2D PNEUMATIC DIGITAL SERVO VALVE

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ABSTRACT

The digital servo valve is composed of 2-stage pneumatic servo valve developed with rotary and linear motions of a single spool, and stepper motor under continual control. To sustain the stability of the 2-stage pneumatic servo valve, an air damper is incorporated into the valve which is intended to increase both the stiffness of "pneumatic spring" and the damping ratio. The height of the circular clearance has a crucial effect on the dynamic characteristics of the valve. In this paper, the model of the pneumatic digital servo valve is established and the static positioning accuracy of the spool and the dynamic response are investigated.

INTRODUCTION

With the availability of low priced microprocessors and the introduction of modern control theory, the performance of pneumatic control has greatly improved and now can meet the requirements of ordinary industries for high accuracy and high speed control purposes. The application of pneumatic servo control demands accurate and swift adjustment of the flow rate, which is achieved by a pneumatic servo valve. Though, the Bernoulli force in the pneumatic control valve is much smaller than that of a hydraulic control system. However, there are many reasons to believe that the pneumatic servo valve should be designed to be of the two-stage type. So far the schemes of pneumatic two-stage flow rate valve are rarely seen in the literatures. The only two-stage pneumatic servo valve is pneumatic nozzle-flapper servo valve which was evolved from its hydraulic counterpart and utilized peculiarly in high pressure pneumatic servo for above mentioned high-pressure system. There are many reasons to believe that the nozzle-flapper servo valve is no longer apt to the low pressure (0.8 MPa (abs.)) pneumatic servo control.

For this reason, a two-stage pneumatic flow rate valve, called 2D pneumatic valve, specially designed by utilizing both rotary and linear motions of a spool, is introduced. In this paper, the static and dynamic characteristics of the valve are presented.

2D PNEUMATIC SERVO VALVE

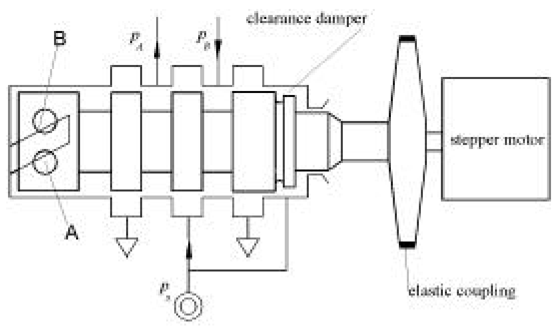

Fig. 1 2D Digital pneumatic servo valve

The 2D pneumatic digital servo valve is shown in Figure 1. With reference to Figure 1, on the left spool land, there are small round holes, labeled A and B, which are connected to the compressed air source and atmosphere respectively. On the left side of the spool cavity there is a spiral groove which is connected to the end of the spool chamber. In the "neutral" position, holes A and B are located on the two sides of the spiral groove as shown and form two small crescent overlapping openings, which are connected in series to form a resistance bridge. The input pressure p_s is piloted to port A and to the right spool chamber through a clearance damper. The output pressure of the resistance bridge is fed to the left valve chamber through the spiral groove. The right end area of the spool is arranged to be half of the left one. Under static conditions, hole A has the same overlap area with respect to the spiral groove as does hole B; the resistance bridge gives an output pressure of $p_s / 2$ ported to the left spool chamber, regardless of coulomb frictional force and Bernoulli's force. In this case, the spool is in aerostatic balance. When the spool is rotated by the stepper motor, which consequently changes the two crescent overlapping openings differentially, the pressure of the left spool chamber will shifts from its static value and cause the aerostatic force acting upon the spool unbalance, which drives the spool to move. The linear motion sends the holes A and B to return to symmetrical sides of the groove and the pressure of the left spool chamber recovers to its initial value.

Obviously, the 2D pneumatic valve is a two-stage flow rate valve. From the point of view of engineering control, the valve is a pneumatic mechanical servo device with the feed back of the spool's linear displacement and the angular displacement of the spool is driven by the stepper motor. The height of the clearance damper has a significant effect on the step response of the 2D pneumatic servo valve. The linear response of the spool to the rotary step motion is presented in Fig. 2.

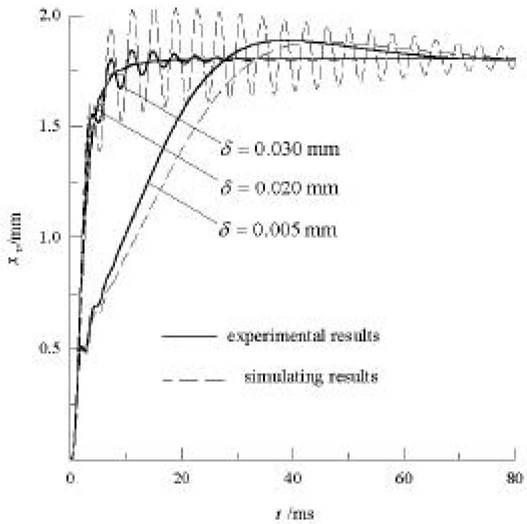

Fig.2 Step response of spool under different height of clearance damper

DIRECT DIGITAL CONTROL

In the design of the 2D servo valve, a small number of steps corresponding to full stroke of the spool is selected to maintain the high responding speed. The accuracy is sustained by introducing continual control of the stepper motor. There are several possible methods to achieve continual control of the stepper motor. One of them is PWM control between two adjacent stepping points. It is realized by a special control program in a micro-computer. Within each sampling cycle, the micro-computer obtains the discrete value of the continuous input signal through A/D conversion or from an upper-stage computer directly. By running the control program, the sampling signal is converted into a PWM signal. For a slope input signal, the signal conversion from the sampling signal to the PWM signal is shown in Fig.3. The signal conversion produces an additional digital fragment. A spectral analysis displays the main energy of the fragment signal as distributed over a high frequency range. Thus the effect of the fragment signal on the dynamic characteristics of the 2D digital servo valve is negligible. However, the existence of the fragment signal is an important approach to provide a dynamic lubrication of the spool and to reduce the friction. This is a unique feature of PWM control which distinguishes it from the other approaches of continual control of stepper motor. The algorithm is just one consideration in the control

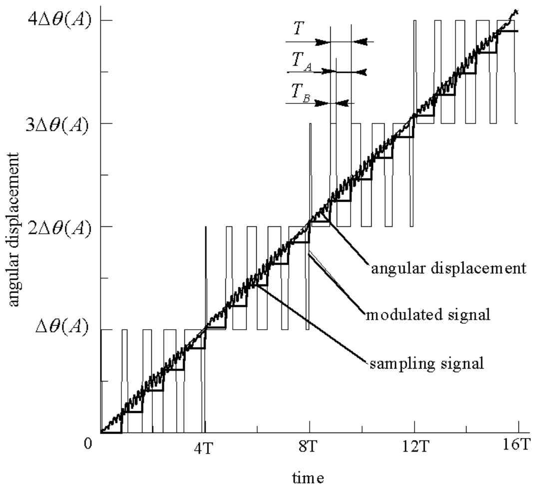

Fig.3 Continual control of step motor with PWM signal

of a digital spool valve. In the complete control program of the digital valve, several other considerations concerning the digital valve have been taken into account. They include initialization, power monitoring and energy saving modes.

Initialization

When the power supply of the controller is turned on, the stepper motor is "zeroed" to some starting position. This process is defined as the initialization of the stepper motor. There are two ways to carry this out; physical initialization and logical initialization.

In physical initialization the spool is positioned (centered) physically to coincide to the zero position of the stepper motor. This requires the setting of a "mechanical dead-point". The stepper motor is first moved to this point to establish a reference. Then, the motor is stepped back a known number of steps to its zero point.

In logical initialization, when the power supply is turned off after use, the stepper motor is returned to zero position through a power monitoring control (to be discussed). At this point, the stepper motor is connected as a generator and the rotor is locked. The stepper motor is kept in the zero position by the action of the permanent magnetic torque of the stepper motor. When establishing a logical initialization, the controller directly controls the phrases of the stepper motor which correspond to the zero position.

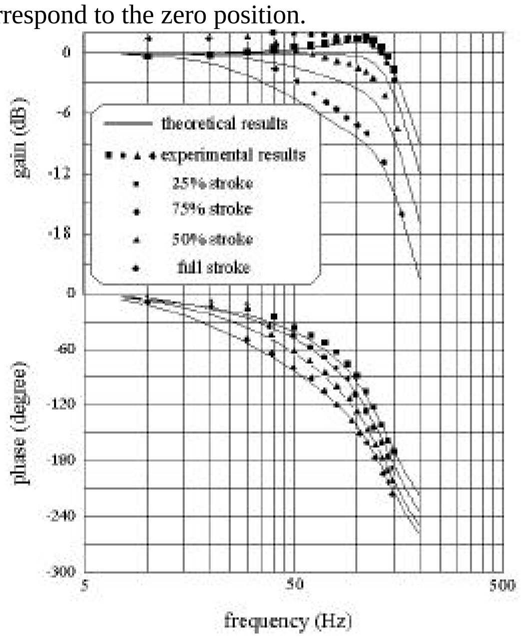

Fig.4 Frequency response of the 2D pneumatic digital servo valve

Power Monitoring

When the power supply turns off or fails due to an accident, the stepper motor is forced to its zero position using a large capacitor.

Energy Saving Working Mode

If the input signal is unchanged for a number of sampling cycles, the phase current of the stepper motor is decreased to a lower percentage of the rated current. When the input signal changes, the phase current is returned to the rated current. This type of control is often found in electro-hydraulic open loop applications.

It can be clearly seen from Fig. 3 that within the full scale of the input signal the PWM signal is repeated for N_0 times and the stepper motor can be regarded as a multi-polar magnet. For this reason, the static error of full scale is reduced N_0 times in comparison with the conventional proportional electro-mechanical convertor, such as proportional magnet and torque motor.

Because of the continual control for the stepper motor, the quatitative error is eliminated. Thus, small step number can be adopted to sustain the fast response of the stepper moter (valve). Fig. 4 gives the frequency response of a typical 2D digital servo valve. For a 25% full scale input signal, it has a bandwidth of 150Hz under the gain of –3 dB.

CONCLUSIONS

Because the stepper motor is an increment actuating component, the response ability of 2D digital servo valve to sinusoid wave is related to both frequency and amplitude. The smaller the amplitude of the signal, the higher the frequency response ability. This characteristic is especially beneficial to the application of the 2D digital servo valve in a close loop control system, where the valve works at a range near zero position to avoid flow rate satiation.

The digital fragment signal can be taken as dithering signal, which will be beneficial to reduce coulomb frictional force and to improve positioning accuracy of the spool further. Both of the repetitive error and hysteresis of the 2d digital servo valve are less 0.1%.

REFERENCES

1 Merritt, H.E. 1967. Hydraulic Control Systems, John Wiley & Sons, New York.

2 Hou, Y., Burton, R., Schoenau, G. and Muto, T. 1995. Feasibility Study on the Development of an Ultra High Speed On-off Valve, Proceedings of the 4th Scandinavian International Conference, pp. 673-685.

3 Ramachandran, S., Ukrainetz, P. R. and Nikiforuk P. N. 1985. Digital Flow Control Valve-an Evaluation, Proceedings of the First International Conference on Fluid Power Transmission and Control, Hangzhou, China, , pp. 508-512

4 Singh, G. and Kuo, B.C. 1974. Modeling and Dynamic Simulation of Multiple-stack Variable-Reluctance Step Motors, Computers and Electrical Engineering, Vol. 1, pp. 481-500.

5 Ruan, J. and Burton, R. T. 1999a. Direct Digital Control of a 2D Directional Valve, Proceedings of the Sixth Scandinavian Conference on Fluid Power, Tampere, Finland, pp. 1335-1348.

6 Ruan Jian Pei Xiang and Lisheng, 2D Digital Directional Valve, Chinese Journal of Mechanical Engineering, Vol.36. No.3, 2000

7 Ruan, J. and Burton, R. 1999b. A New Approach of

Direct Digital Control for Spool Valves, The 1999 ASME International Mechanical Engineering Congress, Fluid Power Systems Technology, FPST-Vol.6, pp. 135-144.
8 Ruan, J., Burton, R. and Ukrainetz, P. 2000. Investigation to the characteristics of 2D flow valve, The 2000 ASME International Mechanical Engineering Congress, Fluid Power, Florida
9 Ruan Jian LiSheng and Yang Jilong, New Approach of Electro-hydraulic Direct Control, Chinese Mechanical Engineering, Vol.11, No.3, 2000
10 Ruan J., Burton R. and Ukrainetz, Frequency Domain Modeling and Identification of 2D Servo Valve, Inter. Journal of Fluid Power Control. Vol.1 No.4, 2000