Stiffness Calculation and Damping Design of Large Rectangular Manipulator

Yun Xue

School of Qingdao University, Qingdao 266071, China

1285436159@qq.com

Abstract

From a high acceleration or deceleration to a constant velocity or the stationary within a short time, the amplitude of the vertical arm of the rectangular manipulator is required a range of the limitation, and its response is required to approach the settling as soon as possible. This paper designs a large rectangular machine arm instead of manual work and presented firstly the computation of the stiffness as the structure of the manipulator for verifying the range of the amplitude. In following, the critical damping value effecting on the vertical arm of the manipulator was determined by the simulation based on Simulink on the settling time, which sets the initial parameters for the simulation analysis.The simulation result shows that horizontal displacement of the system reaches a steady state at the 1s and the value of displacement is 0.15 mm (less than 3 mm).In the subsequent design,the value of b can meet the design requirements unless the value is less than 6792 N.s/m.Reasonable and effective damper will increase the rigidity of mechanical arm and make it smooth and reliable movement.The research provides the basis for the design and selection of dampers.

Keywords

Liquid bag production line; Cartesian robot; Stiffness calculation; Critical damping coefficient; Simulink; Damping design.

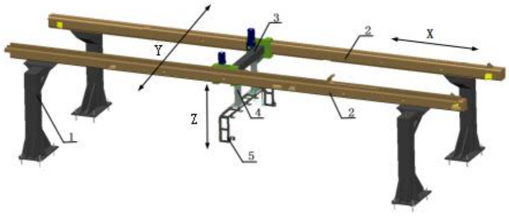
1. Introduction

At present, liquid container bag is a alow cost mode of the long-distance transport of food grade or non corrosive liquid [1-3]. It is composed of multilayer tubular PE plastics and a layer of tubular PP woven material, after the completion of nested then sealed at both ends and hole on surface of the bag to add into/drain valve. The size of the finished product is at about 8 m by 4 m.In spite of all kinds of plastic bag or woven bag has many automatic production and automatic charging system, but this kind of large, multilayer nested and liquid used for the carriage of container bag is artificial production [4]. In this paper, the research content is horizontal topic - a part of the automatic production line for liquid bag - PE and PP tube material nested device.The main body of the device uses a large rectangular robot architecture. Among them, the vertical z shaft connects to the tube materials grasping manipulator, and controls the speed of drag according to changes from 0 to 2 m/s by the form of acceleration. The acceleration or deceleration is 2 m/s. At the end of deceleration or acceleration, on the moving direction (x), drag and drop the oscillation amplitude value is not more than + / - 3 mm. In this paper, to solve the main problem is calculating the equivalent stiffness coefficient along the x axis and building the quality - damping- spring system model of cartesian robot movement part by according to the design of the cartesian robot structure. Then Selected the appropriate damping coefficient by Simulink simulation environment provides the basis for the selection of damper.

2. Working principle of the cartesian robot

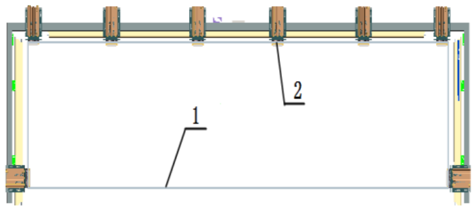
In this paper, Cartesian robot is used for bagging station liquid container bags, adopts servo motor to drive gear and rack driving, and completes set movement along the X direction. Bagging truss robot is shown in Fig. 1, bagged fixture clamping liquid bag state diagram is shown in Fig. 2.

In the process of movement, the vertical arm (z-axis) and bagging jig is regarded as a whole along the X direction (payload), the quality of the payload is 166 kg, the quality of the bagging fixture is 70 kg and the quality of the beam is 400 kg.The length of the beam is 3 800 mm. The distance between the two vertical arms is1 300 mm, The dimension from the centerline of the beam away from the centre of the payload is 900 mm, and gravity center of the beam end of bagging fixture distance is 1 240 mm.



1 – Column; 2 – Guide; 3 – Beam; 4-Vertical Arm (Z-Axis) 5 - Bagging Jig

Fig. 1 Bagging truss robot



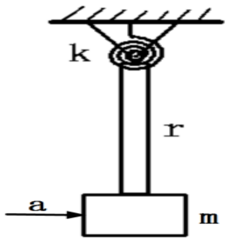
1 - Liquid Bag 2-Pneumatic Manipulator

Fig. 2 Bagging fixture clamping state diagram of liquid bag

3. Stiffness coefficient analysis and calculation

3.1 Dynamics modeling

For the simulation analysis of deceleration of bagging mechanism, it is necessary to establish mathematical model and stress analysis model. Assuming that beam with the guide pin (simplified as torsional spring), the connection methods of Z axis with beams and bagging are rigid connection, and the air drag. Then the mathematic model of bagging system is shown in Fig. 3 and simplified mechanical model (horizontal) is shown in Fig. 4.



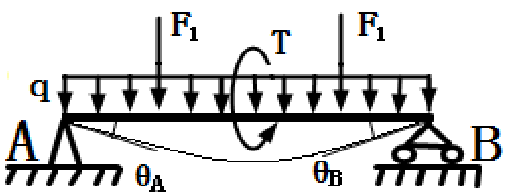


Fig. 3 Mathematical model Fig. 4 Bearing model

According to the theory of classical mechanics [4], combined with the simplified mathematical model, motion differential equations of the system is:

$$m\ddot{x}+b\dot{x}+kx=F \tag{1}$$

In the type, the quality of beam and payload is m.

According to the superposition method, under the action of uniformly distributed load is shown in figure 4 . The biggest deformation of beam in a horizontal is:

$$\begin{cases} w_1 = w_{\max} = (5ql^4/384EI) \\ q=(m_1 a/l) \end{cases} \tag{2}$$

In the type, the deflection of beams is w_1; uniformly distributed load is q; the length of the beam is l; the elastic modulus of steel is E; a moment of inertia of the beam section is I; The quality of the beam is m_1; the acceleration of system is a.

According to the superposition method, under the action of concentrated force is shown in figure 4. The biggest deformation of beam in a horizontal is:

$$\begin{cases} w_2 = w_{l/2} = \dfrac{F_1 b_1\left(3l^2 - 4b_1^{\,2}\right)}{48EI} + \dfrac{F_1 b_2\left(3l^2 - 4b_2^{\,2}\right)}{48EI} \\ F_1 = m_2 a \end{cases} \quad (3)$$

In the type, the deflection of beams is w_2; the distance of two concentration and beams at both ends are b_1 and b_2; the quality of the payload is m_2.

According to the superposition method, under the action of torque T is shown in figure 4. There are relative torsion Angle, horizontal displacement and torsional rigidity on both ends of the beam.

$$\begin{cases} \varphi = (Tl / G\beta hb^3) \times (180^0 / \pi) \\ w_3 = r_1 \sin\varphi \\ T = m_2 a r_1 \end{cases} \quad (4)$$

In the type, the torque of beam is T; the dimension from the center line of the beam to the gravity center of the payload is r_1; β is the factor associated with the beam section length ratio h/b; the shear modulus of beam cross section is G; the relative torsion angle on both ends of the beam is φ.

Beam cross section is hollow rectangular cross section ($d = 250mm, \delta = 14mm$).For the convenience of calculation, the cross section is as solid rectangular cross section. Then, the inertia of beam cross section is I.

$$I = \frac{d^4 - (d - 2\delta)^4}{12} = \frac{d_0^{\,4}}{12} \quad (5)$$

When the mathematical model is set up, the connection of Z axis and bagging clamp is assumed rigid connection completely. Then, the way of connection is equivalent to simplify the model, as shown in Fig. 5.

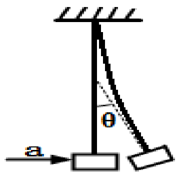


Fig. 5 The simplified model of Z axis and bagging fixture

According to the figure 5, the maximum deformation of the Z axis in a horizontal direction is w_4.

$$\begin{cases} w_4 = (F_2 l_0^{\,3} / 3E_1 I_1) \\ F_2 = m_3 a \end{cases} \quad (6)$$

In the type, the quality of the bagging fixture is m_3; the distance between gravity center of the beam and end of bagging fixture is l_0. The force of the level of the Z axis is F_2. The elasticity of aluminum modulus is E_1. The inertia of aluminum section moment is I_1.

In the numerical, the maximum deformation is w ($w = w_1 + w_2 + w_3 + w_4 = 1.55 \times 10^{-4} m$).

Then equivalent stiffness coefficient is k . $k = \dfrac{F}{w} = 7.3 \times 10^6 \ N/m$

4. Simulation calculation of the damping coefficient

Based on the Matlab Simulink platform, differential equation of mechanical arm is set up and the diagram of the simulation system is established. Then the simulation analysis was carried out through setting the initial parameters of the system block diagram.

$$\ddot{x} = \frac{F}{m} - \frac{b}{m}\dot{x} - \frac{k}{m}x \tag{7}$$

If applying damper is not considered, the value of b is 0. The system simulation system block diagram was established. The block diagram of the system system without damper is shown in Fig. 6. The displacement response curve is shown in figure 7. From Fig. 6 and Fig. 7, we can see that the attenuation of vibration of the system appeared.

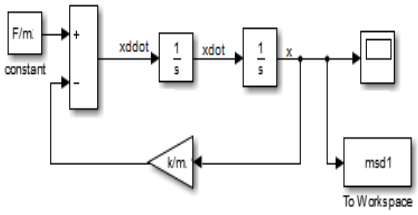


Fig. 6 The block diagram of simulation system

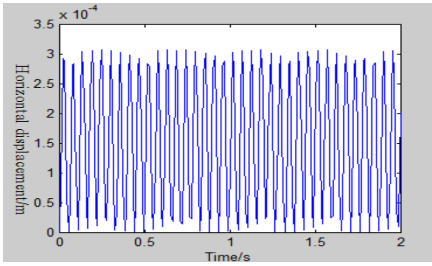


Fig. 7 Displacement response curves of the system

In order to improve the vibration condition, the system was applyed damper. The simulation diagram of system is shown in Fig. 8. The parameter b in Fig. 8 was set up. When the value of b is $6792\,N.s/m$, the displacement response curve of system is shown in figure 9. The horizontal displacement of system reached a stable state at the 1 s and the value of displacement is 0.15 mm (less than 3 mm). In the subsequent design, the value of b is not less than 6792 N.s/m which can meet the design requirements.

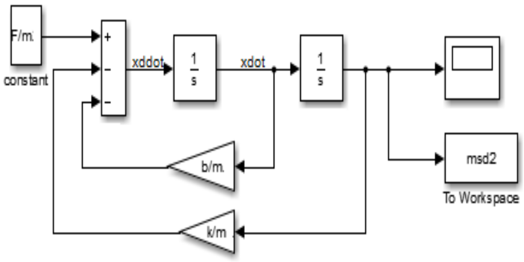


Fig. 7 The block diagram of simulation system

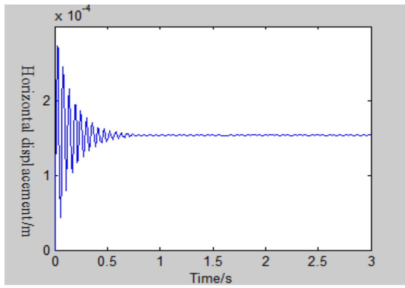


Fig. 8 Displacement response curves of the system

5. Conclusion

In this paper, bagging cartesian robot is simplified and analysed about the model and stress based on the theory of dynamics. It concludes the overall stiffness coefficient. At the same time, combined with the Simulink toolbox, mechanical arm is simulated by adjusting the size of the damping values continuously. Relatively rational damping coefficient is obtained by simulation of the system, which provides a theoretical basis for designers in the structure of the subsequent design. The simulation analysis of damping coefficient may exist the certain error. If you want to get more precise damping coefficient, we should take the length of time of vibration curve to reach stable into considerion. We will focus on this research on the next step.

References

[1] Onaqa E. High Speed Packaging Robot [J]. Robot, 1997(119):12-17.

[2] Y.J.Lin. Research on Current Situation and Development Strategy of Food and Packaging Machinery in China [D]. Tianjin University, 2008.

[3] G.R.Wu. Situation in and Tendency of China Packing Machinery [J]. Packaing and Food Machinery, 2003, 21(6):35-38.

[4] H.W. Liu. Mechanics of Materials [M]. Beijing:Higher Education Press, 2011.1.