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Trimming line development method of auto panel part with undercutting flange

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ABSTRACT

In most of auto-panel manufacturing, trimming is generally performed before flanging. Therefore, the acquisition of the optimal trimming line is one of the keys to obtain an accurate shape of a product. It is not easy to obtain a reasonable trimming line for auto panel part with undercutting flange. Analytical models can only deal with some simple stretch and shrink flanging parts. Section-based method unfolds flange along part outer boundary by defining many section planes. This method may produce inaccurate results for large deformation regions. The incremental simulation based method can generate more accurate trimming line by iterative strategy. However, it is still not widely accepted in the auto-industry since limitation of time and lack of information in the initial die design stage. In this study, a novel fast method to find feasible trimming line is proposed. One-step inverse finite element method (FEM) is used to analyze the flanging process because the strain paths are simple in flanging. The most difficult task of one-step inverse FEM is the generation of initial guess mesh. Robust generation method of initial guess mesh is presented specially to handle the undercutting flange regions. The new geometry method develops the final 3D part mesh with undercutting flange in triangle mesh parameterization way onto the drawing tool surface. The 3D mesh smoothing method with sliding constraint surface technique is utilized to smooth mesh distortion or overstretching after development. Finally, the 3D trimming line is extracted from the outer boundary after one-step inverse FEM simulation. The present trimming line calculation method is successfully applied to the complex industrial applications such as decklid and front fender. This method shows many benefits since trimming line can be obtained in the early die design stage.

1. Introduction

Flanging is a very important sheet metal forming process for welding and assembly. The most of the sheet metal components are necessarily flanged after stamping process. For most of auto panel parts, it is flanging process after deep drawing and the drawing part will be trimmed along trimming line before flanging process. The prediction of the blank shape is one important factor that significantly influences the flanging formability and the forming precision. Therefore, to find the optimal trimming line is essential in obtaining precise product shape after flanging. During last several decades, many researchers have tried to make robust development technique from final product shape.

Wang and Wang analyzed two mathematical models of stretch and shrink flanging operations, respectively [1,2]. Asnafi studied vertical stretch and shrink flanging experimentally and theoretically [3]. Based on Wang's models, Hu et al. proposed two modification analytical models for stretch and shrink flanging [4]. Li developed an analytical model for analysis of stretch flanging of V-shaped sheet metal [5]. However, these analytical models can only get the accurate trim-line profile for simply stretch and shrink flanging operations.

Most of auto panel designers usually use section-based tool of CAD software to design trimming line. In this method, designer generates tool profile and product profile by defining same section plane. Then, product profile is unfolded on the tool profile automatically by CAD tool and the length of production profile is fixed. The end point of unfolded product profile is defined as a trimming line point for this section. In order to get smooth trimming line, this process has to be repeated several hundred times along the product outer boundary. This method usually can obtain good result for the bending dominated part. However this method shows large deviation from real application for part with considerable deformation since it cannot consider section deformation.

In addition, some researchers have utilized incremental simulation code to get the optimal trimming line by several iterative steps [6,7]. This simulation-based method can generate more precise result than the previous one since it can consider contact history

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and deformation mechanism. However, due to lack of tool information, it is difficult to use this method in the early die design stage and it also needs a lot of time to simulate the flanging process.

The one-step inverse FEM based on total plastic theory has high simulation speed because there is only two degrees-of-freedom of each node. The most difficult task using one-step inverse FEM to calculate 3D trimming line is the generation of initial guess mesh, especially the undercutting flange. Many researchers have studied several methods of the initial solution for the one-step inverse FEM. In the early studies, the one-step inverse FEM is mainly used to find initial flat blank [8]. The classic geometric mapping methods are only based on geometric consideration, and could not manage complex industrial products [9]. The energy mapping algorithm with reverse deformation could get the good initial solution for the complicated deep drawing model with quasi-vertical walls [10]. Kim and Huh used the one-step inverse FEM to find the 3D intermediate configuration on arbitrary shaped surface [11]. Chung used a new development method to develop the 3D undercutting part in propagational way from final mesh onto the drawing tool surface [12]. But this method needs to remedy mesh distortion many times by the energy minimization technique during development process. Bao used a similar way as Chung to get the initial guess mesh and the mesh smoothing is needed to be improved [13].

In this article, the one-step inverse FEM is used to obtain the trimming line. Desired final product shape is considered as the final configuration of one-step inverse FEM. The initial curved blank on the drawing tool surface is calculated by the one-step inverse FEM. In order to deal with the undercutting flange regions, the robust generation method of initial guess mesh based on the triangle mesh parameterization way is presented to unfold the final product with undercutting flange onto the drawing tool surface. The mesh distortion and overstretching after development is smoothed by the 3D mesh smoothing method with sliding constraint surface technique. Trimming line is directly extracted from the outline of initial curved blank. The developed trimming lines are compared with that from the experimental results for decklid and front fender products.

2. Description of one-step inverse FEM

The kinematic description of the one-step inverse FEM as that of Guo et al. [8] is used in this paper. Two main assumptions are adopted as follows: one is the proportional loading assumption which avoids the incremental integration of plasticity (deformation theory of plasticity); and the second assumption allows using simplified pressure friction forces instead of the contact conditions between tools and formed sheets. These assumptions lead to a total or direct method independent of the deformation history, so the one-step inverse FEM is very fast and does not need much memory space (only two degrees of freedom per node).

In the one-step inverse FEM for trimming line, only two configurations are considered: the initial curved blank and the final 3D workpiece as shown in Fig. 1. The total strain is calculated in one step by directly comparing the initial curved blank and the final 3D workpiece. Using the Kirchhoff assumption, the initial and final position vectors of a material point q can be expressed:

$$\begin{cases} \boldsymbol{x}_q^0 = \boldsymbol{x}_p - \boldsymbol{u}_p + z^0 \boldsymbol{n}^0 \\ \boldsymbol{x}_q = \boldsymbol{x}_p + z\boldsymbol{n} \end{cases} \quad (1)$$

where $\boldsymbol{u}_p$ is the displacement of the point p on the mid-surface of the sheet, $\boldsymbol{n}^0$ and $\boldsymbol{n}$ are the normals of the mid-surface at p^0 and p. The deformation gradient tensor $\mathbf{F}^{-1}$ can be calculated using Eq. (1), and then the left Cauchy Green deformation tensor $\mathbf{B}^{-1} = \mathbf{F}^{-T}\mathbf{F}^{-1}$.

The eigenvalue calculation of $\mathbf{B}^{-1}$ gives two principal plane stretches λ_1, λ_2 and their direction transformation matrix $[M]$.

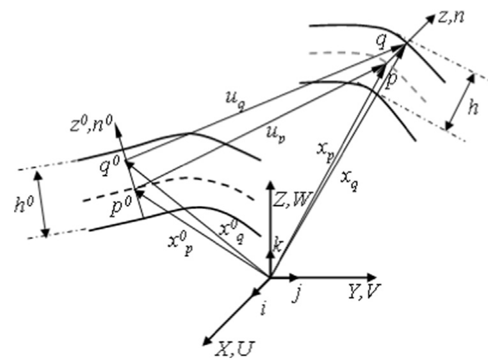

Fig. 1. Kinematics of one-step inverse FEM.

Then the thickness stretch λ_3 is calculated by the incompressibility assumption. Finally, the logarithmic strains are obtained by $[\varepsilon] = [M][\ln\lambda][M]^T$.

Neglecting the transverse shear effects of the thin sheet, the element internal force vector in the global coordinates is obtained:

$$\{F_{\text{int}}^e\} = [T]^T \int_{V^e} \left([B_m]^T + z[B_b]^T\right)\{\sigma\} dz dA \quad (2)$$

where $[B_m]$ is membrane matrix and $[B_b]$ is bending matrix. These resultant forces can be obtained by numerical integration through the thickness at the element central using five or seven Gauss integration points.

In the one-step inverse FEM, the elastic-plastic deformation is assumed to be independent on the loading path and a total constitutive law is obtained,

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{bmatrix} = \frac{2\overline{\sigma}(2+\overline{r})}{3\overline{\varepsilon}(1+2\overline{r})} \begin{bmatrix} 1+\overline{r} & \overline{r} & 0 \\ \overline{r} & 1+\overline{r} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{bmatrix} \quad (3)$$

In the one-step inverse FEM, the tool actions are simply represented by some external forces at the final configuration neglecting continuous contact treatment since it does not consider the loading history. The blank holder's action is replaced by an equivalent load vector due to the friction. The punch and die actions are replaced by a normal pressure force and a tangential friction force. The consideration of the tool actions will give the external force vector, leading to the following non-linear equilibrium system and the Newton–Raphson method is employed to solve the non-linear equations.

$$\{R(U,V)\} = \sum_e (\{F_{ext}^e\} - \{F_{\text{int}}^e\}) = 0 \quad (4)$$

3. Initial guess mesh generation

Initial solution is an essential issue to ensure the success of the non-linear resolution in the implicit static one-step inverse FEM. The Newton–Raphson method expressed by Eq. (4) is highly sensitive to the initial solution. So the initial guess mesh generation as the initial solution is an important task to speed up and guarantee the convergence of Newton–Raphson iteration. As mentioned before, Tang [10] suggested an energy mapping algorithm with reverse deformation to get the initial guess mesh for the 3D complicated work piece. But it can only develop the quasi-vertical walls and cannot unfold the undercutting flanges. Chung and Bao [12,13] develop the undercutting flanges by geometrical unfold method layer by layer. However it needs to smooth the mesh after each step and leads to low efficiency for the complicated undercutting flanges.