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Measurement of Flow Ripple in Positive Displacement pumps (Effect of Approximation Model of Discharge passage in Pump)

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Abstract. The source flow and the source impedance in a hydraulic pump are characteristic values showing fluid-borne vibration characteristics decisively. These values can not be measured directly, but can be measured using the 2P2S(2 pressure and 2 system) method. In the 2P2S method, the length of discharge passageway of pumps to be tested is most important to get accurate flow ripple measuring. In this study, authors suggest a procedure to evaluate the length of discharge passageway of pumps using an analyzing method of pressure wave transfer characteristics in pipes. The effectiveness of a proposed evaluation procedure was proved by experimental results.

Keywords: Flow Ripple, Pressure Ripple, Fluid-borne Noise

1. INTRODUCTION

All positive displacement pumps produce a flow ripple which is superimposed on the mean flow rate. The flow ripple interacts with the characteristics of the pipe circuit in a complex manner to produce a pressure ripple. The flow ripple in positive displacement pumps is characterized with (1) source flow ripple: Q_S and (2) internal impedance of pump: Z_S, defined based on Norton equivalent model(shunt impedance model in electric circuit). Both Q_S and Z_S are physical values which can't be measured directly.

Researches on indirect measurement of Q_S and Z_S have been undertaken by measuring the pressure signals in the pipe which is connected to a pump to be tested[1-6]. The "secondary source" method[5,6] for measuring Q_S and Z_S depicted in Fig. 1 is a representative research outcome of the works[1-6], and the principal concept of the method had been applied to enact ISO 10767-1. Also, a test method for Q_S and Z_S, called "2 pressures & 2 systems" (shortly "2P2S") had been suggested[7-8] The "2P2S" method provides simpler structure in the test system as shown in Fig. 2, and less possibility of error intervening due to not-requiring the information of the impedance Z_T.

In the "secondary source" method and the "2P2S" method, the discharge passage between the point of Q_S generation and the starting point of the pipe where the pump connected were approximated with equivalent pipe models shown in Fig. 3 (a) and (b).

This paper suggests a novel model described in Fig. 3 (c) for the discharge passage in the 2P2S system. In addition, the accuracy of Q_S and Z_S due to the difference of the model of the discharge passage are evaluated

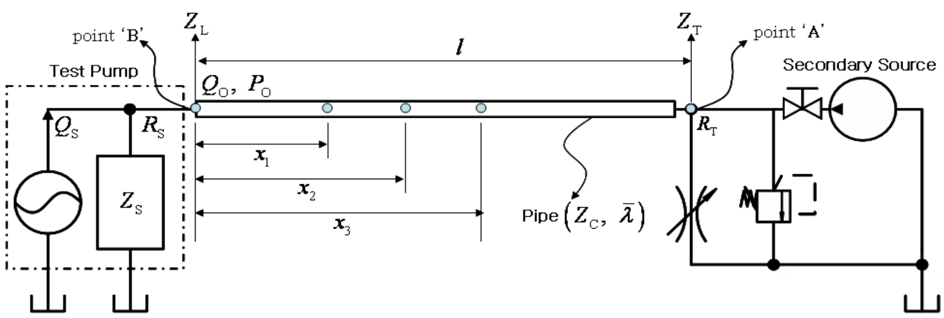


Figure 1. Test system for the "secondary source" method

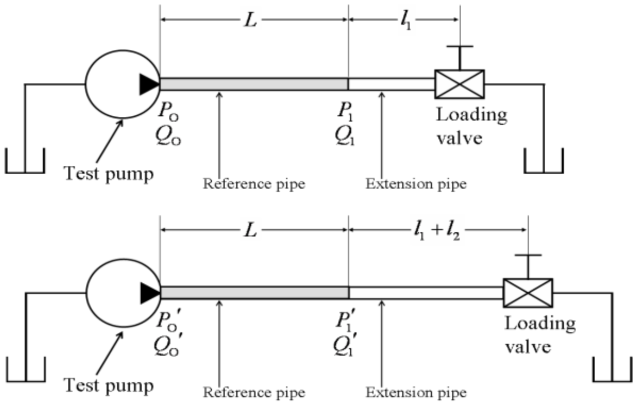
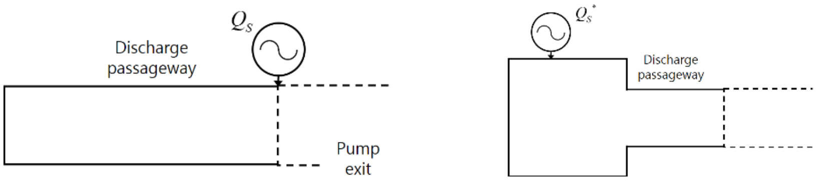
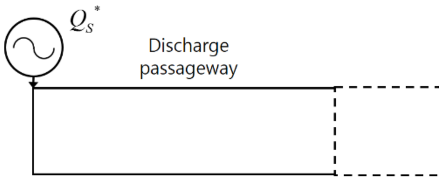


Figure 2. Test system for the “2 pressures & 2 systems” (shortly “2P2S”) method



(a) in the “secondary source” method (b) in the “2P2S” method



(c) the proposed method

Figure 3. The discharge passage in Norton equivalent model

2. A novel model for the discharge passage in the 2P2S system

The authors suggest a process to obtain an equivalent pipe model of the discharge passage in the 2P2S system. Fig. 4 shows the schematic of the preliminary test system applied to an axial piston type hydraulic pump to obtain an equivalent pipe model of the discharge passage. #1 position in Fig. 4 is allocated to the nearest position in the valve plate from the bottom dead center(BDC) where the cylinders starts the delivery stroke. Fig. 5 shows the equivalent hydraulic circuit of the system obtained by approximating the discharge passage(between #1 and #2 position) in Fig. 4 as a pipe element.

In a preliminary test using the anti-resonance method[9], the wave speed c in the test pipe 2(l_2 part in Fig. 5) was measured to be 1350 m/s. In the pipe shown in Fig. 5, the following equation is applicable.

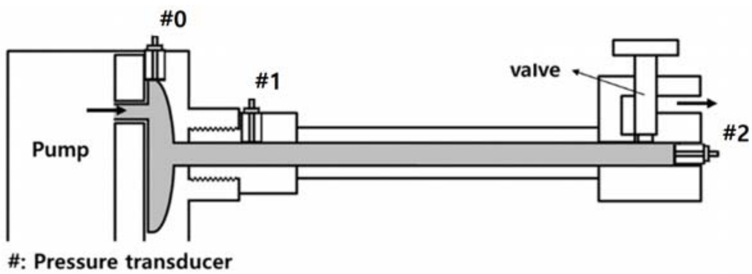


Figure 4. A Schematic of the preliminary test system applied to an axial piston type hydraulic pump

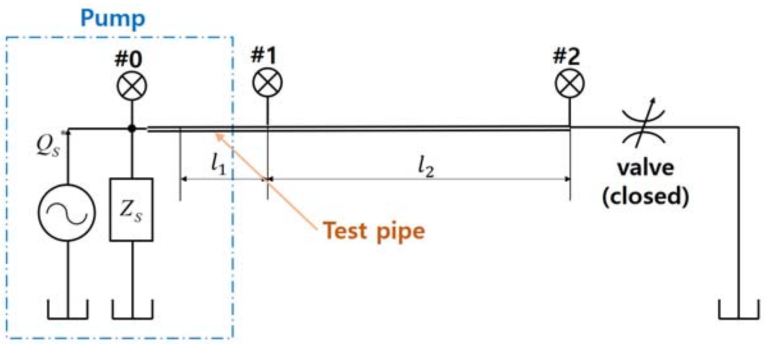


Figure 5. An equivalent hydraulic circuit of the system in Fig. 4

$$\begin{bmatrix} P_0 \\ Q_0 \end{bmatrix} = \begin{bmatrix} \cos(\beta l) & j Z_c \sin(\beta l) \\ j / Z_c \sin(\beta l) & \cos(\beta l) \end{bmatrix} \begin{bmatrix} P_2 \\ Q_2 \end{bmatrix} \tag{1}$$

where, P and Q are Laplace transformed variables of pressure ripple and flow ripple respectively, and the subscripts show the positions in the circuit. From Eq. (1), P_2 / P_0 is described as

$$\frac{P_2}{P_0} = \frac{1}{\cos(\beta l) + \left(\frac{Q_2}{P_2} \right) j Z_c \sin(\beta l)} \tag{2}$$

where, l is $l_1 + l_2$, and l_1 is the length of the equivalent pipe obtained when the wave speed in pipe 1(l_1 part) is assumed to be the same as the one in pipe 2(l_2 part).
Fig. 6 shows the photograph of the preliminary test system for obtaining an equivalent pipe model of the discharge passage in an axial piston pump. The length and the inside diameter of the pipe 2(l_2 part in Fig. 5) are 0.028 m and 5.6 mm respectively.

Equivalent pipe length l_1 can be evaluated by comparing the numerically computed result and experimental result of P_3 / P_1. The experiment is carried out while the discharge valve is closed, thereby at the condition of $Q_3 = 0$. Eq. (2) is used for the numerical computation of P_3 / P_1. Fig. 7 shows P_3 / P_1 obtained in the experiment and numerical computation. In the process, the value l_1 was obtained to be 30 mm.

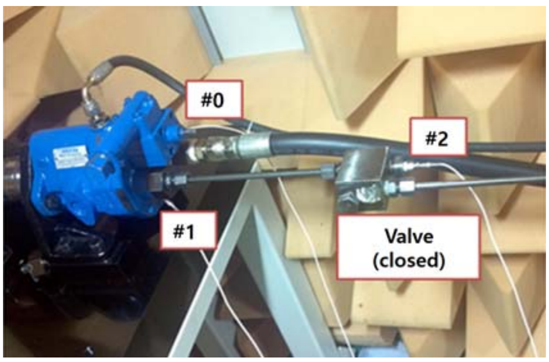


Figure 6. Photo of the system for the preliminary test

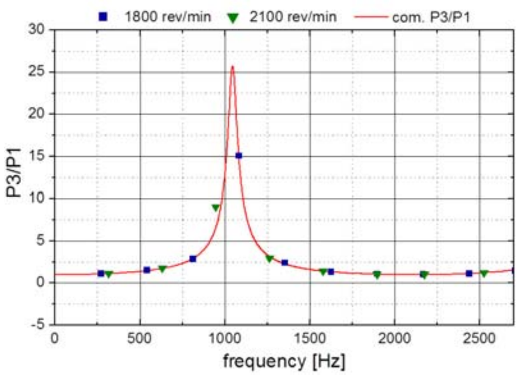


Figure 7. Comparison of the computed and numerical results of P_2 / P_0

Figure 7. Comparison of the computed and numerical results of P_2 / P_0

3. Application of the equivalent pipe model of the discharge passage

3.1 Flow ripple measurement using the 2P2S method

In the 2P2S method, internal impedance Z_s and flow ripple Q_s are computed from the following equations.

$$Z_s = jZ_c \frac{(P_o - P_o')\sin(\beta L)}{P_1 - P_1' - (P_o - P_o')\cos(\beta L)} \tag{3}$$

$$Q_s = j\frac{1}{Z_c}\frac{P_o P_1' - P_o' P_1}{(P_0 - P_0')\sin(\beta L)} \tag{4}$$

In Eqs. (6) and (7), (P_o, P_1) and (P_o', P_1') are measured in experiments with different extension pipes shown in Fig. 2. Q_o (the flow ripple at pump outlet) can be computed from Eq. (8) by using Z_s and Q_s obtained in (6) and (7). A pressure ripple at an arbitrary position in the pipe is computed in the Eq. (9).

$$Q_o = Q_s - \frac{P_o}{Z_s} \tag{5}$$

$$P_x = \cos(\beta l) P_o - j Z_c \sin(\beta l) Q_o \tag{6}$$

where, l is the pipe length between the position o and x. The accuracy of Z_s and Q_s obtained in Eqs. (6) and (7) can be evaluated by the error equation (10).

$$error = \frac{\int_0^T \left| P_{x-\exp}(t) - P_{x-com}(t) \right| dt}{\int_0^T \left| P_{x-\exp}(t) \right| dt} \tag{7}$$

3.2 The accuracy of Q_s and Z_s in the 2P2S method with the equivalent pipe model

(P_o, P_1) and (P_o', P_1') were measured in the system shown in Fig. 8. In this system, the reference pipe(between #0 and #1 position, length 150 mm) consists of 30 mm(the equivalent pipe) and 120 mm pipe(inside diameter 5.6 mm). Z_s and Q_s computed using Eqs. (6) and (7) are shown in Fig. 10 and 11. To investigate the accuracy of Z_s and Q_s, the computed value of P_1 and the measured value of P_1 were compared in Fig. 12. The error computed by Eq. (10) with the data shown in Fig. 12 was less than 0.3 %. Therefore, it is ascertained that Z_s and Q_s measurement with very high precision can be realized with the suggested equivalent pipe model for the discharge passage of pumps.

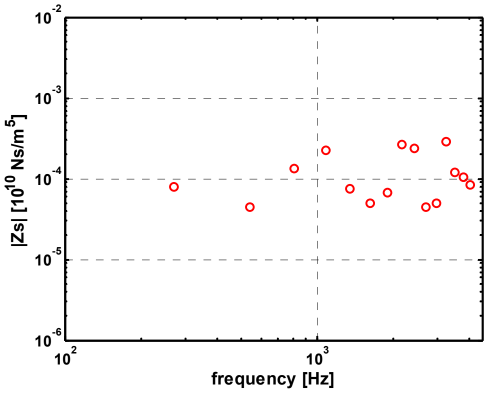


Figure10. Measured source impedance(Z_s)

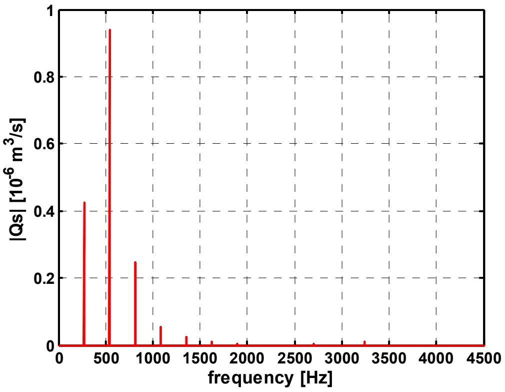


Figure11. Source flow ripple(Q_s)

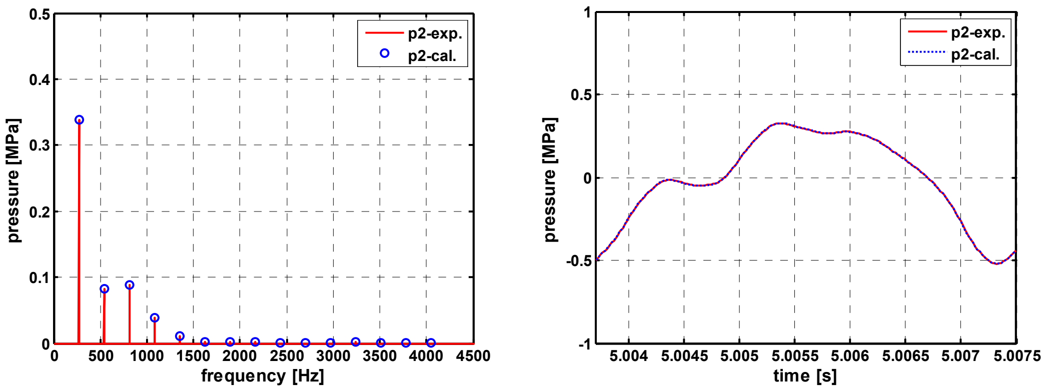


Figure12. Measured and calculated pressure ripple for confirming the reliability of Q_s

4. conclusion

In this paper, a novel model of the discharge passage in the 2P2S method for measuring internal impedance and flow ripple was suggested. In addition, the accuracy of Q_S and Z_S due to the difference of the model of the discharge passage was evaluated. The effectiveness of the suggested model of the discharge passage in the 2P2S method was ascertained by comparing the numerical result and the experimental result of pressure in an arbitrary position in the pipe.

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