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Underwater docking installation technology of submerged floating tunnels

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Abstract. Since the underwater docking construction of submerged floating tunnels is difficult because of many disturbance factors such as ocean currents and waves, an auxiliary structure system for the underwater docking installation of floating tunnels is designed in this paper. This system consists of a cylindrical steel truss, a vertical and horizontal mobile mechanism, a clamping structure, an auxiliary position monitoring device and so on, realizing the accurate underwater docking of floating tunnel tubes. In addition, this paper gives an underwater docking construction process of floating tunnel tubes. The technical solution to the underwater docking installation of submerged floating tunnels in this paper has important reference value for the research and construction of the floating tunnel structure.

1. Introduction

The submerged floating tunnel, also known as the Archimedes Bridge, maintains its balance and stability in the water through the joint action of the structure's dead weight, buoyancy and anchoring system. Submerged floating tunnels are a new transportation concept proposed in recent years[1-2], as compared to traditional transportation forms such as cross-sea bridges and immersed tube tunnels. Submerged floating tunnels will surely have a very broad application prospect in the future because of their economic, environmentally friendly, anti-seismic and convenient nature. However, the transportation concept of submerged floating tunnels involves a wide range of technical fields and many key technical problems need to be resolved[3-5]. Therefore, a practical submerged floating tunnel has not yet been built in the world so far. The underwater docking of tunnel tubes has been one of the key technical problems that hinder the construction of floating tunnels.

At present, the docking technology of submerged tunnel tubes mainly refers to the sinking technology of immersed tube tunnels. Although immersed tube tunnels are constructed on the seabed and are less affected by currents and waves, it is very difficult to accurately interconnect tube sections due to various complex factors such as the marine climate, the marine fluid environment, the submarine topography, and so on.

Currently, there is no construction technology for the accurate underwater docking of submerged floating tunnels. Unlike immersed tube tunnels, submerged floating tunnels are usually located between ten and thirty meters underwater. In addition to the factors affecting the underwater docking installation of immersed tube tunnels, currents and waves can cause oscillations of floating tunnel tubes and installation and lifting vessels. This greatly increases the difficulty in the underwater docking of floating tunnel tubes.

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2. Underwater Docking Construction Technology of Submerged Floating Tunnels

2.1. Design of an Auxiliary Structure for Underwater Docking Construction

The auxiliary structure system for the underwater docking of submerged floating tunnels comprises a cylindrical steel truss, a vertical and horizontal mobile mechanism, a clamping structure, an auxiliary position monitoring device and so on. This system can achieve the docking operation of the to-be-installed tube section 1a and the installed tube section 1b.

As shown in Fig. 1, the steel ring-pulls for traction are welded respectively at both ends of the cylindrical steel truss. In order to prevent the marine environment from corroding the structure, the surface of the truss is coated with an anticorrosion polyurethane coating. The inner diameter of the truss is larger by one to two meters than the outer diameter of the tunnel tube section, and the axial length is 20 to 30 meters. The rear half of the truss is sleeved on the outer periphery of the installed tube, and is supported on the outer periphery of the installed tube through the roller on the rear half of the truss. Several circumferential rails are arranged at different axial positions on the inner side wall of the front half of the truss. The circumferential rails are centered on the medial axis of the truss and have the same ring radius R1. They are in the axial equidistant distribution, with the spacing of two to three meters. Axial rails pass through between the circumferential rails. Two longitudinal rails are symmetrically arranged with the axis of the truss as the center of symmetry; the head and the tail of these rails are retracted respectively by 0.3 to 0.5 meters.

As shown in Figs. 2 and 3, a temporary rail is arranged along the axial direction on the outer side wall of the docking tube. The temporary rail is made of glass fiber and a ceramic toughened epoxy material, running through the installed tube section and the to-be-installed tube section. Supported on the temporary rail, the roller can move axially along the temporary rail so that the docking tube and the truss are coaxial and can move in the axial direction.

In this technical scheme, the slot is provided at a fixed position on the temporary rail. When the truss reaches a designated position, a diver inserts a temporary baffle into the front and rear slots of the roller in order to prevent the sliding of the roller and achieve positioning. In the second half of the truss, the rollers are arranged at least in two groups that are parallel to each other, with two rollers at least in each group. This aims to restrain each other and prevent the truss from moving and overturning under a large flow velocity. The rollers are arranged in two groups, and the angle between three rollers in each group is 120°.

As shown in Figs. 3 and 4, several telescopic manipulators are supported on the axial rails by means of the rotatable rollers, and can move on the axial rails and the circumferential railsthrough the rollers. The telescopic manipulators are arranged in pairs in the positions with the axis of the truss as the center of symmetry, clamping the to-be-installed tube.

On the outer side wall of the to-be-installed tube section, a temporary positioning elastomeris arranged at the position of the front end of the docked truss, and the positioning slot is provided at the corresponding position of the truss. Therefore, the docked truss can be positioned by means of the temporary positioning elastomer. As shown in Figs. 5a and 5b, in this technical solution, on the outer side wall of the positioned tube, the temporary positioning elastomer of natural rubber is arranged at the position of the front end of the tube-docked truss. In addition, the cubic positioning slot with the side length of 0.3 to 0.5 meters is provided at the corresponding position of the truss. Thus, the tube-docked truss can be positioned through the temporary positioning elastomer. The front end of the truss refers to one end of the front half of the truss. The temporary positioning elastomer has the characteristics of large elasticity. After the next section of tube is moved to the docking position, the elastomer can be compressed by manual operation. When the elastomer is rotated to the positioning slot, elastic force will be released and the elastomer will be inserted into the positioning slot. The observation by the diver can help to identify the positioning situation at the docking position of the tube section.

As shown in Figs. 6a and 6b, the telescopic manipulator has an arc pressure plateat the front end that can closely be linked to the outer side wall of the positioned tube. The surface of the arc pressure plate has a non-slip elastic cushion, and the support rod of the arc pressure plate is a hydraulically extendable rod. The roller and the support rod can be rotated at a relative angle of 900. The telescopic manipulator is controlled by a computer to expand and rotate, pushing the movement of tube joints in combination with an external force. This can realize the tube joint fixation and radial positioning and accomplish accurate docking through pushing and rotation.

In order to achieve automatic control, a position sensor is provided in this technical scheme for real-time detection of the relative distance between the to-be-installed tube and the positioned tube during the docking process. The position sensor is an ultrasonic sensor, consisting of a transmitting end and a receiving end. These two ends are at the docking ends of the positioned tube and the to-be-installed tube respectively. The position sensor collects the distance data between the to-be-installed and installed tube sections and transmits the data to the computer terminal. After analysis of the data by the computer, the telescopic manipulator is controlled to expand and rotate.

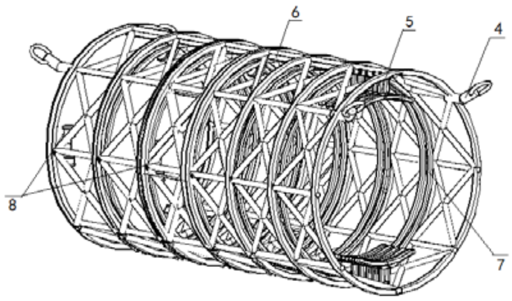

Figure 1. Schematic diagram of the auxiliary steel truss for underwater docking of floating tunnels

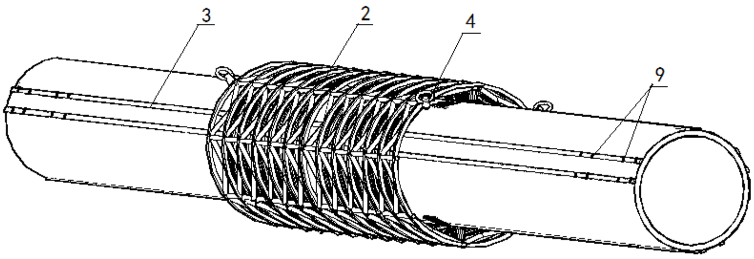

Figure 2. Schematic diagram of initial sinking of tunnel tube sections

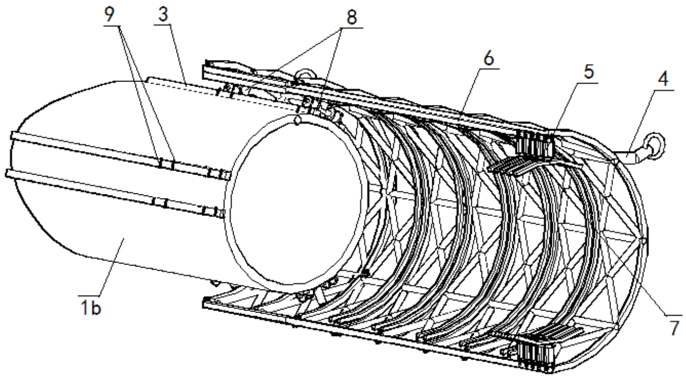

Figure 3. Schematic diagram of the installed tube section and its peripheral steel truss

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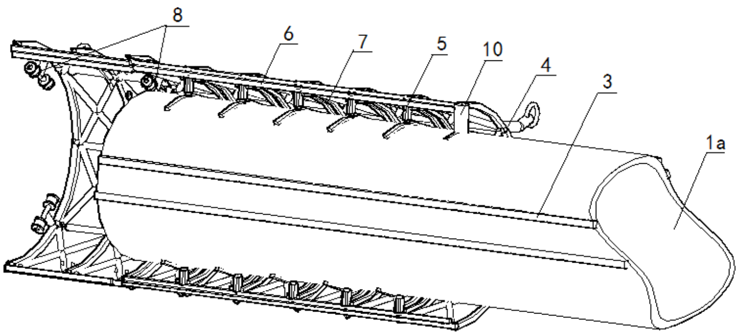
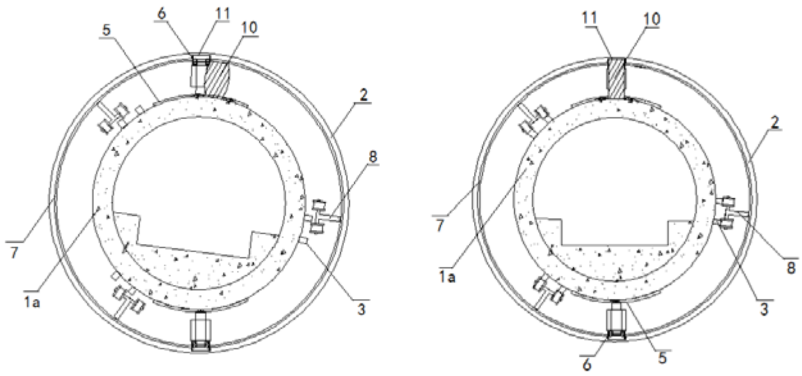
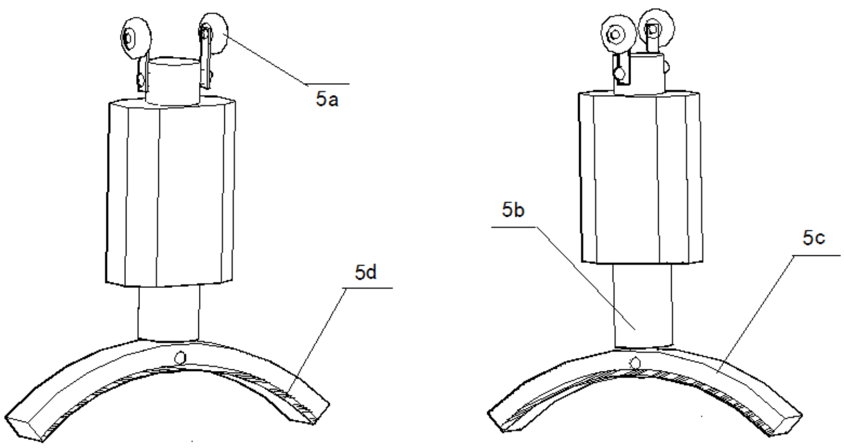


Figure 4. Schematic diagram of the to-be-installed tube section and its peripheral steel truss



a) Before rotation and positioning b) After completion of positioning

Figure 5. Phase diagram of the section of the to-be-installed tube



a) When the manipulator is on an axial rail b) When the manipulator is on a circumferential rail

Figure 6. Schematic diagram of the manipulator structure

Legends: 1a installed tube section, 1b to-be-installed tube section, 2 steel truss, 3 temporary rail, 4 steel ring-pull, 5 manipulator, 5a roller, 5b support rod, 5c arc pressure plate, 5d elastic cushion, 6 axial rail, 7 circumferential rail, 8 roller, 9 slot, 10 temporary positioning elastomer, 11 positioning slot.

2.2. Underwater Docking Construction of Submerged Floating Tunnels

For ease of description, the end of the first half of the steel truss is called the front end, and the end of the second half the rear end. The circumferential rails in the steel truss are arranged in the order of the first, the second and the n-th circumferential rails from the side of the rear end of the steel truss toward the front end. The n refers to the number of tracks of the circumferential rails. The telescopic manipulators in pairs supported in the axial rail are arranged in the order of the first, the second and the n-th pairs from the side of the rear end of the steel truss toward the side of the front end.

As shown in Figs. 3 and 4, in the technical scheme in this paper, the auxiliary structure system of underwater docking realizes the underwater docking of submerged floating tunnels according to the following steps:

- Step 1: Use the roller in the second half of the steel truss to support the truss on the installed tube, and make the first half of the steel truss overhung at the docking end of the installed tube.
- Step 2: Insert the docking end of the to-be-installed tube from the front end of the steel truss. The first pair of telescopic manipulators stretches and clamps the to-be-installed tube. Push the to-be-installed tube and the first pair of telescopic manipulators toward the rear end of the steel truss by an external force.
- Step 3: The position sensor can collect and transmit distance data to the computer terminal. When the first pair of telescopic manipulators reaches the n-1th circumferential rail along the axial rail, the second pair of telescopic manipulators extends and clamps the to-be-installed tube. Further push the to-be-installed tube, the first and the second pairs of telescopic manipulators toward the rear end of the steel truss by an external force, until the first and the second pairs reach the positions of the first and the second circumferential rails respectively. In this way, when the n-th pair of telescopic manipulators reaches the n-th circumferential rail, the axial movement of the to-be-installed tube is completed. Make the first and the second pairs of telescopic manipulators on the first and the second circumferential rails respectively. Thus, the n-th pair of telescopic manipulators is on the n-th circumferential rail.
- Step 4: When the distance between two to-be-docked tube sections is 0.3-0.5 meters, the diver will compress the temporary positioning elastomer vertically into the steel truss and observe the situation. Use an external force to rotate the to-be-installed tube, and adjust this tube and the installed tube so that they are located at the same central angle. When the temporary positioning elastomer moves to the positioning slot, the elastic release occurs and the elastomer is fixed. At this time, remove the position sensor quickly and pull the steel truss backward by an external force, thus completing the docking construction at the docking end of the to-be-installed tube and the installed tube.
- Step 5: Withdraw all the telescopic manipulators, and use the temporary rail and the roller to move the steel truss to the to-be-installed tube. Then, continue the docking installation of the subsequent tube sections.

The above-mentioned external force can be provided by marine construction and operation equipment such as ships and machines. In the specific construction, as shown in Fig. 2, the first tube sections are docked on land after they have been prefabricated on land. At the same time, install the temporary rail and the position sensor, insert two tube sections into two steel trusses, and sink them. The two tube sections can be docked leftward or rightward according to the sinking situation, which greatly saves the construction time. The structural system of underwater tube docking in the technical scheme in this paper mainly applies to the docking of tube sections with a deviation of 20 to 50 centimeters.

After completing one docking, remove the temporary positioning elastomer on the to-be-installed tube in order to further push the steel truss by an external force. All the bolt holes and slots for temporary installation are positioned and preset on land, enabling quick installation and disassembly of the temporary installation parts.

2.3. Advantages of the Auxiliary Structure of Underwater Docking Installation of Submerged Floating Tunnels
Compared with the existing technologies, this auxiliary structure has the following beneficial effects:

- Mechanized methods are used to fix and convey tunnel tube sections according to the technical solution in this paper. They overcome the influence of weather, currents, waves and other unfavorable factors on the docking operation of submerged floating tunnels, and avoid the swinging of floating tunnel tubes and installation ships, ensuring smooth docking construction.
- The underwater docking device adopts a lightweight, easy-to-install steel truss structure, which is combined with the rails laid on the outer wall of the submerged floating tunnels. They are pulled forwards and backwards by external forces such as ship lift and mechanical force to realize two-way movement, solving the problem of difficult re-adjustment after failed docking.
- This auxiliary structure can achieve continuous propulsion and repeated use on the outer wall of a floating tunnel, greatly quickening the construction progress and reducing the construction cost.
- Position sensors are used for position detection. In combination with a setting control system, they help to automatically control the expansion of the telescopic manipulators and the rotation of the support rods and to achieve a semi-automatic operation mode of the docking process. This greatly reduces manual underwater operation, guarantees safe construction, and significantly shortens the construction period.

3. Conclusion
The technical scheme in this paper is based on the prototype of submerged floating tunnels and describes an underwater docking Auxiliary system of submerged floating tunnels and its application, in the hope of realizing the accurate underwater docking installation of submerged floating tunnels in a semi-automatic mode. The technical scheme can also be applied to the docking construction of long and slender structures such as underwater immersed tube tunnels, offshore oil and natural gas pipelines, and so on.

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