Sensors & Transducers, Vol. 166, Issue 3, March 2014, pp. 261-267

Sensors & Transducers

The Wood Strengthening and Decorative Automated Production Line ZY-06L-Type Manipulator Motion Analysis and Simulation

[1] Wu Hao, [2,*] Huang Hanqi, [1] Ren Shan
[1] Faculty of Engineering, Honghe University, Mengzi of Yunnan, 661100, China
[2] Faculty of Humanity, Honghe University, Mengzi of Yunnan, 661100, China
[1] Tel.:18760729177, [2] tel.: 15187336529
[1] E-mail:85975497@qq.com, [2,*] E-mail:154818324@qq.com

Received: 20 December 2013 /Accepted: 28 February 2014 /Published: 31 March 2014

Abstract: ZY-06L-type manipulator is the important components of Wood Surface layer Strengthening and Decorative Automated Production Line, designed for a variety of sheet metal or semi-finished components handling, distribution and laying work in the workshop. Through the establishment of the manipulator kinematics equations, combined the position coordinates of the manipulator and object in the actual work environment, and solving this equation to get the relationship between the manipulator end-effectors position and posture with the joint variables. The use of engineering software UG NX8.0 for modeling and simulation of the manipulator, and analysis the reasonableness of structural and workflow design. Provide the basis and reference to the manipulator structure optimization and control systems developments.

Keywords: Timber processing, Manipulator, Kinematics equations, Simulation analysis.

1. Introduction

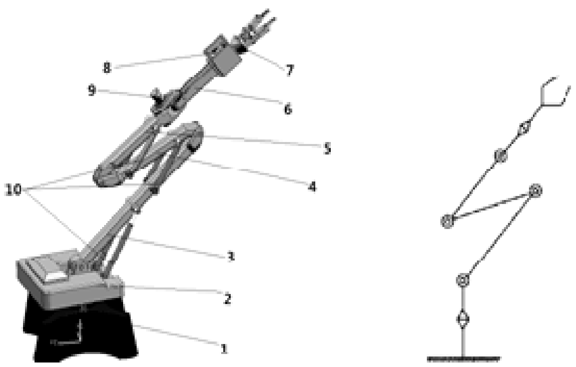
Manipulator (Industrial robots), the important manifestation of advanced manufacturing technology of modern industry, play an important role in many industrial categories. Industrial robots and flexible manufacturing systems combined, changing the basic design of the manufacturing system, greatly improved the production automation, efficiency and product quality [1].

ZY-06L-type manipulator is the important components of Wood Surface layer Strengthening and Decorative Automated Production Line. Undertakes the role of sheet metal or semi-finished components handling, distribution and laying in the system, and plays an important role that improve production line efficiency and product quality.

2. Manipulator Structure

Manipulator composed by the drive original, control module, and the main structural parts of base, rotating base, lower arm, intermediate arm, upper arm, swing arm, the end effectors, etc. as shown in Fig. 1.

This manipulator designed for a variety of sheet metal or semi-finished components handling, distribution and laying work in the workshop. Due to the material needs to move back and forth in the workshop, and the space pose complex. So for manipulator the carrying capacity, DOF, scope of work and efficiency of requirements higher, for motion accuracy requires relatively low. Therefore, manipulator rotating base, lower arm, intermediate arm, upper arm, swing arm, and the end effectors are hydraulic drive, and control joints variable error in the range of design requirements by angle sensor feedback.



1 – base support; 2 – rotating base; 3 – lower arm; 4 – intermediate arm; 5 – upper arm; 6 – Swing arm; 7 – end effectors; 8 – wrist hydraulic motor; 9 – Swing arm hydraulic motor; 10 – hydraulic cylinder.

Fig. 1. ZY-06L manipulator.

3. Kinematics Equations

In the Space opened-chain mechanism, various structural components connected by joints, one end of the opened-chain mechanism mounted on the base and the other end connected to the end effectors.

Each joint by the motor, hydraulic cylinders, hydraulic motors to drive, the relative movement mechanism causes the joint movement, thereby determining the end effectors position and orientation in the 3D coordinates.

The equations kinematics of institution building and solving, fundamental purpose is to establish end-effectors position and orientation relationship with the joint variables. Further studies on the mechanism and optimization, provide a theoretical basis for mechanism design, and provide a basis and parameter for the control systematic study [2-4].

Each components of the mechanism as a rigid body, then the components movement in space becomes rigid body motion.

Space arbitrary motion of a rigid body can be regarded as the synthesis of two sub-movement, around a rotation axis and a translation along an axis [1]. Therefore, the main structural member of the manipulator as a rigid body, establish kinematical diagram shown in Fig 2.

The coordinate system transformation relationship in the kinematical diagram as follows.

$x_0y_0z_0 \to x_1y_1z_1$. First around the Z_0-axis deflection θ_1, then along Z_O axis translation L_1.

$x_1y_1z_1 \to x_2y_2z_2$. First around the X_1-axis deflection θ_2, then along Z_1 axis translation L_2.

$x_2y_2z_2 \to x_3y_3z_3$. First around the X_2-axis deflection θ_3, then along Z_2 axis translation L_3.

$x_3y_3z_3 \to x_4y_4z_4$. First around the X_3-axis deflection θ_4, then along Z_3 axis translation L_4.

$x_4y_4z_4 \to x_5y_5z_5$. First around the Y_4-axis deflection θ_5, then along Z_4 axis translation L_5.

Homogeneous transformation matrix parameters of coordinate system are shown in Table 1.

According to kinematical diagram and coordinate system transformation relationship, establish the manipulator kinematics equation as follows [5].

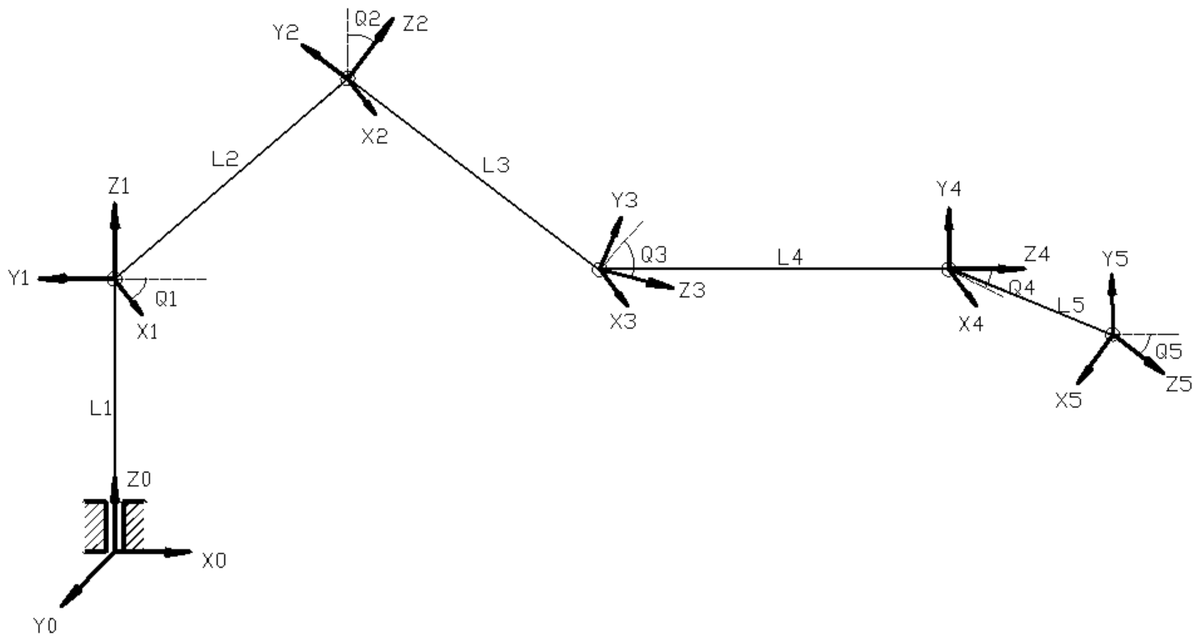


Fig. 2. Manipulator kinematical diagram.

Table 1. Manipulator rod D-H parameter table.

No. rod	Joint variables	Rod twist angle	Rod length	No. rod	Joint variables	Rod twist angle	Rod length
1	θ_1	0	L_1	4	θ_4	0	L_4
2	θ_2	0	L_2	5	θ_5	0	L_5
3	θ_3	0	L_3				

$$
\begin{aligned}
{}^0_1T &= rot(z_0,\theta_1)trans(0,0,L_1)\\
&= \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}
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}
= \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}\\
{}^1_2T &= rot(x_1,\theta_2)trans(0,0,L_2)\\
&= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_2 & -\sin\theta_2 & 0 \\ 0 & \sin\theta_2 & \cos\theta_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}
= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_2 & -\sin\theta_2 & 0 \\ 0 & \sin\theta_2 & \cos\theta_2 & L_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}\\
{}^2_3T &= rot(x_2,\theta_3)trans(0,0,L_3)\\
&= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_3 & -\sin\theta_3 & 0 \\ 0 & \sin\theta_3 & \cos\theta_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}
= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_3 & -\sin\theta_3 & 0 \\ 0 & \sin\theta_3 & \cos\theta_3 & L_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}\\
{}^3_4T &= rot(x_3,\theta_4)trans(0,0,L_4)\\
&= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_4 & -\sin\theta_4 & 0 \\ 0 & \sin\theta_4 & \cos\theta_4 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}
= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_4 & -\sin\theta_4 & 0 \\ 0 & \sin\theta_4 & \cos\theta_4 & L_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}\\
{}^4_5T &= rot(y_4,\theta_5)trans(0,0,L_5)\\
&= \begin{bmatrix} \cos\theta_5 & 0 & \sin\theta_5 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_5 & 0 & \cos\theta_5 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}
= \begin{bmatrix} \cos\theta_5 & 0 & \sin\theta_5 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_5 & 0 & \cos\theta_5 & L_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}\\
{}^0_5T &= {}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T\,{}^4_5T\\
&= \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_2 & -\sin\theta_2 & 0 \\ 0 & \sin\theta_2 & \cos\theta_2 & L_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_3 & -\sin\theta_3 & 0 \\ 0 & \sin\theta_3 & \cos\theta_3 & L_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}\\
&\quad \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_4 & -\sin\theta_4 & 0 \\ 0 & \sin\theta_4 & \cos\theta_4 & L_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} \cos\theta_5 & 0 & \sin\theta_5 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_5 & 0 & \cos\theta_5 & L_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}\\
&= \begin{bmatrix} A_1 & B_1 & C_1 & D_1 \\ A_2 & B_2 & C_2 & D_2 \\ A_3 & B_3 & C_3 & D_3 \\ A_4 & B_4 & C_4 & D_4 \end{bmatrix}
\end{aligned}
$$

where

$$
\begin{aligned}
A_1 &= \cos\theta_1\cos\theta_5 - \sin\theta_1\cos_2\sin\theta_2\cos\theta_3\sin\theta_4\sin\theta_5\\
&\quad + \sin\theta_1\sin\theta_2\sin\theta_3\sin\theta_4\sin\theta_5 - \sin\theta_1\cos\theta_2\sin\theta_3\cos\theta_4\sin\theta_5\\
&\quad - \sin\theta_1\sin\theta_2\cos\theta_3\cos\theta_4\sin\theta_5\\
B_1 &= -\sin\theta_1\cos\theta_2\cos\theta_3\cos\theta_4 + \sin\theta_1\sin\theta_2\sin\theta_3\cos\theta_4\\
&\quad + \sin\theta_1\cos\theta_2\sin\theta_3\sin\theta_4 + \sin\theta_1\sin\theta_2\cos\theta_3\sin\theta_4
\end{aligned}
$$

$$
\begin{aligned}
C_1 &= \cos\theta_1\sin\theta_5 + \sin\theta_1\cos\theta_2\cos\theta_3\sin\theta_4\cos\theta_5\\
&\quad - \sin\theta_1\sin\theta_2\sin\theta_3\sin\theta_4\cos\theta_5 + \sin\theta_1\cos\theta_2\sin\theta_3\cos\theta_4\cos\theta_5\\
&\quad + \sin\theta_1\sin\theta_2\cos_3\cos_4\cos_5\\
D_1 &= L_5\sin\theta_1\cos\theta_2\cos\theta_3\sin\theta_4 - L_5\sin\theta_1\sin\theta_2\sin\theta_3\sin\theta_4\\
&\quad + L_5\sin\theta_1\cos\theta_2\sin\theta_3\cos\theta_4 + L_5\sin\theta_1\sin\theta_2\cos\theta_3\cos\theta_4\\
&\quad + L_4\sin\theta_1\cos\theta_2\sin\theta_3 + L_4\sin\theta_1\sin\theta_2\cos\theta_3 + L_3\sin\theta_1\sin\theta_2
\end{aligned}
$$

$$A_2 = \sin\theta_1 \cos\theta_5 + \cos\theta_1 \cos\theta_2 \cos\theta_3 \sin\theta_4 \sin\theta_5 \\ -\cos\theta_1 \sin\theta_2 \sin\theta_3 \sin\theta_4 \sin\theta_5 + \cos\theta_1 \cos\theta_2 \sin\theta_3 \cos\theta_4 \sin\theta_5 \\ +\cos\theta_1 \sin\theta_2 \cos\theta_3 \cos\theta_4 \sin\theta_5$$

$$B_2 = \cos\theta_1 \cos\theta_2 \cos\theta_3 \cos\theta_4 - \cos\theta_1 \sin\theta_2 \sin\theta_3 \cos\theta_4 \\ -\cos\theta_1 \cos\theta_2 \sin\theta_3 \sin\theta_4 - \cos\theta_1 \sin\theta_2 \cos\theta_3 \sin\theta_4$$

$$C_2 = \sin\theta_1 \sin\theta_5 - \cos\theta_1 \cos\theta_2 \cos\theta_3 \sin\theta_4 \cos\theta_5 \\ +\cos\theta_1 \sin\theta_2 \sin\theta_3 \sin\theta_4 \cos\theta_5 - \cos\theta_1 \cos\theta_2 \sin\theta_3 \cos\theta_4 \cos\theta_5 \\ -\cos\theta_1 \sin\theta_2 \cos\theta_3 \cos\theta_4 \cos\theta_5$$

$$D_2 = -L_5 \cos\theta_1 \cos\theta_2 \cos\theta_3 \sin\theta_4 + L_5 \cos\theta_1 \sin\theta_2 \sin\theta_3 \sin\theta_4 \\ -L_5 \cos\theta_1 \cos\theta_2 \sin\theta_3 \cos\theta_4 - L_5 \cos\theta_1 \sin\theta_2 \cos\theta_3 \cos\theta_4 \\ -L_4 \cos\theta_1 \cos\theta_2 \sin\theta_3 - L_4 \cos\theta_1 \sin\theta_2 \cos\theta_3 - L_3 \cos\theta_1 \sin\theta_2$$

$$A_3 = \sin\theta_2 \sin\theta_3 \sin\theta_4 \sin\theta_5 + \cos\theta_2 \cos\theta_3 \sin\theta_4 \sin\theta_5 \\ +\sin\theta_2 \sin\theta_3 \cos\theta_4 \sin\theta_5 - \cos\theta_2 \cos\theta_3 \sin\theta_4 \sin\theta_5$$

$$B_3 = \sin\theta_2 \cos\theta_3 \cos\theta_4 + \cos\theta_2 \sin\theta_3 \cos\theta_4 - \sin\theta_2 \sin\theta_3 \sin\theta_4 \\ +\cos\theta_2 \cos\theta_3 \sin\theta_4$$

$$C_3 = -\sin\theta_2 \cos\theta_3 \sin\theta_4 \cos\theta_5 - \cos\theta_2 \sin\theta_3 \sin\theta_4 \cos\theta_5 \\ -\sin\theta_2 \sin\theta_3 \cos\theta_4 \cos\theta_5 + \cos\theta_2 \cos_3 \cos\theta_4 \cos\theta_5$$

$$D_3 = -L_5 \sin\theta_2 \cos\theta_3 \sin\theta_4 - L_5 \cos\theta_2 \sin\theta_3 \sin\theta_4 \\ -L_5 \sin\theta_2 \sin\theta_3 \cos\theta_4 \cos\theta_5 \infty + L_5 \cos\theta_2 \cos\theta_3 \cos\theta_4 \\ -L_4 \sin\theta_2 \sin\theta_3 + L_4 \cos_2 \cos\theta_3 + L_1 + L_2 + L_3 \cos\theta_2$$

$$A_4 = 0;\ B_4 = 0;\ C_4 = 0;\ D_4 = 1$$

Through the establishment of the manipulator kinematics equations, combined the position coordinates of the manipulator and object in the actual work environment, and solving this equation to get the relationship between the manipulator end-effectors position and posture with the joint variables.

4. Motion Analysis and Simulation

UG NX8.0 motion simulation analysis module UG / Motion providers sport / dynamic simulation analysis capabilities. Motion simulation exercise can interfere with the analysis, motion trajectory tracking, and analysis of parts of displacement, velocity, acceleration, force, torque reaction and so on. The results can guide the design optimization and tuning, design changes can be reflected in the assembly of the model.

In the motion simulation, set up 55 pairs of ordinary deputy campaign and 3 pairs of special deputy campaign, the specific types and quantities are as follows [6-8].

Fixed deputy campaign. 1 pair, connected to the base support and geodetic coordinate system.

Sliding deputy campaign. 7 pairs, connected to the 7 cylinders and piston.

Cylinder deputy campaign. 1 pair, connected to the manipulator swing arm and end effectors.

Rotational deputy campaign.46 pairs, connect all remaining connecting rod.

Gear deputy campaign. 3 pairs, connection gear.

4.1. Motion Scheme

In order to obtain the manipulator motion parameters, according the actually situation to simulation the manipulator complete movement, test the reasonableness of the manipulator movement and motion states any time.

Referring to the actual position of the manipulator in the production line, obtained the coordinates of manipulator initial position, object initial position and the target location, as shown in Table 2.

Table 2. The coordinate parameters of manipulator end effectors in three kinds of position and orientation (Referring to Fig 2. coordinates $X_0Y_0Z_0$).

Location	Coordinate values(mm)
Manipulator initial position	$X_0Y_0Z_0$ (1500,0,3200)
Object initial position	$X_0Y_0Z_0$ (-2100,600,4050)
Object target location	$X_0Y_0Z_0$ (3210,0,4100)

Solving motion equations according coordinate parameters of Table 2. get each joint variable values that manipulator end effectors in the manipulator initial position, object initial position and object target location, as shown in Table 2. According to the parameters in Table 3, and reference the shape of manipulator carrying objects, arrangement manipulator motion program, as shown in Table 4.

Tab 3. The joint variables of manipulator in three kinds of position and orientation.

joint variable	Manipulator initial position	Object initial position	Object target location
Q_1	0°	166°	-14°
Q_2	45°	34°	50°
Q_3	160°	68°	63°
Q_4	-160°	-89°	-62°
Q_5	0°	150°	0°

4.2. Motion Drive

The number of manipulator DOF is 6, need 7 motion driving. According to motion scheme, the use of STEP function to add the drive, as shown in Table 5.

4.3. Simulation and Results

Set motion simulation time is 185S, step number 18500, the solver of ADAMS inspection and solver the simulation model. If the simulation model has errors, the error message dialog box pops up, and debug the model according to the message. If the simulation model is correct, then the simulation results output [9, 10]. Simulation according to the motion scheme of Table 4, the action of manipulator shown in Fig 3, the motion parameters of manipulator end effectors as shown in Fig. 4, Fig. 5 and Fig. 6.

Table 4. Motion scheme.

Time	Action
0 s~9 s	Base counter-clockwise 166 °
9 s~11 s	All stationary
11 s~20 s	Lower arm swings clockwise 11 °
20 s~35 s	Upper arm swings counter-clockwise 71°
25 s~40 s	Intermediate arm swings clockwise 92°
40 s~50 s	End effectors turn 90°
50 s~55 s	End effectors fingers open
55 s~65 s	Swing arm turn left 150°
65 s~70 s	Fingers together (pinching)
70 s~80 s	Swing arm return (-150°)
80 s~90 s	Upper and intermediate arm return; Lower arm swings counter-clockwise 45°
90~100 s	Rotating base clockwise rotation 180°
100 s~115 s	Intermediate arm swings clockwise 97°
110 s~120 s	Upper arm swings counter-clockwise 63°
120 s~123 s	The still (sensor feedback correction time)
123 s~135 s	End effectors turn 90°
135 s~138 s	The still (corrected again)
138 s~150 s	Upper arm swings counter-clockwise 35°
143 s~153 s	Lower arm swings clockwise 29°
153 s~158 s	End effectors fingers open (Down objects)
158 s~163 s	The still (detecting objects final position)
163 s~173 s	Lower arm return
170 s~180 s	Upper arm return
175 s~185 s	Intermediate arm return

Table 5. Motion drive.

Motion	Motion Drive
Base rotation	STEP(TIME,0,0,9,2.9)+STEP(TIME,90,0,100,-3.14)
Lower arm swings	STEP(TIME,11,0,20,-0.2)+STEP(TIME,80,0,90,0.7) +STEP(TIME,143,0,153,-0.5)+STEP(TIME,163,0,173,0.3)
Intermediate arm swings	STEP(TIME,25,0,40,1.6)+STEP(TIME,80,0,90,-1.2) +STEP(TIME,100,0,120,1.7)+STEP(TIME,175,0,185,-1.7)
Upper arm swings	STEP(TIME,20,0,35,1.25)+STEP(TIME,80,0,90,-1.3) +STEP(TIME,105,0,120,1.1)+STEP(TIME,138,0,150,0.6)
Swing arm swings	STEP(TIME,55,0,65,2.6)+STEP(TIME,70,0,80,-2.6)
End effectors swings	STEP(TIME,40,0,50,3.2)+STEP(TIME,123,0,135,3.1)
End effectors task	STEP(TIME,50,0,55,26)+STEP(TIME,65,0,70,-100) +STEP(TIME,153,0,158,100)

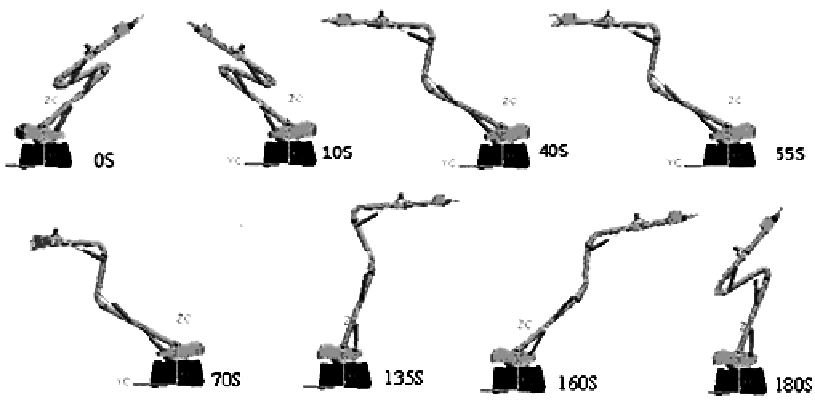


Fig. 3. Motion simulation action Screenshots.

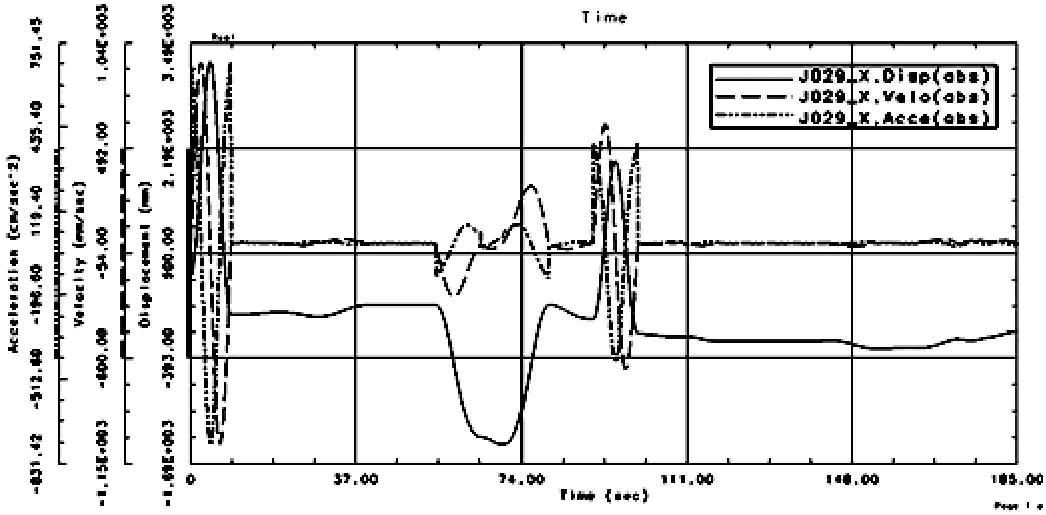


Fig. 4. The end effectors displacement, velocity, acceleration curve (X-axis component).

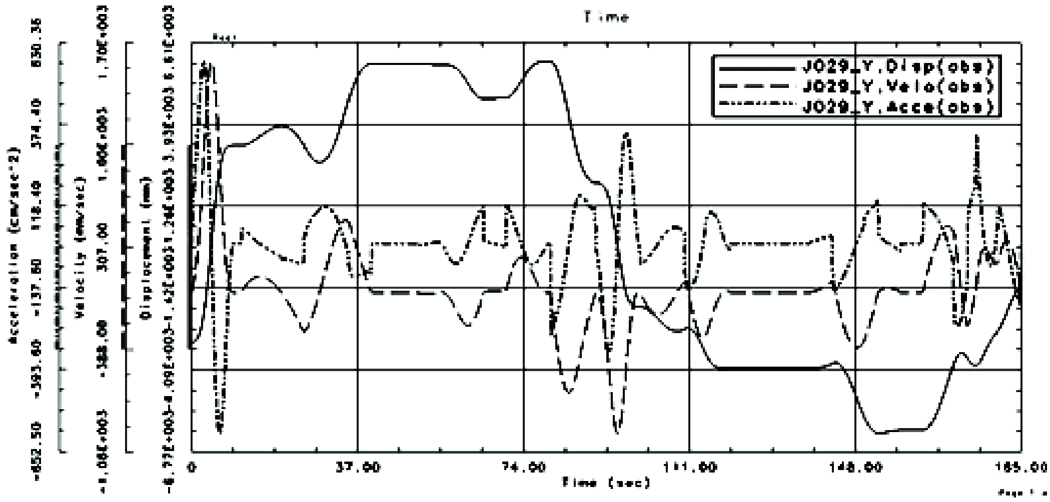


Fig. 5. The end effectors displacement, velocity, acceleration curve (Y-axis component).

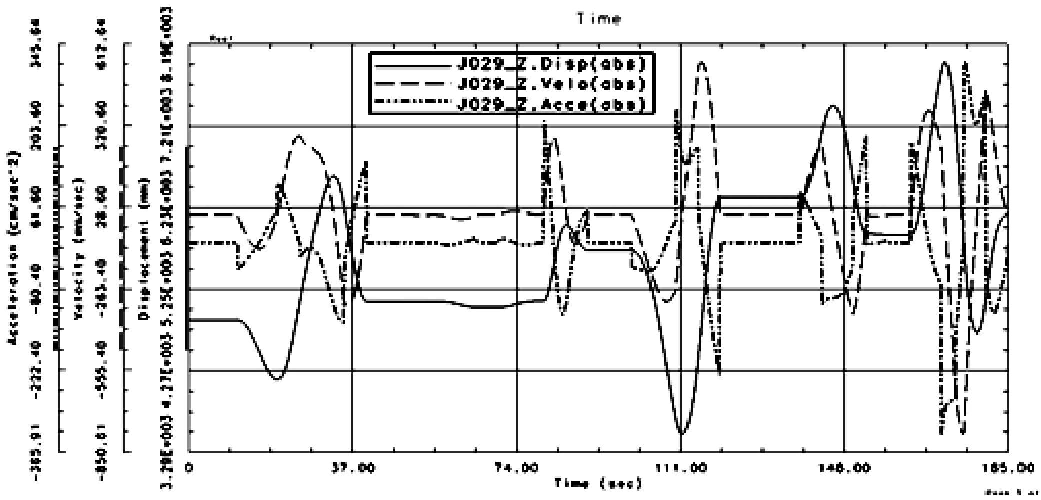


Fig. 6. The end effectors displacement, velocity, acceleration curve (Z-axis component).

7. Conclusions

ZY-06L-type manipulator developed. The purpose is to improve the production efficiency, degree of automation, product quality of wood surface layer strengthening and Decorative Automated Production Line, and improve enterprise efficiency.

Through the establishment of the manipulator motion equations, get the relationship between the manipulator end-effectors position and posture with the joint variables. Analysis manipulator working process, substituting the parameters and solving the motion equations, and get the manipulator joint variables of three kinds of conditions. According manipulator workflow, the simulation results are as follows. The displacement of manipulator end-effectors achieves the design requirements. When the end-effectors in the initial position (0S), the object initial position (70S) and object target location (160S), the position and attitude is consistent with the expected value, and the speed and load changes are within the scope of the requirements. The creating and solving of manipulator motion equations is correct, action reasonable, the manipulator design is feasible.

References

[1]. Z. X. Cai, Robotics, *Qinghua University Press*, 2009.

[2]. H. Sun, Z. M. Cheng. Mechanical principles, *Higher Education Press*, 2006.

[3]. Z. Huang, Y. S. Zhao. Advanced spatial mechanism, *Higher Education Press*, 2005.

[4]. Y. P. Cheng, Z. Y. Ma, C. M. Yuan. The 6 DOF manipulator motion simulation, *Computers Application Research*, Vol. 6, 2006, pp. 205-209.

[5]. H. Wu, X. B. Dong, J. P. Li. Theoretical study on rotating platform design for platform-based lifting, *Journal of Northeast Forestry University*, Vol. 38, 2010, pp. 96-99.

[6]. C. K. Gong, J. G. Xiong, C. L. Huang. Delta parallel manipulator kinematics and dynamics simulation analysis, *Manufacturing Automation*, Vol. 3, 2013, pp. 5-7.

[7]. J. M. Liu, L. Z. Liu, W. J. Liang. The UG motion analysis study conducted by ADAMS solver, *Computer Simulation*, Vol. 23, 2006, pp. 289-292.

[8]. X. S. Weng. The loader working device motion simulation based on UG and ADAMS, *Electromechanical Product Development and Innovation*, Vol. 19, 2006, pp. 105-106.

[9]. Z. B. Wang, J. J. Ren, C. W. Wang. The motion simulation and stress analysis on EBZ220TY boring machine turntable, *Manufacturing Automation*, Vol. 2, 2013, pp. 5-7.

[10]. S. C. Yu, J. L. Zhang, J. G. Yang. Automotive welding fixture motion simulation based on ADAMS, *Manufacturing Technology and Machine Tool*, Vol. 4, 2009, pp. 137-139.
