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A transmissibility-based approach to identifying the dynamic behavior of a seawater hydraulic piston pump under pressure excitation

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ABSTRACT

An investigation into the dynamic behavior of the piston pump is an important method to reduce its vibration and noise. In this paper, an approach to predict the dynamics of a seawater hydraulic piston pump (SWHPP) from output-only transmissibility measurements is introduced. In order to eliminate the harmonic interference generated by spindle rotation, the excitation in this method is the pressure which caused by the SWHPP operating at a constant speed and under different loading conditions. The first four modes of the SWHPP were estimated utilizing the method proposed in this paper, and the influence of the pressure on the dynamics of the SWHPP structure was further studied. The experimental results indicated that peak occurred around the frequency of 20 Hz, and the reason is that the estimated second-order natural frequency (19.8 Hz) is near to the frequency of 20 Hz which is the excitation frequency of the swash plate and the flat valve of the SWHPP. In addition, this method can identify modal parameters of the piston pump structure in the working state, so it can effectively predict the dynamic behaviors of the piston pump.

1. Introduction

Owing to high working pressure and high volumetric efficiency, the piston pump is widely used to adjust buoyancy in submarines and autonomous underwater vehicles (AUVs). However, the vibration and noise generated by the piston pump will not only interfere with the concealment of the submarine and AUVs, but also be one of the main factors that cause the mechanical failure, which has great influence on the personal and property safety. With the advancement of submarines and AUVs, the vibration and noise control of piston pump must be investigated (Xu et al., 2016).

The research on piston pump vibration and noise control has gotten more attention in recent years. Pettersson et al. (1991) described the mechanism of vibration and noise generation in piston pumps, and the vibration of piston pump can be divided into the fluid vibration and the mechanical vibration (Quan et al., 2016). Palmen (2004) found that the vibration and noise of piston pump could be reduced by optimizing the pump housing. Wu et al. (2017) discovered that the port valves' materials have an effect on the noise of water hydraulic pump through experimental and theory simulation methods. However, other scholars have proven that the fluid-born noise generated in the pump also contributes significantly to its dynamic (Pettersson et al., 1991; Ericson, 2005). But, fluid vibration and mechanical vibration coexist within the actual working process of the piston pump (Xu et al., 2015). In general, in order to reveal the dynamic behaviors of the piston pump effectively, it needs to extract the vibration modes (such as natural frequencies, damping coefficients and mode shapes) from measured data at pump operation. Therefore, it is of great significance to analyze the dynamic behavior of the piston pump structure under the working conditions.

In the last few decades, modal analysis has become a key technology in structural dynamics analysis (Maia and Silva, 1997; Peeters et al., 2004). There are three methods to identify the dynamic parameters of the piston pump. The first method is computational modal analysis. Palmen (2004) used computational modal analysis to estimate the dynamic behavior of the piston pump shell. Due to the complex structure of the piston pump, this method can not accurately predict the dynamic parameters of the piston pump. The second method is experimental modal analysis (EMA), and EMA usually measures input forces and output responses using artificial excitation (Menon and Zhao, 2005). Xu et al. (2016) used EMA method to optimize the piston pump housing, and the experiment results indicated that the vibration and noise of the optimized piston pump were reduced significantly. Minette et al. (2016) estimated the modal parameters of an electrical submersible pump using the EMA technique, and results showed that the identified natural frequencies

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were within the operational frequency range. However, the EMA can only be applied in the stationary state of the pump. Therefore, this is the disadvantage of using EMA to identify the modal parameters of piston pump. But, the modal parameters identified in the stationary state might be different with those measured in the actual operating condition. Wang et al. (2012) found that the torsional natural frequency of pump system shifts with changed with the load condition. Therefore, the modal parameters of the piston pump in the working state should be considered. The third method is operational modal analysis (OMA), and OMA has been developed to predict the modal parameters from the structure under its operational conditions (Lardies and Larbi, 2001a, 2001b; Parloo et al., 2002; Cauberghe et al., 2003). Thus, the aforementioned disadvantage exists in EMA, but it will not appear in OMA. However, the classical OMA method can be applied under the assumption that the input forces are white noise. This requirement is not met for the piston pump because the piston pump structures contain rotating parts (e.g. crankshaft, swash plate and bearing), and the harmonic interferences will be present in the response during the working process of the piston pump. The classical OMA techniques may encounter difficulties to correctly identify the modal parameters of the piston pump (Mohanty and Rixen, 2004). Carden and Lindblad (2015) demonstrated the use of OMA to identify torsional modes on a water pump. However, it needs to measure the speed of shafts in the method. This will increase the settings and the cost of the experiment.

In order to effectively identify the modal parameters of piston pump under operating condition, a recently developed modal analysis technique will be studied: transmissibility based operational modal analysis (TOMA) (Devriendt, 2010). The advantage of the TOMA technique is that it does not rely on the presupposition that the input excitations must be white noise signals (Devriendt et al., 2009), so this method can be used in the applications that the input signals contain harmonic excitation components. Devriendt and Guillaume (2007) used the TOMA technique to estimate modal parameters of a beam which the excitation acting on the beam is a multi-sine excitation. Since the conditions of a laboratory forced-vibration test are always significantly different from the actual working conditions. There are few literature to estimate the dynamic parameters of the piston pump using this method. Therefore, the dynamic behaviors of the piston pump under operating conditions need further study.

In this paper, a transmissibility-based method to predict the modal parameters of piston pump under pressure excitation was developed, and experiments were carried out for identifying the dynamic behavior of a SWHPP. Besides, the influence of the pressure on the dynamics of the piston pump was studied.

2. Excitation force of the SWHPP

This section detailed the working principle of experimental system, and the excitation source and its corresponding excitation frequency of the SWHPP were analyzed.

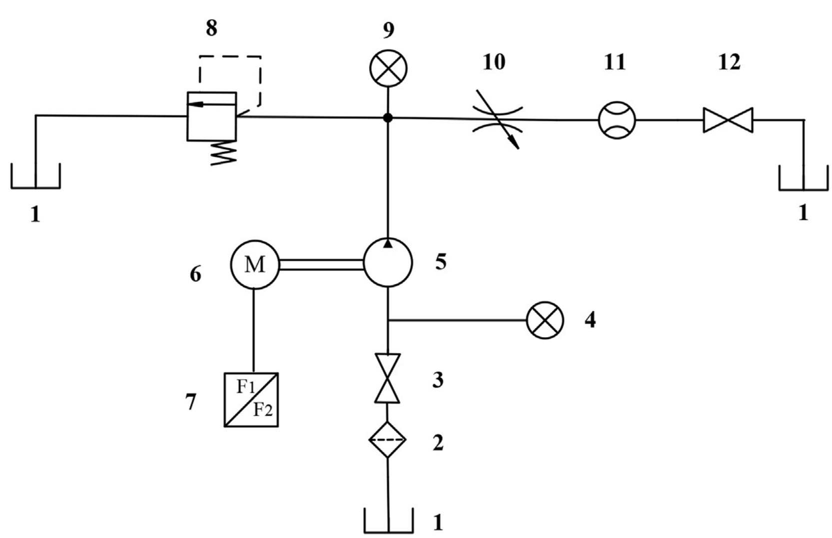
2.1. The working principle of experimental system

Fig. 1 details the working principle of experimental system. The SWHPP 5 is driven by variable-frequency motor 6 to realize the process of absorbing and draining water. The discharge pressure of the SWHPP 5 is adjusted with the hole size of throttle valve 10 in this experiment. The discharge pressure can be measured by pressure gauge 9. The speed of variable-frequency motor 6 can be to maintain constant by adjusting the frequency of the variable-frequency power source 7.

All tests in the current paper are carried out on a SWHPP: The configurations of the SWHPP as shown in Fig. 2. The SWHPP is made up of end cover, oriented ring, pump casing, cylinder block, outlet port, valve port, inlet port, base plate, crankshaft, bearing, swash plate, piston and flat valve. The pump with this structure has the characteristics of high pressure, large flow and low noise (Luo et al., 2015; Zhang et al., 2016a, 2016b). The main parameters of the pump in this paper are listed in Table 1.

2.2. Excitation of the SWHPP

The SWHPP is an axial piston pump, and the excitation source and its



1-water tank, 2-filter, 3 12-shutoff valve, 4-vacuum gauge, 5-SWHPP, 6-variable-frequency motor,

7-variable-frequency power source, 8-relief valve, 9-pressure gauge, 10-throttle valve, 11-flow-

transmitter

Fig. 1. The working principle of experimental system.

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