

The Design of A Robot for Laser Cladding of Inner Walls of Pipes

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ABSTRACT

This paper presents a design scheme of an adaptive laser cladding robot for the inner wall of variable diameter pipes. The robot is in the shape of a capsule, with an adaptive walking system, a mechanical support and balance system, a laser cladding system and a water cooling system, which can achieve efficient laser cladding and strengthening of the inner walls of different pipes. Among them, innovative designs such as pressure overload protection device and beam focusing lens adjustment motor have significantly improved the stability and accuracy of robot operation. Compared with traditional equipment, the robot is simple in structure, easy to disassemble, reliable in performance, high in automation, easy to maintain, and low in energy consumption. It provides an effective solution for laser cladding of pipe inner wall under complex and changeable working conditions, and helps to promote the wide promotion and application of laser cladding technology.

KEYWORDS

Adaptive Robot; Pipe Lining; Laser Cladding; Pressure Overload Protection; Beam Focusing Lens Adjustment Motor; Efficient Intensification of Operations; Automation; Low-cost Design.

1. INTRODUCTION

With the rapid development of industrial technology, piping system plays a vital role in many fields. However, due to long-term operation, corrosion and wear and tear, the inner wall of pipeline often suffers from damage and defects, which seriously affects its normal operation and safety. Therefore, efficient and accurate repair and strengthening of the inner wall of pipelines is particularly important. Laser cladding technology, as an advanced surface treatment technology, has the advantages of heat concentration, fast heating and cooling speed, green environmental protection, etc., and has a broad application prospect in the field of pipeline inner wall repair.

However, there are many shortcomings in the traditional pipe wall laser cladding equipment, such as complex structure, low degree of automation, poor adaptability to the pipe, and so on, it is difficult to meet the needs of repairing under the complex and changing working conditions. In order to solve these problems, this paper proposes the design of an adaptive variable diameter pipe wall laser welding robot. The robot is equipped with adaptive walking, mechanical support and balance, laser cladding and water cooling modules, which can realize efficient and accurate laser cladding of different pipe walls.

This design aims to improve the efficiency and quality of laser cladding on the inner wall of pipeline through innovative structural design and advanced technology application, and provide a reliable and efficient solution for pipeline repair and reinforcement in the industrial field. At the same time, the development of this robot is also in line with the sustainable development concept of green and

environmental protection, which can help promote the wider popularization and application of laser cladding technology.

In this paper, the design principle, structural characteristics, innovations and application value of the adaptive variable-diameter pipe wall laser cladding robot will be introduced in detail, with a view to providing useful references and lessons for the research and application in this field.

Keywords: Adaptive Robot; Pipeline Wall; Laser Cladding; Efficient Repair; Automation; Innovative Design; Value of Application.

2. DESIGN OVERVIEW

The Adaptive Variable Diameter Pipe Wall Laser Coating Robot is a state-of-the-art equipment designed to solve the problem of pipe wall repair. Its design concept combines automation, intelligence and efficiency, aiming at realizing efficient and precise laser cladding of pipe walls of different diameters and shapes.

The design of the robot is based on a capsule shape, which allows the robot to move flexibly inside the pipe and adapt to different pipe geometries. The core components of the robot include an adaptive traveling system, a mechanical support and balancing system, a laser cladding system, and a water cooling system, all of which work together to perform the laser cladding of the pipe wall.

Adaptive walking system is the key part of the robot, through the servo motors, gearboxes and spindles of the synergistic effect, to realize the robot in the pipeline wall of the flexible walking and accurate positioning. The mechanical support and balancing system ensures stable support and balancing of the robot under complex working conditions through the support component group and pressure overload protection device, so as to prevent equipment damage or work interruption caused by vibration or impact.

The laser cladding system is the core unit of the robot, which adopts high-precision cladding head and beam focusing lens adjusting motor to realize precise focusing of the laser beam and uniform spraying of the cladding powder. By adjusting the position of the welding head and the focusing point of the laser beam, the robot can realize precise welding of different areas of the inner wall of the pipe and improve the quality and efficiency of welding.

The water cooling system is responsible for the heat dissipation of the robot to ensure that the equipment can maintain stable operation during long time operation. Through rational water circuit design and efficient cooling elements, the water cooling system can effectively reduce the temperature of the robot and prevent equipment failure or performance degradation due to overheating.

In addition, the robot also adopts a modular design, so that each system can work independently or collaborate with each other, improving the flexibility and maintainability of the equipment. At the same time, the robot is also equipped with an intelligent control system, which can automatically adjust the operating parameters according to the actual situation of the inner wall of the pipeline, realizing automatic operation and intelligent management.

In summary, the design of the adaptive variable-diameter pipe wall laser cladding robot outlines its unique advantages and potential application value in the field of pipe wall repair. With the advanced structural and functional design, the robot will be able to realize efficient and precise laser cladding operations on the inner walls of different pipes, providing a reliable and efficient solution for pipe repair and reinforcement in the industrial field.

3. DETAILED DESIGN

The detailed design of the adaptive variable-diameter pipe wall laser cladding robot takes into full consideration the actual needs and technical difficulties of pipe wall repair to ensure that the robot can efficiently and accurately perform laser cladding operations.

3.1. Adaptive Walking Systems

Adaptive walking system is the core component of the adaptive variable-diameter pipe wall laser cladding robot design, and its goal is to realize the robot in different diameters and shapes of the pipe wall flexible and stable walking. The system mainly consists of servo motors, gearboxes, spindles, walking legs and pressure sensing devices.

3.1.1. Servomotors and Gearboxes

Servo motors are used as the power source of the walking system to provide stable and controllable driving force for the robot by precisely controlling the speed and steering of the motors. The gearbox is responsible for converting the output speed of the motors into a suitable speed for the robot to travel, and transmitting the power to the spindle through the meshing of the gears.

3.1.2. Spindle and Walking Foot Support

The main shaft is the key component connecting the gearbox and the walking legs, which can convert the rotational power transmitted by the gearbox into the linear motion of the walking legs. The walking legs are the parts of the robot that are in direct contact with the pipe wall, and their design needs to take into account the geometric characteristics of the pipe to ensure that the robot is able to walk in close contact with the pipe wall. Each walking foot is equipped with a retractable and rotatable mechanism to allow for adaptive positioning in pipes of different diameters and shapes.

3.1.3. Pressure Sensing Devices

In order to monitor in real time the contact pressure between the walking legs and the inner wall of the pipe, the system is equipped with pressure sensing devices. These sensors can accurately measure and feed back the pressure on each leg, and when the pressure exceeds a preset threshold, the control system will automatically adjust the position or attitude of the walking leg to maintain a stable walking condition.

3.1.4. Control Algorithms and Strategies

The core of the adaptive walking system lies in its control algorithms and strategies. Through the integration of advanced sensors and algorithms, the robot is able to sense the shape and size changes of the inner wall of the pipe in real time, and dynamically adjust the position and attitude of the walking foot according to this information. At the same time, the control system is able to optimize the walking strategy according to the feedback information during the walking process, ensuring that the robot can maintain a stable and efficient walking state under various complex working conditions.

In summary, the design of the adaptive walking system takes into full consideration of the actual needs and technical difficulties of pipe wall repair. By integrating advanced servo motors, gearboxes, spindles, walking legs, pressure sensing devices and other components, as well as adopting advanced control algorithms and strategies, it realizes the flexible and stable walking of the robot in the inner wall of pipes of different diameters and shapes. This design not only improves the adaptability and reliability of the robot, but also lays a solid foundation for the efficient execution of laser cladding operations on the inner wall of pipes.

3.2. Mechanical Support and Balancing Systems

Mechanical support and balancing system is a key part in the design of the adaptive pipe wall laser coating robot, which is responsible for ensuring the stable support and balancing of the robot in the process of operation. The system mainly consists of support components, pressure overload protection device and balance adjustment mechanism.

3.2.1. Groups of Support Elements

The support component group is the core part of the mechanical support and balancing system, which consists of a number of telescopic rods and connectors that can be adaptively adjusted according to the shape and size of the inner wall of the pipe. The telescopic rods are made of high-strength materials with excellent compression resistance and stability, ensuring stable support for the robot under various complex working conditions. The connectors are responsible for connecting the telescopic rod to the main body of the robot to ensure the effective transmission of the support force.

3.2.2. Pressure Overload Protection Devices

In order to prevent the robot from being damaged or destabilized due to excessive support force during operation, the system is equipped with a pressure overload protection device. The device monitors the change of the support force in real time through the pressure sensor integrated in the support member. When the support force exceeds the preset safety threshold, the protection device will automatically activate to reduce the support force by releasing part of the pressure or adjusting the length of the telescopic rod to ensure the safety and stability of the robot.

3.2.3. Balance Adjustment Mechanism

Due to the differences in the shape and size of the inner wall of the pipeline, the robot may encounter uneven or tilted areas during the walking process, which requires a balance adjustment mechanism to maintain the stability of the robot. This mechanism includes gyroscopes, accelerometers and other sensors as well as a servo control system, which monitors the robot's attitude changes in real time and uses servo motors to fine-tune the position and angle of the support components to ensure that the robot always maintains a horizontal and stable state.

3.2.4. Control Strategies and Algorithms

The effective operation of the mechanical support and balancing system cannot be separated from the advanced control strategies and algorithms. By integrating sensor data fusion, attitude estimation and servo control technologies, the system is able to sense the robot's attitude and support state in real time, and dynamically adjust the position and angle of the support components and the output of the balance adjustment mechanism according to this information. In addition, the system also has the ability to learn and optimize the control strategy based on historical data and operational experience to improve the stability and operational efficiency of the robot.

The design of the mechanical support and balancing system takes into full consideration the stability and safety requirements of the robot during the operation in the inner wall of the pipeline. Through the integration of key components such as support components, pressure overload protection device and balance adjustment mechanism, as well as the adoption of advanced control strategies and algorithms, the system can ensure stable and reliable support and balance of the robot under various complex working conditions, which provides a strong guarantee for the efficient execution of laser cladding operations.

3.3. Detailed Design of Laser Cladding Systems

The detailed design of the laser cladding system, as the core unit of the adaptive pipe wall laser cladding robot, is crucial to ensure the quality and efficiency of the cladding. The system mainly

consists of key components such as high-precision cladding head, beam focusing lens, adjustment motor, cladding powder spraying device and laser generator.

3.3.1. High-precision Welding Heads

High-precision welding head is the core component of the laser welding system, and its design needs to fully consider the welding precision and stability. The fusion head is made of high temperature and wear resistant special alloy material to ensure stable performance under long time high temperature operation. The internal structure of the fusion head is optimized for uniform and efficient interaction between the laser beam and the cladding powder to form a dense cladding layer. In addition, the head is equipped with a precision nozzle structure that allows precise control of the powder injection direction and flow rate, further improving the cladding accuracy.

3.3.2. Beam Focusing Lenses and Adjustment Motors

The beam focusing lens is responsible for focusing the laser beam generated by the laser generator to the cladding area, and its quality and precision directly affect the cladding effect. The lens is made of high-quality optical material with high transmittance and low thermal distortion, which ensures that the laser beam has little loss during transmission and is focused accurately. The adjusting motor is responsible for adjusting the position and angle of the lens in real time according to the changes of the welding area, so as to ensure that the laser beam is always focused on the welding point. The precision and responsiveness of the motors are critical to achieving accurate cladding.

3.3.3. Molten Powder Injection Unit

The powder spraying unit is responsible for the uniform and continuous spraying of the powder into the cladding area. The unit utilizes the pneumatic conveying principle, whereby the powder is transported under high pressure from the tank to the nozzle. The nozzles are designed with a special flow channel structure, which ensures that the powder is evenly dispersed and mixed with the laser beam during the spraying process. At the same time, the device is also equipped with a precise powder flow control system, which can adjust the powder injection volume in real time according to the welding demand.

3.3.4. Laser Generators

The laser generator is the power source of the laser cladding system, its performance and stability directly affect the operating effect of the whole system. The system adopts high-performance solid-state laser or fiber laser, which has the advantages of stable output power, good beam quality and long service life, etc. The control system of the laser can adjust the output power and pulse frequency according to the actual operation requirements to achieve the best cladding results. The control system of the laser can adjust the output power and pulse frequency according to the actual operation requirements to realize the best cladding effect.

3.3.5. Control and Monitoring Systems

The control and monitoring system is responsible for precise control and real-time monitoring of all components of the laser cladding system. Through the integration of advanced sensors and control systems, the system is capable of real-time sensing of key parameters such as temperature, pressure, powder flow rate, etc. during the cladding process, and automatically adjusting the laser power, cladding speed and other operating parameters according to these parameters. At the same time, the system is also equipped with fault diagnosis and alarm functions, which can send out timely alarms and take appropriate measures in case of abnormalities.

The detailed design of the laser cladding system covers a number of key components, such as the high-precision cladding head, beam focusing lens, adjusting motor, cladding powder spraying device and laser generator. By optimizing the structure and function of each component, as well as adopting advanced control and monitoring technologies, the system is capable of realizing highly efficient and

precise laser cladding operations, providing powerful support for pipeline repair and reinforcement in the industrial field.

3.4. Detailed Design of the Water Cooling System

The water cooling system is an indispensable part of the adaptive pipe wall laser welding robot, and its main function is to dissipate the heat of the key components of the robot through the circulation of cooling water, so as to ensure that the robot can maintain stable performance during the long time and high intensity operation. The design of the water cooling system is described in detail as follows.

3.4.1. Cooling Water Circuit Design

The cooling water circuit is the core part of the water cooling system, and its design needs to fully consider the cooling effect and fluid dynamics. The cooling water circuit adopts a closed-loop design, which consists of water inlet, outlet, water pipe and radiator, etc. The inlet and outlet are connected to the robot cooling demand components and radiator respectively to form a complete cooling system. The water inlet and outlet are connected to the robot's cooling demand components and radiators to form a complete cooling cycle. The water pipes are made of corrosion- and heat-resistant materials to ensure good performance under long periods of high temperature.

3.4.2. Radiator Design

Radiator is a key cooling system cooling components, its performance directly affects the efficiency of the entire cooling system. The radiator adopts large area and multi-piece design to increase the heat dissipation area and improve the heat dissipation efficiency. There are enough gaps between the fins to ensure that the cooling water can flow smoothly and carry away the heat. At the same time, the radiator is also equipped with a fan to further improve the cooling effect through forced convection.

3.4.3. Water Pumping and Flow Control

The pump is responsible for driving the cooling water circulation in the system, and its performance directly affects the cooling effect. This system adopts high-efficiency, low-noise pumps to ensure that the cooling water can be stable and continuous flow. At the same time, in order to realize the precise control of the cooling water flow, the system also integrates a flow control valve, which can adjust the cooling water flow in real time according to the cooling demand of the robot.

3.4.4. Temperature Monitoring and Control Systems

To ensure that the robot operates within a suitable temperature range, the water cooling system is equipped with a temperature monitoring and control system. The system monitors the temperature of the robot in real time through temperature sensors integrated into key components, and when the temperature exceeds a preset threshold, the control system automatically adjusts the speed of the water pump, the fan speed of the radiator and the opening of the flow control valve to increase the cooling effect and prevent the robot from overheating.

3.4.5. Safety and Security Measures

In order to prevent damage to the robot caused by leakage or high temperature of the cooling water, the water cooling system is equipped with multiple safety measures. For example, water leakage detection sensors are installed in key components, once water leakage is detected, the system will immediately cut off the power supply of the pump and issue an alarm; at the same time, the system also integrates an over-temperature protection device, when the water temperature exceeds the safe range, the system will automatically shut down and start emergency cooling measures.

The detailed design of the water cooling system takes into full consideration the heat dissipation needs and safety requirements of the robot during high-intensity operation. By optimizing the design of key components such as cooling water circuit, radiator, water pump, etc., and integrating advanced

temperature monitoring and control system as well as safety protection measures, the system can provide a reliable guarantee for the stable operation of the robot.

4. INNOVATIVE POINTS AND APPLICATION VALUE

The adaptive laser cladding robot for the inner wall of variable diameter pipes has shown many innovations in design and function, and has significant application value.

First of all, in terms of innovation, the robot adopts a unique self-adaptive walking system, through the front and rear of the three sets of walking feet and pressure protection device synergistic effect, can adapt to different diameters and shapes of the pipe wall, to realize the flexible operation of the variable diameter pipe. In addition, the pressure overload protection device in the mechanical support and balancing system not only ensures the stability of the robot in the process of operation, but also realizes the precise control of pressure and overload protection through the insertion of the spline and hollow screw and the circumferential fixation of the spring, so as to enhance the safety and reliability of the equipment.

As for the laser cladding system, the robot adopts a beam focusing lens adjustment motor, which can precisely adjust the position of the laser focusing point together with the reflector to make the powder sprayed by the cladding nozzle converge at one point, thus improving the cladding precision and efficiency. This design not only solves the problems of fixed laser focusing point position and low melting accuracy in traditional equipment, but also makes the robot more flexible and adaptable in laser melting operations on different pipe inner walls.

Secondly, in terms of application value, the adaptive variable diameter pipe wall laser welding robot has a wide range of application prospects. It solves the bottleneck of traditional equipment in the complex and variable working conditions of the inner wall of the pipe laser welding process, and improves the quality and efficiency of repair. At the same time, the robot has a simple structure, easy to disassemble, reliable performance, high degree of automation, reducing maintenance costs and difficulties in use, and improving operational efficiency. In addition, the design concept of the robot is characterized by practicality and low cost, which makes it possible to popularize and apply the laser cladding technology more widely.

To sum up, the adaptive laser cladding robot for the inner wall of variable diameter pipes has shown significant advantages in terms of innovation and application value. It not only solves the shortcomings of traditional equipment in the field of pipeline inner wall repair, but also provides a reliable and efficient solution for pipeline maintenance and reinforcement in the industrial field through innovative design and advanced technology application. With the further development and optimization of the robot, it is believed that it will play a more important role in the field of pipeline maintenance and reinforcement in the future.

5. CONCLUSION

As an efficient and precise pipe repair technology, the design of the adaptive pipe wall laser coating robot involves several key systems, including the adaptive traveling system, the mechanical support and balance system, the laser coating system and the water cooling system. The design of these systems not only takes into full consideration the actual needs and technical difficulties of pipe wall repair, but also reflects the advanced design concept and engineering technology.

The adaptive walking system realizes flexible and stable walking of the robot in the inner wall of pipes of different diameters and shapes by integrating servo motors, gearboxes, spindles, walking legs and pressure sensing devices. The mechanical support and balancing system ensures the stable support and balancing of the robot in the process of operation by means of support components, pressure overload protection device and balancing adjustment mechanism. The laser cladding system,

as the core operation unit of the robot, realizes efficient and precise cladding operation through the synergistic action of the high-precision cladding head, beam focusing lens, cladding powder spraying device and laser generator, etc. The water cooling system, on the other hand, realizes efficient and precise cladding operation through the optimized cooling system. The water cooling system ensures stable heat dissipation during high-intensity operation by optimizing the cooling water circuit, radiator design and integrated temperature monitoring and control system.

In summary, the design of the adaptive variable-diameter pipe wall laser cladding robot fully demonstrates the advanced design concept and engineering technology, which provides an efficient and reliable solution for pipe repair and reinforcement in the industrial field. With the continuous progress of technology and application, it is believed that this kind of robot will play a greater role in the future and make a greater contribution to industrial production and social development.

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