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The Structure Design and Motion Analysis for a Heavy-Load Palletizing Robotic

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Abstract. Pallet refers to pile up one by one per certain mode to facilitate the transportation logistics activities used as material handling, storage, loading and unloading of unitized pallet. This paper mainly introduces a design of heavy-load palletizing robotic structure for coating handling, special grabs design for barrel, the finite element analysis and motion analysis.

Introduction

Palletizing technology has become a new application technology in the field of modern logistics automation. By using palletizing robot, it is capable of stacking single product or material into a pile according to certain rules, which can facilitate transportation and storage and shows great application values in alleviating heavy labor and improving labor productivity. With the requirement of handle materials quickly and accurately, palletizing robot develops under the trend of high reliability, high performance, heavy-load and low-cost, a local enterprise whose biggest paint bucket weights 100kg, designed an important and practical palletizing robot to solve material handling during manufacturing process. This paper tends to make an overall structure introduction to a heavy-load palletizing robot for coating handling in the aspects of development cost and performance.

The Overall Structure of Palletizing Robot

This palletizing robot is composed of four degrees of freedom robot, whose entire equipment consists of mechanical system, driving part and control sensing device. The mechanical system is divided into four parts, namely bottom of the base, waist, arm and wrist. The bottom of the base is fixed on the ground as installed base. Waist can drive the rotary motion of the robot. Arm mainly includes forearm, rear arm, mini-arm and auxiliary linkage. The forearm bottom of horizontal motion and the rear arm bottom of up-and-down motion can drive the end of the mini-arm to move front and back, up and down. Wrist, the installed position of manipulator, controlled the rotational positioning of the manipulator by the motor. Details of the structure are shown in Figure 1.

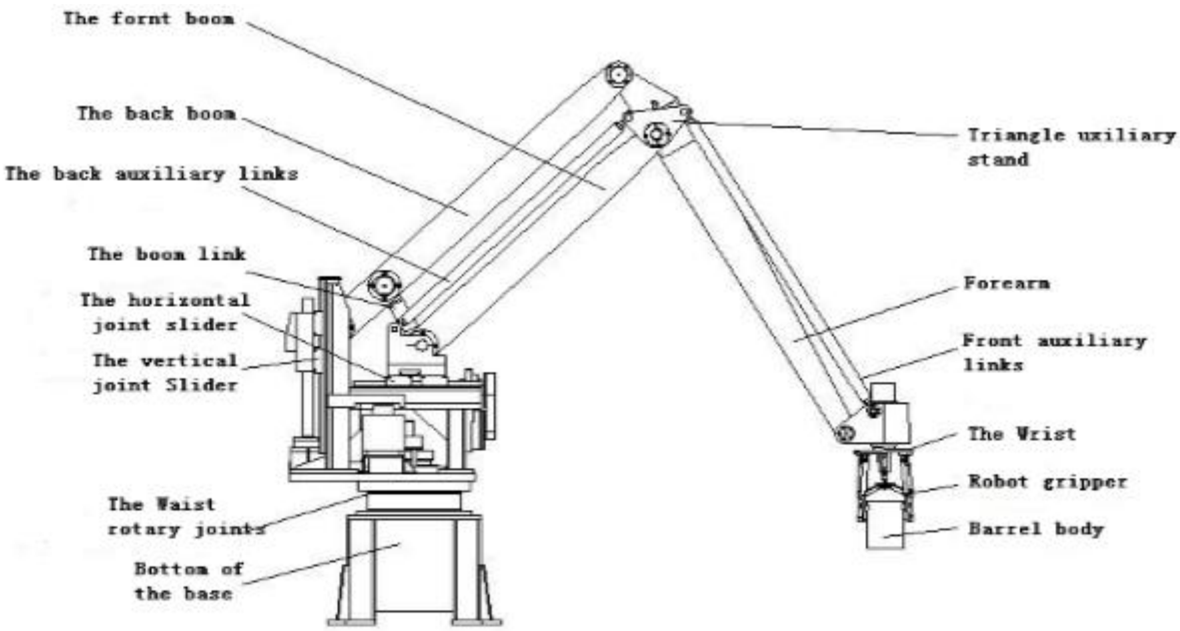

Figure 1. The overall structure of palletizing robot

The Structure Design of the Arm

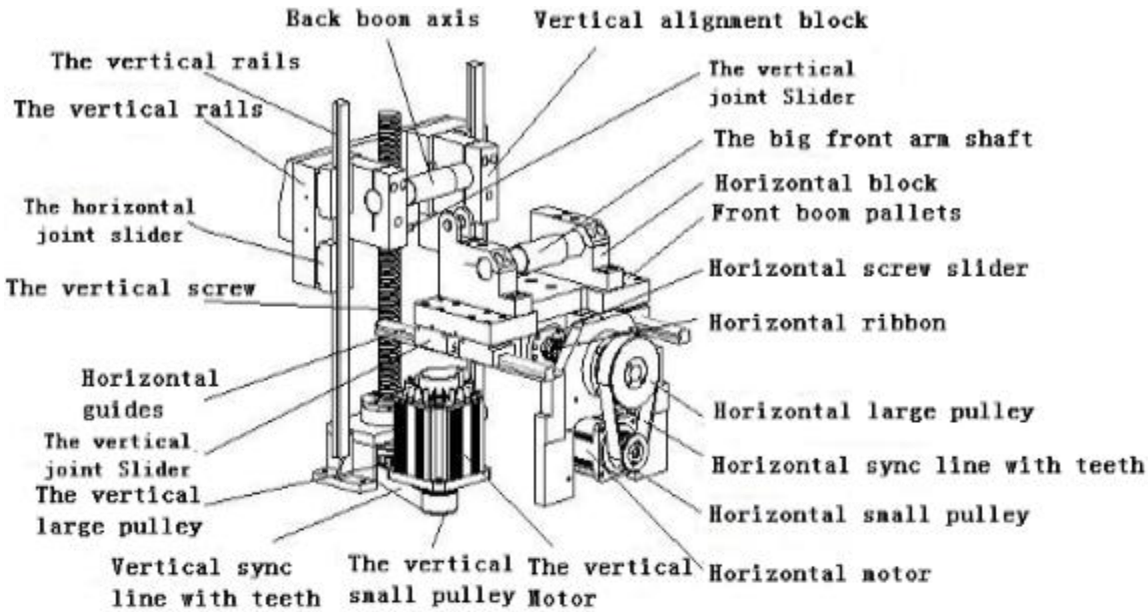

Figure 2. The structure design of the arm

The arm is used to achieve the movement of different location in a plane. The forearm, rear arm, arm connecting rod and mini-arm form a parallelogram mechanism. The horizontal motor to drive the horizontal screw sliders through synchronized tooth belt to drive the blade of forearm, which moves back and forth in horizontal guide rail along horizontal module. The forearm blade can drive the bottom of forearm move back and forth by horizontal chunk and the shaft of the forearm to achieve the movement of wrist along the vertical line.

The fore and aft auxiliary connecting rod, triangle auxiliary support, horizontal chunk, forearm, rear arm and wrist also form a parallelogram mechanism, which ensure the wrist remain level and untitled during arm movement, enabling translational material handling to realize stacking into a pile. Meanwhile, auxiliary linkage can play the role of auxiliary bearing. The structure details are shown as Figure 1 and Figure 2.

The Structure Design of the Waist

Waist, as the supporting unit of arm, is a rotational part, whose rotary motion together with the plane motion of arm can achieve position changes during material handling. The rotary motion of waist requires the motor drive the graduating device fixed on bottom dock through synchronized tooth belt. By using the slow down and increase torque on graduating device with big reduction ratio, the moment of inertia of the entire drive disk assembly on arm and big raft can be overcame.

CYCLO, a new arranger adopted planetary transmission principle and CYCLO tooth mesh, featuring high transmission efficiency and high Transmission ratio, is mainly used for heavy load robot and engineering machinery.

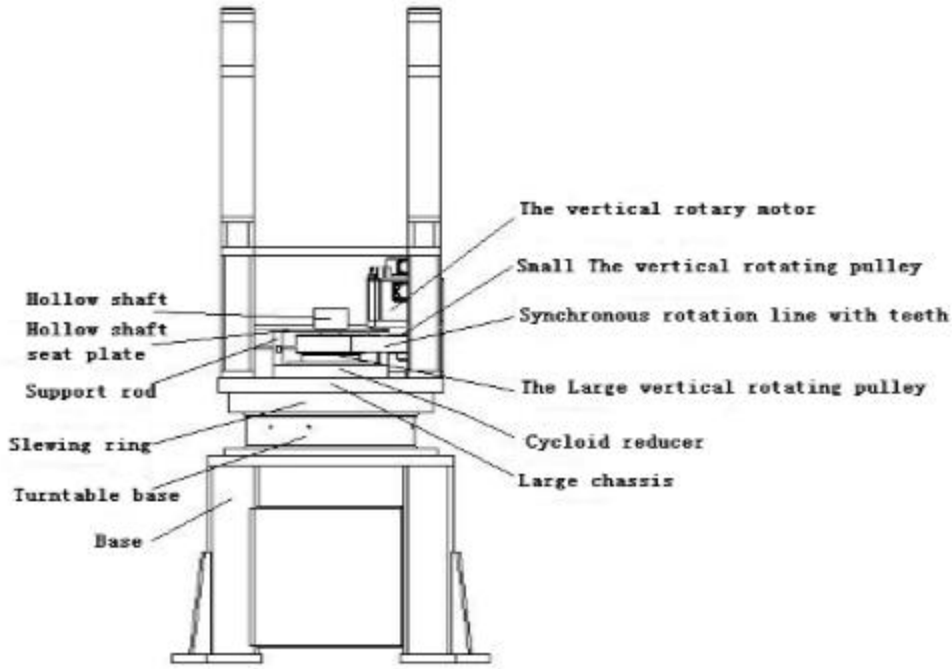

Figure 3. The structure design of the waist

Suppose the input rotate speed of high speed shaft of CYCLO as n, low speed shaft fixed on the bottom dock and the chassis as output to drive big raft swing of the wrist, the reduction ratio can be expressed as follows:

$$i = \frac{1}{n+1} \tag{1}$$

The swing movement of big raft depends on large-size bearing, which is a large bearing that can endure combined load.

The bearing, composed of mounting holes, internal gear or gear, grease holes and sealing device, can ensure the compact size of main engine, easy guide and maintenance.

Reduction gear adopts FC-A65 Cycloidal reducer, while slewing bearing applies Type 010.25.400 of JB/T2300-1999 Standard. The structure details are shown as Figure 3.

The Structure Design of the Wrist

The mechanical grab on wrist, which can grasp the material quickly, is equipped with motor, planetary gear reducer and mechanical finger. The motor can control the rotational positioning after retardation. This paper mainly researches barrel mechanical grab, which is designed to complete the process of fetch and release barrel-shaped subject in palletizing operation.

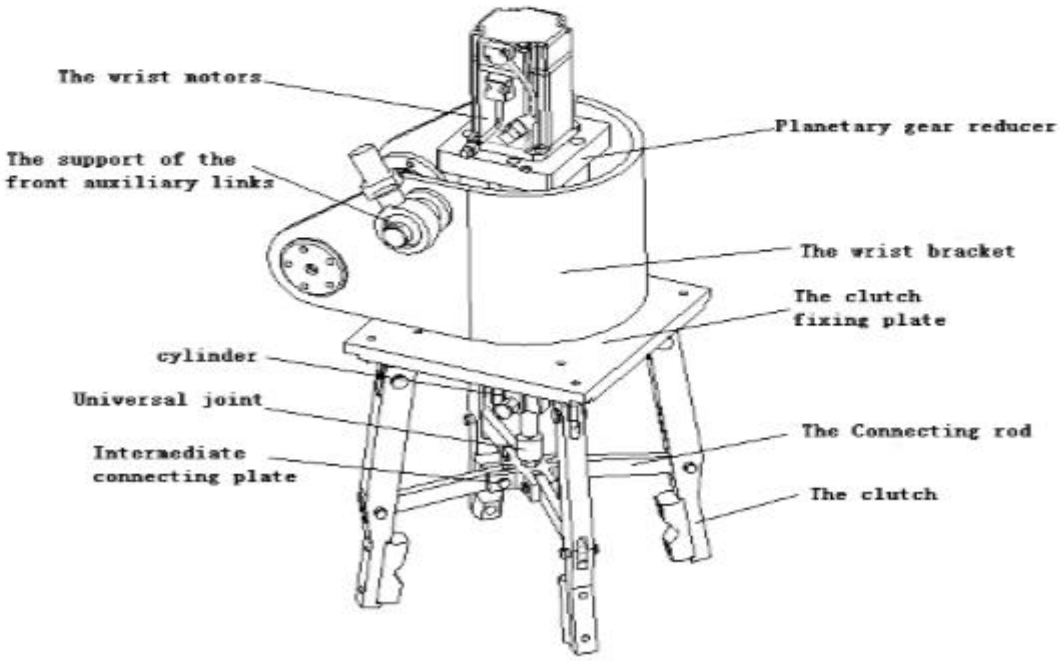

Figure 4. The structure design of wrist

The mechanical grab, which installs air cylinder connecting high-compressive gas inside, controls high pressure gas by solenoid valve, making the air cylinder rod stretches so as to drive the up-and-down motion of the middle connection plate to achieve the extend-retract of four grabs through four joint lever, by which complete the clamping and put down process. To balance the movement and avoid the lightly inclination of the middle connection plate making the cylinder piston suffers moment interaction, cardan joint is installed. The structure details are shown as Figure 4.

The Selection Calculation of Motor and Reducer on the Wrist

The wrist load is composed of end-effector and coating tank. When the motor propel load-rotating, resisting moment includes resisting moment caused by friction and load-rotating caused by inertia moment. The resisting moment comes from the rolling friction of bearing, whose value is small and negligible.

Suppose the coating tank as a cylinder of 300mm diameter and 500mm high, the moment of inertia of Z axis can be expressed as:

$$J = \frac{1}{2} m R^2 \tag{2}$$

R refers to the diameter of the barrel, R=800mm

M refers to the weight of packing bag, m=100kg

Suppose J=6.67kg and the moment of inertia of end-effector around z axis as 12.53 kg calculated from SolidWorks, the moment of inertia of wrist-load will be I4=6.67+12.53=19.2kg. Because the inertia moment = moment of inertia x angular acceleration, the motor model and gear reduction ratio can be determined.

Finite Element Analysis Based on Solidworks Simulation

Simulation finite element analysis software is one seamless plug-in of SolidWorks that can provide static analysis and various analysis on heat conduction, distortion and frequency. Using Simulation to conduct static analysis on assembly model can acquire the analysis result of strength and stiffness of assembly model. By establishing mathematical model of forearm, rear arm, mini-arm and arm connecting rod assembly, setting part material, mainly part joint, as pin connector, carry out force analysis on the peak, fixing the bottom of forearm and that of rear arm and choosing proper unit type and size to make grid division on hanging stick, running analysis can lead to the stress distribution and displacement distribution, by which the mini-arm and rear arm connecting hole turn out to be the maximum stress point.

Meeting the requirements for strength and stiffness of component, simulation finite element analysis can rationalize the structure and size of component to reduce its weight and moment of inertia so as to save material and lower manufacturing cost.

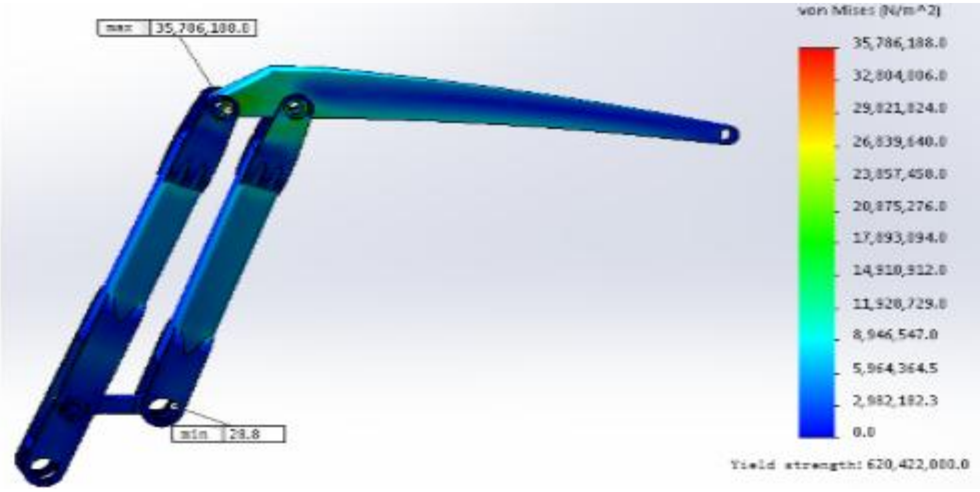

Figure 5. The stress distribution of arm components

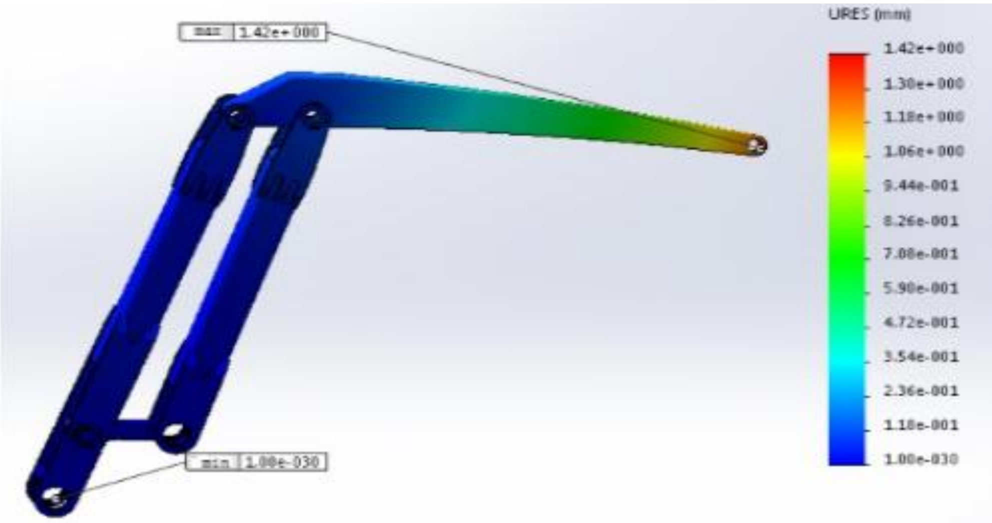

Figure 6. The displacement distribution of arm components

Motion Analysis on Palletizing Robot

The kinematics analysis on palletizing robot should establish coordinate per analytic geometry method to analyze the kinematics characteristics, calculate the relations between the position and attitude of end-effector with various depending on parameters and draw out Kinematic diagram.

Whereby a1=60, a2=280, a3=400, a4=260.

Position coordinates

$$A: \begin{bmatrix} x_A \\ z_A \end{bmatrix} = \begin{bmatrix} O \\ O \end{bmatrix} \quad (3)$$

$$\text{B:}\ \begin{bmatrix} x_B \\ z_B \end{bmatrix} = \begin{bmatrix} l_{AB}\cos\theta \\ l_{AB}\sin\theta \end{bmatrix} \tag{4}$$

Whereby θ represents the included angle between AB and positive axis

$$\text{C:}\begin{bmatrix} x_C \\ z_C \end{bmatrix} = \begin{bmatrix} x_B - l_{AB}\sin\alpha \\ z_B + l_{AB}\cos\alpha \end{bmatrix} = \begin{bmatrix} l_{AB}\cos\theta - l_{AB}\sin\alpha \\ l_{AB}\sin\theta + l_{AB}\cos\alpha \end{bmatrix} \tag{5}$$

Whereby α represents the included angle between BC and positive part of Z axis

$$\text{D:}\begin{bmatrix} x_D \\ z_D \end{bmatrix} = \begin{bmatrix} -300 \\ 300 \end{bmatrix} \tag{6}$$

$$\text{E:}\begin{bmatrix} x_E \\ z_E \end{bmatrix} = \begin{bmatrix} x_C - l\cos(\pi-\beta) \\ z_C + l_{EC}\sin(\pi-\beta) \end{bmatrix} \tag{7}$$

$$\text{F:}\begin{bmatrix} x_F \\ z_F \end{bmatrix} = \begin{bmatrix} x_D - l_{DF}\cos(\pi-\beta) \\ z_D + l_{DF}\sin(\pi-\beta) \end{bmatrix} \tag{8}$$

$$\text{G:}\begin{bmatrix} x_G \\ z_G \end{bmatrix} = \begin{bmatrix} \frac{l_{FG}}{l_{EF}}(x_F - x_E) + x_F \\ \frac{l_{FG}}{l_{EF}}(z_F - z_E) + z_F \end{bmatrix} \tag{9}$$

Through geometrical analysis, the following relations can be acquired:

$$\text{H:}\,(x_F - x_E)^2 + (z_F - z_E)^2 = l_{EF}{}^2 \tag{10}$$

$$\text{I:}\, l_{EC}\frac{l_{FG}}{l_{EF}} - l_{DF}\frac{l_{FG}}{l_{EF}} = 0 \tag{11}$$

$$\text{J:}\ \begin{cases} x_G = (\frac{l_{FG}}{l_{EF}} + 1)x_D - l_{DF}\cos(\pi-\beta) - \\ \quad \frac{l_{FG}}{l_{EF}}\left(l_{AB}\cos\theta - l_{BC}\sin\alpha\right) \\ z_G = (\frac{l_{FG}}{l_{EF}} + 1)z_D - l_{DF}\sin(\pi-\beta) - \\ \quad \frac{l_{FG}}{l_{EF}}\left(l_{AB}\sin\theta + l_{BC}\cos\alpha\right) \\ \quad \sin(\alpha-\theta) = \cos(\theta-\alpha+\frac{\pi}{2}) \end{cases} \tag{12}$$

Formula (12) is the equation of motion for palletizing robot at G point. Palletizing robot can realizes precise positioning by controlling the horizontal and vertical pair of servo motor and changing the value of θ, β and θ1, θ2.

Conclusion

This paper gives introduction to the structure of palletizing robot and special grabs customized by 3Trees coating company in Fujian province and proves that this palletizing robot possesses the characteristics of compact structure, flexible motion, high carrying capacity and easy assembly.

Meanwhile, this palletizing robot adopts the mechanical manipulator with four-finger linage and pneumatic control to quickly fetch and release barrel coatings. The welded elements used in the entire equipment can greatly reduce manufacturing cost and complete the process of stacking barrel coatings into multi-layers quickly and accurately in practice so as to fulfill the need of coating handling in produce line.

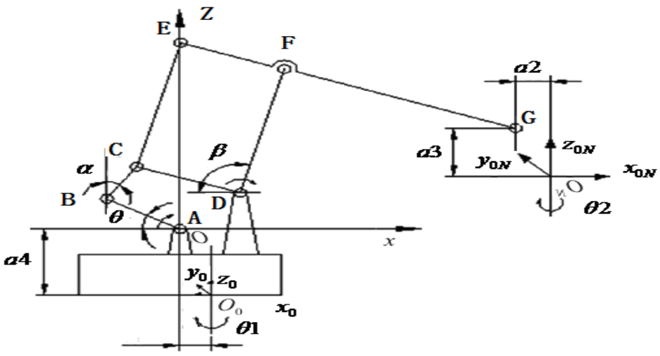

Figure 7. Kinematics analysis on palletizing robot

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