2010 3rd International Conference on Computer and Electrical Engineering (ICCEE 2010)
IPCSIT vol. 53 (2012) © (2012) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2012.V53.No.1.34

An Improved Wall Climbing Robot for Ship Rust Removal

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Abstract. This paper presents an improved wall climbing robot for boarding ship rust removal cleaner (WCRSRR). The robot includes two pneumatic motors for driving, two big permanent magnets for adsorption and tow crawlers for walking. Firstly, the design scheme of the improved WCRSRR is proposed, the technical difficulties are pointed out, and the technical route is defined. Secondly, the driving principle is planned, and the driving performance is optimized. Finally, the walking obstacle negotiation performance is analyzed, and the graph of the comparison between the original and improved three sprocket obstacle negotiation performance is proposed. The experiments show that the improved WCRSRR works better than the original WCRSRR, and has the optimal capacity such as the adsorption capacity, driving performance and obstacle negotiation performance.

Keywords: Wall climbing robot; ship rust removal; design scheme; driving principle and performance analysis; walking obstacle negotiation performance analysis.

1. Introduction

The main function of the wall climbing robot for boarding ship rust removal cleaner (WCRSRR) is loading the cleaner which can remove the rust on ship surface by water jetting. The main characteristics of the WCRSRR are the big loading and strict adsorption performance. It brings challenges for studying the WCRSRR [1-2]. Many scientific research institutions have carried out study on this robot, such as JPL of Caltech, DSIE in Cartagena of Spain, and some famous companies like Flow, Kamat, Hammelmann and so on[3-4]. At present, the study on the WCRSRR is still at the starting stage, and the research reports are few. A type of WCRSRR was developed by reference [5]. According to the experiments, the robot adsorption and driving performance is good. But, the loading ability is still not able to meet the working requirement. It mainly embodies in three respects of unstable walking, not flexible movement and big tuning friction damage [6]. And the main reasons are the weight robot body, big loading, big adsorption force and the not flexible structure. An improved DMU WCRSRR is researched, which will solve the above problems.

From this argument, the first purpose of the present paper is to propose the design scheme of the WCRSRR, point out the technical difficulties, plan the technical route, and design an improved WCRSRR body structure.

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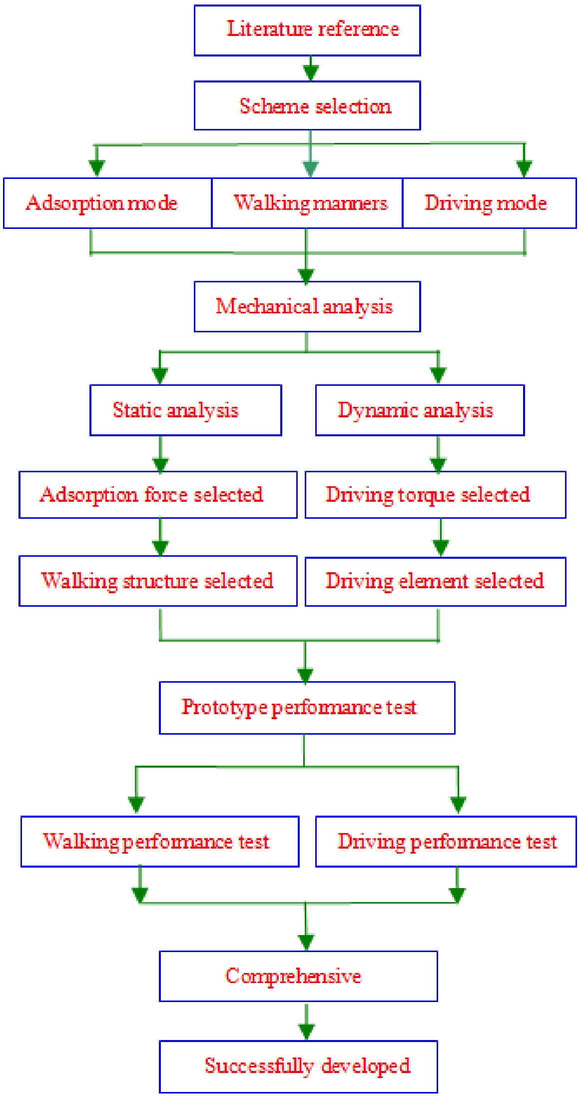


Figure.1 The WCRSRR technical route diagram

The second purpose is to analyze the robot driving characteristic based on the optimized model which proposed in the reference [7], and to analyze the walking obstacle negotiation performance according to the comparison between the original and improved WCRSRR.

The rest of this paper is organized as follows. Section II represents the design scheme and the structure of the improved robot. Section III introduces the driving principle and performance analysis. Section IV presents the walking obstacle negotiation performance analysis. Section V introduces the performance comparison of two type robot by experiments, and section VI concludes the paper.

2. Design Scheme

2.1 Technical route

Firstly, as the climbing robot, the WCRSRR should have the reliable adsorption ability. Secondly, the WCRSRR carries loading of ultra-high pressure water pipes and vacuum residue recycle pipes about 30 meters, whose gross weight may reach 80Kg, so the WCRSRR should have the reliable driving ability. Finally, the WCRSRR should have the reliable walking ability. The technical route is shown in the Fig.1.

2.2 Technical difficulties

The loading of the WCRSRR is big, so the adsorption force and the driving torque are big. But, the big adsorption force will cause the difficulty about the walking and turning, and the big driving torque will cause the big weight about the driving element. So there is a complicated relationship between the weight and performance, as shown in Fig.2.

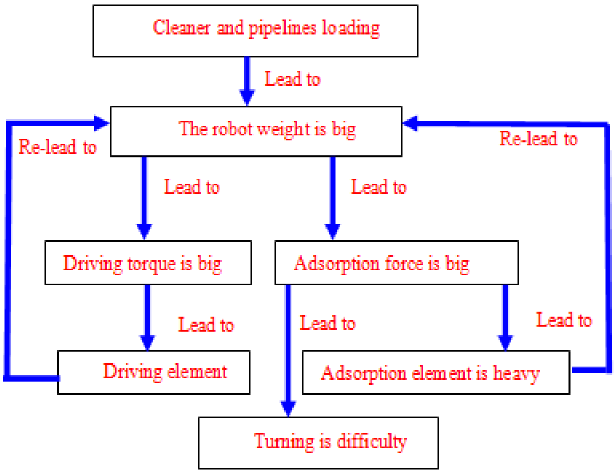
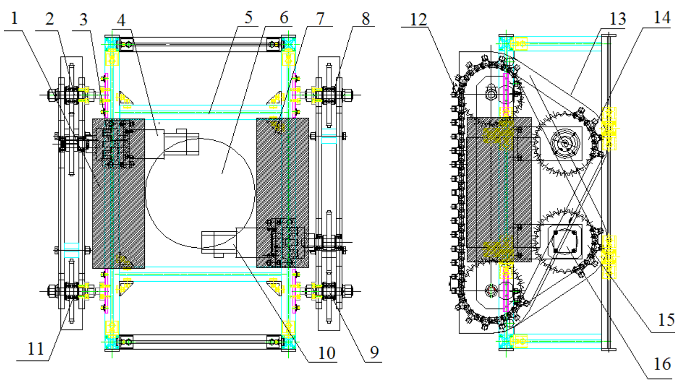


Figure.2 Technical difficulties about complicated relationship between the weight and performance

2.3 Robot structure



1. Lift adsorption permanent magnet 2. Left upper driven sprocket 3. Left track joint bearing 4. Lift driving pneumatic motor shaft coupling 5. Frame 6. Rust cleaner servomotor 7. Right adsorption permanent magnet 8. Right upper driven sprocket 9. Right inferior driven sprocket 10. Right driving pneumatic motor 11. Left inferior driven sprocket 12. Marching crawler chain 13. Chain guard 14. Lift driving sprocket 15 Right driving sprocket 16 Right track joint bearing

Figure.3 Structure of WCRSRR

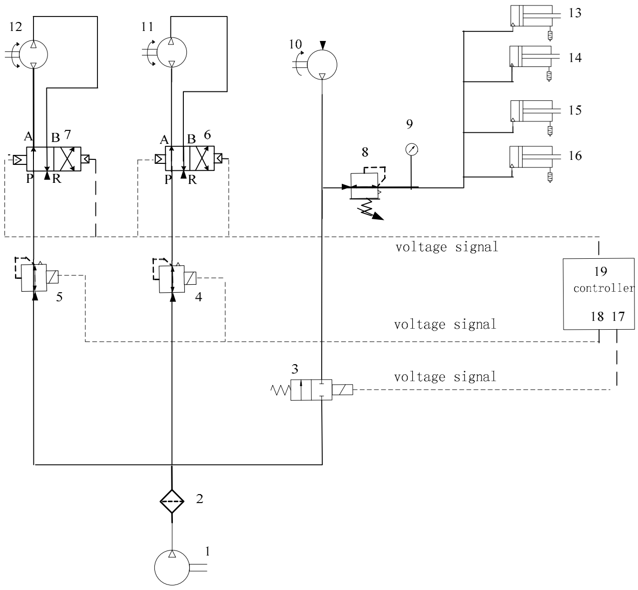
Therefore, the first and the most important step is choosing the adsorption, walking and driving method, and defining the robot body structure.

The climbing robot structure is designed as shown in Fig.3. It is driven by two pneumatic motors that are connected with each driving sprocket. The adsorption mechanism is using two big permanent magnets. Tow crawlers are used for the robot walking along the ship wall. A rust cleaner with four nozzles are set in the centre of the robot. The WCRSRR body consists of four parts: the adsorption mechanism, the walking mechanism, the driving mechanism and the frame. It is centrosymmetric structure.

3. Driving Principle and Performance Analysis

3.1 Driving principle

According to the Fig. 3, there are three parts about the robot driving system. The first part is the power mechanism, which consists of an air compressor, two driving pneumatic motors and a cleaner rotating pneumatic motor. The second part is the loading mechanism, which includes four cleaner ballast cylinders that push the cleaner on the ship wall. The third part is the control mechanism, which contains a cleaning rotary switch valve, two proportional electromagnetic flow regulating valves, two driving pneumatic motor rotating reversing valves and a cleaner ballast cylinder pressure regulator valve. The controller send the signal to control the every part is shown in Fig. 4.



1. Air compressor 2. Filter 3. Cleaning rotary switch valve 4. Lift proportional electromagnetic flow regulating valve 5. Right proportional electromagnetic flow regulating valve 6. Lift driving pneumatic motor rotating reversing valve 7. Right driving pneumatic motor rotating reversing valve 8. Cleaner ballast cylinder pressure regulator valve 9. Cleaner ballast cylinder pressure gauge 10.Cleaner rotating pneumatic motor 11. Lift driving pneumatic motor 12. Right driving pneumatic motor 13-16. Cleaner ballast cylinder 17. Rotary switch signal source 18.Driving handle ectopic signal source 19. Static handle median signal source

Figure. 4 Driving principle diagram

3.2 Driving performance

As the reference [5] and [7], the robot driving model is established as equation [1] and the optimization model is established as equation [2].The concrete derivation process is in the reference.

$$M_{\mathrm{Q}} \geq \left[(F_{\mathrm{m}} + \frac{F_{\mathrm{S}} - F_{\mathrm{f}} - (kl + G_{\mathrm{DJ}} + G_{\mathrm{K}})\sin a}{n}) \cdot (\sum_{i=1}^{n/2} l_i) \cdot \mu \cdot R \right] / L \tag{1}$$

$$M_{\mathrm{Q}} \geq [(G_{\mathrm{DJ}} + G_{\mathrm{K}})H_1 + kl(\frac{l}{2}\sin a + h_{\mathrm{r}})](\frac{1}{2} + \frac{h}{2l_1})\cos\alpha \tag{2}$$

Define a robot climbing high as 5 meters, and the concrete parameters of the improved and original robot are set in the equation [2]. Then the improved and original driving performance comparison is shown in the Fig. 5. The range of the inclination angle of ship wall α is from 0°-90°.

According to the Fig.5, the driving performance is improved obviously. When the inclination angle of ship wall α is close to 90°, the original driving torque is about 65 Nm, but the improved driving torque is only 55 Nm. And in the range of 0°-45°, the improved driving torque is less than original driving torque about 10Nm uniformly. However, in the range of 45°-90°, the improved driving torque approaches the original driving torque gradually.

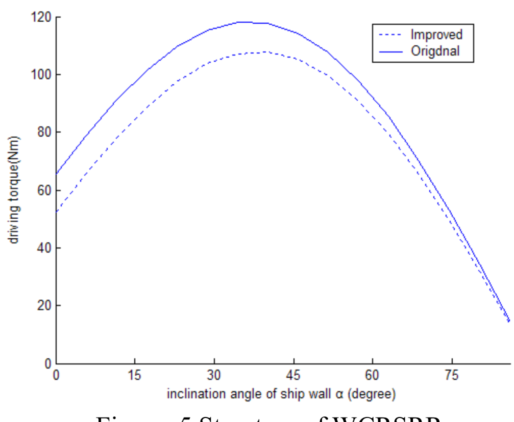


Figure. 5 Structure of WCRSRR

Without question, the robot crawling area is the both sides of the ship hull, which are vertical generally. So the driving performance improvement is very beneficial.

4. Walking Obstacle Negotiation Performance Analysis

Due to the track joint bearing is used in the improved robot structure, the robot obstacle negotiation performance is good. The track joint bearing is shown in the Fig. 3, the left and right track joint bearing may move flexibly as in Fig. 6.

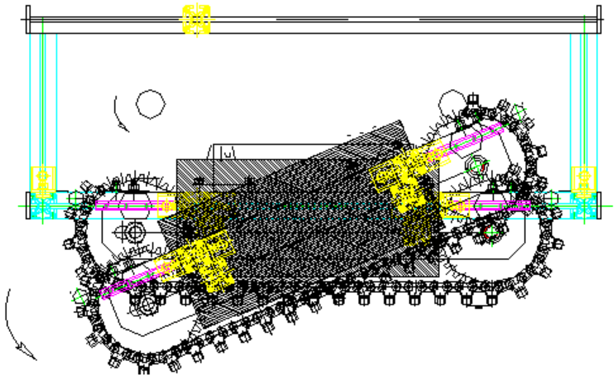
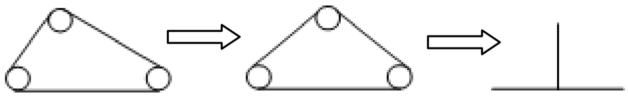


Figure. 6 Rotational walking structure of WCRSRR

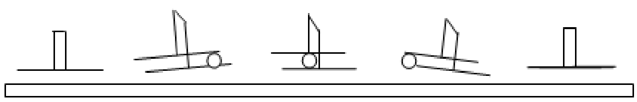
The three sprockets are shown in Fig. 7(a), and it can be simplified as Fig. 7(b). In order to descript the walking station simply, the three sprocket walking structure can be simplified furtherly as Fig. 7(c).



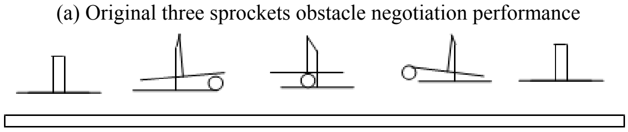
(a) (b) (c)

Figure. 7 Simplified walking structure of WCRSRR

The original and improved three sprocket obstacle negotiation performance is shown in Fig. 8. The fixed type three sprocket of the original robot is used in the robot as Fig. 8(a).When the robot cross the obstacle with fixed type of three sprockets, the robot body will be inclined, and the center of gravity will be significantly higher. Because of the track joint bearing of the improved robot, the marching crawler is very flexible. When the robot crosses the obstacle with track joint bearing, the robot body will be balanced.



(a) Original three sprockets obstacle negotiation performance



(b) Improved three sprockets obstacle negotiation performance

Figure. 8 Three sprockets obstacle negotiation performance

The comparison between the original and improved three sprocket obstacle negotiation performance is shown in Fig. 9. According to the Fig. 9, the original center of gravity is described by curve B, and the improved center of gravity is described by curve A. Obviously, the C area is the optimization part, and the curve A is more stable than curve B.

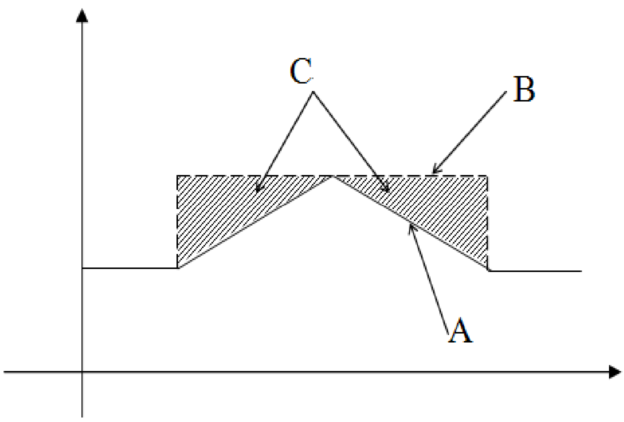


Figure. 9 Comparison between the original and improved three sprocket obstacle negotiation performance

5. Prototype Experiments

The two type of WCRSRR prototype were tested on some steel plates in the Cosco-Shipyard and DMU laboratory. The purpose of these tests was to compare the original and improved WCRSRR performance. The prototype experiments show that the improved WCRSRR works better than the original WCRSRR, and the adsorption capacity, driving performance and obstacle negotiation performance of the improved WCRSRR are improved obviously.

The comparison between the original and improved DMU WCRSRR table is as follows:

Table 1 The comparison between the original and improved DMU WCRSRR 1

	weight	driving performance	obstacle negotiation
Original	Heavy	Good	Poor
Improved	Light	Very good	Very good

Table 2 The comparison between the original and improved DMU WCRSRR 2

	adsorption performance	turning performance	loading performance
Original	Good	Very poor	Good
Improved	Very good	Good	Very good

6. Conclusions

This paper presents the research on the driving characteristics.

(1) A design scheme of the WCRSRR was proposed, and the design difficulties were pointed out, and the technical route was made.

(2) An improved WCRSRR body structure was designed, the driving principle was planned, and the driving performance was optimized.

(3) The walking obstacle negotiation performance was analyzed, and the graph of the comparison between the original and improved three sprockets obstacle negotiation performance was proposed.

(4) The two types of WCRSRR prototype were developed and tested. According to the prototype performance comparison, the improved WCRSRR works better than the original WCRSRR, and has the optimal capacity as the adsorption capacity, driving performance and obstacle negotiation performance.

7. Acknowledgment

This work was supported in part by National Natural Science Foundation of China under Grant 50805011, the Basic Research Item of Ministry of Transport of the People Republic of China under Grant 225030, and the Major Project of Cosco-Shipyard under Grant G2-07-0060.

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