PROCEEDINGS OF SCIENCE

The mechanic and optical properties of the OM for the NEON neutrino project

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The interaction of neutrino and matter can produce charged particles. By detecting the Cherenkov light generated by these charged particles the neutrinos can be observed. We propose a cubic-kilometer scale high-energy neutrino detector located in the South China Sea, Neutrino Observatory in the Nanhai (NEON). The detector will use tens of thousands of optical modules (OMs), in which multiple photomultipliers tubes (PMTs) are housed in a transparent glass sphere. To get the optimum performance, these PMTs should have homogeneous photocathode response. In this work, we test the response of PMTs under different lighting angles, obtaining the collection efficiency of individual PMTs. Finally, the mechanical structure of the module is designed and tested for shockproof packaging during transportation. In addition, we designed two types of robotic arms to improve the efficiency of measuring the optical properties of PMT and OM.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

ICRC2023
38th International Cosmic Ray Conference
The Astroparticle Physics Conference

*Speaker

PoS(ICRC2023)1014

1. Introduction

The Neutrino Observatory in the Nanhai (NEON) is a undersea cubic-kilometer scale high-energy neutrino detector deployed in the South China Sea. It will be constructed offshore with a deep of 4km. The NEON is a three dimensional array of optical modules distributed over large volumes of the transparent water in the South China Sea. The optical module will record the arrival time of Cherenkov light generated in the sea water by charged particles generated by the interaction between Neutrino and sea water. The module will also record the brightness of the light and the position reached, and then transmit the data to the computer on the shore. The trajectory of Neutrino can be reconstructed by analyzing the data.

Following the KM3NeT design[1], our OM consists of a glass sphere with a diameter of 17 inches, 31 3-inch PMTs, electronic boards, internal support structures, etc. The OMs are arranged along vertical strings anchored on the seabed and pulled up by a buoy. In order to make the detected data more accurate, we first need to measure the performance of each PMT and select the best performing PMT through comparison. In addition, we need to understand the optical properties of OM and design a reasonable mechanical structure for OM to withstand the enormous pressure in seawater and extend its service life.

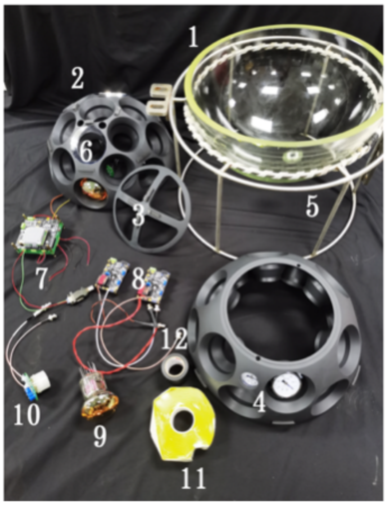
The paper is organised as follows: in section 2 design of internal structure, functions of various components, and assembly process of OM were introduced; in section 3 internal structure test of OM were discussed; in section 4 two types of robots used for optical testing and response distribution to PMT photocathodes were introduced.

2. Design and assembly of OM

The Neutrino telescope relies on OM arranged in transparent medium to detect Cherenkov optical signal caused by charged secondary particles generated by Neutrino reaction.For each OM, the plan is to assemble over 31 3-inch PMTs to maximize the photocathode area. OM will finally be put into the deep sea for work. Due to the extreme and special nature of the environment, it has high requirements for high pressure resistance and stability of internal mechanical structure. We have designed and optimized the internal structure and components of our OM based on the design of KM3NET.

For an OM, all modules will eventually be loaded in the low activity borosilicate glass sphere, as shown in component 1 in Figure 1, the outer diameter of the glass sphere is 17 inches, the glass thickness is 14 mm, and the rated high pressure that can be withstood is 6.7×10^7 pa. In order to prevent the sea water from flowing into the gap during deployment, Double-sided tape and waterproof adhesive tape (components 11 and 12 in Figure 1) will also be pasted at the equator.

PMT is a very sensitive single photo detection equipment and an important part of neutrino telescope used to observe neutrino signals. We chose the three inch PMT produced by North Night Vision, which has a smaller volume and can effectively solve the problem of insufficient internal space in OM. The PMT will be installed in the support structure shown in number two in Figure 1, and a light collection ring (component 6 in Figure 1) will be pasted around its head to increase the photon acceptance rate. We used FPGA mode and controlled the total power of one OM within 10W.



1、Glass hemisphere (bottom)
2、Section of a bottom support structure
3、Top readout electronics support structure
4、Pressure gauge
5、Support frame for OM hemisphere
6、Light collection ring
7、Power board and central Logic board
8、Signal transmission boards
9、PMT
10、PMT base
11、Double-sided tape (putty)
12、Waterproof Tape

Figure 1: Photo of the internal components of an OM

Component 3 in Figure 1 is the readout electronic support structure. Currently, we are using a 3D printed plastic component. In future tests, we will replace plastic with metal and reduce the hollow area to better dissipate heat. Component 7 is the Power board and Central Logic board, which provides high voltage for the entire readout electronic. The logic board is used to measure data arrival time and ToT, and can determine the trigger inside the sphere. Component 8 is Signal transmission boards, which are directly connected to the PMT to provide high voltage for the PMT, collect PMT data, and convert the data into LVDS signals. At present, we have achieved miniaturization of the electronics section. The readout electronic installed on the support structure is shown on the left side of Figure 2.

During the assembly process, each module component in OM will be installed on the support structure first. In order to make the module more stable, we use adhesive to stick to the corresponding hole of the support structure. Then we put the assembled support structure into the glass hemisphere. We designed the support structure to fit well with the inner surface of the glass sphere, and the surface of the PMT will not contact the inner wall. The installed support structure will be placed in glass sphere. After that, the two glass hemispheres are closely bonded, and then the interior is pumped to 0.5 times the atmospheric pressure, and then sealed and reinforced along the equator of the sphere with double-sided tape and waterproof tape.

Afterwards, we also designed an installation plan for OM on the cable, as shown on the right side of Figure 2. The number 1 represents the Kevlar rope, making the overall structure more stable and less prone to breakage during the lowering process. The number 2 is an optical cable used for power supply and signal transmission. The number 3 is a triangular rudder used to reduce the oscillation of OM in seawater.

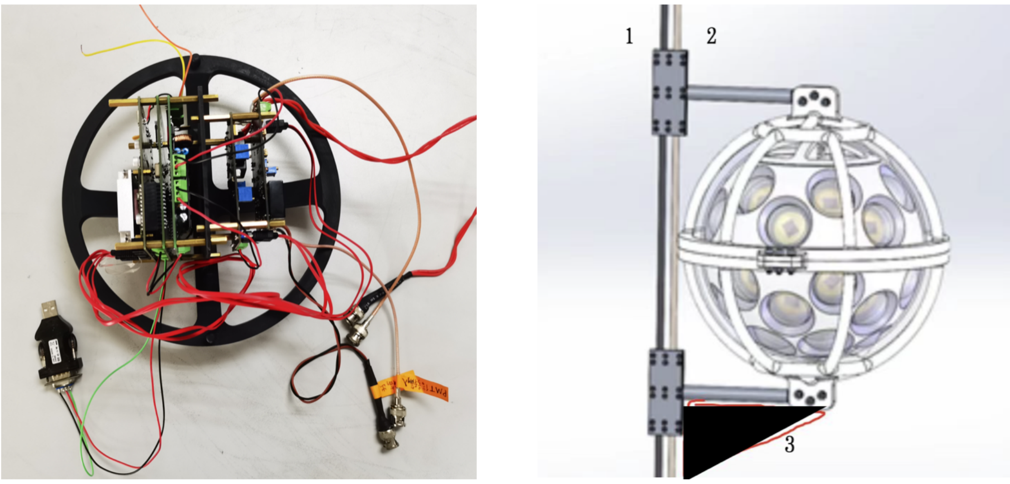


Figure 2: The left photo shows the electronic board installed on the support structure, and the right photo shows the design scheme for installing OM on the cable.

3. Testing of OM

3.1 Pressure withstand test of OM

In order to test the pressure resistance of the glass sphere, it is necessary to put it into the water pressure tester to simulate its situation in the deep sea. First, record the initial value of the pressure gauge in the glass sphere, and then put the assembled glass sphere in the iron frame. After the upper and lower parts are firmly fixed, put it into the water pressure tester with a hoist, and set the pressure in the tester to 10MPa, 15MPa, 20MPa in turn. When the water pressure reaches the corresponding pressure, keep the pressure stable. During this period, observe whether the instrument is normal, such as checking whether there is water leakage. Maintain the pressure for two hours after reaching the target pressure of 20MPa, observe the pressure condition displayed on the working platform, and take out the glass sphere after two hours if everything is normal. Observe the external condition of the glass sphere. If there is no obvious damage, continue to observe the pressure gauge in the glass sphere. If the value is the same as that of the pressure gauge before putting in, it can be proved that the glass sphere has passed the pressure test. After testing, the sphere did not show any damage and the pressure gauge value did not change significantly, proving that our OM has good pressure resistance.

3.2 Shockproof design

In the shockproof structural design, in order to make the installation of each component more stable, we used glue to stick it to the support structure, which can prevent them from falling when shaking. We use rubber washers between the support frame and the glass ball to prevent the internal structure from shaking. In future designs, we will inject silicone between the glass ball and the internal support structure without the need for rubber washers. During the shaking test, there was no significant shaking of the internal structure of OM, and after the test, there was no significant internal displacement, proving that our shockproof structural design meets the requirements.

In the shockproof packaging design, we first install the assembled OM into protective shells, which is made of LDP (low-density polyethylene). Each protective shell consists of two flanged halves secured by stainless steel bolts with washers and self-locking nuts. Synthetic fiber pads between the glass sphere and the shell absorb shock and retain the sphere in its position. Then put the protective shell containing OM into the carton with buffer airbags, and fill the gap with EPE (Expandable Polyethylene) foam buffer particles. Afterwards, we conducted express transportation testing on the packaged OM and inspected the OM after transportation, and found that the sphere and internal structure were intact.

4. Testing of optics

4.1 Two types of robots for optical testing

Understanding the response distribution of PMT photocathodes and the optical properties of OM is crucial for our future work. In order to improve the efficiency of measuring the optical properties of PMT and OM, we designed two types of robots as shown in Figure 3.

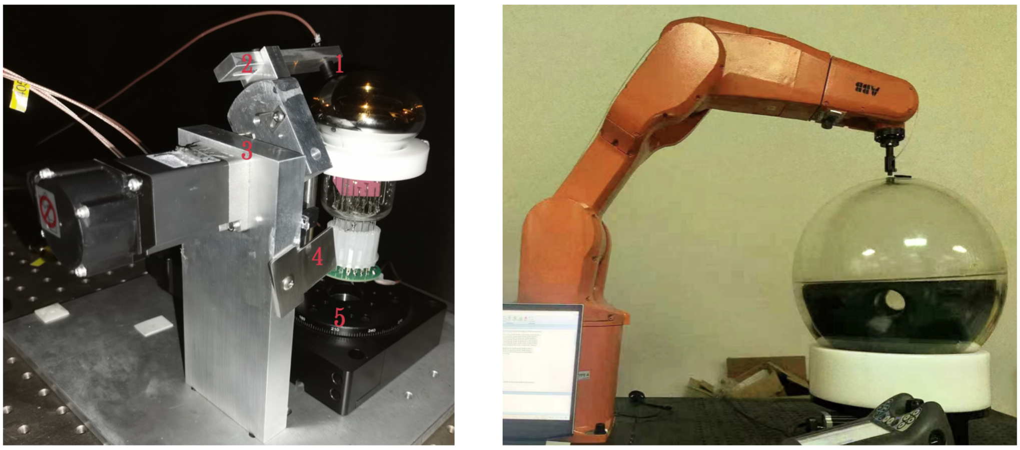


Figure 3: Photo of two robots. The left photo shows a rotating platform for measuring the response distribution of PMT photocathodes, while the right photo shows a robotic arm for measuring OM optical properties and batch testing of PMT.

In order to better measure the response distribution of photocathode[2], we designed a rotating platform shown in the photo on the left side of Figure 3. In this photo, number 1 represents the LD with collimator, which can emit light of 405nm wavelength. The position of LD and PMT center can be changed by adjusting the position of number 2. Before the test, we adjusted the position so that the LD is facing the center of PMT. A motor is installed at the position where No. 3 is located, so that the mechanical arm can rotate in the direction perpendicular to the ground. The rotation angle range is 0-90 °, the speed is 120 °/s, and the accuracy is ± 0.1 °. It can make the LD move along the curved PMT surface to ensure that the light is perpendicular to the PMT surface. A limit sensor is installed at the position of No. 4, which can limit the rotation of the mechanical arm and prevent damage to the instrument due to excessive rotation angle. No. 5 is a platform that can rotate around the direction parallel to the ground. The rotation angle range is 0-360 °, the speed is

20 °/sec, and the accuracy is ± 0.1 °. The PMT will be fixed on this platform, so that the light can shine on the PMT from different positions when the machine is running.

In order to better understand the impact of glass spherical shells on incident photons, we have also designed experiments to explore this issue.We used a small robotic arm produced by Asea Brown Boveri Ltd. (ABB) as shown in the photo on the right side of Figure 3, which has an LD with a collimator and can emit 405nm light. Its scanning route can be independently programmed and designed, and we have designed a scanning route for it to emit light into OM from different angles.

In order to investigate the optical properties of OM, we applied 2.64V DC voltage, and then use ABB's Robotic arm to make the light shoot at the OM at the angles of 15 °, 30 °, 45 °, 60 °, 75 ° and 90 ° respectively. The light at each angle will scan the designated OM surface according to the array of 5 * 5. There is a PMT installed under this area for detection, and light will trigger the PMT to generate a current signal. At present, we are still debugging the robotic arm and have not yet obtained valid data.

Later, we also plan to arrange a large number of PMTs in order on the platform, design a suitable running path for the Robotic arm, apply 1kHz pulse light to the LD, and make the light vertically shine at the center of each PMT to test the performance of PMT. Adopting this method can significantly improve our work efficiency.

4.2 Response distribution of photocathode

The current converted by photons arriving at PMT not only depends on quantum efficiency, but also on the angle of incidence. The dominant factor in angular dependence is just the amount of photocathode area which can be seen from various directions. In order to facilitate the reconstruction of Neutrino tracks in the future, we need to measure the overall response distribution of the PMT photocathode, which is the quantum efficiency in different directions.

We tested PMT of North Night Vision and Hamamatsu, mainly including dark counting, quantum efficiency, gain-high voltage, Peak-to-Valley ratio[3], in order to select the appropriate PMT. In the end, we chose the PMT produced by Northern Night Vision.

Firstly, apply appropriate high voltage to the PMT according to the calibration maintain its gain at 10^6, and then apply a 2.64V DC voltage to the LD. After this, control the robotic arm to make the LD shine on the surface of the PMT from different angles. Photons trigger the PMT from different angles to generate and transmit the corresponding current. The relationship between the current and the quantum detection efficiency is:

$$I_A = \eta \times QE \times Gain \times N \tag{1}$$

Among them, η is the collection efficiency, and we use the manufacturer's calibrated value for this parameter. N is the number of incident photons. When the DC voltage input to the LD is fixed, this parameter can also be considered a constant. The gain of PMT depends on the high voltage applied to it, and when the high voltage is fixed, its value is also fixed. Therefore, the magnitude of the current is directly proportional to the quantum efficiency, and we can directly determine the change in quantum efficiency caused by different incident angles based on the change in current.

5. Conclusion

In this work, we referred to the scheme of KM3NeT to design the internal structure of OM, introduced the functions of each component and the assembly method of OM, and designed a fixing scheme for OM on the cable. In order to better extend the service life of OM, we conducted tests on its pressure resistance and shock resistance. Then we tested the response distribution of PMT photocathode to better reconstruct the Neutrino track. We also designed two different Robotic arm to improve our efficiency in optical property testing.

Acknowledgements

This work is supported by the National Natural Science Foundation of China (NSFC) grants 12005313, 12205388, 12261141691 and 42150105.

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