Heuristic Optimization for Skid Lines in Automobile Covering Parts

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ABSTRACT

The skid line on the automobile covering parts is a critical problem in sheet metal forming, which will impact significantly the appearance of automobile products. A heuristic optimization method is presented to control the affected region of skids lines incorporating finite element analysis. In this method, the simulation analysis and optimization are repeated by adjusting drawbead restraining forces and the affected region of skids lines decreases until skids lines are restricted to the local features that cause skid lines. Finally, a typical automobile covering part is employed to verify the effectiveness of the proposed method and the results show a favorable effectiveness and practicability in drawbead optimization concerning skids lines.

INTRODUCTION

A skid line is defined as a visually observable surface distortion band on automobile covering parts. Skid lines are very common defects and may occur when material follows over the feature line radii on the stamping tools. Skid lines affect seriously the appearance of automobile covering parts, which will lead to dramatic reduction in the competitiveness of automobile products [1].

For gaining better control of skid lines, some researchers have concentrated on the studies of formation mechanism and influence factors of skid lines [2-4]. Besides, some commercial CAE software, such as AutoForm and FASTAMP, provide the functionality of prediction of skid lines. However, the adjustment of process parameters for skid lines still needs to be performed manually, which not only depends dramatically on engineers’ experience but also leads to low efficiency. To avoid the disadvantages of the trial and error process, finite element analysis (FEA) combined with optimization methods are often used to perform the adjustment of process parameters [5-7]. However, few of them have taken skid lines into account.

Heuristic optimization algorithms are the techniques that construct the optimization criteria based on intuitive experience to obtain approximate optimal
solution in the limited condition of resources and time [8]. The major merits of heuristic optimization algorithms are the good accessibility and low computational complexity, which are applicable to deal with large and complex models. Sheet metal forming process is such a highly nonlinear complex problem. Azaouzi et al. [9] combine a heuristic optimization algorithm with inverse approach to optimize the blank shape of high precision thin metallic parts obtained by a particular stamping process. The result shows the high efficiency and accuracy of their algorithm. However, the effect of skid lines is neglected in the algorithm.

In this paper, a heuristic optimization method for controlling the harmful effect of skid lines is presented combined with FEA. FEA is first used to simulate the stamping process and trace the motion trajectory of skid lines. Then, the proposed heuristic optimization algorithm attempts to release the effect of skid lines in the next simulation by adjusting the drawbead restraining forces. The optimization process is repeated until the effect of skid lines is restricted to the feature line radii that cause skid lines.

**TRACE OF SKID LINE**

In this paper, the previously developed trace method of skid lines is adopted [3]. As shown in Figure 1, the initial contact line (marked as 0) between the tool and material is first obtained and is tracked until the stamped process is finished. The final contact line (marked as 1) is then obtained at the die closing point with area coordinate method. Hence, the affected region of the skid line is identified between the initial and final contact lines. In general, the affected region can’t exceed the scope of the feature line radius.

![Figure 1. Skid line: (a) the initial contact line marked as 0, (b) the final contact line marked as 1.](image-url)
The trace of contact line in the stamping process is based on the local fixed point assumption, which is that the relative location of a material point in a finite element is constant with respect to the vertices of the finite element. As shown in Figure 2, \( P \) is a material point and the local area coordinates of \( P \) in the triangular element is invariable in the stamping process. The area coordinates are calculated by:

\[ L_i = \frac{A_i}{A}, i = 1,2,3, \]  

where \( L_i \) is the \( i \)-th coordinate component, \( A_i \) is the corresponding area and \( A \) is the total area of the triangular element. At the initial contact moment, the local area coordinates of contact material points are calculated by Eq. 1. The global coordinates of final material points are calculated by:

\[ \varphi' = \sum_{i=1}^{3} L_i \varphi_i', \varphi = x, y, z \]  

where \((x', y', z')\) are the coordinates of final material points and \((x_i', y_i', z_i')\) are the final coordinates of the vertex \( P_i \).

![Figure 2. Calculation of local area coordinates in the triangular element.](image)

**HEURISTIC OPTIMIZATION ALGORITHM**

In this paper, a heuristic optimization method is developed to release the harmful effect of skid lines on the surface quality of automobile covering parts. As shown in Figure 3, the heuristic optimization process is mainly divided into two steps: (1) invoke FEA code to simulate the stamping process and then calculate the motion trajectory of skid lines, (2) update the layout of drawbeads based on the skid information in Step1. These two steps are repeated until the skid lines are restricted to the area of feature line radii.
Design Variables

The equivalent drawbead is a drawbead line that possesses different restraining forces and is applied in FEA. In the proposed algorithm, a long equivalent drawbead is divided into the short drawbead segments (generally thousands of segments), the restraining forces of which can be freely adjusted based on the forming quality. Therefore, the restraining force of each drawbead segment can be determined as design variables:

$$\boldsymbol{\mu} = \{\mu_1, \cdots, \mu_j \cdots, \mu_r\},$$  \hspace{1cm} (3)

where $\mu_j$ is the restraining force of the $j$-th drawbead segment and $r$ is the number of drawbead segments.

Heuristic optimization strategy

In Step 2 of the algorithm, the evaluation for drawbeads concerning skid lines is first performed and the evaluation of $j$-th drawbead segment is expressed as:

$$\gamma_j = \sum_{i=1}^{n} s_i l_ip_i,$$  \hspace{1cm} (4)

where $n$ is the number of skid segment, $s_i$ is the skidding distance of $i$-th skid segment, $l_i$ is the length of $i$-th skid segment and $p_i$ is the position factor of $i$-th skid segment. Obviously, the effect of drawbeads on skid lines is influenced by angle and distance, i.e.:

$$p_i = \cos \theta_i \cdot \frac{d_i}{d_0}.$$  \hspace{1cm} (5)
As shown in Figure 4, $\theta_i$ is the included angle between the normal direction $N$ of $i$-th skid segment and the direction $M$ determined by the drawbead segment and the skid segment. It is noted that $N$ is in coordination with the skidding direction of the skid segment and $M$ starts from the middle point of skid segment to that of drawbead segment. $d_i$ is the distance from the middle point of skid segment to that of drawbead segment and is normalized by the maximum distance $d_0$.

The drawbead restraining forces are adjusted iteratively. Suppose that $\mu_j^k$ is the drawbead restraining force of the $j$-th drawbead segment in the $k$-th iteration. $\mu_j^{k+1}$ is determined by:

$$\mu_j^{k+1} = \mu_j^k - \alpha \gamma_j^k,$$

(6)

where $\alpha$ is the learning rate and $\gamma_j^k$ is the evaluation of the $j$-th drawbead segment in the $k$-th iteration.

**Objective Function**

This paper adopts minimax method to assess the effect of skid lines. Thus, the maximum skidding distance is taken as objective function:

$$s_{\text{max}}^k = \max\{s_i^k\}, i = 1,2,3 \ldots n,$$

(7)

where $s_i^k$ is the skidding distance of the $i$-th skid segment in the $k$-th iteration. And the heuristic optimization algorithm is used for minimize the objective function.

**Convergence Condition**

The terminal iteration condition is:

$$s_{\text{max}}^k \leq \epsilon,$$

(8)
where $\epsilon$ is the user-specified maximum skidding distance.

RESULT AND DISCUSSION

A decklid, which is a typical automobile covering part, is used to verify the effectiveness of the proposed heuristic optimization method. The CAD model of the tested decklid is presented in Figure 5 (a). Due to the symmetry of the component, half of the model is applied for simulation analysis and optimization. The material properties are listed as follows: thickness $t_0 = 0.7$mm, yield stress $\sigma_s = 215$ MPa, Young’s modulus $E = 207$ GPa, Poisson’s ratio $\nu = 0.3$, strengthen coefficient $K = 547$ MPa, hardening exponent $n = 0.19$, R-value $R_0 = 1.53$, $R_{45} = 1.07$, $R_{90} = 1.85$. The Swift-Krupkowsky hardening law describes the material flow stress as $\sigma = K(0.001 + \epsilon^p)^n$. And the friction coefficient is set as 0.125 and the blank holder force is set as 140t. For achieving both high-quality performance and appearance, the proposed heuristic optimization method for skid lines and the previously developed intelligent optimization algorithm concerning FLD [10] are combined to optimize the layout of drawbeads.

The initial equivalent drawbead restraining forces are set as 100N/mm. The maximum admissible skidding distance $\epsilon$ is set as 3 mm and the learning rate $\alpha$ is set as 1. The left portion of Figure 6 shows the initial simulation result. The maximum skidding distance reaches to 12.74 mm and the skid line has exceeded the feature line radius, which may lead to visible skid mark. The proposed heuristic optimization method is exploited to optimize the drawbead restraining forces to control the skid line. After several heuristic adjustments of the drawbeads, the optimized simulation result, as shown in the right portion of Figure 6, the maximum skidding distance has dropped to 2.52 mm and the potential skid line has been limited in the feature line radius. The optimized drawbead scheme is shown in Figure 5 (b). The variation of the objective function $s_{max}$ following the iteration number is shown in Figure 7.
Figure 5. The model of the tested decklid: (a) the tool setting, (b) the optimized drawbead scheme (unit: N/mm).

Figure 6. Skid lines before and after optimization.

Figure 7. The variation of the objective function following the iteration number.
CONCLUSIONS

In this paper, a heuristic optimization method for releasing the harmful effect of skid lines is presented for automated die design in sheet metal forming. The optimization method is combined with FEA to realize an iterative optimization by adjusting drawbead restraining forces. The effectiveness and practicability of the proposed method is validated by the process optimization of an actual decklid. The proposed method is difficult to guarantee the optimal solution, which is the common problem of heuristic optimization algorithm.

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