The Measurement and Analysis of Pressure Square Wave Generator

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Abstract. Investigating the dynamic characteristics is a significant study for actual hydraulic pressure system because the dynamic environment is used more often than static one. A dynamic pressure generator is called pressure square wave generator (PSWG) that developed in our team and generate square-like waveform and change testing pressure and frequency form 0.1 to 5 MPa and 12 to 2 KHz, respectively. In this study, dynamic performance of PSGW was investigated under different testing tangent velocity of rotor of PSGW including detailed transient response of a pressure square-like wave, rise time and deviation of magnitude. Results show that the tangent velocity of the rotor of PSGW affects the transient response of pressure square-like wave form. The desired transient response can be obtained when the tangent velocity is larger than 0.5 m/s. Furthermore, the larger the tangent velocity used, the smaller the rise time will be.

1. Introduction
Dynamic pressure generator has been developed to evaluate the dynamic performances and widely employed for dynamic calibration. This device creates periodic pressure waves for exciting the dynamic characteristics of the hydraulic devices, such as hydraulic hose or pressure transducers. The property of compressive medium are usually variable, therefore the dynamic reactions of components of hydraulic systems need strongly to be considered. Dynamic pressure generator is a majority testing device for detecting the dynamic characteristics. This device is able to generate the acceptable standard pressure and divided into two classes: aperiodic and periodic pressure generator.

The aperiodic pressure generators which include the shock tube or the quick-opening valve create pressure steps or pulses for detecting the transient response of pressure devices. The shock tube is comprehensively used to calibration the dynamic characteristics of pressure transducer [1]. The periodic pressure generators which include the siren or the rotating valve create pressure sine wave or square wave for detecting the frequency response of the pressure devices [2]. Those dynamic pressure generators are equally important for investigating the dynamic performances of pressure system.

PSWG has the capability of creating periodic pressure square-like waves, which can be used to measure and evaluate the dynamic characteristics of hydraulic system [3]. The maximum working range and testing frequency of PSGW are 2 kHz and 5MPa. This device has also identified the pressure transducers and pressure tubes [4]. In this study, the generated pressure square wave has been further clarified for PSGW. The variable flow coefficient is an important factor that generates various
pressure square-like waveform size of channel gap. Therefore a desirable pressure square wave of PSWG would be decided in this study.

2. Pressure square wave analysis

PSWG is composed of a stator and a rotor. Numbers of channels on the circumference of stator and rotor can obtain by machining. The grooves on the rotor are divided equally into two sections. One is the filled oil channel with high pressure, another is a drainage way. The pressure square wave can be formed by these different pressure volume during the rotor is rotating. When the pressurized oil flows to the sensing chamber, the signals then can be derived from piezoelectric pressure transducer.

The analysis of transient response of generated pressure square wave can be taken as a unit-step response and presumed as a second order transient response. Thus the performances of the pressure square waves are able to compare with the standard specifications. The damped oscillation of each pressure square wave could be seen as the underdamped case, so the output \( c(t) \) is written as

\[
\begin{align*}
\hat{c}(t) &= e^{-\frac{\xi}{2} \omega_d t} \sin(\omega_d t + \tan^{-1} \frac{\sqrt{1 - \xi^2}}{\xi}) \\
\end{align*}
\]

(1)

Where \( \xi \) is damping ratio \((0 < \xi < 1)\) and \( \omega_d \) is called the damped natural frequency. The periodic pressure square wave could also be represented as the standard Fourier series expansion of \( f(t) \) is shown in equation (2). The periodic pressure square wave consisted with infinite basic waves.

\[
\begin{align*}
f(t) &= a_0 + \sum_{n=1}^{\infty} \left( a_n \cos \frac{n\pi t}{p} + b_n \sin \frac{n\pi t}{p} \right) \\
\end{align*}
\]

(2)

In addition, the effect of the flow coefficient is occurred by the varying size of channel gap so that the mass flow \( Q \) is written as

\[
Q = cA \sqrt{\frac{2\Delta p}{\rho}}
\]

(3)

Where \( c \) is the flow coefficient and the value depends on the gap size, as indicated in figure 1. The mass flow is not a constant for PSWG, too. It depends only on the flow coefficient because other parameters are all constant in this experiment. So the effect of tangent velocity of channel gap is an important factor when the size of channel gap is hanged.

3. Experimental method

The experimental setup consists mainly of three sections: (1) the pressure supplier, (2) PSWG, and (3) measuring system, as indicated in figure 2. First, the pressure supplier provided regulating pressurized oil and the oil temperature was monitored by a thermometer to keeping the measuring temperature among 25°C. Second, the tangent velocity of rotor of PSWG was controlled by a connected servo.
motor and detected by a tachometer. Finally, the measuring system consisted of a piezoelectric pressure sensor and a data acquisition. The piezoelectric pressure sensor has the advantages of good dynamic characteristics, high sensitivity, stable quality and good temperature compensation for measuring the dynamic pressure. The entire control and measuring system are connected by a GPIB device which plugged in a computer. In this experiment, the two levels of pressure square wave were regulated to 2.2 MPa and 0.1 MPa, respectively; the tangent velocity was the controlled between 0.03 and 0.8 m/s.

![Figure 2. Sketch of experiment setup.](image)

### 4. Results and discussion

The flow coefficient of hydraulic oil flows to the pressurized chamber is a variable, which leads the complex transient response of pressure square wave. The damped oscillation mode was divided into three types according to the tangent velocity of rotor of PSWG. The mainly difference between these three types reflects on the first oscillation and the maximum peak value of the pressure square wave, as indicated in figure 3. The first type of damped-oscillation is called irregular transient response which occurred under the tangential velocity among 0.03 to 0.25 m/s. The damped oscillation of irregular transient response is dissimilar to the classic transient response. The first oscillation of the irregular transient response is not a maximum value of amplitude, as indicated in figure 4. However, the second oscillation is just the maximum value of amplitude. This may be attributed the result to the variable flow coefficient. When the tangent velocity less than 0.25 m/s, the pressurized chamber is filled and the channel gap is small, and therefore the first oscillation was formed due to the lower flow coefficient. So the amplitude of first oscillation is smaller than second one which formed with higher flow coefficient.

The second type of damped-oscillation is called regular transient response which occurred under the tangent velocity from 0.25 to 0.5 m/s. The regular transient response is similar to the classic transient response that the maximum amplitude occurred at first oscillation. Because the tangent velocity is large enough to supply its energy to the first oscillation. In this tangent velocity range, the maximum amplitude increases with the increasing tangent velocity.

The third type of damped-oscillation is referred to as desired transient response. When the tangential velocity larger is than 0.5 m/s, the desired transient response can be obtained. The oscillation of this type is almost the same, such as the maximum amplitude and the numbers of the damped oscillation, as revealed in figure 5. In this tangent velocity range, the mainly difference of wave form is the fall-time position only. The higher the tangent velocity, the smaller the period of pressure square wave. This result demonstrates that the effect of flow coefficient of PSWG could be disregarded when the tangential velocity larger than 0.5 m/s.
Finally, figure 6 shows the rise time of PSWG under different tangent velocity and illustrates that the rise time of the desired transient response is nearly 0.4 ms. However, the rise time of irregular or regular transient response increases with the increasing tangent velocity. These results prove that the desired transient response formed when the tangent velocity of rotor of PSWG is larger than 0.5 m/s.

![Figure 3. The magnitude of oscillation.](image)

![Figure 4. Irregular transient response.](image)

![Figure 5. Stable transient response.](image)

![Figure 6. The rise time of pressure wave.](image)

5. Conclusion
The generated pressure square-like wave of PSWG has been investigated under the tangent velocity of rotor from 0.03 to 0.8 m/s. The transient responses could be divided to three types according to the tangent velocity. The desired transient response of pressure square-like wave could be found when the tangent velocity is larger than 0.5 m/s. The desired transient response reveals a short rise time and steady damped oscillation. This result demonstrates that desired transient response can be formed under the tangent velocity of the switch valve larger than certain value. Therefore the tangent velocity of switch of hydraulic valve is apparently the significant index for precision control.

References
[1] Bean V E 1993 Dynamic Pressure Metrology Metrologia 30 737-741
[2] Kobata T and Ooiwa A 2000 Sensors and Actuators 79 97-101
[3] Tsung T T, Chang H and Chen L C 2003 Measurement Science and Technology 14 1972-73
[4] Tsung T T and Han L L 2004 Measurement Science and Technology 15 1133-39
[5] Lai G E 1985 Oil pressure technology 126