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A NEW METHOD TO STUDY THE FORMING PROCESS OF COMPLICATED SHEETMETAL AERO–PARTS

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Abstract

This paper proposes a new method to study the forming process of complicated sheetmetal aero–parts. The shape of the aero–part is described by parametric cubic patches, nonlinear FEM is used for calculating the stress and strain, and the grid measuring is used for checking the result.

The success of the proposed method lies in two aspects: (1) The same grid system is being used in geometric description, FEM analysis and verification. This makes data transmissing and comparing convenient. (2) The "divide and revise" approach is used to treat changies of boundary conditions and load distribution in FEM calculation. This enables the simulation of complicated forming process to be possible.

Some examples indicated the feasibility of the proposed method and its relevant package CASF01. Which is implement on a microcomputer.

I. Introduction

The plate or shell parts take an important part in aero–structure. The quality of these parts has directive influence on the performance and life of the aircraft, so it is a problem which the aircraft manufacturing enginners and companies are interested in.

The complicated shape of sheet parts are always made by forming process on the mould and some special equipments. The forming process in the key process in sheet parts manufacturing. To get an excellent part, you must know the mechanics laws of forming process very well, that is to say, it is necessary to calculate the stress and strain distribution during forming.

A lot of theoretical and experimental studies have been made, and get some important progress such as FLD (forming limit diagram)(1), but the application of FLD is limited just for lack of effective method to calculate all the stress and strain during complicated forming process until now.(2)

The forming process of complicated sheet parts is still an unexposed "black box".

The developments of computer and numerical analysis bring about a new way to calcutate all the stress and strain in the forming process of complicated sheet parts. The new method proposed in this paper integrates the surface discribing in computing geometry, nonlinear FEM in computing mechanics, FLD and grid measuring. Its success lies on two aspects. One is the "divide and revise" used for solving the problems caused by large deformation, the other is the same grid system used for surface discribing, FEM analysing and grid measuring.

II. Outlines of the New Method

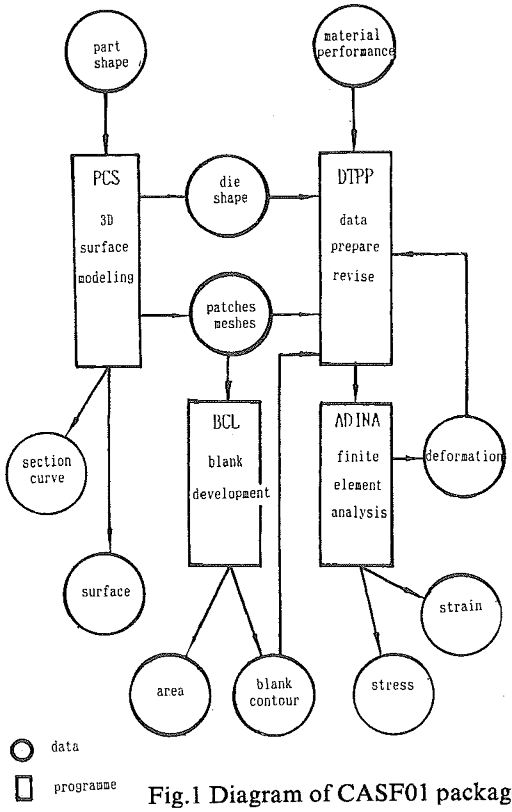

Fig.1 Diagram of CASF01 package

The main programme in the new method is shown in Fig.1, as follows:

(a) Firstly, the shape of the complicated part is defined as a sculpture surface mathematically. The parametric cubic patches are chosen here and the calculation of the surface is discussed in next section. The original data for the surface definition can be obtained from the drawing or from the physical part by measuring.

(b) From the defined surface, the data for NC machining of the moulds (convex and concave surface) can be obtained by geometric calculation. The data of the plate blank are also obtained by geometric calculation. All of these data form a data file and stored in a computer. The data file is arranged in the format consistent with the input file of FEM analysis.

(c) Take the grid of the surface definition as the discrete mesh for FEM analysis, and print the grid on the blank of the part by electric corrosion. So the displacement of node points can be measured directly after the forming process completed.

(d) Added the relevant data such as the mechanical properties of sheetmetal and the loading function, the stress and strain of the part in forming can be calculated by Nonlinear FEM. The mathemetics or mechanics of the FEM is discussed in section Ⅳ.

(e) The FEM program can operate on a microcomputer, give the stress and strain of any element, and give the node displacement. As a consequence it is possible to predicate that which location would broken or wrinken by comparing the FLD and the value to computing stress.

(f) The value of node displacement obtained by calculating can be compared directly with the corresponding value by measuring the part after forming process. It is necessary to point out that the grid printed on the blank of the part is just the discrete grid in FEM calculation, the comparision between two value does not include any conversion. It is one of the sucess of our method.

Ⅲ. Surface Discribing of Complicated Parts

There are several methods to discribe a sculpture surface in computing geometry such as parametric patches, Bezier surface, B–spline surface etc⁽³⁾. The parametric patches method is chosen here because of its interpalational characteristics.

A section of parametric cubic curve is:

$$\vec{R}(\mu) = \sum_{i=0}^{3} \vec{V}_i \mu^i \tag{1}$$

here, μ is the parameter, its value changes from 0 to 1 i.e. $\mu \in [0,1]$ .To clear the geometic meaning of vectors $\vec{V}_i$, equation (1) can be expressed in another from:

$$\begin{aligned}\vec{R}(u) &= \vec{P}_0 F_0(u) + \vec{P}_1 F_1(u) \\ &+ \vec{P}'_0 G_0(u) + \vec{P}'_1 G_1(u)\end{aligned} \tag{2}$$

here $\vec{P}_0$ and $\vec{P}_1$ are position rectors at the both ends of the curve section, as shown in fig.2, $\vec{P}'_0$, $\vec{P}'_1$ are the tangential vectors at the ends. The cubic functions $F_0(u)$, $F_1(u)$,$G_0(u)$ $G_1(u)$ are called blending functions. According to Hermit interpolation, the blending functions should satisfy that:

$$\begin{cases} F_0(0) = 1, F_0(1) = F'_0(0) = F'_0(1) = 0 \\ F_1(0) = 0,\ F_1(1) = 1,\ F'_1(0) = F'_1(1) = 0 \\ G_0(0) = G_0(1) = 0,\ G'_0(0) = 1,\ G'_0(1) = 0 \\ G_1(0) = G_1(1) = G'_1(0),\ G'_1(1) = 1 \end{cases} \tag{3}$$

as a consequence the cubic blending function are:

$$\begin{bmatrix} F_0 & F_1 & G_0 & G_1 \end{bmatrix} = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \tag{4}$$

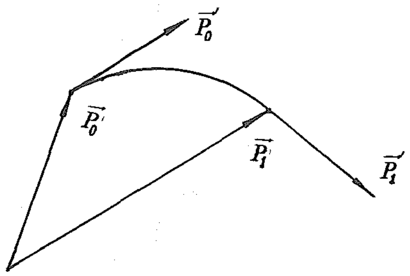

Fig2. A parametric cubic curve scetion

Among the given n position vectors, n–1 curve sctions can be made and form a parametric cubic spline. The tangential vectors can be determined by the equation⁽⁴⁾:

$$\vec{P}'_{i-1} + 4\vec{P}'_i + \vec{P}'_{i+1} = 3\vec{P}_{i+1} - 3\vec{P}_{i-1} \qquad (i = 2,\ 3,\ \cdots,\ n-1) \tag{5}$$

the end tangential vectors of the spline $\vec{P}'_1$ and $\vec{P}'_n$ should be given in aduance. It is C^2 continuous at the node of the obtained spline.

Similarly, a parametric cubic patch can be expressed as

$$\vec{P}(u,w) = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \overrightarrow{00} & \overrightarrow{01} & \overrightarrow{00}'_w & \overrightarrow{01}'_w \\ \overrightarrow{10} & \overrightarrow{11} & \overrightarrow{10}_w & \overrightarrow{11}_w \\ \overrightarrow{00}'_u & \overrightarrow{01}'_u & \overrightarrow{00}''_{uw} & \overrightarrow{01}''_{uw} \\ \overrightarrow{10}_u & \overrightarrow{11}'_u & \overrightarrow{10}''_{uw} & \overrightarrow{11}''_{uw} \end{bmatrix} \begin{bmatrix} 2 & -3 & 0 & 1 \\ -2 & 3 & 0 & 0 \\ 1 & -2 & 1 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} w^3 \\ w^2 \\ w \\ 1 \end{bmatrix}$$

or simply:

$$\vec{P}(u,w) = UM\vec{B}M^T W^T \qquad (6)$$

in above equation, the $\overrightarrow{00}$ means the cornor vector $\vec{P}(0,0)$, the $\overrightarrow{00}'_u$ means the cornor tangential vector in the u direction $\partial\vec{P}(u,w)/\partial u$(while u=0, w=0), and $\overrightarrow{01}''_{uw}$ menas $\partial^2\vec{P}(u,w)/\partial u\partial w$(while u=0, w=1) etc.

The parametric cubic spline surface is made up of (n−1) × (m−1) patches when mxn position vectors are known, and adjacent two patches keep C^2 continuity along the common boundary and across the boundary. Fig.3 is an example of the parametric surface.

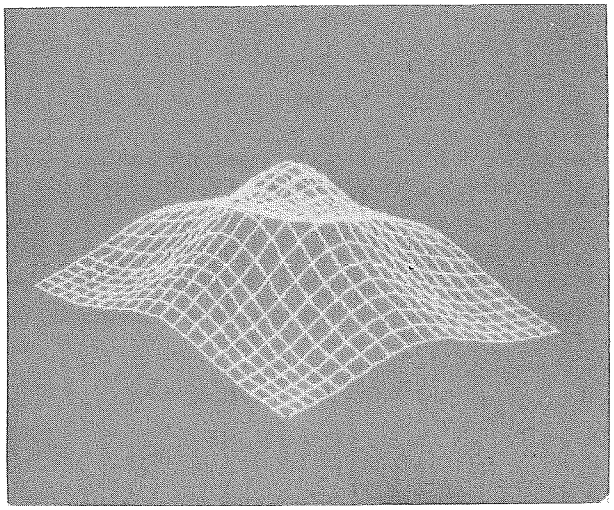

Fig.3 A parametric cubic spline surface

Ⅳ. FEM and Simulation

The Total Lagranian FEM is used here to calculate the stress and strain in complicated forming process because the deformation start from a plate blank. the basic equation(5) can be expressed as:

$$(K_1 + K_2)\{u\} + \{R\} - \{F\} \qquad (7)$$

herein, K_1 and K_2 are linear and nonlinear stiffness matrices individually. {u} is the node displacement, {R} and {F} represent the external force and the initial stress individually, that is :

$$\begin{cases} K_1 = \sum_1^n \int_v B_1^T C B_1 dv \\ K_2 = \sum_1^n \int_v B_2^T C B_0 Dv \\ \{R\} = \sum_1^n (\int_s N^T \{Q\} ds + \{R\}) \\ \{F\} = \sum_1^n \int_v B_1^T C B_0 dv \end{cases} \qquad (8)$$

in (8), n is the number of elements, matrix C represents the relation of elastic–plastic stress to strain. B_1,B_2 and B_0 are matrices which represent the relations of the element strain to node displacements. N is called the shape function matrix. $\{R_C\}$ is the central force and $\{Q\}$ is the pressure. v and s represent the valume and pressured area of elements individually.

The proposed method has been tested and verified by several examples. One of them is the bulging test, as shown is Fig.4. In this test, the values of node displacement obtained by calculating and by measuring appear well concordant(6).

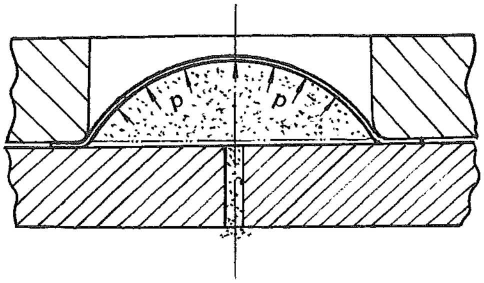

Fig.4 bulging of circular plate

Another example is a complicated part, as fig.5. In FEM calculating, the fatal difficulty lies on that the contact state of the blank to moulds greatly changed because of the large deformation of the blank. The change of contact state makes the restrains and the load distribution quite different from begining. As a result the FEM calculation can not continue, or get a wrong solution.

In order to overcome the difficulty in calculating, a method, called "divide and revise", was proposed two years ago(7). The forming process of a complicated part is divided into several steps to complete FEM analysis. At the moment that the contact state changes obviously, the stiffness metrix is revised according to actual situation. Sometimes it is necessary to divide and revise many times in order to get values of stress and strain more exactly. By this way, we can analysis and simulate the forming process of complicated part from begining to end. Fig.5 is the example.

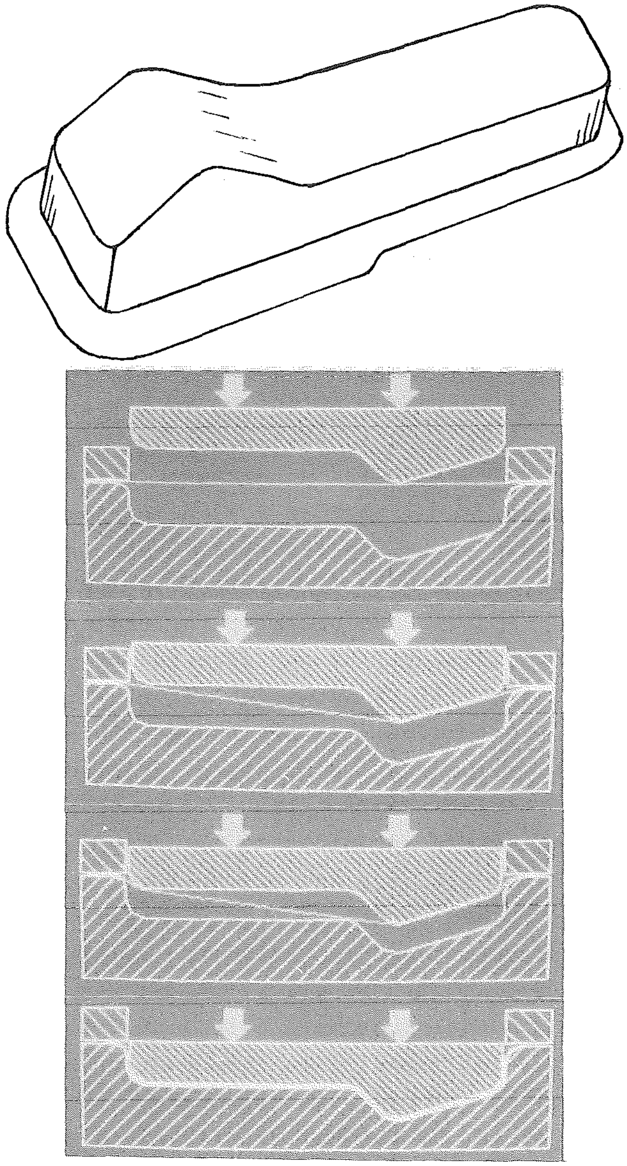

Fig.5 The part and the simulation of its forming

The process is divided into four steps, and the result obtained in simulation is concordant basically with the measured displacements.

V. Conclusion

A new method is proposed based on the application of sculpture surface describing in computing geometry, nonlinear FEM in computing mechanics and grid measuring to study the forming process of complicated sheetmetal aero–parts.

The same grid system used for surface discribing, FEM calculating and grid measuring makes data transmissing and data checking convenient. The "divide and revise" enables the nonlinear FEM to simulate the complicated forming process and get the value of stress and strain. It breaks through the limitation that the classical plastic mechanics can solve only axialitic forming problems.(2)

Some examples completed indicate the feasibility of the proposed method and the relevant package CASF01. By means of the result obtained by the proposed method, technologic parameters can be determined more exactly and the process planning can be made more reasonable in advance. As a result the quality sheetmetal parts will be made in forming process.

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