Numerical simulation analysis of die ring spinning process

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Abstract. Aiming at the technical challenge of spinning forming used for ultra long tubular parts, a new spinning technology based on floating die and synchronous rotation of both ends of the spinning blank was put forward. That is die ring spinning, which is divided into die ring forward spinning and die ring backward spinning. The die ring spinning utilizes to improve the stress condition of deformed metal parts and enhances the fluidity of crystal phase structure along the slip surface. It can not only eliminate the phenomenon of material bulging before spinning wheels, but also improve the straightness and reduce the ellipticity of pipes at the same time.

1. Introduction
Ultra long tubular parts are often used as key structural compositions in the fields of aerospace, ship and energy [1-4]. The length of such parts usually exceeds 6 meters, which poses a huge challenge for manufacturing process. After theoretical research and practical operation, die ring spinning was put forward. Based on the finite element theory, this paper respectively established the finite element analysis model of the die ring forward spinning and die ring backward spinning of cylindrical parts. Then, we aimed at solving the problem of load and constraint in the process of model establishment to approach the actual working conditions as much as possible. Credible analysis results were finally obtained to reflect the real deformation law under different spinning conditions. For comparison, non-die ring spinning was also simulated, which was selected to reveal the differences in forming process.

2. Finite element numerical simulation of spinning process

2.1. The establishment of geometric model
In this paper, the Pro/E software was used to establish the three-dimensional model of the actual production. Then the model was imported into the analysis software. Four types of spinning processes were modelled as shown in Figure 1: die ring forward spinning, die ring backward spinning, non-die ring forward spinning, and non-die ring backward spinning.
2.2. **Gridding**

In this paper, hexahedral elements were used for mesh generation. The radial and axial lengths of hexagons needed to be specified for automatic mesh generation. Then, the two-dimensional mesh was divided on the axial section of the pipe. For the tube, the Ringmesh division module was adopted to set the lengths of axial and radial units. A rotation axis is specified, around which the divided two-dimensional mesh rotated to divide the whole tube. The infinite interpolation algorithm was used to generate the mesh automatically with 26843 nodes and 23980 cells in total.

2.3. **Establishment of material model**

The material used in the simulation is 304 stainless steel. The material model is included in the material database of the selected finite element simulation software. Since the spinning process was conducted at room temperature, the thermodynamic properties of the material were not considered. The mechanical property parameters of the simulated material are listed in Table 1.

### Table 1. Mechanical properties of 304 stainless steel

| Modulus of elasticity / GPA | Poisson's ratio | Yield strength / MPa | Tensile strength / MPa | Hardening index |
|----------------------------|----------------|-----------------------|------------------------|----------------|
| 193                        | 0.28           | 205                   | 520                    | 0.193          |

3. **Finite element simulation results**

3.1. **Influence of die ring on stress and strain**

The simulation results are shown in Figure 2. Compared with the non-die ring backward spinning, in the process of die ring backward spinning, the role of applying die ring is to change the stress-strain state of the pipe in the deformation, especially to increase the axial stress and improve the fluidity of metal.

Compared with the equivalent stress-strain distribution of the die ring forward spinning and die ring backward spinning, the area and the value of the maximum equivalent stress in the die ring backward
spun tube are greater than those in the die ring forward spun tube. However, the maximum equivalent strain of die ring backward spinning is smaller.

3.2. Influence of thinning rate on forming process

3.2.1. Effect of thinning rate on material flow. According to the simulation, when the thinning rate is 10%, the flow velocity of the material decreases gradually from the outside to the inside in the radial direction, and the tangential flow is obvious in the contact area between the wheel and the blank. When the thinning rate increases to 50%, the flow instability occurs, which makes the forming difficult to continue, as shown in Figure 3.

3.2.2. Effect of thinning rate on uplift. The axial sections of the tube in the stable stage of the four simulated pinning process were selected to measure the height of the uplift and the change of the wall thickness before and after the spinning.

The calculation (see Figure 4) shows that when the thinning rate is small, the material has no obvious uplift. With the thinning rate increasing, the height of uplift increases continuously; on the contrary, it decreases after an axial tension produced by die ring is applied on the tube. Comparatively, the die ring forward spinning presents a smaller uplift.

3.2.3. The influence of thinning rate on diameter expansion. When the thinning rate is small, the tangential flow is obvious, and the total tangential elongation deformation is larger than the tangential shrinkage deformation, resulting in the workpiece expanding. The application of die ring makes the material flow more easily along the axial direction, and the tangential flow is relatively reduced. When the elongation deformation is less than the shrinkage deformation, the gap between the workpiece and the model decreases, which is conducive to improving the dimensional accuracy of the final product.
3.3. Influence of feed rate on forming process
According to the simulation, it is found that the uplift is generally smaller in the case of die ring than in the case of non die ring, and the uplift is particularly obvious in the die ring forward spinning. A small feed rate not only reduces the production efficiency, but also causes instability and uplift, as shown in Figure 5. So it is appropriate to set the feed rate at about 1 mm/r.

3.4. Influence of stagger distance on forming process
The actual thinning rates of non-stagger spinning with the radial reduction of 1 mm and the stagger spinning with the radial reduction of 0.5 mm, 0.3 mm and 0.2 mm distributed to the three spinning wheels are shown in Table 2. It can be seen that the thinning rate of stagger spinning is 26.75%, higher than that of non-stagger spinning.

| Radial reduction of non offset spinning wheel (mm) | Actual thinning rate (%) |
|-----------------------------------------------|--------------------------|
| non-stagger spinning                          | 21.12                    |
| stagger spinning                              | 26.77                    |
3.4.1. **Influence of axial stagger on forming process.** Through the analysis of the component forces of the spinning wheels under different axial staggers, it can be found that there is an optimal value of the axial stagger, which makes the forces on all directions of the spinning wheels more balanced.

3.4.2. **Influence of radial stagger on forming process.** The relative balance of the force on each spinning wheel is the necessary condition to ensure the spinning stability. The reduction distribution of each spinning wheel is measured whether it is reasonable by the mean square error of the radial forces on each spinning wheel. Table 3 shows the influence of the reduction distribution ($\Delta t_1, \Delta t_2, \Delta t_3$) of each spinning wheel on the radial force of the spinning wheel when the reduction rate is 30%. It can be seen from the table that the mean square error of the radial force on each spinning wheel is the smallest when $\Delta t_1 > \Delta t_2 > \Delta t_3$.

| Reduction of each wheel (mm) | Radial force of spinning wheel (KN) | Mean square deviation |
|-----------------------------|------------------------------------|---------------------|
| An example                  | $\Delta t_1$ $\Delta t_2$ $\Delta t_3$ | wheel1 wheel2 wheel3 |
| 1                           | 0.8 0.6 0.4                         | 6.02 5.88 5.75      |
| 2                           | 0.8 0.5 0.5                         | 6.57 6.34 6.29      |
| 3                           | 0.6 0.6 0.6                         | 6.82 6.63 6.27      |

4. **Conclusion**

The die ring spinning can provide an axial tension to one end of the workpiece during the spinning process, significantly improving the flow state and uplift of the deformed material. It can also eliminate the diameter expansion and improve the straightness of the pipe. Therefore, the die ring spinning process is preferred.

With the exception of axial tension, the influences of other process parameters on material uplift and diameter expansion is basically the same. However, in case of axial tension, the material uplift and diameter expansion is significantly reduced. Based on the research results, it can be concluded that the thinning rate is about 30%, the feed rate is about 1 mm/r, the transverse stagger is about 3 mm, and the longitudinal stagger is distributed according to $\Delta t_1 > \Delta t_2 > \Delta t_3$.

**References**

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