STUDY ON STRUCTURAL SIMULATION OF PICK-TO-PLACE ROBOT ON TOSHIBA DC650B HORIZONTAL PRESSURE CASTING MACHINE

Nguyen Tien Sy[1,*], Nguyen Xuan Chung[2], Trinh Van Long[1]

DOI: http://doi.org/10.57001/huih5804.2024.172

ABSTRACT

This paper uses the method of analysis and simulation on NX software to design the Robot for picking up molded products on the Toshiba DC650B horizontal pressure casting machine. The simulation results serve as a basis for designing and manufacturing a product picking robot suitable for the working cycle of the molding machine (molding stroke, material filling time, curing time, mold opening stroke, product picking time, cleaning and lubrication time).

Keywords: *Simulation Analysis, Picking Robot, Toshiba DC650B Pressure Casting Machine*

[1]School of Mechanical and Automotive Engineering, Hanoi University of Industry, Vietnam
[2]Vietnam - Japan Center, Hanoi University of Industry, Vietnam
[*]Email: nguyentiensy@haui.edu.vn
Received: 05/8/2023
Revised: 18/10/2023
Accepted: 25/5/2024

1. INTRODUCTION

Industrial robot (IR) is an automatic manipulator that can operate multi-purpose. Industrial robots can be programmed and controlled entirely automatically. Industrial robots can be fixed or mobilized to apply for industrial automation applications [1, 2]. There are many research groups focused on the design of gripper robots to get structure optimization, dynamic balancing, and design optimization [3-7]. Kinematic and structural analysis are really important issues to receive stable working condition of industrial robotics. This paper demonstrates the structural simulation of pick-to-place robot on the TOSHIBA DC650B horizontal pressure casting machine. The robot performs the manipulation of picking up the molded product, moving forward in the direction of the mold opening and then moving the product out by rotating joints and dropping it on the conveyor. The CAE analysis is applied to determine the dimensions of the links of the picking robot arm on the Toshiba DC650B horizontal pressure casting machine.

2. THE PRODUCT PICKING ROBOT

Picking robots are industrial robots that are widely used in various industrial production fields. The picking robot has simple structure and convenient for operations of maintenance and repair. The picking robot is very flexible in manufacturing systems. This robot arm ensures high working efficiency in the small working spaces. Fig. 1 shows an image of a picking robot working on a pressure casting machine [9].

Fig. 1. A picking robot working on a pressure casting machine [9]

Basically, robotic arms have construct of many degrees of freedom. That can be moved along an axis or rotated in certain directions. The reference axes are usually attached to a point on the robot arm to mathematically represent a robotic arm. Therefore, a relationship of the point and the robot arm can be determined. Fig. 2 shows the structure of the gripping robot with 4-links and 3-joints. Each link of the robot is attached to a reference axis system to track the position and orientation of the link and modeling the entire robot system [1.8]. The geometric parameters of this robotic arm can be described by d_i, l_i, θ_i, and α_i as below:

- d_i: The distance from the i-1[th] original coordinate to the intersection of the z_{n-1} axis and xi axis following the z_n-1 axis.

- l_i: The distance from the intersection of the z_{i-1} axis and xi axis to the i[th] coordinate system following the x_i axis.

- θ_i: The rotating angle from x_{i-1} axis to x_i axis around z_{i-1} axis.

- α_i: The rotating angle from z_{i-1} axis to z_i axis around x_i axis.

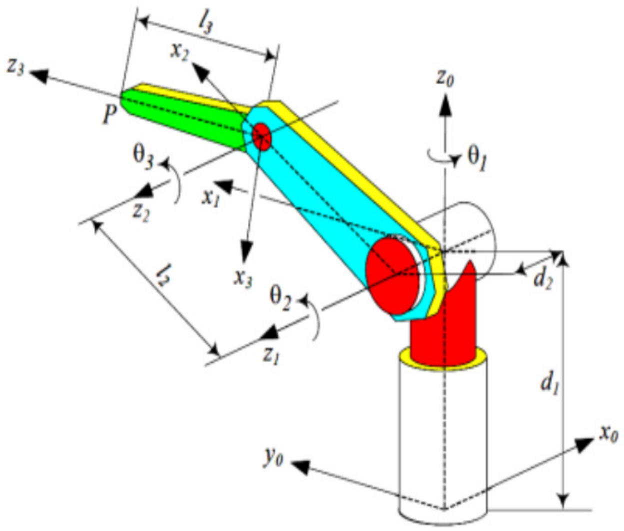


Fig. 2. The structure of a robot with 4-links and 3-joints [1.8]

The operation and control processes are displayed on the HMI display screen of the control cabinet. The robot can work continuously during 24 hours per day and the robot's performance produces benefits of replacing workers, saving costs, lowering product costs [2].

3. KINATIC ROBOTS

The picking robot is designed to pick up the molded products with the weight of 1 kilogram on the TOSHIBA DC650B horizontal pressure molding machine. The pressure molding machine has the technical characteristics of the size of W x H of 930 x 930mm, the molding stroke of 760mm, and the center height 1350 mm. The working process of the molding machine can be addressed in a cycle of the mold opening and closing of a pressure die casting machine including minor steps of the cleaning and lubrication, mold closing, material pouring, setting, mold opening, and product removal. The design of the working principle is proposed following the above working process. The kinematic diagram of picking robot was designed with 5-links and 4-joints as shown in Fig. 3. The working mechanism of the picking robot can be explained by the operation of motors to control the movements of the links and joints. Following that, when the molding machine performs the mold opening stroke. Firstly, the O_1 and O_2 servo motors move together the corresponding to rotation angles of q_2 and q_3. Secondly, the gripper is moved into the mold cavity to pick the molded product. Thirdly, the robot base performs forward movement q_1 following the mold opening direction to lift the product out of the mold cavity. Next, the servo motors O_1 and O_2 run to move the picker arm out of the machine to the conveyor position. Finally, the O_3 swivel joint turns an angle of q_4 and drop the product onto the conveyor belt to finish the working cycle. Table 1 shows the parameters of the picking robot arm [3, 8].

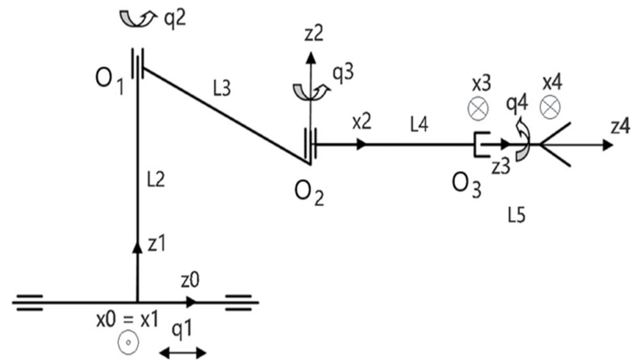


Fig. 3. The kinematic diagram of the picking arm robot

Table 1. The parameters of the picking arm robot

Joint	d_i	θ_i	L_i	α_i
1	q_1	0	0	π/2
2	L_2	q_2	L_3	0
3	0	q_3	L_4	0
4	L_5	q_4	0	0

The displacement of the links can be expressed by following matrices [1].

- The displacement matrix of the link 1:

$$H_1^0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & q_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

- The displacement matrix of the link 2:

$$H_2^1 = \begin{bmatrix} c(q_2) & -s\,(q_2) & 0 & l_3 c\,(q_2) \\ s\,(q_2) & c\,(q_2) & 0 & l_3 s\,(q_2) \\ 0 & 0 & 1 & l_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

- The displacement matrix of the link 3:

$$H_3^2 = \begin{bmatrix} c\,(q_3) & -s\,(q_3) & 0 & l_4 c(q_3) \\ s\,(q_3) & c\,(q_3) & 0 & l_4 s\,(q_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

- The displacement matrix of the link 4:

$$H_4^3 = \begin{bmatrix} c\,(q_4) & -s\,(q_4) & 0 & 0 \\ s\,(q_4) & c\,(q_4) & 0 & 0 \\ 0 & 0 & 1 & l_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$D_4^0 = H_1^0 H_2^1 H_3^2 H_4^3 \quad (5)$$

$$= \begin{bmatrix} c(q_4)\,c(q_2+q_3) - s(q_4)\,s\,(q_2+q_3) & -s(q_4)c(q_2+q_3) - c(q_4)s(q_2+q_3) & 0 & l_4c(q_2+q_3) + l_3c\,(q_2) \\ 0 & 0 & -1 & -l_5 - l_2 \\ c(q_4)\,s(q_2+q_3) + s\,(q_4)c\,(q_2+q_3) & -s(q_4)s(q_2+q_3) + c(q_4)c(q_2+q_3) & 0 & q_1 + l_4s(q_2+q_3) + l_3s(q_2) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

From the displacement matrices, the positions (x_e, y_e, z_e) and angular φ in the final direction of picking robot can be determined.

$$\begin{pmatrix} x_e \\ y_e \\ z_e \\ \varphi \end{pmatrix} = \begin{pmatrix} l_4c(q_2+q_3) + l_3c(q_2) \\ -l_5 - l_2 \\ q_1 + l_4s(q_2+q_3) + l_3s(q_2) \\ q_4 \end{pmatrix} \quad (7)$$

4. THE SIMULATION ANALYSIS METHOD

4.1. Picking robot modeling

Table 2 shows the technical limitations of the links of the robot. These limitations are based on the working space of the robot, the mold opening and closing strokes of the Toshiba DC650B molding machine, and the location of the robot.

Table 2. The technical limitations of the picking arm robot

No.	Parameters	Value
1	Total length of links: L_3, L_4, and L_5	≤ 1500 (mm)
2	The height of robot	≤ 1350 (mm)
3	The weight of the molded product	≤ 1 (kg)
4	The material of the product	A5052
5	Diameter	ϕ 380 (mm)
6	Number of links/joints	5/4
7	Velocity of robot arm	≤ 1 (m/s)

Assuming that the strength condition of the link has the corresponding length addressed by following relationships:

$L_4 = x$; $L_5 = 2x$; $L_3 = 3x$,

Then:

$L_3 + L_4 + L_5 = 3x + x + 2x = 6x \le 1500$mm

So the link has the minimum length as L_4:

With:

$L_4 \le 250$ (mm)

The robot links was designed by using a design SIM SOLID software, the dynamic analytic data of the robot, the dynamic parameters as shown in Table 3, and the parameters of the links as shown in Table 4.

Table 3. The moving limitation of the degrees of freedom (DOF) of picking robot

Links	Angular θ	Limitations	
1	0	0	
2	θ_2	0	180
3	θ_3	0	145
4	θ_4	-90	90

Table 4. The dimensions of the links of the picking robot

l_1	l_2	l_3	l_4	l_5
150mm	1000mm	750mm	250mm	500mm

4.2. Design of the picking arm assembly

Fig. 4 shows the picking arm assembly of the picking robot. The picking mechanism has the operations of closing or opening the clamp. The L_5 gripper is connected to the L_4 arm by the θ_3 swivel joint (rotating around the center of the arm) [10] to change the direction of the product in order to drop onto the conveyor belt.

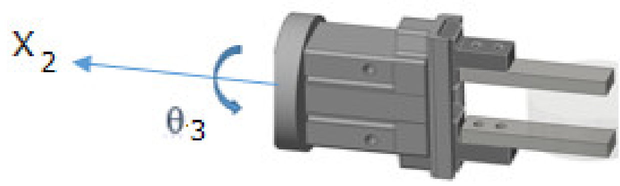


Fig. 4. The picking arm assembly of the picking robot

Fig. 5 shows the analysis model of the force components acting on the picking arm and product.

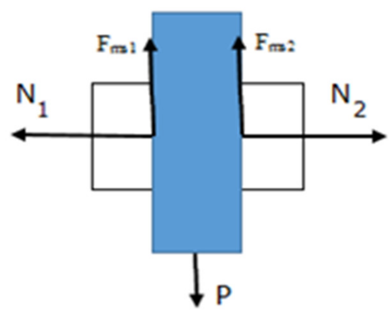


Fig. 5. The analysis model of the force components acting on the picking arm and product

The clamping force is calculated by following equation with the purpose of ensuring that the part does not fall when the gripper moves [1].

$$P.k < (F_{ms1} + F_{ms2}) = 2F_{ms} \quad (8)$$

Since the materials for making the two grips are the same, the coefficient of friction and clamping force generated by the two grips are the same.

$M.g.k < 2.F_k.\mu$

$$F_k > \frac{M.g.k}{2\mu} = \frac{10*10*2}{2*0.7} \text{ (N)} \quad (9)$$

Where:

m is the molded product.

μ is coefficient of friction

k is the safety coefficient

$F_k > 142.8$ (N)

4.3. Arm design

The design criterion of the robot's structural principle is to minimize the material and weight of the links based on the weight of the molded product (1 kg). The length of the links are allocated reasonably according to the strength conditions of the structure. The strength analysis and testing of the links are performed by simulation tool based on standard details such as rotating piston, material standards. The results of simulation analysis are the basis for selecting the detail dimensions of the links to design drawings for manufacturing robot.

The surveyed dimensions are analyzed based on the structural durability conditions and the material used to make the robot arm as cast steel according to TCVN 7571-1: 2006 standards. The 3D structural model was built based on the design parameters of the options materials. Applying Sim Solid software [11] to analyze durability based on lifting load and moving speed of the gripper with three design options. Based on the color spectrum on the analyzed result, the appropriate structure was selected corresponding to the load (weight of the product and the robot's links). For example, blue is the safe state, red is a dangerous state, and yellow is a structurally optimal state.

4.3.1. The L5 link design

The L_5 link has the duty of connecting the gripper with the moving part of the rotary joint θ_4 [10] as shown in Fig. 6. Table 3 shows the dimensions for investigating and analyzing of the L_5 link. The dimensions was selected as shown in Fig. 6.

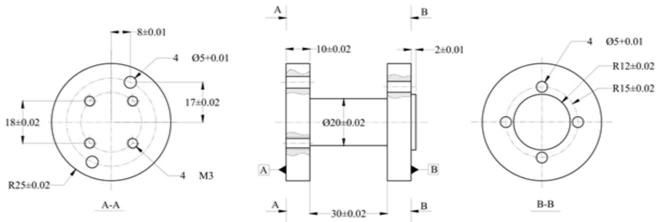


Fig. 6. The L_5 link arm assembly

4.3.2. The L4 link design

The L_4 link arm assembly has the duty of connecting the picking arm assembly with the elbow by joints θ_3 and θ_2 as shown in Fig. 7. Table 5 shows the dimensions that need to be surveyed and analyzed for the L_4 link. The analytic results were shown in Fig. 7.

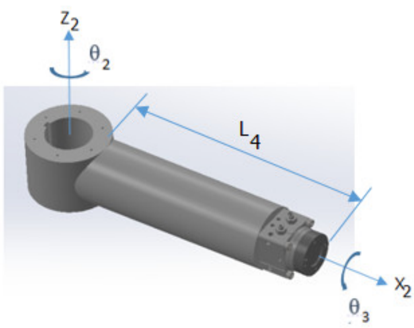


Fig. 7. The L_4 link arm assembly

Table 5. The L_4 link dimensional parameters

Design	Dimensions of L_4 link	Diameter (mm)		Weight (g)
		D (out)	d (in)	
1	250	60	56	715
2	250	60	55.6	782.5
3	250	60	55	887.5

Fig. 8 shows the strength analysis results of three design model by using CAE analysis tool [11].

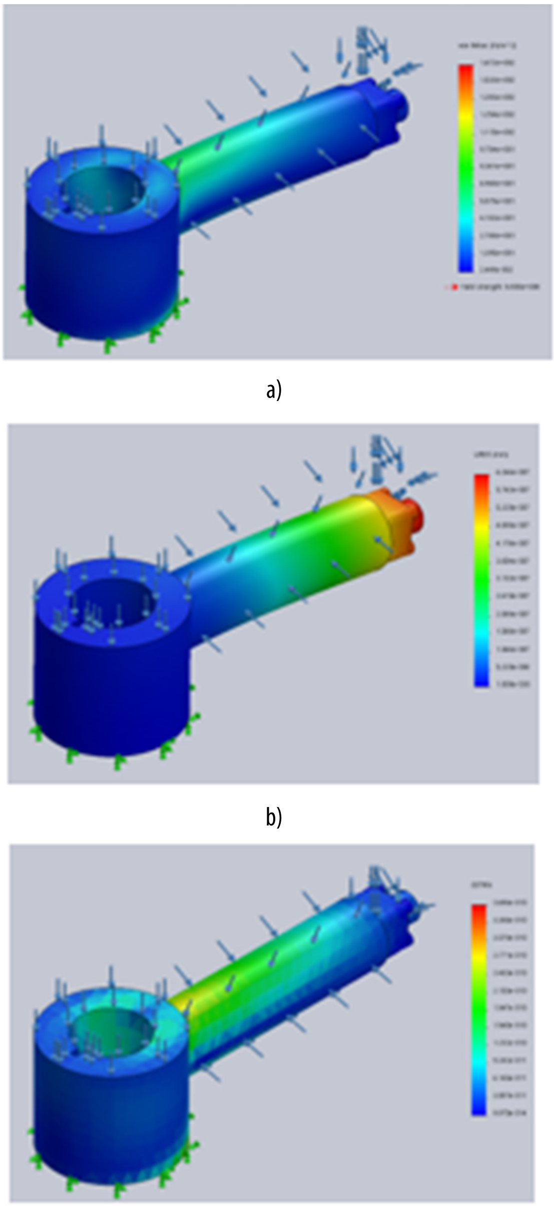


Fig. 8. The strength analysis results of three design model of the L_4 link

4.3.3. The L_3 link design

The L_3 link elbow assembly connects the rotating joints θ_1 and θ_2. These are two rotating joints driven by servo motors connecting the robot body to the arm as shown in Fig. 9. Table 6 shows the dimensions that need to be surveyed and analyzed for the L_3 link. The analytic results were shown in Fig. 9.

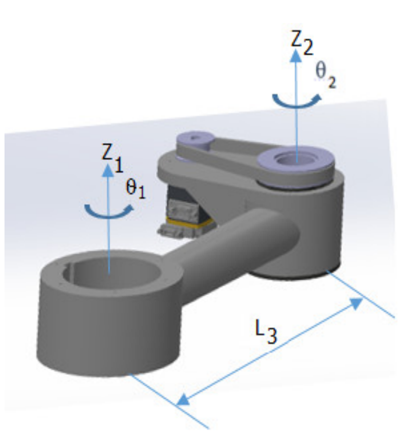


Fig. 9. The L_3 link elbow assembly

Table 6. The dimensional parameters of the L_3 link

Design	Dimensions of L_3 link	Diameter (mm)		Weight (g)
		D (out)	d (in)	
1	750	60	56	2145
2	750	60	55.6	2347.5
3	750	60	55	2662.5

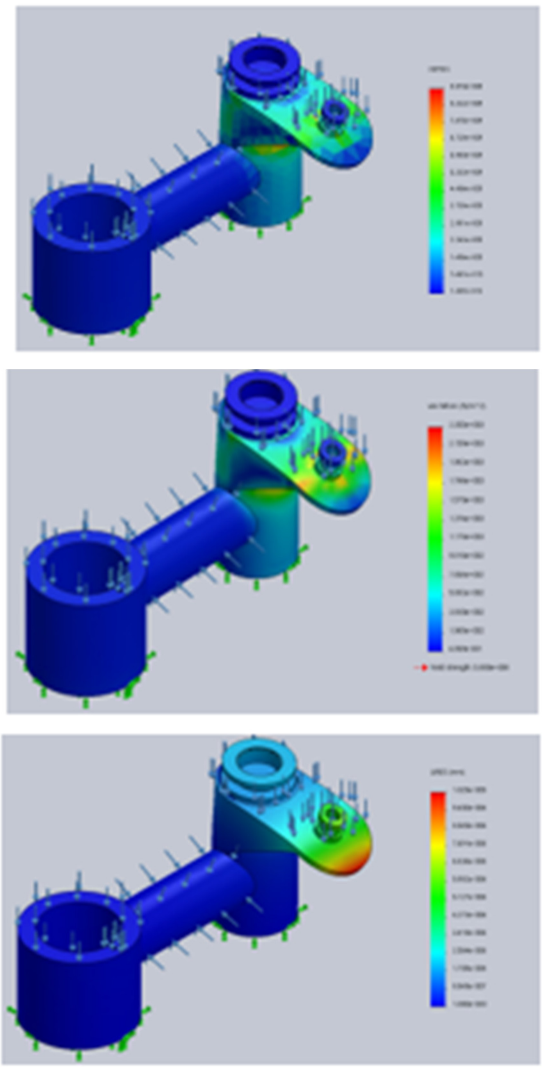


Fig. 10. The strength analysis results of three design options of the L_3 link

4.3.4. The L_2 link design

The robot body is the L_2 link that has the duty of ensuring the rigidity of the entire robot during work. The L_2 link connects the translational joint to the swivel joint θ_1 as shown in Fig. 11. Table 7 shows the dimensions to be investigated and analyzed for the L_2 link. The analytic results were shown in Fig. 11.

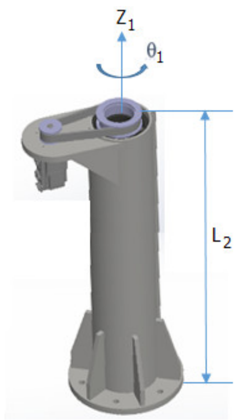
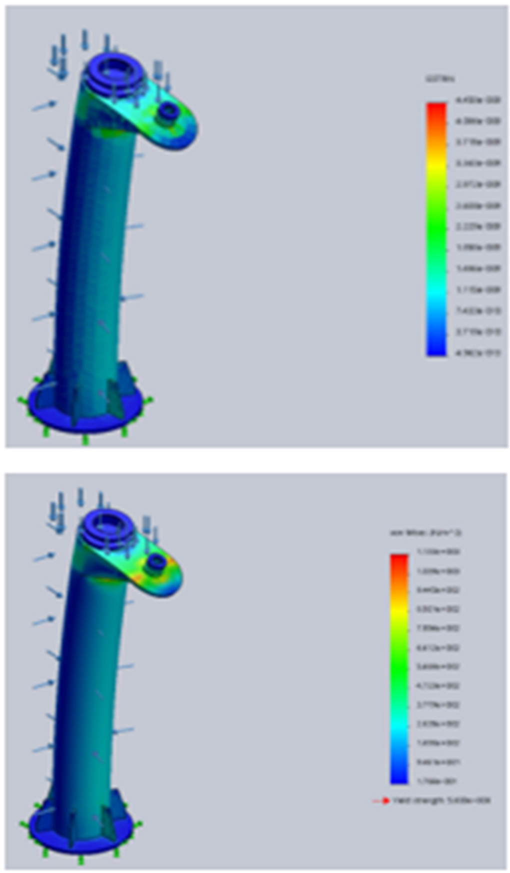


Fig. 11. The robot body (L_2 link)

Table 7. The dimensional parameters of the L_2 link

Design	Dimensions of L_2 link	Diameter (mm)		Weight (g)
		D (out)	d (in)	
1	1000	120	104	22100
2	1000	120	102	24700
3	1000	120	100	27200



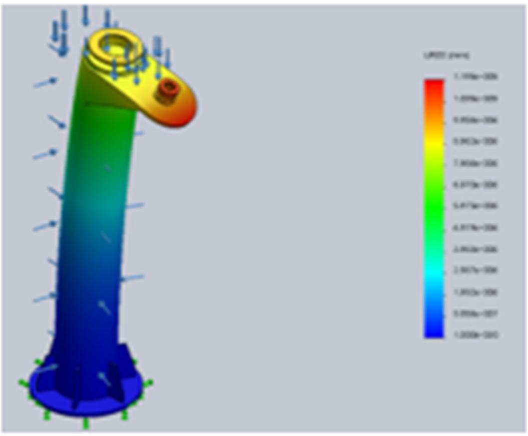


Fig. 12. The strength analysis results of three design options of the L_2 link

4.3.5 The robot base design

Fig. 13 shows the structure of the robot base assembly. The robot base is the L_1 link that provides the translational motion to lift the product out of the mold cavity with a stroke greater than the product height.

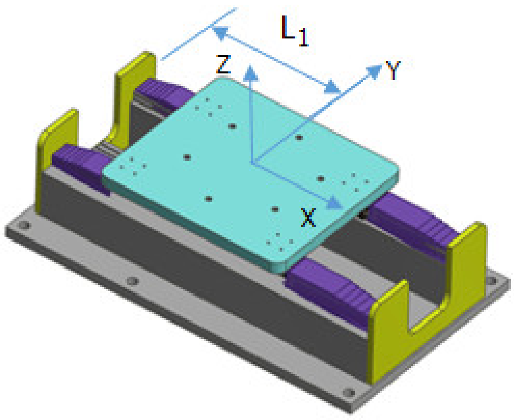


Fig. 13. The structure of the robot base assembly (L_1 link)

The strength analysis is performed for the links of the product picking robot on the Toshiba DC650B horizontal pressure die casting machine to select the initial dimensions of the links as shown in Table 8.

Table 8. The dimensional parameters of the links

Link	Link length (mm)	Diameter (mm)		Weight (g)
		D (out)	d (in)	
L_1	150			
L_2	1000	120	102	24700
L_3	750	60	55.6	2347.5
L_4	250	60	55	887.5
L_5	500	54	49.6	1405

Fig. 14 shows the position and the working principle of the product picking robot. The links are linked together by sliding joints, rotating joint, and thrust bearing. The two rotary joints are used servo motors to drive the toothed belts. The sliding joints are driven by pneumatic force. The workpiece direction is control by using a 90^0 rotating piston.

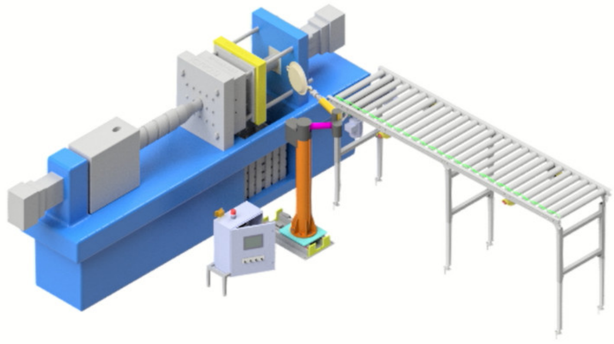


Fig. 14. The model and working principle of the product picking robot

5. CONCLUSION

The robotic kinematic analysis process is performed base on the injection molding machine's working space to calculate and design the structure of the robot's links and joints in accordance with the weight of the molded product and the product's moving trajectory. The simulation results are the basis for surveying, designing, and fabricating a realistic picking robot for the TOSHIBA DC650B horizontal pressure casting machine.

ACKNOWLEDGEMENT

This work was sponsored by Hanoi university of industry, 298 Caudien Street, Hanoi 10000, Hanoi, Vietnam, under contract No. 03-2023-RD/HĐ-ĐHCN.

REFERENCES

[1]. Hägele M., Nilsson K., Pires J. N., Bischoff R., *Industrial Robotics*. In: Siciliano B, Khatib O, editors. Springer Handbook of Robotics. Cham: Springer International Publishing, 1385-422, 2016.

[2]. ABB palettizer, *ABB robot palletizer catalogue*, 2015. www.abbpalletizers.com/

[3]. Vjekoslav Damic, Maida Cohodar, Marko Tvrtkovic, "Inverse dynamic analysis of hobby Robot uarm by Matlab-Simulink," in *the 27th DAAAM International Symposium* - Vienna, Austria, 2016.

[4]. Chung W.K., Cho H.S., "On the dynamic characteristics of a balanced PUMA-760 robot," *Industrial Electronics*, 35(2), 222-230, 1988.

[5]. Ondrej Hock, Jozef Sedo, *Forward and Inverse Kinematics Using Pseudoinverse and Transposition Method for Robotic Arm DOBOT*. Licensee InTech, 2017.

[6]. Yongbin Li, Yipeng Zhao, Tian Zhang, Tiejun Li, "Forward kinematics analysis and experiment of hybrid high-altitude board installation robot based on screw theory," *Advances in Mechanical Engineering*, 2019.

[7]. Meiyu Lv, Jinquan Li, Binglei Duan, Rong Fu, "A Palletizing Robot Dynamics Analysis," *International Journal of Advancements in Computing Technology* (IJACT), 2012.

[8]. Han Sung Kim, *Development of a 4-DOF Industrial Robot System*. School of Mechanical Engineering, Kyungnam University, 2018.

[9]. https://www.youtube.com/shorts/4cyDoLJYMuk.

[10]. https://www.smcin.com.

[11]. https://www.upviet.com.vn/simsolid/simsolid