Kinematics Analysis and Simulation of Suspension Type Koji Turning Robot Based on ADAMS

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Abstract

According to the solid fermentation liquor in the brewing process, the need for manual turning and handling koji in the koji room leads to the problem of labor intensity, the suspension type turning koji robot was designed to complete automatic turning koji and koji's carrying. The robot structure was designed by using the SolidWorks software, and its trajectory planning has been initially carried out. By using the D-H method and the homogeneous matrix trans formation, the robot motion model was established , the forward and inverse kinematics equations have been solved. Kinematics simulation analysis was performed by ADAMS software, the obtain curve proved the correctness of the parameters selection of the robot which could complete the task according to the given requirements, has a guiding role in control system design. Using the turning koji robot to replace workers to turn koji which can help to realize the automation of turning koji process.

Keywords

Turning koji robot, Kinematics, ADAMS, Simulation.

1. Introduction

The solid-state fermentation of liquor-making enterprises still rely on manually operation for koji turning in koji workshop where arises the problem of hostile environment, heavy workload, low efficiency, a automatic suspension type koji turning robot has been designed to replace the manual work[1]. The robot base was designed on its waist part and fixed on the suspension track which over the workshop so that the robot can move along the track and make full use of the workshop space, which can achieve the machinery automation for koji turning, solve the problem of manual turning and handling koji in liquor-making enterprises, improve the efficiency of liquor making [2].

2. Structure Design of the Robot

According to the requirements of the koji turning process, parameters of the size of the block and workshop space layout, the robot body structure has been designed as shown in Fig. 1.

The component 1 is the end of the robot, the forearm 13 parallel to link2, with the forearm 13, the end 1 and the triangle bracket 3 a parallel quadrilateral is formed; link 4 and the arm 12 are parallel, with arm 12, bearing 11 and triangle bracket 3, forme a parallel quadrilateral; link 5 and the arm 12 are parallel, with arm 12, forearm 13 and link 6, a parallel quadrilateral is formed; the end of the robot is always maintained level by these three parallelograms. The robot is hanging on the tracks by the suspension support 7of the waist which can make the robot rotate in the horizontal plane. Counterweight 9 and balance cylinder 8 can respectively reduce effect of starting torque of the arm and forearm [3].

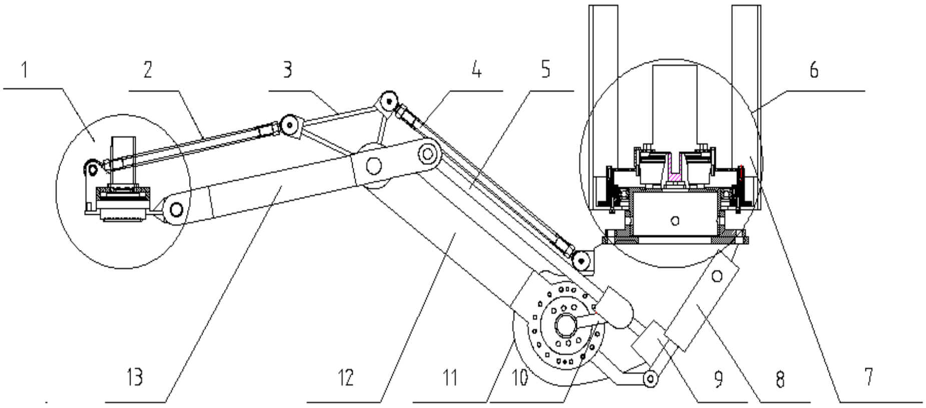

Fig. 1 Robot structure

1.The End 2,4,510.Link 3. Triangular Bracket 6. Waist 7. Waist Suspension Support
8. Balancing Cylinder 9. Counterweight 11. Bearing 12.Arm 13. Forearm

The solid model of the robot was built by SolidWorks. In order to simplify the analysis and calculation, the physical model has been simplified in the condition of not affecting the analytical results (the main dimensions of the structure wasn't changed)[4]. After the dimension and assembly relation of each part of the model have been checked, the finally simplified model as shown in Fig. 2.

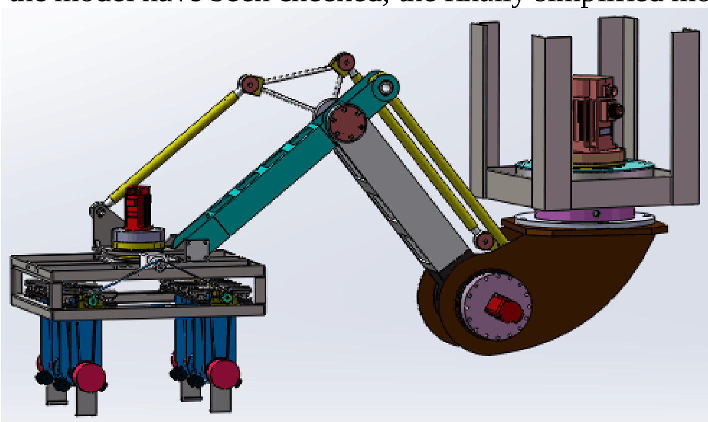

Fig. 2 Simplified simulation model

3. The Robot Trajectory Planning

In order to facilitate the simulation analysis, the total simulation time was set to 6s, the robot completes each movement specific time allocation as shown in Table 1.

Table 1 Robot travel time planning

Component action	Simulation time
From the initial position to the koji block	0.3 s
Grab koji block	1 s
Handling blocks to the appropriate location	2 s
Place blocks	0.7 s
Return to initial position	2 s

In ADAMS three drivers was stetted, the robot simulation time was set to 6S, step was set to 500, the robot's trajectory as shown in Fig. 3. During the 6 seconds, the robot moved from the initial position to where koji blocks were placed, then clamped and handled koji to the ground on the other end, and then return to the initial position. In that process, the robot rotated 180 degrees clockwise and then rotated 180 degrees back. According to the trajectory of the robot, it can complete work in accordance with its predetermined trajectory.

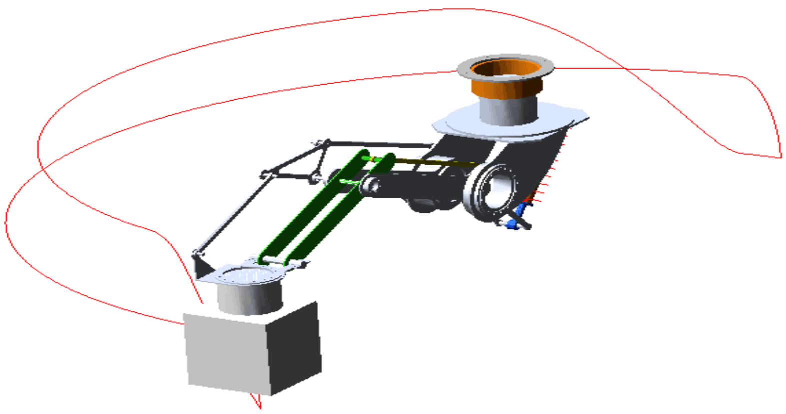

Fig. 3 Robot simulation trajectory

4. Kinematics Analysis and Simulation of the Robot

4.1 Kinematic Analysis

In the kinematics analysis of the robot, the wrist rotation has little effect on the end execution device motion; within the limits of the auxiliary parallelogram four-link structure, the wrist is always maintain a level condition. Therefore, in the solution of position and posture of the robot, the wrist rotational degrees of freedom should not be concerned with, only three degrees of freedom including the movement of waist rotation, arm swing and forearm pitching should be taken into consideration. The robot link coordinate system is shown in Fig. 4.

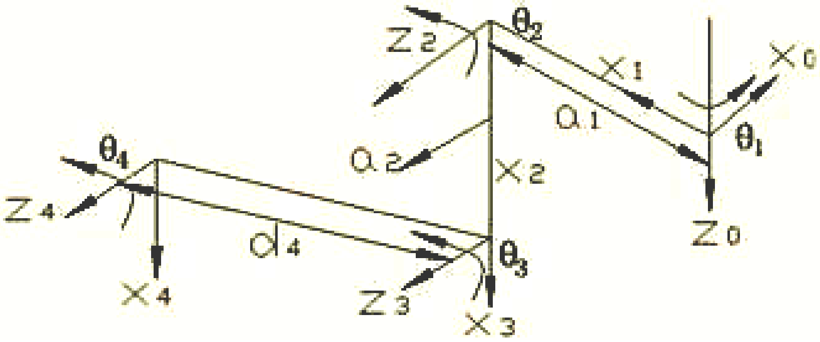

Fig. 4 Robot link coordinate system

The D-H parameters of the robot can be obtained from the above link coordinate system, as shown in Table 2, in which a_1， a_2 respectively represent the length of the arm and forearm of the robot .

Table 2 Robot D-H parameters

Link i	Variable θ_i	α_{i-1}	a_{i-1}	d_i	Variable Range
1	$\theta_1\,(90^o)$	0^o	0	0	$-180^o \sim +180^o$
2	$\theta_2\,(90^o)$	-90^o	a_1=700	0	$-20^o \sim +30^o$
3	$\theta_3\,(0^o)$	0^o	a_2=650	0	$-30^o \sim +25^o$
4	$\theta_4(0^o)$	90^o	0	d_4=700	$-180^o \sim +180^o$

4.2 Forward Kinematics Solution

Since the 4 joints of the robot are all rotary joints, the link homogeneous transformation matrix is:

$$ {}^{i-1}_{i}\mathrm{T} = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -d_i s\alpha_{i-1} \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & d_i c\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1} $$

From (1) to know that the robot has four degrees of freedom, it has four transformation matrix, the robot forward kinematics equation is:

$$ {}^{0}_{4}\mathrm{T}={}^{0}_{1}\mathrm{T}{}^{1}_{2}\mathrm{T}{}^{2}_{3}\mathrm{T}{}^{3}_{4}\mathrm{T} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2} $$

The parameters in Table (2) could be substituted into the Formula (1), according to the kinematic equation (2), the robot end position and posture can be obtained. Among them:

$n_x=(c_1c_2c_3-c_1s_2s_3)c_4-s_1s_4$

$n_y=(s_1c_2c_3-s_1s_2s_3)c_4+c_1s_4$

$n_z= (-s_2c_3-c_2s_3)c_4$

$o_x=(c_1c_2c_3-c_1s_2s_3)c_4-s_1c_4$

$o_y=-(s_1c_2c_3-s_1s_2s_3)s_4+c_1c_4$

$o_z=(s_2c_3-c_2s_3)s_4$

$a_x= c_1c_2s_3+c_1s_2c_3$

$a_y= s_1c_2s_3+s_1s_2c_3$

$a_z=-s_2s_3+c_2c_3$

$p_x=c_1s_{23}d_4+c_1c_2a_2+c_1a_1$

$p_y=s_1s_{23}d_4+s_1c_2a_2+s_1a_1$

$p_z= -c_{23}d_4+s_2a_2$

wherein:

$s_i = \sin\theta_i, c_i = \cos\theta_i, s_{ij} = \sin(\theta_i+\theta_j), c_{ij} = \cos(\theta_i+\theta_j), i = 1,2,3,4$。

4.3 Inverse Kinematics Solution

In the robot motion simulation[5-10], the position of robot end in space is generally known, and the rotation angle of each joint can be solved through the inverse solution. The position and orientation vectors are known when the robot's end coordinate system relative to the base coordinate system, in order to solve the various angles and distances, by inverse transform of ${}^{i-1}_{i}\mathrm{T}^{-1}$ left multiplication the both sides of Formula (2) and each joint variable can be obtained, the solve order is: θ_1, θ_3 and θ_2, shown as the following formula:

$$ \theta_1 = \arctan\frac{p_y}{p_x} $$

$$ \theta_3 = \arcsin\left(\frac{p_x^2+p_y^2+p_z^2-a_1^2-a_2^2-d_4^2}{2a_2d_4}\right) $$

$$ \theta_2 = \theta_{23}-\theta_3 = \arctan\left[\frac{a_2c_3p_z+(a_2s_2-d_4)(s_1p_y-c_1p_x)}{a_2c_3(s_1p_y+c_1p_x)-(a_2s_3-d_4)p_z}\right]-\arcsin\left(\frac{p_x^2+p_y^2+p_z^2-a_1^2-a_2^2-d_4^2}{2a_2d_4}\right) $$

4.4 Kinematics Simulation

The robot should be designed to meet the requirements of koji turning, ADAMS software can be used to simulate and analyze the main kinematics parameters of the robot structure, as the simulation does not involve the quality of the components, the friction and other factors were not taken into account when the simulation model was simplified.

Above all, the related parameters of the robot end effector have been analyzed, the robot end effector along the X, Y, Z direction displacement time curve is shown in Fig. 5, robot end effector in the vertical direction of the lowest point displacement is about 800mm, in addition, the 250mm is extended by the vertical direction of the end effector, the total length is greater than the downward vertical space requirements 900mm, so the robot can realize the koji handling and turning over the ground. At the same time the robot maximum displacement in the horizontal X direction is approximately 1650mm, greater than the robot's working radius 1500mm (that is, half the width of the room), so the size of the robot can meet its work requirements.

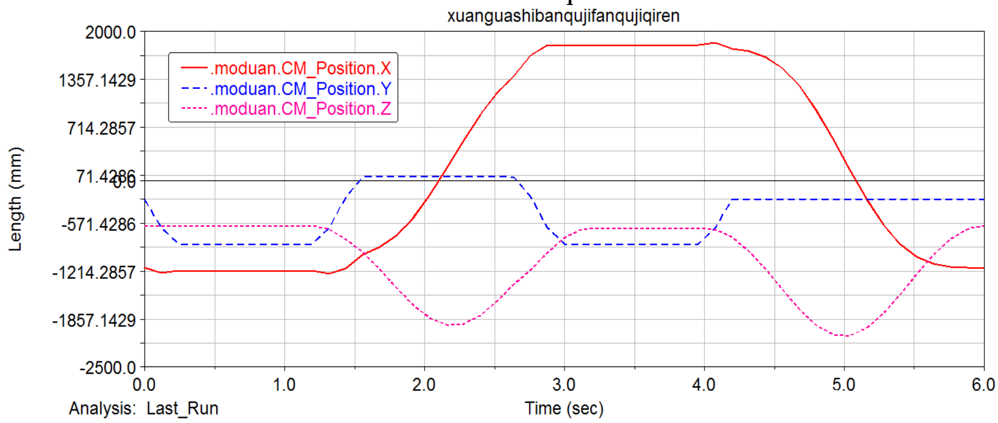

Fig. 5 The end displacement curve

As shown in Fig. 6, the curves of the velocity and resultant velocity of the end effector along the X, Y, and Z directions versus time can be viewed from the post processing results. Robot end effector can accelerate to the maximum speed in a relatively short time to achieve the requirement of the 1000 mm/s, in addition, velocity change rate is relatively stable in acceleration and deceleration phase, which can meet the design requirements.

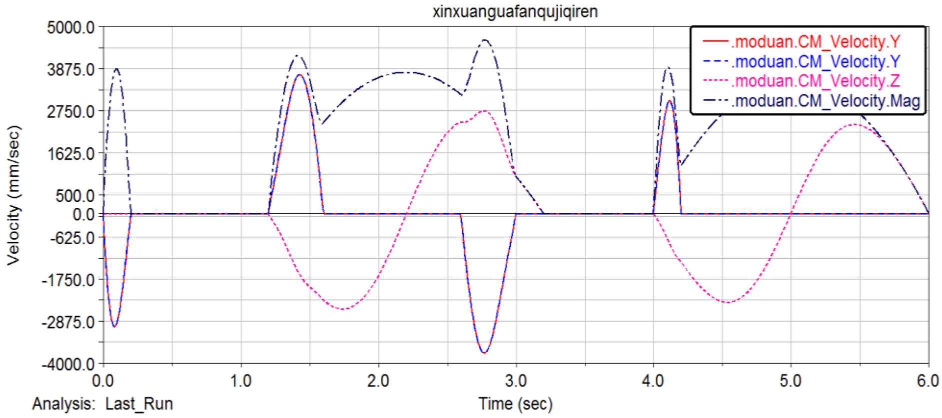

Fig. 6 The end velocity variation curve

As shown in Fig. 7, the angles of the waist joint, elbow joint and shoulder joint versus time curves can be viewed from the post processing results, and the curves change smoothly. In accordance with simulation settings, waist joint turned 180 degrees from the initial position to handle koji blocks to the appropriate position, then 180 degrees turned and returned to its initial position preparing for the next operation.

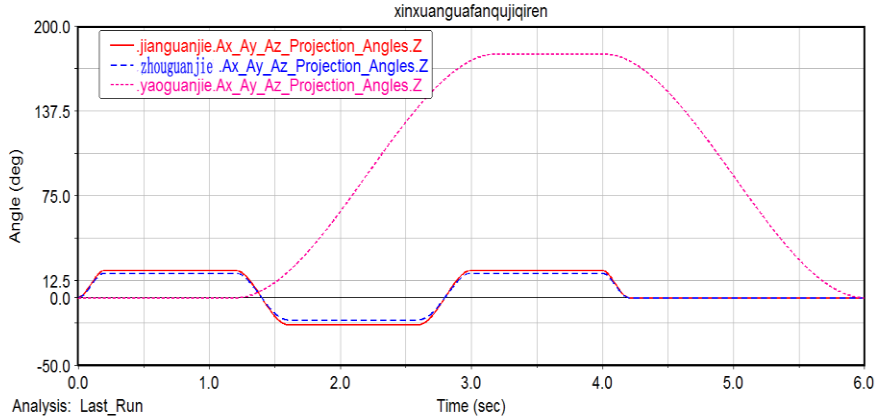

Fig. 7 Angle variation curve of each link

The angular velocity of the waist joint, elbow joint and shoulder joint can be viewed from the post processing results as shown in Fig. 8, the angular velocity can reach high values in a short time, the maximum angular velocity of each joint is more than the maximum designed speed to reach 90 °/ s, the angular velocity of each joint changes smoothly, it has little impact on joints.

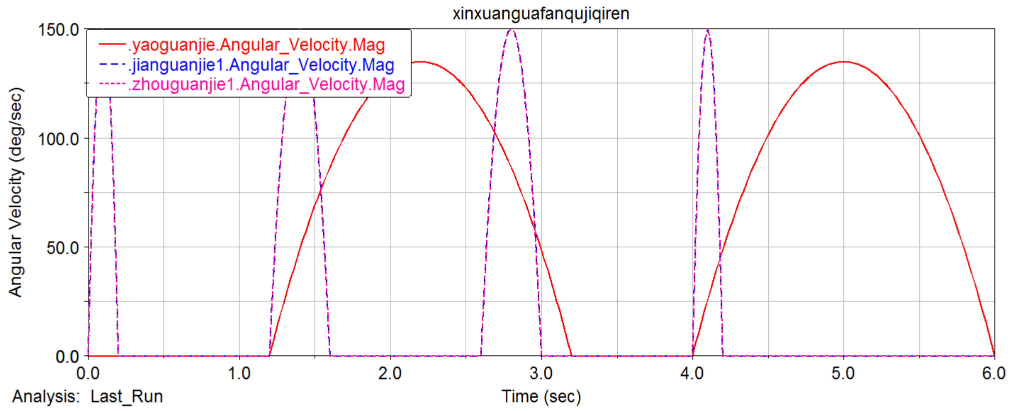

Fig. 8 Angular velocity variation curve of each link

5. Conclusion

The simulation model of the koji turning robot has been established by SolidWorks and ADAMS, and the robot's kinematics behavior was simulated and studied, the correctness of the robot kinematics parameters' selection was identified which could provide basis for subsequent robot trajectory optimization. Simulation results showed that the displacement and velocity of the robot end in all directions were smooth and continuous, and the change of the velocity curve of each joint was smooth, that the rationality of the robot structure design has been indicated, which can play a guiding role in the control system programming and provide a theoretical basis for the control system designing, has a certain reference value for the development of mechanical automation in the process of solid brewing process.

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