difference of the heterogeneous signals (acceleration and angular velocity) of coal mine bolting jumbo is investigated by using the variation of the signal characteristics in the time and frequency domains. Secondly, according to the noise-sensitive characteristics, the dual decomposition layer and energy fluctuation model are constructed, so that the decomposition parameters have the ability of adaptive optimization and the synchronous optimal decomposition of the inertial-guide heterogeneous signals is realized. Based on the Pearson correlation coefficient (PCC), the modal component screening parameter, correlation coefficient P, is designed to consider the noise sensitivity difference, to achieve screening practical modal components and simultaneous noise reduction of heterogeneous signals. Finally, the proposed method is compared with the noise reduction results of complementary ensemble empirical mode decomposition (CEEMD) and improved complete ensemble empirical mode decomposition with adaptive noise (ICEEMDAN). The results show that the method proposed in this paper considers the noise sensitivity differences of heterogeneous signals, thereby improving the signal-to-noise ratio of inertial measurement and enhancing the attitude initialization accuracy of bolting jumbo. The pitch error is reduced by 81.818 %, and the yaw error is reduced by 87.958 %, which lays a good foundation for accurate roadway support.

Keywords variational mode decomposition; noise reduction; inertial navigation heterogeneous signal; bolting jumbo

Corrosion Evaluation Technology by Electromechanical Impedance for Grounding Conductors

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Abstract A novel approach based on electromechanical impedance is proposed to evaluate the corrosion degree for grounding conductors, which are difficult to simply detect and evaluate for traditional methods. Firstly, according to the electrochemical corrosion model of metals, the grounding conductor parametric corrosion model is established by importing the change of grounding conductor radius as corrosion parameter. Secondly, the corrosion model between an electromechanical impedance resonance frequency and corrosion parameter is established with the analysis of system electromechanical impedance and conductor mechanical admittance. Then, the resonance frequency and corrosion parameter signal of grounding conductors are obtained via finite element simulation method, while the coefficient of the corrosion model is obtained by the least square method. The results show that the electromechanical impedance detected by asymmetrical sensor layout can reflect variations of the corrosion parameter more clearly than that by symmetrical sensor layout. Linear model by finite element simulation and the least square method can predict the corrosion parameter. Moreover, the high consistency between the datum predicted by the linear model and the experimental datum, indicates the linear model is very accurate and can be used to detect the conductor corrosion in field applications.

Keywords grounding conductor; parametric corrosion model; electromechanical impedance; finite element simulation

Study on the Characteristics of Fluid-Structure Interaction Wind Effects in Super High-Rise Buildings Subject to Various Inflow Conditions

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Abstract To study the wind effect characteristics of super high-rise buildings in different incoming flows under the fluid-structure interaction effect, a full-scale numerical wind tunnel simulation of Pingan Financial Building in Shenzhen is carried out using the detached eddy simulation (DES), established the aeroelastic model. A new turbulent fluctuating flow field generation method named the discretizing and synthesizing random flow generator (DSRFG) is used to simulate the turbulent flows of the atmospheric boundary layer and the uniform flows. The wind pressure and wind-induced response results of the model are obtained. The calculated results are compared with the corresponding data from wind tunnel tests and field measurements to verify the accuracy of the numerical simulation. The analysis shows that the wind pressure of the building under turbulent incoming flow obtained from the DES is consistent with the distribution trend of wind tunnel test and field measurement results. The distribution of the mean wind pressure coefficient of the building under both conditions is similar, and the fluctuating wind pressure coefficient on the windward side under turbulent incoming flow is larger than that under uniform incoming flow. In addition, the cross-wind acceleration response is larger under turbulent incoming flow than that under uniform incoming flow, and the acceleration response power spectrum shows three peaks and the displacement response power spectrum shows two peaks under uniform incoming flow, while the turbulent incoming flow only shows a single peak. The acceleration response power spectrum shows three peaks and displacement response power spectrum shows double peaks under uniform incoming flow with only single peak under turbulent incoming flow. In the flow field, the wind velocity is more uniform in the uniform incoming flow than in the turbulent incoming flow, the wake vortex is flatter and narrower, and the overall vorticity magnitude is smaller.

Keywords fluid-structure interaction; super high-rise building; detached eddy simulation; field measurement; wind-induced response

Wheelset Bearing Fault Detection Based on Multi-resolution Siamese Network

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Abstract In order to improve the fault detection performance of wheelset bearings under small sample image conditions, a machine vision inspection method based on a novel multi-resolution siamese neural network (MrSNN) is proposed for surface defect detection of wheelset bearings. First, the siamese neural network (SNN) is used as the basic model framework. A multi-resolution convolution fusion block (MrCFB) containing convolution kernels of different sizes and dilation factors is constructed to comprehensively extract the detailed features and contour features from images. Then, a dual attention mechanism combining channel and spatial information is adopted to recalibrate the multi-resolution feature weights, further enhancing the image feature extraction capability of the model. Finally, the algorithm is validated through the detection and analysis of four types of wheelset bearings images: normal, scratched, pitted and spalled. Experimental results show that the recognition rate for the three types of faulty images reaches 100%, the recognition rate for normal images is 95%, and the overall recognition accuracy is 98.75%. The recognition accuracy is superior to that of traditional SNN and YOLO-V5 models.

Keywords rolling bearing; fault diagnosis; neural network; image detection; multi-resolution feature

Simultaneous Full-Field Strain and Temperature Testing on Welded Structures of Engines

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Abstract To investigate the fatigue strength of welded structures under high cyclic loads, a synchronized coupled testing method combining digital image correlation (DIC) and infrared thermography (IR) is employed to simultaneously acquire full-field strain and temperature data on the structural surface, explaining the evolution of structural damage. First, tensile testing is performed on 45# steel specimens, and the patterns of variations in surface temperature and strain during the tensile process are obtained. The temperature characteristics at various stages of the damage process agree well with the material load-time curve, reflecting the different stages of damage in 45# steel. Finally, ultra-low cycle fatigue testing is conducted on GH4061 welded structure used in engines, capturing the entire process of crack initiation, propagation, and fracture under cyclic loading, with synchronized full-field strain and temperature testing and analysis performed. The experimental results demonstrate the feasibility and effectiveness of this method in monitoring fatigue damage in welded structures.

Keywords welded structures; superalloys; infrared thermography; digital image correlation (DIC); crack

Dual-Fiber Timing Technique for Tip Clearance Measurement and Experimental Verification

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Abstract For tip clearance measurement, a multi-section tip clearance measurement and verification simulation rotor test bench is established, and multi-channel tip clearance online measurement software is developed. First, tip clearance is measured using a customized dual-fiber sensor based on laser triangulation. Second, a high-precision displacement platform is utilized to change the tip clearance value, and accurate tip clearance values are measured at different rotational speeds. Last, to address the trigger threshold voltage issue of the acquisition card for measuring tip clearance with dual-fiber sensors, a multi-channel integrated voltage comparator has been designed, which eliminates the time difference on the order of 10^{-5} s caused by simultaneous measurement of the two channels of the dual-fiber sensor. The results show that, based on the tip timing principle, the tip clearance can be calculated by measuring only the arrival time of the tip. The mean error of each set of clearances is within 5%, and the standard deviation of the tip clearance measurements in each group is less than 22 μm, demonstrating the accuracy and repeatability of the tip clearance measurement system.

Keywords rotating machinery; tip clearance; laser triangulation; tip timing

Non-Gaussian Probability Distribution Characteristics and Extreme Wind Pressure on Long-Span Roofs

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Abstract Wind tunnel pressure tests are conducted on a high-speed railway station roof to study the non-Gaussian characteristics and extreme wind pressure distribution on the long-span roof surface. First, the surface wind pressure is classified into Gaussian and non-Gaussian distributions. Then, the fitting effects of three different single probability distributions (Gumbel, Lognormal, and Weibull) and their corresponding combined distributions (double Gumbel, double Lognormal, and double Weibull) on the wind pressure time history of the roof surface are compared. The extreme wind pressures obtained from the combined probability distributions are compared with the estimates from the modified Hermite method. Finally, the extreme wind pressure distribution on the roof under all wind directions is presented. The results show that the combined probability distributions provide a better fit to the wind pressure time history than the single distributions. The extreme value estimates from each combined distribution at the same guarantee rate are more accurate than those from the single distribution. The combined distributions generally yield better estimates at the 99.90% guarantee rate compared to the modified Hermite method. The extreme wind pressure varies significantly with the wind direction, and under all wind directions, the minimum pressure coefficient reaches its lowest value at the middle of the roof edge side, reaching −5.9.

Keywords long-span roof; non-Gaussian characteristics; extreme wind pressure; combined probability distribution; extreme value estimation method

Rapid Detection Method for Metro Rail Corrugation Based on Vibration Energy Ratio

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Abstract To investigate the data-driven evolution of rail corrugation in subways, a spatio-temporally dense measurement method is proposed for rapid detection. First, high-precision sensors are used to measure car-body vibration, collecting triaxial acceleration data. Second, vehicle speed and mileage position are estimated by fusing triaxial vibration acceleration from different car bodies. Then, the vertical vibration acceleration of the car body is decomposed via wavelet packet analysis, and a vibration energy ratio index is defined as the ratio of the energy in the characteristic frequency band excited by rail corrugation wavelength to the total vibration energy. The vibration energy ratio threshold is set to automatically identify rail corrugation and output mileage information. Finally, the corrugation wavelength is derived from the ratio of vehicle speed to characteristic frequency, and the relationship between vibration energy ratio and corrugation amplitude is analyzed. Results show that using a vibration energy ratio threshold of 0.2 yields corrugation mileage distribution consistent with that from noise-based identification, and the calculated corrugation wavelength matches the measured value of 175 mm from a corrugation analyzer. Statistical clustering reveals that the relationship between rail corrugation amplitude and vibration energy ratio is not purely linear. Line-wide rapid detection shows that non-corrugated sections account for 76.56% of the track, while corrugation sections account for 23.44%. Among the corrugated sections, those with wavelengths below 60 mm dominate (77.88%), whereas those above 60 mm account for 22.12%.

Keywords rail corrugation; car-body vibration acceleration; wavelet packet analysis; vibration energy ratio; characteristic frequency band

Parameter Identification for Dielectric Elastomer Actuators Based on Transient-Extracting Transform

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Abstract A parameter identification method is proposed to accurately capture the nonlinear dynamic characteristics of dielectric elastomer actuators (DEAs). First, the response signal of the actuator is acquired under swept-frequency excitation using the time-frequency analysis capability of the transient-extracting transform (TET). Then, the harmonic and fundamental frequency components are separated and extracted, and the transfer functions for each component are computed to derive the overall transfer function of the DEA. Finally, the results are compared with experimental data. The proposed method achieves a fitting accuracy of 92.11% for the fundamental frequency transfer function and 90.35% for the second harmonic transfer function. This approach does not require prior knowledge of material properties or free energy density functions, and incorporates the influence of high-order harmonic components, offering a novel solution for parameter identification in electroactive material structures.

Keywords dielectric elastomer actuator; parameter identification; transfer function; transient-extracting transform

Analysis of the Influence of Surrounding Metal Objects on the Electromagnetic Transmission Performance of Balise Uplink

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Abstract To address the issue of metallic objects around a balise affecting its electromagnetic transmission performance, a balise antenna model is established in electromagnetic simulation software. The simulation experiments are carried out by varying three parameters: the metal surface area, the vertical distance between the metal surface and the balise, and the metal surface thickness. The uplink signal amplitude curves of the balise under different parameters are obtained, and the transmission performance metrics are calculated to analyze the impact. Results show that: a larger metal surface area leads to lower performance metrics, such as a reduced number of safety message frames received by the balise transmission module (BTM), with a more significant degradation and greater interference from the sidelobe region. When the metal area is greater than 320 mm×320 mm, the uplink field strength consistency requirement can no longer be met. A greater absolute distance between the metal surface and the balise results in less interference from the sidelobe region, and the distance must be greater than 123 mm to satisfy the field strength consistency requirement. Increased metal surface thickness causes greater interference from the sidelobe region, and the thickness should not exceed 1 mm.

Keywords balise; metallic objects; uplink; transmission performance

Effect of Holed Structure of Friction Block on Braking Characteristics of High-Speed Trains

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Abstract The friction block of high-speed train brake pads exist in two configurations: holed and non-holed. To investigate the influence of the holed structure on the braking performance, drag braking tests using both types of friction blocks are carried out on a self-developed scaled brake dynamometer for high-speed trains. In addition, finite element simulations are carried out to analyze vibration noise and interface thermal distribution during braking. Experimental and numerical results indicate that the non-holed friction blocks produces continuous self-excited vibration and excites high-intensity squeal noise, whereas the perforated block effectively suppress system instability and reduce squeal noise to some extent. Moreover, the holed structure improves the interfacial thermal distribution, leading to more uniform temperatures on both the friction block surface and the matching brake disc compared to the non-holed blocks.

Keywords high-speed trains; braking; friction block; vibration noise; thermal distribution