Test and Analysis of Self-excited Pressure Oscillations and Noise in a Hydraulic Jet-pipe Servo-valve

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***Abstract*—Self-excited high frequency pressure oscillations in the flow field of a hydraulic servo-valve are usually the source of high frequency noise. In this paper, by using a piezoelectric dynamic pressure transducer and a microphone, the self-excited high frequency pressure oscillations and noise in a hydraulic jet-pipe servo-valve are measured. The experiments are carried out when the supply pressures of the servo-valve are 11MPa and 20MPa respectively. In order to obtain more precise information, FFT and wavelet analysis are applied to resolve the tested pressure oscillation and noise signals into several basic wave signals. The possible causes of the self-excited high frequency oscillations and noise are predicted according to the analysis results. Based on the results, suggestions are given to reduce the pressure oscillations and noise in hydraulic servo-valves.**

Keywords—self-excited pressure oscillations; noise; hydraulic jet-pipe servo-valve.

I. INTRODUCTION

Hydraulic servo-valves are the most important components for hydraulic control systems, which are very widely applied in the areas of industry, aerospace, agriculture and automobile machines [1,2]. The characteristics of a hydraulic servo-valve influence the performance of a hydraulic control system significantly. There are several types of hydraulic servo-valves, for example flapper-nozzle servo-valves, jet-pipe servo-valves and deflection flapper servo-valves. Because the jet-pipe servo-valve has a larger resistance to the contamination of hydraulic oils than any other types of servo-valves, it is becoming more and more popular in many application areas nowadays [3].

Self-excited pressure oscillations and noise are the most frequently appearing phenomenon in hydraulic servo-valves, especially in the hydraulic jet-pipe servo-valves, if the sizes of different parts in a hydraulic jet-pipe servo-valve are not selected or manufactured correctly. The self-excited pressure oscillations inside the flow field of a hydraulic servo-valve may excite the vibration of the servo-valve spool or the torque motor armature which is the driving part of the servo-valve. So that the servo-valve may lose its stability and the hydraulic control systems may not be able to work properly. At the same time, the self-excited noise in a hydraulic servo-valve usually appears as an unpleasant, high frequency whistle or squeal. It pollutes the working environment and brings damage to the worker's hearing [2,3]. It is important for the servo-valve application to find out the possible cause of the noise, so that corresponding methods can be taken to address the noise problem of a servo-valve.

Test and FFT analysis of the oscillations and noise in a hydraulic counterbalance valve has been carried out by Weber and Rahman [4,5] to find out the possible cause of the problem. Watton [6] studied the high frequency noise in a hydraulic flapper-nozzle servo-valve and concluded the reason to be the shear layer instability in the servo-valve flow field. Geometric modification of the servo-valve is one of the practical methods to get rid of the self-excited oscillations and noise in the servo-valve. Sometimes a damper or orifice in the servo-valve return line can also be introduced to eliminate the influence of the oscillation and noise problems if the oscillations and noise are caused by cavitations inside the flow field.

In Weber's paper [4], the sources of self-excited noise in a hydraulic valve are divided into three types. They are oscillation of the valve components, cavitation and shear layer instability [7,8]. Oscillation of valve components generates a noise at a low frequency. This source of noise can be confirmed if the moving components of a hydraulic valve are fixed in a position. Cavitation generates a noise over a wide frequency. While shear layer instability is often identified as the cause of high frequency, pure tone sound that is described as a whistle or squeal.

In this paper, the self-excited pressure oscillations and noise in a hydraulic jet-pipe servo-valve are tested when the servo-valve works with different supply pressures. The wave signals of pressure oscillations and noise are recorded. Wavelet analysis method and FFT are used to analyze the characteristics of the tested pressure oscillations and noise more precisely. The experimental results are compared and the possible causes are predicted.

II. FLOW FIELD IN A HYDRAULIC JET-PIPE SERVO-VALVE

Usually a hydraulic jet-pipe servo-valve contains a valve body with a spool, a torque motor, a jet pipe and a plate with two ports receiving the jet flow from the jet pipe. As the

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electro-mechanical mechanism in hydraulic servo-valves, torque motors are used to stroke hydraulic servo-valves from electric signals. The schematic of a hydraulic servo-valve torque motor with a jet pipe is shown in Fig. 1. A hydraulic servo-valve torque motor usually contains an armature, permanent magnets, cores and coils. The jet pipe in a hydraulic jet-pipe servo-valve is linked with the torque motor armature.

When the power of the torque motor is off, the armature will stay at the middle position under the working of the permanent magnets. The opening areas between the jet pipe and any of the two ports are the same. When an electric current is supplied to the torque motor coil, the armature will rotate until the output torque of the motor equals the load torque. The jet pipe will rotate with the armature. Then the opening between the jet pipe and one of the two receiving ports will be larger than that between the jet pipe and the other port. There will be more flow going to one port than going to the other.

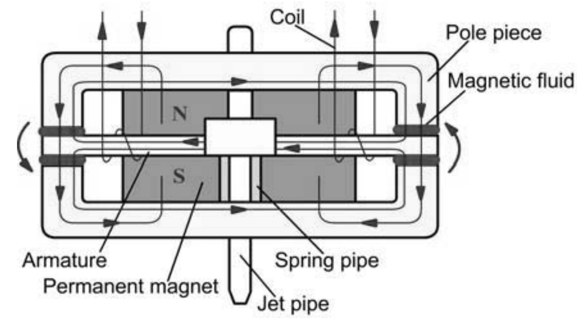


Fig. 1. Schematic of a hydraulic servo-valve torque motor

The schematic of flow field between the jet pipe and the two receiving ports is shown in Fig.2. As shown in Fig.2, when the jet pipe rotates with the armature, the pressure on one side of the servo-valve spool will be larger than that on the other side. Therefore the servo-valve spool will move to a new working position. It also can be seen that in Fig. 2 the supply pressure of the servo-valve is the supply pressure of the jet pipe. The return pressure of the jet pipe is also the return pressure of the servo-valve.

When the flow is jetted out from the jet pipe and impinging the edges of the two receiving ports, there will be vortex or cavitations appearing in the flow field between the jet pipe and the two ports. Pressure oscillations in the flow field and the vibrations of the torque motor or the valve spool may be excited.

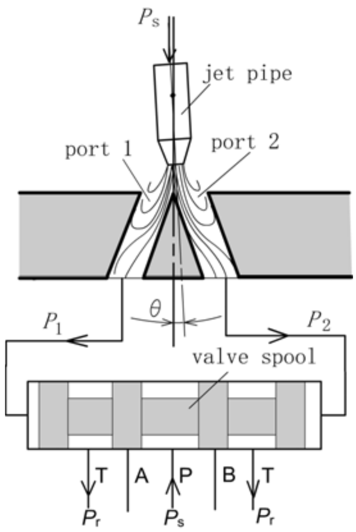


Fig. 2. Flow field in a hydraulic jet-pipe servo-valve.

III. Experiments

A. Test of pressure oscillations and noise.

In this paper, the self-excited pressure oscillations and noise of a hydraulic jet-pipe servo-valve are tested when the servo-valve is working at a steady state. The hydraulic test rig for servo-valve static characteristics is shown in Fig.3. The test rig basically consists of a hydraulic pump 1, a relief valve 2, the tested jet-pipe servo-valve 3, some pressure gauges 4, two pressure transducers 5, a flow rate meter 6, a pressure control valve 7 and a cooler 8. In order to record the self-excited noise in the servo-valve, a microphone 9 and a computer with acquisition systems are also used.

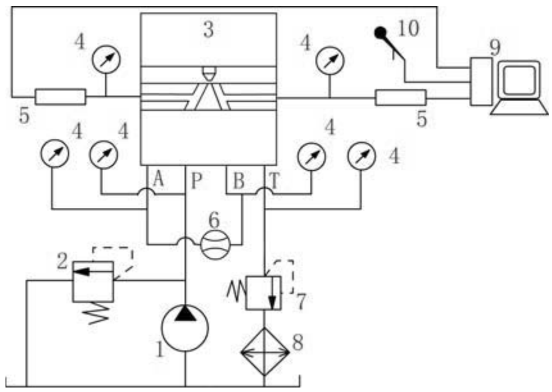


Fig. 3. Test rig for pressure oscillations and noise. 1 Pump. 2 Relief valve. 3 Tested servo-valve. 4 Pressure gauge. 5 Pressure transducer. 6 Flow rate meter. 7 Loading valve. 8 Cooler. 9 Computer and data acquisition system. 10 Noise recording device.

In order to test the self-excited pressure oscillations inside the flow field of the jet-pipe servo-valve, two piezoelectric pressure transducers 7 for dynamic pressure testing are used. The parameters of the pressure transducers are:

- Natural frequency >200KHz

•Pressure range 0~6MPa

•Sensitivity 498.7 pC/10^5 Pa

•Temperature range -40~150 °C

•Nonlinearity <1%

The two piezoelectric pressure transducers are connected respectively with the two ports, port 1 and port 2, which receive the flow coming out from the jet pipe and running into the two chambers besides the servo-valve spool. Therefore the pressure oscillations inside the flow field can be tested by the pressure transducers. The tested pressure oscillation data is transported into a computer through an acquisition system linked to the transducers. If a certain value of electric current is supplied to the servo-valve, the jet pipe and the servo-valve will work at a steady state. In this paper, the experiments are carried out when the rated electric current is supplied to the coil of the servo-valve torque motor. If the servo-valve works at different supply pressures, the flow rate running across the jet pipe will be different. The flow will be jetted out with different velocities.

The self-excited noise is recorded by a computer through a high precision microphone. Professional recording software for Microsoft Windows is used and the sample frequency is selected to be 44 KHz.

B. Tested pressure oscillation signals.

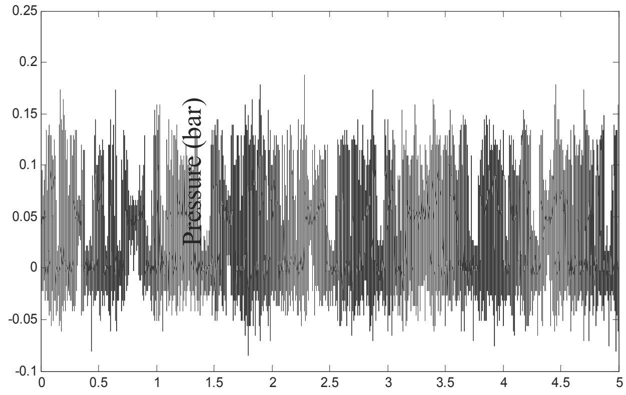
The pressure oscillations inside the flow field of the servo-valve are tested at different supply pressures and different input electric current of the servo-valve. The sample frequency of the acquisition system and the recording process is 100 KHz for the pressure testing. The rated flow rate of the servo-valve at a 20MPa pressure difference is 200 L/min. The pressure in the return line of the servo-valve is 1MPa. The rated electric current of the servo-valve is 40 mA. Some important geometric parameters of the tested servo-valve are:

•Diameter of the jet pipe 0.2mm.

•Distance between the jet pipe and the two receiving ports 0.12mm.

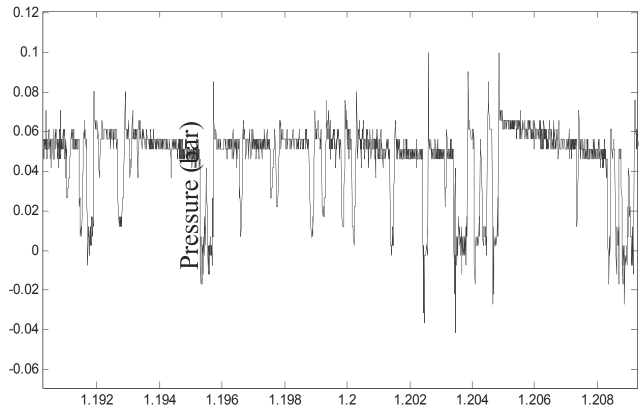
•Diameter of any of the two receiving ports 0.2mm.

Experiments for pressure oscillations were carried out when the rated electric current was supplied to the servo-valve. The pressure oscillation signals tested at 11MPa and 21MPa supply pressure are shown in Fig.4 and Fig.5 respectively. As the self-excited pressure oscillations tested by the pressure transducers linked to port 1 and port 2 are almost the same, only the tested pressure oscillations at port 1 are shown.



Time (s)

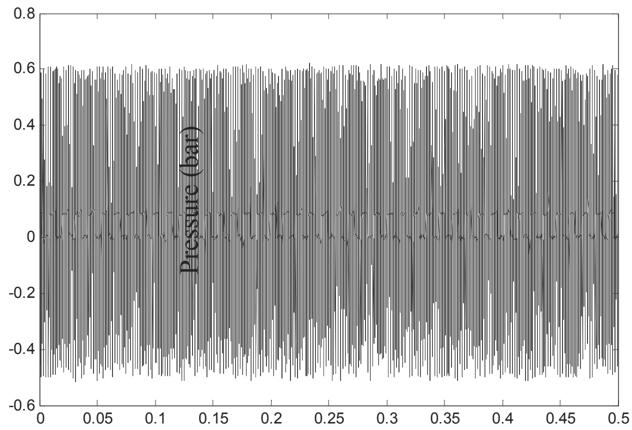
(a) Tested pressure oscillations



Time (s)

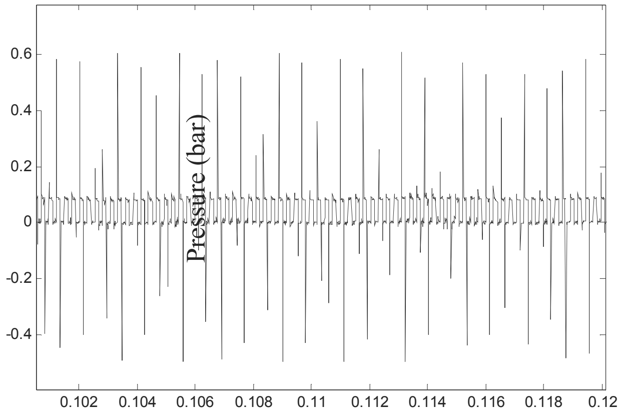
(b) Zoom-in signals

Fig. 4. Tested results (supply pressure is 11MPa).



Time (s)

(a) Tested pressure oscillations



Time (s)
(b) Zoom-in signals

Fig. 5. Tested results (supply pressure is 21MPa).

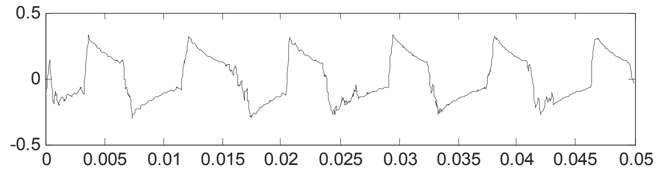
From Fig.4 and Fig.5, the amplitudes and the frequencies of the two tested pressure oscillations can be compared. When the supply pressure of the servo-valve is 21MPa, it can be seen obviously that there are much higher frequency components in the tested pressure oscillation signals than in the tested results when the supply pressure is 11MPa. The low frequency component in the pressure oscillations is supposed to be the pressure pulsations of the hydraulic power supply system. The amplitude of the pressure oscillations tested when the supply pressure is 21MPa is different from that tested when the supply pressure is 11MPa too. The amplitude of the pressure oscillations under 11MPa is about 20KPa. While the amplitude of the pressure oscillations under 21MPa is 100KPa. The supply pressure increased the amplitude of the pressure oscillations. When the supply pressure of the servo-valve is 21MPa, a very loud whistle noise can be heard besides the background noise produced by the power source of the test rig. When the supply pressure is only 11MPa, the whistle noise can hardly be heard except the background noise of the power source.

It is difficult to recognize the frequency components by looking at the time domain signals in Fig. 4 and Fig.5, as they are not the regular sinusoidal waves. FFT or wavelet analysis should be used to transform the signals from the time domain to the frequency domain.

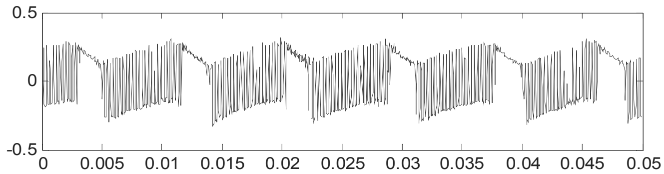
C. *Tested noise signals.*

When the supply pressure is 11MPa, the self-excited noise of the servo-valve almost cannot be heard. But when the supply pressure is raised to 21MPa, the self-excited noise appears. It shows the existence of the self-excited pressure oscillations inside the flow field of the servo-valve. The two power signals of the noise when the test supply pressures are 11MPa and 21MPa are shown in Fig.6 (a) and Fig.6 (b) respectively. The waves are shown in the amplitude ratio which is the tested sound pressure level ratio to a reference sound pressure level given by the recording software.

Fig.6(a) shows that the noise wave has only a low frequency component. It is supposed to be the noise of the test background, basically the noise of hydraulic power supply system. While Fig.6 (b) shows that the wave contains not only a low frequency component, but also a high frequency component. The high frequency component is supposed to be the self-excited noise. This agrees with the test results of the pressure oscillations. It also shows that the self-excited oscillations and noise tend to appear when the supply pressure of servo-valve is increased.



Time (s)
(a) Supply pressure is 11MPa



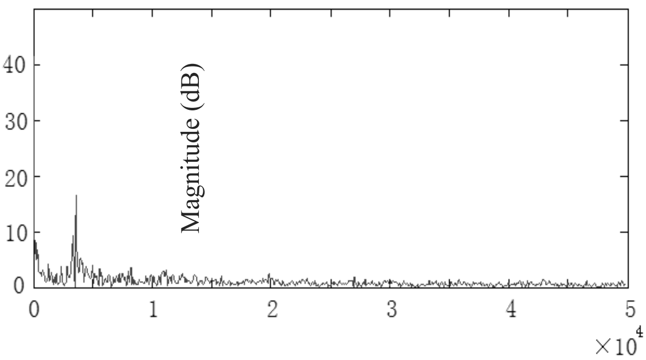
Time (s)
(b) Supply pressure is 21MPa

Fig. 6. Tested noise wave signals

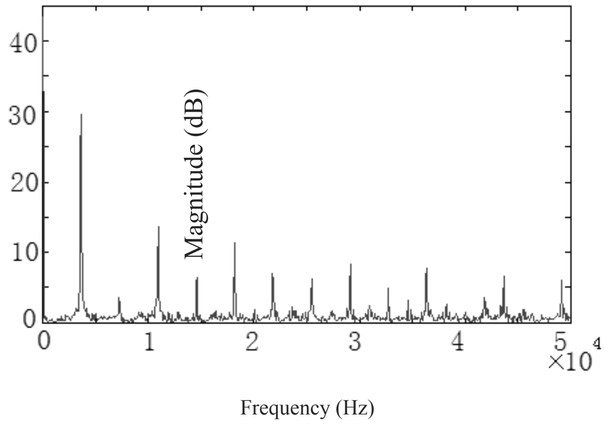
IV. RESULTS AND DISCUSSIONS

A. *FFT analysis*

For the condition when the supply pressure of the servo-valve is 11MPa, the power spectrum of the tested pressure oscillation signals is shown in Fig.7 (a). For the condition when the supply pressure of the servo-valve is 21MPa, the power spectrum of the tested signal is shown in Fig.7 (b).



Frequency (Hz)
(a) Supply pressure 11MPa



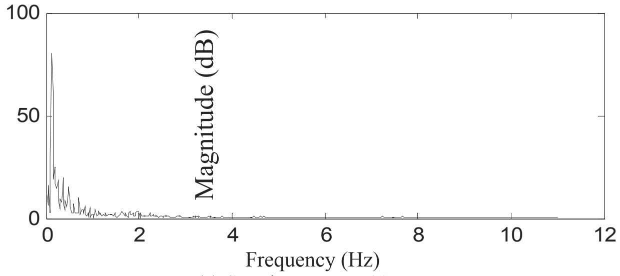
(b) Supply pressure 21MPa

Fig. 7. FFT analysis of pressure oscillations

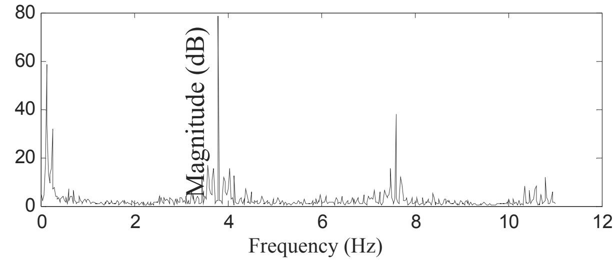
From Fig.7 (a), it can be seen that the tested pressure oscillation signal contains mainly two frequency components at about 120Hz and 3.8 KHz. The 120Hz frequency signal has larger amplitude than the 3.8 KHz frequency signal. The 120Hz pressure oscillations can be recognized as the pressure oscillations produced by the hydraulic power supply of the test rig. The 3.8 KHz pressure oscillations can be recognized as the self-excited pressure oscillations produced by the shear-layer instability inside the flow field of the servo-valve. But from Fig.7 (a), it can be seen that the amplitude of the 3.8 KHz pressure oscillations is very low.

From the FFT results in Fig.7 (b), it can also be seen that the pressure oscillation signal also contains two frequency components at about 120Hz and 3.8 KHz when the supply pressure of the servo-valve is 21MPa. But in Fig.7 (b), the 3.8 KHz frequency component has a much larger amplitude than the 3.8 KHz frequency component in Fig.7 (a) when the supply pressure is 11MPa. Therefore the power of the self-excited pressure oscillations because of the shear-layer instability has a relationship with the supply pressure of the servo-valve. The higher the supply pressure is, the larger the power of the pressure oscillations.

The tested noise signals of the servo-valve can also be analyzed using FFT method. The FFT analyzed results of the two tested noise signals are shown in Fig.8 (a) and Fig.8 (b) when the supply pressures are 11MPa and 21MPa respectively.



(a) Supply pressure 11MPa



(b) Supply pressure 21MPa

Fig. 8. FFT analysis of noise signals

From the FFT analysis results in Fig.8 (a), it can be seen that there is only one frequency component at about 120Hz. This doesn't agree with the FFT analysis results in Fig.7(a). It's possibly because the self-excited pressure oscillations inside the flow field are too weak to appear as a noise when the supply pressure is 11MPa. Fig.8 (b) shows that the noise signal at 21MPa supply pressure can be divided into two components at about 120Hz and 3.8 KHz. This agrees well with the FFT results of pressure oscillations in Fig.7 (b). The low frequency component is supposed to be the background noise produced by the hydraulic power supply system.

B. Possible cause of the self-excited pressure oscillations and noise.

From the experimental results, if the frequency of pressure oscillations and noise inside hydraulic valves goes up to as high as several Kilo Hz and the signal shows as a pure tone signal, the oscillations and noise are most probably because of the shear-layer instability inside the flow field. As the frequency of the tested self-excited pressure oscillations and noise is 3.8 KHz, the possible cause of the noise should not be the resonance of the moving components inside the servo-valve. The tested high frequency noise shows as a pure tone sound and the return pressure of the servo-valve is set to be as high as 1MPa. Therefore the possible cause of cavitations should be excluded. So we can conclude that there is shear-layer instability inside the flow field of the tested jet-pipe servo-valve in this paper.

V. CONCLUSIONS

In this paper, the measurement of pressure oscillations and noise inside the flow field of a jet-pipe servo-valve is carried out at different supply pressures of the servo-valve (11MPa and 21 MPa). From the test and analysis above, several conclusions can be made as:

1. Both the tested pressure oscillation signals and the noise signals contain a 3.8 KHz high frequency component. This high frequency pressure oscillation component is supposed to be the reason for the self-excited noise of the tested servo-valve.

2. It can be concluded that the high frequency pressure oscillations are produced by the shear-layer instability inside the flow field between the jet pipe and the two receiving ports because of the pure tone and high frequency characteristics of the signals.

3. The 3.8 KHz high frequency pressure oscillation has a relationship with the supply pressure of the servo-valve. The amplitude of the high frequency oscillation increases with the supply pressure of the servo-valve.

4. The high frequency pressure oscillations because of the shear-layer instability can only be depressed by the geometric modification of the servo-valve. For example, the distance between the jet pipe and the two receiving ports is increased or decreased.

5. In order to reduce the self-excited pressure oscillations and noise in the tested jet-pipe servo-valve, further works need be done on the relationship between the self-excited pressure oscillations and the geometric parameters of the flow field between the jet pipe and the two receiving ports.

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