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Actuation and Control of a Micro Electrohydraulic Digital Servo Valve

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Abstract. Structure of the micro digital servo valve is given. A micro stepper motor is used as electrical-to-mechanical interface of the valve. A special mechanical device is designed to convert the rotation of the stepper motor into the linear motion of the spool. This moving conversion device functions through an eccentric ball head rigidly connected to the axis of the stepper motor and plugged into a slot at the central spool land. While the stepper motor rotates, the eccentric ball head will actuate the spool to make a linear motion. Unlike conventional servo or proportional valves, in which the spool is forced to central position by a spring force, when the current supply is switched off, the digital valve has a program to control the spool to its central position each time the electrical power supply is switched on or off. The two end screws are used to adjust the position of the sleeve to sustain a mechanical central position coincided with electrical central position given by the stepper motor after initialization. The adjustment has to be carried once before the first time the servo valve is put into service. This paper presents theoretical analysis and experimental study of dynamic characteristics of the proposed micro digital servo valve. Experimental results demonstrated that the valve takes the advantage of high accuracy and fast response.

1. Introduction

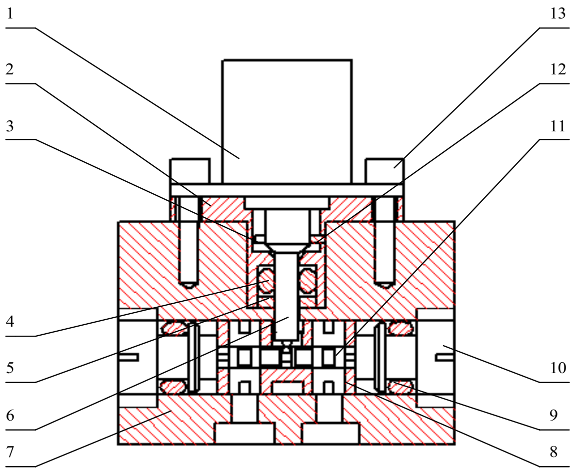
Control system with micro computer will become more important in modern industry, along with production scale expand and automation level increase. Application of hydraulic control system is restricted in many fields by its big structure such as medical apparatus and furniture. Micro hydraulic control system will be applied to many occasions because of its little volume and weight, high precision and frequency response. When the micro electrohydraulic valve is digitized, it has advantages of high reliability, low cost, wide speed regulation, non-sensitive to medium pollution, and being easily controlled by micro computer. Otherwise, because stepping motor can be applied as electro-mechanic converter, non-linear of lag loop can be eliminated; non-linear caused by friction and etc. can be eliminated by the method of algorithm software compensation [1]. Therefore, simple structure can be applied in micro electrohydraulic valve, and the valve will work reliably because of its little volume and weight.

2. The micro electrohydraulic digital servo valve

Structure of the micro electrohydraulic digital valve is shown as Figure 1.

The output shaft of the stepper motor actuates to the spool through an eccentric ball mechanism, and makes the spool move linearly. So the motion of the spool can be controlled by the stepper motor. The maximal moving stroke of the spool is 0.4mm, and the eccentric of the mechanism is 0.2mm.

Axial chink is applied as throttling hole. Circumference of the valve bush is made holes symmetrically. The holes are square. Throttling chink is formed between spool land and the hole. Throttling area will change when the spool move axially. This kind of throttling hole belongs to thin wall hole, and the flow in the throttling hole is not sensitive to the fluid temperature. And otherwise, in this kind of throttling hole, hydraulic radius is big when the flow is big ,and the flow is steady when the flow is small.



1 stepper motor 2 motor seat
3 spacing pin 4 seal 5 sealing washer
6 eccentric ball head 7 valve base
8 valve bush 9 seal 10 end cap
11 valve core 12 spacing pin 13 screw

Figure 1. Structure of the micro electrohydraulic digital valve.

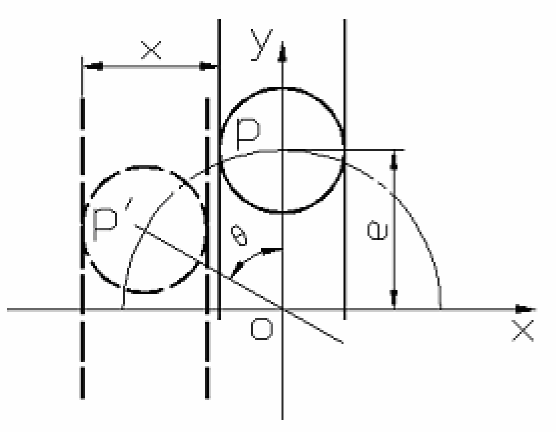


Figure 2. Sketch of the eccentric wheel and spool movement.

2.1. Analysis of static characteristics of the rotary

The movement of eccentric wheel and spool can be analyzed with Figure 2.

where, e : eccentricity of two circles;

p : contact of the wheel and the spool in x-o-y coordinate system;

p': contact of the wheel and the spool when axis of the stepper motor rotates angular;

From Fig.2 we can get relationship between spool stroke x and eccentric wheel rotating angle θ:

$$x = e \sin\theta \quad (1)$$

$$y = e \cos\theta \quad (2)$$

2.1.1. Stroke. It is shown in Figure 3 that axial stroke x of the spool changes with the stepping motor rotating by simulation in MATLAB [2] (neglect influence of the gap between the wheel and the slot).

In Figure 3, the spool stroke x change between -0.5mm and 0.5mm, and there is relative good linear relationship between the spool stroke x and wheel angle θ.

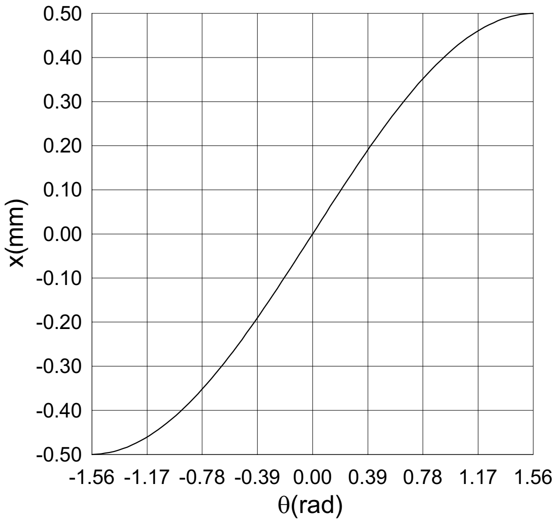


Figure 3. Spool stroke x changes with wheel angle θ.

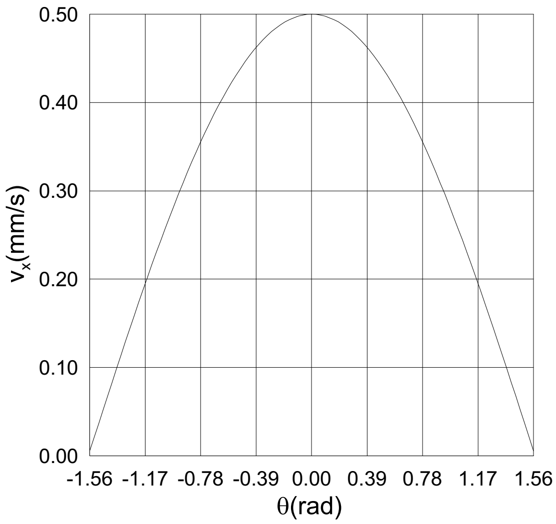


Figure 4. Spool speed v_x changes with wheel angle θ.

2.1.2. Speed. From derivation calculus to eq. (1), we get:

$$v_x = \frac{d\theta}{dt} \cdot e \cdot \cos\theta \tag{3}$$

Suppose $d\theta/dt$ =1(rad/s), relationship between spool stpeed v_x and wheel angle θ is shown in Figure 4.

2.2. Linearity analysis between spool stroke and wheel angle

According to the definition of Linearity:

$$unl = \frac{\Delta x_{\max}}{X} \tag{4}$$

in which, $\Delta x_{\max}$ is maximum value deviating from linear value in measuring region; X is linear range in measuring region.

As shown in Figure 5, for $\theta \in [-\Theta, \Theta]$, we have:

$$\Delta x = x - x_1 = x - \theta \frac{X}{2\Theta} = e\sin\theta - \theta \frac{X}{2\Theta} \tag{5}$$

in which, x_1 is linear value of output, X=2$e$sinΘ.

in region [−Θ, Θ], we take partial derivative for Δx to θ:

$$\frac{\partial \Delta x}{\partial \theta} = e\cos\theta - \frac{X}{2\Theta} \tag{6}$$

For getting maximum value $\Delta x_{\max}$ of Δx in region [−Θ, Θ], we set

$$\frac{\partial \Delta x}{\partial \theta} = 0$$

Then

$$\theta = \arccos\frac{X}{2e\Theta} \tag{7}$$

So

$$\Delta x_{\max} = e\sin\theta - \theta\frac{X}{2\Theta} = e\sin\left(\arccos\frac{X}{2e\Theta}\right) - \frac{X}{2\Theta}\arccos\frac{X}{2e\Theta} \tag{8}$$

Figure 6 illustrates simulating result of stroke linearity to rotating angle. As shown in Figure 6, there is relative good linearity between spool stroke and wheel angle for $\theta \in [-0.4, 0.4]$.

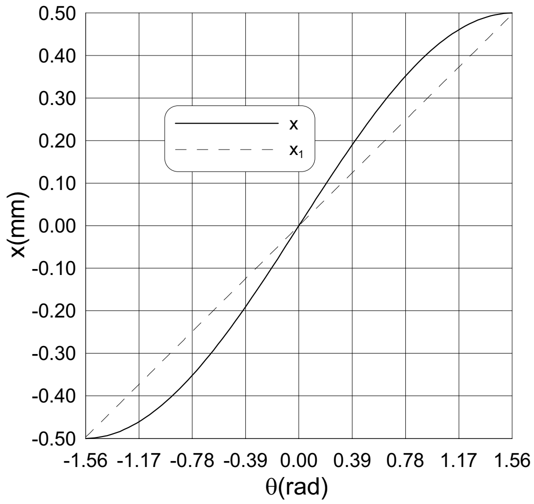


Figure 5. Definition of Linearity $unl=\Delta x_{max}/x$.

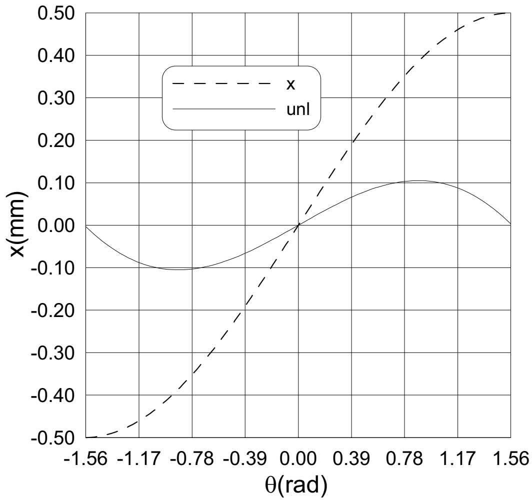


Figure 6. Linearity between spool stroke and wheel angle.

3. Experiment and result

For obtaining dynamic characteristics of the micro digital valve, we established an experimental stand. Measuring principle is illustrated in Figure 7.

Signal engendered by signal generator is sent to control board, then it is converted to digital signal and sent to the drive of the stepper motor. So the stepper motor rotates, brings spool moving. Spool displacement is measured by eddy current sensor, and signals are transmitted to data collecting system BNC2090, and then to personal computer. Besides, personal computer can also signal to BNC2090 to control spool. Algorithm of continuous following control is applied to control stepper motor.

There are 20 analogous output ports for setting in National Instruments BNC2090 data collecting system.

When sending typical triangle, rectangle and sine wave to control board by a signal generator, the spool will engender dynamic respond process. Characteristics measured by sensor are illustrated by Figure 8. As shown in Figure 8, a signal with high frequency is superposed in responding process. This signal is called digital segment signal. It similar to a higher mode vibration, and there is important role in reducing influence of Columb frictional force and backlash.

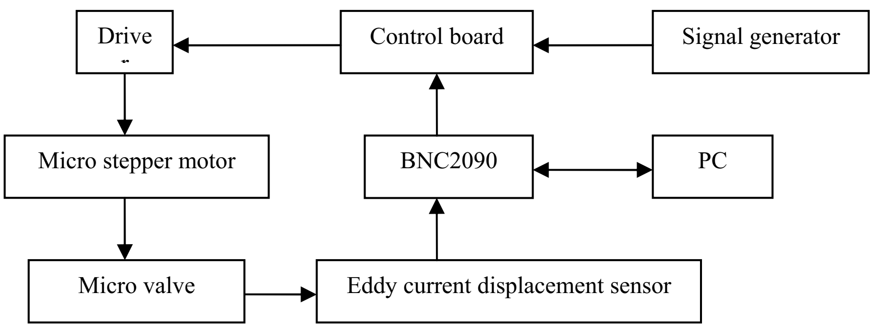


Figure 7. Diagram of measuring principle.

4. Conclusion

The micro digital electrohydraulic servo valve is directly droved by stepper motor. Output shaft of the stepper motor actuates to the spool through an eccentric ball mechanism, and the mechanism converts rotation of the stepper motor to rectilinear motion. So the stepper motor directly controls movement of the spool. A micro stepping motor with algorithm of continuous following control is applied to digital valve as electro-mechanic converter, and this makes the valve have good precision and high respond. It can be seen from curves of dynamic respond for typical signals, there are ideal characteristics of dynamic respond for the micro electrohydraulic digital valve.

Also as shown in Fig.8, a digital segment signal is superposed in dynamic process, it is beneficial to reduce influence of Columb frictional force and backlash, and to raise precision of valve response.

References

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