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Control System of a Wall Climbing Robot for Automatic Welding

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***Abstract*-This article designs a wall climbing robot for automatic welding of large steel member. In the past, welding of large member was generally carried out through manual welding or orbital semi-automatic welding, both of which have such disadvantages as low efficiency and poor flexibility. For these problems, this article proposes a wall climbing robot, primarily introduces its control system and planning of welding operation process. This robot can conduct Omni-directional movement on large member, and laser vision is adopted in the system for automatic tracking of seam. Based on the foregoing, a simulation and an automatic welding test is carried out, and the test result proves that this robot can complete automatic welding of large members.**

Keywords-control system; wall climbing robot; automatic welding

I. INTRODUCTION

With the economic and social development, the demand for large-scale manufacture of large member is increasing, such as high-power thermal and hydro power generation equipment, high-yield petrochemical equipment, large ships, heavy machinery, aerospace and aeronautical equipment and so forth [1-3]. As a significant manufacturing technique, welding plays an important role in the manufacturing of large member. However, there are two difficulties in the welding process of large member: the first difficulty is that the structure is too huge, and the traditional welding robot, limited by its working scope, cannot cover the welding operation of large steel member; the second one is that most of the seams of large member are long and irregular in shape, and it is hard to arrange such external devices as the orbit of the special orbital welding machine.

Currently, there are two welding methods for large member: manual welding and preset orbital semi-automatic welding. For welding [4] of large oil storage tank and large ships in the field of petrochemical industry, manual welding method is usually adopted (as shown in Fig. 1). This method features disadvantages of high risk and low efficiency.

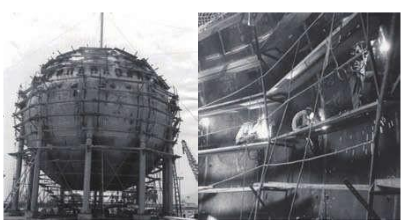

Fig. 1. Manual Welding of Large Member

There are two types of semi-automatic welding equipment for large member: one is permanent magnetic orbital welding equipment from the U.S. BUG-O Company and Canadian GULLCO Company; the other one is suspended welding equipment as shown in Fig. 2, which improves the automation level to some extent. However, this equipment has complicated operating procedure and high requirement on the installation of orbit, thus, constraining its popularization and application [5].

Fig. 2. Permanent Magnetic Orbital Welding Equipment

Based on the foregoing, a wall climbing robot that can freely move on large member and conduct tracking welding for the seam on workpiece is designed in this article. This article firstly gives a brief introduction to the wall climbing robot system, then details its control system and motion planning, and at last, carries out omni-directional moving performance test and automatic welding test separately to verify the feasibility of the wall climbing robot system.

II. OVERVIEW OF THE ROBOT SYSTEM

A. Introduction to Wall Climbing Robot System

As shown in Fig. 3, the wall climbing robot system mainly comprises four parts: control system, wall climbing robot, seam tracking vision system and welding equipment; the control system of the wall climbing robot is installed on a dolly on the ground and connected with the robot through a communication line of 10m long, and the welding operation process can be real-time monitored.

1) Control system: it is mainly composed of an industrial personal computer, a motion control card, a motor drive, a protection circuit and so forth;

2) The wall climbing robot is composed of a caterpillar type dolly and an XY mobile platform. The XY platform is provided with a zero-position sensor and a limit sensor;

3) The seam tracking vision system is composed of a tracking controller, a CCD industrial camera, a line laser and an optical filter. Such CCD industrial camera, line laser and optical filter are fixed together by aluminum alloy clamps, and the seam tracking vision system is communicated with the control system through Ethernet;

4) The welding equipment is mainly composed of a welding power supply, a wire feeder, shielding gas and a welding torch. The welding torch and the above seam tracking vision system are fixed and installed oppositely to the end of the XY platform, and the welding torch is located at the back of the seam tracking vision system in the welding direction;

B. Working Process

The working process of the wall climbing robot on large member is as follows:

1) Calibrate the seam tracking vision system and the welding torch with nine-point calibration method, so as to obtain data acquired by the seam tracker and the location relation between the seam tracking vision system and the end of the welding torch, and further obtain distance between the end of the welding torch and the seam tracker;

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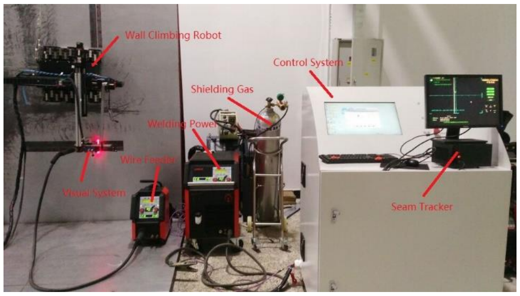


Fig. 3. Wall Climbing Robot System

2) Manually control the wall climbing robot to move to the place near the seam through the control software of the wall climbing robot on the control panel, and enable the workspace of the XY platform at the top of the wall climbing robot, so as to cover the seam. The XY platform is detected whether it is located at zero position; if not, such platform shall automatically return to zero position;

3) Start the laser, control the XY platform to make the laser locate at the welding start position, set such position as the zero position of the XY platform, and start the seam tracking system for track welding;

4) After the tracking system is started, the dolly of the wall climbing robot is adhered to the wall surface and kept still, and the XY platform moves in a straight line from the current position to the current point in the welding direction (direction Y as shown in Fig.4) at proper speed, and meanwhile the welding equipment is started to weld after receiving a successful striking signal;

5) When the limit sensor in direction Y responds to the signal, turn off the welding equipment and seam tracker; after the movement stops, the dolly of the wall climbing robot moves in a straight line in direction Y at a speed of V, and meanwhile the XY platform moves towards the negative direction Y at the same speed until the XY platform moves back to zero position of axis Y. Before and after the movement, the location of the welding torch basically stays the same;

6) Procedures 3-5 are repeated until the welding of the whole seam is completed;

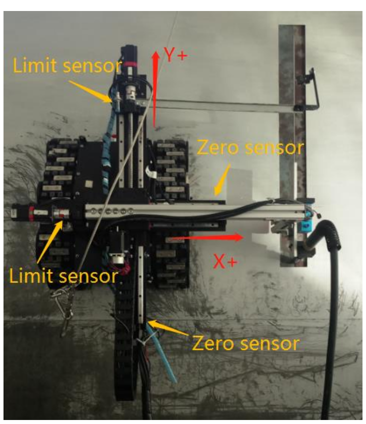


Fig. 4. Structural Drawing of Wall Climbing Robot

III. CONTROL SYSTEM FOR ROBOT

Manual and automatic control modes are required for the wall climbing robot for welding of large structural member, and multiple the equipment sets involved in welding operation are too many, therefore, it is particularly important to properly coordinate and control all the equipment. This section is primarily aimed to provide detailed introduction to the control system of the wall climbing robot.

A. Overview of Control System

In consideration of scalability of the system, an opening control framework [6] based on PC and motion controller is adopted as the control system of the wall climbing robot as shown in Fig. 5. At the control terminal, the industrial PC is used to provide operation system for the robot and the control software of the robot is developed on the basis of VC++, so as to remotely control [7] the robot. The equipment to be controlled by the control system of the wall climbing robot include: left and right servos of the dolly, two servo motors of the XY platform, seam tracker, welding equipment and other position sensors. To reduce the burden on the wall climbing robot, all servo motor drives and seam tracking system controllers are arranged near the PC. The direction of the dolly of the wall climbing robot is controlled through differential rotational speed, and the travel distance of the dolly can be obtained by using a dolly motor encoder and through kinematic calculation. The zero-position sensor and limit sensor are installed to the XY platform above the dolly for determination of system zero and boundary area of the XY platform, and the welding torch and seam tracker are fixed to the end of the XY platform. The dolly and XY platform are controlled separately. The seam tracker is beyond the control of the wall climbing robot controller and interact with the wall climbing robot controller through TCP/IP. The seam visual recognition algorithm is integrated to the seam tracker, and the wall climbing robot controller is used to intensively handle the planning of the task layer. The information fed back by the seam tracker and the movement location information of the welding torch are based on the coordinate system of the XY platform. The welding equipment and wire feeder are connected to the wiring terminal plate, and an analog interface of the control card can be used to real-time set parameters of the welding equipment.

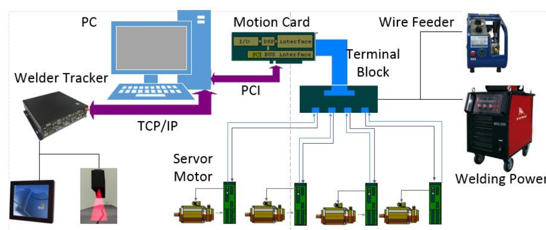


Fig. 5. Control System of Wall Climbing Robot

B. *Implementation of Control System Software*

The software of control system of the wall climbing robot is developed on the basis of VC++ by modular design method, and can be designed into six modules: a dolly module, an XY module, a seam tracker module, a communication module, a motion planning module and a user interface module. The dolly module is used to control the dolly to move forward and backward, turn left and right, stop and feedback position; the XY module has such functions of establishment of zero position and movement coordinate system of the XY platform, basic interpolation, PT/Jog basic motion model and position information feedback; the seam tracker module is used to define TCP/IP communication protocol between the seam tracker and control software; the communication module is used to define corresponding API according to the communication protocol of the seam tracker; the most important module of the whole system is the motion planning module, which is used to define motion data structure, data process and motion planning function of the system. The data fed back by the seam tracker module is firstly sent to the planner for data process, then the data is transmitted to the XY module and dolly module after motion planning, so as to realize automated control for welding of the wall climbing robot; finally the user interface module is used to define such functions as system state visualization, parameter setting and user interaction, and the module is served as the window between the whole system and the user. Fig. 6 shows the software of control system of the wall climbing robot.

Fig. 6. Control Software of Wall Climbing Robot

IV. Motion Planning

As the wall climbing robot is of large mass, resulting in large inertia during the motion. Thus, there are too many problems to be solved in welding while moving: the first one is the vibration incurred during the motion: the special structure of caterpillar type magnetic absorption will cause large vibration to the dolly during the motion, and will also cause large error to the welding torch at the end; another problem is that the large inertia dolly is lagged during the control process, and it is hard to control the robot in a real-time manner[8] according to the feedback information. Therefore, the article presents a segmented control mode as shown in Fig. 7:

Step 1: keep the dolly of the wall climbing robot still on the wall surface, and the XY platform starting tracking operation from the zero position;

Step 2: when the XY platform welds to the boundary position, stop welding;

Step 3: enable the XY platform and dolly to move together, keep the position of the welding torch basically still, stop moving when the XY platform moves back to the zero position; at this time, start the welding equipment to track the seam; repeat the above process until the welding of the whole seam is completed;

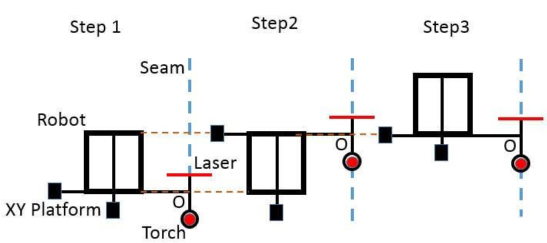


Fig. 7. Diagram of Welding Process of Wall Climbing Robot

A. Data Filtering

To remove the point with large noise, the data collected by the weld seam tracker will be filtered and processed. In this article, mean filtering is adopted: namely, use the mean of 10 data points at the front and back of the data acquired to evaluate the point; and based on a given tolerance, if the data point is within the tolerance range of the mean, use the mean to substitute the data point, or else, reserve it.

B. Motion Data Processing

The zero point of the XY platform is used as the origin for establishing a motion coordinate system. The positive motion directions X and Y of the orbit are set as the positive directions X and Y. The moving coordinate system is set as the reference coordinate system for all motion data. Feature points of the seam after passing through the data filter enter into the motion planner, which is mainly used to fit the discrete data points to produce smooth motion path. To avoid impact and keep smooth speed during the motion, cubic polynomial is adopted in this article for data processing: during the welding process, data are feedback of high frequency, the continuity between the front and back segments of data should be guaranteed, and cubic polynomial fitting is conducted on 1000 points each time. Such 1000 points include the last 500 data points of the front segment of data and first 500 data points of the back segment of data as shown in Fig. 8.

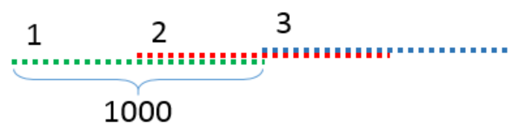


Fig. 8. Diagram of Data Segments

V. Simulation And Experiments

To verify the feasibility of the system, kinematic process of the wall-climbing robot is simulated and analyzed. At last, the welding experiment is carried out. The model of wall-climbing robot is established in SolidWorks and imported into ADAMS. The material properties of each component are set up and the corresponding constraints are added to set up the external environment such as gravity, as shown in Fig. 9.

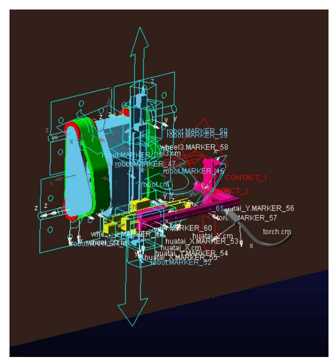
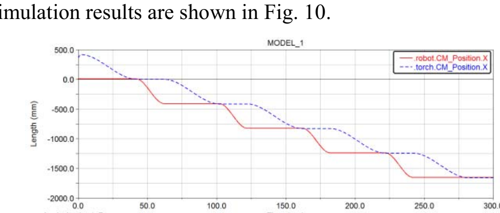
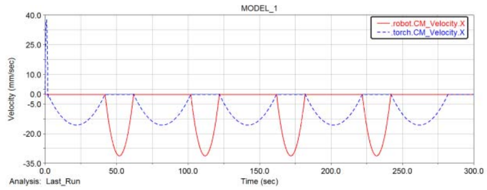


Fig. 9. Simulation Model of Wall-climbing Robot

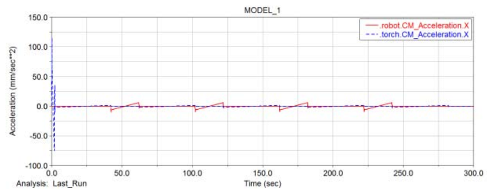
Apply contact force to the crawler on both sides of the wall-climbing robot. Based on the friction coefficient of steel and rubber, the static friction coefficient is set as 0.9 and the dynamic friction coefficient 0.7. To simulate the magnetic adsorption force, a vertical wall inward force is set. According to the calculation, the size is set to 3000N. The driver is added to the two sides of the active wheel, the simulation time is set as 300s, and the welding speed is consistent with the actual welding speed by 10mm/s. The simulation results are shown in Fig. 10.



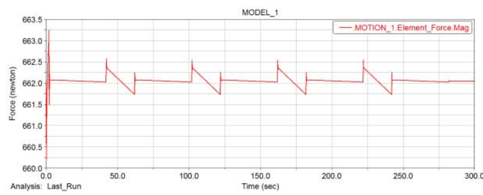
(a)Displacement Curve



(b)Velocity Curve



(c)Acceleration Curve



(d)Friction Curve

Fig. 10. Simulation Results

From figures (a) and (b), we know that in the welding process, the wall-climbing robot remains motionless, and when the torch completes a stroke, the wall-climbing robot runs at the same speed as the XY platform, and the position of the torch remains unchanged. From (c), we can know that the acceleration of the torch remains basically unchanged during the whole motion, which indicates that the torch runs smoothly and the body of the wall-climbing robot has a slight impact at the beginning and the end of each motion. Since the wall-climbing robot is basically static friction during its motion, it can be seen from (d) that the static friction is consistent with the gravity of the system (the system weight of the wall-climbing robot is about 66Kg), and there is a sudden change at the beginning and the end of the motion. However, the variation is very small, and the torch is not welding during the movement of the wall-climbing robot, so the welding will not be affected.

On this basis, an experimental platform is established for the welding of large structural member. The platform is made of an I-shaped iron tower with length of 4m, width of 2.5m and height of 4m through vertical placement, and several long straight butt-jointed seams (most of the seams for large structural member are long straight seams or nearly straight seams) are arranged on the iron tower. The width of the seam is 2-3mm, the plate thickness is 5mm, as shown in Fig. 11.

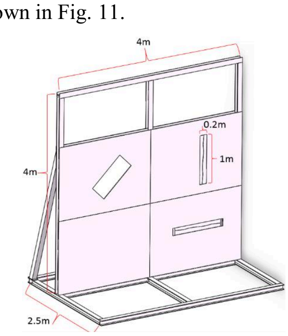


Fig. 11. Experimental Platform

To test the mobile absorption capacity of the wall climbing robot, control the wall climbing robot through the control panel to move towards all directions on the experimental platform. The test result shows that the wall climbing robot has excellent moving performance in transverse and longitudinal directions and in oblique direction without slip, as shown in the following Fig. 12.

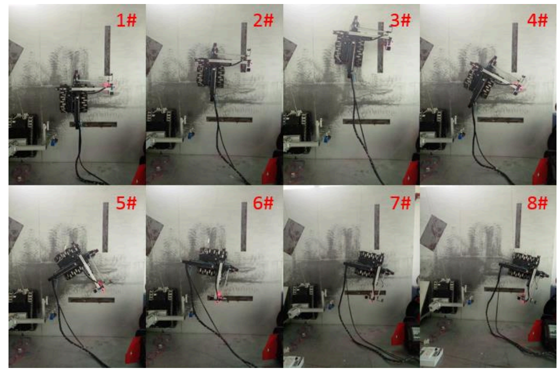


Fig. 12. Stick Slip Test of Wall Climbing Robot

Based on the foregoing, a tracking welding test is conducted on one seam thereof, control the dolly through the control panel to move to the target area, start automatic tracking welding mode, set the tracking speed of the XY platform at 10mm/s, welding current at 133A, wire feeding speed is 5.5m/min, and voltage at 21V [9]. The automatic welding results are as shown in Fig. 13. The test shows that the wall climbing robot presented in this article is applicable to the automatic welding operation of large structural member, and it improves the automation level in this field.

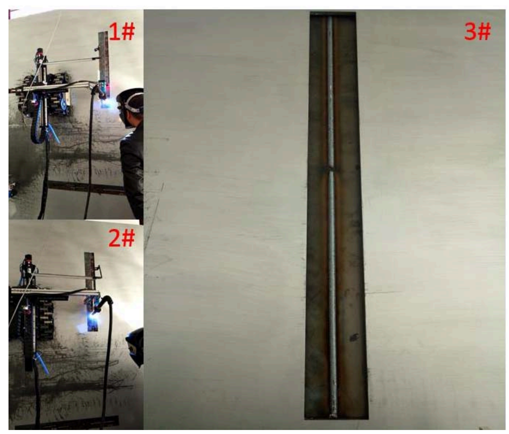


Fig. 13. Automatic Welding Test and Results

VI. SUMMARY

For the problem of low automation level of welding in large structural member, this article presents a wall climbing robot. Firstly, this article states the general framework and working process of the wall climbing robot, then it introduces the control system and discusses the planning of the welding motion process. To verify the feasibility, a simulation and two tests are conducted in this article: the first one is Omni-directional mobile performance test; the second one is automatic welding test. The test result shows that the wall climbing robot system meets the requirement of automated welding of large structural member.

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