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Research on intelligent ultrasonic thickness measurement system applied to large area of hull①

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Abstract

For a ship in service, seawater corrosion is unavoidable. In order to ensure navigation safety and master the steel plate thickness in service ship, thickness of the ship steel plate must be tested periodically by a scientific method. After consideration of an actual situation of thickness measurement, the bearing mechanism of ultrasonic thickness meter probe has been designed on the basis of wall-climbing robot, and preliminary experiments have been carried out. The device is mainly used for thickness measurement of a large area of ship hull plate when the docking ship has been sand-blasted. Efficiency and safety can be improved to finish thickness measurement by using the device.

Key words: thickness measurement, ultrasonic, intelligent device

0 Introduction

Within recent years, with rapid economic development in the world, marine transportation industry has become an important part of the global logistic industry. Marine shipping, with large volume and low tariffs, is a main means of transportation by playing an increasingly important role and bearing more than 75% of international cargo. A ship is a complex engineering subject in the seawater, with corrosion a problem in harsh environments. In order to prevent corrosion, regularly monitoring the thickness of hull is required as an important means to ensure safe navigation. The thickness of a hull's metal component will be reduced due to seawater corrosion year after year, and the hull will become thinner with an increase in the usage of the ship. In particular, situation is more serious and more harmful for second-hand ships[1-4].

In order to ensure safe navigation, scientific means must be taken to regularly check and comprehensively measure the thickness of the hull, which will objectively reflect the actual condition of the hull. According to the specification for hull thickness measurement of China Classification Society (Ver. 4.0), an excerpt of the hull thickness measurement specification is set as follows: (1) The measure of pitting region should be listed separately in the thickness measurement reports and an accurate thickness graph should be included, points and areas of substantial corrosion should be detailedly labeled, and the longitudinal and lateral position of the areas of substantial corrosion should be reflected on the map. (2) Measuring range: the range of areas that requires mandatory thickness measurement; the range of area that requires close investigation and the range of areas that has substantial corrosion previously. (3) Precision requirement: plate thickness <10mm, accuracy of ±0.1mm; plate thickness ≥10mm, accuracy of ±0.2mm. (4) When the measurement shows significant corrosion, the surveyor should determine the area that needs to be further measured, and this area should be accurately determined and the replacement areas should be defined. With stricter requirements from national regulations and specification for hull thickness measurement of China Classification Society, and increasing safety awareness, the hull thickness measurement has drawn more and more attention by the industry. Currently the main hull thickness measurements are conducted by manual hand-held ultrasonic thickness gauge which is less automatized with high labor intensity. Typically the work has a long cycle in harsh environments and measurement is uneven and less efficient. In order to improve working environment, reduce labor intensity, and optimize thickness measurement process, this paper, based on the ship thickness rule and actual environment of hull thickness measurement, introduces a thickness measurement device, which is a combination of a smart wall-climbing

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robot and an ultrasonic thickness applicant to develop ship hull plate thickness measurement device. The measuring mechanism is driven by the motor and the double cam system. The device meets the ship standard thickness measurement requirements, and is able to obtain more uniform thickness measurement points and take more comprehensive data on hull condition. This intelligent thickness measurement device will improve efficiency, reduce labor intensity and labor costs, save time and reduce maintenance time. The intelligent thickness measurement device complies with marine equipment and integrated automation development requirements, and also fills the needs for a remote hull plate thickness measurement device[5-8].

1 System design of intelligent thickness measurement device

1.1 Overall design

After the ship docked blasting decontamination, gauging staff preliminarily measures the surface and selects thickness measuring points. The thickness measurements are conducted on the measuring points. An ultrasonic thickness device commonly applies the piezoelectric wafer probe. In order to ensure accuracy of thickness measurement, coupling agent is applied on the top of test probe with some pressure before the measurement. According to actual measurement conducted by human, this paper designs an intelligent thickness measurement device that consists of three parts: a smart wall-climbing robot, an ultrasonic thickness gauge and a bearing mechanism. The wall-climbing robot carrying an ultrasonic thickness gauge and a bearing mechanism climbs the hull surface based on the remote command. Hence it replaces the thickness measurement staff crawling on the hull surface. Loading mechanism is able to apply coupling agent on the top of test probe and provides constant pressure to the probe (measuring thickness and pressure sensors shall be operated synchronously) to ensure more precise measurement results. Climbing robot moves to the selected thickness measurement point, to press the test probe (with the coupling agent on the top) against the hull surface and apply pressure, and the ultrasonic thickness gauge will gauge and store data automatically. Fig. 1 is the flowchart of an intelligence thickness measurement device.

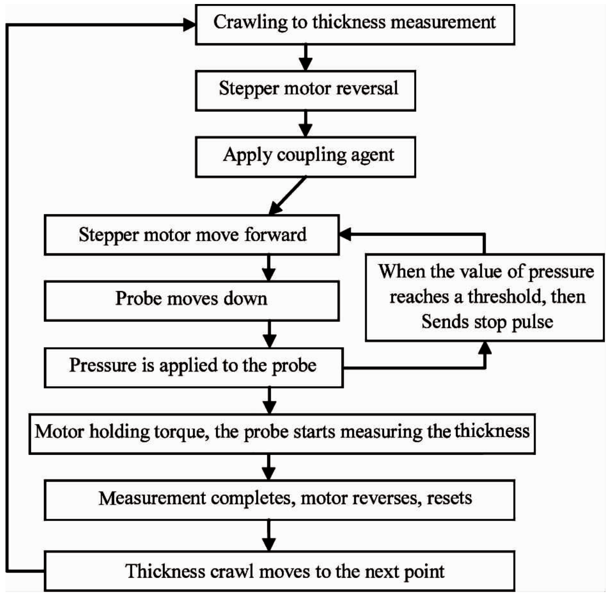


Fig. 1 Flowchart of an intelligence thickness measurement device

1.2 Climbing robot loading mechanism

When staff conducts thickness measurement, it's necessary to take the wire back and forth to crawl on the hull surface, and often results in accidents. In order to replace staff crawling on the surface of the hull and reduce the occurrence of accidents, this device designs a climbing robot as the loading mechanism. At the time of the measurement, climbing robot will gauge and carry devices adsorbed on the surface in accordance with the remote command. Crawling vacuum equipment PB-300 wall-climbing robot is selected, which is small in size, having quick response, fixable mobility, good environmental adaptability, low energy consumption and other advantages such as magnetic compound adsorption. It can work under rust and other hazardous environments, such as metal detection, to replace the human staff completely. Basic parameters of a climbing robot are shown in Table 1. PB-300 wall-climbing robot has excellent magnetic adsorption capacity and load capacity, with the ability to adapt to curvature and rough hull surface, and is able to complete crawling work on different types of hull plates. Climbing robot has four wheels, of which the main material is permanent magnets and the material of appearance is soft rubber with high coefficient of friction that has a better ability to adapt to uneven surface, so that it can adapt to different types of hull surfaces. Climbing robot is embedded with a control system, of which the main function is to receive and interpret commands from remote terminal and complete negative pressure control and measure mechanism of adsorption system. At the same time, it is able to collect sensor information, achieve safe and reliable robot adsorption and semi-autonomous control.[9-12]

Table 1 Climbing robot basic parameters

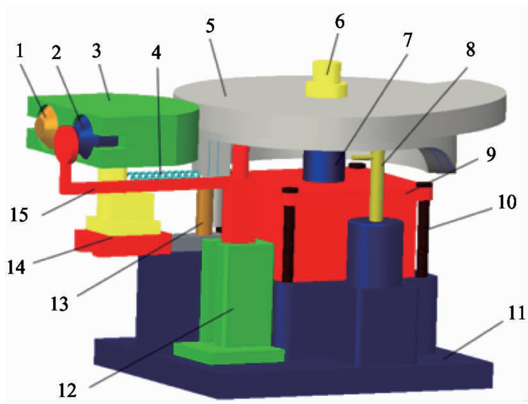
Self weight	Load	Adsorption mode	Negative pressure max.	Speed max.	Transmission distance	Drive mode
6.5kg	5kg	Compound adsorption	3.6kPa	12m/min	100m	Four-wheel drive

1.3 Ultrasonic thickness gauge

Ultrasonic thickness gauge is an industrial widely used device simple to be operated, with great measurement precision, easy to carry and can be used in all kinds of materials. When a hull plate thickness measurement is completed, the gauge will store the minimum thickness values of different measuring points. Intelligent thickness measurement device will use Olympus 26MG Ultrasonic Thickness Gauge which has several advantages including light weight, small size, simple operation, one-side measurement only and etc. It is widely used in tank, piping, pressure vessels, hull and other structures. 26MG Ultrasonic Thickness Gauge processes at 20 scans per second and quickly freezes scan results with a minimum saving mode. When the work is completed, the value of each measurement point can be found. 26MG Ultrasonic Thickness Gauge uses twin probe to detect the thickness based on the principle of "pulse echo," and calculates thickness through a high frequency sound waves reflected from the inner surface of the plate. Ultrasonic attenuation will be reduced significantly while traveling through air, so it needs coupling agent between the surface of hull and the probe. The sound waves launched by the twin probe will travel through the hull plate, and be reflected from the inner surface of the plate to the coupling layer. The pulse probe will receive and translate the reflected pulse into electronic signals. Thickness gauge precisely calculates the pulse and the echo signal of the first time interval (t), while zero position compensation which is caused by probe delay has been deducted. The thickness of the measured piece is then calculated by multiplying the velocity of material (C), and divided by 2. The microprocessor will process the above calculation and display the result on the LCD screen[13,14].

1.4 Bearing and actuators

An intelligent thickness measurement device consists of five mechanical mechanisms, as shown in Fig. 2, base bracket of measured mechanical arm, smear probe motion mechanism, measuring probe motion bearing mechanism, coupling agent supply mechanism, and main cam switch mechanism. This device adopts cam mechanism as a way of transmission mechanism. The advantage is that it is simple and easy to design. As long as the cam contour is designed effectively, it can achieve a variety of complex movement.

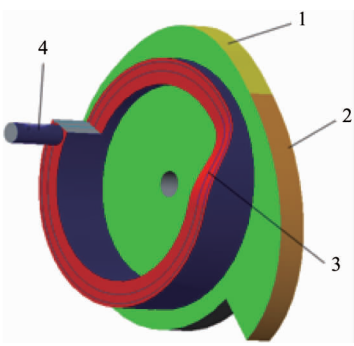


1. Pressure sensor; 2. Thickness gauge probe; 3. Test probe bearing block; 4. Return spring; 5. Main cam switch; 6. Shaft; 7. Coupling; 8. Emulsion pump mechanism; 9. Stepper motor; 10. Fixed pin; 11. Base; 12. Smear probe base; 13. Spring fixed bracket and limit switch; 14. MGN Guide; 15. Smear probe

Fig. 2 Mechanical arm structure diagram of intelligent thickness measurement device

The main cam switch mechanism is composed of two planar cams (two cam surfaces using a base circle to save material) and a cylindrical cam, as shown in Fig. 3. Kinematic pair comes into being between the cam surface of plane cam A/B and the cam surface of measuring probe bearing mechanism. Planar cam A and B act as the active part, measuring probe bearing mechanism cam as a driven part. The active part rotates with the motor, and the driven part does a linear movement. Planar cam A and B contact with the driven cam alternately to realize forward and backward of the measuring probe carrying mechanism, such a mechanism is designed to meet the need of mechanical arm. Cylindrical cam acting as active part is the trigger switch of coupling agent supply mechanism and smear probe motion mechanism. Kinematic pair comes into being between cylindrical cam and the cam of coupling agent supply mechanism and smear probe motion mechanism. Cylindrical cam rotates with the motor and driven part, the cam of coupling agent supply mechanism and smear probe motion mechanism, does a linear movement. As a trigger limit switch device, block 4 is used to limit the main cam to the initial position.

The concrete working process can be described in this way: when the mechanical arm starts to measure, stepper motor moves forward and the main cam moves forward through the shaft and coupling. Planar cam A moves with the probe bearing cam, based on the special design of planar cam A and B, and the probe bearing mechanism moves forward. At this point, the cylindrical cam presses coupling agent supply mechanism and supplies coupling agent to smear probe, so the procedure of smear is achieved. And then, because of the outline of planar cam A and return spring, probe bearing mechanism moves backward, leaves the smear probe, cylindrical cam of the active part begins to contact with the cam of the smear probe mechanism, press the slider and slider downwards, then the smear probe bracket moves downwards, and the probe leaves the test probe track and avoids unnecessary interference. At the same time, planar cam B of the active part begins to contact with the cam of test probe bearing mechanism, so test probe bearing block moves forward. The test probe begins to touch the hull surface, completes the measurement under the control system. After the measurement, the motor reverses, under the action of planar cam B of the active part, test probe bearing mechanism will move backward and leave the measuring surface, cylindrical cam reverse, and smear probe mechanism moves upward and back to the initial position. Then planar cam A of the active part starts acting on the test probe bearing mechanism which moves forward, presses smear probe again, and smears the probe again. Repetitive smearing is favorable for the next measurement. Then cylindrical cam rotates backward, loosens the cam of coupling agent supply mechanism, and coupling agent supply mechanism is reset. Because of the outline of planar cam A and return spring, the test probe bearing mechanism moves back to drive stop block, motor stops rotating, and each mechanism is back to initial position, ready for the next measurement.



1. Planar cam A; 2. Planar cam B; 3. Cylindrical cam; 4. Stop block

Fig. 3 Schematic diagram of main cam switch

Nylon 66 is selected, which is light and has good self-lubricating property. After the design of various parts in PROE, it will import engineering drawings into mastercam through NC milling machine, and get the corresponding parts. The requirement of processing environment is not high and the material cost is low, which results in the opportunity of mass production.

2 Control system design

This device's control system shown as Fig. 4, mainly includes the following modules: a power supply module, a motor module, a pressure sensor module, an A/D conversion module, a Limit switch module, a wireless module and a master control chip module. The master control chip, using atmega128 single-chip microcomputer produced by ATMEL, is a brain center control system, responsible for systematical data acquisition, analysis and processing. The pressure sensor module will collect the voltage signal that has been converted through A/D conversion module and transfer the signal back to the single-chip computer. The output of the pressure sensor is the 0V ~ 5V standard voltage signal, and the voltage signal and the pressure value are linear. In this system the pressure sensor provides only a threshold which determines the contact pressure between the thickness gauge and the surface to be measured. Through artificial repeated experiments, this threshold has been obtained. The wireless transmitting receiving module is used for sending the orders to device by FSK/FM. The power supply module is responsible for the power supply to single chip microcomputer and stepping motor. The actuator adopts two phase four wire stepper motor, the controller ATmega128 generates eight beat control signals, and the stepper motor is controlled by the driver. The system hardware circuit diagram is shown in Fig. 5.

3 Data acquisition

Fig. 6 shows nRF24L01 connected to MCU and composited to the wireless transmitting and receiving modules. nRF24L01 module and external pins of the wireless module CE, CSN, SCK, MISO. MISO connected to the microcontroller P1.0 ~ P1.4 pins respectively, IRQ pin is connected to the microcontroller INT0. CE is chip selected terminal, the combination of CE and the CONFIG register PWR_UP and PRIM_RX is used to select the work module; CSN is SPI chip selected signal which is at work when CSN is on low level. SCK is a serial clock line; MISO is the data input

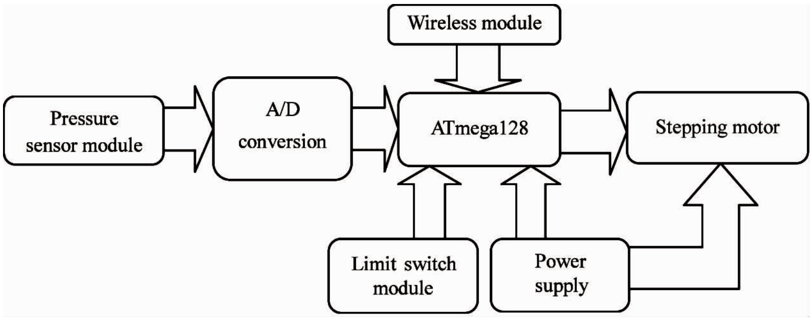


Fig. 4 Control system of intelligent thickness measurement device

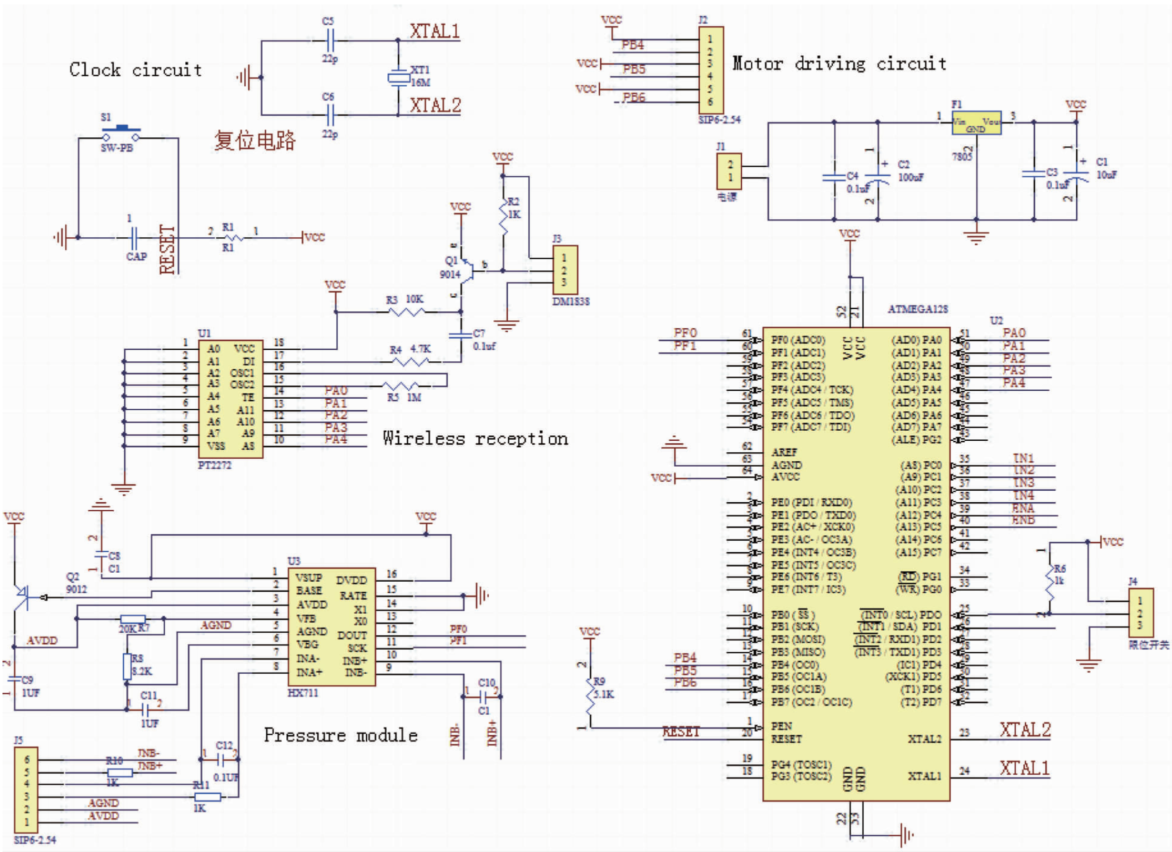


Fig. 5 The system hardware circuit diagram

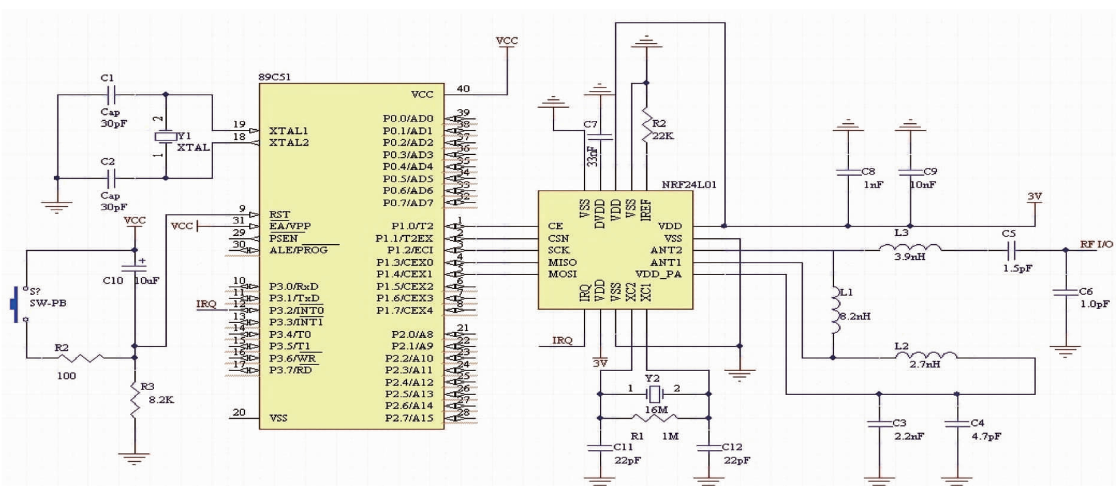


Fig. 6 nRF24L01 connected to MCU

port of SPI, and MOSI is data output port; IRQ is the interrupt request signal of the module, when nRF24L01 has the interrupt, IRQ will be set to low level. When MCU detects the interruption the data transceiver of the nRF24L01 module is learned from program. After receiving the distance signal, MCU starts to display and process data.

4 The preliminary experimental results and data processing

Numerical calculation software Matlab consisting of numerical analysis, matrix calculation and graphic functions, encapsulates a large number of mathematical functions to reduce the difficulty for the user to write complex function. Because of its calculation accuracy, high efficiency, the advantages of quick and powerful functions, it is widely used in the field of scientific research and engineering design. Based on the convenient data processing Matlab and mapping function of the thickness data for 3D graphics rendering, the table below is the data that the device collected from a bulk carrier larboard hull plate, the measurement area has a height of 30m and length of 80m and thickness of 20mm, with the climbing robot's adsorption starting point as the origin (0, 0). Climbing Robot on the hull, an artificial control device in the region, measures the thickness and stores the data. After the measurement and storage, Matlab is used to draw a 3D view, corresponding to numerical size and thickness. Colors will change and allow the users to have more intuitive view. Thickness data is shown in Table 2. This data are consistent with the results of manual measurements.

Table 2 Thickness data from intelligent thickness measurement device

x(mm)	0				
y(mm)	0	20	40	60	80
z(mm)	18.4	18.3	18.2	18.5	18.4
x(mm)	10				
y(mm)	0	20	40	60	80
z(mm)	18.6	18.9	18.8	18.7	18.6
x(mm)	20				
y(mm)	0	20	40	60	80
z(mm)	17.9	18.1	18.2	18.5	18.7
x(mm)	30				
y(mm)	0	20	40	60	80
z(mm)	19.1	19.5	19.2	19.4	18.8

In Table 2, x represents the height of thickness area, y represents the length of thickness area and z represents the thickness of thickness area. Fig. 7 is a comprehensive picture incorporating 20 data and shows the 3D view of the thickness measurement data. The diagram is a one-to-one correspondence with the actual hull height and length size. The thickness of different positions of hull plates can be reflected directly from the picture. To the area that the thickness is less than the limits of planking corrosion, it should be measured again to determine the corrosion thickness values and precisely determine the real area of the planking that need to be repaired and maintained[15-17]. The measured data are in agreement with the results of the manual measurement.

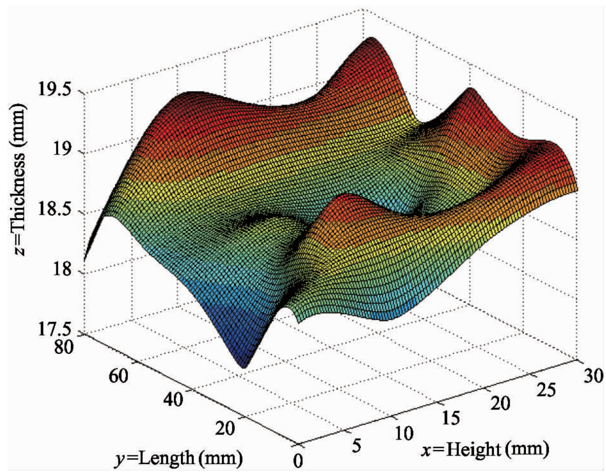


Fig. 7 3D view of the thickness measurement data

5 Conclusions

The marine intelligent measurement thickness device is used to improve the measurement environment of ship cervix thickness, reduce labor intensity, and optimize the process. Under the condition of thickness specification, the device can obtain a full acquisition point and is advantageous to the comprehensive understanding of the hull plate. The device not only satisfies thickness measurement requirements of the large ship plate on the docking vessels after the sandblasting process, but also applies to dock ship plate thickness between ship light load and overload line. The development of the device can meet the development of marine equipment automation and integration, and to fill the void in the domestic ship hull plate auxiliary intelligent thickness devices. The device is also advantageous to map thickness data and to better visualize the ship cervix thickness data. It should be noted that the device still needs a number of improvements: first of all, the coordination of the action of the device can be improved. When ultrasonic thickness gauge measures thickness, it needs to apply a coupling agent on the probe which is right under the daub head thickness sensor. When the sensor moves downward, it is very easy to touch the head, which may cause a movement problem. The lightweight materials may be able to effectively reduce the weight of the device and to make the device smaller and lighter. Second, the intelligent level of the device can be improved. The climbing robot can be improved by choosing single ultrasonic thickness detector, and direct use of climbing robot development platform to send and receive ultrasonic pulse and control stepper motor motion.

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