Test Data Analysis on Voltage Regulation of Proportion Relief Valve

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Abstract

The miniature reform design was to improve the voltage regulation of regular valve and proportional valve. LabVIEW was used to develop CAT voltage regulation of proportion relief valve with electro hydraulic proportional control and visual instrument. The content of the pressure adjustment of proportional relief valve was introduced from different angles and the steady-state. Test on voltage regulation of proportion relief valve was analyzed. The sampling data were processed and analyzed on a time domain and frequency domain basis. Related conclusions are made by analysis on current linearity, steady-state pressure, and pressure-adjusting delay. Systematic methods and references are provided for the development of other valves to improve the function and the system of proportional valve.

Keywords: proportion relief valve, voltage regulation, LabVIEW, CAT

1. Introduction

As one of the most important control components in hydraulic circuit, the main function of relief valve is to adjust the pressure of hydraulic circuit [1]. By using the test system and CAT on voltage regulation of proportion relief valve, the content of voltage regulation on proportion relief valve was selected to analyze the data on a time domain and frequency domain basis in order to get the result of voltage regulation, delaying and precision, all of which can provide references for manufacturers to produce proportional valve [2, 3], and provide guidance for manufacturers to enhance the quality and function of proportional valve. It is also helpful for users to use proportional valve better and to achieve better development and application of electro-hydraulic proportion. References can also be provided for other electro-hydraulic proportional valves.

2. Design and Innovation Plan of Test Platform

In order to achieve the test requirements about proportion relief valve in the experiment, a special hardware system was required to test the voltage regulation [4]. The hydraulic principles shown as Figure 1.

To test piloted proportion relief valve, the range of pressure value was 0~10 MPa and the moving speed of hydraulic cylinder on a test rig was 0.02~0.05m/s. The proportion relief valve in the experiment should be controlled under normal pressure and low discharge. According to the primary parameter, the highest pressure was set up as 6MPa, and the highest flow rate was 10~20L/min. The original relief valve and pressure gauges were replaced by piloted proportion relief valve and pressure sensor according to QCS003B. See Figure 2.
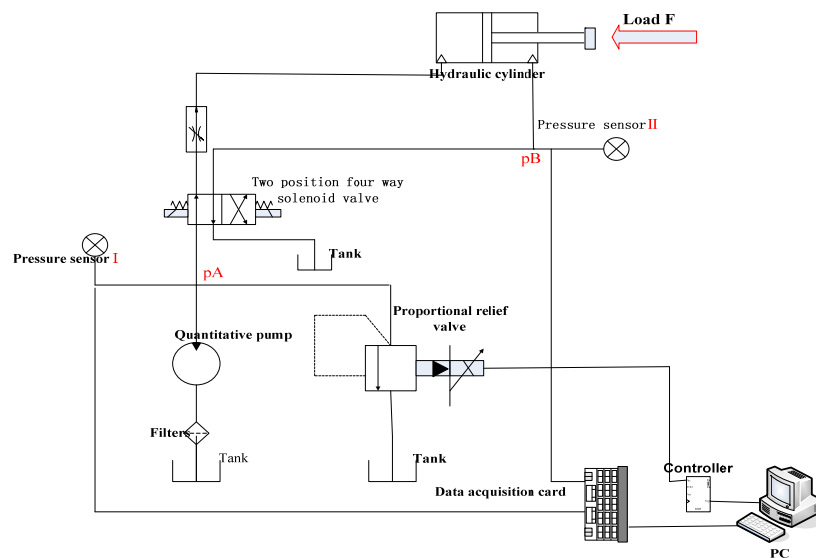
Figure 1. Schematic Diagram of Hydraulic System

Figure 2. Reform Design Diagram of Pressure Adjustment Platform of Proportional Relief Valve

3. CAT of Pressure Adjustment Platform of Proportional Relief Valve

Combined with virtual techniques, the adjustment platform was established a computerized system with data collection and electric system. The target and the process were controlled by digital computer and the data collection of parameter such as pressure and flow were processed so that the test can be achieved quickly and precisely [5, 6].

3.1. The Design and Model of Hardware System

As the pressure value from the valve port in the test should be measured, diffusion silicon pressure sensor HG2000 was selected on the basis of the requirement for hardware and measurement precision. During the data collection, the pressure should not be collected too fast. Considering both precision and cost, data collection card PCI-9112 was chosen from ADLINK compatible with LabVIEW [7].

To realize the switch of I/V from 4∼20mA to 0∼+5V, circuit amplification was designed to be compact size, stable performance, low power consumption and extensibility. See Figure 3.

LM324 amplifier, precision resistor and capacitor were designed for switch adjusting board, which can be used to amplify signal, filter noise and switch I /V from the signal from pressure sensor.
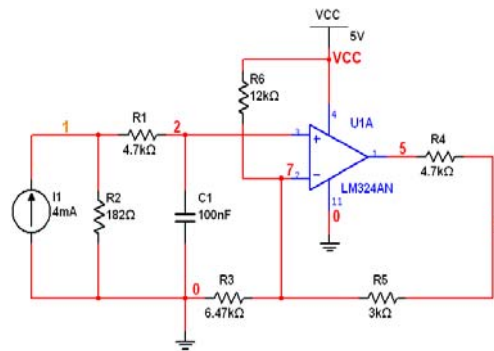
Figure 3. Schematic Picture of I/V Circuit Switch and Amplification

3.2. Software System Design

Software test platform with virtual instrument was designed by using related programing software, and CAT can be used to the test requirement such as items, contents and methods, which can process the data from the controlled, and test and control both the steady-state and transient process if the related output information was set in advance [8].
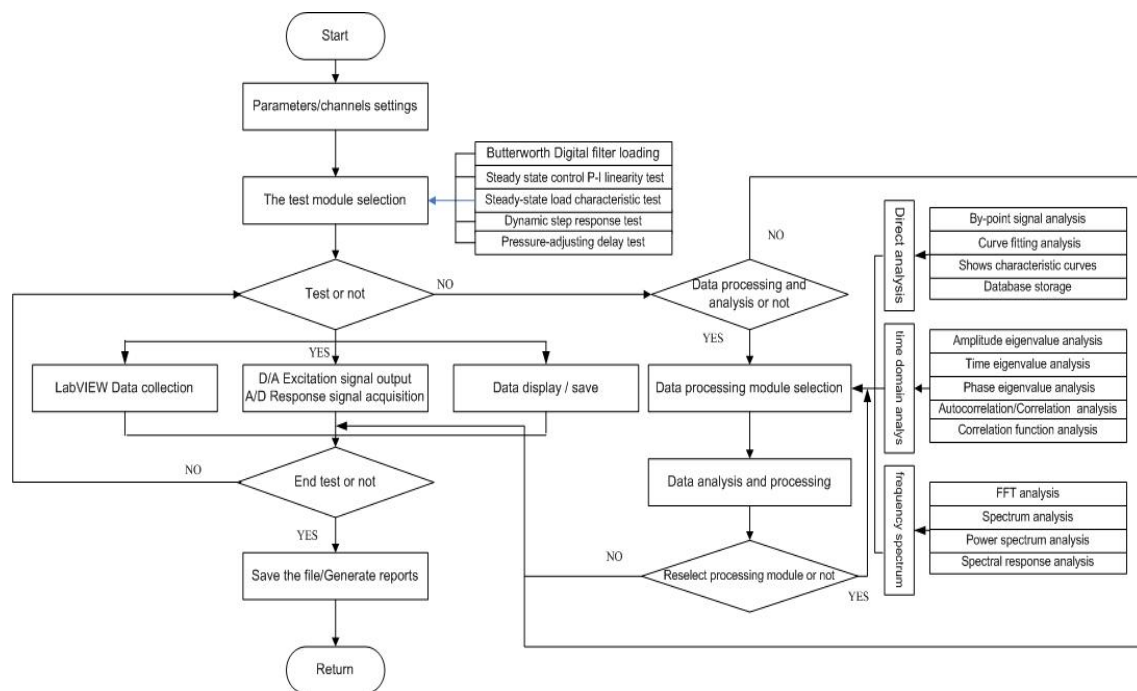

Figure 4. Flow Diagram of Modularization Design

LabVIEW was used to design and program 'Test modularity', which can divide the main program into four sub-modules such as test, control, data collection and data analysis. See Figure 4.

1) In the main program, first, the monitoring and the signal input of the test point and were set, and reflux controller was added to monitor the flow rate from the hydraulic platform

2) Second, two wave controllers were added to be connected with the entrance of every modular program so that the regular hydraulic test can be done, and the normal pump and valve can be controlled (pressure from adjustment platform and the flow can be monitored) without the engagement of the proportional relief valve.

3) The three tests for steady-state, dynamic response and pressure adjusting delay, and data collection and digital filter loading were designed as sub-modules, and were set in the front main board as buttons so as to collect data by pressing the buttons.

4) Data record, data preservation, record displaying and result printing were designed as the second level module by using the button control so as to realize the recording, preservation and printing of the data.

5) Fault alarming signal was set in the program interface by using the unique program fault system to stop the suspend feature. When there is something wrong with the hydraulic system, data collection card or software programming system,the program will be stopped immediately [9, 10].

4. Test and Data Analysis on Reform Design of Pressure Adjustment of Proportional Relief Valve

Pilot type electro-hydraulic proportional relief valve DBE10-30B-100YM was chosen as the test object can be accorded with any feature of normal valves.

4.1. Steady-state Control Pressure – Current Linearity Test and Data Analysis

The best way to measure the performance and the pressure adjustment of a proportional relief valve is to test the linearity, the feature of the pressure output and the current input under the normal hydraulic system condition. The pressure adjustment can be tested by analyzing the linearity of the valve.

1) Test Methods

(1) As the hydraulic system was working under low pressure and small flow, the highest pressure of the proportional relief valve should be 6MPa and the effective control of the input current signal for the proportional control amplifier was 400mA.

(2) After the pressure valve was recorded, a current signal was sent between the starting current signal and the rated current signal of the proportional amplifier. Repeat the process and measure the pressure of each current value while the proportional relief valve was working steady-state, record the complete cycle of P⊣ curve composed of positive sample and negative sample.

(3) Combined with curves, a group of data was collected according to the above process, and the linearity curve of steady-state pressure-current can be analyzed and compared with the ideal linearity of proportional relief valve, then the linearity of pressure adjustment can be concluded.

The analysis formula of steady-state control for proportional relief valve is:

$$\text{linearity } \Delta = \frac{\Delta L_{max}}{A} \times 100\% \leq 3.5\% \tag{1}$$

In formula

ΔL_{max} --- The maximum deviation between steady-state control curve and its best fitting line

A ---- D-value of the rated current and initial current

Because of the nonlinearity of initiation of pressure adjustment for the proportional relief valve, the starting value of linear current should be set as the lower dead point by using MATLAB to get the best fitting curve through least square method of best approximation.

2) Original Data and Calibration Analysis of Pressure-current Test

A complete cycle of linearity of steady-state control of pressure-current for proportional relief valve by using MATLAB to get the best fitting curve through three least square methods of best approximation. See Figure 5.
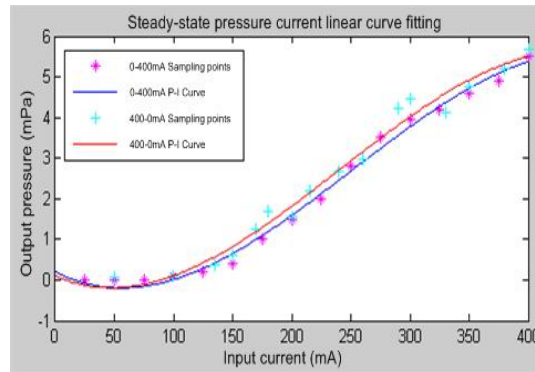
Figure 5. The Linearity Curve of Steady-state Pressure-current

It is showed in Figure 5 that pressure zero dead zone appeared between 0～100mA in the proportional amplifier, and no pressure was shown even the current drive was added to the proportional valve. It is suggested that the area should be passed as quickly as possible. When the input current was 100～250mA, the pressure signal data acquisition point was fluctuated, it is showed that nonlinearity exists in the signal during the pressure adjustment.

Table 1. Test Data of Pressure-current Linearity

0～400mA Forward sampling test (No.)	Input signals (mA)	Output pressure value (mPa)	0～400mA Reverse sample test (No.)	Input signals (mA)	Output pressure value (mPa)
1	0	0.00	1	400	5.67
2	25	0.00	2	380	5.20
3	50	0.00	3	350	4.75
4	75	0.00	4	330	4.46
5	100	0.10	5	300	4.21
6	125	0.20	6	290	4.11
7	150	0.40	7	260	2.97
8	175	1.07	8	240	2.66
9	200	1.50	9	215	2.20
10	225	2.00	10	200	1.55
11	250	2.80	11	180	1.70
12	275	3.50	12	170	1.25
13	300	3.97	13	150	0.60
14	325	4.20	14	135	0.37
15	350	4.66	15	100	0.10
16	375	4.90	16	50	0.05
17	400	5.51	17	0	0.00

The maximum derivation between steady-state control curve and the best fitting line is 240～250mA, and the data and formula can be concluded from Table 4 and Formula (1).

$$\text{linearity } \Delta = \frac{\Delta L_{max}}{A} \times 100\% = \frac{250 - 240}{400 - 0} \times 100\% = 2.5\% < 3.5\%$$

It is showed from the above that the test was engaged under the steady-state condition of proportional relief valve. The linearity of pressure-current was 2.5%, which is less than the standard linearity error 3.5%. It is also showed that the performance of proportional relief valve was stable, and the nonlinearity error was normal, the design of the pressure adjusting platform was reasonable and the adjustment precision was correct. The proportional relief valve can be used in a practical situation with actual data and analysis to correction error compensation in order to better improve the performance of proportional relief valve.

4.2. Steady-State Pressure-Current Test Analysis on Time Domain and Frequency Spectrum

a) Methods

The pressure load in the hydraulic cylinder should be kept to be 1, the pressure in the proportional relief valve should be adjusted to 5.5, and 400mA was added to the proportional amplifier.

The data wave was recorded by the test software system, and the changing linearity of steady-state pressure time domain wave was analyzed.

The data from the collection card was analyzed by MATLAB. The frequency spectrum was programed, and the FFT was engaged immediately. To analyze the proportional relief valve under the adjustment pressure, and to analyze the spectrum distribution of pressure signal and fluctuation, noise and pressure fluctuation in the hydraulic system.

b) Test Analysis

(1) Time Domain Analysis

The rate of sampling card was 40960S/s through point sampling. It is showed in Figure 6 that the time domain wave was within 0.05s, and the sampling points were from 17888 to19991.

It is showed from the Figure 6 that the pressure curve collecting from the adjusted pressure value of 5.5MPa in the proportional relief valve was not a linear but a curve with irregularity and fluctuation, which suggested that under the steady-state load condition, hydraulic cylinder would produce pressure disturbance to the pipeline system to overcome the work load. And what is more, the hydraulic cylinder would be delayed while producing pressure disturbance or delayed by the external disturbance. It can be seen large fluctuation in the sampling of 18000, 18800, and 19200 of the curve time domain.
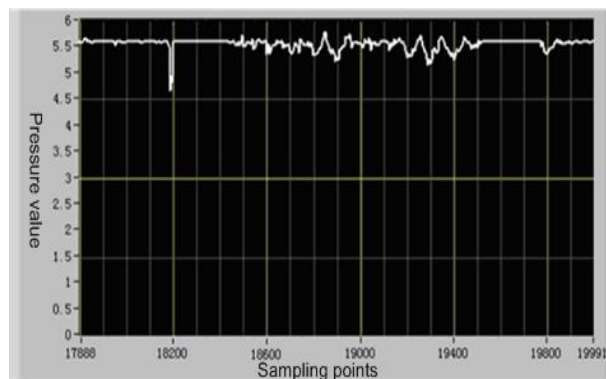

Figure 6. Analysis of Time-domain Waveform

(2) Power Spectral Density-Frequency Analysis

The mathematical integral of stable random signal cannot be converged just as the specific statistical average value cannot be showed the reflected random signal as the set signals, as a result, function in the frequency domain and power spectral density function should be used to show the average spectral characteristics. The purpose of frequency domain characteristics is to record both FFT function in the frequency domain and power spectral density function.

Spectrum density waveform is the most important parameter for testing stationary random signal and it can clearly display the distribution of discrete stationary random signal, machine or fluid vibration signal. Spectrum density waveform analysis is easy to find breakdown, noise and vibration problem during the operation.

The energy spectrum analysis in the time domain waveform data acquisition point was seen in the Pic 37 when the pressure value was 5.5MPa. To test the actual vibration signal, bilateral power spectral density analysis would be used in the MATLAB time frequency toolbox, and it is shown in the Figure 7 as the Bilateral Spectrum, whose sampling frequency was 200Hz, only unilateral power spectral density of 0～100Hz will be analyzed.
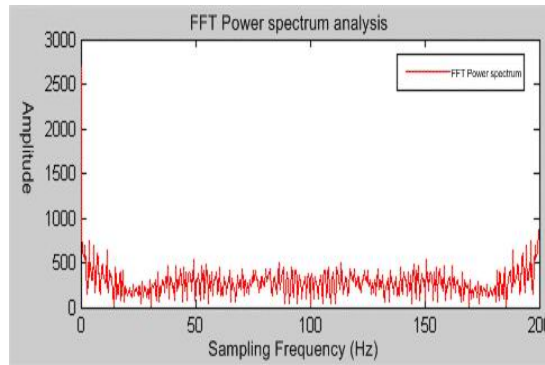
Figure 7. Analysis Graph of Spectrum Density Waveform

It is showed from the curve of power spectral density that within the pressure signal of finite sampling point data, the maximum spectrum peak was at 10Hz, and its amplitude was 740; another larger peak was at 50Hz, and its amplitude was 500; the third larger peak was at 80Hz, and its amplitude was 450, however, other power spectral density were distributed sparsely, and their amplitude was between 100 and 400.

It is concluded from the above that under the low pressure and small flow condition, the pressure fluctuation from the pressure adjusting system of the proportional relief valve was focused to a large extent on the low frequency, and vibration and low-frequency pressure pulsation were showed in the hydraulic system and test system because of disturbance.

4.3. Pressure-adjusting Delay Test
1) Theoretical analysis

Hypothesis test of average difference t was engaged with the two discrete stationary random sequences, and their normality and independence were tested. There is no significant difference between sampling value and theoretical value.

Relative analysis was to describe whether linearity exists between two variables. In a broad sense, two stationary random sequence $x(n)$ and $y(n)$,their cross correlation coefficient was:

$$Z_{xy} = \sum_{n=0}^{N-1} x(n) \cdot y(n) / [\sum_{n=0}^{N-1} |x(n)|^2 \cdot \sum_{n=0}^{N-1} |y(n)|^2]^{\frac{1}{2}} \qquad (2)$$

To evaluate the relative function of the two random sequences, and observe the change direction whether positive correlation, negative correlation or zero correlation. If the change direction of $x(n)$ 、 $y(n)$ is the same, the coefficient correlation will be z>0; and if the change direction of $x(n)$ 、 $y(n)$ is the opposite, the coefficient correlation will be z<0; and if there is no change direction of $x(n)$ 、 $y(n)$, the coefficient correlation will be z=0.

Table 2. Measurement Dates of Pressure-adjusting Delay

Input current (mA)	Output pressure value (mPa)	Delay time (s)
0.100	0.10	0.056
0.150	0.40	0.061
0.175	1.07	0.060
0.200	1.50	0.054
0.225	2.00	0.049
0.250	2.80	0.050
0.275	3.50	0.051
0.300	3.97	0.037
0.375	4.90	0.053
0.400	5.51	0.047

2) Test analysis

In the test, a group of control current signals were sent from the computer to the proportional relief valve, and timing. Observe the current value and pressure value and record and monitor the time when changes from the current input to the output of the pressure, and then analyze the two random numerical sequences.

The original data of pressure adjusting delay test was shown in Table 2.

3) Visualization analysis of 3D space

Visualization of 3D space, programed by MATLAB, can be clearly and directly display the internal relations between current input, pressure output and pressure-adjusting delay into the 3D space. It is showed in Figure 8 that after the operation of the test system, the pressure adjustment of proportional relief valve was not stable when the initial current adjustment was chaged, and because the overflow was not fully finished when the hydraulic pump was started with low pressure, the initial time for pressure adjustment was delayed longer, however, whrn the system was operated normally, the pressure adjustment delay was shortened.
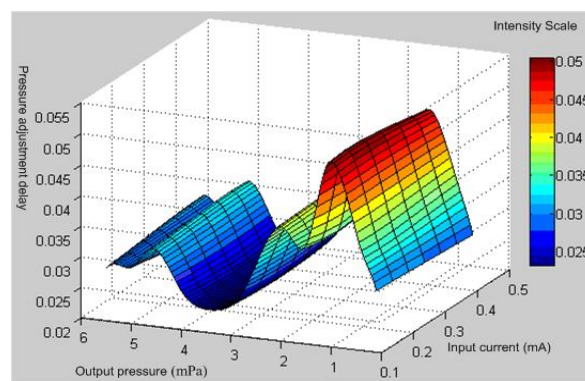

Figure 8. Visualization Analysis of 3D Space

Figure 8 shows Visualization analysis of 3D space for the current imput, pressure output and pressure adjustment delay.

It can be concluded from the above analysis that there are significant changes in current input and pressure output in the proportional relief valve, and the coefficient correlation is positive, which signified that the changing speed and the pressure value are in the same direction every time in the current adjustment sampling point, and the pressure adjustment delay is short at the speed of ms, which can be achieved within 100ms.

Some current adjustment and weak pressure voltage follower still exist in the test, which shows that pressure adjustment delay exists in the proportional relief valve during the test, and the problem is that the pulsation interference in the hydraulic system and electromagnetic and noise disturbance could be responsible for the nonlinearity of the test result.

4. Conclusion

The pressure adjusting delay platform of proportional relief valve is a reform of self-design and study with low-cost combined with electro hydraulic proportional control and visual instrument of CAT. The content of the pressure adjustment of proportional relief valve was introduced from different angles and the steady-state, dynamic and delay characteristics in the pressure adjustment were tested and analyzed, and the sampling data were processed and analyzed on a time domain and frequency domain basis, and the reference data were acquired and the conclusion of the pressure adjustment characteristics were reached.

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