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Assembly variation analysis of flexible curved surfaces based on Bézier curves

Key words: Assembly variation analysis; Feature points; Side lines; Flexible curved surfaces; Bézier curves

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Motivations

1. Product performances are influenced by deviations which are generated in surface shapes in the manufacturing process. Assembly variation analysis is needed to calculate the final assembly deformation, which reflects product performance to some extent according to manufacturing deviations.

2. Most of the current variation analysis methods either neglect the relationships among feature points on part surfaces or regard the distribution of all feature points as the same.

Main ideas

1. The problem of flexible curved surface assembly is simplified to the matching of side lines. A methodology based on Bézier curves is proposed to represent the side lines of surfaces.

2. The deviations of feature points on side lines are obtained through control point distribution and then regarded as inputs in commercial finite element analysis software to calculate the final product deformations.

Major works

1. Tolerance zone constraint of flexible curved surface side lines based on Bézier curves

Compared with a rectangular tolerance zone of a straight-line feature, curved side lines are obtained by making an offset to both sides of Bézier curves along the normal direction of all points.

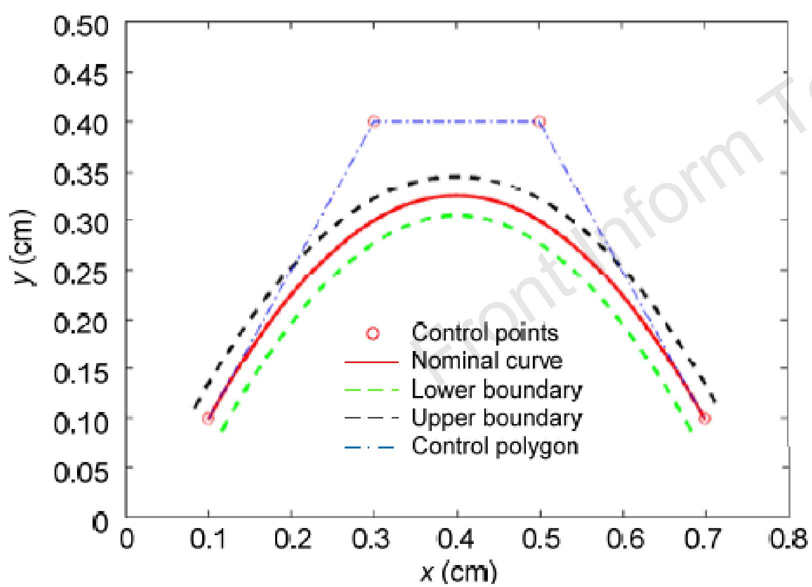

Fig. 3 Nominal position and boundaries of the side line on the curved surface part (References to color refer to the online version of this figure)

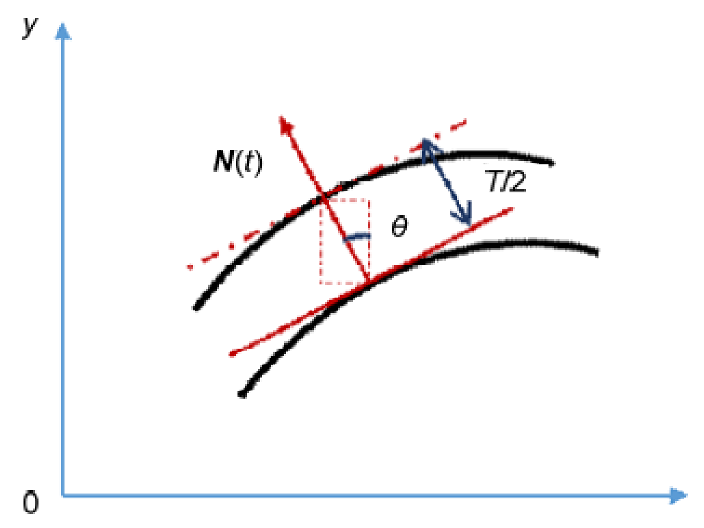

Fig. 4 The nominal position and boundary of side lines on the curved surface part

Major works

2. Calculation of flexible curved surface assembly deformations

The feature points are regarded as the inputs of FEA. Then the sensitivity matrix is obtained and we can construct the linear relationship between initial deviations and assembly deviations. Finally, assembly deviations are obtained and the assembly quality is evaluated.

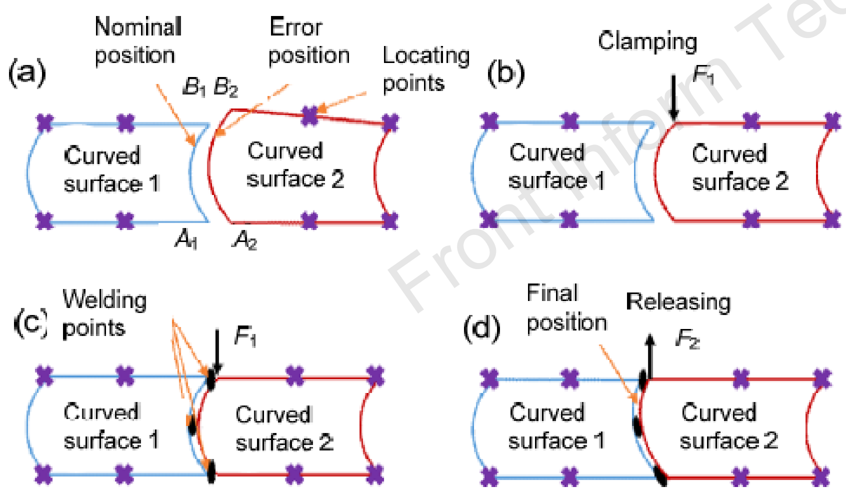

Fig. 6 Four steps of a compliant assembly process: (a) locating process; (b) clamping process; (c) welding process; (d) releasing process

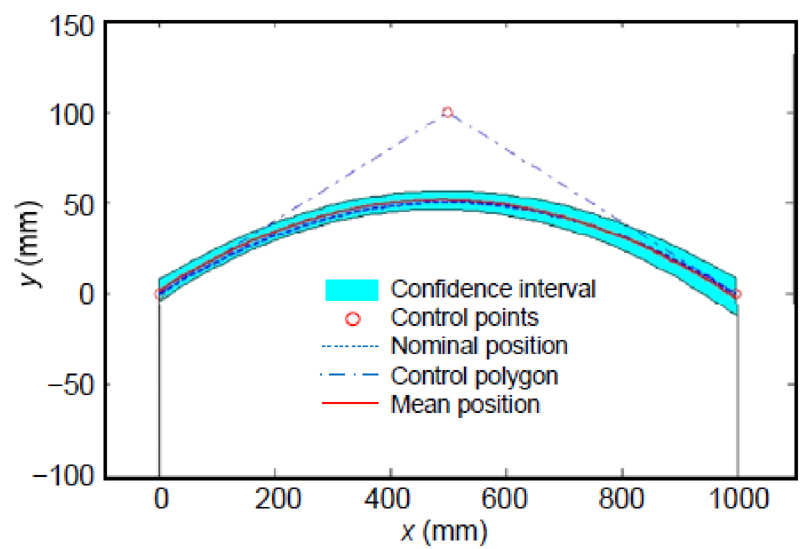

Fig. 7 Nominal position and confidence interval of the welding line (References to color refer to the online version of this figure)

Case study

1. Reflector antenna surface assembly

An example of reflector antenna surface assembly is shown in figures. Deformations of the product after assembly are calculated in Abaqus® software. The result shows that the success rate of reflector antenna assembly in this situation is 96.5%.

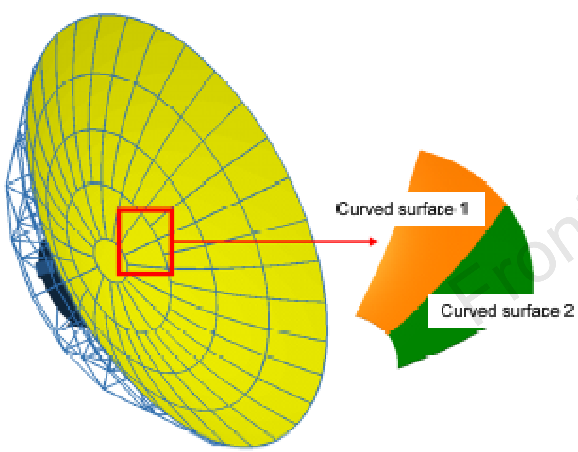

Fig. 8 Assembly of two parts of a reflector antenna

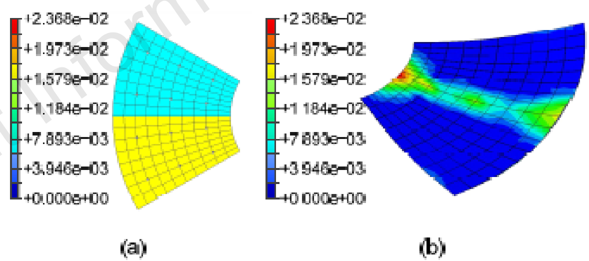

Fig. 11 Variation analysis of the reflector antenna in Abaqus®: (a) locating reflector antenna surfaces; (b) deformations of the welding line after assembly (References to color refer to the online version of this figure)

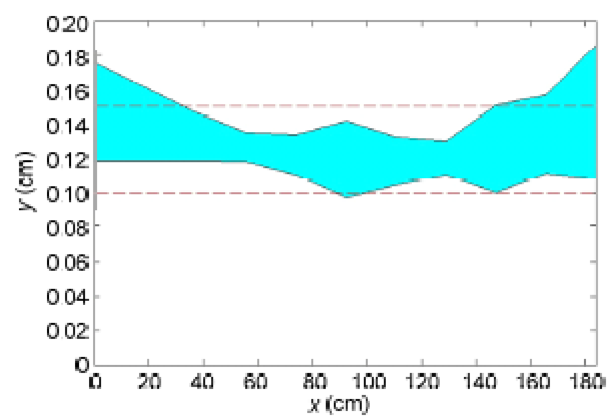

Fig. 12 Contrast of the interval of welding points after assembly and the allowed range of deviations (References to color refer to the online version of this figure)

Case study

2. Assembly of aircraft skins with a conformal array antenna

Another example is the assembly of aircraft skins that have a conformal array antenna. The maximum deviation of feature points in the region of the conformal array antenna on the aircraft skin is (0.17±0.38) mm.

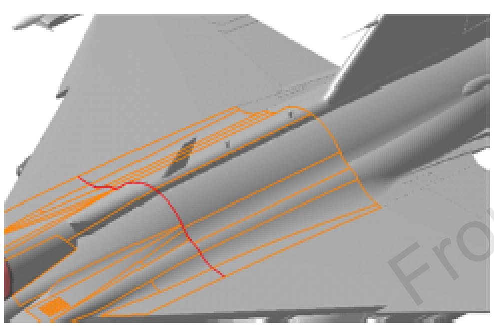

Fig. 13 Assembly of aircraft skins with a conformal array antenna (References to color refer to the online version of this figure)

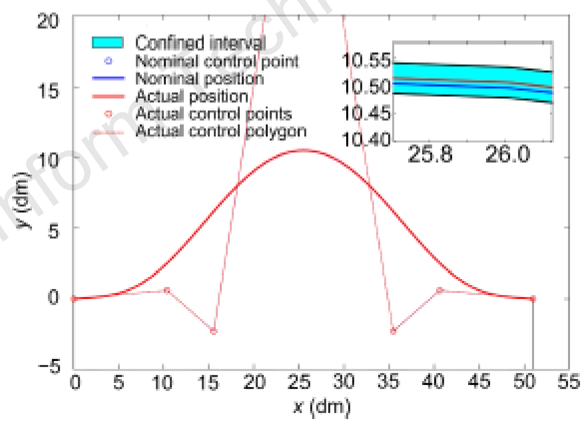

Fig. 16 Mean and variance distributions of feature points on the side line of the aircraft skin (References to color refer to the online version of this figure)

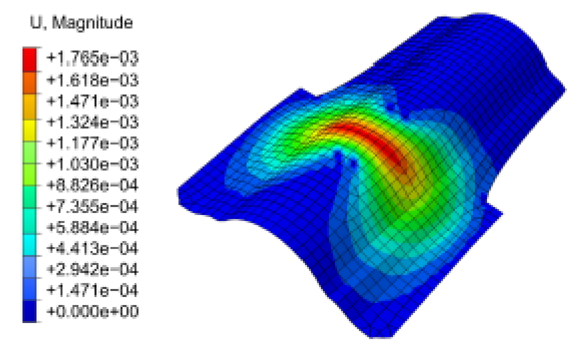

Fig. 18 Deformations of the aircraft skin welding line

Conclusions

1. A kind of flexible curved surface assembly that can be simplified to the matching of side lines is considered based on Bézier curves to solve these two problems in antenna assembly.

2. The distributions of feature points on side lines are obtained using control points. They are regarded as the inputs of FEA, and the deformations of final products are calculated.

3. The quality of assembly is predicted according to the clearance of the mean position and the nominal position of the welding line, as well as the width of the confidence interval.