Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 8, No. 1, 2023

Kinematic analysis of Manipulator for Insulating Glass Production Line

Liang Zhang[1, 2, 3], Shuzhen Li[1, 2, 3], Lei Shi[1, 2, 3], Zhiyu Liu[1], Jingjing Yu[1]

[1]College of Mechanical and Electronic Engineering, Hebei Normal University of Science & Technology, Qinhuangdao 066004, China
[2]Hebei Technology Innovation Center of Photovoltaic Module Manufacturing Equipment, Qinhuangdao 066004, China
[3]Hebei Engineering Research Center of PV Module Encapsulating and Measuring Equipment, Qinhuangdao 066004, China

Abstract: Aiming at the current situation of loading and unloading operation of insulating glass production line, and according to the workstation and process requirements of the manipulator in the insulating glass production line, a manipulator suitable for vertical insulating glass production line is designed. The manipulator body adopts a series structure with two moving pairs and one rotating pair. The kinematics of manipulator is analyzed by D-H method. The manipulator can meet the production requirements of insulating glass.

Keywords: Insulating glass, Manipulator, Kinematic.

1. Introduction

Various robots have been widely used in the manufacturing industry, but some insulating glass production lines are still manually loading and unloading, resulting in low production efficiency. According to the workstation and process requirements of the manipulator in the insulating glass production line, a manipulator suitable for vertical insulating glass production lines is designed to improve the production quality and productivity of insulating glass. The manipulator body adopts a series structure, with two moving pairs and one rotating pair, which can reach the designated position to suck and release glass according to instructions.

2. Manipulator Structure of Insulating Glass Production Line

2.1. Production process of insulating glass

The vertical insulated glass automated production line equipped with manipulators is shown in Figure 1. The dashed box represents the current insulated glass production process. The raw materials are manually placed on a conveyor, and the insulated glass is manufactured through three processes: cleaning, gluing, and pressing. Finally, the finished product is manually removed and placed in a designated location.

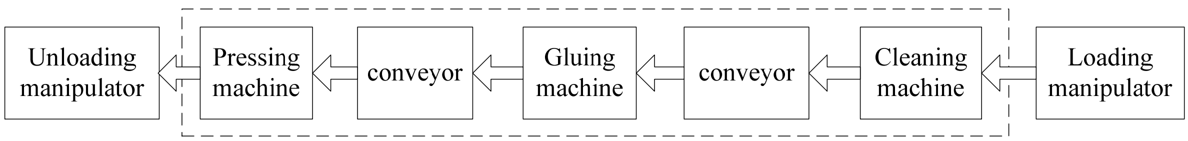


Figure 1. Production process of insulating glass

2.2. Manipulator structure

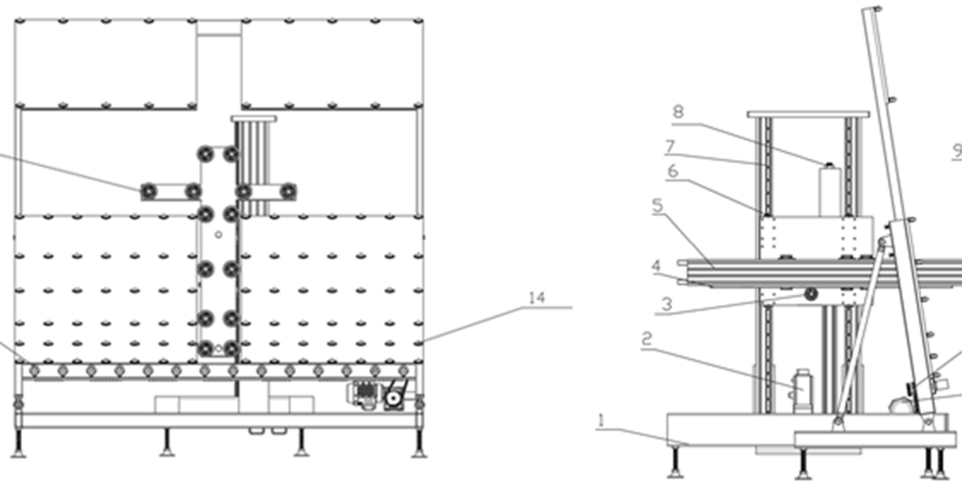
The working process of the manipulators in the insulating glass production line is as follows: the loading manipulator extends to the given stroke, then descends to the specified position to extract the glass and return along the original path, the glass is placed on the conveyor, which then undergoes cleaning, gluing, and pressing processes, the glass is then transported to the position of the unloading manipulator through the conveyor, and the unloading manipulator completes the stacking work. Both the loading and unloading processes require 3 degrees of freedom to meet the requirements.

The manipulator has 2 moving pairs and 1 rotating pair, mainly composed of a base, rack and pinion, electric push rod, end effector, etc. The structure is shown in Figure 2. According to the process requirements of the production line, the forward and backward movement range of the robotic arm is 0-1350mm, the lifting range is 0-950mm, the load capacity is 300kg, and the flipping angle range of the robotic arm end effector is $-30^0 \sim 60^0$.

3. Kinematic Analysis of Manipulator

3.1. Kinematic model of manipulator

The D-H method is used to establish the coordinate system of the manipulator[1], as shown in Figure 3. The D-H parameters of the manipulator are shown in Table 1.



(a) View 1 (b) View 2

1. Base 2, 11 Servo motors 3. Servo motor output gear 4. Rack 5. Section bar 6. Slider 7. Guide rail 8. Electric pushing rod 9. Brake motor 10. Sprocket 11. Chain 12. Vacuum suckers 13. Conveyor 14. Contact roller

Figure 2. Manipulator structure

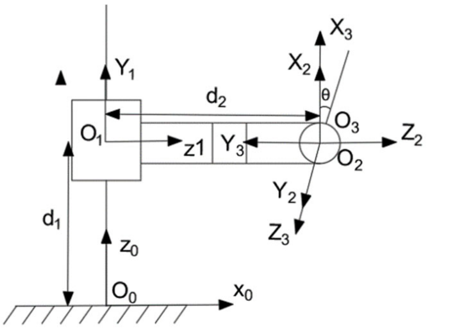


Figure 3. Manipulator structure diagram

Table 1. Manipulator D-H parameters

Joint	L_{i-1}/mm	$\alpha_{i-1}/(°)$	d_i / mm	θ_i / (°)	variable range
1	L_0	0	d_1	0	400-600mm
2	L_1	0	d_2	0	700-900mm
3	0	0	0	θ_3	90^0-360^0

The general formula [2-3] for connecting rod transformation is

$$ {}^{i-1}_{i}T=\begin{bmatrix} c\theta_i & -s\theta_i & 0 & L_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -d_i s\alpha_{i-1} \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & d_i c\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

Substituting the D-H parameters of the robotic arm into equation (1), yields

$$ T_1=\begin{bmatrix} 1 & 0 & 0 & L_0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad T_2=\begin{bmatrix} 1 & 0 & 0 & L_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ T_3=\begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 0 \\ s\theta_3 & c\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

The pose of the end effector can be obtained from equation (2).

$$ {}^{0}_{3}T=\begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & C\theta_3(L_0+L_1) \\ s\theta_3 & c\theta_3 & 0 & s\theta_3(L_0+L_1) \\ 0 & 0 & 1 & d_1+d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

Where $s\theta_3=\sin\theta_3$; $c\theta_3=\sin\theta_3$.

Equation (4) represents the pose of the end effector, as follows.

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

By equating the corresponding elements of equations (3) and (4), it can be obtained that

$$n_x = c\theta_3\text{；}\ n_y = \theta_3\text{；}\ n_z = 0\text{；}\ o_x = -s\theta_3\text{；}\ o_y = c\theta_3\text{；}\ o_z = 0\text{；}$$
$$a_x = 0\text{；}\ a_y = 0\text{；}\ a_z = 1\text{；}\ p_x = c\theta_3(L_0 + L_1)\text{；}\ p_y = s\theta_3(L_0 + L_1)\text{；}$$
$$p_z = d_1 + d_2$$

3.2. 2.2 Kinematic analysis example

Take $\theta_3 = 0\text{mm}$, $d_1 = 400\text{mm}$, $d_2 = 700\text{mm}$, $L_0 = 500\text{mm}$, $L_1 = 800\text{mm}$; MATLAB software is used to solve equation (4), it can be obtained

$$ {}_3^0T = \begin{bmatrix} 1 & 0 & 0 & 1300 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1300 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

The results are consistent with the actual posture, and the kinematic equation is correct.

3.3. Kinematic simulation analysis

The 3D model of the robotic arm is imported into ADAMS software, the attributes, constraints, and simulation time of the part T=120s are set, and the driver functions shown in Table 2 are added. The displacement curve and motion trajectory of the end point shown in Figure 4 are obtained through simulation. The displacement at any given moment on the end point displacement curve is basically consistent with the value calculated by MATLAB. From Figure 5, it can be seen that the running trajectory of the endpoint matches the expected glass grasping path.

Table 2. Joint driving function

	Driving function
Driving_1	step（time,0,0,20,-200） +step（time,100,0,120,200）
Driving_2	step（time,20,0,40,200） +step（time,80,0,100,-200）
Driving_3	step（time,40,0d,60,-10d）+step（time,60,0d,80,10d）
Driving_4	step（time,40,0,60,-60） +step（time,60,0,80,60）

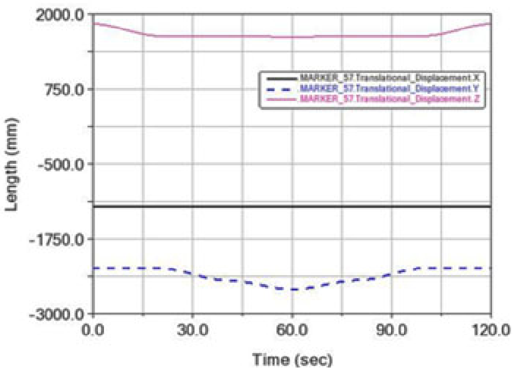


Figure 7. End point displacement

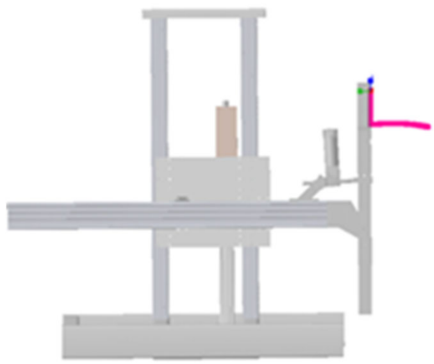


Figure 8. End point motion trajectory

4. Conclusion

In order to improve the automation level of the insulating glass production line and meet the needs of the production line, a vertical insulating glass production line manipulator has been designed. The D-H method is used to analyze the kinematic problem of the robotic arm, and the correctness of the kinematic solution is verified using ADAMS software.

Acknowledgment

This work is supported by Teaching Reform Project of Hebei Normal University of Science & Technology, Project number: JYYB202322 and JYYB202320, and Hebei Province College Student Innovation and Entrepreneurship Training Program Project S202310798016.

References

[1] LIU Xiangchen, CAI Xiaojun, JIANG Lipei, et al．Study on methods of the solution to robot kinematics[J]. Machine Tool & Hydraulics, 2009, 37(8):184-185+188.

[2] CHEN Lixin. Application of industrial robot in the automatic stamping production line[J]. Machinery Design & Manufacture, 2010,10: 94-96.

[3] LIU Xinjun, YU Jinjun, KONG Xianwen. Rototic Mechanisms [M]. Beijing: China machine press, 2021.

[4] SUN Long. Development and research of loading and unloading manipulator based on stamping press[D]. South China University of Technology, 2015.

[5] ZHANG Qiang. Robotics mechanism, kinematics, dynamics and motion planning[M]. Beijing: Tsinghua university press, 2019.

[6] WANG Hongqi, WU Diyi. Kinematic simulation of object grasping manipulator based on ADAMS and Pro/E[J]. Journal of Henan Mechanical and Electrical Engineering College, 2018, 26(4): 1-6+22.