Analysis of motion characteristics of three degrees of freedom decoupling hydraulic self-servo joint

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Abstract: Multi degree freedom robot joint has the common problems, such as its motion is coupled and not stable enough, the output torque is small. Aiming at these problems, a new hydraulic swing cylinder with radial oil distribution and single vane rotating angle self-servo valve is proposed. And based on this new hydraulic swing cylinder, three degrees freedom decoupling hydraulic self-servo joint with motion decoupling and larger workspace is designed in this paper. The motion decoupling of three degrees of freedom decoupling hydraulic self-servo joint is analysed and verified by using ADAMS software. The simulation results show that three degree freedom hydraulic joint has the characteristics of smooth motion, large output torque, and motion decoupling.

Keywords: rotating angle self-servo; radial oil distribution; motion decoupling; smooth motion; large output torque; hydraulic self-servo joint.


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1 Introduction

Hydraulic robot joint performance will directly affect the overall performance of the merits of the hydraulic robot, which is a key component of hydraulic robot (Zeng et al., 2013). The most common research on the hydraulic robot joint is external servo valve control piston and the swing cylinder type of hydraulic joints, the size of the joints are large (Richard et al., 2015); Bulgarian scholars developed a series painting hydraulic robot joints (Wang et al., 2013) which is the use of swing cylinder hydraulic joints controlled by an external servo valve. The joints have large output torque and strong robustness, also the size of the joint is large.

Hydraulic self-servo technology which is applied to the field of hydraulic robot has been developed in recent years, Xing-long Zhu, from Yangzhou university, who studied the three degrees of freedom hydraulic servo joint, which has the characteristics of compact structure and large output torque, but driving control valve of valve core radial force is unbalanced and the servo blind area is not ideal (Mahadhir et al, 2014). Jiang et al. (2011a; 2011b; 2012) from Wuhan university of science and technology designs a kind of hydraulic rotating angle self-servo joint which has a small blind servo area and valve core of balanced radial force, but joint integration is not very ideal.

In this paper, a single-blade radial hydraulic oil with a self-servo swing cylinders, as a hydraulic robot joint drive has been designed, whose axial and radial forces are balanced and dynamic characteristics is good. Using the agency as a joint drive can reduce the hydraulic robot joint radial and axial size improve the integration of the hydraulic robot joints.

The motion coupling problem of robot joint has always been a hot research for many scholars, robot kinematic coupling problem will happen when each robot joint is moving. If the robot manipulator arm can achieve movement decoupling, not only better movement precision can obtain, but also the difficulty of its control system design and the size of the robot joint workspace can be reduced. Zhang et al. (2013b) from the Tianjin University did kinematics analysis and delay control for five degrees of freedom rigid manipulator arm and analysed the coupling between the joint angle and the motor angle, but he did not discuss for the coupling between the joints. Zhang et al. (2013a) established a positive inverse decoupling mode by the analysis of the series-parallel CNC machine tool servo system motion coupling state, but this method is very complicated. Based on above all, this paper makes decoupling verification for design three degrees of freedom decoupling hydraulic servo joints by ADAMS software and uses kinematics to calculate three degrees of freedom decoupling hydraulic servo joint end position coordinates.

2 Structure design of three degrees of freedom hydraulic self-servo joints

2.1 Structure design of single vane hydraulic self-servo swing cylinder

The axial profile of hydraulic swing cylinder with single vane rotating angle self-servo valve is shown in Figure 1.
As shown in Figure 1, hydraulic swing cylinder with single vane rotating angle self-servo valve is mainly composed of left cover, cylinder 1, sealing cap, cylinder 2, valve sleeve, valve cover, valve core, bearing, bearing cover and couplings. The interior of the hydraulic swing cylinder is respectively equipped with high and low pressure oil port. The left faces of the left cover have high and low pressure oil ports. The left cover is connected with the left face of cylinder 1. The internal cylinder is equipped with servo bracket on which the servo is fixed. The output shaft of the servo is connected to the valve core inside valve cover. The right face of cylinder 1 and the left of cylinder 2 are connected. The internal cylinder 2 is equipped with valve sleeve. The internal valve sleeve is equipped with valve core inside. The internal valve sleeve contains valve core. The right face of cylinder 2 is connected to the bearing cover. The output shaft of the right face of valve sleeve and coupling are connected through the pin.

Hydraulic self-servo technology is the use of motor control technology and hydraulic servo technology, which magnifies output power by combining with the small size, small torque motor and hydraulic self feedback mechanism. Large torque hydraulic system is achieved by the internal feedback for a small torque motor adaptively followed by output shaft and it can reduce hydraulic joint size and achieve built-in oil duct.

As shown in Figure 1, the working principle of hydraulic swing cylinder with single vane self-servo valve: high-pressure oil leads to inlet oil port, low-pressure oil leads to returned oil port. When the servo is static, valve core is static. The oil outlet of valve core is closed by convex set of valve sleeve. High and low pressure oil cannot enter A and B cavity, now hydraulic swing cylinder with single vane self valve keeps middle state. When servo rotates some angle through circling clockwise, it can drive the valve core to rotate some angle, the P oil port and T oil port on the valve core are open. At this point, the high pressure inside the valve core leads to A cavity from P oil port through the oil port 1, the low pressure inside the valve core leads to returned oil port through the oil port 2 to oil port T. Because internal pressure in B and A cavity is different, the two cavities under the action of pressure difference, makes the valve sleeve and body together rotate.
in clockwise. When the valve is set with the same rotary angle of the valve body and valve core, until the valve port on the valve core shuts down. The valve output shaft rotation will drive the right load to complete the process of hydraulic swing cylinder with single vane self-servo valve output torque and achieve the position of the body of the valve core to track. When the servo rotates counterclockwise, inner workings of hydraulic swing cylinder with single vane self valve contrast to the clockwise. Because the hydraulic swing cylinder adopts hydraulic drive, the output torque is not less than 100 N·m and radial size of the hydraulic robot joints is less than 150 mm in diameter, so it has the advantages of the smooth movement, the output large torque and small radial size of the hydraulic robot joints.

2.2 Structure design of three degrees of freedom hydraulic self-servo joints

In order to achieve the motion decoupling and large workspace, the three degrees of freedom hydraulic servo joint which is mainly composed of the following two rotary joints and a swing joints is designed.

2.3 Structure design of rotary joint

The structure of rotary joint is shown in Figure 2. In order to make the joints having large work space, the hydraulic swing cylinder with single vane self-servo valve as a rotary joint is employed and it has one degree of freedom and the rotation angle range can be up to ±150°.

Figure 2 Model of rotary joint (see online version for colours)


2.3.1 Structure design of swing joint

The schematic of the swing joint is shown in Figure 3.

Swing joints are composed of a coupling, a hydraulic swing cylinder with single vane self-servo valve and a link. When the valve sleeve rotates some angle, the hydraulic
swing cylinder will be driven to rotate together with the adjacent link so that the joint achieves a certain range of angles of adjacent pitch motion.

Figure 3  Spatial structure model of swing joint (see online version for colours)

Notes: 1: couplings, 2: hydraulic swing cylinder with single vane rotating angle self-servo valve, 3: link.

3 Analysis of characteristics of three degrees of freedom decoupling hydraulic self-servo joint

In order to verify the designed three degrees of freedom hydraulic self-servo joint decoupling, the simulation experiment has been carried on by ADAMS software and the simulation results are analysed.

3.1 Rigid body model and extra constraints of three degrees of freedom hydraulic self-servo joint have been established

3.1.1 Rigid body model of three degrees of freedom hydraulic self-servo joint has been established

After the modelling and assembling of three degrees of freedom hydraulic self-servo joints in Pro/E, the assembled model is simplified for to import it into ADAMS easily. Its rigid model is shown in Figure 4.
3.1.2 Extra constraints

After completing three degrees of freedom hydraulic servo joint rigid body model, fixed constraint is firstly established between a rigid body rotating joint and the earth in ADAMS. Because rotary joint 1, swing joint 2 and rotary joint are the rotary motion, thus revolute is established between the three rigid body.

After establishing motion pair, organisation movement must be also defined; Movement is added to motion pair to drive the whole body to move.

3.2 Motion decoupling simulation of three degree of freedom hydraulic self-servo joint ADAMS

3.2.1 Drive and simulation

Defining the drive function of the rotary motion can make the model complete the simulation movement according to the predetermined drive function. Rotating joint 1 of rigid body, swing joint 2 of rigid body and rotary joint three of rigid body in this paper defines the drive function by using AKISPL to call the date of spline curve.

According to the movement of the decoupling conditions, after the joints move in accordance with the order of different sports movement, its end position and orientation does not change. This paper defines the drive function of three joint rotational movements by establishing six curves. Those six curves are divided into two groups. The first, second, third curve is used to define joint 1, joint 2 and joint 3 sequential operation(as a first set of motion) driver functions. The fourth, fifth, sixth curve are used
to define joint 2, joint1 and joint 3 sequential operation (as a second set of motion) driver functions.

In order to verify whether three degrees of freedom hydraulic self-servo joint decouples, the following two cases will be discussed:

The first group exercise, the second group exercise and the fifth group exercise contrast with each other;

The third group exercise, the fourth group exercise and the fifth group exercise contrast with each other.

As shown in Table 1, X represents time, Y represents rotation angle. Because the rotary joint and swing joints with rotational angle range is up to ± 150°, so the angle range of the driving function of the ADAMS simulation is –150 to + 150, however this article is used in the range of 0 ~ 150° angle.

As shown in Table 1(a), Spline_1 drives joint 1 to rotate 90°, then Spline_2 drives joint 2 to rotate 110° and finally Spline_3 drives joint 3 to rotate 90°. In order to achieve sequential operation of the joint 1, joint 2, joint 3, this is the first set of motion. As shown in Table 1(b), Spline_4 drives joint 2 firstly to rotate 110°, then Spline_5 drives joint 1 to rotate 90° and finally Spline_6 drives joint 3 first to rotate 90° in order to achieve joint 2, joint 1, joint 3, this is the second set of motion.

Table 1 The drive function of three joints in turn

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3.2.2 Analysis of result simulation by ADAMS software

The first and second group compared with the fifth group

The decoupling simulation diagram one of the first group, the second group and fifth group motion of the first case is discussed in Figure 5. The simulation time is set 10 s. Figure 5(a) is the first group of motion screenshot. Then the first, second, third curve as a drive function drive the joints 1, joint 2 and joint 3 sequential motions and three joints posture screenshot is in the 0 s, 5 s, 10 s. As shown in Figure 5(b) is the second group of motion capture. The fourth, fifth, sixth curve as a drive function drive the joint 2, joint 1, joint3 sequential motion and three joints posture screenshot is in the 0 s, 5 s, 10 s.
Figure 5  The first group, the second group and the fifth motion decoupling simulation diagram (see online version for colours)

Figure 6  The motion decoupling end posture validation figure of the first group, the second group (see online version for colours)
With the group of the first, second and fifth simulation done, first_results, second_results and fifth_results are saved in orderly. It results the three degrees of freedom hydraulic self-servo joint coordinates under the world coordinate system at the end of the test. The end of joint 3 (PART84) centre of gravity is chosen as a measurement point. X, Y and Z are respectively selected as measurement component. The first case of the measured results ‘first_results, second_results and five_results’ are drawn as shown in Figure 6. Comparing with the motion decoupling end posture validation figure of the first group, the second group and the fifth group, the end position does not change due to different joint movement sequence and its various components.

4 Conclusions

1 A radial oil distribution of hydraulic swing cylinder with single vane self-servo valve has been designed, which is regarded as driving mechanism of robot joint and can reduce the size of hydraulic robot joint. After fully considering the motion decoupling mechanism, a kind of three degrees of freedom hydraulic self-servo joint is designed according to certain combination and the joint has the characteristics of motion decoupling and large workspace.

2 After the three degrees of freedom hydraulic self-servo joint model is simplified, it will be done the motion decoupling which is validated through ADAMS software. By setting the six curves, the motion decoupling simulation and the end posture of motion decoupling validation are analysed and compared. The results indicate that the joint motion decouples and the decoupling thought is promoted to multi-joint.

Acknowledgements

This work was supported by National Natural Science Foundation of China (NO. 61105086).

References


