Based on Numerical Control Fold the Speed of Curved Robot System from Meet Speed with Swing to Study

Minghui She¹²*, Wei Weng³, Huihuang Chen², Adi Yang² and Lun Yu¹

¹College of Physics and Information Engineering, Fuzhou University, Fuzhou City, Fujian Province, China
²Department of Automation Engineering, Meizhou Bay Vocational and Technical College, Putian City, Fujian Province, China
³Department of Automation Engineering, Fujian Information and Technology College, Fuzhou City, Fujian Province, China

Email: smh7791@126.com

Abstract. In order to solve the current domestic sheet metal enterprise users has increased rapidly, but there are still most bending machine or manual operation problem, involving the employment difficult problems, according to labor shortage problem, must promote intelligent enterprise transformation, realize the exchange Labour “machine”, the development and application of nc bending robot system is the inevitable developing trend of sheet metal industry, speed adaptive speed and oscillation is important in the development and application of nc bending robot system. This paper describes the system model of the speed adaptive speed and swing of the CNC bending robot system, and analyzes the performance of the speed adaptive speed and swing system comprehensively. The results of computer simulation show the consistency between simulation and theory.

Keywords: Bending robot, speed adaptation, bending machine.

1. Introduction

As all industries, regions and enterprises seize the development opportunity of “made in China 2025” and “industry 4.0”, they constantly increase investment in technical upgrading projects, promote intelligent transformation of enterprises, and gradually realize “machine replacement” and CNC bending robot system. The development of integrated application will be the inevitable trend of sheet metal industry [1].

But now in numerical control fold the curved etc. field of manufacturing industry on, the most proprietor of an enterprises will show for artificial operating or robot handwork shows religion mainly, firstly because of abroad is in the lead the numerical control of tycoon fold curved robot integrated systematic price relative expensive, and according to specific numerical control, fold curved type number; Secondly because of domestic most automations, enterprise is faced with to develop cost input, develop technical difficulty higher reason, robot develops technology and application level stays only, is carrying, the simple applications such as sorting and about material on.

In order to solve the above problems and improve the integrated application level of robot technology in CNC bending and other manufacturing fields, we need to focus on how to ensure the two precision problems of robot bending after forming, namely the Angle of the product and the size of the product [2]. In order to solve the problem of the product Angle of the robot bending, this paper analyzes the bending mechanism of the robot at multiple levels, and proposes a set of speed adaptive
speed and swing system based on the CNC bending robot system [3-5]. The system has been tested repeatedly on several production lines, and it is compatible with hundreds of products with different processes, which improves the competitiveness of the enterprise.

2. System Introduction

The speed that this paper indicates from meet speed is in robot fold curved movement course in, robot winds to fold the curved machine of lower mould, carry out the sport speed of relocatable sport, need and fold the of upper mould of curved machine from clip location the down sport speed to the location of dead center appearance from suit, reach synchronism to fold curved movement. Otherwise in the course that material warps in plasticity, the quality and precision that can force product get great influence. In which common speed from meet speed way have mainly two: It is the first kind of to be the real time that location real time matches and asks to fold communication as well as the instance of curved machine location collection, often, the bandwidth of 100 M on current Ethernet communication industrial technology can not also satisfy these requirements [6-7]. Second kind is fold bend use match, ask to fold curved machine to fold curved course use is equal to robot fold curved course use; its data collection is simple.

This paper adopts second kind way, it gathers numerical control through PLC control system to fold the down time used of curved machine (from clip location go to the location of dead centre use always) and down sport locus (from clip location the location data of upper mould of real time to the location of dead center), additionally through going up position machine control system gather industrial robot follow the time used (with match speed follow movement use always), soon afterwards combine relatively feasible speed from suit appropriate with swing system calculate again to go to work trade robot follow to match speed, eventually, reach the purpose between two that speed matches [8]. Systematic model sketch shows as figure 1.

![System model diagram](image)

**Figure 1.** System model diagram.

3. Systems Analysis

3.1. Speed from Meet Speed Control Analysis

System knows exceptional quantity to test, fold the down sport locus of curved machine for numerical control to carry out analysis, get sport locus curve map as figure 2 shows, divide into 5 stages approximately: Pause, accelerate and share speed and deceleration and lift knife.

Through figure 2, we can know, entire need matches course, is accelerated mainly, even fast and deceleration stage, crucial stage is C→D even fast stage. Therefore first through last position machine use the discriminate of curve slope (1), but handling loses A→B stage (slope is equal to 0) and E→F stage (slope is smaller than 0);

\[ k = \frac{\Delta s}{\Delta t} \]  

(1)
Figure 2. Curve analysis diagram of downward motion curve of bending machine. The curve in the figure is the trajectory curve of downward motion of the bending machine, where A→B represents the stage of stopping; B→C indicates that this stage is acceleration; C→D indicates that the phase is uniform; D→E indicates that this stage is deceleration; E→F indicates that the stage is knife lifting.

Among them, k, Δ s, Δ t for the corresponding stage of the slope, displacement falls in a timely manner.

Then, the upper computer USES the inflexion discriminant (2) to judge the inflexion from B→C to C→D and the inflexion from C→D to D→E.

\[ (k_{ab} - k_{bp}) \times (k_{pc} - k_{cd}) < 0 \]  

where, a, b, p, c and d are the points connected in the descending trajectory curve, and p is the inflection point in the curve.

Reach acceleration interval section displacement finally through the location of inflection point quantity with long, even quickly interval section displacement quantity with length as well as deceleration interval section displacement quantity with length.

Industrial robot with fold curved machine speed from meet speed control minute point is, first, speed matches to divide into 3 stages, the displacement with its every stage formula of corresponding interval section quantity/corresponding interval length, so calculate the 3 initial stages that robot follows match speed. Secondly through folding curved machine for numerical control, the down time used follows the time used with robot to carry out comparison, and has gradient adjustment according to the two-time bad increments that match speed for sharing quickly interval section.

3.2. Swing Control Analysis

Each axle of industrial robot is formed respectively by generator and deceleration machine etc., therefore in the course that industrial robot follows movement, and phenomenon can swing since the reason of gear gap appears [9]. Considering that following movement to occur when swinging, industrial robot can drive panel with fold curved machine upper mould between drag, so, it can affect quality and the precision of product.

The rectangular coordinate system O (origin), X (X direction) and Y (Y direction) of the bending robot are shown in figure 3. The arrow direction in the picture is positive.

Therefore through the installation tool on industrial robot flange plate, in tool two side installations height precision displacement sensor stop to block tool, so for it in fold the curved robot department of rectangular coordinates X direction on swing to measure test. The test tools are shown in figure 4.
Figure 3. Bending robot rectangular coordinate schematics.  

Figure 4. Test equipment.

Figure 5 shows the oscillation trajectory of the industrial robot obtained from a large number of experiments. It can be seen from the figure that the robot oscillates obviously in the process of following. Most of the oscillation phenomenon occurs in the early movement state, and the oscillation will shift to the right with a deviation of 0.1-0.3 mm.

3.3. Algorithm and Program Analysis

The flow chart of the system speed adaptive speed and swing algorithm is shown in figure 6.

Where, VR is the initial velocity value; V acceleration represents the speed when accelerating; V constant velocity is expressed as the velocity at constant velocity; V deceleration represents the speed when decelerating; T is the difference between the bending time of the bending machine and the bending time of the robot; VD1 and VD2 represent the increment of velocity value;

Where, the initial velocity value of the robot is required to be set during the first operation of the system. Therefore, the relation curve between time and velocity during the following process of the industrial robot is obtained through a large number of experiments, as shown in figure 7.

Through figure 3 curve data, use MATLAB March line to draft suit, reach the course of following of industrial robot in speed will join equation (1).
\[ V_R = 68.007 \times T_R^{-1.3737} \] (3)

VR and TR are respectively the speed and time of industrial robot in the process of following.

![Flow chart](image)

**Figure 6.** Speed adaptive speed control flow chart.
4. Data Verification and Analysis

The robot used in this system is Yukawa robot MH50, and the selected CNC bending machine is hydraulic.

4.1. Test Conditions

(1) Test parameter: (a) fold curved machine traversal speed: 2 mm/s; (b) robot folds curved radius: 244.085 mm;
(2) Test material: (board thick and board length is mm).

For the requirements of test parameters, the relevant parameters of plate thickness and length are given for testing. The operating speed and radius parameters of the bending machine are shown in table 1.

| Parameter  | Passages |
|------------|----------|
| Thickness  | 1        |
| 1.5        | 2        |
| 2          | 2.5      |
| 3          | 4        |
| Board grows| 400      |
| 800        | 1200     |
| 400        | 800      |
| 1200       | 400      |
| 800        | 1200     |
| 400        | 800      |
| 1200       | 400      |

4.2. Test Data

(1) When the plate length and thickness are different, the test data of speed adaptive and manually given speed are shown in table 2.

(2) In the process of manually given speed swing, the average Angle of the corresponding plate thickness and the average Angle of the compensation 0.3mm when the plate length is not compensated in the x direction are tested. The x-direction uncompensated and compensated test data of the bending machine origin are shown in table 3.
Table 2. Test data of average time and downforce stroke of bending machine.

| Thickness (mm) | 1          | 1.5        | 2          | 2.5        | 3          | 120        |
|----------------|------------|------------|------------|------------|------------|------------|
| Boardgrows (mm) | 400       | 800        | 1200       | 400        | 800        | 1200       | 400        | 800        | 120        |
| Average time of bending (s) | 1.92       | 2.25        | 2.02       | 2.55       | 2.33       | 2.98       | 2.08       | 3.22       | 3.54       | 3.56       | 3.62       | 4.28       | 4.44       | 4.16       |
| Downstroke (mm) | 3.02       | 3.20        | 3.02       | 4.07       | 3.20       | 4.174      | 3.778      | 4.388      | 4.60       | 5.629      | 5.807      | 6.01       | 7.256      | 7.128      |
| Speed adaptive adjustment times | 3          | 4          | 3          | 3          | 3          | 4          | 5          | 4          | 5          | 6          | 4          | 4          | 7          | -          |

In the case of adaptive speed, the measured product Angle data average

| Speed (°/s) | 26.43       | 23.8       | 26.61      | 18.65      | 22.08      | 16.37      | 19.07      | 15.83      | 14.71      | 13.46      | 13.46      | 10.27      | 10.97      | -          |
| Mean values of measured angles (°) | Left: 89.57       | 88.48      | 90.91      | 90.86      | 90.82      | 90.76      | 91.01      | 89.49      | 89.77      | 90.59      | 90.50      | 90.24      | 90.29      | 90.65      |
| Right: 89.04       | 88.31      | 89.13      | 90.71      | 90.81      | 90.02      | 90.81      | 89.88      | 89.12      | 86.01      | 89.86      | 90.01      | 90.12      | 90.13      | -          |

Under the condition of manual given speed, measured product Angle data

| Speed (°/s) | 25          | 25          | 25          | 22          | 25          | 16.2       | 22.8       | 15.6       | 15.6       | 14.5       | 14.5       | 14.5       | 10.7       | 10.7       | -          |
| Mean values of measured angles (°) | Left: 89.89       | 88.77      | 91.16      | 89.97      | 89.75      | 90.95      | 90.10      | 90.95      | 90.60      | 89.78      | 90.27      | 90.18      | 89.91      | -          |
| Right: 89.73       | 88.05      | 89.65      | 89.58      | 89.40      | 90.33      | 90.41      | 90.33      | 89.95      | 89.88      | 89.21      | 89.96      | 89.43      | -          | -          |

Table 3. Uncompensated and compensated test data in x direction.

| Thickness (mm) | 1          | 1.5        | 2          | 2.5        | 3          | 120        |
|----------------|------------|------------|------------|------------|------------|------------|
| Boardgrows (mm) | 400       | 800        | 1200       | 400        | 800        | 1200       | 400        | 800        | 120        |
| The average angle in the x direction without compensation under the condition of Right: 89.73       | 89.07       | 90.03      | 90.58      | 89.40      | 90.33      | 89.41      | 90.33      | 89.95      | 89.88      | 89.01      | 89.96      | 89.43      | -          |
| manual given speed, measured product angle data (°) | Left: 90.07       | 89.95      | 90.96      | 89.71      | 89.89      | 90.67      | 89.77      | 90.19      | 90.38      | 90.09      | 89.78      | 90.27      | 90.44      | 89.89      |
| X direction compensation angle 0.3mm, average (°) | Right: 89.872     | 88.383     | 89.83      | 89.477     | 89.797     | 90.161     | 89.403     | 89.163     | 89.203     | 89.847     | 89.21      | 89.969     | 90.028      | 89.431     |

4.3. Test Analysis

(1) Speed from the course of suiting in, for different panel length with the speed carried out by thickness from suit with artificial given speed-distance curve picture is as follows:

Through above chart and test data in figure 8, we can know, robot folds curved speed, is thick along with board to increase and it is little to reduce; Speed from meet income fold curved speed-distance curve value and man-days give to fold the fluctuation scope between curved
speed-distance curve value little; The Angle deviation range of the two products is within ±0.5°;

(2) Artificial given speed the course of swinging in, fold the x direction of curved machine origin do not compensate and compensate rear around angle value curve map as follows:

![Figure 8. Speed adaptive and artificial a given graph.](image)

From the above figure 9, it can be seen that different plate lengths and thickness have little influence on the left and right side angles after compensation. It can be seen that the swing deviation can be absorbed by the flexible sucker.

![Figure 9. The value of the x-direction is the same as the value of the left and right angles.](image)

5. Conclusion

After verification and analysis of a large number of test data, the system described in this paper can obtain: after 3 to 4 times of speed adaptive, the Angle deviation range of the measured product is basically within ±0.5°, which meets the bending accuracy requirements. The conclusion shows that the system needs to sample data for many times when producing new products, which will cause inconvenience to the operator. In the future, it is necessary to adopt gradient mode to set the speed increment value in figure 6 flow chart to improve the efficiency.

Acknowledgement

The projects are funded by the national natural science foundation of China (60672146); Putian science and technology project fund: application development and research of industrial robots in CNC bending machine (2017G2011).
References

[1] Barraquand J, Kavraki L, Latombe J, et al. 1997 A random sampling scheme for path planning Int. J. Robotics Research 16 (6) 113-125.

[2] Chan S P 1995 A neural network compensation for uncertainties in robotic assembly J. Intelligent and Robotic Systems 13 (2) 127-141.

[3] Chung H X, Chen B C and Lin J J 1998 A PI-type fuzzy controller with self-finning scaling factors Fuzzy Sets and Systems 9 (3) 23-28.

[4] Mataric M J and Cliff D 1996 Challenges in evolving controllers for physical robots Robotics and Autonomous Systems 19 (1) 67-83.

[5] Sameer M P 1995 ANN based adaptive robot controller J. Intelligent and Robotic Systems 15 (1) 3-10.

[6] Chu J 1991 Robot and Control Technology (Hangzhou: Zhejiang University Press).

[7] Yun W M and Xi Y G 1996 Intelligent information system of the robot Robot 18 (5) 257-263.

[8] Cai Z X, Xie G H, Wu C H, et al. 1998 Directly control the robot in the position of the adaptive fuzzy control force/position Robot 20 (4) 297-302.

[9] Sun L L, Xu W J and Cai H G 1999 Parallel robot based on fuzzy CMAC neural network adaptive control research Robot 21 (3) 198-203.