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SIMULATION OF DOUBLE ROBOT COOPERATIVE SHEET METAL BENDING PRODUCTION LINE

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Preliminary Note – Prethodno priopćenje

Aiming at the problem that large sheet metal bending parts cannot be processed by single robot, and the manual assisted bending method has high labor intensity and low work efficiency; double robots work together to complete the handling of the plate; Firstly, according to the actual production requirements of sheet metal bending, the process planning and three-dimensional modeling of the production line are completed. Secondly, the kinematics analysis and base coordinate system calibration of the dual robot are completed. Then, by establishing the mathematical model of each unit, the end pose matrix in the local coordinate system of the robot is finally obtained, and the joint angles of the robot machine are obtained by inverse kinematics. Finally, the production line simulation is completed by Rapid offline programming. The research results show that the kinematics model is correct, and the production line can complete the sheet metal bending work without collision, which can provide reference for the research of large sheet metal bending.

Keywords: sheet, bending, double-robot cooperation, mathematical model, production line simulation

INTRODUCTION

Sheet metal bending is the core process of sheet metal bending forming process. The quality of bending process directly affects the final forming quality and appearance of the product. [1] At present, robots have been widely used in the field of metal processing. In view of the simple forming process and large production volume, robot bending has completely replaced the traditional manual bending, which solves the problems of high labor intensity, low work efficiency and poor product quality stability in manual bending. But for large sheet metal bending parts, also need more people with auxiliary bending.

Many scholars at home and abroad have done a lot of research on metal plate bending robot. On the basis of designing a metal bending system of a seven-degree-of-freedom industrial robot, Li Zhen Xing [2] studied the accuracy of metal forming, and designed a metal forming synchronous tracking system and a rear index detection device to ensure accuracy. The experimental results show that under the premise of ensuring accuracy and stability, the working efficiency of the bending system is twice as high as that of manual assisted bending. Zhang Tao [3] calculated the theoretical posture of the robot in the bending process by establishing the geometric model of the robot bending process, and proved the accuracy of the model through experiments.

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Aiming at the problem that some production work cannot be completed by a single robot, many scholars have carried out research on the dual robot coordinated working system. Tan Ding [4] completed the simulation of space curve weld based on double robots and Robotstudio. Wang Wei [5] proposed a multi-objective genetic algorithm to optimize the spot welding path. A dual-robot coordinated welding workstation was established in RobotStudio, and the planning results were verified by simulation experiments. At present, most of the research on dual robots is applied to welding machines, handling and other working scenarios, and the dual robots are rarely used in sheet metal bending work.

Using RobotStudio software to simulate the production line can effectively integrate production resources. Its powerful off-line programming ability to plan robot motion makes the working process intelligent, the simulation is more intuitive and consistent with the actual motion effect, shortens the actual debugging time of the production line [6], and finds and quickly repairs problems before production.

SHEET METAL BENDING PROCESS PLANNING

After field research, the automatic bending of double robot collaborative metal plate robot mainly includes the following process flows : 1 Two robots collaboratively grab the plate from the raw material; 2 The grabbed sheet is placed on the positioning table for precise positioning of the workpiece and then the workpiece is grabbed again; 3 The double robots send the sheet metal to the middle of the upper and lower molds of the bending machine and put it on the lower mold, and then correct and locate the bending size of the sheet metal through the rear index finger of the bending machine; 4 At this time, the dual robot needs to follow the bending action, the slider of the bending machine presses down to perform sheet metal bending forming, and the dual robot needs to follow the bending action; 5 According to the needs of the sheet metal bending process, after completing the turning / transposition process of the workpiece, the bending and other process processes are repeated until the bending operation is completed. 6 Palletizing the workpiece to the finished product stacking.

CONSTRUCTION OF PRODUCTION LINE MODEL

As shown in Figure 1, it is a dual-robot collaborative sheet metal bending production line.

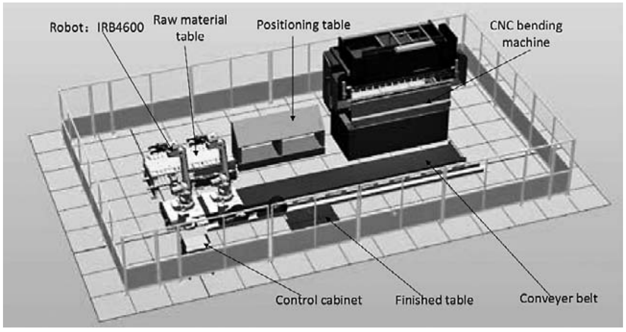

Figure 1 Double robot collaborative sheet metal bending production line

ESTABLISHMENT OF KINEMATICS MODEL OF MECHANICAL ARM

In the selection of the bending robot, according to the actual processing of the plate thickness, size, weight and other data and combined with the robot arm spread and load capacity to determine the use of ABB 's two IRB4600 model robots.

By inputting the robot parameters into the MATLAB robot toolbox, the robot structure diagram can be obtained as shown in Figure 2. The correctness of the robot kinematics model can be verified by the toolbox.

FORWARD AND INVERSE KINEMATICS ANALYSIS OF ROBOT

In order to visually show the bending process of the robot, the simulation platform must simulate the kinematics of the robot based on the forward and inverse kinematics analysis of the robot. Given the joint angle of the robot, the pose of the end link coordinate system relative to the base coordinate is the forward kinematics of the robot. According to the D-H parameter method, the transformation matrix between the coordinate systems of each link of the robot can be obtained. The coordinate transformation matrix is shown in formula (1).

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

The transformation matrix between the connecting rod coordinate system {0} and the connecting rod coordinate system {6} is shown in formula (2).

$$ {}^{0}_{6}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T\,{}^{4}_{5}T\,{}^{5}_{6}T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

Kinematics is to calculate the value of six joint angles by the product of the coordinate transformation matrix of the six links of the robot. The derivation process of inverse kinematics is complicated, and it is no longer displayed due to the limited space of this paper.

DOUBLE ROBOT BASE COORDINATE CALIBRATION

After establishing the kinematics model of the robot, if you want to realize the coordinated motion of the two robots, you also need to solve the problem of calibration of the base coordinate system of the two robots. The spatial position relationship of the base coordinate system is a necessary condition for constructing a coordinated control closed-loop kinematic chain.

The calibration of the base coordinate system calibration robot is divided into two types: contact and non-

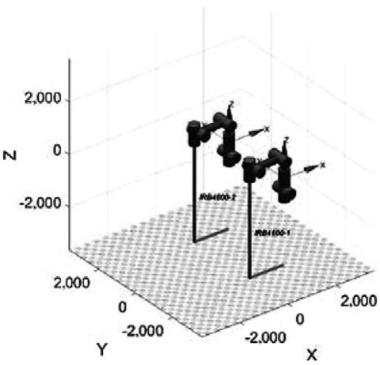

Figure 2 Robot structure diagram

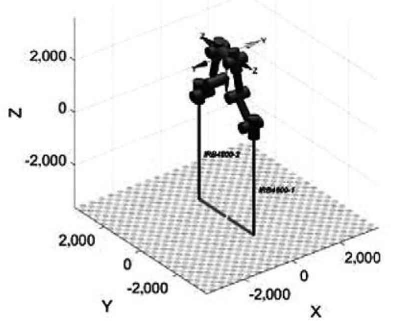

Figure 3 Simulation of dual robot calibration method

contact. In this paper, a contact calibration method with lower cost is adopted, as shown in Figure 3, and the calibration method is verified by MATLAB.

At this point, the kinematics model of the dual robot is established.

OPERATION TASK POSE MATHEMATICAL MODEL

After completing the modeling of the robot system, in order to carry out the simulation of the sheet metal bending production line smoothly, it is necessary to configure the completion parameters and the local coordinate system to establish the mathematical model of each unit, and then establish the spatial pose relationship between the robot and each working unit to generate the target pose matrix at the end of the robot, which is convenient for output to the robot motion simulation module for pose verification. Under different tasks, the spatial pose relationship between the robot and the operating objects is shown in Figure 4.

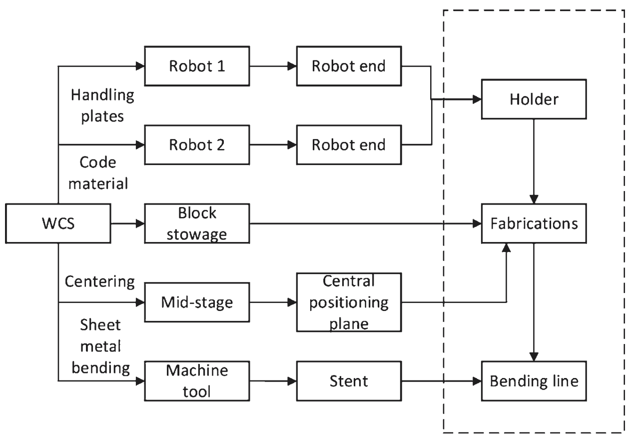

Figure 4 Schematic diagram of spatial pose relationship under different tasks

In this paper, the mathematical model and the method of establishing the local coordinate system are introduced by taking the end sucker holder and sheet metal parts of the robot as an example. The methods of other components are similar and not listed.

The suction cup holder is assembled at the end of the robot to complete the operation of sucking and clamping the sheet metal parts. The establishment of the mathematical model of the gripper is related to the pose calculation of each operation task of the robot. As shown in Figure 5, the sucker gripper establishes a local coordinate system with the geometric center of the end connected to the robot as the origin $o_g x_g y_g z$.

In the robot sheet metal bending processing environment, the sheet metal part is the object of the robot to perform the bending processing operation, so the data parameters of the sheet metal part are the core elements of the target pose calculation when the robot performs the task. Due to the different processing plane will lead to different bending line positioning plane. When pro-

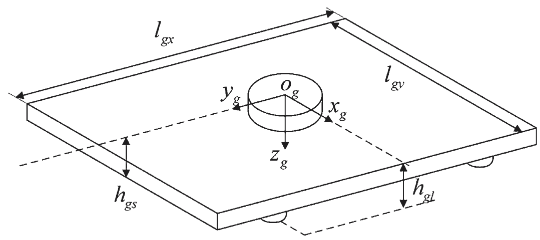

Figure 5 The mathematical model diagram of the gripper

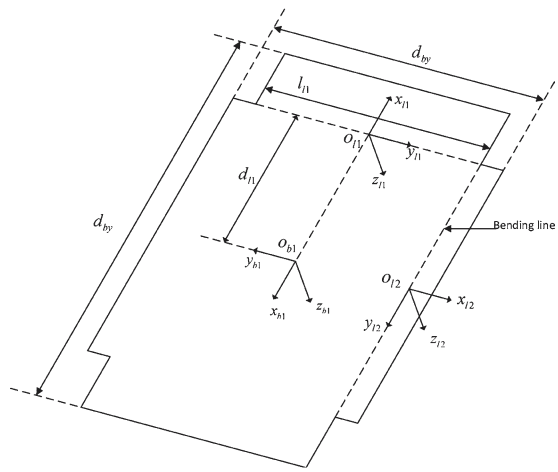

Figure 6 Sheet metal parts mathematical model diagram

cessing different planes, the sheet metal parts will change the reference plane of the robot clamping and perform the turning operation. Therefore, two clamping coordinate systems are defined on two surfaces respectively $o_{b1}x_{b1}y_{b1}z_{b1}$ and $o_{b1}x_{b1}y_{b1}z_{b1}$. As shown in Figure 6, a schematic diagram of the mathematical model for sheet metal parts

After obtaining the mathematical model of each unit, the target pose matrix of the end of the robot operation can be obtained. Due to the need of the working range, the bending robot is usually assembled on a translation slide rail parallel to the bending machine mold. Therefore, the end pose matrix in the local coordinate system of the robot can be obtained by translation transformation, and then the rotation angle of each joint can be obtained by inverse kinematics, and the motion simulation can be carried out.

I/O SIGNAL CONFIGURATION

According to the requirements of production tasks, the I/O controller is configured for the robot first, and then the workstation logic is set up to complete the signal connection between the sub-components of all Smart components according to the design. Finally, the offline program is written according to the actual work requirements and the optimization program is continuously modified through multiple simulations.

PROGRAMMING

Offline programming with Rapid in robotstudio software. Considering the path of plate adsorption, handling, bending and following, as well as the principle of placement, the main program of the robot is edited. Some main programs are as follows:

```
PROC main()
MoveL home,v1000,FINE,tVacuum\WObj:=wobj0;
WaitSyncTask sync1,all_tasks;
SyncMoveOn sync2,all_tasks;
MoveL
reltool(Target_10,0,0,-500)\ID:=1,v1000,fine,t
Vacuum\WObj:=wobj0;
MoveL
Target_10\ID:=2,v1000,fine,tVacuum\WObj:=wobj0;
SET DO0;
WAITTIME 1;
MoveL
reltool(Target_10,0,0,-500)\ID:=3,v1000,fine,t
Vacuum\WObj:=wobj0;
MoveL
home\ID:=100,v1000,FINE,tVacuum\WObj:=wobj0;
MoveL
DUIZHONGDIANWEI\ID:=4,v1000,fine,tVacuum\
WObj:=wobj0;
MoveJ
JIAODU45\ID:=5,v1000,fine,tVacuum\WObj:=wobj0;
……
ENDPROC
```

CONCLUSION

In this paper, a dual-robot cooperative sheet metal bending production line scheme is proposed. The simulation model of the production line is built by RobotStudio software. By deducing the mathematical model of each unit, the end pose matrix in the local coordinate system of the robot is obtained, and the angle of each joint of the robot is obtained by inverse kinematics. Finally, the simulation of the production line is completed by Rapid offline programming, which verifies the correctness of the kinematics model and the feasibility of the scheme.

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Note: The responsible for English language is Y. Q. Cai, Hebei, China