WEP Warwick Evans Publishing

International Journal of Mechanical and Electrical Engineering

ISSN: 3005-9615 (Print), ISSN: 3005-7132 (Online) | Volume 6, Number 3, Year 2025
DOI: https://doi.org/10.62051/ijmee.v6n3.07
Journal homepage: https://wepub.org/index.php/IJMEE/index

Review of Current Status and Research Progress of Metal Dampers

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ABSTRACT

As a kind of energy dissipation and vibration reduction equipment with simple structure, stable performance and cost economy, the metal damper shows many advantages. Its working principle is based on the hysteretic energy dissipation characteristics of metal materials in the process of plastic deformation. Through this characteristic, the energy is converted into equivalent damping force, and then the vibration reduction target is realized. This study first reviews the basic principles, classification and development of metal dampers, and then focuses on the progress of several typical metal dampers for in-depth discussion, and summarizes the results of theoretical research and type innovation practice. In view of the existing deficiencies in this field, several potential research directions are proposed.

KEYWORDS

Metal Damper; Shock Absorption; Principle.

1. BASIC OVERVIEW OF METAL DAMPER

1.1. Principle of Operation

As a control strategy that does not rely on external energy sources, the operation mechanism of structural passive control technology usually involves the introduction of auxiliary subsystems in key areas of the structure, or the optimization of structural design of local components of the structure, so as to adjust the dynamic response characteristics of the structure. Such control methods are widely used in isolation, energy absorption and energy dissipation to consume the energy in the process of structural vibration, so as to reduce the structural vibration response. The generation of the control force shows a passive characteristic, that is, while the control device is accompanied by structural vibration, its motion state spontaneously forms a control force.

1.2. The Significance of the Topic

In the field of structural engineering, it is very important to study the destructiveness caused by earthquakes, and it is of great academic value to explore effective vibration control technology. By integrating energy-consuming components in the structural system, a reliable safety vibration reduction strategy is realized, which can significantly reduce the energy of seismic waves and ensure the stability of the structure. As a key damping element, metal damper has been widely used in construction, bridge, aerospace and other fields. This study is devoted to the experimental and theoretical analysis of the application of a new type of metal damper in shock-absorbing structures.

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Under the background of sustained economic growth, the public 's expectations for the seismic performance of buildings are increasing, which has led to the rise of energy dissipation technology. This kind of structural design shows significant advantages in terms of safety, economic benefits, rationality and applicability. The United States, Japan, Canada, Italy, Mexico and other countries and regions in the field of energy dissipation technology research started earlier, all kinds of dampers have been widely used in new buildings and seismic reinforcement projects. Although China 's research in this field started late, with the economic growth and scientific and technological progress, energy dissipation technology has been gradually applied to engineering practice.

2. RESEARCH HISTORY OF METAL DAMPER

2.1. Study on the Background

As a devastating natural disaster, earthquake poses a serious threat to human society. Traditional seismic strategies rely on the resilience of load-bearing structures. However, such methods are not only costly, but also often difficult to recover once the structure is damaged. Structural control technology reduces the dynamic response of the structure by optimizing the dynamic performance of the structure (including key parameters such as mass, damping and stiffness) or applying external forces to resist wind load and seismic load, so as to ensure that it meets the safety standards. Since the 1970 s, scientists have successfully explored a structural vibration control strategy with ' shock absorption ' as the core. This study mainly relies on the control force applied to the structure by the non-load-bearing control device to achieve effective suppression of its vibration. Compared with the traditional seismic technology, this method not only avoids its disadvantages, but also has significant advantages such as economy, practicability and clear force transmission mechanism, so it is widely used[1].

2.2. Origin and Development

Vibration control structure design can be divided into four main categories : passive, active, semi-active and hybrid. In these categories, passive control equipment is widely used in engineering practice because of its low cost and easy installation, excellent performance in cost-effectiveness, reliability and ease of operation. There are many kinds of passive control equipment. According to its control principle, it can be roughly divided into three technical systems : base isolation, energy dissipation and dynamic response absorption.

In the practical application of energy dissipation technology, the energy dissipator, as a key component, can be divided into two categories : velocity response type and displacement response type according to the current seismic code in China. The restoring force characteristics of the displacement response energy dissipater are closely related to the change of relative displacement, and its energy dissipation mechanism is activated only when the displacement exceeds the preset trigger value. Friction dampers and metal dampers have become the mainstream devices in displacement response energy dissipators due to their wide application[2].

Kelly first conducted in-depth research and experiments on metal yield dampers. The core function of the device is to yield first before the building structure has not yet entered the plastic deformation stage during the earthquake, so as to effectively dissipate the energy transmitted from the ground motion to the building structure. Kajima Company of Japan has successfully developed a soft steel yield energy dissipator with honeycomb structure, which can be embedded in the wall or beam body. If installed in the beam, its significant advantage is that no additional support structure is required, which greatly improves the flexibility of architectural space design.

In 1997, Mito and other researchers conducted an experimental study on the rectangular shear plate damper. However, it was found that under the action of plane force, the four corners of the steel plate of the damper were easy to form stress concentration, resulting in fracture under small deformation displacement, showing low energy dissipation performance. In 2003, Tirca et al.proposed a new type of plane force steel damper, and analyzed the performance of the damper installed in the middle and high-rise structure. The results show that the damper has good energy dissipation and shock absorption efficiency[3].

In 2006, Li et al.developed five types of steel dampers based on the theory of ' increasing the in-plane stiffness of the steel plate to enhance the initial bending resistance and adjusting the plane geometry of the steel plate to improve the deformation energy dissipation efficiency '. It is found that the I-shaped and double-hole steel dampers perform poorly in terms of deformation energy dissipation performance. The single-hole steel damper shows excellent energy dissipation performance. There are some defects in the stability of strip steel damper. The double X-shaped steel damper shows a significant energy dissipation advantage.

In 2008, Hebei University of Technology successfully developed a SMA damper that integrates energy consumption and reset functions, and comprehensively evaluated its cost-effectiveness in the field of structural vibration control. In addition, this study proposes a genetic algorithm based on an improved binary tournament to improve the computational efficiency and optimization effect of the multi-objective optimization algorithm, and conducts multi-objective optimization research on the structure using the damper.

In 2009, a new type of ' dual-function ' steel damper was developed based on the research and innovation ideas of Li Hongnan and Li Gang from the School of Civil Engineering and Water Conservancy of Dalian University of Technology. The device ensures that the structure has sufficient initial stiffness under normal use and small earthquake disturbance by installing an energy dissipation system composed of steel diagonal braces and new ' dual-function ' dampers between the first floor columns. When encountering a large earthquake, the damper can enter the plastic deformation stage and effectively dissipate seismic energy[4].

In 2010, researchers introduced a new type of seismic structure protection system-composite metal damper into the structure to improve the seismic performance of the bridge structure. The damper has stable hysteresis characteristics and good plastic deformation ability.

In 2012, Fu et al.proposed a new type of energy-consuming and stable wall-type combined metal damper, which can meet the needs of sufficient open space and openings. While improving the seismic capacity of the building structure, it also improves the comfort of the building.

In the same year, Yan Weiming et al.also proposed a composite metal damper. Its working principle is : because there is a certain gap between the piston and the extrusion cylinder, and a certain number of small holes are symmetrically opened on the piston, during the reciprocating motion of the piston, the composite metal filled in will be squeezed, prompting the composite metal to dissipate energy through the plastic flow between the holes and the voids.

Xing Baipeng et al.developed a bidirectional torsional metal damper, which uses the plastic deformation process of the material to complete energy dissipation. The core design adopts the multi-layer structure of hollow constrained steel, and the arrangement angle of adjacent steel layers is set in reverse. This unique structural design can effectively amplify the relative torsional deformation amplitude of the damper under axial load, thereby improving the dissipation efficiency of the input vibration energy.

On the other hand, Wang Xiaowei developed a new type of bridge transverse metal damper. The damper not only has excellent energy dissipation performance and can adapt to the longitudinal deformation demand of bridge structure, but also has the advantages of simple structure and convenient installation and operation[5].

In 2015, Wang Wei et al.applied for a patent for a new type of woven metal damper. When an earthquake occurs, the position of the peak and trough formed by the bending deformation of the low-strength steel bar will change with the horizontal earthquake. In this process, part of the seismic energy can be dissipated, effectively ensuring the safety of the building structure. Jia Chuanguo also proposed a new type of braided metal damper, which relies on the plastic deformation of braided steel bars to complete energy consumption. Considering that the bending moment in the mid-span of the coupling beam is the smallest and the shear force is uniformly distributed under the action of earthquake, Li Donghan proposes to cut the coupling beam in the mid-span and install a shear-type metal energy dissipation damper at this position.

In 2017, Lu Liang et al.proposed an axial tension-compression metal damper. The web of the damper realizes yield energy dissipation through axial tension and compression, which effectively avoids the problem that the shear-loaded metal damper squeezes the beam bottom due to the incompatibility with the overall structural deformation, which leads to local damage of the structure.

In 2018, Zhu Baijie et al.proposed an assembled shear metal damper with optimized shape of equal stress line to improve its energy dissipation efficiency in view of the stress concentration of shear metal damper and the influence of thermal stress in welding zone. Huang Zuhuan et al.proposed a new type of slotted energy dissipation composite wall to improve the performance of shear wall with small height-width ratio and control the damage of shear wall. From the dimensions of bearing capacity, deformation capacity, energy dissipation capacity and failure mode, the difference of seismic performance between the composite wall and the traditional low shear wall was compared and analyzed. On the basis of the bending yield casing damper, in order to reduce the friction between the inner and outer tubes and improve the manufacturing convenience, Sun Yingzhi et al.changed the inner tube section to I-shaped.

In order to solve the stress concentration problem of the traditional shear metal damper with long slit and the thermal effect caused by welding, and then improve the energy dissipation capacity of the damper, Zhang Lingxin proposed a diamond-shaped shear metal damper with equal strength line to optimize the shape of the opening. Chen Yun proposed a new type of graded yielding metal damper, which is composed of two annular metal dampers with different sizes. In view of the high yield strength and uncontrollable defects of metal dampers, He Haoxiang proposed a composite metal damper composed of low yield point steel and ordinary carbon steel. The classification of metal dampers is shown in Fig.1.

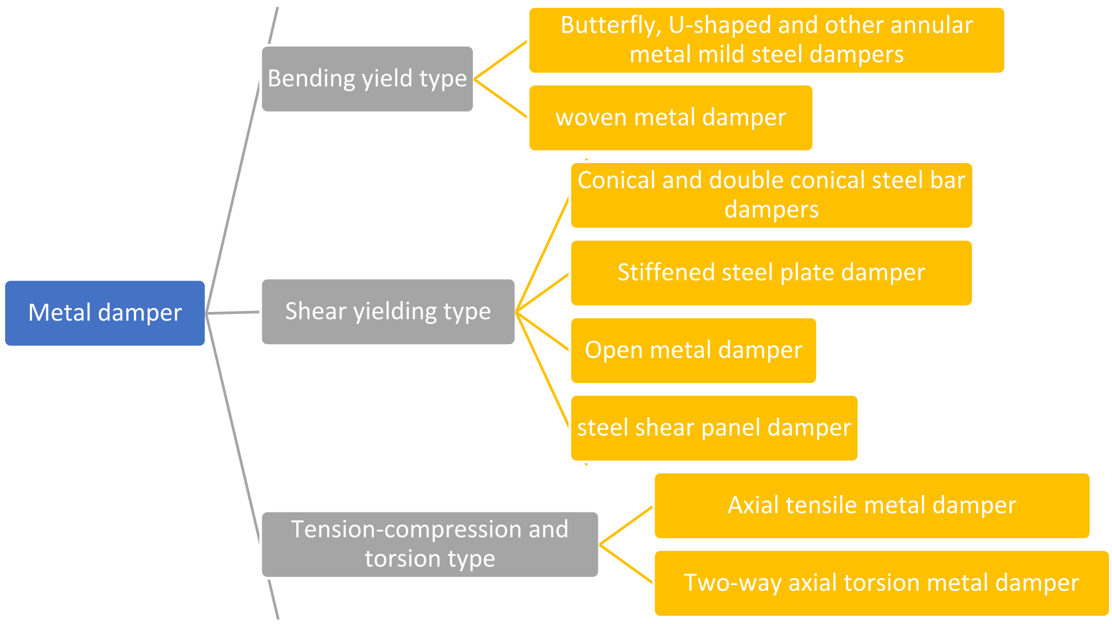

Fig 1. Classification of metal dampers

In 2019, Chen Yun proposed a graded yield metal damper, which is composed of two annular metal dampers with different sizes nested each other[6].

In 2020, Wang Xin designed a new type of cross-shaped metal damper to solve the problems of local premature buckling, poor bearing capacity and energy dissipation capacity of partial shear metal damper. Huang Haixin et al.focused on the shortcomings of conventional metal dampers in terms of small design displacement, weak fatigue resistance, and complicated production and installation processes. Based on the design concept of variable cross-section plastic yield, an L-shaped metal damper was proposed. Chen Xiaomei et al.designed an assembled friction-soft steel energy dissipation bearing suitable for bridges. The bearing is mainly composed of dumbbell-shaped components, circular friction plates and soft steel rods.

In 2021, based on previous research, Cheng Yang proposed a three-stage yield metal damper composed of rectangular shear steel plate and U-shaped bending steel plate. Aiming at the problems of stress concentration and low initial stiffness of double U-shaped metal dampers, Cheng Yang et al.further proposed two optimization schemes for adding different forms of steel plates. Han Songlin developed coupling beam metal dampers with different opening forms, and proposed a new type of bending-tensile deformation conversion metal damper suitable for building structure vibration reduction[7].

In 2022, Wang Debin et al.designed a new type of interlayer torsional metal damper to solve the problem of uneven stress distribution of existing metal dampers. Bao Xiaohui uses a multi-limb U-shaped metal damper to assemble a new type of metal damper. The damper is not only convenient, simple in structure, reasonable in cost, but also has the characteristics of large initial stiffness. Combined with a specific support system device, it can achieve displacement amplification and full energy consumption. Levinchen proposed a rotational metal damper-torsional steel tube damper that can be used for the connection of precast beam-column members.

In 2023, Tian Minglun proposed a new type of step-yield metal damper based on sliding connection, which can be arranged in the middle of the coupling beam to form an energy-dissipation coupling beam. Combining the working principle of buckling restrained brace and long hole friction damper, Zhang Cunjin proposed a new type of damper composed of two in series. Feng Huan has developed a new type of Butterfly metallic damper (BMD), which is composed of a connecting end, a transmission component and a U-shaped metal energy dissipation element. Fu Yuhao proposed a new three-dimensional global yield metal damper with global yield characteristics, which can dissipate energy in any direction and can work under small displacement. In order to achieve the goal of shock absorption and fortification under different earthquakes, Chen Bowen proposed a new type of phased yield metal damper.

In 2024, Chen Xiaotong proposed a new type of global yield energy-consuming steel bar damper to improve the seismic performance of building structures, aiming at the problems of uneven stress, small ductility and difficult replacement of existing metal dampers. In order to solve the problems of low bearing capacity and poor energy dissipation performance of U-shaped dampers, Wu Ziying proposed a new combined bending metal damper composed of U-shaped metal plate and X-shaped metal plate.

3. PROBLEMS TO BE SOLVED

On the basis of the double U-shaped metal damper, a rectangular shear steel plate is added to form a bending-shear combined metal damper. This improvement can significantly improve the initial stiffness and energy dissipation capacity of the damper, make the stress distribution more reasonable, and the staged yield characteristics are more prominent. However, the corner of the rectangular shear steel plate is prone to stress concentration, which leads to premature failure and adversely affects plastic deformation and ductility. Therefore, the shape will be optimized reasonably according to the stress distribution and mechanical performance.

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