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Effect of materials on the noise of a water hydraulic pump used in submersible

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ABSTRACT

Open-circle sea water hydraulics, utilizing surrounding water as a working medium, has become more and more popular in submersible. Axial piston pump with port valves is used frequently in the open-circle water hydraulic system. Port valve is one of the important parts in this type pump. However, there are few literatures about the effect of the port valves' materials on the noise characteristic of the water pump. In this study, the effect of materials on the noise of the pump was researched through experimental and theory simulation methods. The influences of three kinds of plastics (Polyetheretherketone (PEEK), Polytetrafluoroethylene (PTFE), Aliphatic polyamides (NYLON)) and one kind of anti-corrosion stainless steel (316 L) are compared. The noise of the pump with the different materials port valve seat ranges from high to low as the order: 316 L > NYLON > PEEK > PTFE. The differences would contribute to the collision between valve spool and seat, which is identified by the simulating results. The experimental results showed that the difference of noise between PEEK and PTFE is small. In addition, the lifespan and volumetric efficiency are also taken into considering. The PEEK is selected to use in the seawater pump for a large submersible.

1. Introduction

In recent years, water hydraulics, which utilizes water as the working pressure medium instead of traditional mineral oil, has become more and more popular owing to several advantages such as environmental friendliness, low operating cost, cleanliness and easy disposal (Lim et al., 2003; Wang and Gao, 2013). Especially, sea water hydraulics is very feasible to underwater apparatuses. Because it utilizes the surrounding water freely as working medium and discharges drainage to the open surroundings. This open-circuit type system is simple, without the return line and reservoir. The simplification not only improves the power density, but also vanishes the risk of penetrating water in the traditional oil system and inducing some breakdown. The water hydraulic variable buoyancy system (WHVBS) is a typical application of water hydraulic in submersible. The WHVBS adjusts the weight and pitch angle of the submersible by a pump to transmit the water between the ballast and surroundings and has become more and more popular in submersible (Liu et al., 2015; Tangirala and Dzielski, 2007; Walden and Brown, 2004; Wang et al., 2015; Zhong-liang, 2008). The variable buoyancy system is an important part of advancing underwater vehicle capabilities. The advances include: lower operating cost and energy consumption; increased mission duration and range; increased payload capacity; simplified pre-dive maintenance; improved maneuvering and vehicle control; and reduced noise emissions at hovering condition (Font and García-Peláez, 2013; Jensen, 2010; Zhao et al., 2016).

The water hydraulic pump is one of the key components in such open-circuit system. The natural water medium suspends much silt. Appropriate structure of the pump is in favor of improving its three-body abrasion resistance. In traditional oil system, gear and vane pumps are widely used. However, the two structures are unsuitable to the high pressure water pump. Since the high contacting stress of gear and vane pairs and the poor lubrication of water would induce serious abrasion. In addition, the less seal area of gear and vane would leak a great deal of working medium due to the low viscosity of water. Thus, piston pump is more feasible to the water hydraulics due to its low contacting stress and well seal.

Furthermore, water hydraulic axial piston pump with port valves (PV-water pump) is more suitable in the silt-laden water due to its better abrasion resistance structure. The major tribopairs in this type pump do not rely on the lubrication properties of the pumped fluid for their operation, and of being relatively insensitive to fluid contamination. In the PV-water pump, each piston has two corresponding port valves: the inflow valve and the discharge one. The inflow valve is

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closed and the discharge valve is opened when the piston chamber is enlarged; the inflow valve is opened and the discharge valve is closed when the piston chamber is diminished. The pistons are held against the swash plate through the slipper pad and driven by the shaft. During this motion, the piston chamber is periodically enlarged and diminished and then the fluid is ported in and out of the pump.

Compared to PV-water pump, the water hydraulic axial piston pump with a port plate (PP-water pump) distributes the flow by the port plate instead of the port value. This type pump is commonly used in water hydraulic system onshore due to its compact structure (Ivantysyn and Ivantysynova, 2001). However, this type water pump is required to work in clean water (the water must be filtered through a 10 μm absolute filter with a β10-value > 5000 or better). In fact, it is very difficult to filter finely for the open-circle water hydraulic system. Because silt laden in natural water is numberless and fine (Wu et al., 2016). In this serious operating condition, the PV-water pump has irreplaceable advantages, such as abrasion resistances and the sealing ability. The numbers of tribopair in PV-water pump lubricated under silt-laden water is decreased when driven chamber is separated from the piston chamber by a seal ring. The principles of solid abrasion in the two type water pump by the silt suspending in natural water are showed in Fig. 1.

In PV-water pump, port valves are the key parts that control the inlet and outlet flow and have a great influence on the total characteristics of the pump such as noise, volumetric efficiency, and life span. And there are some researches about the flow and cavitation characteristics of the valves and orifices when using water as the working media. Johnston et al. (1991) researched on the non-cavitating conditions of a wide variety of poppet and disc valves when operating under steady flow and turbulent flow. Oshima et al. (2001) also researched the flow characteristics of poppet valves using water as the working media by half-cut model. Liu et al. (2006) also once carried out experiments on the flow characteristics of poppet valves and orifices when using water as the working media. Leino et al. (2005) studied the flow characteristics of a water hydraulic seat valve, in which the cavitation had been investigated visually and the sound pressure had been detected outside the valve.

To research the dynamic response of port valve, Liu et al. (2009) studied on the port valve's lag phenomenon caused by the dead volume between piston and port valve, poppet mass and spring stiffness, and its influences on the flow characteristics at different pressure and rotational speed. He et al. (2011) studied the influences of port valve's initial spring force on air suction characteristics of the pump. Tanaka, found that pressure and flow rate fluctuations occur due to oscillating cavitation or water column separation at rapid transient operations of the port valve (Tanaka and Tsukamoto, 1999). These researchers mainly concern on the geometric parameters of the port valve.

However, there are few researches on the effect of materials of the port valve on the performance of the pump. In fact, the different materials may influence the noise, efficiency, and lifespan of the pump. In general, there are two kinds of materials used in port valves: one is soft material such as engineering plastic which is easy to machine, excellent in sealing performance, but unsuited for applications in high-pressure situation because of low strength and rigidity; the other is metal material, which has high strength, but demands higher manufacturing precision in order to ensure sealing performance.

Thus, this paper is aimed to research the influence of different port valves' materials on the noise of the pump. In addition, the effect of materials on volumetric efficiency and life span of the port valve is also taken in considering for material selection by experimental results. Then, one material is selected to manufacture the port valve seat of a PV-water pump, which is used to adjusting a large autonomous underwater vehicle (AUV).

2. Structures and materials of port valves

2.1. The structures of pump and port valve

In the natural water, there are numbers of silt suspending in water. The contamination levels adhere to the ISO4406 standard, which defined by three numbers divided by slashes. The numbers correspond to 4, 6 and 14 μm particle. The contamination level of natural silt-laden seawater is 25/23/18, exceeding the allowable contamination level of a traditional hydraulic system using mineral oil as the working medium.

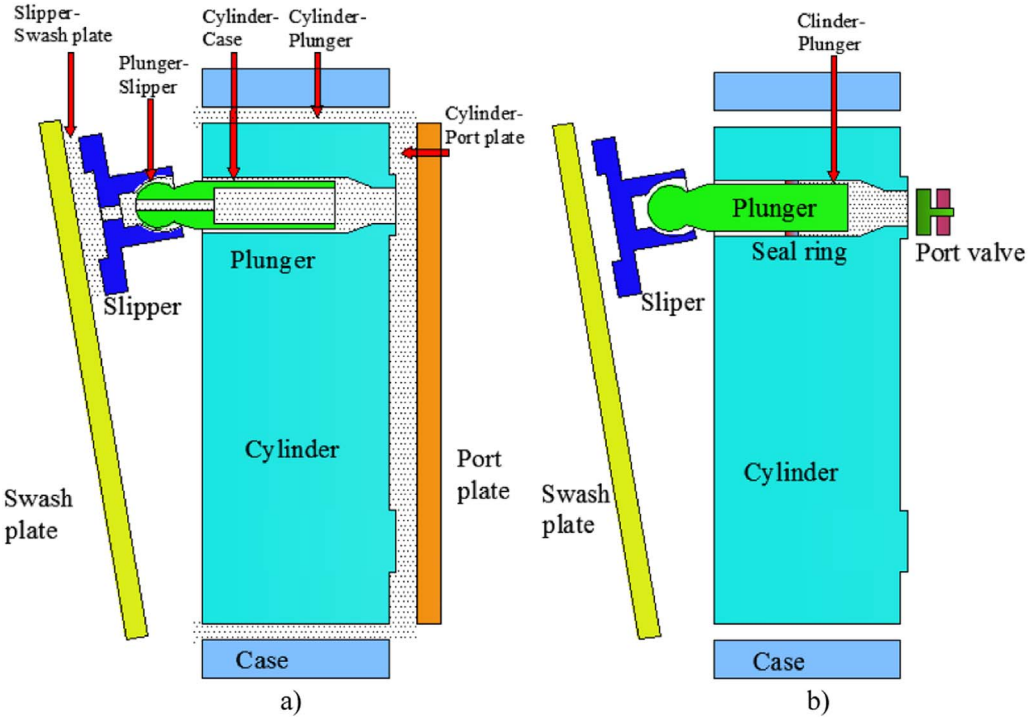

Fig. 1. The principles of abrasion wear in water pump by silt suspended in natural water: a) PP-water pump; b) PV-water pump.