Research on frequency response experiment of servo valve based on LabVIEW

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Abstract. In order to meet the testing requirements of a certain enterprise for servo valves, the test method for the dynamic performance of electro-hydraulic servo valves was designed. The programming of the servo valve frequency response in the LabVIEW framework is described in detail. The actual test shows that the test system works well and the experimental data is reliable and effective.

1. Introduction
With the development of the domestic steel industry towards high-end, the electro-hydraulic servo control system has gradually become the main power control system in the steel production line [1]. Since the performance of the servo valve directly affects the control accuracy, stability and reliability of the electro-hydraulic servo system, the electro-hydraulic servo valve is required to undergo strict performance test before and after maintenance [2]. The dynamic characteristic test is necessary. According to the testing requirements of an enterprise, a dynamic test system for servo valve was developed. The servo core displacement signal was used to analyse the frequency response, which simplified the test method. The entire test process is controlled by a computer, which improves the accuracy of the test.

2. Hydraulic System for Testing Servo Valves
The hydraulic schematic of the test system is shown in Figure 1.
1. oil tank; 2,3,4. filter; 5,6,7,8. check valve; 9,10. relief valve; 11. motor; 12. inverter-fed motor; 13,14. shaft coupling; 15,16. oil pump; 17,18,19,20,21,22. ball valve; 23,24,25,26,27. pressure sensor; 28. speed sensor; 29. displacement sensor; 30. servo cylinder

Figure 1. Schematic diagram of the hydraulic system.

As shown in Figure 1, the left part is the oil source, and the ‘Pa’ road is the control oil circuit, which provides the control oil to the external control type servo valve. The ‘Pb’ path is the oil source of system, and the variable frequency motor 12 drives the pump 16 to provide flow and pressure to the test system. The test circuit is on the right side, and the speed sensor 28 and the displacement sensor 29 are mounted on both sides of the dynamic cylinder.

3. Composition of Test System
First, the industrial computer sends an excitation signal to the servo amplifier. Second, the servo amplifier is output to the servo valve. Then, the acquisition card collects the spool feedback signal of the servo valve. Finally, the computer software plots the amplitude-frequency curve and the phase-frequency curve by processing the data.

3.1. Hardware Design of Measurement and Control System
The hardware schematic diagram of the measurement and control system is shown in Figure 2. It is mainly composed of industrial computer, acquisition card, servo amplifier, sensor, signal conditioning module and so on.

Figure 2. Hardware schematic
In order to improve the stability and accuracy of the test system, the test system adopts the form of ‘the upper computer + the lower computer’. The upper computer selects the IPC industrial computer of Taiwan Advantech Co., Ltd., and the measurement and control software selects the LabVIEW software of American NI Company. The industrial computer communicates with the PLC through Ethernet to control and display the switch quantity in the hydraulic system, such as the start and stop of the motor, the on/off state of the ball valve, and the alarm of the fault signal. The lower machine selects the Siemens S7-200SMART software to control the electrical part of the hydraulic system. Advantech’s PCI1716 data acquisition card was selected to collect the signals of each sensor in the measurement and control system and output control signals.

3.2. Software Design of Measurement and Control System

The system uses NI LabVIEW11.0 software. The test software is mainly composed of data acquisition module, signal processing module, signal generator, spectrum analysis module and report saving module. The software can display the FFT spectrum of the input and feedback signals in real time during the test, as well as monitor the control signals in real time. The frequency response test is performed by the frequency sweeping method through the waveform generator that comes with the LabVIEW software. At the end of the experiment, the test data is processed to generate a Bode diagram. The test flow chart is shown in Figure 3.

4. The Program Design in LabVIEW

The program of the frequency sweeping method for testing the servo valve based on LabVIEW is as follows. First, the parameters of the appropriate waveform generator should be set up. Second, the sampling parameters are determined according to the actual conditions of the test system. Third, the test system measures the amplitude at the reference frequency, and then match the frequency of the acquisition card to the servo valve frequency through correction and calibration. Fourth, it performs the frequency sweeping test of the servo valve and record the data.

4.1. Waveform Generator Settings

The LabVIEW software comes with a basic function generator. In order to generate the waveforms required for the test, the frequency, amplitude, phase, sampling frequency and other information are set in vi according to actual needs.
4.2. Sampling parameter setting

Usually, the signals collected during the test are Fourier transformed and expanded into a Fourier trigonometric function in order of frequency. It is analysed in the frequency domain, a process called spectrum analysis. FFT is a fast algorithm for discrete Fourier transform. There are several types of FFT spectrum analysis controls in the LabVIEW software and the FFT spectrum (Mag- Phase).vi is selected here. As shown in Figure 5, this vi calculates the average FFT spectrum of the time signal and returns the amplitude and phase. The amplitude can be selected to be displayed in decibel form, and the phase can be converted to degrees. The input signal and the output signal collected are respectively subjected to FFT conversion to obtain respective amplitudes and phases.

Suppose a certain period signal is \( x(t) \), expand it into a trigonometric function of the Fourier series:

\[
x(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos n\omega_0 t + b_n \sin n\omega_0 t) = a_0 + \sum_{n=1}^{\infty} A_n \cos(n\omega_0 t + \phi_n) \quad (1)
\]

In equation (1): \( a_0 \) is a constant component; \( a_n \) is the amplitude of the cosine component; \( b_n \) is the amplitude of the sinusoid component; \( \omega_0 \) is the fundamental frequency; \( A_n \) is the amplitude of the signal; \( \phi_n \) is the phase of the signal[3].

\[
\begin{align*}
a_0 &= \frac{1}{T} \int_{-T/2}^{T/2} x(t) dt \\
a_n &= \frac{2}{T} \int_{-T/2}^{T/2} x(t) \cos n\omega_0 t dt \\
b_n &= \frac{2}{T} \int_{-T/2}^{T/2} x(t) \sin n\omega_0 t dt \\
A_n &= \sqrt{a_n^2 + b_n^2} \\
\phi_n &= \tan^{-1} \frac{a_n}{b_n}
\end{align*}
\]

After sampling the control signal and the feedback signal during the test, the FFT operation can clearly identify the features in the frequency domain. Suppose the sampling frequency is \( f_s \) and the number of samples is \( N \). After the FFT operation, the frequency represented by any one of the points is as follows:

\[
f = (n - 1) \frac{f_s}{N}
\]

Figure 4. Waveform generator parameter settings
According to the above analysis, it was found the n-th point \( n \neq 1, \text{ and } n \leq N/2 \) signal to the expression:

\[
x(t) = \frac{A_n}{N/2} \cos 2\pi ft + \varphi_n
\]  

(3)

It can be seen from equation (3) that the amplitude of the signal is \( \frac{A_n}{N/2} \) and the phase is \( \varphi_n \).

When \( n=1 \), this signal is a DC component with an amplitude of \( \frac{A_1}{N} \).

It can be known from equation (2) that the FFT resolution is \( \frac{f}{N} \). When the sampling frequency is equal to the number of samples, the FFT can be analyzed to 1 Hz, and increasing the number of sampling points can improve the resolution.

From the above analysis, in LabVIEW, the sampling frequency, the number of samples, and the number of reads per channel should be the same to improve the resolution of the FFT, so that the resolution can reach 1Hz. In the actual test, the acquisition rate per channel needs to be determined according to the total sampling rate and the number of channels. The Advantech PCI1716 acquisition card selected for this test system has a sampling rate of 250K/s and 16 channels, so the sampling rate per channel should not exceed 15625.

4.3. Measuring the Reference Amplitude at the Reference Frequency

In the test experiment, since the input frequency of the waveform generator is inconsistent with the frequency of the actual board output, the frequency calibration is first required. After setting the reference frequency, the function generator generates a sinusoidal signal to the board at the reference frequency. The frequency of the output signal is corrected within ±1 Hz of the waveform generator frequency, and the frequencies are considered to be the same, and the calibration of the registration frequency is completed.

At this time, the amplitude of the reference frequency (5 Hz or 10 Hz, generally 5 Hz or less) is recorded by the FFT spectrum analysis control, and the amplitude is used as the reference amplitude.

4.4. Frequency Sweeping Test

Bandwidth is an important parameter to measure the dynamic characteristics of electro-hydraulic servo valves. It is divided into amplitude bandwidth and phase bandwidth according to the angle of frequency consideration. The frequency at which the amplitude ratio is \( 20 \log \frac{A}{A_0} = -3 \text{dB} \) is called the amplitude bandwidth. The frequency at which the phase is delayed by 90° is called the phase bandwidth[4].

The waveform generator increases the frequency at a rate of 1 Hz/s starting from the reference frequency of 5 Hz. The amplitude of the output signal is synchronously recorded by an FFT operation. At the same time, the frequency response control Frequency Response function (Mag-phase).vi is used to analyze the input and output signals to calculate the phase difference. When the amplitude ratio of the amplitude of the output signal to the amplitude of the reference amplitude drops to -3 dB, this frequency is recorded to obtain the amplitude bandwidth. When the phase difference of the frequency response drops to -90°, this frequency is recorded to obtain the phase bandwidth.
5. Analysis of Experimental Data
As shown in Figure 6, it is the test curve of the ‘MOOG D662-P ’ servo valve which is used on the production line of the company.

![Figure 6. Frequency response curve of the servo valve](image)

The test parameters are set to: the starting frequency is 5 Hz, the test signal is 25% of the rated signal, and the system pressure is 21 MPa. The frequency corresponding to the amplitude ratio of -3 dB is 87 Hz, and the frequency corresponding to the phase difference of -90 is 96 Hz.

By consulting the valve sample parameters, it can be seen that at the pressure of 21 MPa and the rated signal of 25%, the frequency corresponding to -3 dB is 100 Hz, and the frequency corresponding to -90° is 100 Hz. The results of the comparison experiments are within a reasonable range and the test results are accurate.

6. Conclusion
In the article, a frequency sweeping method based on LabVIEW software for servo valves is proposed in detail. The designed test system meets the requirements of a company for testing the frequency response characteristics of servo valves, and the operating system is friendly, stable and reliable.

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