TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.4, April 2014, pp. 2753 ~ 2761
DOI: http://dx.doi.org/10.11591/telkomnika.v12i4.4277

Design of Electric Load Measuring and Controling System for Steering Sevro

Pan Wentao, Peng Zhaoqin*, Caochun Li Bo
School of Automation Science and Electrical Engineering, Beihang Uinversity
NO.37 Xueyuan Road, Haidian District, China, 010-82338192
*Corresponding author, e-mail: pengzhaoqin@buaa.edu.cn

Abstract

An automatic loading simulation and testing system of steering servo was designed in this paper. Design of hardware and software of the testing system were illustrated, and the Load testing principle and test strategy were analyzed. Torque servo motor was used to simulate the loading added to the steering servo. The torque magnitude was controlled proportional to the angular displacement of the steering servo to simulate elastic load. Fuzzy PID control algorithm was used to make torque servo motor follow the change of angular displacement quickly and accurately. The effectiveness of the automatic testing system was proved by the experimental results.

Keywords*: automatic test, loading simulation, fuzzy PID*

1. Introduction

In the field of flight control system, load simulator is one of the main devices which can simulate the loading added to the actuator. The load simulator can imitate the aerodynamic loads of the actuator suffered by the aircraft during the flight by adding loading to the actuators system of the missiles or aircrafts.

Recent years, many institutes do researches on the loading simulator [1-3]. The main loading mode of the load simulators are electro-hydraulic loading and electro loading. Electro-hydraulic loading method has the advantage of high precision, wide frequency band, big torque, etc. However, there is still some disadvantages, such as oil leakage, pollution, and inconvenient maintenance. Electro loading method has the advantage of no heavy oil source, light pollution, easy to maintain, high response speed, simple structure, high reliability. With the development of the theory of driver and control, the electro load simulator now can realize bigger torque loading, high precision, and wide frequency band. Electro loading simulator is the best choice for the lower loading motor [4, 5]. Torque motor is suitable for torque loading measuring system with low speed, high torque and accurate torque output. Servo box could be reduced when test system used torque motor as the load, so the error that was caused by mechanical backlash could be avoided.

Torque output was linear with the angular displacement of the steering servo output for simulating the real state. So the torque motor must be able to follow the signal of angular displacement quickly. In order to improve the controlling performance, torque signal was controlled with fuzzy PID controller. Fuzzy PID controller consists of fuzzy controller and PID controller, which contains both the accuracy of PIDcontroller and real-time feature of fuzzy controller. Its good robustness can cater to need of nonlinear system [6, 7].

2. Structure of the System

The automatic electro loading simulation and measuring system designed in this paper is to realize torque loading for some kinds of steering sensors, and was used to finish some static and dynamic performance automatic testing for the steering servos.

Received August 12, 2013; Revised October 28, 2013; Accepted November 16, 2013

2.1. Mechanical Structure

The mechanical platform was consisted of base, tested steering motor, coupling, encoder, bearing seat, torque sensor, loading motor and all kinds of fixtures. The mechanical structure of the experiment platform was shown as Figure 1. The tested steering servo is the work object of the testing platform, and the testing system tested the static and dynamic performance of the steering motor automatically. The required torque was added by the loading motor, the value of loading torque varied with the change of the input voltage of the loading motor which resulting in continuous and smooth loading.

2.2. Structure of Measurement and Control System

The performance of the measurement and control system decided the accurate of steering servo measuring system. The efficiency, quality, and cost of hardware should be considered.

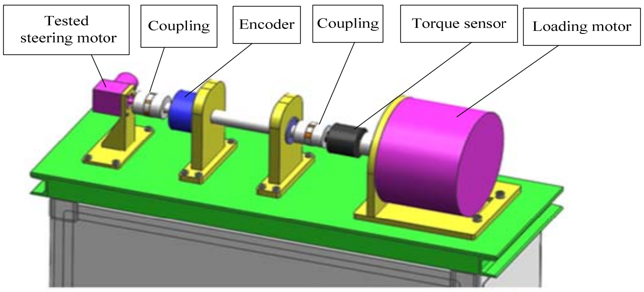

Figure 1. The Mechanical Structure of the System

Because the system need control the loading motor and the tested actuator besides the data analyzing and processing. The structure of up and lower computers was adopted in this system. The up computer which run in windows operating system mainly to finish data acquisition, data saving, data analyzing, data displaying, etc, and the lower computer was mainly to take as loading controller. According to the requirements of the loading in the static and dynamic performance testing, DSP technique was adopted in the lower computer, which was consisted of DSP minimum system, A/D, D/A, RS485 communication module, sensor signal transmitter, power module, auxiliary circuits. The composition diagram of the system was shown in Figure 2.

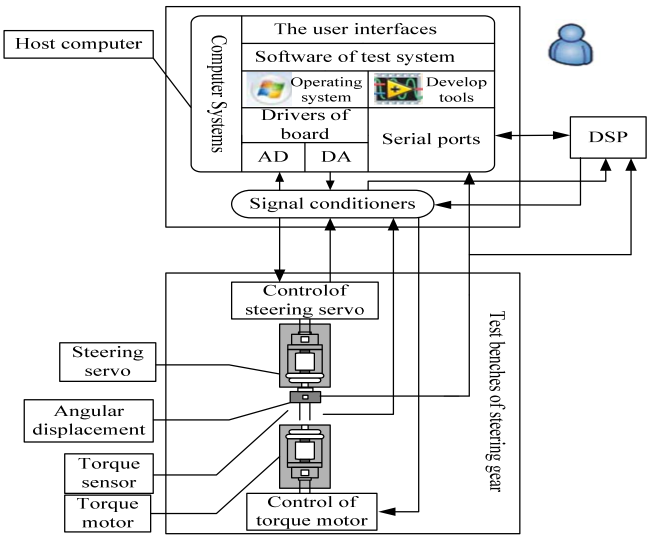

Figure 2. Overall Structure Diagram of Measuring System

Torque motor and steering servo were both fixed on the mechanical platform, and were connected into a whole through the couplings, torque sensor and angular displacement sensor. Industrial computer and DSP board output excitation signal of steering servo and torque motor, and acquisition boards collected output signal of sensors and the feedback signal of steering servo.

2.3. Structure of the Software System

The function of the software was to realize online integrated management for the system, performance test, security, protection and monitoring of steering servo measuring system. Modular structure was adopted in the software system. Each modular was independent of each other. The software of measuring system mainly included two parts: host computer program and lower computer program.

1) Host computer program: The functions of this part include parameter settings, status display, data display and processing, and serial communications. The host computer program was programmed in Labview environment with higher readability and compatibility. The function of the program was shown in Figure 3 .

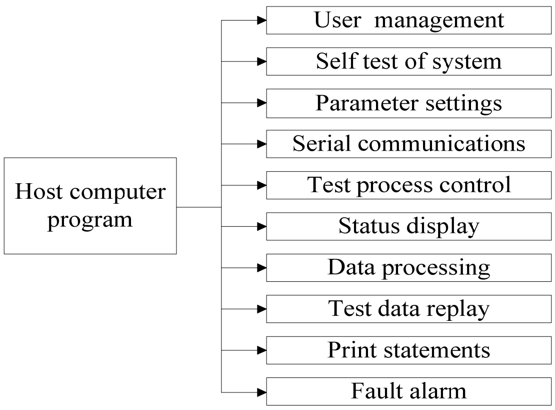

Figure 3. Software Functions of System

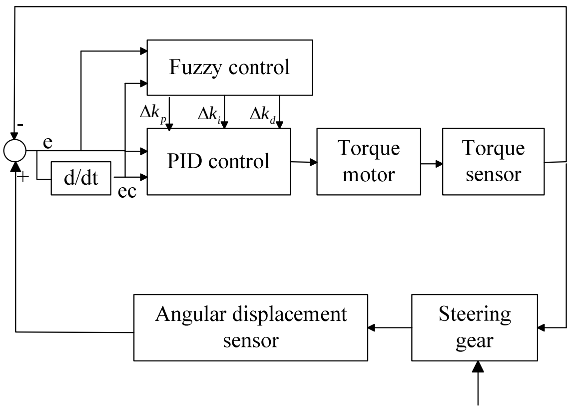

Figure 4. The Control Block of System

2) Lower computer program: The program mainly controlled the torque motor and steering servo by DSP board. The program was programmed with C program language in CCStudiov3.3. The control block diagram was shown in Figure 4.

DSP board received order from the host computer through serial communication, and output the control signal to steering servo. According to the signal steering angular displacement signal and torque sensor, the DSP board output the control signal to the torque motor. Thus the measuring system could load elastic load to steering servo.

3. Control Algorithm

In the measuring system, the control signal of torque motor must follow the output signal of the angular displacement of the steering servo. So the system must response quickly to the change of input signal. Traditional PID control method was widely used in the industrial control process currently. The parameter of PID control was defined by engineering experience, However, It was difficult and time-consuming to get perfect parameter. The speed of response could not meet the requirements if the measuring system was controlled just by PID control.

Fuzzy controller measured controlled object, and converted the measuring signal to fuzzy amount that described by human language through the fuzzy interface converter. Then the fuzzy control output fuzzy amount by the rules based on human language. Accurate output could be got by defuzzification. Fuzzy control has better robustness and adaptability and was fit to the measuring system [8].The parameters k_p, k_i and k_d were the kernel of PID control. Self-tuning fuzzy PID controller was composed by PID control and fuzzy control. The parameters of

PID control were corrected online by fuzzy control. Fuzzy PID control not only maintained the features of PID control, but also had flexibility, better control accuracy and quickly response.

As shown in Figure 4, the error e and the error rate ec were the input of the fuzzy control, ΔK_p, ΔK_i and ΔK_d were the output of fuzzy control. The fuzzy amount E and EC of e and ec could be obtained from Equation (1).

$$K_e = < \frac{2m}{e_H - e_L} \cdot \left(e - \frac{e_H + e_L}{2} \right) > \tag{1}$$

Where e_H, e_L are the maximum and minimum of e, m is the maximum of fuzzy amount. K_e is the fuzzy amount of e. The accurate output Δk_p, Δk_i and Δk_d could be obtained from Equation (2).

$$u = \frac{u_H - u_L}{2l} \cdot U + \frac{u_H + u_L}{2} \tag{2}$$

Where u is the accurate output of fuzzy control, u_H and u_L are the maximum and minimum of output, l is the maximum of the fuzzy amount, and U is fuzzy output of the fuzzy control.

The measuring system assumed the fuzzy subsets of E, EC and U were both {NB, NM, NS, ZO, PS, PM, PB}, where NB is negative big, NM is negative middle, NS is negative small, ZO is zero, and PS is positive small, PM is positive middle, PB is positive big.

The fuzzy control chooses Gaussian function $u_{A_i}(x) = e^{-\frac{(x-a_i)^2}{b_i^2}}$ as distribution function. Where a_i is the central of function and b_i is the width of function. The central of {NB, NM, NS, ZO, PS, PM, PB} is {-3, -2, -1,0,1,2,3}. The sharp of the distribution function was shown in Figure 5.

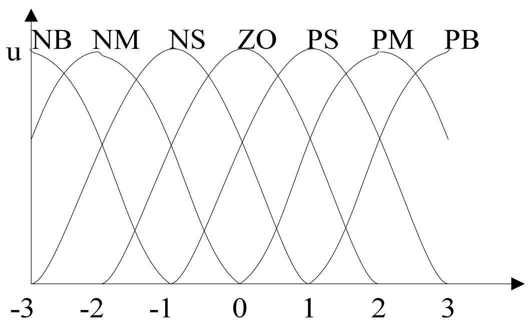

Figure 5. The Membership Distribution Function

The error e and error rate ec were the input signal of fuzzy and PID control. The fuzzy amount E and EC could be get by fuzzy control. The measuring system set the initial values k_{p0}, k_{i0} and k_{d0} of the PID control. The three fuzzy amounts ΔK_p, ΔK_i and ΔK_d could be obtained by fuzzy inference table, which was shown in Table 1.

Table 1. $\Delta K_p / \Delta K_i / \Delta K_d$ Fuzzy Inference Table

E \ EC (U)	NB	NM	NS	ZO	PS	PM	PB
NB	PB/NB /PS	PB/NB /NS	PM/NM/NB	PM/NM/NB	PS/NS /NB	ZO/ZO /NM	ZO/ZO /NS
NM	PB/NB /PS	PB/NB /NS	PM/NM/NB	PS/NS /NM	PS/NS /NM	ZO/ZO /NS	NS/ZO /ZO
NS	PM/NB /ZO	PM/NM/NS	PM/NS /NM	PS/NS /NM	ZO/ZO /NS	NS/PS /NS	NS/PS /ZO
ZO	PM/NM /ZO	PM/NM/NS	PS/NS /NS	ZO/ZO /NS	NS/PS /NS	NM/PM/NS	NM/PM/ZO
PS	PS/NM /ZO	PS/NS /ZO	ZO/ZO /ZO	NS/PS /ZO	NS/PS /ZO	NM/PM/ZO	NM/PB /ZO
PM	PS/ZO /PB	ZO/ZO /NS	NS/PS /PS	NM/PM/PS	NM/PM/PS	NM/PB /PS	NB/PB /PB
PB	ZO/ZO /PB	ZO/ZO /PM	NM/PS /PM	NM/PM/PM	NM/PM/PS	NB/PB /PS	NB/PB /PB

The accurate output Δk_p, Δk_i and Δk_d be obtained through defuzzification. The parameters k_p, k_i and k_d were corrected by the Equation (3) as shown.

$$\begin{cases} k_p = k_{p0} + \Delta k_p \\ k_i = k_{i0} + \Delta k_i \\ k_d = k_{d0} + \Delta k_d \end{cases} \quad (3)$$

The measuring system had accurate output and quickly response and achieved the desired control effect through fuzzy PID control.

4. Testing Principle

The measuring system was shown in Figure 6. Zero position characteristic, linearity and transfer coefficient, frequency characteristic and maximum torque of sreering sevro was measured through the measuring system that was be designed to verity the performance of the system. The principles and methods that were used to measure the parameters of sreering sevro were as follows.

Figure 6. The Measuring System

1) When the input signal of steering servo was zero. The feedback voltage signal and angular displacement signal of steering servo were both zero, and the feedback voltage signal was symmetric about the origin with the input signal. However, there was always some deviations which was caused by electrical, magnetic, mechanical, fabrication, assembly and other factors between electrical zero position and mechanical zero position. The feedback signal of steering servo was always not zero when the input signal was zero, and there was a no-linear region near the origin. The purpose of zero position testing was to measure the deviations between electrical zero position and mechanical zero position.

The triangular wave control signal was treated as the input signal of steering servo, and the data acquisition board collected the feedback voltage signal of the steering servo simultaneously. The voltage value of feedback was calculated and recorded by the host computer program.

2) Transfer coefficient and linearity are two parameters that reflect the degree of electric linear of electric steering servo. The input and output of steering sevro were proportional relationship theoretically. However, there was always varying degrees of nonlinearity due to systematic error and random error. Therefore, linearity and transfer coefficient characteristics of steering servo needed to be analyzed in practical engineering. In the real experimental, taking m voltages x_i in the range -10V to +10V was treated as the input signal of steering servo, and measured the corresponding angular displacement signal y_i. The best fitting straight line was found by the program, and all of the output signal should be as close as possible to the line. The essence of fitting straight line was calculated the best slope and intercept estimate. Fitting method commonly used commonly least square method fitting parameters [9].

Measuring data points (x_i, y_i) could be fitted with the line $y = kx + b$. The relationship between input signal and feedback signal could be described by the fitting line. The principle of least squares method was to make the sum of absolute values of deviations $\sum_{i=1}^{i=m} |y_i - kx_i - b|$ or $\sum_{i=1}^{i=m} (y_i - kx_i - b)^2$ as small as possible.

The value of k and b could be estimated by the equation (4), where the slope of the fitting line k is the transfer coefficient of steering servo.

$$\begin{cases} k = \overline{y} - b\overline{x} \\ b = \dfrac{\sum_{i=1}^{m} x_i y_i - m\overline{x}\,\overline{y}}{\sum_{i=1}^{m} x_i^2 - m\overline{x}^2} = \dfrac{\sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n} (x_i - \overline{x})^2} \end{cases} \quad (4)$$

The maximum distance between measuring points and fitting line is $\Delta L_{\max}$. The linearity of steering servo could be obtained through the Equation (5).

$$\gamma_L = \frac{|\Delta L_{\max}|}{Y_{FS}} \times 100\,\% \quad (5)$$

Where γ_L is the linearity of steering servo, and Y_{FS} is full-scale angular displacement output value of the steering servo.

3) Frequency characteristic was used to describe the mathematical model of steering servo system. Frequency characteristic reflected the inherent characteristics of steering servo and was mainly used to measure the amplitude-frequency characteristic, phase-frequency characteristic and pass band.

In the frequency characteristic testing, the steering servo was controlled by 0.1Hz to 10Hz sinusoidal signal. The data acquisition board collected the feedback voltage signal and angular displacement signal of steering servo. The curves of amplitude-frequency characteristic and phase-frequency characteristic were drawn according to the collected data. The pass band and phase lag was most important parameters of frequency characteristic. Low pass band would limit the steering servo response speed, and high pass band would affected by the noise. The phase lag is the phase difference between the phase of input and phase of corresponding output signal [10, 11].

4) In the maximum torque characteristic testing, the output of torque motor increased with the increasing of angular displacement. The data acquisition board collected the maximum torque until the angular displacement of steering servo no longer increased.

4. The results

The steering servo was controlled by four period's 2V triangular signal; the data acquisition board collected the voltage feedback signal. The result of the zero position characteristic tests was shown in Figure 7. The black curve was the control signal of steering servo, and the red was the voltage feedback signal. The average value of voltage feedback was 0.0239V when the control signal was zero.

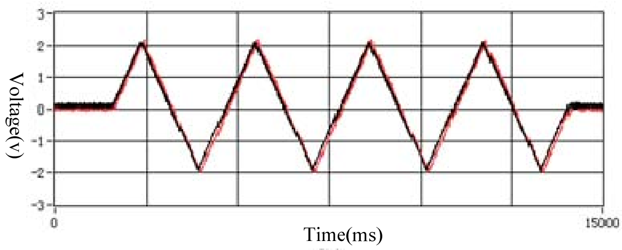

Figure 7. The Result of Zero Position Characteristic Tests

Taking some voltages in the range -10V to +10V was treated as the input signal of steering servo, and measured the corresponding angular displacement signal. The fitting line was found through least square method. The original curve and fitting line were shown in Figure 8 as follows:

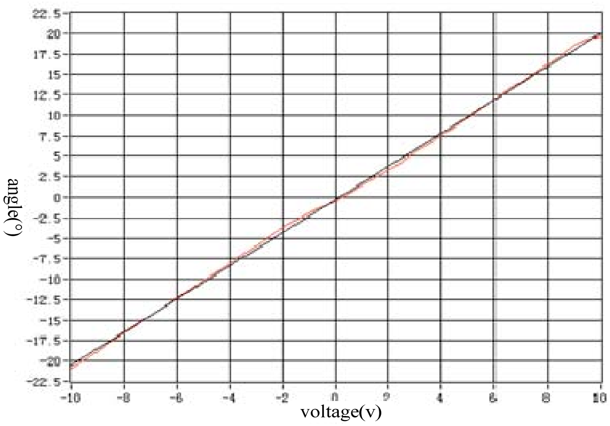

Figure 8. The Result of Linearity and Transfer Coefficient Tests

Where the red curve was the origin curve and the black was the fitting straight line. The angular displacement output was linear with the input of steering servo. The linearity was 2.58% and the transfer coefficient 2.01 $°/V$.

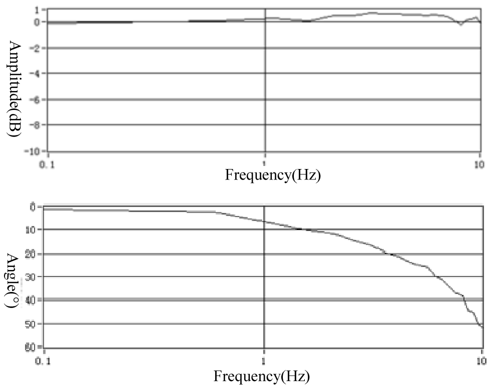

Figure 9. The Result of Frequency Response Tests

The steering servo was controlled by from 0.1Hz to 10Hz sinusoidal consecutive signal. The data acquisition board collected the voltage feedback signal and angular displacement signal of steering servo. Frequency response of the steering servo was shown in figure 9. The width of pass band was greater than 10Hz. The steering servo could quickly follow the control signal when the frequency of control signal was less than 10Hz. The phase angle difference between input and output signal was about 52 ° at 10Hz.

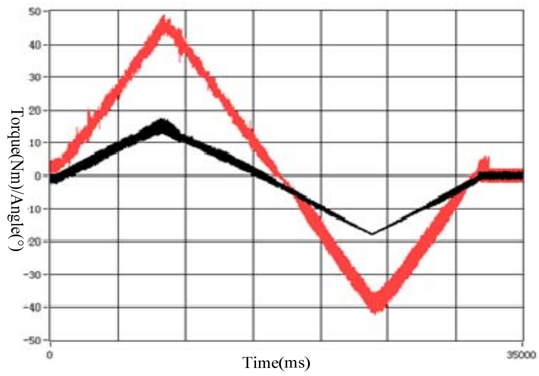

Figure 10. The Result of Maximum Torque Tests

The maximum torque $T_{\max}$ should be estimated through the engineering experience. The ratio between the angular displacement of the steering servo and the input of torque motor $k^{'}$ was set firstly, so that the output of torque motor was greater than maximum torque of steering servo when the angular displacement of steering servo was greater than 90% of full scale. The amplitude of steering servo control signal increased slowly. The data acquisition board collected the signal of torque sensor and angular displacement signal of steering servo. The curves of torque and angular displacement were shown in Figure 10.

Where the black curve was the angular displacement of steering servo and the red is the signal of torque sensor. The forward maximum torque was 48.41Nm and reverse maximum torque was 41.01Nm.

4. Conclusion

This paper mainly designed and researched the principle, hardware system, and software system and control strategy of the steering servo measuring system. The torque motor was treated as the load for simulating the real state of steering servo. The accuracy of torque and the speed of the measuring system were improved through fuzzy PID control method. The virtual instrument technology and automated testing techniques were combined for completing the design and development of the steering servo measuring system.

Acknowledgements

This research is a general project (61305131) supported by Natural Science Foundation of China. Special appreciation should be given to Research Centre of Fluid Power Transmission and Control, Beihang University for the sake of their selfless help.

References

[1] Cui Huayang. Electro-Hydraulic Actuator Load Simulation Control System. Xi'an. Northwestern Polytechnical University. 2006.
[2] Wang ShouKun, Wang Junzheng. Dynamic Loading for Missile Actuators. *Transactions of Beijing Institute of Technology.* 2007; 27(3): 247-250.
[3] Kang Chen, Jianhua Wang, Jie Yan. Experiment and Study of Electric Loading Simulator for Llinear Rudder. *IEEE Intelligent Control and Automation*. WCICA 7th World Congress on 2008; 4798 -4802.
[4] Liu Jianxing. Research on Electric Loading System of Rudder Based on DSP. Harbin. Harbin Institute of Technology. 2010.
[5] Yaoxing Shang, Shuai Wu, Zongxia Jiao. *Study on Ultimate Performance of Light-duty Electro-Hydraulic Torque-Load Simulator. Robotics, Automation and Mechatronics*. IEEE Conference on 2008: 387 -392.
[6] Wang Shuyan, Shi Yu, Feng Zhongxu. A Method for Controlling a Loading System Based on a Fuzzy PID Controller. *Mechanical Science and Technology for Aerospace Engineering*. 2011; 30(1): 166-172.
[7] Rubaai A, Castro-Sitiriche MJ, Ofoli A. *DSP-Based Implementation of Fuzzy-PID Controller Using Genetic Optimization for High Performance Motor Drives.* IEEE Industry Applications Conference. 2007: 1649 -1656.
[8] Huang Weihua. Fuzzy Control Systems and Applications. Beijing. Electronics Industry Publishing House. 2012.
[9] Wang Xinhe, Cheng Shizhou. The Method of Least Squares Carve Fitting. *Journal of Xinjiang Vocational Uinversity*. 2004; 12(2): 84-86.
[10] Wang Jun. The Study of Frequency Characteristic Measurement System for a Kind of Missile Actuator. Taiyuan. North University. 2008.
[11] Xiaoqi Huang. *The Amplitude Frequency-Response Characteristic and Phase Frequency-Response Characteristic in measuring Harmonic Fluid Temperature.* Proceedings of the 7th Asian Thermo physical Properties Conference. 2004.