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Experimental investigation on the noise reduction of an axial piston pump using free-layer damping material treatment

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ABSTRACT

Discrete-frequency tones at integral multiple of the pumping frequency are often the main contributor to the noise of axial piston pumps. It is an effective method to reduce the noise by suppressing the discrete-frequency tones. In this study, the most dominant discrete-frequency tone of an axial piston pump was suppressed using free-layer visco-elastic damping material treatment. The noise and vibrations of the axial piston pump were experimentally measured and analyzed at several steady-state operating conditions. Dramatic reductions in the noise and vibrations were found. In particular, the noise and vibrations at the 2nd harmonic at the rated speed of 1500 r/min were significantly reduced. An experimental modal analysis (EMA) was conducted to identify the cause of the reductions in the discrete-frequency tone. The EMA result showed that one prominent natural frequency around 457.8 Hz of the untreated pump increased to around 484.5 Hz of the treated pump. The increase of the prominent natural frequency contributed greatly to the decrease of the modal displacement, leading to the reductions in the vibration and noise. The study shows the feasibility of using the free-layer visco-elastic damping material for potential applications of reducing the vibration and noise of hydraulic displacement pumps.

1. Introduction

Nowadays, axial piston pumps with high power density and convenient controllability play a pivotal role in modern hydraulic fluid power systems such as press and ships. However, their applications have been limited by serious noise and vibration as the operating conditions get harder (i.e. higher pressure and displacements). Decreasing the noise and vibration level of hydraulic displacement pumps is highly demanded in these applications [1–4]. The noise signature for an axial piston pump includes a broad-band noise level with large tones at integral multiple of the pumping frequency. These discrete-frequency tones generated by the periodic pumping dynamics are often predominant, and these tones are often considered to be the main cause of annoyance owing to their periodic nature [5–8].

Many researches proposed different active and passive methods to reduce the noise and vibration which include actively decreasing the strengths and passively isolating the effects of excitation sources respectively. The cross-angle design of piston pumps was proposed to reduce the sensitivity of excitation sources to shaft rotational speed. The effects of cross-angle on the excitation sources, vibrations and noise were numerically and experimentally analyzed. Their results showed the effectiveness of cross-angle in reducing the structural vibrations, flow pulsations and noise [9–11]. A parametric analysis was conducted to analyze the effects of length, width and depth of grooves in the valve plate on the pressure ripple of an axial piston pump, and the pumping dynamics were optimized by modifying these parameters to smooth the piston pressure transient [12]. An optimization method based on genetic algorithm was proposed to optimize the valve plate structural parameters, and the experimental results showed that the overall noise levels were reduced using the optimized valve plate [13]. A design criterion of the spline of the cylinder block was proposed to enhance the performance of axial piston pumps [14]. The pumping dynamics were also actively controlled using a reversing valve with two different types of control algorithms, and the measurements showed that the noise levels were reduced by about 2 dB(A) [15]. Active control system and algorithms were proposed to reduce the vibration of swash plate [16].

Another effective method in controlling the vibration and noise of machinery is to optimize the transmission characteristics so as to isolate

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the influence from excitation sources. The noise level of centrifugal fan was demonstrated to be high at the blade passing frequency and its harmonic frequencies [17,18]. Hence, Open metal foam was used to passively reduce the centrifugal fan noise [19,20]. The effects of different types of metal foam on the aerodynamic performance and noise level of the centrifugal fan were experimentally investigated. Their findings showed that the tonal and broad-band noise can be effectively reduced by about 5 dB(A) using open metal foam. The sound quality of a diesel engine was improved by optimization of the block structure [21–23]. In their study, a numerical approach was first employed to model the noise emission of the engine, and then the block was optimized to reduce the simulated noise. Finally, the sound quality of the engine using the original and optimized blocks was experimentally evaluated. The vibration and noise of axial piston pumps can be effectively reduced by optimizing the housing structure [5,24]. In the study, the amplitudes of the frequency response functions of the housing were reduced by optimizing the housing with topology optimization method [5]. Ribs were added in the strong vibrating position [24]. The measured noise and vibrations were decreased at a wide range of discharge pressures.

In recent years, the visco-elastic damping treatment as a cost-effective method has been widely used to reduce the vibration and noise level of automobiles, commercial airplanes and other industrial machinery [25–27]. Damping materials can be divided into two categories, the free-layer and constrained layer damping. The free-layer damping treatment is to attach the visco-elastic damping material directly to the base structure. While the constrained layer damping treatment is to place the damping material between the base structure and the constrained structure.

The effects of visco-elastic damping materials on the dynamics of an open three-dimensional aluminum box were numerically and experimentally investigated [28]. The effects of discrete damping elements and constrained layer configurations on the modal parameters and frequency response functions were compared, and their results indicated that partially covering the box with constrained layer dampers was more effective than full coverage of the structure with the same mass addition. Three types of visco-elastic damping materials, including the bitumen-based, water-based and butyl rubber damping materials were used in the sleeper carriages to reduce the interior vibration and noise in a railway vehicle [29]. Moreover, two kinds of wheels, including resilient wheel and wheel with constrained layer damping treatment, were developed to decrease the rolling noise [30]. In automobile industry, squeal of brake system has been one of the most concerns [31], and additional damping was applied to reduce the occurrence of disc brake squeal noise [32]. For thin walled parts with visco-elastic materials in aircraft applications, vibration energy was efficiently dissipated to reduce the cabin noise [33].

Although the visco-elastic damping materials have been widely used in the fields mentioned above, their applications in reducing the vibration and noise of hydraulic displacement machines were rarely reported. Toward this end, this paper investigates the feasibility of reducing the vibration and noise of an axial piston pump using water-based visco-elastic damping material. The paper is organized as follows. The experimental details of the measurement are described in Section 2. The noise and vibrations of the axial piston pump are measured, analyzed and compared at a wide range of discharge pressures, and the effectiveness of the free-layer visco-elastic damping material treatment on reducing the discrete-frequency tone is shown in Section 3. A modal experiment is carried out to identify the cause in Section 4. The conclusion is given in Section 5.

2. Experiments

2.1. Free-layer damping material treatment

In the present study, a swash plate axial piston type variable displacement pump utilizing nine pistons was employed. The rated discharge pressure of the axial piston pump is 35 MPa, the rated rotational speed is 1500 r/min, and the maximum displacement is 40 cm^3/r.

The water-based visco-elastic vibration damping compound was used here. The damping material was prepared on the external surface of the axial piston pump using brush. The damping material has excellent adhesion to both cast iron and aluminum. The density of the damping material is about 1.8×10^3 kg/m^3. The thickness of the free-layer damping material on the pump was approximately 3 mm, resulting in an increase of the pump mass of approximately 0.3 kg. The service temperature range of the damping material is from −40 °C to 120 °C. Therefore, the damping material can be used in this application because the temperature in the pump surface is often lower than 100 °C under normal operating conditions.

Three procedures are required to attach the visco-elastic damping material firmly and reliably to the pump surface. First, the external surface of the pump was cleaned with acetones to remove the oil, rust, dust, dirt, grease, mould-release agent, etc. Second, the visco-elastic damping material was applied on the external surface of the pump using a thick nylon bristle brush. During this process, the damping material should be well-distributed. Last, the treated pump was placed in the room to allow the damping material to dry naturally. The damping material was completely dry after around 72 h at a room temperature of approximately 35 °C.

2.2. Experimental test rig

The experimental test rig is shown in Fig. 1. The sizes of the length, width and height of the test room were around 6 m, 4 m and 5 m, respectively. The hydraulic station was placed in the center of the test room. Sound-absorbing materials were used to reduce the noise reflection from the rigid concrete walls. A sound-absorbing cover was employed to insulate the noise emitted from the electric motor and the shaft coupling.

The schematic of the hydraulic system is shown in Fig. 2, and the detailed descriptions of each main component are listed in Table 1. An inverter-fed motor was used to drive the test pump. The outlet pressure was adjusted by a pressure relief valve. The maximum relief pressure was 35 MPa. The output flow rate was measured by a flow meter.

Vibro-acoustics acquisition system included the data acquisition pad (type LAN-XI 3050, Brüel & Kjær), microphone (type 4189-A-021, Brüel & Kjær), and piezoelectric accelerometers (type 4507-B-001, Brüel & Kjær). The accelerometers were attached to the external surface of the pump by 502 Super Glue, and the microphone was placed in front of the pump with a distance of 1 m from the center of the test pump. FFT analyzer was used to obtain the auto spectrum of the measured signal.

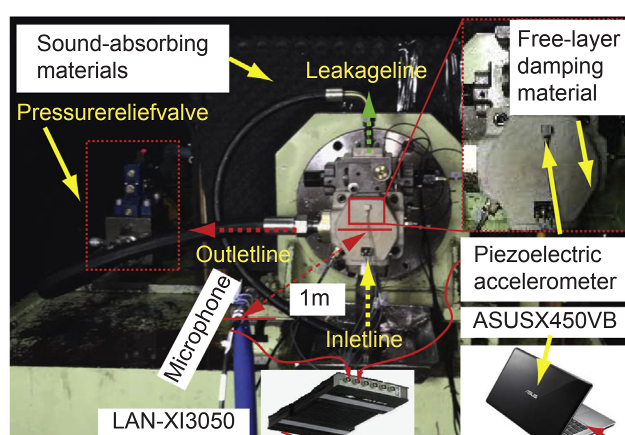

Fig. 1. Layout of the experimental test rig.