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Study on Flexible Bending Process of Sheet Metal and Its Production Equipment

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***Abstract*—In order to solve the problem that it was difficult to ensure the bending quality of sheet metal in the actual production process by using traditional bending tooling, a flexible sheet metal bending process and its production equipment were studied on the premise of analyzing the influencing factors of the sheet metal bending process. Structural flexibility design technology was adopted in this equipment. For different product bending sizes, only the bending punch inserts needed to be replaced. Flexible servo control design was adopted to control the bending process. The bending process parameters were accurately conformed according to the real-time measurement about the part thickness The coordinated motion control strategy about blank holder servo motor and bending servo motor was adopted to achieve the required bending size of the products. Closed-loop control technology was used to ensure that the bending angle of finished products was 100% qualified by means of the bending angle closed-loop real-time correction based on on-line real-time detection. The simulation results of a same sheet metal bending product by using traditional tooling and flexible equipment showed that the bending process and its production equipment which were studied in this paper were obviously superior to the traditional tooling method in bending quality.**

Keywords—sheet metal bending; flexibility; closed-loop control

I. INTRODUCTION

A large number of sheet metal bending parts are used to instead of mechanical parts in order to adopt the development of automobile and aviation. It takes a long time and a high cost to tooling designed, manufactured and repaired. Because of some objective factors such as the slight difference of thickness and the difference of internal structure of sheet metal in different batches or even in the same batch, the finished bending parts have great differentia that the same bending tooling is used to do bending process which leads lower qualified rate of products. Mold testing and tooling repairing must be carried out before every bending process which increases the production cost and prolongs the production time.

The main difficulty in sheet metal bending process is the prediction and controlling of the bending spring-back. It is also a hot issue which is concerned by technicians and difficult to be brought through completely. So far, experts and scholars at home and abroad have done a lot of research on prediction and control of spring-back and put forward many solutions. The research methods mainly include theoretical analysis method, numerical simulation method, and experimental research method and so on. Chunfeng Huang [1] deduced formulas for calculating bending moment and spring-back of sheet metal. Wei Peng [2] et al. studied the method of double bending. Gang Xu [3] et al. studied the effect of forming speed and load on the bending spring-back of high strength steel plate. Ying Li [4] et al. studied the influence of blank holder force on spring-back. Yihao Wu [5] et al. studied the influence of gap between punch and die on spring-back. Most of the researching results showed that the calculation error and discreteness of bending spring-back are very large and the calculation accuracy is unsatisfactory. Therefore, the metal bending production still depends more on experience for die design and process parameter adjustment.

A flexible sheet metal bending machine was studied in this paper. A typical sheet metal bending part is selected, and the finite element simulation analysis about this part was carried out by using the flexible sheet metal bending equipment. The results showed that the equipment could ensure the bending quality and could solve many problems existing in the current bending process by using bending tooling.

II. CURRENT SITUATION AND DEMAND ANALYSIS ABOUT BENDING PROCESSING TECHNIQUE

Generally, the main problems in sheet metal bending process can be described as follows:

- Because of the difference of internal structure of materials, spring-back is difficult to control and predict, which makes the follow-up calibration workload heavy and more number of substandard products. Even for same batch of raw materials, the gap between punch and die cannot be adjusted in real time according to the different thickness of blanks, which cause different bending quality of sheet metal bending parts.
- A set of bending tooling can only bend one sheet metal part. For different shapes, different material thickness, different bending radius and even different materials, a set of special bending tooling is needed, which makes it difficult to achieve universality.
- Because of the existence of external friction in the bending process of the bending tooling, the plastic deformation force and deformation work are increased which creates additional forces, and which also can lead to cracking of parts, bonding and abrasion of the parts. This problem can affect the bending quality, increase tool wear, and shorten the life of the bending tooling.
- In the process of bending using tooling, some important technological parameters cannot be

accurately controlled, such as friction, bending moment, forming speed and blank holder force, which affect the bending quality.

Therefore, in order to improve the quality of sheet metal bending parts and control the spring-back after sheet metal forming, it is necessary to reasonably and accurately control the process parameters in the forming process such as forming speed, load, blank holder force, friction and son on. At present, the gap between punch and die is usually designed according to the theoretical thickness of materials. However, the thickness of raw materials varies from batch to batch, and the gap between punch and die has a great influence on spring-back after bending forming. Therefore, the quality after bending is different by using the same bending tooling. It is necessary to define different parameters for blanks with different thickness to improve the forming quality of sheet metal bending parts. But it is difficult to achieve in the die.

In order to solve the above problems, a new type of bending forming equipment should accurately control the process parameters which impact on the forming quality. And it can greatly reduce or eliminate friction. It also can adjust the process parameters according to the real-time online thickness measurement results. The spring-back of sheet metal after bending forming can be reduced or eliminated by precisely controlling the technological parameters of bending forming. Therefore, the forming quality of sheet metal bending structural parts can be improved. The following key problems should to be solved in this process:

- Flexibility: Different sheet metal parts, different shapes, different bending angles, different bending radius, different material thickness and other different shape characteristics could be bended directly by the equipment.
- Accurate: Each blank bending process parameters can be controlled accurately in order to improve the quality of sheet metal bending structural parts.
- Closed-loop control: The online real-time detection should be used to correct the products whose rebound exceeds the limit in real time.

III. Flexible Sheet Metal Bending Equipment and Bending Process

A. Flexible Sheet Metal Bending Equipment

The quality of sheet metal bending parts is unstable due to the inconsistency of materials and inherent characteristics of bending process, the friction between parts and bending tooling cannot be overcome in bending process, and the bending process parameters cannot be accurately controlled. In order to improve the quality of sheet metal bending and solve these problems, a flexible sheet metal bending equipment was designed. Its principle and structure are shown in Figure I.

- The sheet to be bent is placed on the positioning board of the upper part of the universal die set (8). The bottom of the universal die set (8) is supported by a one-way cylinder (7) with adjustable pressure, and the one-way hydro-cylinder (7) provides the blank holder force in the bending process.
- The upper of the universal punch (9) connected with down voltage servo motor (4) through screw mechanism, it install replaceable bending punch (2) at lower front end. Replaceable bending punch (2) Customized according to the bending radius required by part drawings, The Down voltage servo motor (4) drives the universal punch (9) to move downward. Firstly, the blank to be bent (1) are pressed on the die set (8) to complete the positioning and pressing of the parts. After the bending starts, the down voltage servo motor (4) drives the die set and punch to move down simultaneously according to the speed set by the process parameters.
- The bending servo motor (6) is connected with the rotating shaft (11) of the bending device (10) through the reducer. During the bending process, the bending servo motor (6) drives the bending device (10) to rotate upward and bend around the rotating shaft (11) according to the bending speed set by the control system.
- In order to achieve the adjustment of the gap between the curved convex and concave molds, thereby ensuring the best bending forming effect, The clearance Adjustment servo(5) motor drives the bending device(10) to move back and forth by the screw mechanism according to the thickness of the sheet to be bent.
- The sensor (12) collects and calculates the bending angle and bending rebound angle of the parts during bending.

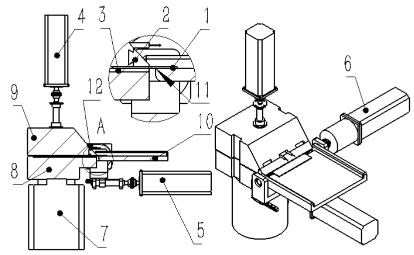


FIGURE I. EQUIPMENT SCHEMATIC DIAGRAM

The flexible design of flexible sheet metal bending forming equipment is reflected in the following aspects:

- The parameters such as the clearance of the die and punch required for bending can be flexibly adjusted by the process parameters within a certain range, thereby ensuring that the sheet metal parts of different material thicknesses, different materials and different shapes can be directly bent by using the equipment.
- Sheet metal parts with different bending radius can be bent and formed using this equipment by simply replacing the punch inserts to achieve equipment versatility

- Using servo motor to drive can realize flexible adjustment of some important process parameters that affect bending quality, such as bending moment, forming speed and blank holder force.
- Realizing the Down voltage servo motor and the bending servo motor can ensure that the sheet metal is adhered to the punch during the entire forming process and there is no relative sliding tendency. This can improve the quality of sheet metal bending forming and solve the effect of friction on the quality of bending forming.

B. *Flexible Sheet Metal Bending Process*

According to the structural design of the flexible sheet metal bending device described above, the specific bending forming process flow is shown in Figure II.

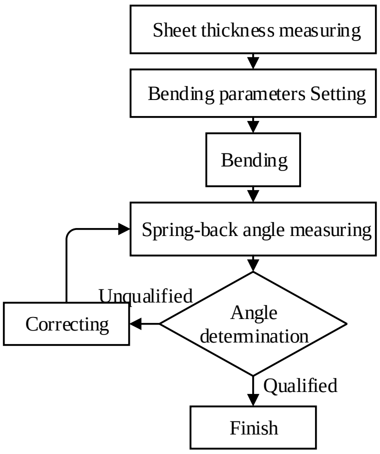


FIGURE II. PROCESS FLOW CHART

The specific steps of this process flow are as follows:

- STEP 1: Replace the corresponding curved punch insert according to the technical requirements of the bending radius of the sheet metal part.
- STEP 2: Measurement of the sheet's thickness before bending. This gap value is directly related to the thickness of the material. But the national standard has a larger thickness deviation range for hot rolled or cold rolled sheets, especially for medium and thick plates with a thickness greater than 3mm.Even the same batch of sheets has a large thickness deviation. Therefore, this process flow first adjusts the gap between the convex and the concave mold by measuring the actual thickness of the material to solve the influence of external differences on the bending forming results.
- STEP 3: Bending process parameter setting: The control system automatically sets process parameters such as bending angle, blanking force, bending moment and forming speed according to the part forming requirements.
- STEP 4: The bending equipment adjusts the blanking force of the one-way cylinder according to the set value, then control the coordinated movement of the servo motor and the bending servo motor to complete the entire bending process.
- STEP 5: Pressing the servo motor up after the bending process is completed, then the bending servo motors correspond to each other at a certain angle and the sensor measures the rebound angle of sheet metal in real time.
- STEP 6: The control system judges whether the bending angle is qualified according to the rebound angle calculated by the measurement. If the rebound causes the bending angle to be small, the control system will adjust the control parameters to control the bending servo motor to perform the correction bending again until the part requirements are met.
- STEP 7: If the rebound angle measured by the sensor after the rebound is too large, the equipment will shut down alarm because it can no longer correct the part, at the same time, it will automatically adjust the process parameters for the next processing. If the bend angle measured by the sensor is qualified, the pressing servo motor and bending servo motor will be back and complete the bending process equations

IV. COMPARATIVE ANALYSIS OF FLEXIBLE BENDING PROCESS SIMULATION

In order to verify the theoretical feasibility of the flexible sheet metal bending equipment described in this paper, the following finite element simulation methods were used to simulate the traditional die bending process and the flexible sheet metal bending equipment bending process respectively, and the simulation results were compared and analyzed.

A. *Establishment of Bending Parts Simulation Model*

The simulation experiment took a simplified bending process of automobile brake pedestal as the object. The parts before and after forming are shown in Figure III.

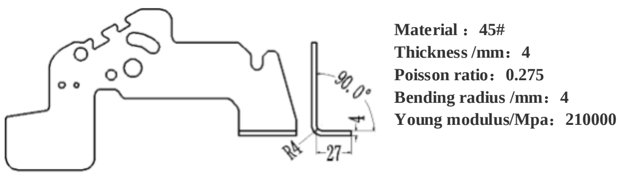


FIGURE III. BENDING FORMING SHEET METAL PARTS

Establishment of material model: In experimental tests, the data obtained are usually nominal strain-nominal stress curves. In the definition of plastic data in Abaqus, real strain and real stress are used. Therefore, in order to ensure the reliability of the simulation results, the nominal strain can be converted into real strain by the following formula, and the nominal stress can be converted into real stress.

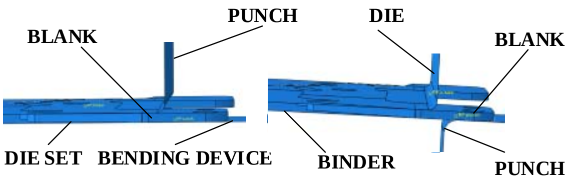
$$\varepsilon_{true} = \ln(1 + \varepsilon_{nom}) \quad (1)$$

$$\sigma_{true} = \sigma_{nom}(1 + \varepsilon_{nom}) \quad (2)$$

Dividing mesh: The partitioned mesh is shown in Figure IV In this paper, the bending forming of the dimensioned area in Figure III is mainly studied. In order to improve the calculation accuracy and speed up the calculation, the mesh of deformed area is refined. The seed size of the mesh defined in the deformed area is 0.5, and the other area is 5. Using hexahedral mesh and sweeping mesh generation technology.

FIGURE IV. PDIVIDED MESH

The simplified model of flexible sheet metal bending equipment is simulated and analyzed by means of the schematic diagram of the equipment in Figure I. The simplified model of the flexible sheet metal bending equipment is shown in Figure V. Punch, die and Blank holder are all defined as rigid body, and blank is defined as three-dimensional deformable entity. The revolving center of the punch is close to the sheet metal, and the distance from the die L1 = 4mm. The sheet metal is close to the punch. The stroke of punch is a=π/2≈1.57 and that of concave die is L2=8mm.



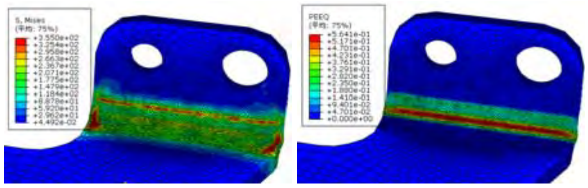
A. BENDING EQUIPMENT B. BENDING TOOLING

FIGURE V. SIMPLIFIED FINITE ELEMENT MODEL

A simplified bending tooling for bending this part is shown in Figure. V. Punch, die and blank holder were defined as rigid body and blank as deformable entity. Blank was defined as deformable entity. The punch and die were defined as rigid bodies and the sheet metal as three-dimensional deformable bodies. 4.02mm clearance is between punch and die. In the first step, the blank is completely fixed by the die and the blank holder. The punch moved forward along the Z axis with a stroke of 40mm and a velocity of 40mm/s. The friction coefficient was defined as 0.28. In the second step, the punch moved in the opposite direction until the end of contact [8], and the bended sheet metal structure begins to spring-back.

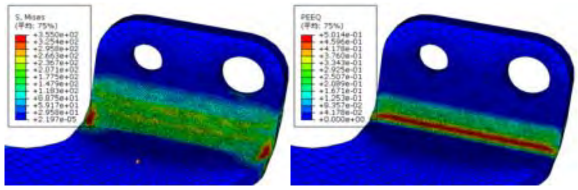
B. Finite Element Simulation and Molding Result Analysis

Figure VI and Figure VII are the finite element simulation results of flexible sheet metal bending equipment and die bending, respectively. The curvature of rebound measured by finite element analysis software is 1.557 and 1.556, respectively. The maximum residual stress area after spring-back is obviously smaller than that of die forming, and the effect on surface flatness is better than that of die forming. The equivalent plastic strain is obviously larger than that of bending tooling forming, the plastic deformation of the equipment would be more sufficient. In conclusion, the quality of sheet metal bending parts formed by this equipment is obviously better than that of the bending tooling under almost the same conditions.



A STRESS COMPONENT B EQUIVALENT PLASTIC STRAI

FIGURE VI. FORMING RESULT OF FLEXIBLE SHEET METAL BENDING EQUIPMENT



A STRESS COMPONENT B EQUIVALENT PLASTIC STRAIN

FIGURE VII. BENDING RESULTS OF BENDING TOOLING

V. CONCLUSION

A new flexible sheet metal bending process method was proposed and a flexible sheet metal bending equipment was designed to solve the common problems in the current sheet metal bending process. The forming process of the bending process was simulated by finite element method, and the simulation results were compared with those of the bending tooling bending process. The simulation results showed that the bending quality of sheet metal bending structure parts was obviously better than that of bending tooling, and many problems in bending tooling production were solved.

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