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SMOOTHING METHOD OF AUTO-BODY PART CONTOUR FOR THE DIE-FACE DESIGN SYSTEM BASED ON THE CAE PLATFORM

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ABSTRACT–The method of die-face design based on the CAE platform for automobile panels can fast modify the die addendum. In contrast with the process of the die-face design based on the CAD platform, there are some special steps for the die-face design based on the CAE platform. The most obvious difference is that the auto-body part contour needs smoothing earlier than the design of addendum surfaces does. It is helpful to improve the design quality of addendum surface. In spite of extensive researches on the smoothing technique, there is still dearth of the published solutions about smoothing the part contour with additional surface. This paper attempts to analyze the difficulties and provides practical solutions. Main results include the algorithm to calculate the segments needing to be smoothed on boundary, the strategy to create the smoothing curve and the procedure of surface generation. The relevant function modules for parametric design are developed. A few examples and suggestions for future work conclude the paper.

KEY WORDS : Die-face design, Surface extension, Die addendum, Automobile panel

1. INTRODUCTION

Sheet metal forming technique is widely applied in automotive manufacturing industry. The automobile panel is the most difficult component in the domain of sheet metal forming (Xing *et al.*, 2002). Compared with the common stamping parts, there are some typical characteristics in the automobile panel stamping (Gang, 2004): complex configuration, heavy demand for surface quality and rigidity, great plastic deformation, etc. Abundance of experiments and CAE simulations has already proved that the shape of addendum surface for drawing die has great effect on the accuracy of the CAE analysis. In the traditional way, engineers have to design the die addendum through CAD code by hand, and their experiences play the key role. Along with the development and application of CAE technique, the CAE analysis is more and more widely used to test the quality of die-face design. The designs of die addendum need amending frequently when they fail to pass the examination of CAE analysis. Usually, we must send the model back to CAD system to modify it, and then transfer the new design to do CAE analysis again. Some complex and time-consuming processes must be operated once more, such as the finite element mesh generation, flanging, holes filling etc. In order to avoid these limitations, the die-face design methods based on CAE platform begin to attract more attention. As a developing trend, these means have advantages in convenience and efficiency because it can modify the design of die-face in CAE system directly. There are many famous CAE software tools which have developed the module for die-face design, for instance, Pam-stamp, Autoform, Hyperworks (The Virtual Try-out Space Co., 2003; Autoform Engineering GMBH, 2001; ALTAIR Engineer Inc., 2004). In spite of their faulty functions, they offered a new direction for die-face design.

The die-face design method based on CAE platform plays the similar role to the design method based on CAD platform. However, some special steps are required for the die-face design based on CAE platform. For example, the most obvious differentia is that the part boundary needs to be smoothed with additional surfaces before creating the addendum surfaces. It is helpful to improve the design quality of addendum surfaces. In spite of extensive researches on surface extension methods (Kim *et al.*, 2005; Kim, 1997; Shetty *et al.*, 1991; Wolters, 2000), there is still dearth of the published solutions about the generation of additional surfaces for smoothing the part contour. So this paper concentrates on the

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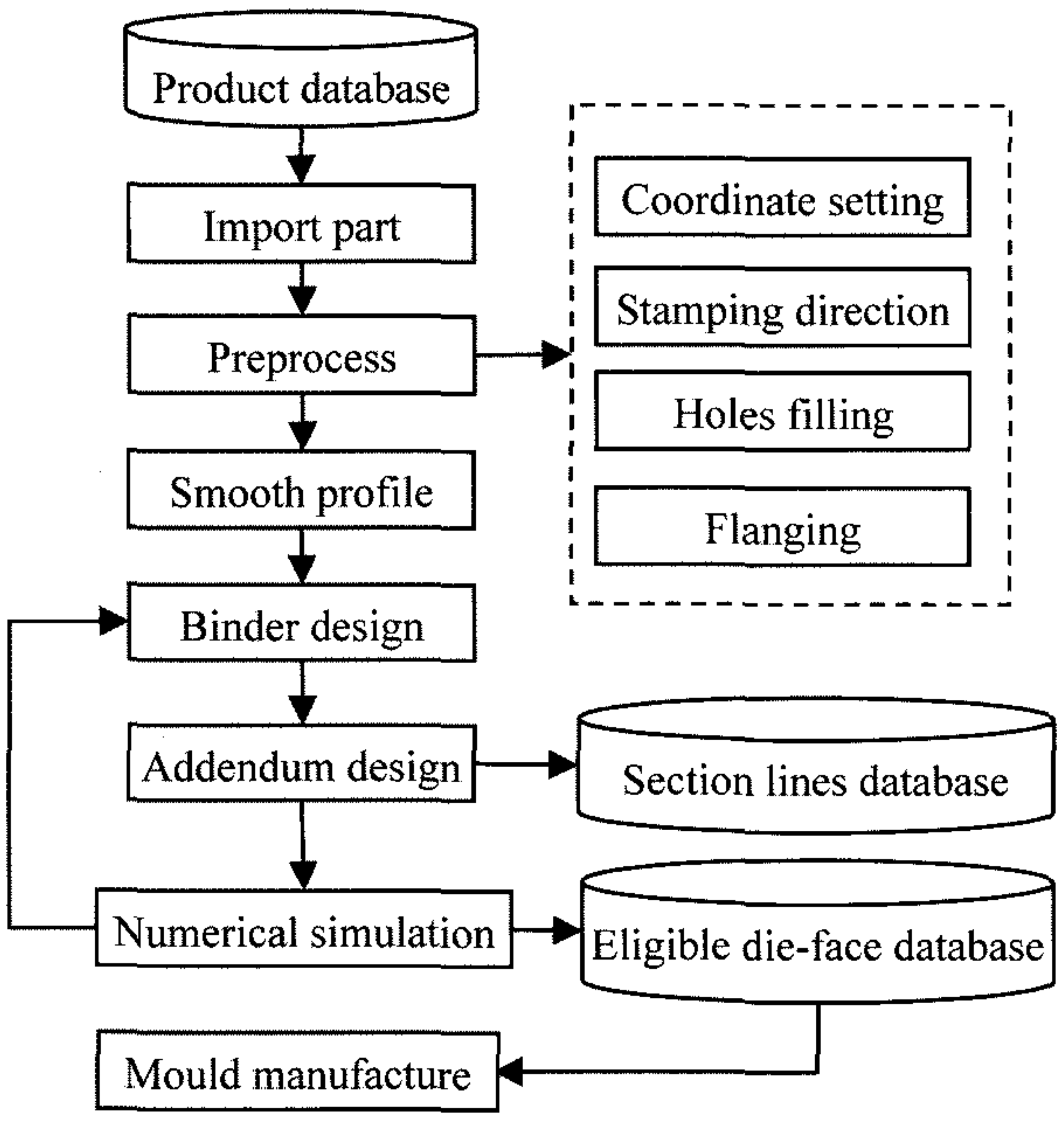


Figure 1. Procedure of CAE-driving die-face design.

techniques to create additional surfaces for stamping part. The additional surfaces, which are created by the contour of automobile panel and the smoothing curve, have the G^1 continuity with the part surfaces at the boundary. The smoothing curve is used to smooth the part contour and created by the algorithm presented in the paper. The aim of smoothing the part contour is to close open regions on the original part, to change different drawing depth into an even one, to decrease the quantity and the depth of the concave regions on part contour.

Some key techniques about how to smooth the auto-body part contour are discussed in this paper. An algorithm to calculate the segments needed to be smoothed on boundary, and a strategy to create the smoothing curves and a surface generation procedure are presented. The relevant function modules as above are developed.

2. OVERVIEW OF THE DIE-FACE DESIGN PROCESS BASED ON CAE PLATFORM

Main processes of the die-face design based on CAE platform include part preprocessed, boundary smoothed, binder surfaces created, addendum surface generated and the numerical simulation for formability. The overview of the process is given in Figure 1. The design of binder also can reduce the manual work by building a knowledge library which is similar with the design of the addendum surface.

There are several CAE software tools have the modules for die-face design. The main differences among these tools include following aspects: the interface, work flow and the fashion of operation. The character of Autoform-DieDesigner is its excellent intelligentized ability. The manual ability to modify the model is offered in the same way. However, the inconvenience is caused by the just intelligentized ability when users want to modify some places on die-face by manual acting. The interface of PAM-DIEMAKER can help jackaroo to master it fast, but the stability of PAM-DIEMAKER™ 2G needs meliorating. Unlike those software tools mentioned ahead, the feature of more artificial interferences during running gains HyperForm an advantage over the others. However, the interface of HyperForm is not as friendly as those of other software tools.

Smoothing part contour is so important for the die-face design based on CAE platform and the known record are so rarely that it is worthy to pay more attentions to research on it.

3. TECHNIQUES TO SMOOTH PART CONTOUR

3.1. Overview of the Smoothing Process

Smoothing techniques of auto-body part contour include three mainly modules: judging the regions needed to be smoothed on part contour, creating the smoothing curves and generating the additional surfaces.

The regions include opening boundary, different drawing depth and deep concave on the part contour all need smoothing. The roll cylinder algorithm can be used for judging it (see Figure 2). After getting the regions, we use NURBS curves to smooth the part contour. The strategy to create the smoothing curves is stated in the paper. The additional surfaces used for smoothing the part contour are created from two NURBS curves. One is the smoothing curve, another is a compound curve constructed with several curves on boundary. We use surface skinning algorithm (Hohmeyer, 1991; Tokuyama, 2000) to create additional surface.

3.2. Roll Cylinder Algorithm

Roll cylinder algorithm can be used for identifying the regions which need smoothing. However, several pre-

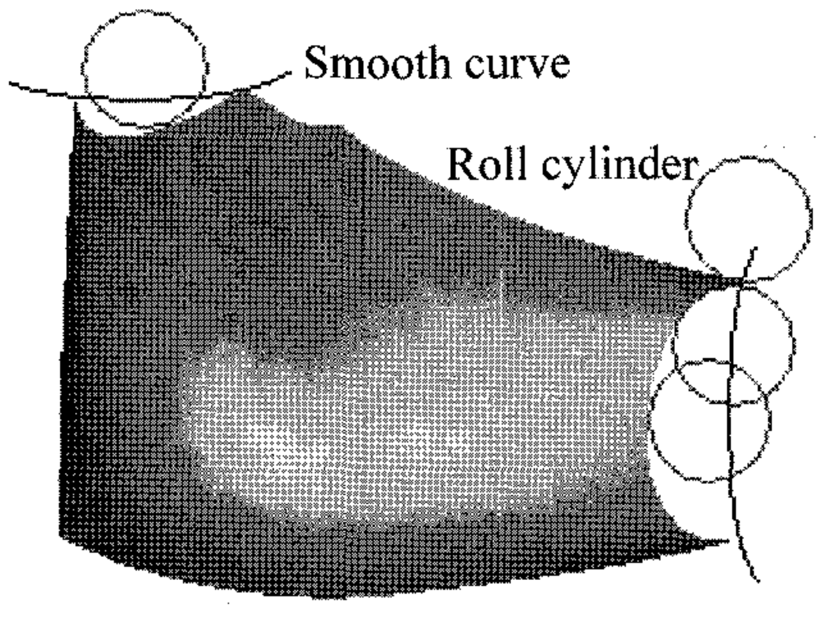


Figure 2. Example for rolling cylinder.

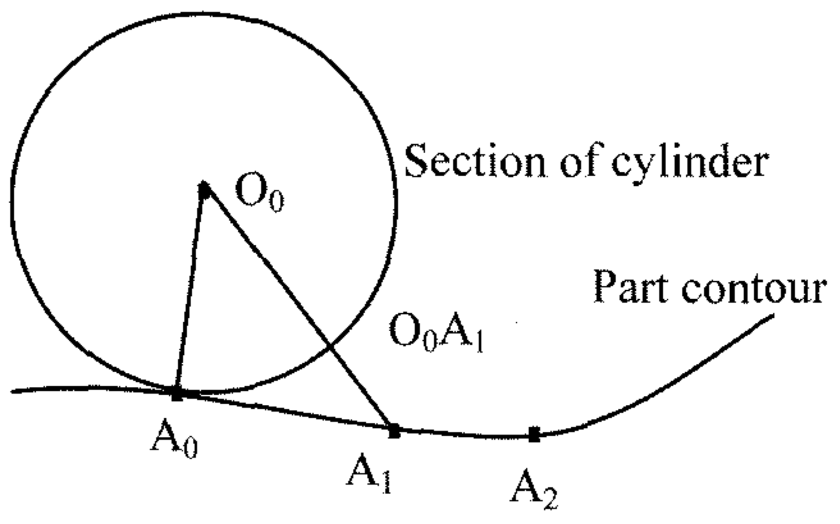


Figure 3. Judge the regions which need smoothing.

processes must be taken before the application of roll cylinder algorithm. For example, surfaces which have negative angles with the stamping direction must be hided. Roll cylinder algorithm must be applied on the plane which is perpendicular with the stamping direction. So the projection of the part contour on plane must be calculated. Figure 3 gives an example:

The detailed algorithm is described as follows:

(Step 1) Disperse the part boundary and choose a discrete point A_0 randomly as the initiatory point of the rolling cylinder, choose an adjacent point A_1 and calculate a tangent circle on A_0. R is a given radius by user.

(Step 2) Calculate O_0A_1, $O_0A_2 \cdots O_0A_j$, $j > 1$ with the other points on contour; if $O_0A_i < R$, $1 < i < j$, select another point A_n, $n \neq i$, $n \neq 0$, 1 as the beginning point, repeat the judgment till the condition is satisfied. Supposing A_n is the point, continue the next step.

(Step 3) Compute a tangent circle at point A_{n+1}, the radius is R. Suppose Q_{n+1} is the centre of the circle. Circulate all the points on boundary and Calculate the distance d from these points to Q_{n+1}, if there can't find any point satisfying $d < R$, set $n = n + 1$. If there find just one point A_j, it denote that the curve needs smoothing from the start point A_{n+1} to the end point A_j. If the points collection $\{A_i | 1 < i < j\}$ satisfied the condition, for each point A_i in the collection, make circles with R for the radius cross A_{n+1} and A_i. Among these circles, there must have a circle excluding other points in the collection. The point A_i on this circle is the end point of the curve section which needs smoothing.

(Step 4) Circulate all discrete points on part boundary to find all regions needing to be smoothed.

3.3. Strategy to Create the Smoothing Curve

The smoothing curve generation of the part contour needs the following steps.

(Step 1) Calculate an arc with a given radius to cross the ends of the curve segment.

(Step 2) Sweep arc to be cylinder along the stamping direction.

(Step 3) Create rays along the vector U or V on the points of part contour and calculate the intersect-points with the cylinder.

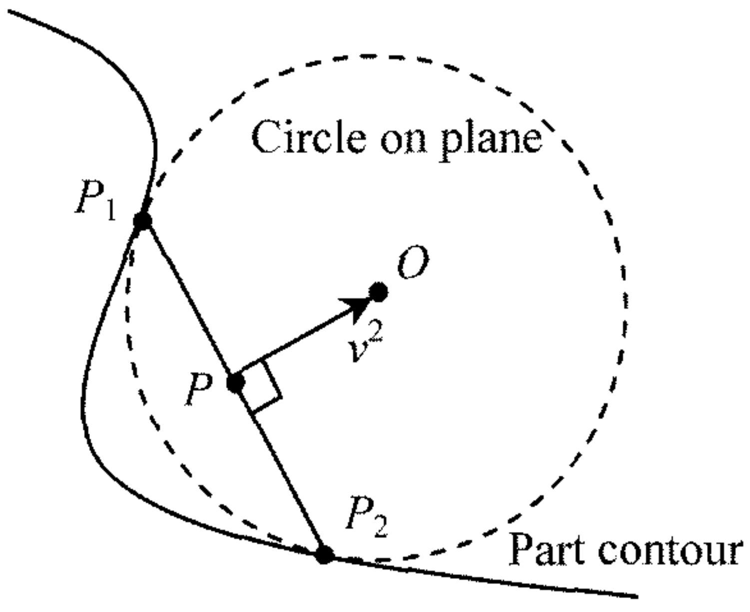


Figure 4. Calculate the center of a circle.

(Step 4) Use a NURBS curve to fit all intersect-points. The NURBS curve is the smoothing curve of the part contour.

There only have the coordinates of P_1, P_2 and a given radius R as the known conditions for calculating the arc. We can find two centers of circles with the conditions. For confirming the only one, we need to judge the distance from two centers O_1, O_2 to P_3. P_3 is a random point on the curve segment which need smoothing. The correct point has the larger distance than the other one.

As shown on Figure4, the midpoint P of the line segment P_1P_2 is demanded for calculating the center of a circle. Supposing the coordinates of the point P is (P_x, P_y), the coordinates for the center of a circle O is:

$$\begin{cases} Q_x = P_x \pm v_x^2 \cdot \sqrt{R^2 - |PP_1|^2} \\ Q_y = P_y \pm v_y^2 \cdot \sqrt{R^2 - |PP_1|^2} \end{cases} \tag{1}$$

where

$v^2(v_x^2, v_y^2)$ is unit vector with the direction from P to O.

Cylinder can be generated by the sweeping method. The sweeping surface can be denoted by the following equation:

$$S(u, v) = r(u) + c_1(u, v)N + c_2(u, v)B \tag{2}$$

Where $r(u)$ is the ridge curve, $c_1(u, v)$, $c_1(u, v)$ are the section curves. The section curves can be transformed and twisted along the ridge curve. N, B are the unit vector along the direction of the ridge curve. For the sweeping curve here is an arc, the sweeping surface can be denoted accurately by NURBS. The curve $c_2(u, v)$ can be generated by offsetting $c_1(u, v)$ (Guoping *et al.*, 2002; Tiller *et al.*, 1984).

Smoothing curves were created by fitting discrete points which calculated with the intersect algorithm between rays and cylinder. Rays are constructed by the discrete points and the tangent vectors on these points. However, the intersection among the rays will lead to self-intersection of the fitting curve (see Figure 5).

In order to avoid self-intersection, we take the strategy as following:

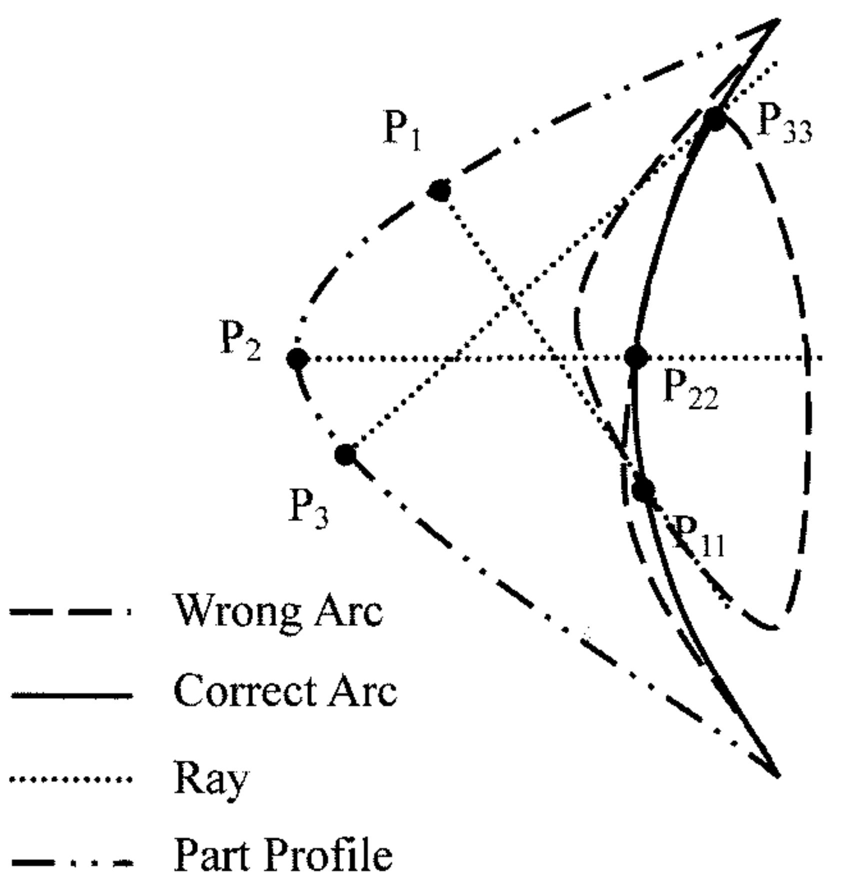


Figure 5. Example for the intersection ray.

(Step 1) Create rays with the discrete points on boundary and the vectors on points; calculate the intersect points between rays and cylinder.
(Step 2) Make the line segments with discrete points and their intersect points, and then find their projection on the plane which is perpendicular with the stamping direction.
(Step 3) Judge whether intersect among the line segments or not. If the line segments intersect each other, exchange the order of points.
(Step 4) Resort the sequence of all points on cylinder.

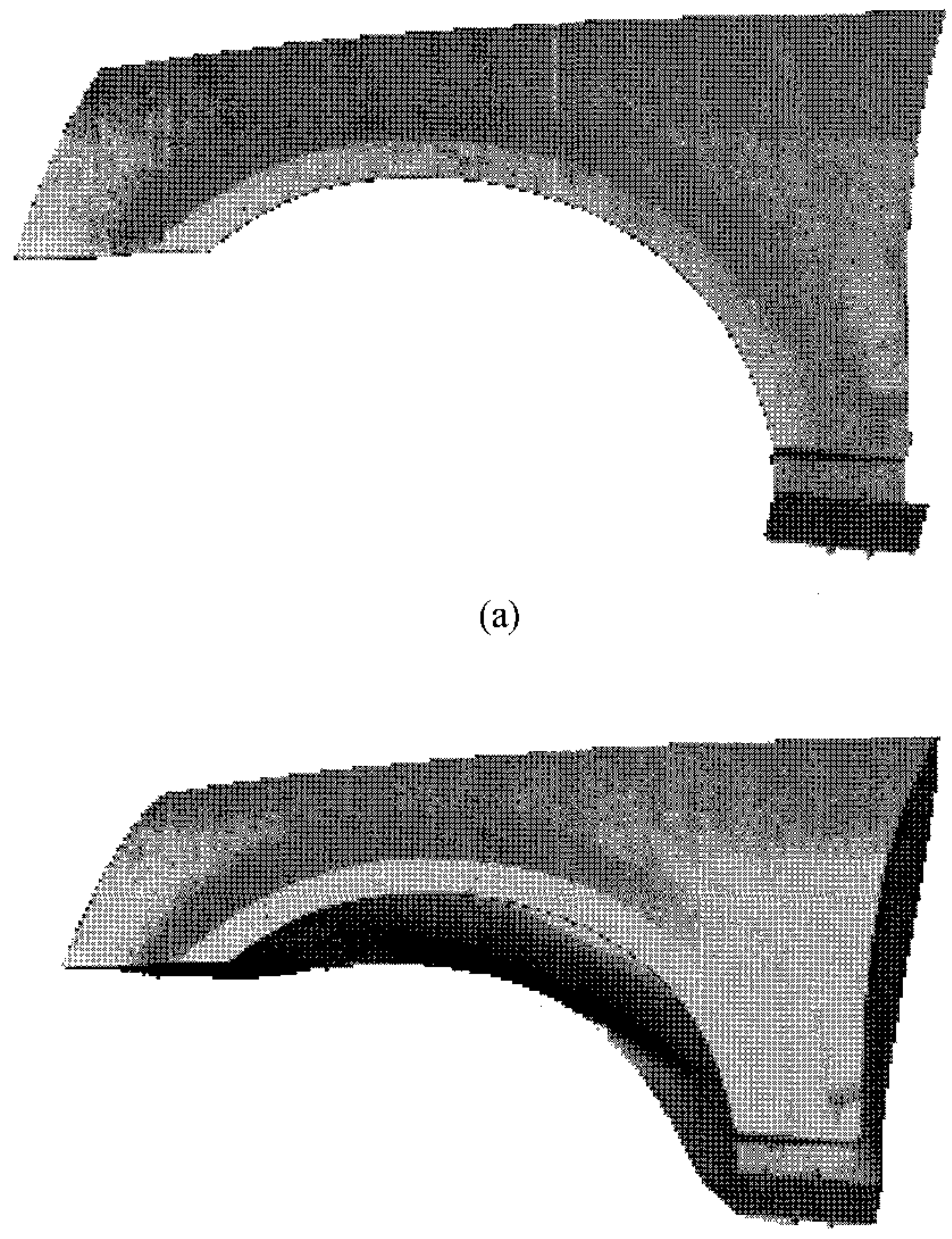
After getting discrete points, we use a NURBS curve to fit these points. The 3-degree NURBS interpolate curve is used most frequently in practical application. Besides the boundary conditions on the first point and on the last point, the coordinates and the weights of interpolate points are necessary for computing the control points of 3-degree NURBS curve. We take the tangent vector as the boundary condition and use below expression of the homogeneous coordinates to denote the NURBS curve.

$$P(u)=H\{P(u)\}=H\left\{\sum_{0}^{n} D_i N_{i,k}(u)\right\},\ 0 \le u \le 1 \qquad (3)$$

Where, $D_i=\omega_i d_i$, ω_i, i=0, 1, ⋯, n are the weights on control points, d_i, i=0, 1, ⋯, n are control points of NURBS curve. $N_{i,k}(u)$, i=0, 1, ⋯n is k-degree B-spline basis function. They are decided by the vector on control points $U=[u_0, u_1, \cdots, u_{n+k+1}]$. Equation (3) denotes k-degree NURBS interpolate curve.

3.4. Procedure to Generate Additional Surfaces

Additional surface generation is the question about how to generate a NURBS surface by two NURBS curves. Two kinds of methods can be carried out to generate the surface based on two NURBS curves. They are surface skinning and least-squares surface fitting. The least-squares surface fitting is an approach way. Just the characters let us give up the way because the boundary of the additional surface must keep the same with the part contour. Giving attention to the surface quality and efficiency, a fast surface skinning algorithm to generate the additional surface is presented.


(a)

(b)

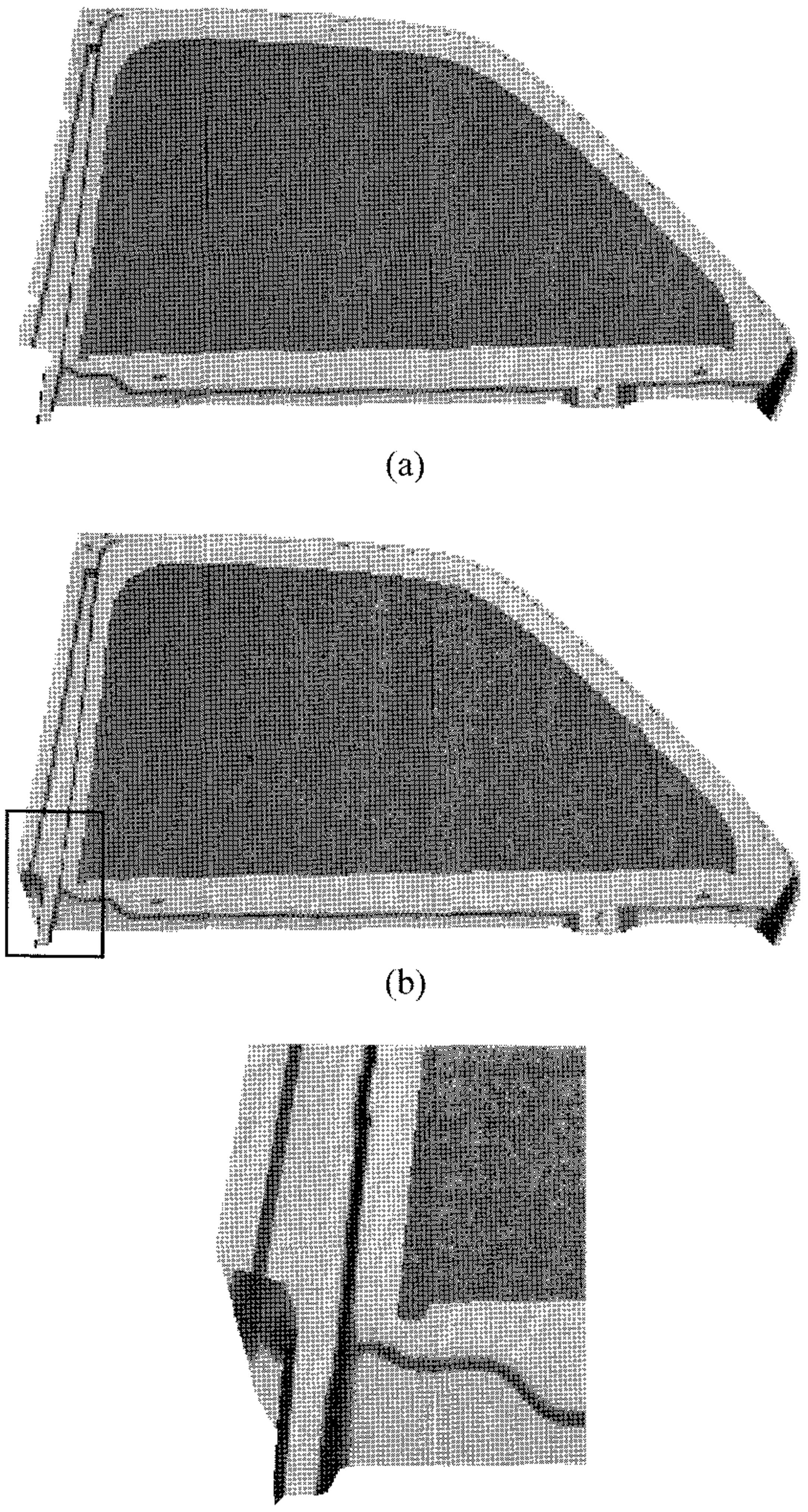
Figure 6. Smooth the profile of front fender.

Surface skinning requires all curves having the same number of control points and degree. Cohen algorithm (Cohen *et al.*, 1985) can be taken to make curves compatible and elevate the degree of two NURBS curves. The Boehm point-insert technique (Boehm *et al.*, 1985) can be used to realize that all curves have the same number of control points. The process of surface skinning is explained as follows.

Giving m pieces of NURBS curves in u direction, where the highest degree of these curves in u direction is p. The skinning surface can be formulated:

$$S^w=\sum_{i=0}^{nu} \sum_{j=0}^{n+q-2} N_{i,p}(u)N_{j,q}(v)P_{i,j}^w \qquad (4)$$

where $N_{i,p}(u)$, $N_{j,q}(v)$ is B-spline basis functions, $P_{i,j}^w = (w_{i,j}x_{i,j}, w_{i,j}y_{i,j}, w_{i,j}z_{i,j}, w_{i,j})$ is defined by a set of weighted control points. nu+1 is the sum of control points in u direction of surface. The knot vectors are $T_u[t_0, t_1 \cdots t_{nu+p+1}]$, $T_u[t_0, t_1 \cdots t_{m+2q-1}]$.



(a)

(b)

(c) Zoom out the black frame in (b)

Figure 7. Smooth the profile of doorframe.

4. APPLICATIONS

We choose two typical auto-body parts to generate the additional surfaces. The first example is an automobile front fender. The result is displayed in Figure 6. The roll cylinder radius R=1500 mm and the arc radius r=3000 mm.

The second example is a doorframe. Figure 7 shows the result after smoothing the contour of the automobile doorframe. The roll cylinder radius R=50 mm, the arc radius r=500 mm. We can modify the shape of surfaces by changing these two parameters.

5. CONCLUSIONS

A smoothing method of auto-body part contour for the die-face design system based on CAE platform has been presented. By means of the algorithm of additional surface generation, the outer contour of stamping part can be smoothed with the advantage of the computational efficiency and high surface quality. The method which is adopted to create the controllable and revisable surfaces in the paper is a commendable method. The work to smooth the part contour can shorten the design cycle of die-face engineering and improve the design quality of the die addendum. Basing on the technique, code is written and is integrated into the independently developed commercial CAE software KMAS™. The technique has been carried out successfully to smooth the contour of some practical stamping parts, such as automobile doorframe, front fender and so on.

Future work may concern alternative methods for computing additional surfaces. On the part boundary, the part and the additional surfaces can be satisfied with higher continuity.

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