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RESEARCH ON THREE-POINT CENTERING DEVICE OF CYLINDRICAL DRILL PIPE

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ABSTRACT

In the process of tightening up and screwing off the iron roughneck, it is required that the center of clamping pliers and the center of drill pipe are coincident, so as to avoid the damage of the circular guide in clamping system, and to ensure the iron roughneck work normally. While the traditional method of centering is artificial in iron roughneck, its precision is low, so it is easy to damage the drill pipe because of the great eccentricity between clamping pliers and drill pipe, besides, its work efficiency is low. Aiming at the cylindrical drill pipes, a method of three-point centering based on the ultrasonic sensors is proposed in this paper, that is to say, through comparing the feedback of three ultrasonic sensors which are arranged on the same the circle of clamping pliers' nips, the center of clamping pliers is adjusted to be coincident with the center of drill pipe. In this paper, the related hardware and software system of the automatic centering are designed, and the simulation experiment is demonstrated by the SimMechanics. The result of simulation indicates that the method of automatic centering is feasible, and valuable to engineering application.

Keywords: *Automatic centering, Ultrasonic sensor, Simulation, Iron roughneck*

1. INTRODUCTION

At present, the iron roughneck is moving forward towards the direction of high efficiency and intellectualization [1]. In the equipment of iron roughneck, the auxiliary operation, such as automatic centering of drill pipe, is a key problem in developing towards high efficiency and intellectualization of iron roughneck. Thus the method about the fast and automatic centering of iron roughneck is put forward to in this paper.

The traditional method of centering is to change the position and pose of drill pipe or centering device through the floating mechanism, so as to accomplish the centering process. But in the process of centering, the centering device will contact the drill pipe, sometimes even lead to collision between the centering device and the drill pipe, it is easy to damage the surface of drill pipe and break the position and pose of drill pipe [2-3]. Due to the drill pipes are cylindrical steel-made members, combined with the method of automatic centering based on external surface of cylindrical drill pipe in [4], we put forward the method of three-point automatic centering based on the ultrasonic sensors in this paper. Through comparing the feedback information of three ultrasonic sensors which are arranged around the circle of clamping pliers' nip, the center of clamping pliers is adjusted to be coincident with the center of drill pipe. That is to say, adjusting the manipulator through comparing the feedback voltage of the three ultrasonic sensors, until the voltage values of three ultrasonic sensors are equal, so as to the center of three ultrasonic sensors and the center of drill pipe are coincident, accomplishing the process of automatic centering. The system of automatic centering is used in the process of automation in iron roughneck; it can achieve the purpose of shortening auxiliary time, improving the production quality and the work efficiency.

The structure of this paper: 1) Introducing the significance of automatic centering in iron roughneck; 2) Describing the principle of automatic centering and installation of ultrasonic sensors; 3) Discussing the process of implementation the automatic centering; 4) Demonstrating the simulation of automatic centering; 5) Giving the conclusion about this paper.

2. THE PRINCIPLE OF AUTOMATIC CENTERING AND INSTALLATION OF ULTRASONIC SENSORS

2.1. The Principle of Automatic Centering

In the measurement range of ultrasonic sensors, we can measure the distances from ultrasonic

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sensors to the surface of drill pipe, and the ultrasonic sensors output the distance in analog (current value), the analog (current value) is converted into the digital value through the A/D converter. Suppose the feedback digital values of ultrasonic sensors 1, 2, 3 are x1, x2, x3 respectively. Adjusting the manipulator through comparing x1, x2 and x3, until x1, x2 and x3 are all equal. That is to say, the distances from ultrasonic sensors to the surface of drill pipe are all equal, accomplishing the purpose of automatic centering.

As shown in Fig.1, it is supposed that O1 is the center of the cylindrical drill pipe, and O2 is the center of three ultrasonic sensors in the same circle. The adjusting process of the manipulator is as follows: firstly, it must be in the measurement range of ultrasonic sensors, as shown in fig.1(a); secondly, if x1 is not equal to x3, make sure x1 and x3 are equal by adjusting the revolute joint, in another word, the distance from the ultrasonic sensor 1 to the drill pipe's surface is equal to the one from ultrasonic sensor 3 to the drill pipe's surface, as shown in fig.1(b); at the end, make sure x1, x2 and x3 are equal to each other by adjusting the prismatic joint, that is to say, the distances from three ultrasonic sensors to drill pipe's surface are the same, the automatic centering process is finished, as shown in fig.1(c).

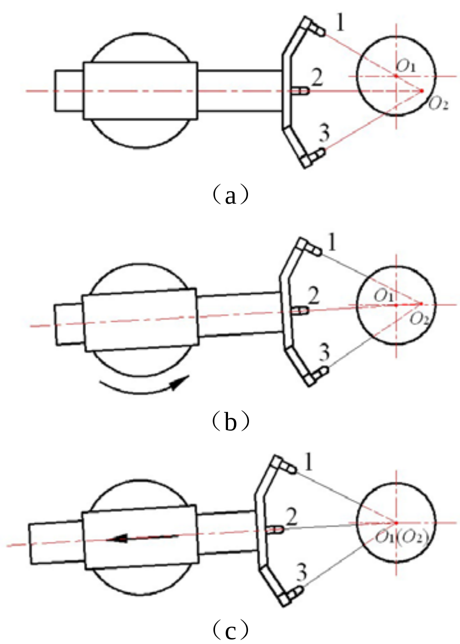

Figure 1. The Regulating Process Of Manipulator

$$\begin{cases} \sigma_1 = \sqrt{\dfrac{(x_1-\bar{x})^2+(x_3-\bar{x})^2}{2}} \\ \bar{x} = \dfrac{x_1+x_3}{2} \end{cases} \quad (1)$$

$$\begin{cases} \sigma_2 = \sqrt{\dfrac{(x_1-\bar{X})^2+(x_2-\bar{X})^2+(x_3-\bar{X})^2}{3}} \\ \bar{X} = \dfrac{x_1+x_2+x_3}{3} \end{cases} \quad (2)$$

In (1), (2):

x_1: The distance from Ultrasonic sensor 1 to drill pipe's surface;

x_2: The distance from Ultrasonic sensor 2 to drill pipe's surface;

x_3: The distance from Ultrasonic sensor 2 to drill pipe's surface.

In this paper, standard deviation σ1 will be used to decide whether x1 was equal to x3, as shown in (1). While σ1≤3.536, that is to say, the measurement error of ultrasonic sensor ε1≤0.221mm, x1 is considered to be equal to x3, which also means the distance from the ultrasonic sensor 1 to drill pipe's surface is considered to be equal to the one from ultrasonic sensor 3 to the drill pipe's surface. Standard deviation σ2 will be used to decide whether x1, x2 and x3 were equal to each other, as shown in (2). While σ2≤4.082, that is to say, the measurement error of ultrasonic sensor ε2≤0.255mm, x1, x2 and x3 are considered to be equal to each other, which also means the distances from ultrasonic sensors to the drill pipe's surface are the same.

2.2. The Selection and Installation of Sensors

In this paper, the automatic centering system consists of three parts: sensors, manipulator and PLC controlling system, and the centering system is based on the center line of the drill pipe perpendicular to horizontal projection panel of sensors, it can quickly finish the whole process of automatic centering.

The sensor will be used to measure the distance between the surface of cylindrical drill pipe and sensor, it is required to be less than 200mm based on the design requirements. Due to the installation constraint, the sensor's volume should be as small as possible. Based on the above conditions, the following three sensors just meet the requirements: the differential transformer type displacement

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sensor, laser displacement sensor and ultrasonic sensor. Compared by the characteristics of these three kinds of sensors, ultrasonic sensor is the best selection due to high frequency, short wavelength, small diffraction, especially its perfect directional characteristics and the feature of easy becoming the ray for directional propagation. As the interference among ultrasonic sensors should not be ignored, there must be adequate minimum installation distance A while installing the ultrasonic sensors, as shown in fig.2. Based on the maximum measurement distance and requirements of small size for ultrasonic sensor, UM18-60/250-CD-HP is the suitable choice and the minimum installation distance A is 10mm.

Figure 2. The Installation Distance Of Ultrasonic sensor

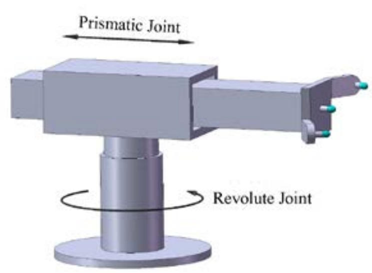

Figure 3. The Mechanism Diagram Of Manipulator

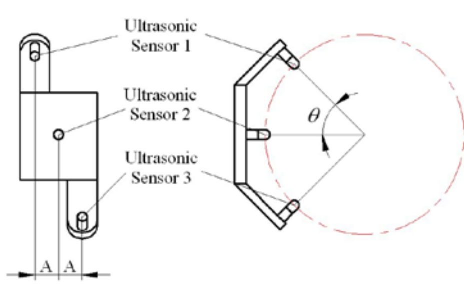

Figure 4. The Distribution Chart Of Sensors

The sensors are installed in the manipulator with a revolute joint and a prismatic joint, as shown in fig.3. There is adequate minimum installation distance A between the ultrasonic sensors, as shown in fig.4, and $0<\theta\leq 90°$, the centering range becomes bigger and bigger when θ becomes smaller and smaller. Based on the requirements, the maximum measuring distance is 200mm, after calculating $\theta\leq 31.28°$, and we choose $\theta=30°$ in this paper.

3. THE DESIGN OF THE AUTOMATIC CENTERING METHOD

3.1. Hardware System

The Mitsubishi PLC and A/D converter supply the hardware support platform in this paper [5-6]. According to the principle of automatic centering, the system of automatic centering needs 7 input modules and 4 output modules, 7 input modules are start, stop, reset, the left limit of revolute joint, the right limit of revolute joint, the front limit of prismatic joint and the back limit of prismatic joint; 4 output modules are pulse port of motor 1, direction port of motor 1, pulse port of motor2 and direction port of motor 2. So according to the number of input and output ports, we choose the Mitsubishi PLC FX2N-16MR-001. The output of ultrasonic sensor is analog value, while the PLC can only identify the digital value, so we need a A/D converter with three channel to convert the analog values into the digital ones. According to the number of channels, we choose the A/D converter FX2N-4AD which has property of high precision and high conversion speed. The wiring diagram of hardware system is shown in fig.5, in the diagram, M1 is the stepping motor of revolute joint; M2 is the stepping motor of prismatic joint.

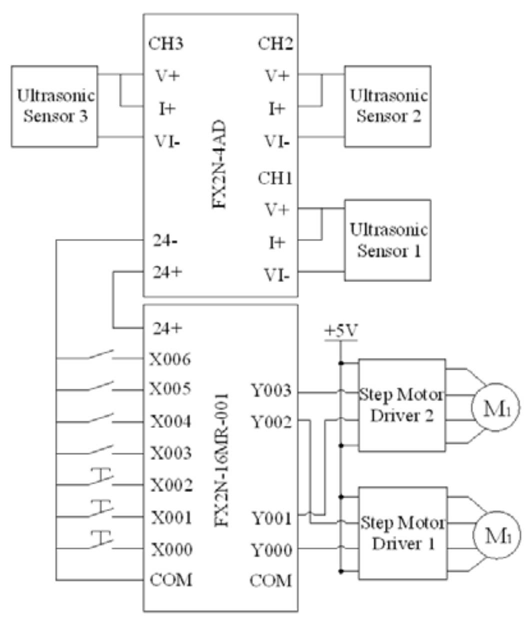

Figure 5. The Wiring Diagram Of PLC And A/D Converter

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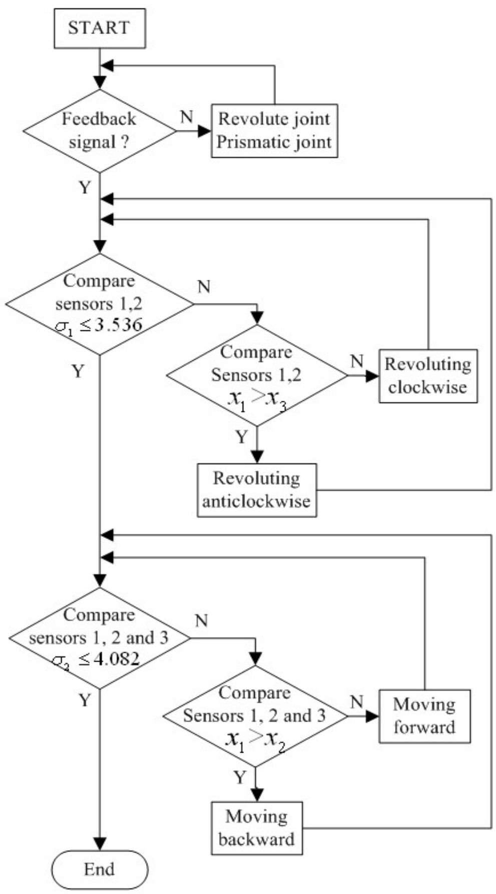

Figure 6. The Program Flowchart Of Automatic Centering

3.2. Software System

According to the requirements of the control system, we adopt GX-Developer to programme. The GX-Developer is a kind of programming software which is aiming at FX-series PLC and developed by MITSUBISHI, and the program can real-time control the working state of each element in PLC. The whole though of control process is: firstly, check the drill pipe is in the measuring range of ultrasonic sensors or not; then accomplish the alignment of drill pipe through the revolute joint; at last, accomplish the centering of drill pipe through the prismatic joint. The program flowchart of automatic centering is shown in fig.6.

4. THE SIMULATION OF AUTOMATIC CENTERING

SimMechanics of Matlab is a software package which includes modeling, simulation and analysis for dynamic system [7]. The module set of SimMechanics can do modeling and simulation for body which is connected by the kinematic pair; it can also accomplish the design and analysis of mechanism system. The SimMechanics contains 5 module units: Bodies module unit, Joints module unit, Constraints & Actuators module unit, Sensors & Actuators module unit and Utilities module unit [8-9].

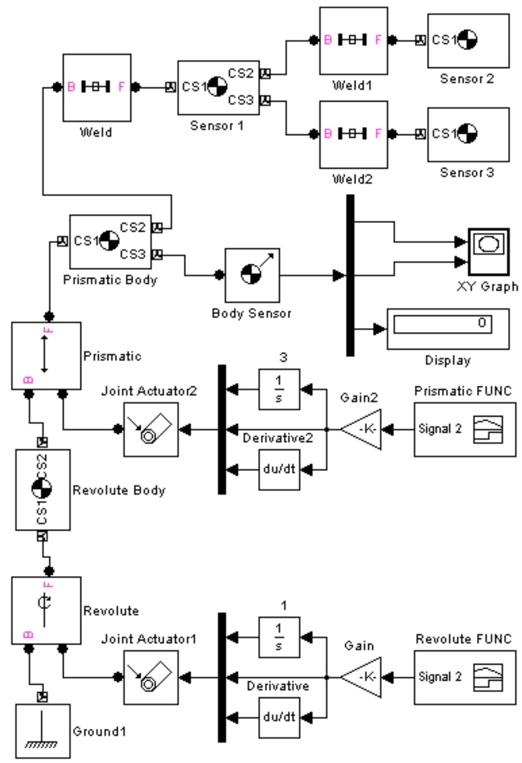

Figure 7. The Simmechanics Block Diagram Of Manipulator

Drawing the simulation block diagram according to the motion process of manipulator in automatic centering system, the SimMechanics block diagram of manipulator is shown in fig.7. First, drawing the fixed frame which could be represented by the Ground module in Bodies module unit; and then, constructing a rotary pair by Revolute module in Joints module unit and building a revolute body by Bodies module unit; and then referencing the revolute body, constructing a prismatic pair by Prismatic module in Joints module unit and building a prismatic body by Bodies module unit; at last, constructing the ultrasonic sensors by Sensors & Actuators module unit. The simulation needs function-waves to respectively actuate the module of rotary pair and the module of prismatic pair, so we need to figure out the functions of rotary pair and prismatic pair through the kinematics analysis.

According to the structural characteristics of manipulator, establish coordinates of the joints of

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manipulator under the premise of real parameters of manipulator, as shown in fig.8, and among them, the origin of coordinate 2 locates in the center of three ultrasonic sensors. After establishing coordinates of the joints of manipulator, determine the parameters of each joint according to the coordinates of adjoining joints, the parameters of manipulator's links are shown in TABLE 1. Among the link parameters, θ represents the joint angle of coordinates of adjoining joints, d represents the link's length of adjoining joints, a represents the link's deviation of adjoining joints, α represents the torsional angle of coordinates of adjoining joints, and each joint angle is positive clockwise [10].

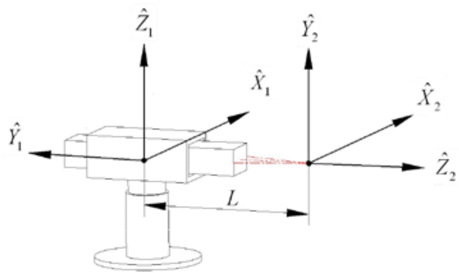

Figure 8. The Arrangement Of Manipulator's Coordinates

Table 1. The Parameter Table Of Manipulator's Links

Joint i	α i-1 / (°)	a i-1 /mm	d i /mm	θi / (°)
1	0	0	0	θ1
2	90°	0	L+d2	0

Substitute the parameters into the formula of homogeneous transfer matrix, we can get the transformation matrix between the adjoining coordinates:

$$ {}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

$$ {}^{1}_{2}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & -(L+d_2) \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4) $$

Unit (3) and (4), the kinematics equation of manipulator is:

$$ {}^{0}_{2}T = {}^{0}_{1}T\,{}^{1}_{2}T = \begin{bmatrix} \cos\theta_1 & 0 & \sin\theta_1 & (L+d_2)\sin\theta_1 \\ \sin\theta_1 & 0 & -\cos\theta_1 & -(L+d_2)\cos\theta_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5) $$

Suppose the target point of the center of three ultrasonic sensors is ${}^{0}P = \begin{bmatrix} x_0 & y_0 & 0 & 1 \end{bmatrix}^T$, through the movements of rotary pair and prismatic pair, the center of three ultrasonic sensors and the target point would be coincident, so the target point could be represented as ${}^{2}P = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}^T$.

So we can establish the equation:

$$ {}^{0}P = {}^{0}_{2}T\,{}^{2}P \quad (6) $$

Unit (5) and (6), analyzing the kinematics equations, and getting:

$$ \theta_1 = \arctan\left(-\frac{x_0}{y_0}\right) \quad (7) $$

$$ d_2 = \frac{x_0}{\sin\arctan\left(-\frac{x_0}{y_0}\right)} - L \quad (8) $$

Equation (7) is the function of revolute joint, (8) is the function of prismatic joint, and according to these equations, we could establish the actuators of revolute joint and prismatic joint.

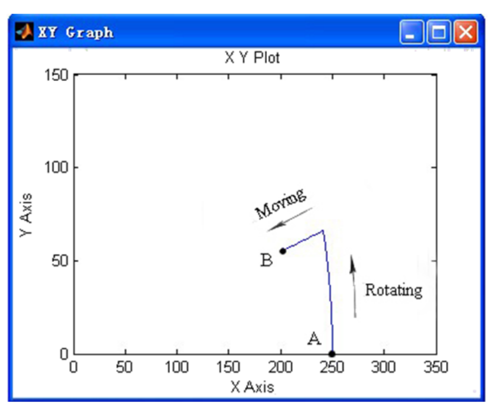

Figure 9. The Trajectory Of Three Ultrasonic Sensors' Center

The simulation starts after inputting the initial position of manipulator and the position of target point. The simulation results are output to the display module through the body sensors, the trajectory of three ultrasonic sensors' center is

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shown in fig.9, point A is the initial point, point B is the target point. The center of three ultrasonic sensors starts from point A, after rotating angle of θ and moving length of d2, reaches point B, the real trajectory is the same with the path which is setting beforehand. The animation display of simulation results is shown in fig.10, from the simulation results, the manipulator's movement is smooth and accurate to locate the target point, it completely accords with the movement requirements of automatic centering.

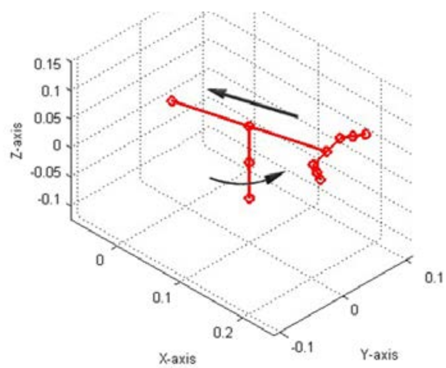

Figure 10. The Animation Display Of Simulation Results

5. CONCLUSION

Through the analysis of traditional centering, we put forward the method of three-point centering which is based on the ultrasonic sensors. First, we analyzed the components of automatic centering system, chose proper ultrasonic sensors, and the installation method of ultrasonic sensors was given; and then, we described the principle of automatic centering which was based on the ultrasonic sensors, and presented the judgment formula of whether accomplishing the centering; at last, we designed the hardware and software system of automatic centering system according to the principle of automatic centering, and did the simulation about automatic centering by the SimMechanics. In this paper, the three-point centering system based on the ultrasonic sensors has the merits of compact structure, wide application range, high precision of centering and high efficiency, and it laid a solid foundation for automation of iron roughneck.

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