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Systematic analysis of Structural optimization design of post-disaster emergency rescue robot

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Abstract. Natural disasters do great to human life and post-disaster relief is significantly essential. Moreover, the post-disaster emergency rescue robots play an important role in searching, rescuing, transportation and detection. This paper wants to enhance the stiffness and force limit through the characteristics of the mortise and tenon structure by applying the mortise and tenon structure to the mechanical arm of the post-disaster emergency rescue robot. By analyzing the mechanism of robotic arm movement and mortise and tenon structure, it demonstrates the feasibility of the optimization of mortise and tenon structure applied on the mechanical arm. Through the application examples of mortise and tenon structure in related fields, the advantages and disadvantages of mortise and tenon structure in mechanical arm are demonstrated. The future prospect of mortise and tenon structure in mechanical arm is very optimistic, which can be used as an auxiliary connection mode in the design of mechanical arm, combined with traditional methods such as welding and bolt connection, to balance performance, cost and maintainability.

Keywords: Post-disaster emergency; rescue robot; mortise and tenon; mechanical arm.

1. Introduction

Natural disasters are located together with human society, and every major emergency will cause great losses to the region or even the whole country. After a disaster, a very efficient emergency rescue is particularly important. Intelligent robots act as an important member of the rescue team in disaster rescue. It can help rescue workers to search and rescue personnel, transport materials, detect dangerous environment, detect life information, etc., etc. At the same time, the post-disaster emergency rescue robot can also carry out related medical rescue [1]. Facing a very dangerous environment, the post-disaster rescue robot itself should have the characteristics of high strength and high durability.

Inspired by the traditional Chinese building structure—mortise and tenon structure, this paper wants to enhance the stiffness and force limit through the characteristics of the mortise and tenon structure by applying the mortise and tenon structure to the mechanical arm of the post-disaster emergency rescue robot [2, 3]. Through the application examples of mortise and tenon structure in related fields, the advantages and disadvantages of mortise and tenon structure in mechanical arm are demonstrated.

2. Physical construction

2.1. Mechanism of robotic arm movement

The common motion principle of the mechanical arm is mainly based on the combination of joint movement and chain expansion. By controlling the angle of the joint and the length of the chain enables flexible movement of the robotic arm in space. The control mode of the mechanical arm is mainly divided into two kinds: position control and force control. Position control is to accurately control the trajectory of the robotic arm by controlling the angle of the joint and the length of the chain. Force control is to allow the mechanical arm to make corresponding adjustments according to the change of external force to achieve more flexible work.

2.2. Mechanism of mortise and tenon structure

Moron and tenon is a concave and convex joint used on two wooden members. The convex part is called tenon (or tenon); the concave part is called tenon (or tenon, tenon groove), with tenon and tenon joint bite. The mortise and tenon structure are a precise combination of mortise and tenon, representing a delicate coordination of the quantity, height, and length among wooden components, effectively preventing them from twisting and moving in various directions. The most fundamental mortise and tenon structure consists of two parts, where the tenon head of one part is tightly inserted into the mortise hole of the other, ensuring a stable connection between them.

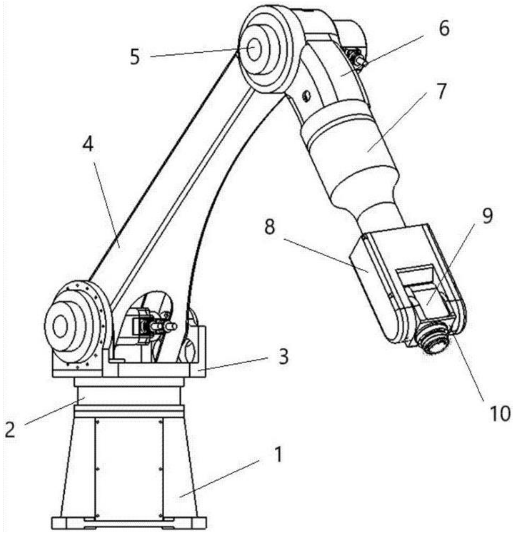

Fig. 1 Schematic diagram of mechanical arm structure [4]

For example, a six-axis connecting rod mechanical arm shown in the figure 1, the structure includes the fixed base 1, 2, the rotating base 3, the rotation of the whole mechanical arm, the rotation of the front limb of the mechanical arm; 8,9,10 can be applied to the mortise and tenon connection structure, and applied to the end of the mechanical arm, so that the installation link of the mechanical arm can be flexibly adapted to more types of work pieces, more flexible operation, and the installation parts can be replaced to clip different types of work pieces.

3. Moron and tenon structure applied to the analysis of robotic arms

3.1. Application of mortise and tenon structure in similar fields

Liu Sicong designed a new type of spiral mortise and tenon structure bracket with mortise and socket respectively at the two ends [5]. During the expansion and rebound, the bracket tenon structure is closed and locked to avoid further narrowing of blood vessels and improve the support effect. In order to verify the performance of this new stent. Liu Sicong chose the traditional stent as the control group, and established the precise model of mortise stent and traditional stent and conducted simulation analysis. The results show that the quality of the new mortise and tenon structure stent has been lost, but the whole stent is not seriously broken. This finding demonstrates the superiority of the mortise and tenon structural scaffold in maintaining the structural integrity and support force. The new vascular stent not only effectively reduces the radial rebound rate after stent expansion, but also shows better support performance.

In Zhu Yilin’s paper, it based on the principle of male tenon (M & R) originated in ancient China, a prefabricated negative Poisson ratio honeycomb combination structure with modular components is proposed [6]. The structure boasts low manufacturing costs and high technological maturity, exhibiting a more stable stress plateau phase and a wider deformation range. Additionally, it effectively reduces the reaction force on the protected structure and can be easily produced using traditional manufacturing techniques.

Gu Jinchao applied the mortise and tenon structure to the hollow ball, improve the rotational stiffness of the hollow ball structure, and the appearance design is simple and beautiful, but also can make the structure has faster construction speed, higher positioning accuracy [7]. The mortise and tenon hollow ball have a new node with complex shape curvature and meets the required carrying capacity. Simultaneously, various crucial requirements are met by this structure, such as the ease of on-site assembly and the adaptability to connect rod pieces of various cross-sectional shapes, greatly expanding its application scope in the engineering field.

Zhigang Zhu purposed a new type of prefabricated concrete beam-column node with mortise and tenon connection [8]. And the finite element method is also used to compare the stress performance of the node and the cast-in-place node of the same size. The research results indicate that, compared to conventional cast-in-place beam-column joints, the proposed MT joints exhibit superior mechanical behavior. Additionally, the MT connection method, characterized by standardized construction, aligns with the concept of sustainable development and can significantly reduce construction time. This study also successfully demonstrates the feasibility of using MT joints as beam-column joints in prefabricated concrete structures within traditional wooden frameworks, providing unique insights into the innovative application of new building materials.

Zhang Pengfei invented a new type of fire wall through the research of mining safety of one of the several major disasters - coal mine fire accident [9]. The study of fire wall can effectively prevent coal mine fire. The commonly used materials of coal mine fire wall at home and abroad are red brick or cement block. Affected by the material structure, the wall is prone to cracking, deformation, air leakage, or even collapse after the impact or roadway deformation pressure. In order to solve the above problems, Zhang Pengfei proposed a tenon and tenon block structure, which forms a strong binding force between the blocks, making the masonry sealed wall a whole, with higher impact resistance, and can maintain the integrity of the wall in case of fire and explosion.

Zhang Xingui proposed a new mortise and tenon prefabricated gravity retaining wall [10]. He tested three different wall forms for the force deformation model loading test, and the results show that the displacement patterns of the three forms of retaining walls are consistent Basically, the wall body rotates around the wall toe (RB mode), Then the whole wall body away from the soil direction of translation (T mode) two modes, The ultimate transverse displacement of retaining wall is prominent within 0.4H~0.67H distance from the bottom of the wall, And the soil pressure curve behind the block retaining wall is consistent with the displacement curve of the retaining wall, Its calculation should be combined with the block displacement, It provides a reference for the design of the block retaining wall.

Li Ziyi explored the possibility of traditional Chinese wood structure buildings to improve their seismic performance by setting up shear walls [11]. He paid special attention to a light steel shear wall with excellent shear resistance and lateral displacement stiffness, which is ideal for wood structure reinforcement. In order to verify its effect, Li Ziyi innovatively integrated the light steel shear wall into the tenon and tenon wood frame and used the ABAQUS finite element software to build a model with such reinforcement parts, and made a detailed comparison of their seismic performance. He simulated a variety of seismic waves and conducted an in-depth analysis of the dynamic response of wood frames under rare earthquakes. The results reveal the significant effect of light steel shear wall: it not only greatly increases the self-vibration frequency of the structure, but also effectively reduces the interlayer displacement of the wooden frame under the impact of seismic waves, thus significantly enhancing the stability of the structure. In addition, because the light steel shear wall shares a part of the stress, the bearing capacity of the mortise and tenon joints is also improved, which further strengthens the seismic performance of the wood frame. This study provides new ideas and methods for the seismic reinforcement of traditional wood structure buildings, which has important practical guiding significance.

Xu Rongrong cleverly designed a fan-shaped viscoelastic damper, which is specially used to reinforce the mortise and tenon joints [12]. She not only detailed the construction of the two different shaped dampers SX-1 and SX-2, but also analyzed the depth of their working mechanisms. With the help of powerful ABAQUS software, Xu Rongrong carefully compared various performance indexes of these two sector dampers under repeated loads, including the full degree of hysteresis curve, energy consumption coefficient and equivalent viscous damping ratio. These meticulous analyses aim to comprehensively assess the deformation performance and energy dissipation properties of the dampers. The results show that the construction of these two dampers is very reasonable, and their stagnation area, energy consumption coefficient and equivalent damping ratio will increase with the increase of amplitude. With the small displacement loading amplitude, the energy consumption coefficient and the equivalent damping ratio of the SX-1 and SX-2 specimens are relatively small. However, it is worth mentioning that the SX-2-shaped sector viscoelastic damper shows more superior performance, with a fuller hysteresis curve, stronger energy consumption capacity, and greater deformation ability.

3.2. Advantages and disadvantages of the application part of the mortise and tenon structure

Tenon and tenon structure play a very important role in many fields. By citing the application examples of mortise and tenon structure in different fields above, the advantages and disadvantages of mortise and tenon structure in related fields are summarized, which are summarized in the following table 1. It provides theoretical and factual support for the application of mortise and tenon structure to the mechanical arm structure.

Table 1. Advantages and disadvantages of the application part of the mortise and tenon structure

Application scenarios	Advantages	Shortcomings
Zinc-alloy vascular stent	High strength, high stress performance after degradation to a certain extent;	The processing process is precise, the cost is high, and the parts replacement is complex
Structural hollow ball	Improved the rotating stiffness of the hollow ball structure, concise and elegant appearance structure, faster construction speed, higher positioning accuracy	The machining accuracy of parts is high; there may have some limitations when bearing heavy load;
New prefabricated concrete beams and columns	High construction efficiency, good structural stability, environmental protection and energy saving, strong durability	High processing precision requirements, high transportation and storage requirements, and high cost of the initial design and processing stage.
Prefabricated honeycomb composite structure with negative Poisson's ratio	Exhibits a more stable stress plateau phase and a wider range of deformation capabilities.	High manufacturing accuracy requirements, material limitations, structural stability problems
Moron and tenon prefabricated gravity retaining wall	The limit lateral displacement increase, pressure curve and retaining wall displacement curve are highly consistent	Connecting reliability, durability, high technical requirements for construction personnel, limited scope of application
Tenon and tenon wood frame reinforced with light steel shear wall	The self-vibration frequency of the structure increases greatly, the structural stability is enhanced, the bearing capacity is improved, and the seismic performance is enhanced	High material cost, high construction complexity, and high adaptability requirements to the extreme environment
Fan-shaped viscoelastic dampers reinforced by mortise and tenon joints	The hysteresis curve is fuller, has strong energy consumption ability, has a large deformation ability, and more effectively improves the earthquake resistance ability of the traditional bucket wood frame	High manufacturing cost, difficult maintenance, material performance degradation, and high requirements for installation accuracy

4. Challenges and prospects

4.1. Difficulties and advantages of mortise and tenon structure applied to the mechanical arm

With the progress of material science, if high strength, lightweight materials can be developed for mortise and tenon structures, it will help reduce the weight of the mechanical arm and improve its flexibility and energy efficiency; mortise and tenon structures provide certain environmental adaptability without additional fasteners, especially in extreme environment, can avoid fastener loosening caused by thermal expansion, cold contraction or vibration. The mortise and tenon structure have no bolts, nuts and other parts easy to wear and loose, which may reduce the frequency of maintenance and replacement of parts in the long term.

However, the mortise and tenon structure requires extremely high machining accuracy, which may lead to the increase in manufacturing cost, especially in mass production; compared with the traditional mechanical connection mode, the strength and durability of the mortise and tenon structure have not been fully verified, once the mortise and tenon structure is damaged, it may require overall replacement rather than local repair, which will increase the maintenance cost and time.

4.2. Future Outlook

The future prospect of mortise and tenon structure in mechanical arm is very optimistic, which can be used as an auxiliary connection mode in the design of mechanical arm, combined with traditional methods such as welding and bolt connection, to balance performance, cost and maintainability. At the same time, with the development of new materials (such as carbon fiber composites, polymer materials, etc.) and new technologies (such as 3D printing, precision machining, etc.), the performance of mortise and tenon structure may be improved, which is more suitable for the comprehensive performance of disaster emergency rescue robots in rescue.

To sum up, mortise and tenon structure has a good application prospect in the application of post-disaster emergency rescue robot and mechanical arm. Meanwhile, if new materials and processing technology can be combined, mortise and tenon structure will gain great advantages in the application field of mechanical arm.

5. Conclusion

This paper is inspired by the ancient Chinese traditional architectural structure — mortise and tenon structure, The idea of mortise and tenon structure in the robotic arm of post-disaster emergency rescue robot is proposed, By explaining the structural mechanism of the mechanical arm and analyzing the rationality of mortise and tenon structure in the mechanical arm, While citing many relevant facts and examples, Further prove the rationality of mortise and tenon structure in the mechanical arm structure of post-disaster emergency rescue robot, However, there are many limitations of mortise and tenon structure in the field of mechanical arm, But in a general view of its development prospects, The application prospect of mortise and tenon structure in the mechanical arm of post-disaster emergency rescue robot is very promising and invested, Moron and tenon structures can be used in the mechanical arm structures.

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