Research on Deformation Mechanism in Draw Spinning of LED Radiator Parts Based on SIMUFAC Simulation

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Abstract. With the rapid development of spinning technology, the spinning forming of LED radiator parts has important significance for the development of parts manufacturing technology. This paper is based on the characteristic analysis of deformation zone and the mathematical analysis of stress field in LED radiator parts forming, with the principal stress method in the theory of metal plastic forming and consider the influence of material thickness change and work hardening to establish mathematical model of stress field and calculation formula of spinning force, and use SIMUFAC simulation and MATLAB calculation to further analysis.

Introduction

The instability of the spinning are closely related to the required spinning force and stress-strain state during forming. The spinning force is the most important parameter of the design mechanism, and the scientific basis of preparation and design process equipment [1]. Hayama and Murota [2] assumed the spinning is axisymmetric deformation for the general spinning and put forward the mechanical model, and the calculation formula of spinning component is obtained from the stress distribution calculation. Chen [3] proposed the formulas for calculating the component of the shear spinning in the theoretical model of bending and shear deformation, with the roller fillet, slab thickness, the feed speed and the spindle speed. In order to no longer rely on the experience and repeated experiments in process control and mold design, and shorten the production cycle and costs, this paper provides scientific theoretical guidance for the control of the production process with the theoretical analysis and simulation of the spinning deformation mechanism.

The Mechanism Analysis for LED Radiator Parts

The Stress and Strain Analysis

LED radiator parts spinning as shown in Fig. 1(1. Spinning roller; 2. Slab; 3. Tailstock; 4. Mandrel), the slab is accumulated into a whole by continuous local plastic deformation that occurs only in the contact area between the roller and the slab, and the deformation has a continuous and rapid change [4]. According to the stress and strain state, deformation is divided into four parts: dead zone A, deformed zone B, deformation zone C and undeformed zone D, as shown in Fig. 2. And and \( \sigma_r \) and \( \varepsilon_r \) are stress and strain of thickness direction, respectively; \( \sigma_t \) and \( \varepsilon_t \) are radial stress and strain of slab extension direction, respectively. \( \sigma_\phi \) and \( \varepsilon_\phi \) are circumferential tangential stress and strain, respectively.

The dead zone A is not deformed, which holds the fixed area for the mandrel and the tailstock, and is affected by thickness compressive stress \( \sigma_t \), radial tensile stress \( \sigma_r \), and circumferential tangential tensile stress \( \sigma_\phi \). The deformed zone B is affected by the tensile action of the deformation zone C and the radial tensile stress \( \sigma_r \), and in zone B the fillet zone E is affected by radial and tangential tensile stresses \( \sigma_r \), \( \sigma_\phi \) and the thickness compressive stress \( \sigma_t \) by slab bending, it tends to thin for the thickness. In the deformation zone (contact area) C the slab contact with the fillet of the roller, the slab paste mandrel and bending deformation is produced under the roller feed force, the stress and strain are similar and mainly bear the radial tensile stress \( \sigma_r \) and circumferential tangential compressive stress \( \sigma_\phi \), meanwhile due to the roller pressure and bending, it have
compressive stress $\sigma_t$ in the slab thickness direction. The undeformed zone D in front of the roller and the slab has no plastic deformation, only the rigid body movement.

**The Establishment of Mathematical Model in Stress Field**

The spinning deformation of thickness direction is very small than radial and tangential, so the slab forming can be a plane strain problem, and according to references [5], the hypothesis can be got. It can be considered that the contact force of the plastic deformation is the spinning force. The spinning of the LED radiator parts are shown in Fig. 3(a) in the Cartesian coordinate system. In the deformation zone below the roller to take an element, which is divided by two radial planes intersecting the Z-axis and two planes parallel to the R-axis and perpendicular to the Z-axis [6]. The detailed stress relationship is shown in Fig. 3(b), the N is the average unit pressure acting on the normal plane of the element and the $S_1$ is the ADFE area of the element top area, the $S_2$ is the side area DCGF, the $S_3$ is the neutral surface area, and the $\mu$ is the friction coefficient between the roller and the slab, the $\mu_0$ between the mandrel and the slab. According to the principle of static equilibrium, the radial and normal equilibrium equations of the element can be obtained.

\[ \sigma S_1 + d(\sigma S_1) - \mu NS_3 + \mu_0 NS_3 - \sigma r S_1 + 2\sigma_\phi S_2 \sin(\theta/2) = 0 \]  
\[ N S_3 - 2\sigma_\phi S_2 \sin(\psi/2) = 0 \]  

Slightly high-order trace, $\sin(\theta/2) = \theta/2$ and $\sin(\psi/2) = \psi/2$, from the geometric relationship in Fig. 3(b), $Rd\gamma = Rd\theta / \sin\alpha = Rd\psi / \cos\alpha$, $S_1 = tRd\gamma$, $S_2 = tR / \sin\alpha$, $S_3 = Rd\gamma R / \sin\alpha$.

In the previous analysis, in the deformation zone the radial stress $\sigma_r$ is tensile stress and the circumferential tangential stress $\sigma_\phi$ is compressive stress, so the order of the principal stress in the deformation zone is $\sigma_\phi < \sigma_r$, according to the modified Tresca yield criterion $\sigma_r - \sigma_\phi = \beta \sigma_s$, the $\beta$ is the main stress influence coefficient of the material, the $\sigma_s$ is the material yield stress [5]. According to the static equilibrium equation and plastic material yield conditions, it is obtained.

\[ d\sigma_r / dR + [2 - (\mu - \mu_0) \cot\alpha] \sigma_r / R = [1 - (\mu - \mu_0) \cot\alpha] \beta \sigma_s / R \]  

To solve this first order ordinary differential equation, to $A = (\mu - \mu_0) \cot\alpha - 2$, and using the Taylor’s formula to ignore the high-order trace.

\[ \sigma_r = C[1 + A(R_0 - 1)] + (A + 1) \beta \sigma_s / A \]  

Taking into account the end of the spinning where the $R_0$ of radius, the radial stress $\sigma_r = 0$, the boundary condition $\sigma_r |_{R=R_0} = 0$ is brought into the formula, get the $C = -(A + 1) \beta \sigma_s / A[1 + A(R_0 - 1)]$, So the $\sigma_r$ and $\sigma_\phi$ are obtained.

\[ \sigma_r = (A + 1) \beta \sigma_s / A - [1 + A(R - 1)][(A + 1) \beta \sigma_s / A[1 + A(R_0 - 1)] \]  
\[ \sigma_\phi = \beta \sigma_s / A - [1 + A(R - 1)][(A + 1) \beta \sigma_s / A[1 + A(R_0 - 1)] \]
The Effect of Material Hardening, Additional Bending Effect and Slab Thickness

The foregoing derivation is based on the yield criterion of the isotropic ideal plastic material, the \( \sigma_s \) is a constant and does not take into account the hardening of metal cold forming, the cold working of the material under the absence of the recovery and recrystallization temperatures is accompanied by a different hardening, for the isotropic ideal plastic material the yield criterion \( f(\sigma_{ij})=Y \), for the hardened material \( Y \) has different ways to express, and the stress-strain curve can be described by the tensile test. It can be used according to the reference [5] approximation curve formula of the material stress-strain for practical application requirements.

In the deformation zone the relative movement between the roller and the slab is the helical feed process, in the radial direction it will bend which is generated by the additional axial direction stress \( \Delta \sigma_r \) as shown in Fig. 4 (a), and the bending and reverse bending around the R-axis is generated by the additional tangential stress \( \Delta \sigma_\phi \) in the R-Z plane, as shown in Fig. 4(b). According to reference [5] the \( \Delta \sigma=(tY)/(4R) \) is the additional stress from the bending, so the axial direction additional stress \( \Delta \sigma_r=(tY)/(4Rr) \), where the \( R_r \) is the radius of curvature of the bending portion which is generated in the radial direction about the rotation axis perpendicular to the Z-axis, the \( r_\rho \) is the fillet radius of roller, the Circumferential tangential additional stress \( \Delta \sigma_\phi=(tY)/(4R_\rho) \), where the \( R_\rho \) is the radius of the roller.

In fact, the thickness is changing in single pass draw spinning, according to the fact that Szildez [7] had studied the thickness change in the necking process, and combined with the actual situation of spinning, it is assumed that the thickness is linearly related to the radius, introduce thickness influence coefficient \( k=0.5[1+(R/R_0)^{1/2}] \) to approximate consider the effect of thickness variation.

The normalized pressure \( N \) is calculated from the normal equilibrium equation and taking into account the effect of the work hardening, the bending and the change of the thickness.

\[
N=Yt\cos \alpha [1+(R/R_0)^{1/2}] \frac{\beta}{A} \frac{1}{A+1} \left[ 1+A(R-1) \right] + \frac{t}{4r_\rho} + \frac{t}{2R_\rho} \right] / 2R
\]

The Establishment of Mathematical Model of Spinning Force

In the practical application, there is a great significance of the spinning component, which the radial component \( F_r \) of perpendicular to rotation axis of workpiece, the axial component \( F_Z \) of parallel to rotation axis of mandrel, and the circumferential component \( F_\phi \) of tangent to circumferential of
workpiece. The positional relationship between the instantaneous component $F_r$, $F_t$, and $F_\phi$ and the spinning components $F_R$, $F_Z$ and $F_\Phi$ is shown in Fig. 5. And they can be obtained by the contact area of the spinning roller in main directions [8,9], many scholars have long been given in the reference of similar deformation contact area, so the contact area $A_z A_\phi A_r$ in three direction between the slab and roller in the rectangular coordinate system [10,11].

The formula of spinning component:

$$F_r = K N A_z / \cos \alpha$$
$$F_t = K N A_r / \cos \alpha$$
$$F_\phi = K N A_\phi$$

$$F_R = F_t \cos \alpha + F_r \sin \alpha$$
$$F_Z = F_t \sin \alpha - F_r \cos \alpha$$
$$F_\Phi = F_\phi$$

$$F = (F_R^2 + F_Z^2 + F_\Phi^2)^{1/2}$$

Where $K$ is the comprehensive compensation factor that takes into account the effects of errors and forming quality problems and this article takes 3.2.

The Simulation Analysis of the Draw Spinning

The Spinning Simulation Parameters Setting for the LED Radiator Parts

This material is A6061 round slab of 2mm thickness and the radius is 66mm. The main stress coefficient $\beta$ of the material is 1.155. The plastic stress-strain constitutive model (Table 1 for the main mechanical parameters) is as follows $Y = 205 e^{0.122}$, where the $\varepsilon$ is the real strain, $\varepsilon = \ln(1 + R/R_0)$.

According to the actual size of mold and slab in the 3-D software Solidworks to establish a geometric model, and assemble it as an entity by the processing position parameters, and convert to STL format into the Simufact software. Setting the spinning temperature to 20°C, and the friction type is the combination of coulomb friction and shear friction, and $\mu = 0.08$, $\mu_0 = 0.10$, and the rotational speed of mandrel $n$ is 700r/min, the installation angle $B$ is 10°, $R_\rho = 62.5mm$, $r_\rho = 18mm$, $f = 1.2mm/r$.

Table 1. Mechanical properties of 6061 aluminum.

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<td>68647</td>
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<td>51.59</td>
<td>146.12</td>
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The Simulation Analysis of Spinning Force

The relationship between the spinning component and the time can be obtained by the simulation results, as shown in Fig. 6. According to the shape of the part, the component curve can be divided into two stages, the fillet stage, and the curved generatrix stage, in order to convenient analysis, there is the transition stage between the end of the fillet and the beginning of the curved generatrix.

For the fillet stage the roller suddenly enters the load state, because of the impact of the contact between the roller and the slab, the axial component curve has a large fluctuations in the initial stage. There is a intersection between the axial and the radial component, before the intersection, the radial component is greater than the axial, the deformation is mainly caused by rolling deformation, and after the intersection, the deformation is mainly based on drawing.

![Figure 6. The spinning component of simulation.](image)

![Figure 7. The comparison of spinning component.](image)
In the transition stage, the radial component curve shows a local peak and then decreases, this phenomenon shows that the slab deformation requires a larger radial component, meanwhile it will be like ordinary punching deep to form a dangerous section, when the deformation resistance of the material to withstand more than a certain limit, the dangerous section produce significant necking, and result in unloading effect, then the deformation force shows a downward trend. In the process of declining deformation force, the axial component also decreases, when it drops to a certain extent, the necking will stop, while components will rise again.

In the curved generatrix stage, the radial and the axial component have a steady upward trend and reach the local extremum maximum, and then they curves are down, at this point the spinning near the end, the roller does not leave the workpiece, the material constraint is reducing in front of the deformation zone, the spinning force weakened, it is also the reason for the fracture of the workpiece. In this stage, the spinning component suddenly fluctuates during steady growth in the oval circle, it shows that the deformation is not stable, which is related to wrinkle during forming.

**Contrastive Analysis between the Simulation Results and the Calculation Results**

The previous calculation of the spinning component model uses MATLAB with the same parameters of simulation, and both the simulation data and the calculated data are smooth, as shown in Fig. 7, the Fz in the fillet and curved transition stage is better, The Fr is better in the curved generatrix stage. In the fillet stage, due to the large change in the cone angle α, the deformation of the slab is more complicated, which leads to the difference between the simulated data and the calculated data. In the final stage of spinning, because the numerical calculation neglects that the effect of the reduction of deformation material in front of roller on spinning component, the calculated data is finally seen on the graph which is the curve that the force is still rising, the corresponding part of the simulation curve of the component has gradually decreased, remove the part of the calculated and simulation data consistent trend. There is an error between the simulated and the calculated data of the spinning component during the spinning, as the spinning component prediction model that can be used for the prediction of the component change trend, and it can be used to predict the radial and axial component for the curved generatrix stage, and the axial component for the fillet and transition stage, and the maximum of the radial component, so this model has a certain engineering application value.

**Conclusion**

In this paper, based on the analysis of the spinning stress field, the forming is divided into four parts, and approximated as a plane strain problem, then the stress field mathematical model and spinning force calculation model considering the effect of additional bending and hardening are established by using the principal stress method, and contrast analysis simulation and calculation results of spinning component, the fillet stage has a complex change, the simulation and calculation curves have similar trends in the curved generatrix and the transition stage. The calculation formula predicts that the spinning component has a high application value. Through the analysis of the parts of the spinning force simulation curve, the deformation is mainly caused by rolling deformation in initial forming, when the radial curve intersects the axial curve the deformation is mainly based on drawing. Necking phenomenon in spinning occurs to produce dangerous section in the transition stage. At the commencing and terminating of the spinning a sudden change about the roller load and a decrease about material constraint in front of the roller cause a large fluctuation in the spinning component curve that directly reflects the change of forming and indicates the unstable forming of wrinkle and fracture. By analyzing the influencing factors of forming, the spinning is adjusted and compensated at the beginning and end to solve such problems in the slab spinning.
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References


