A new type of hydraulic swing drive with integrated motion sensor for narrow spaces

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The automation of mobile hydraulic machinery, such as bionic robot, requires high power-to-volume ratio and high performance control solutions, which means miniaturized, integrated, and intelligent hydraulic systems. The purpose of the paper is to present a new type of hydraulic swing drive for narrow spaces, where the position sensor is integrated as a part of hydraulic system. The structural characteristics of this hydraulic swing drive as well as its functionality are presented in detail. Through the comparison with the traditional hydraulic motor, position resolution and power-to-volume ratio have been further improved, therefore the application of hydraulic systems has been expanded, especially in some kinds of bionic robots.

Keywords: Narrow spaces, swing drive, flexible rope, digitalization
Target audience: Mobile Hydraulics, New & Special Application

1 Introduction

Due to the high power-to-weight ratio of the hydraulic system, it has a wide range of applications in many fields, such as aircraft, transport vehicles, robots and so on /1/. The automation of mobile hydraulic machinery, such as bionic robot, requires high power-to-volume ratio and high performance control solutions, which means miniaturized, integrated, and intelligent hydraulic systems /2/. In particular, traditional hydraulic components and systems are difficult to be applied to the current field of robots /3/. Currently, the swing of the axis is known to use hydraulic motor directly, or use linkage mechanism driven by hydraulic cylinder. It is difficult to meet the requirements from the host for response and installation dimensions. Wen desheng et al. studied the leakage and volumetric efficiency and seal improvement for double-stator swing hydraulic motor, and a new type of double-stator swing hydraulic motor is put forward, which combines the structure of vane swing hydraulic motor and the thought of double-stator /4/. Zhu Zhichao et al. used a door-shaped sealing structure to decrease the frictional force and improve the movement efficiency and stability of the hydraulic swing vane cylinder /5/. Tao Yong et al. presented a hydraulic swing arm-driven robot hydraulic arm, which driven by the hydraulic swing cylinder. This invention gets more output torque, and the carrying capacity gets improved /6/. This paper presents a new type of hydraulic swing drive for narrow spaces, where the position sensor is integrated as a part of hydraulic system, which can overcome the problems of response and installation dimensions. The research results show that the position resolution and power-to-volume ratio have been further improved, therefore the application of hydraulic systems has been expanded, especially in some kinds of bionic robots.

2 Structure and Principle of the Swing Drive

2.1 Structure of the swing drive

This hydraulic swing drive mainly consists of a servo motor, two hydraulic cylinder, carbon fiber rope, manifold block, the outer tube and some screws. Its 3D structure diagram shows in the Figure 1.

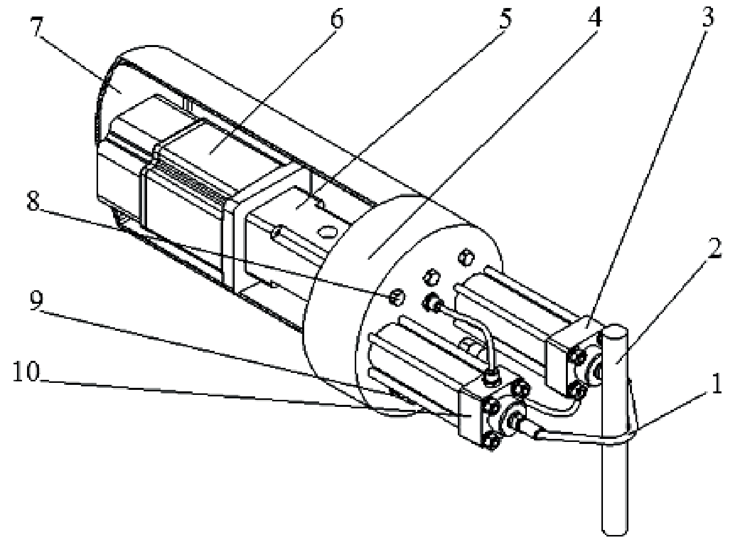

Figure 1: The 3D structure diagram of the swing drive.

The flexible rope structure includes a carbon fiber rope (1) and a swing shaft (2), the midpoint of the carbon fiber rope (1) is fixed on the swing shaft (2), both ends of the carbon fiber rope (1) are fixed on the output rod of the hydraulic cylinder (3), the flexible rope The structure can translate the linear motion of the hydraulic cylinder (3) into the rotation of the swing shaft. The hydraulic drive structure comprises a hydraulic cylinder (3) and a hydraulic cylinder (10) with an integrated position sensor, a manifold (4), a small axial piston pump (5), a servomotor (6), a tank (7), a check valve (8) and a relief valve (9).By controlling the rotation speed of the servo motor (6), the output flow of the pump (5) can be controlled. Because of the working mode of the pump control cylinder, the pump (5) can supply oil in both directions and control the extension and retraction of the hydraulic cylinder (3) and the hydraulic cylinder (10).Thereby achieving the pivot shaft (2) is rotated.

2.2 Principle of the swing drive

Figure 2 shows the hydraulic system diagram of the swing drive.

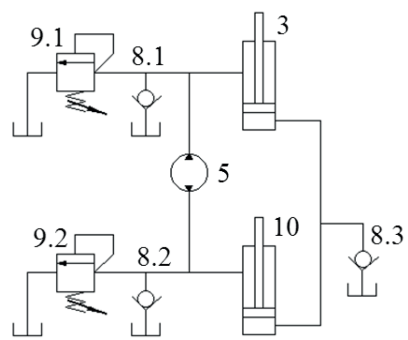

Figure 2: The hydraulic system diagram of the swing drive.

The working principle of the swing drive is that when the oil enters the rod chamber of the hydraulic cylinder (7), the swing shaft rotates counter clockwise and the swing angle α of the swing shaft can be obtained by the Equation (1):

$$\alpha = (\tau \times 360) \div (D \times \pi) \tag{1}$$

The unit of angle is degrees. When oil enters the rod chamber of the cylinder (3), the swinging shaft (2) rotates clockwise. Due to the traction of the carbon fiber rope (1), the cylinder (3) and the rodless chamber of the cylinder (10) communicate with each other, so that the cylinder (3) and the cylinder (10) are synchronized in opposite directions, that is, the moving distances are equal. Because the system is a closed loop, considering the system has a leakage effect, the swing drive through the one-way valve 8.3 access rodless chamber oil-way, one-way valves 8.1 and 8.2 access to the small axial piston pump inlet and outlet oil, to achieve the lack of hydraulic oil through the valve block (4) on the oil hole in time to fill the oil. When the working pressure of the system exceeds the set pressure of the relief valve, the oil is relieved through the oil hole in the valve block (4) through the relief valve 9.1 or the relief valve 9.2 to prevent the traction of the carbon fiber rope (1) from being broken.

The integrated position sensor, the digital controller and the control method also have a significant influence on the oscillating drive capability of the oscillating shaft (2). The hydraulic cylinder (3) and the hydraulic cylinder (10) in the system are each integrated with a position sensor for providing the position information of the hydraulic cylinder to the digital controller. The difference between the measured displacement signal of the hydraulic cylinder (3) and the hydraulic cylinder (10) is the elongation of the carbon fiber rope (1), which is used for the controller to control the servo motor (6) to compensate the variation of the carbon fiber rope (1).

2.3 Design parameters

The tensile strength of Carbon fiber rope can reach 3000Mpa, while the tensile strength of wire rope is about 1770Mpa. The structure which transforms the linear drive into a swing drive by flexible rope increases the power-to-volume ratio of the drive device and the response. Table 1 gives some of the main parameters of an implementation case of this scheme.

Physical quantity	Operating hours	Frequency	Amplitude	Torque	Shaft diameter	Rated pressure
Symbol	t	f	θ	T	d	p
Unit	h	Hz	°	N·m	mm	bar
Value	200	1.2	45	1200	52	200

Table 1: The main parameters of an implementation case of this scheme.

The design parameters of the swing drive designed according to the above data are shown in Table 2, which includes working pressure, material density, cylinder thickness, piston diameter, piston rod diameter and force arm. According to the material density, we can see that the main material selected in this design case is aluminum alloy.

Physical quantity	Working pressure	Material density	Cylinder thickness	Piston diameter	Piston rod diameter	Force arm
Symbol	*p*	*ρ*	*Δ*	*D*	*d*	*l*
Unit	bar	g/cm^3	mm	mm	mm	mm
Value	170	2.7	5	50	25	40

Table 2: The design parameters of the swing drive.

Through some basic formulas, we calculated the data, which is shown in Table 3, which we are very concerned about in the design process, such as hydraulic cylinder load, stroke, rod cavity area and rodless cavity area. The thickness of the force arm and the length of hydraulic cylinder rod are closely related to the dimensions and weight of the actuator. Table 3 also shows the design values.

Physical quantity	Load	Stroke	Rod cavity area	Rodless cavity area	Thickness of force arm	Length of rod
Symbol	*F*	*L*	A_B	A_A	$\triangle'$	*1.5L*
Unit	kN	mm	cm^2	cm^2	mm	mm
Value	33.38	31.42	14.73	19.63	28	47.124

Table 3: The intermediate data of interest.

The swing drive input flow is:

$$q = \frac{(2 \times f \times 60 \times L \times A_B)}{10} / 1000 \tag{2}$$

Hydraulic pump power is:

$$P = \frac{(p \times q)}{\eta} / 60 \tag{3}$$

The volume of two hydraulic cylinders is:

$$V = \left(\frac{\pi \times (D + 2\Delta)^2}{4} - \frac{\pi \times D^2}{4}\right) \times 2L/1000 \tag{4}$$

The weight of two hydraulic cylinders is:

$$G = \frac{\rho \times V}{1000} \tag{5}$$

The weight of two hydraulic cylinders' rods is:

$$G_r = \frac{\pi \times d^2}{4} \times 1.5L \times \frac{2\rho}{1000} / 1000 \tag{6}$$

Table 4 gives the results of the data above.

Physical quantity	Input flow	Hydraulic pump power	Volume of hydraulic cylinders	Weight of hydraulic cylinders	Weight of hydraulic cylinders' rods	Efficiency of hydraulic cylinder
Symbol	*q*	*P*	*V*	*G*	G_r	*η*
Unit	L/Min	kW	cm3	kg	kg	---
Value	6.66	1.89	54.28	0.15	0.13	Assumed to be 100%

Table 4: The final parameters of the system.

3 Test System

The simulation system shows in Figure 3. The parameters of each component in the system are set according to Table 3 and Table 4. In order to test the feasibility of the system, the simulation system uses a sinusoidal load. Figure 4 provides the load curve. The peak load is 1200N·m. The flow rate of the pump shows in Figure 5. The pressure of the pump's right port gives in Figure 6. And its peak pressure is 210bar. Simulation system runs 10s, the sampling period is 0.01s.

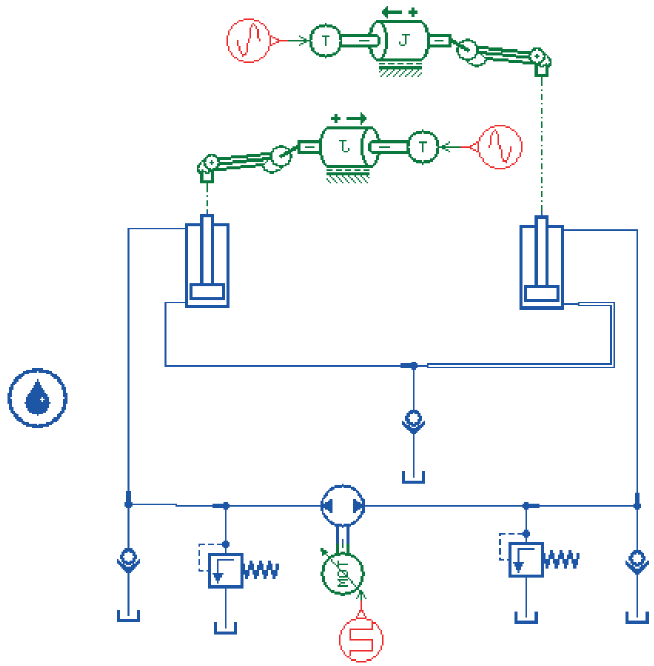

Figure 3: The simulation system of the swing drive.

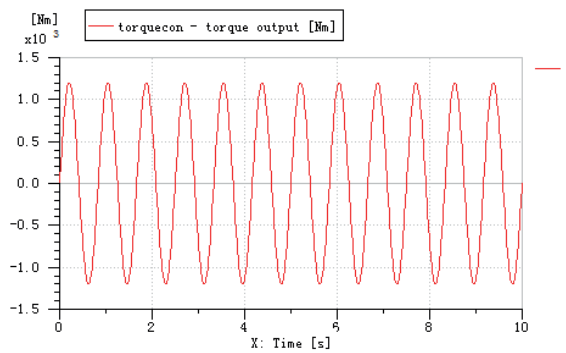

Figure 4: The load curve.

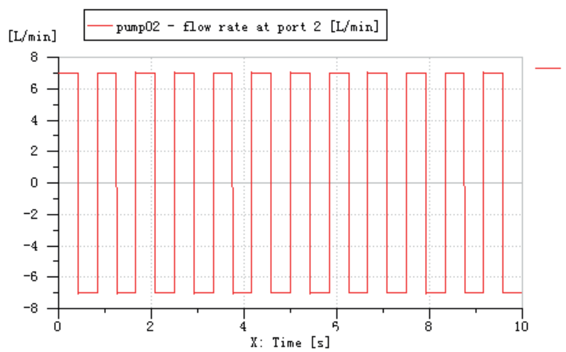

Figure 5: The flow rate of the pump.

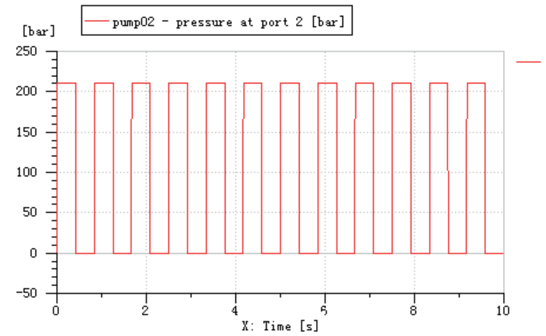

Figure 6: The pressure of the pump's right port.

4 Experimental Results

The displacement of the two actuators shows in the Figure 7, which illustrates the two actuators completed alternating telescopic movement. The results show that the design meets the requirements.

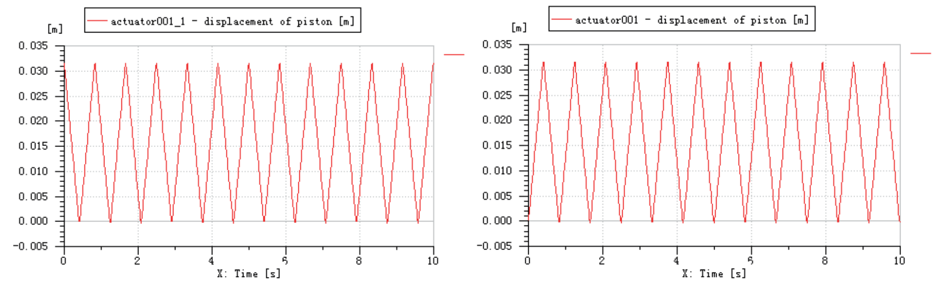

Figure 7: The displacement of the two actuators.

5 Conclusion

The new type of hydraulic swing drive with integrated motion sensor for narrow spaces can increase the power-to-volume ratio of the drive device and the response, and be applied to special robots. Compared with the hydraulic motor, this swing drive overcomes the problem of bulky and inflexible layout. At the same time, the noise of this swing drive is very small compared to mechanical drives such as rack and pinion. Because there is none direct contact between the structures. The simulation system proves the feasibility of the design, but the response of the swing drive needs to be further studied.

6 Acknowledgements

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Nomenclature

Variable	*Description*	*Unit*
α	Swinging angle	[°]
τ	The distance the cylinder moves	[mm]

D	Diameter of the swing axis	[mm]

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