Underwater Robotic Arm Test Platform

Junwei Tian
School of Mechanical and Electrical Engineering, Xi'an Technological University
Xi'an, China
E-mail: junweitian@163.com

Qin Wang
School of Mechanical and Electrical Engineering, Xi'an Technological University
Xi'an, China
E-mail: 709972930@qq.com

Shuzhao Huang
School of Electronic Information Engineering, Xi'an Technological University
Xi'an, China
E-mail: 1945980733@qq.com

Xuehang Zhao
School of Mechanical and Electrical Engineering, Xi'an Technological University
Xi'an, China
E-mail: 2469212190@qq.com

***Abstract*—For the problem that the mechanical arm is unstable under water and the position accuracy is low. This paper designed an underwater manipulator test platform. Good attitude control and high grip accuracy can be achieved. Through the analysis of the mechanical body, the overall structural layout of the mechanical arm and the hardware control of the mechanical arm are determined. Considering the working requirements of the test platform is to meet the load-bearing weight of 30kg, the operating range is not less than 400mm, etc., and design a motor suitable for this platform. Finally, stress simulation and finite element analysis of the load-bearing parts (U-shaped plate) of the platform are carried out. The results show that the maximum displacement of the U-shaped bottom plate is located in the middle of the bottom plate, which is approximately 4.553e-0.002mm. The maximum stress is 1.505e+0.007N/m^2. The yield stress of the material is 6.204e+0.008N/m^2, which satisfies the requirement of yield stress. Prove that the design is reasonable.**

Keywords-Underwater Robot Arm; Test Platform; Motor; Finite Element Analysis

I. INTRODUCTION

In recent years, with the advent of the intelligent era, underwater robot technology has also been greatly developed. Widely used in underwater search and rescue, archaeology and other fields[1]. The development level of robot technology highlights the strength of a country's economic development. Therefore, many countries continue to increase the research of robots and research a large number of robots with different working environments[2]. The robot must also use the robot arm to complete the task, so the research on the robot arm is more and more[3].

In the literature4, he kinematics model of the manipulator is established, and the forward and backward kinematics equation is obtained. From this, the Jacobian matrix of the finger is derived, which improves the grasping precision of the manipulator. In the literature 5, the problems of the underwater robot operating environment are mild and time-varying. The classical DH model method is used to determine the variable parameters of each joint, the parameters are brought into different transformation matrices, and the MATLAB software is used for the six-degree-of-freedom underwater manipulator. The DH kinematics model is solved and the forward kinematics equation of the manipulator is obtained. Achieve precise control of the robot arm. In order to In the literature6, In order to make the aircraft have more control to maintain the posture in the operation and cope with the external disturbance, the Newton-Eulerian method is used to reversely recurs the dynamic model of the system, and the underwater unmanned vehicle and manipulator system coordination is established. Motion trajectory optimization algorithm. In the literature7, the problem of large-scale overturning moment is caused by the small internal space of the micro-sized underwater robot and the manipulator's unfolding operation. A fuzzy double closed-loop PID method suitable for the attitude control of the underwater robot is proposed. The PID parameters are adjusted online by fuzzy logic to adapt to The nonlinear characteristics of the underwater robot provide better control of the robot's attitude. In the literature 8, an adaptive bilateral control strategy is proposed for the mathematical model of the underwater manipulator during teleoperation and the uncertainty caused by external disturbance. The overall system is stable and reliable, and robust and adaptive.

At present, although researchers have more and more research on robotic arms, many algorithms have been proposed to solve many practical problems[9]. But these algorithms are mostly suitable in their own application background and field. Therefore, designing a multi-field, stable attitude, high precision underwater manipulator test platform[10] is crucial.

The problem is that the working posture of the mechanical arm under water is unstable and the position accuracy is low. The corresponding land-based working platform is designed, and the mechanical part of the platform plays an important role in the stability and control accuracy of the test platform[11]. The mechanical part is mainly the control of the motor and the force analysis of the U-shaped plate. Therefore, this paper mainly analyzes these two aspects. Finally, the simulation shows that the maximum displacement of the U-shaped bottom plate is located in the middle of the bottom plate, which is roughly 4.553e- 0.002mm. The maximum stress is 1.505e+0.007N/m^2. The yield stress of the material is 6.204e+0.008N/m^2, which satisfies the requirement of yield stress. Therefore this design is reasonable.

II. MECHANICAL ONTOLOGY ANALYSIS OF THE TEST PLATFORM

In order to meet the work of the 6-DOF manipulator at any point in the space, the design tests platform designed a three-degree-of-freedom mechanical structure in space. The weighing load is required to be no less than 30kg and the operating range is not less than 400mm. In order to meet this requirement, the designed platform mainly includes pan/tilt, motor, U-shaped plate, U-shaped plate baffle, rib plate, bearing with bearing cover and Base. In the selected scheme, the PTZ part contains two degrees of freedom, and the U-shaped plate part is a degree of freedom, controlled by a motor, and constitutes a three-degree-of-freedom test platform. The mechanical body of the test platform is shown in Fig. 1.

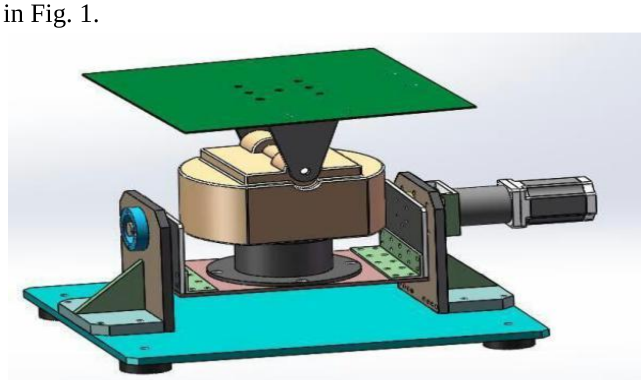

Figure 1. Test platform mechanical body

A. *Structural Layout of the Mechanical Body*

For the structural layout of this mechanical structure, because the entire mechanical test platform as a whole, to meet the test of the 6-degree-of-freedom manipulator, a three-degree-of-freedom test platform is adopted. In this paper, the two-degree-of-freedom part of the first part is added, and the lower part is added. Another degree of freedom is the degree of rotational freedom parallel to the plane of the ground and the degree of freedom of rotation perpendicular to the plane of the ground. The lower part adopts a third degree of freedom perpendicular to the upper two planes and perpendicular to the ground. Therefore, the upper part of the test platform adopt a two-degree-of-freedom monitoring pan-tilt system and an U-shaped plate layout driven by a motor at the lower part. The entire structure layout realizes the related driving of each rotating surface of the 6-degree-of-freedom manipulator, and the entire layout structure is simple and the rotation direction is clear. Clear. And for the test of the mechanical arm has a good flexibility test capability.

III. TEST PLATFORM HARDWARE DESIGN

A. *Platform Design*

The two-degree-of-freedom mechanical structure of the upper horizontal planes rotation and the vertical plane rotation of the test platform is called a gimbal. The top part of the gimbal is to directly mount the arm to the upper platform, so the gimbal is a load-bearing piece. The working requirement of the test platform is to meet the bearing capacity of 30kg, the operating range is not less than 400mm, and the same as other communication methods in the operation of the test platform, to achieve the purpose of information exchanged transmission. Considering the above problems, the whole system of this design test platform adopt rs485 communication mode, and chooses 303 aluminum alloys outdoor waterproof all-round rotation monitoring PTZ 485 control built-in decoder 24V. The permanent omni-directional pan/tilt of this platform outdoor use a permanent magnet synchronous motor. It has the characteristics of high temperature resistance, aging resistance, corrosion resistance, strong wind resistance, waterproof and acid rain resistance. These features provide a strong guarantee in the application of the underwater underwater manipulator test platform. The size structure of the gimbal is shown in Fig. 2.

Figure 2. Platform size structure

B. *Motor Design*

The movement of the arm is achieved by the rotation of the motor at each joint. The performance of the motor also directly determines the control accuracy of the arm. Therefore, it is important to select a suitable motor[12]. Through the analysis of the requirements of the mechanical arm test performance to be satisfied by the underwater manipulator test platform, the selection of the motor needs to be satisfied, the high torque supports load, high precision, and the rotation and stop. Taking into account the above situation, the acceleration and deceleration can solve the above two problems on the basis of the stepping motor. Therefore, it is undoubtedly a better choice to choose the stepping motor.

The choice of the motor mainly faces two relatively large problems. The first problem is that the torque is generated during the working process. The second problem is that the motor has low speed torque fluctuation and the high speed torque is insufficient. Therefore, the motor here uses deceleration stepping Motor.

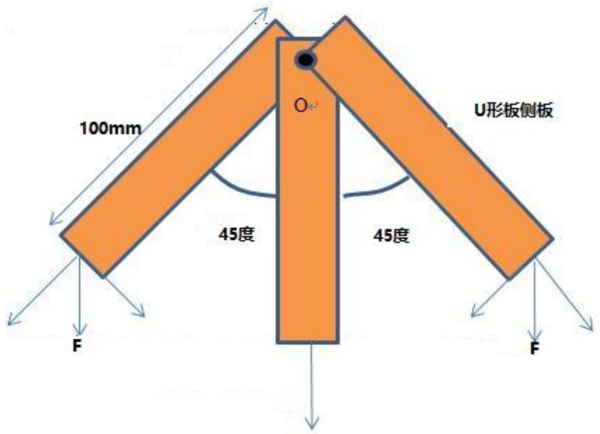

Figure 3. Force analysis diagram of the motor driving the U-shaped plate

According to the force analysis of the U-shaped plate side plate in Fig. 2, the torque of the stepping motor at the O point can be obtained as follows:

$$M0(F) = \sum_{i=0}^{N} M0(Fi) \quad (1)$$

$$\mathrm{M0(F) = FSCOS}\theta \quad (2)$$

Because the load capacity of the test platform is 30kg, and the weight of some of the gimbals on the test platform is 3.7kg, the load bearing capacity is roughly 35kg, and the U-shaped plate is designed to have a length of 100mm in the 3D modeling process.

The U-shaped plate is driven by the deceleration stepping motor, and the maximum limit angle θ reached in this plane is plus or minus 45 degrees, and the approximate force generated by the load of 35 kg is 350N. The moment formed by converting the force of the U-shaped plate to the O point is 247.45kg.cm.

Considering the static torque problem of the stepping motor, as long as the torque of the O point is smaller than the static torque of the stepping motor, the entire test platform can be stabilized without being energized. According to the magnitude of the torque, the 56GP-57H250D40 stepping motor with a reduction ratio of 57 is selected. Its static torque is 339.5kg.cm, which is much larger than 247.45kg.cm. Therefore it is reasonable to use it on the test platform.

IV. TEST PLATFORM CONTROL PART DESIGN

A. *Underwater Mechanical Arm Console Internal Control Circuit*

The underwater robot arm joint control part is divided into a brake part and a circuit control part[13]. The brake part can be realized by a steering gear. In the circuit control part, the movement of the steering gear can be controlled by controlling the PWM wave, thereby achieving joint control.

The test of the underwater manipulator maintains the test accuracy of the entire test platform, thereby achieving the purpose of the test platform for the underwater manipulator test. The main consideration for achieving this goal is to control the position of each point in space. For the position control, it can be divided into the decomposition of the control of the joints of the mechanical arm, and the control of the steering gear can be simply understood as the control of the motion of the steering gear, that is, the steering gear Stop, the reverse rotation of the steering gear, the control of the steering speed[14]. The circuit control part consists of five partial control modules, indicator modules, power supply modules, switch modules and communication interface modules. The overall block diagram of the test platform is shown in Fig. 4.

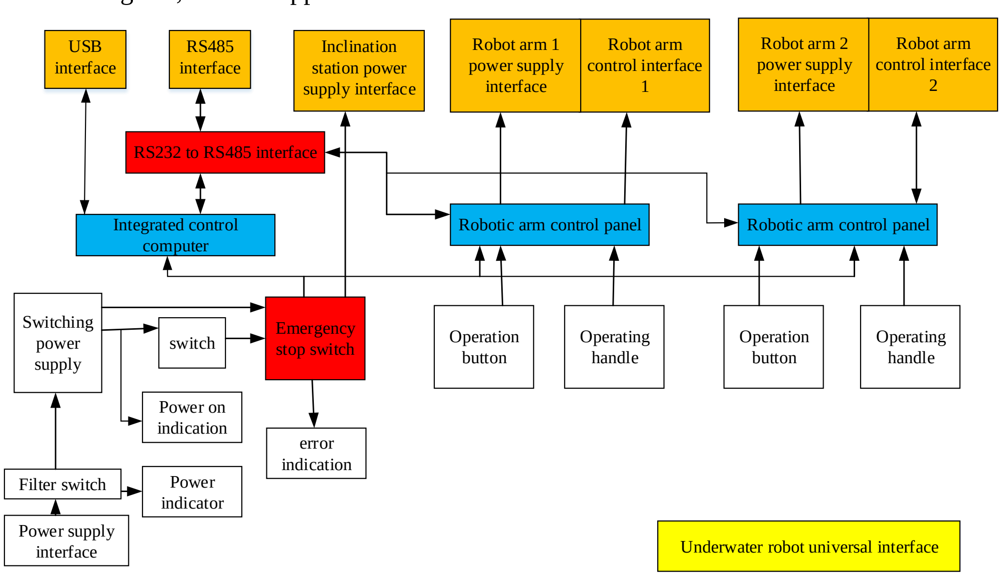

Figure 4. Robot arm control block diagram

V. MOTOR TEST AND STRESS SIMULATION ANALYSIS OF U-SHAPED PLATE

As can be seen from the analysis of the mechanical part, the mechanical body portion of the test platform includes three degrees of freedom, respectively, in three different directions of rotation. The upper mechanical part is controlled by a two-degree-of-freedom operating pan/tilt and an one-degree-of-freedom U-shaped plate, while the U-shaped plate control is the control of the 57-speed stepping motor. Control the speed of the stepper motor, start and stop, forward and reverse. Therefore, the control part of the test software here is mainly the rotation control of the 57 stepping stepping motor.

A. *57 Deceleration Stepper Motor Test Software*

First of all, for the control of the 57 step-down stepping motor, the 57 stepping gear motor has been described in the text. Its control is mainly the control of the speed of the stepper motor. For the control of the stepper motor, the STM32F407vet6 is used to control the three ports of the driver. These three ports are the enable terminal EN port, the pulse signal receiving end STP port, the forward and reverse control terminal DIR port, and the third port. For the control of the ports, the requirements to be met are:

- The rotation of the motor can drive the U-shaped plate to rotate in the plane;
- The motor is on and off;
- The positive and negative control of the motor, so that the U-shaped plate can adjust the angle of motion arbitrarily in the plane;

In order to satisfy the above control functions, the selected solution is:

- The STP pulse signal termination frequency is adapted to the pulse signal to control its rotation; the start and stop are controlled by controlling the high and low levels of its buttons.
- The positive and negative ports of DIR are connected to the high and low levels of the button, and the purpose of the forward and reverse is controlled by the high and low levels of the button.

For the operation angle of the U-shaped plate, it is about plus or minus 45 degrees, that is, 90 degrees. The number of subdivisions of the driver is 8, which is the number of pulses in the entire motion track. Therefore, when designing the program, the entire motion track runs one circle, and the design time is 4 seconds, that is, the pulse frequency is 100HZ. The pulse frequency width is 5000us, because the driver's pulse frequency requirement is up to 12MKHZ, so the choice of this design is reasonable.

B. *Main Load Bearing Parts Selection and Calibration Simulation*

It can be seen from the three-dimensional modeling figure that the gimbal is directly mounted on the U-shaped plate, so the U-shaped plate is a load-bearing part, and the force-applying is 10 tensile-stressed bolts on the U-shaped plate, and Ten bolts subjected to shear stress on the U-plate side panel. These 10 bolts are the force parts of the entire mechanical test platform. Therefore, the selection and verification are carried out here.

If the load-bearing requirements of the test platform are to be met, the dangerous section diameter of the bolts here is too small. Therefore, the bolt can be selected by the size of the U-shaped plate. Select the bolt with the specification M5, the material Q235 and the performance class 4.6. The U-shaped plate is subjected to a stress of approximately 350 N, so that the U-shaped plate of the material alloy steel is subjected to a stress much less than the ultimate stress that causes it to be broken, relative to a thickness of 5 cm. However, this is only a theoretically calculated result, and there may be a certain gap with the actual situation. The rationality is further verified by software simulation below. First of all, it can be seen from the analysis that the load bearing is mainly U-shaped plate, so it is only necessary to carry out mechanical simulation and finite element analysis. The results are shown in Fig. 5 and Fig. 6.

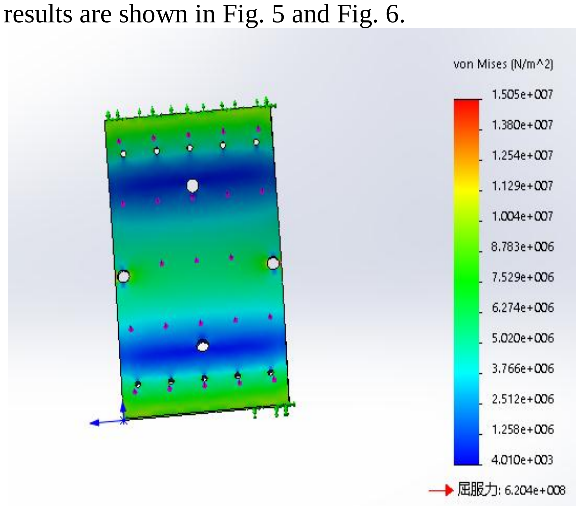

Figure 5. Stress analysis chart

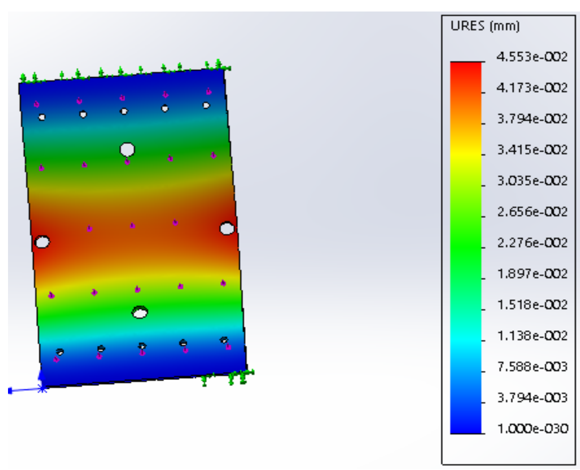

Figure 6. Displacement analysis chart

It can be seen from Fig. 4 that the maximum stress is located at the bolt hole of the U-shaped bottom plate on both sides, and the maximum stress is 1.505e+0.007N/m^2. The yield stress of the material is 6.204e+0.008N/m^2, which satisfies the requirement of yield stress. The maximum displacement is located in the middle of the bottom plate and is approximately 4.553e-0.002mm.

The information on the color observed in Fig. 7 is known. The bottom plate is entirely blue. The minimum safety factor (FOS) here is greater than one. The U-shaped base plate meets the requirements of this subject for load bearing.This is the two main force-bearing parts of the mechanical body of the test platform. By checking the stress here is far less than the ultimate stress of the damage. Therefore, the selection here and the grasp of the material thickness are reasonable.

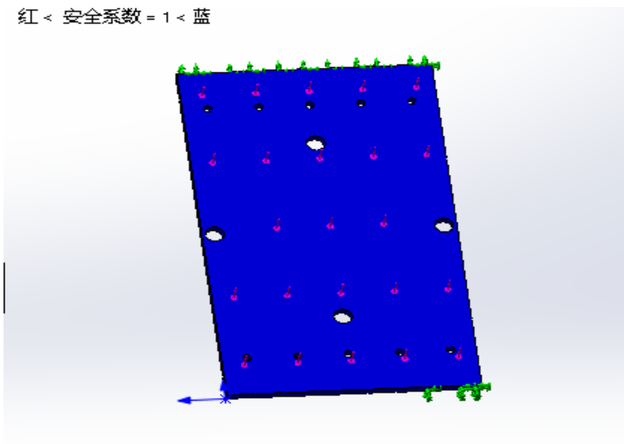

Figure 7. Analysis of safety factor

VI. CONCLUSION

In this paper, the underwater manipulator test platform is deeply studied, aiming at the problems of unstable working attitude and low positional accuracy of the mechanical arm under water. In this paper, an underwater manipulator test platform is designed mainly from the control and mechanical load-bearing part of the motor. It mainly tests the attitude state of the underwater manipulator at a certain point on the land-based test platform, and reaches a certain space in the grab space. The purpose of a little object. Finally, the stress simulation and finite element analysis of the load-bearing components show that the maximum displacement of the U-shaped bottom plate is located in the middle of the bottom plate, which is approximately 4.553e-0.002mm. The maximum stress is 1.505e+0.007N/m^2. The yield stress of the material is 6.204e+0.008N/m^2, which satisfies the requirement of yield stress. Therefore this design is reasonable.

ACKNOWLEDGMENT

Thanks for the fund project: Shaanxi Provincial Science and Technology Coordination Plan (2015KTZDGY-02-01); Shaanxi Provincial Education Department Fund (18JK0395); Xi'an Weiyang District Science and Technology Plan Project (201837) support.

REFERENCE

[1] Luo Tianhong, Wang Qing, Ma Xiangyu.Design of super-smart mechanical arm of propeller cleaning robot[J]. Chinese Journal of Engineering, 2017, 39(06):924-932.

[2] Cos Satja S, Matija R, Joseph C, et al. Collision Detection for Underwater ROV Manipulator Systems [J]. Sensors, 2018, 18(4):1117-.

[3] ta D , Palmieri G , Palpacelli M C , et al. Design of a Bio-Inspired Autonomous Underwater Robot [J]. Journal of Intelligent & Robotic Systems, 2017.

[4] Wang Liquan, Li Ping, Han Jinhua, Meng Qingxin. Kinematics analysis of three-finger underwater manipulators[J]. China Mechanical Engineering, 2004(07): 7-9.

[5] Li Xiaochen, Liu Ziyang, Li Deyuan, Wu Wangyang, Wang Haisheng. Design and research of underwater robot with six degrees of freedom[J]. Chinese Hydraulics & Pneumatics, 2014 (01): 10-12+17.

[6] Huang Hai, Zhang Guocheng, Yang Yi, et al. Dynamic Modeling and Coordinated Motion Trajectory Optimization of Underwater Unmanned Vehicle Manipulator System[J]. Journal of Shanghai Jiaotong University, 2016, 50(9): 1437-1443.

[7] Yang Chao, Zhang Mingwei, Qin Hongde, Guo Guanqun, Wang Yujia.Study on underwater robot-manipulator attitude adjustment system[J].Journal of Harbin Engineering University, 2018, 39 (02): 377-383.

[8] A Bio-inspired Soft Robotic Arm: Kinematic Modeling and, Hydrodynamic Experiments [J]. Journal of Biomimetic Engineering: English, 2018(2): 204-219.

[9] Zhang Jianjun, Liu Weidong, Gao Lizhen, Li Le, Li Zeyu. Adaptive Bilateral Control of Uncertain Teleoperation of Underwater Manipulators[J].Journal of Beijing University of Aeronautics and Astronautics,2018,44(09):1918-1925.

[10] Zhang J (Zhang Jin), Li W (Li Wei), Yu JC (Yu Jiancheng), et al. Development of a Virtual Platform for Telepresence Control of an Underwater Manipulator Mounted on a Submersible Vehicle[J]. On Industrial Electronics, 2017.

[11] Jin S, Bae J, Kim J, et al. Disturbance compensation of a dual-arm underwater robot via redundant parallel mechanism theory [J]. Meccanica, 2016, 52(7): 1-9.

[12] Sverdrup-Thygeson J, Kelasidi E, Pettersen K Y , et al. The Underwater Swimming Manipulator—A Bioinspired Solution for Subsea Operations [J]. IEEE Journal of Oceanic Engineering, 2017: 1-16.

[13] Yu Jiancheng, Zhang Jin, Li Wei. Brain-wave control of underwater manipulator based on event-related potential[J]. Robot, 2017, 39 (04): 395-404.

[14] Zhang Qifeng, Fan Yunlong, Zhang Yuying.Design and Error Analysis of Deep Sea 5 Functional Underwater Electromotive Manipulator[J].Machinery Design & Manufacture, 2015 (04): 140-143.