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Design a Variable Cross-section Roll Forming Machine

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Abstract

In this paper a variable cross-section roll forming machine is designed for variable cross-section parts in car body. Based on the process of the roll forming and motion analysis of sheet metal and roller, the mechanism model and kinematical equation of the variable cross-section roll forming machine are investigated. According to the mechanism model, the variable cross-section roll forming machine is designed. Then the kinematical analysis of the machine based on D-H method and the motion control algorithm are obtained. Finally, the kinematic diagram and three-dimensional mechanical model of the variable cross section roll forming machine are proposed. The research in this paper provides theoretical basis for developing the variable cross-section roll forming machine.

Keywords: *Variable cross-section roll forming, Kinematic diagram, Kinematical analysis*

1. Introduction

As the development of the light weight of the automobile, roll forming as a method of sheet forming can reduce the weight of vehicle weight without reducing strength. In the light of the complex cross-section components of the automobile body, a new technique is proposed, namely variable cross-section roll forming. The variable cross-section roll forming is a new plastic processing technique for the production of sheet metal [1-4]. The University of Darmstadt in Germany cooperated with the data M, a German company, researched the variable cross-section flexible roll forming technology and proposed the concept of the flexible roll forming [5]. H One, a professor of Takushoku University in Japan, had also done a lot of work in the flexible roll forming and developed a series of flexible roll forming machine which can produce unilateral longitudinal edge width cross-sectional profiles [6]. In addition, Ortic, a Sweden company, developed a flexible roll forming machine which is capable of producing the sheet with a certain longitudinal curvature. In China, North China University of technology studied the variable cross-section roll forming technology [7-9].

In this paper a variable cross-section roll forming machine is designed for variable cross-section parts in car body. Based on the process of the roll forming and motion analysis of sheet metal and roller, the mechanism model and kinematical equation of the variable cross-section roll forming machine are investigated. According to the mechanism model, the variable cross-section roll forming machine is designed. Then the kinematical analysis of the machine based on D-H method and the motion control algorithm are obtained. Finally, the kinematic diagram and three-dimensional mechanical model of the variable cross section roll forming machine are proposed. The research in this paper provides theoretical basis for developing the variable cross-section roll forming machine.

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2. Conceptual Design

2.1. Motion Analysis

The traditional uniform section roll forming is a gradually-forming technology. In the process of the traditional uniform section roll forming, the sheet metal moves through a certain amount of fixed shaped rollers which generate a shaped curved surface and is transformed into the final shape of the variable cross-section roll forming parts [9-10]. The process of roll forming is shown in Figure 1.

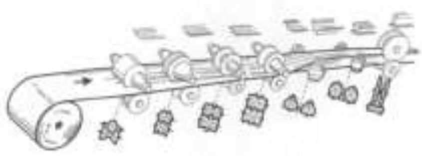

Figure 1. Traditional Roll Forming Process

The variable cross-section roll forming is developed from the traditional uniform section roll forming. The difference of the variable cross-section roll forming is that rollers must complete longitudinal translation and rotation of the roller itself with the forward movement of sheet metal. According to the variable cross-section roll forming process is shown in Figure 2, the sheet and roller need three kinds of motion including translation of sheet metal, translation of rollers (the direction perpendicular to the sheet metal moving direction) and the rotation of rollers.

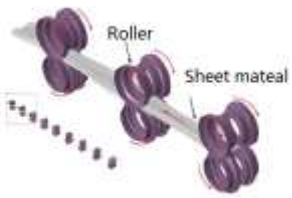

Figure 2. The Variable Cross-Section Rolls Forming

2.2. Mechanism Model

According to the motion analysis of the sheet metal and roller the direction of metal sheets is coincident with *x* axis and the displacement is d_x; the direction of roller is coincident with *y* axis and the displacement is d_y, the rotation of roller is θ rotates about *z* axis. Because the movement of the sheet metal is equivalent to reverse movement of the roller, the mathematical kinematics model of the variable section roll forming prototype is established and the diagram of kinematics model is shown in Figure 3.

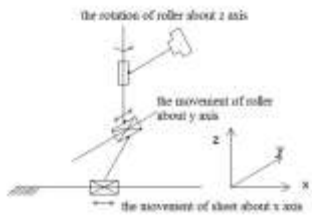

Figure 3. The Diagram of Kinematics Model

3. Kinematical Analysis

3.1. Kinematical Equation

By the D-H (Denavit-Hartenberg) method and actual kinematics model, the kinematical equation is established. The transformation matrix of the roller's end is generated by the homogeneous matrix multiplied in turn.

The steps to establish kinematics equation are followed:

Firstly, setting the link-pole coordinate system and giving the appropriate parameters. Where, r is the distance between the roller end and roller rotation center, the initial coordinates of roller end is $(0, 0, z)$ in spatial rectangular coordinate system.

Secondly, the transformation matrixes of adjacent link-pole coordinate system are established. The movement of the roller which reverse the movement of the sheet metal in x direction can be written as

$$ {}^{0}_{1}T = \begin{bmatrix} 1 & 0 & 0 & d_x \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

Movement of the roller in y direction can be written as

$$ {}^{1}_{2}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & \mathrm{d}_y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

Rotation of roller about z axis can be denoted as

$$ {}^{2}_{3}T = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & r\sin\theta \\ \sin\theta & \cos\theta & 0 & r(1-\cos\theta) \\ 0 & 0 & 1 & \mathrm{z} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

Thirdly, the transformation matrix of the roller end and kinematics equation is set up. With the matrix multiplied in turn, transformation matrix of the roller end is generated as following

$$ {}^{0}_{3}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & d_x + r\sin\theta \\ \sin\theta & \cos\theta & 0 & d_y + r(1-\cos\theta) \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4) $$

The Equation (4) is the kinematics equation of the variable section roll forming machine. The kinematics equation under link-pole coordinate system with the D-H method can be used to solve the kinematics and inverse kinematics problem.

3.2. Analysis of Motion Control

In the process of forming, the sheet metal's forming trajectory is given as $Y = F(X)$, the movement speed is v, and movement time is t, so

$$ \begin{cases} Y = F(X) \\ X = v \cdot t \end{cases} \quad (5) $$

Disserting the curve equation $Y = F(X)$, get a sequence of X_i, Y_i

$$X_i = d_{xi} + r\sin\theta_i \tag{6}$$

$$Y_i = d_{yi} + r(1-\cos\theta_i) \tag{7}$$

This means rollers should be tangent with forming trajectory. The radius of ration should be consistent with the normal direction of the meshing point, then

$$F^{'}(X_i)\cdot\tan(\theta_i) = -1, (i = 1,2,\ldots,n) \tag{8}$$

Substituting the Equation (5) into Equation (7), angle θ_i can be calculated. By the Equation (5)-(8), we can get a sequence of values for d_{xi}, d_{yi}, and θ_i. The obtained values are used to determinate the motion control $d_x(t), d_y(t), \theta(t)$.

Based on the analysis above, this method provides a basis for dynamics analysis and control system of the variable cross-section roll forming machine.

4. Mechanical Design

According to the kinematics model of the variable cross-section roll forming and the basic process of roll forming, double rack-single gear structure is selected to design the variable section roll forming prototype. The structure diagram of the roll forming prototype which is bilateral symmetry is shown in Figure 4.

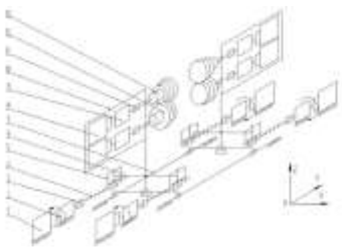

Figure 4. The Kinematic Diagram Roll Forming Prototype

1-ball screw drive servo motor, 2-planetary gear reducer, 3-coupling, 4-ball screw, 6 and 5-rack gear, 7-linear rolling guide, 8-roller drive servo motor, 9-planetary gear reducer rotating, 10-frame, 11-coupling, 12-the upper roller, 13-the upper roller

At the bottom of left and right sides of the prototype has two ball screw drive servo motor. The servo motor 1 is connected with the ball screw 4 through the reducer 2. The rack is installed in the screw seat of the ball screw. So the ball screw driven by a servo motor 1 can make the rack 5 complete the translational motion. Double rack-single gear structure is composed by two racks 5 and a gear. Double rack single gear structure can complete the rotational and translational motion of the gear. Gear is connected with the spindle box through the rotating spindle and four pieces of rolling linear guide rail slider 7 is installed on the bottom of spindle box which is only moved on guide rail. The rotating frame 10 is fixedly connected with gear through bolts. The upper and lower slides whose rotation axis is used to mount roller are installed on the rotating frame. Distance of slides is adjusted by the roll gap adjustment mechanism and is to adapt to different roll diameter and sheet thickness. Movement of the gear 6 drives the rotating rack movement, which is used to complete the translational and rotational roller 12 and roller 13. Servo motor which is connected with the rotation axis through reducer 9 drive the rotation of roller to move the sheet metal toward. Three-dimensional diagram of the variable section roll forming prototype is shown in figure 5.

Figure 5. Three-Dimensional Mechanical Model

According to the technological requirement of variable cross-section roll forming parts in actual production process, multi-pass roll forming production line prototype is designed. When the movement distance perfectly matches with the sheet metal contour curve in time and space between each forming station, the specified variable cross-section molding products can be completely rolled out.

5. Conclusions

According to the requirements of automobile body variable cross-section parts and complex process of three dimensional variable cross-sections roll forming, the mechanism model and kinematical equation of a variable cross-section roll forming machine are established on the motion analysis of sheet and roller. Upon this, the variable cross-section roll forming machine is designed, which has the reasonable motion device and control system. Simulation and experiment show that variable cross-section roll forming machine is capable of producing three-dimensional variable cross-section roll forming parts with high accuracy. And the research in this paper provides theoretical basis for the development of a variable cross-section roll forming machine.

Acknowledgements

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