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A Novel Marine Organism Trap for Important Plant Water Systems in Nuclear Power Plants

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Abstract

As a safety-grade filtration device within the Important plant water systems of nuclear power stations, the marine organism trap bears the vital responsibility of ensuring reactor heat removal. Any blockage would trigger unit fault signals, leading to shutdown and loss of the safety-grade heat trap, with severe consequences. This paper introduces a novel multi-cartridge marine organism trap featuring planetary gear self-cleaning capability. It outlines the structure, operating principle, and design methodology, determining inlet/outlet pipe diameters, cartridge parameters, and filter area based on design specifications. This innovative filter offers reference for selecting and designing filters within Important plant water systems for nuclear power plants.

Keywords

Self-cleaning, seawater system, cleaning device, filter.

1. Introduction

China's nuclear power sector is currently undergoing rapid development, with over 80 operational and under-construction nuclear power plant. All nuclear power plants are located in coastal areas, utilizing the ocean as the ultimate heat sink. Consequently, the quality of seawater supplied to downstream heat exchange equipment directly impacts the safety and stability of nuclear power plants. However, as human activities intensify, the marine environment continues to deteriorate. In recent years, incidents of nuclear units experiencing power reductions, shutdowns, or reactor halts due to seawater intake blockages caused by marine organisms have become frequent[1-2],severely undermining confidence in nuclear power as China's baseload energy source.According to statistics from the National Nuclear Safety Administration, between 2015 and 2023, domestic operating nuclear power plants experienced a total of 31 cold source incidents caused by intake blockages due to marine organisms, floating debris, and sediment accumulation. Cold source intake has thus become a major hidden hazard affecting nuclear safety[3].

In order to reduce the occurrence of nuclear power cold source water intake clogging events, cold source water intake system is equipped with multiple interception and filtration facilities, the sea life trap is one of the key filtration equipment used to filter the important plant water system (SEC) water intake pipe breeding sea organisms, for RRI/SEC plate heat exchanger to provide cleaner seawater to bring out the heat of the nuclear island equipment, and its filtration performance has a direct impact on the economics of the nuclear power plant, Its filtering performance directly affects the economy, reliability and safety of the nuclear power plant, and needs to be paid attention to.

At present, all the marine organism trap in China's nuclear power units in operation and under construction are supplied by foreign manufacturers such as Germany Daji, Alfa Laval and EIMCO, and it is impossible to realise the localization of the products. At the same time, the traditional spherical sea life traps have not undergone significant technological changes in recent decades, and the related product technology capability has been difficult to meet the requirements of the new situation of the cold source. In this context, this paper designs a new type of sea life trap with planetary wheel multi-cartridge innovative structure, which can effectively solve the two key limiting problems of small overflow area and slow cleaning speed of the sea life trap under the current arrangement conditions, and change the status quo of nuclear power seawater filtration equipment supply which has been restricted by others for a long time.

2. Structure and Working Principle of a New Type of Sea Life Trap

2.1. Structure Composition

The new marine organism trap is mainly composed of a gear motor, housing assembly, filter element assembly, mechanical rotating brush, water distribution disc and planetary wheel drive system, etc. The specific structure is shown in Figure 1.

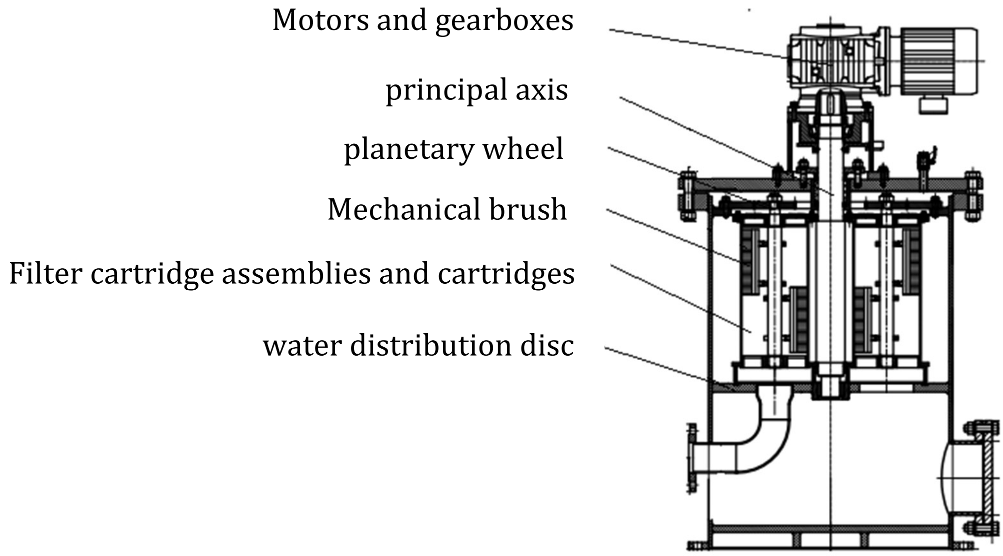

Figure 1. Sketch of the shape of the new type of sea life trap

This new multi-cartridge structure design can reduce the height of the equipment as much as possible in the limited space, greatly increase the filtering area of the screen, and enhance the overflow capacity of the equipment. Moreover, the number of cylindrical filter cartridges and the spacing between adjacent cylindrical filter cartridges can be adjusted according to the actual needs, in order to obtain the ideal filtration effect.Not only that, unlike the traditional spherical marine organism Traps for important plant water systems in land-based nuclear power plants, which use a partial backwashing method in which the backwashing rotor rotates around the filter screen for one week, the present design adopts a full-cylinder backwashing method in which the mechanical rotating brush is physically coupled, which can instantly complete the backwashing operation of a filter cylinder, greatly improving the backwashing efficiency and dirt-collecting effect of the equipment.

2.2. Working Principle

2.2.1. Filtration

The new type of marine life trap adopts a multi-cartridge structure, each cartridge is a separate water filtration unit. When working, when the seawater from the inlet into the filter, through the distribution disc distribution to the water filtration unit, filtered clean seawater through the

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filter mesh into the cavity of the cylinder from the outlet out. In this process than the filter mesh pore size of the sediment and sea life will be intercepted in the inner wall of the filter cylinder waiting to be cleaned.

2.2.2. Backwash Cleaning

The new type of marine organisms trap is equipped with three operation modes: timed backwashing, differential pressure backwashing and manual backwashing, and the frequency of backwashing can be adjusted appropriately according to the operational needs of the system. In the backwash condition, the reducer will drive the main shaft to rotate, relying on the planetary wheel drive structure (Figure 2) nested in the main shaft of the filter cartridge in the sun wheel drive in turn to the front of the sewage platform and the sewage outlet to form a closed sewage space, at this time, part of the seawater will be in the pressure difference under the effect of the outer surface of the sewage cartridges into the inner surface of the sewage cartridge for the whole cartridge to be flushed. At the same time, the mechanical rotating brush inside the cylinder during the sewage process will also be driven by the planetary wheel gears to mechanically scrape the wall of the cylinder, and physically strip the plastic, cloth, rope and other impurities that are not easy to be excluded from the mesh adhering to the mesh.

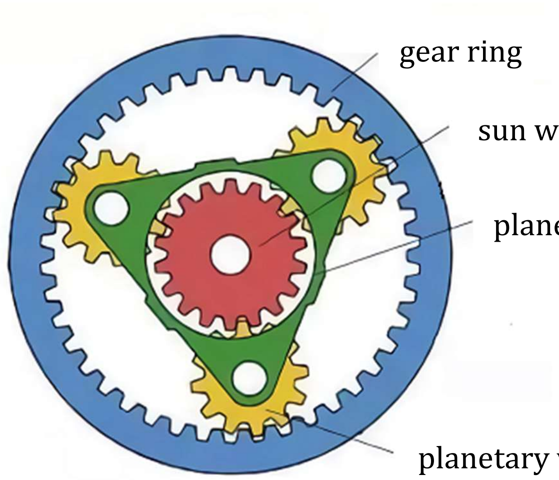

Figure 2. Planetary wheel drive structure

3. Design of a New Type of Marine Organism Trap

3.1. Main Technical Parameters

Taking a nuclear power seawater system as an example, the main design parameters of the innovatively designed new type of sea life trap are as follows: design flow rate of $750m^3/h$, design pressure of 0.88MPa.a, design temperature of 50℃, and filtration precision of 2mm.

3.2. Inlet and Outlet Pipe Diameter Design

The flow rate V1 of the new type of marine organism trap introduced in this paper is selected according to the flow rate of the pipeline, which is usually in the range of 2-3m/s, and the inlet and outlet pipe diameters are obtained according to equation (1).

$$D_i = 0.0188\sqrt{\frac{Q}{v_1}} \tag{1}$$

Where Q is the design flow rate of $750m^3/h$. According to the calculation, the inlet and outlet pipe diameters of the new type of marine organism trap are taken as DN300.

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3.3. Filter Cartridge Sizing and Design

Due to the limitation of layout space, the new type of seabed trap introduced in this paper adopts a multi-cartridge structure design. The new type of seabed trap is equipped with three cartridges, which are uniformly distributed at 120° in the water distribution tray. During normal operation, one of the cartridges and the sewage platform form a closed sewage space for backup, and when the backwash operation is performed, the remaining cartridges are turned to the sewage platform to perform the cleaning operation under the drive of the sun wheel structure. Therefore, the number of effective cartridges in normal operation is 2, and the height of the cartridges is set to H=500mm.

The inlet and outlet pass area of the filter can be calculated according to equation (2):

$$\text{Filter inlet and outlet pass area}=\frac{\pi D_i^2}{4} \quad (2)$$

The area of the inlet and outlet passages of the filter is 77812.43 mm2.

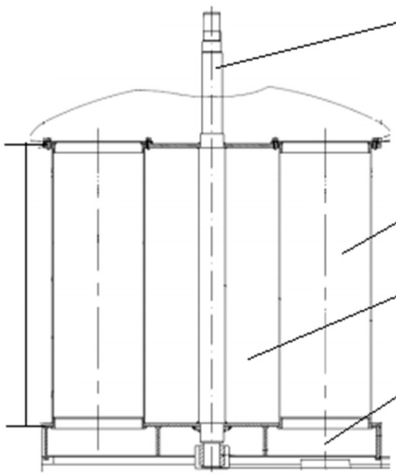

Figure 3. Schematic diagram of multi-cartridge structure

In order to reduce the operating pressure drop of the equipment, the area of the filter inlet and outlet passages is recommended to be less than or equal to the area of the suction port of the water distribution disc, so the diameter of the filter cartridge can be calculated according to equation (3):

$$\text{Filter inlet and outlet pass area}\leq n\times\frac{\pi d^2}{4} \quad (3)$$

Where n is the effective number of filter cartridges, n=2. So the diameter of filter cartridge d is DN200.

3.4. Filter Selection and Design

The strainer is a 60° orifice plate structure strainer to reduce the attachment of sea life.

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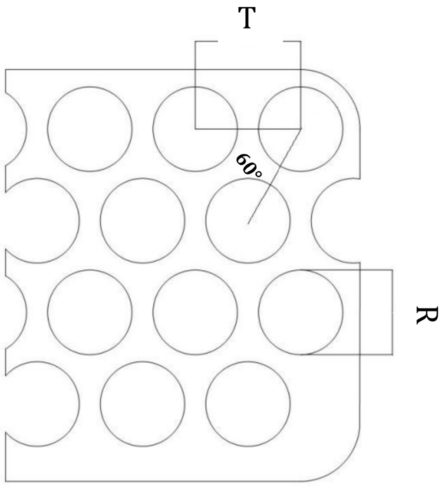

Figure 4. Orifice plate cartridge structure

The orifice plate opening rate is calculated according to equation (4):

$$K = \frac{R^2 \times 90.69}{T^2} \tag{4}$$

Where K is the opening rate of the orifice plate; R is the diameter of the orifice plate, R=2mm; T is the spacing of the holes, T=3mm. then the opening rate of the new type of marine organisms trap introduced in this paper is 40.31%.

The effective cartridge area of the filter can be calculated according to equations (5) and (6):

$$S_1 = n \times S \tag{5}$$

Where S_1 is the total effective cartridge area of the filter, n is the number of effective cartridges, n=2; S is the effective filtration area of a single cartridge, which is calculated as shown in equation (6).

$$S = S_2 \times K \tag{6}$$

Where S_2 is the area of the side wall of a single filter cartridge; K is the opening rate of the orifice plate, and according to the above calculations, K is 40.31%.

The effective cartridge area of the filter S1=2πdHK=267939.83mm2.

Then the flow ratio of the filter = effective cartridge area of the filter/inlet/outlet diameter area of the filter = 267939.83/77812.43=3.44

In summary, the new type of sea life trap introduced in this paper is able to meet the requirement that the effective filtration area of the filter should be not less than three times the area of the inlet and outlet passages[4].

4. Conclusion

Marine organism trap are key filtration equipment in the important plant water system of a nuclear power plant, which can effectively filter out sediment and the growing seafood in the system piping.In this paper, the innovatively designed new type of marine organism trap adopts

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the planetary wheel multi-cartridge structure and the backwashing and discharging method of full-cartridge flushing, which can greatly improve the overflow capacity and cleaning efficiency of the equipment in the limited space compared with the traditional spherical sea life trap, effectively reduce the probability of the occurrence of the blockage event of the water intake from the cold source and safeguard the normal and stable operation of the nuclear power unit in the long term.

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