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Research and Progress of Metal Damper

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Abstract: Metal dampers demonstrate extensive application potential in construction and mechanical engineering, serving as critical components with exceptional vibration damping capabilities. Their compact design and versatile interface configurations enhance structural safety while optimizing project efficiency. These devices effectively protect machinery systems and improve equipment reliability and stability. This paper reviews recent advancements in metal damper research, providing valuable insights for future engineering development.

Keywords: Metal damper, vibration damping, noise reduction.

1. Introduction

A metal damper is a device that dissipates energy through plastic deformation of metal materials under vibration. It features excellent hysteresis characteristics, low cyclic fatigue stability, and strong environmental adaptability. Metal dampers can be categorized into three types: out-of-plane bending type, in-plane shear type, and anti-buckling restrained supports, with the latter further divided into core-filled and non-core-filled variants. The metal damper produced by Li Hui Zhen Kuan employs a self-stabilizing core structure design, which prevents welding stress loss and enhances energy dissipation performance, making it widely used in various vibration control projects. The main installation methods for metal dampers include: Single-point support method: Fixing the damper at a single contact point on the structure, isolated from other components. This approach suits lightweight structures like light steel components and architectural attachments. Dual-point support method: Mounting the damper on two "support points" connected via metal rods. This method applies to medium-importance structures such as bridges and high-rise buildings. Fixed support method: Securing the damper at both ends of the structure to maintain stability. This method is suitable for all types of structures including machinery equipment and underground pipelines. Support-type damper connection: Attaching the damper to structural supports to provide additional damping effects. Wall-mounted damper connection: Mounting the damper on wall structures to reduce structural vibrations. Beam-type metal damper connection: The metal damper is attached to the beam structure to enhance structural stability. Diagonal support, A-frame support, cable-supported, and scissor-type supports: These installation methods are commonly used in buildings to improve structural stability and safety. Scissor-type and elbow-type installations: While these methods amplify the damper's effectiveness with enhanced energy dissipation capabilities, their complex installation processes lead to limited applications. Diagonal installation: Damper series-connected to diagonal supports reduces inter-story lateral displacement but requires larger installation spaces, hindering pedestrian access and window/door layout. A-frame installation: Damper series-connected to horizontal rods at the top of A-frame supports or directly between A-frame supports and frame beams maximizes energy dissipation capacity while requiring consideration for lateral stability during installation.

2. Domestic and International Development Status

Domestic Research Status Leveraging magnetorheological fluid properties that vary with magnetic field strength and foam metal's microscale uniformity, Li Mingzhang and colleagues developed a novel magnetorheological damper by integrating both materials. They established a damping force model for the damper and nonlinear mathematical models for its vibration reduction system. Experimental verification confirmed the damper's performance, demonstrating that the nonlinear model accurately reflects damping characteristics and vibration reduction properties of the magnetorheological damper. Fu Yangqiang and colleagues developed an innovative wall-mounted composite metal damper with energy-dissipating stability, which provides ample open space and structural openings while enhancing seismic resistance and building comfort. Using the finite element analysis software ANSYS, they investigated the damper's mechanical performance under various displacement magnitudes, explored the relationship between initial stiffness and lead weight thickness, and demonstrated its energy dissipation effectiveness through engineering case studies. Nonlinear time-history analysis revealed that this damper delivers significant additional stiffness and damping during minor earthquakes, effectively reducing horizontal deformation and improving internal forces under seismic loads. During major earthquakes, it exhibits a full hysteresis loop with stable energy dissipation, ensuring structural integrity. Li Xiangxiu and team implemented this composite damper in a high-rise shear wall project. A three-dimensional nonlinear finite element model was established using Perform-3D, and plastic-elastic analysis under magnitude 9 earthquakes confirmed the damper's vibration control efficacy. Results showed over 20% reduction in base shear force after installation, demonstrating practical applicability for real-world engineering. Metal's excellent hysteretic behavior during plastic-elastic deformation allows its production of various energy-dissipating devices that efficiently absorb energy during seismic events. Yan Xiaotong and colleagues developed elliptical-opening metal dampers, employing the finite element analysis software ABAQUS to evaluate the hysteretic behavior of elliptical, rhombic, and X-shaped dampers under varying opening ratios. Comparative results demonstrated that elliptical dampers exhibited superior energy dissipation performance, providing valuable guidance for future damper selection. Energy dissipation damping technology enhances structural equivalent damping through strategically placed dampers, effectively reducing seismic response and wind load-induced deformations in building systems. Commonly used dampers include metallic, frictional, and viscous types. While metallic dampers are widely adopted for their manufacturing simplicity, cost-effectiveness, and easy replacement, existing models often suffer from fatigue issues, excessive buckling tendency, and concentrated yield points. To address these limitations, Wang Wei proposed a novel braided metallic damper constructed by interweaving low-strength steel bars with high-strength steel rods. The study systematically investigated the damper's performance through theoretical analysis, numerical simulations, and experimental validation. ANSYS software was utilized to simulate the bending formation of low-strength steel bars and their reciprocating motion relative to high-strength steel rods, optimizing design parameters to generate load-displacement hysteretic curves. The research also explored nonlinear contact mechanisms between steel bars and high-strength round steel rods. A quasi-static test was conducted on a novel woven-type metal damper component, yielding its load-displacement hysteresis curve and demonstrating excellent fatigue performance. The study further investigated a damper configuration combining low-strength steel bars with high-strength spring steel bars in a layered structure. Comparative analysis revealed that this layered steel bar design significantly enhanced both output capacity and energy dissipation efficiency. Through parameter optimization, numerical simulations were performed on a damper featuring spindle-shaped cross-section steel rods. Results showed that the spindle-shaped rod configuration produced fuller hysteresis curves and substantially improved maximum output capacity. Parameter identification of the Bouc-Wen model using redundancy elimination methods enabled parametric fitting of experimental and simulation data to establish the recovery force model. A comprehensive elastoplastic time-history analysis was conducted on a 10-story planar regular frame using SAP2000 finite element analysis software. The results indicated substantial reduction in inter-story displacement parameters following damper installation. Regarding metal damper optimization under different objective functions, Zhao Jie et al. employed two approaches—layer-by-layer arrangement and position parameter method—for energy dissipation analysis in frame structures, targeting either inter-story displacement angle or displacement itself. Comparative results demonstrated comparable vibration reduction effects under identical damper counts when using two optimization methods, with both approaches producing fuller hysteresis curves and superior energy dissipation performance. Based on the application characteristics and limitations of current metal yielding energy dissipation devices, Hu Dazhu and colleagues proposed an axially arranged metal damper. Its main structural feature lies in combining the energy-dissipating steel plate directly with connected steel supports, forming a single vibration damping component that resolves the technical challenge of symmetrical arrangement required by conventional metal dampers. They derived calculation formulas for yield load-bearing capacity and stiffness of axially arranged metal dampers, conducted low-cycle repetitive loading tests, and obtained hysteretic curves and skeleton curves of the axially arranged dampers. Experimental results validated the accuracy of finite element analysis. Simultaneously, test data demonstrated that axially arranged metal dampers exhibit excellent ductility and stable hysteretic performance. Using ABAQUS finite element software, 12 parameter combinations of axially arranged metal dampers were numerically simulated to study the effects of different energy-dissipating plate configurations, quantities, and dissipation modes on mechanical properties. Results indicated that the width-to-thickness ratio of energy-dissipating plates is the primary factor influencing hysteretic performance. Prefabricated buildings offer advantages like high construction efficiency and energy conservation, but their connections between prefabricated components often fail prematurely under seismic loads, compromising overall structural seismic resistance. To address this issue, Levinchen proposed a rotating-type metal damper—a torsion steel tube damper—for connecting prefabricated beams and columns, with focused research on its seismic performance and structural system applications. This study investigates the structural configuration and operational mechanisms of torsion steel tube dampers. Through quasi-static low-cycle cyclic loading tests on five test specimens, we analyzed critical performance parameters including deformation characteristics, failure modes, moment-angle hysteresis loops, skeletal curves, stiffness degradation, strength deterioration, energy dissipation characteristics, and fatigue behavior. Experimental results demonstrate that these dampers exhibit full hysteresis loops with excellent energy dissipation capacity. At the end of loading, all specimens achieved equivalent viscous damping coefficients around 0.5 and ultimate rotation angles exceeding 0.06 rad, while maintaining good low-cycle fatigue performance. Using the finite element analysis software ABAQUS, a three-dimensional solid numerical model was established to simulate cyclic loading under experimental conditions. The simulation results showed excellent agreement with experimental data, validating the model's accuracy. Based on this validated finite element model, we investigated the yield mechanisms and stress-strain distributions under seismic loads, further revealing the energy dissipation principles and seismic resistance capabilities. Results indicate that the damper features simplified force mechanisms and clear energy dissipation patterns. Parameter optimization analysis was conducted for different design configurations, identifying key parameters affecting hysteresis performance. Finally, an optimized structural design scheme is proposed with feasibility analysis. This study investigated the applicability of the Bouc-Wen model in simulating cyclic mechanical behavior of torsion steel tube dampers. Using experimental data, particle swarm optimization (PSO) was employed to identify model parameters. The results demonstrated that while the original Bouc-Wen model exhibited good overall simulation performance, it failed to capture the isotropic reinforcement characteristics observed in experiments. To address this limitation, the model was enhanced by incorporating an isotropic reinforcement control parameter and explaining its operational mechanism. Subsequent parameter identification revealed that the modified model effectively simulated the damper's isotropic reinforcement behavior with superior accuracy compared to the original version. Finally, two alternative recovery models are presented for comparison.

3. Conclusion and Prospect

This article provides a comprehensive review of recent research developments in metal dampers. With the continuous advancement of intelligent technologies, metal dampers are evolving into smart devices. For instance, by integrating smart materials and sensor technology, real-time monitoring and control of metal dampers can be achieved, significantly enhancing their vibration damping, noise reduction, and vibration control capabilities. As technology progresses, metal dampers are expected to expand their application scope even further. Functioning as energy-absorbing or energy-converting devices, metal dampers are widely used in vibration reduction, noise suppression, and vibration control systems. On one hand, with growing environmental awareness, vibration and noise management have become increasingly crucial. Metal dampers, serving as efficient vibration-damping solutions, will see broader applications across construction, transportation, aerospace, marine engineering, and precision instrumentation. In construction, they enhance structural seismic resistance; in aerospace, they help mitigate wing flutter phenomena. On the other hand, emerging materials like titanium alloys and nickel-based alloys—high-strength materials with superior mechanical properties—will further improve the durability and reliability of metal dampers. Additionally, cutting-edge manufacturing techniques such as 3D printing will drive continuous optimization of production processes for these devices. Furthermore, metal dampers demonstrate extensive application potential in smart materials and intelligent structures. These advanced systems—capable of sensing, responding, and self-adapting—automatically adjust their performance and configuration according to environmental changes. As a pivotal component in such systems, metal dampers enable adaptive vibration control and intelligent regulation. Looking ahead, these devices are poised for broader adoption and continuous technological advancement. With growing demands for enhanced functionality and reliability, their design and manufacturing face both challenges and opportunities. Metal dampers will maintain robust application prospects and development space. As technology progresses, we anticipate more innovative and practical variants that will enhance convenience and safety in industrial production and daily life.

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