Kinematic Analysis of Concrete Hydraulic Dismantling Mechanical Arm

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Abstract. Kinematics analysis of concrete hydraulic dismantling mechanical arm is an important of researching concrete hydraulic dismantling robot's movement and its controller design. The concrete hydraulic dismantling mechanical arm was taken as the research target. The connection rod coordinate system of the mechanical arm was established with D-H rule and the kinematic analysis of mechanical arm was finished. Using Adams to carry out kinematics simulation analysis of the model, thus obtained motion envelope diagram of the mechanical arm, measured the displacement, velocity and acceleration curve of the mechanical arm spray gun ends. The correctness of theoretical analysis was verified. Combined with theory and simulation, analyzing the pose and motion condition of mechanical arm spray gun ends in the actual situation, provides a theoretical basis for the trajectory planning and control of the terminal mechanical arm.

Introduction

Concrete hydraulic dismantling robot is safety, efficient, no pollution and no damage to steel bar comparing with traditional mechanical dismantling, which dismantling concrete with ultrahigh pressure water jet. The robot can be widely used to maintenance concrete structure engineering, such as highway, tunnel, bridge, dam and port, which can improve construction environment.

As the actuator of concrete hydraulic dismantling robot, the flexibility and stability of mechanical arm, which determines the performance of robots to a great extent[1]. Therefore the analysis and research of mechanical arm has great practical significance. This paper uses D-H rule to do the kinematic analysis and do the kinematics simulation of mechanical arm in Adams, which provide reference data and theoretical basis for trajectory planning of spray gun that on the terminal of mechanical arm

Kinematics Modeling of Mechanical Arm

It's one of the important factors to select the modeling of kinematics, which determine the absolute accuracy of mechanical arm [3]. This paper uses D-H rule to establish kinematics modeling of mechanical arm. D-H rule was proposed by Denavit and Hardenberg in 1955, which was used to establish additional coordinate on every linkage in a kinematic chain with matrix method. D-H rule using homogeneous coordinate matrix to describe spatial geometric relationship of mechanical arm linkage compared with reference coordinate system [4].Described spatial geometric relationship of adjacent linkage i and i-1 with homogeneous coordinate matrix of 4×4 as equation(1). Spatial poses relationship ${}^{0}T_i$ was derived between reference coordinate system of spray gun that on the terminal of mechanical arm and coordinate system of vertical arm, as equation(2).

$$ {}^{i\text{-}1}T_i = \begin{bmatrix} c_i & \text{-}s_i & 0 & a_{i\text{-}1} \\ s_i c_{i\text{-}1} & c_{i\text{-}1} c_i & \text{-}s_{i\text{-}1} & \text{-}d_i s_{i\text{-}1} \\ s_{i\text{-}1} s_i & s_{i\text{-}1} c_i & c_{i\text{-}1} & d_i c_{i\text{-}1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1} $$

$$ {}^{0}T_i = {}^{0}T_1 \, {}^{1}T_2 \ldots {}^{i\text{-}1}T_i \tag{2} $$

In the formula: $c_i = \sin\theta_i$, $c_{i\text{-}1} = \cos\alpha_{i\text{-}1}$, $s_i = \sin\theta_i$, $s_{i\text{-}1} = \sin\alpha_{i\text{-}1}$, $i = 1, 2, \ldots$.

Mechanical arm has five free degrees of freedom, which was constituted of five joints (main revolute joint, vertical translation joint, transverse revolute joint, vertical pitch joint and transverse translation joint) and six linkages, as Figure 1 shows.

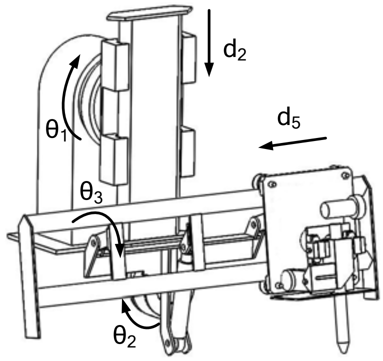

Figure 1.Three-dimensional model of mechanical arm

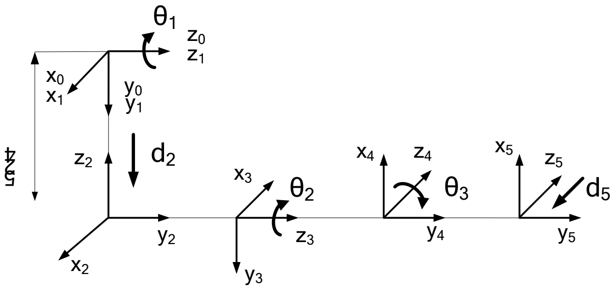

Figure 2. Coordinate system on linkage of mechanical arm

According to D-H rule, took coordinate system $o_0x_0y_0z_0$ of vertical arm as reference coordinate system of mechanical arm [5], and established additional coordinate on every linkage, as figure 2 shows. Determined structure parameters of mechanical arm corresponding linkage according to additional coordinate on every linkage, as Table 1 shows.

Table 1 Structure parameters of mechanical arm linkage

Joint i	θ_i	α_{i-1}	a_{i-1}	d_i /mm	Variable range
1	θ_1	0	0	0	0～360°
2	0	-90°	0	d_2	0～320 mm
3	θ_3	90°	0	208	0～360°
4	θ_4	-90°	0	135	10°～360°
5	0	0	230	d_5	0～1099 mm

Kinematic Analysis

The posture analysis of manipulator end is to determine the space position of manipulator terminal actuator and the relationship between positions of each connecting rod, and is a prerequisite for analysis of manipulator terminal position.

By substitution of D-H parameters obtained from each rod of manipulator into equation (1), the homogeneous transfer matrix of adjacent connecting rod is obtained to be ${}^0T_1, {}^1T_2, {}^2T_3, {}^3T_4, {}^4T_5$,with the above matrix multiplied in turn, the posture of manipulator terminal spray gun relative to the vertical arm coordinate system can be calculated to be ${}^0T_5$ [4], as equation (3).

$$ {}^0T_5 = {}^0T_1\,{}^1T_2\,{}^2T_3\,{}^3T_4\,{}^4T_5 = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_{13}c_4 - s_1s_4 & c_{13}s_4 - s_1s_4 & -s_{13} & a_4(c_{13}c_4 - s_1s_4) - s_{13}(d_5 + d_4) - s_1d_2 \\ s_{13}c_4 & -s_{13}s_4 & c_{13} & a_4s_{13}c_4 + c_{13}(d_5 + d_4) + c_1d_2 \\ s_4 & c_4 & 0 & a_4s_4 + d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

Through the kinematics equation (3),the posture of which manipulator terminal spray gun coordinate system $o_5x_5y_5z_5$ is relative to vertical arm coordinate system $o_0x_0y_0z_0$, according to the matrix is equal, the position vector can be calculated as equation (4).

From the above equation, it can be seen that posture vector of terminal spray gun is a function of mechanical arm joint θ、d , when given the angle θ of 3 rotary joints and the distance d of 2 mobile joints, according to equation (4) , the position vector can be calculated to be $\boldsymbol{n}$、$\boldsymbol{o}$、$\boldsymbol{a}$、$\boldsymbol{p}$,and the pose of which the spray gun coordinate system is respect to the reference coordinate system can be determined .

$$\begin{cases} n_x = c_{13}c_4 - s_1 s_4, n_y = s_{13}c_4, n_z = s_4 \\ o_x = c_{13}s_4 - s_1 s_4, o_y = -s_{13}s_4, o_z = c_4 \\ a_x = -s_{13}, a_y = c_{13}, a_z = 0 \\ p_x = a_4(c_{13}c_4 - s_1 s_4) - s_{13}(d_5 + d_4) - s_1 d_2 \\ p_y = a_4 s_{13} c_4 + c_{13}(d_5 + d_4) + c_1 d_2 \\ p_z = a_4 s_4 + d_2 \end{cases} \tag{4}$$

In the formula: $c_{13} = \cos(\theta_1 + \theta_3)$,the rest is analogical.

Using the mode of sequential action controls ordinal action of manipulator hydraulic motor and hydraulic cylinder, and according to the actual work, different Step functions are established for the main rotary hydraulic motor, lateral moving hydraulic motor, transverse rotary hydraulic cylinder, vertical lifting hydraulic cylinder and lifting hydraulic cylinder to regulate rotary angle of hydraulic motor and stretching stroke of hydraulic cylinder, do the kinematics simulation of mechanical arm.

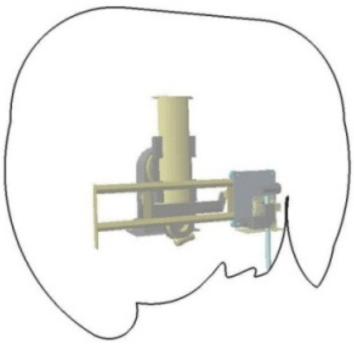

Figure 3 . Motion envelope diagram of the mechanical arm

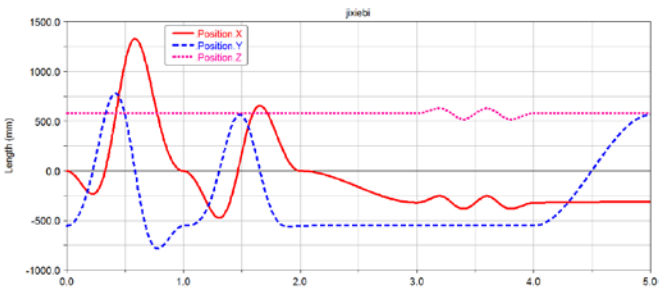

Figure 4 . Displacement curve

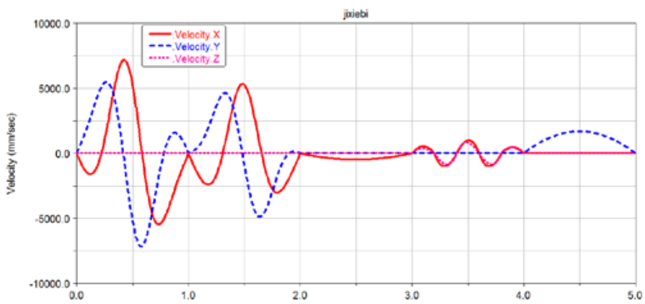

Figure 5 . Velocity curve

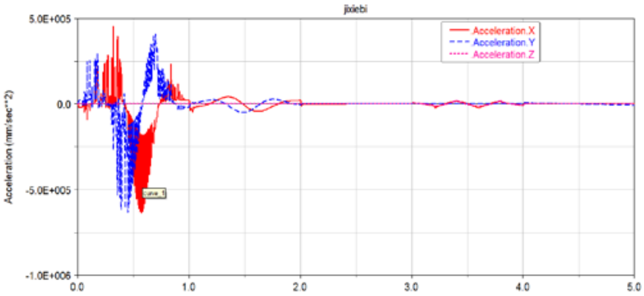

Figure 6 . Acceleration curve

Simulation in Adams, Trajectory (motion envelope diagram of the mechanical arm) of marker pot on the terminal spray gun was obtained after staring simulation, as Figure 3 shows.After the simulation, taking the marker pot on the terminal spray gun as the measuring point, then displacement curve(as Figure 4 shows), velocity curve(as Figure 5 shows) and acceleration curve(as Figure 6 shows) on x, y, z direction of the terminal of spray gun are decided .

By simulation results we can see that displacement and velocity curve of terminal spray gun are relatively stationary under the motion process. However, the amplitude of displacement and velocity on x, y, z direction of terminal spray gun are different. It's because the length of linkage between joints are different, at the same time it's also have relation to the initial position of spray gun (that is has relation to angle value or movement value of joint).

Under the driving of step function, Displacement and velocity curve of terminal spray gun are relatively stationary under the motion process. However, it's unstable for acceleration during 0~1s, as figure 5 shows. It main caused by the start driving time of joint and accorded to the realistic motion that when the driving starts , acceleration is shock, when the driving stability, acceleration is also stabilized. Therefore in order to improve the stability of terminal spray gun during the motion process of mechanical arm, joints can be derived at the same time.

Conclusion

The paper has established kinematics modeling of mechanical arm with D-H rule and finished kinematics analysis, at the same time has completed simulation analysis to the modeling on Adams and has obtained trajectory (motion envelope diagram of the mechanical arm) of marker pot on the terminal spray gun. These works has verified the validity of kinematics model and has important significance for movement controller of the mechanical arm. The paper also has described displacement, velocity and acceleration curve on x, y, z direction of the terminal of spray gun through the simulation analysis to the process of mechanical arm motion. These curves provide a theoretical basis for trajectory planning and control of the terminal mechanical arm spray gun.

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