Establishment and Analysis of Simulation Model for Single-pass 20 Steel Spinning

Yu Yang¹*, Jiao Yang¹
¹ CityChangchun University of Science and Technology, Jilin, 130022, China
*2014800117@cust.edu.cn

Abstract. With the continuous advancement of computer technology, finite element simulation has been gradually applied to the analysis of plastic deformation of metals. If a strong spinning simulation model of 20 steel cylindrical parts can be established to effectively simulate the stress, strain and surface quality of the metal deformation process, it can provide a scientific basis for the setting of spinning process parameters, thus reducing the number of spinning process experiments to determine spinning process parameters.

1. Introduction
At present, the setting of spinning process parameters at home and abroad requires repeated spinning process experiments to observe the forming quality of the blank, explore the forming rules, and make repeated corrections to finally obtain the spinning process parameters. This method requires a lot of time and economic costs. With the development of industry, various industries have higher and higher requirements on the forming quality of spinning products, and the disadvantages of traditional process parameter setting methods have become more and more prominent.

2. Establishment of Mathematical Model
In the severe plastic deformation process of the strong spinning method, the spinning pressure of the blank in the radial, axial and tangential directions is very complicated. It is usually measured by electric method, which is obtained by measuring the spinning force on the roller in the radial, axial and tangential directions[1-6]. In the process of severe plastic deformation by forced spinning, the spinning forces acting on the blank in radial, axial and tangential directions are very complex. It is usually measured by electric method, which is obtained by measuring the spinning force on the spinning wheel in the radial, axial and tangential directions. The spinning force is one of the important bases for setting spinning process parameters. Thamasett algorithm is usually used to calculate the spinning force in China, which assumes that the metal material flows smoothly in the spinning process and there is no accumulation in front of the spinning wheel. However, in the actual spinning process, metal materials will form a stable accumulation in front of the spinning wheel, resulting in the deviation between the calculated value and the measured value of spinning force. Based on the above reasons, this paper compares the calculated spinning force with the measured spinning force, finds out the deviation between them, and corrects the tangential force, axial force and radial force of Thamasett algorithm. Table 1 shows the comparison table of the spinning force obtained by the 20# steel electrical measurement method and the Thamasett algorithm under the same conditions.
Table 1. Spinning force obtained by electrical measurement method and Thamasett algorithm

| Tangential force Pi | Axial force Pz | Radial force Pr |
|---------------------|---------------|-----------------|
| electrical measurement | electrical algorithm | 0.22KN | 0.28KN | 11.36KN | 13.06KN | 23.26KN | 47.05KN |
| Thamasett algorithm | 0.26KN | 0.33KN | 12.73KN | 14.64KN | 25.88KN | 50.21KN |
| electrical measurement | electrical algorithm | 0.28KN | 0.35KN | 13.54KN | 15.57KN | 28.03KN | 55.42KN |
| Thamasett algorithm | 0.30KN | 0.37KN | 14.68KN | 16.88KN | 31.33KN | 63.01KN |

By comparing the calculated value with the measured value, the following deviation rules are found: the radial spinning force deviation is about 100%, the axial spinning force deviation is about 15%, and the tangential spinning force deviation is about 25%. Comparing the calculated value with the measured value for other metal materials, it is found that the deviation law is basically the same. Therefore, according to the above-mentioned deviation law, the parameters of the Thamasett algorithm are modified as follows:

The radial force on the spinning wheel is:

$$P_r = \frac{\Delta t \sigma_m \cdot \sqrt{R_y \cdot f \cdot \tan \alpha}}{\sqrt{2} \cdot 2.5\eta}$$

(1)

The axial force on the spinning wheel is:

$$P_z = \frac{\Delta t \sigma_m \cdot \sqrt{R_y \cdot f \cdot \tan \alpha}}{\eta}$$

(2)

The tangential force on the spinning wheel is:

$$P_t = \frac{5 \Delta t \sigma_m}{4\eta}$$

(3)

In the formula: $\Delta t$ is thinning amount; $\sigma_m$ is average deformation resistance of deformed material; $R_y$ is induced radius; $f$ is feed rate; $\alpha$ is installation angle of roller; $\eta$ is deformation efficiency.

In summary, this article compares and analyzes the actual spinning pressure measured by the spinning process experiment with the theoretical spinning pressure calculated by the Thamasett algorithm. The reason and law of the error in the theoretical value of the Thamasett algorithm are found, and the Thamasett algorithm is modified by using this law to make the calculation accuracy more accurate. Applying this algorithm to the establishment of a simulation model for powerful spinning of cylindrical parts will further improve the accuracy of the simulation model.

3. Establishment of Simulation model

In recent years, more and more simulation softwares have been applied to the simulation of metal plastic forming, such as ANSYS/DYNA, ABAQUS/Explicit, MSC.MARC, Deform3D, etc. They can be classified according to implicit algorithm and display algorithm. The implicit algorithms are: MSC.MARC, Deform3D, etc. Its advantage lies in high calculation accuracy, but it takes a long time and is difficult to converge. The display algorithms are: ANSYS/DYNA, ABAQUS/Explicit, etc. Its advantage lies in short time-consuming and easy convergence. Considering the industrial use of the model, and on the basis of meeting the accuracy, the simulation time-consuming is shortened as much as possible, so ANSYS/LS-DYNA is selected as the simulation platform to establish the simulation model.

3.1. Simulation Assumptions

In the process of strong spinning of cylindrical parts, while the blank rotates with the core membrane, it feeds under the action of the rotating wheel. During this process, the metal flows in three directions, namely radial, tangential and axial. The forming track of the rotating wheel on the surface of the
Blank is a spatial spiral. Because the strong spinning forming process of cylindrical parts is very complicated, in order to facilitate the processing of finite element simulation softwares, the following assumptions need to be made before modeling:

- Blanks are defined as elastoplastic materials.
- The core mold and the rotating wheel are defined as rigid bodies.
- Influencing factors such as temperature and inertia force are not considered in the simulation analysis.
- Simplify the construction of geometric models.
- All friction types in the forming process are defined as shear friction.

3.2. Geometric Model Construction

In order to reduce the calculation time of the simulation software, the entire spinning equipment needs to be simplified in the construction of the geometric model. Only the three main components, the blank, the rotating wheel and the core membrane are selected for modeling. First, the core membrane, rotating wheel, and blank are used to construct geometric models through CATIA software, and the constructed geometric models are saved in iges format and imported into Hypermesh software for pre-processing.

3.3. Mesh Division

The content of pre-processing includes mesh generation, material and performance setting, friction setting, contact and constraint setting.

The grid type selected in this paper is hexahedron, which has the advantage of preventing grid distortion on the basis of ensuring the accuracy of finite element analysis, thereby effectively reducing the calculation time.

After selecting the hexahedron as the unit type of meshing, the meshing of the blank, the core membrane and the rotating wheel is carried out. The shape of the blank and core membrane are regular, which is beneficial to the division of hexahedral units. Relatively speaking, due to the irregular shape of the rotating wheel, the mesh division is more complicated and fine. Meshing must satisfy that the contact between the discrete elements is continuous to ensure that nodal forces can be transferred between the elements. At the same time, it is necessary to ensure the accuracy and efficiency of simulation calculation. At the boundary of the rotating wheel, the grid division needs to be more refined to prevent grid distortion and ensure the smooth progress of simulation analysis.

3.4. Contact and Restraint

The element nodes are established at the center points of the core membrane, the blank and the wheel. Triangular mesh elements are used to connect the core membrane, the blank and the rotating wheel, and establish contact and constraints between the three to make it a whole. Subsequently, a torsion force is applied to the core membrane, while two rods are extended on the rotating wheel and two output points for outputting the spinning force are established.

After the above work is completed, the ANSYS / LS-DYNA solver is used to solve the strong spinning process of cylindrical parts.

4. Simulation experiment and result analysis

Through ANSYS / LS-DYNA simulation software, the forming quality results of two spinning schemes are obtained. The same parameters were used for spinning experiments. The experimental scheme is shown in Table 2. The forming quality is analyzed as shown in Table 3.

| Scheme  | Spindle speed | Feedrate | Thinning rate |
|---------|---------------|----------|---------------|
| Scheme 1 | 100rpm        | 100mm/min| 20%           |
| Scheme 2 | 150rpm        | 100mm/min| 20%           |
Table 3. Simulation results and analysis of forming quality

| Scheme   | Simulation results                                                                 | Process test results | Forming quality analysis                                                                 |
|----------|------------------------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------------------|
| Scheme 1 | ![Simulation result](image1.png) Grid distortion occurs.                             | ![Process test result](image2.png) | Grid distortion occurs.                                                                    |
| Scheme 2 | ![Simulation result](image3.png) The film condition and the surface forming quality are good. | ![Process test result](image4.png) | The film condition and the surface forming quality are good.                               |

5. Conclusion
The simulation results of the three schemes are basically consistent with the spinning results of the spinning process experiment, which verifies the accuracy of the model. The simulation model will provide the basis for the setting of process parameters, so that the setting of spinning scheme no longer depends on the experience of scientific researchers. And at the same time, the spinning experiment to determine the process parameters is avoided. The experimental time and cost are saved. The breakthrough of this technology provides a strong support for the further development of spinning technology.

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