Underwater Cylindrical Acoustic Array Structure Design
Scheme

Chong Yang*, Sibin Zhoub and Guoguang Zhang*
Kunming Shipborne Equipment Research and Test Center, Kunming, China
*Corresponding author e-mail: zgg136@163.com, e_yangchong@163.com, zhousibin123456@163.com

Abstract. In this paper, the mathematical model of cylindrical array is analyzed. A cylindrical matrix structure scheme is designed for the complex environment of the ocean. The structure of the array is briefly introduced, and the situation of the array being affected by current and tow is carried out. The calculations show that the cylindrical array can resist the horizontal current impact and maintain its stability. In extreme cases, it needs more than 50t to lift the matrix or displace the array. The double cylindrical array arrangement can be used. Automatic tracking and monitoring of underwater moving targets is achieved within 300.

1. Introduction
Sonar is an electronic device that uses underwater sound waves to detect, locate and communicate underwater targets. It is the most widely used and most important device in hydroacoustics. The sonar device generally consists of a matrix, an electronic cabinet and an auxiliary device. The array is composed of sonars arranged in a certain geometric pattern, and the shape is usually spherical, cylindrical, flat or linear. In engineering design, the cylindrical array is a classic matrix pattern, which can be used for water surface target orientation in 360°, geometrical structure, and directivity in both horizontal and vertical directions, eliminating spatial azimuth blurring. Better suppress noise and interference, improve measurement accuracy and measurement gain. The cylindrical array can form multiple beams in the horizontal plane. When the target is found, three or five beams are formed in each target direction for azimuth estimation, and the orientations of different targets are tracked. In view of the complex situation of the ocean, this paper proposes a corresponding structural scheme to solve the problem of deploying the array on the seabed.

2. Cylindrical matrix mathematical model
Schematic diagram of the geometric structure of the N×M cylindrical array is shown in Fig 1 [1-3], where N is the number of circular arrays, M is the number of array elements of each circular array, and the array elements are evenly distributed on the circumference, and the spacing of the circular arrays is d, the radius is R, the bottom plane of the cylinder is the xoy plane, and the origin of the coordinate system is at the center of the bottom circular array. Assuming that a far-field single-frequency plane wave is incident from the k direction, the frequency-beam response of the cylindrical acoustic array to the plane wave signal can be expressed as:
\[ B(\theta, \phi) = \sum_{n=1}^{N} \sum_{m=1}^{M} W_{nm}^* \exp(j(2\pi/\lambda)((R\sin\theta \cos(\phi - \phi_m) + Z_n \cos\theta) - (R\sin\theta_s \cos(\phi_s - \phi_m) + Z_n \cos\theta_s)) - \sin\theta_s \cos(\phi_s - \phi_m))) \times \sum_{n=1}^{N} W_{m}^* \exp(j(2\pi/\lambda)R(\sin\theta \cos(\phi_m) - \sin\theta_s \cos(\phi_m))) = B_{\text{lin}}(\theta, \phi) B_{\text{circ}}(\theta, \phi) \]  

(1)

Where, \((\theta, \phi)\) is the direction of arrival of the plane wave; \((\theta_s, \phi_s)\) is the direction of the array; \(\phi_m\) is the angle between the mth element and the x-axis; \(\lambda\) is the wavelength of the plane wave; \(W_{nm}^*\) is Weighted value of the nmth array element; where \(W_{nm}^* = W_n^* \times W_m^*\), \(W_{n}^*\) is the weighted value of the nth circular array, and \(W_{m}^*\) is the mth array element on each circular array Weighted value; \(B_{\text{lin}}(\theta, \phi)\) is the linear array beam pattern, and \(B_{\text{circ}}(\theta, \phi)\) is the beam pattern of the circular array.

It can be seen from the above analysis that the beamforming of the cylindrical array can first beamform N circular arrays containing M number of array elements, and then perform beam combining of the N beams in the z direction. When the signal propagates to the cylindrical acoustic matrix, the signal output by each array element has a path difference. The Chebyshev weighting combined with the interpolation beamforming technique and the multiple beams are used to estimate/resolve the target, which can improve the system's target estimation ability [4-6].

**Figure 1.** Schematic diagram of the geometry of a cylindrical array

3. **Cylindrical array design**

3.1. **Cylindrical array design requirements**

Full consideration of the working distance, positioning error, environment and other factors, the design of the cylindrical array structure has the following requirements:

1. The structure of the array is fixed by underwater self-sinking.
2. In order to improve the target orientation, positioning accuracy, and target resolving power of the system, it is necessary to determine the most economical and suitable matrix aperture, which is beneficial to the system to expand the working distance and improve the target resolving power.
3. The array can meet the needs of the system, and the array should be easy to assemble and deploy underwater, while considering the convenience of maintenance.
4. In order to ensure long-term use in complex environments, the anti-corrosion, anti-biological and underwater safety and reliability of the array should be improved.
(5) The array has reliable anti-overturning stability, preventing the water flow from causing it to tip over or change its position;

(6) The underwater electronic cabin has reliable waterproofness to ensure normal operation of the system.

3.2. Cylindrical array design scheme
Because the mobility of underwater targets is not strong, the frequency of radiated noise is not high (generally within 4 kHz). If a small angle of beamforming angle is required, the aperture of the array is required to be larger, and the number of basic array elements needs to be more. Both cost and engineering will bring greater cost and difficulty. Considering the monitoring area and engineering cost, a cylindrical sonar array structure scheme is proposed, and its structure is shown in Figures 2 and 3. The cylindrical array design is about 3.2m in diameter, consisting of arrays, hydrophone rods (64 in total, 6 elements in each hydrophone bar), watertight electronic cabin, watertight transfer cabin, and 16 turns 1 Wiring compartment, arc-shaped baffle, array base, self-test launch transducer, array adapter cable, etc.

The watertight electronic cabin is used to install the underwater components of the cylindrical array, including the preamplifier circuit, the electro-optical conversion circuit, and the electronic magnetic compass.

Figure 2. Schematic diagram of cylindrical array scheme

1 glass fiber reinforced plastic sound mask; 2 lug; 3. Transmitting transducer; 4 vertical rod; 5. Arc baffle; 6 drainage pipe; 7 array body; 8. Hydrophone rod; 9 base; 10. Watertight electronic cabin; 11 anti-smashing structure; 12 watertight transfer compartment; 13 cable

Figure 3. Schematic diagram of cylindrical array structure

The array body is made of large-caliber standard stainless steel circular pipe and steel plate welded together, and the cavity baffle and array body can be assembled and disassembled quickly through the
interface. Four adsorption cavities are designed at the bottom of the baffle, and the cylindrical array can be firmly attached to the sea bed after sinking to the sea floor. The bottom of the array body has an anti-slip structure, which can prevent ocean currents. The array body has an anti-smashing structure, which can protect the underwater electronic cabin and cables from external objects. The upper and lower protection plate and vertical bar can protect the baffle plate and hydrophone bar from external objects. There are cable anchor points at the lower part of the array body. The cables entering the array body from the anchor points can be coiled along the array body. A nut is welded on the upper and lower protective plate of the array body, which is used to install the sound transmission protective cover to prevent the large amount of water exchange inside and outside the sound transmission protective cover. The sound barrier can improve the sensitivity and directivity of transducer, which is an indispensable acoustic structure for array design. Meanwhile, the barrier is the installation platform for hydrophone rod.

The weight and buoyancy of the cylindrical array are mainly concentrated in the array body, watertight electronic cabin, baffle, hydrophone rod, sound transmission shield, 16 revolution 1 transfer cabin, watertight transfer cabin, base, top cover and other parts, the rest of which can be ignored. The weight and buoyancy of each part are shown in table 1. When the array is connected to the base, it weighs about 8.5t in the air and 7t in the water.

| project                        | Volume(m^3) | Weight per item(kg) | Quantity | Total weight(kg) | Buoyancy(kg) |
|-------------------------------|-------------|---------------------|----------|------------------|--------------|
| Array of body                 | 0.345       | 2695                | 1        | 2695             | 345          |
| Watertight electronics        | 0.01397     | 109                 | 1        | 109              | 31           |
| mask                          | 0.108       | 842                 | 4        | 3368             | 690          |
| hydrophone                    | 0.00157     | 2.8                 | 64       | 179              | 96           |
| Acoustic shield               | 0.00525     | 42                  | 4        | 168              | 21           |
| 16 turn 1 transfer bay        | 0.00525     | 41                  | 4        | 164              | 16           |
| Watertight transfer compartment| 0.0124      | 97                  | 1        | 97               | 29           |
| Pedestal                      | 0.213       | 1662                | 1        | 1662             | 213          |
| Top cover                     | 0.0153      | 120                 | 1        | 120              | 15           |
| total                         | 1.09        | ---                 | ---      | 8562             | 1456         |

4. Cylindrical array related calculation

4.1. Sea flow calculation

According to JTS-144-1-2010 "Port Engineering Load Specification", the standard value of water flow should be calculated as follows

$$F_{\text{fluid}} = C_d \frac{\rho}{2} V^2 A$$

(2)

Where: $F_{\text{fluid}}$ is the standard value of water flow; $\rho$ is the standard value of water flow, the value is $\rho = 1.03kg/cm^3$; $C_d$: coefficient of flow resistance, taking $C_d = 0.73$ for the array; $V$: water flow velocity (m/s); $A$: Calculate the projected area of the component on the vertical plane (m²), and take $A = 3.15m^2$;

It is assumed that the current velocity gradient is evenly distributed along the vertical sea floor. The forces acting on the array in the horizontal direction of the current at different currents are shown in Table 2.
Table 2. Calculation of the force of the current on the array under different currents

| Speed   | F_{fluid} |
|---------|-----------|
| V=0.5Kn | 0.006t    |
| V=1Kn   | 0.027t    |
| V=2Kn   | 0.1t      |
| V=3Kn   | 0.25t     |
| V=4Kn   | 0.44t     |

Under the condition that the flow velocity of the seabed is 0.5 to 1.0 knots, the impact force of the underwater array cylinder is between 0.013 tons and 0.052 tons, that is, the flow force in the position of the array is extremely small. The matrix cylinder can maintain its own stability against the horizontal current impact force even if its frictional force is not fixed at the bottom of the sea. It is worth noting that the installation process is subject to large flow forces near the sea surface. Installation and construction need to be considered during the flat tide period (lower flow rate). If the flow rate is large, the array cylinder itself is subjected to flow. The force can reach 0.5 to 0.8 tons, and the flow of the pedestal structure is even greater. Therefore, the installation must be carried out during the period when the flow velocity is small.

4.2. Analysis of the situation

Considering the situation when the pile legs are inserted into the sea, the force of the current on the array is basically negligible. However, it is sometimes necessary to understand how much the matrix needs to be raised in an extreme case (such as the need for array repairs or the substrate to be hooked by foreign objects) to lift the array or cause a large displacement of the array. We need to make some assumptions about this:

1. Under the load, the embedded member and the embedded body are elastic bodies, following the principle of stress superposition, the unique principle of solution and the principle of Saint-Venant, the stress distribution function can be continuously guided;
2. The pile and the foundation soil satisfy the axisymmetric condition;
3. Under the limit pulling load, the frictional resistance of the pile side surface is fully exerted, and the pile-soil interface follows the friction law.

Based on the above assumptions, the process of the substrate being hooked by foreign objects needs to overcome the following resistances:

\[ F_{\text{Total}} = G_{\text{Self weight}} + F_{\text{Adsorption}} + F_{\text{Side}} + F_{\text{Soil}} + F_{\text{Cut}} \]  
\[ F_{\text{Adsorption}} = S_{\text{area}} \Delta P \]  
\[ F_{\text{Side}} = q_{\text{side}} A_i \]

Where: \( G_{\text{Self weight}} \) is the gravity in the base array water, taking \( G_{\text{Self weight}} = 3t \); \( F_{\text{Adsorption}} \) the adsorption force of the adsorption cavity formed by the matrix (including the adsorption force at the bottom of the leg); the \( F_{\text{Side}} \) is the frictional resistance of the side of the leg; \( F_{\text{Soil}} \) is the pressure of the soil covering the upper part of the pile leg (this pressure can be ignored); \( F_{\text{Cut}} \) is the shear failure force of the pile side soil (can be ignored); \( S_{\text{area}} \) is the area of the adsorption cavity, take \( S_{\text{area}} = 7.62m^2 \), \( \Delta P_{\text{Seat}} \) the pressure difference between the inside and outside of the adsorption pedestal cavity, take \( \Delta P_{\text{Seat}} = 0.044Mpa \), take \( S_{\text{pile}} = 0.09m^2 \), \( \Delta P_{\text{Pile}} \) is the difference between the internal and external pressure of the pile leg cavity, taking \( \Delta P_{\text{Pile}} = 1MPa \); \( q_{\text{side}} \) is the characteristic value of the friction resistance of the pile side soil; \( A \) is the pile and soil action area.

\[ F_{\text{Adsorption}} = S_{\text{area}} \Delta P_{\text{Seat}} + S_{\text{Pile}} \Delta P_{\text{Pile}} = 425kN \]

The frictional resistance of the leg side is calculated as shown in Table 3 below.
Table 3. Calculation of frictional resistance on the side of the leg

| Soil layer       | $q_{sia}$ (kpa) | Soil thickness (m) | Side frictional resistance (kN) | 4 piles total |
|------------------|-----------------|--------------------|--------------------------------|--------------|
| Muddy clay 1     | 11              | 0.2                | 1.38                           | 27kN         |
| Muddy clay 2     | 15              | 0.8                | 7.5                            | 27kN         |

Therefore, $F_{Total} = 30 + 425 + 27 = 482kN \approx 50t$

Based on the above force calculation analysis, it can be known that the array requires a force greater than 50t in an extreme case to lift the matrix or displace the array.

5. Application

An oilfield security system adopts two sets of cylindrical arrays to measure the underwater moving target and calculate the target position. The tracking trajectory of a non-registered vessel is shown in Figure 4, which can achieve the surface area of the central platform. Automatic monitoring of vessel activities and underwater operations, real-time safety warning of submarine oil (gas) pipelines, reducing the risk of damage caused by dangerous behaviors such as construction, operation or anchoring of unidentified vessels in the vicinity, with obvious economics Benefits and social significance.

![Figure 4. Tracking trajectory of an unregistered vessel in an oil field](image)

6. Conclusion

Underwater cylindrical arrays are used to track underwater targets, and also as an important surface target detection device. For the complex situation at sea, this paper proposes a cylindrical matrix structure design scheme, which adopts modularization. The design idea, high structural reliability, simple assembly, easy processing, good anti-overturning, low cost, easy to implement, and easy to construct and deploy on the seabed, can be used in the offshore areas of China’s offshore areas or other areas with engineering equipment. Security.

Acknowledgments

We are grateful to the other colleagues in the first laboratory of the Kunming Shipborne Equipment Research and Test Center for their support and assistance in this research. We are grateful to our reviewers for their valuable suggestions and comments, and also to the MAME Organizing Committee. Finally, I would like to thank Director Wang for the language support.
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