International Journal of Engineering Innovation & Research
Volume 10, Issue 6, ISSN: 2277 – 5668

Finite Element Simulation of Flexible Roll Forming of Automobile Variable Section Longitudinal Beam

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Date of publication (dd/mm/yyyy): 17/11/2021

Abstract **– Flexible roll forming is a new forming process developed on the basis of traditional constant cross-section roll forming. It can produce variable cross-section products flexibly and efficiently, which is of great significance to automobile lightweight. In this paper, the rolling forming process of automobile variable cross-section longitudinal beam is simulated, the finite element model of roll and sheet metal is established in ABAQUS software, the DXF file of sheet metal is read, it is transformed into the motion track of roll by calculation and interpolation method, and the deformation and stress distribution of sheet metal in variable cross-section rolling forming process are analyzed. The pass design, roll design and speed matching design between strip and roll are carried out by using engineering shaping theory. The deformation characteristics in the forming process of longitudinal beam are verified. The finite element simulation tests of various schemes are carried out according to the plastic large deformation theory, and the causes of defects in key parts are analyzed to make the products meet the design requirements.**

Keywords **– Variable Section Longitudinal Beam, Flexible Roll Forming, Finite Element Analysis.**

I. INTRODUCTION

Truck longitudinal beam is the main component of truck frame, which mainly bears various loads from the body [1]. The left and right longitudinal beams are the main body of the whole frame. Since the truck needs to meet certain bearing requirements, the longitudinal beams are generally designed to be thicker and longer in size. At present, the processing of automobile longitudinal beam mostly adopts die forming [2]. Although this process has a wide range of application, it has high cost and is not conducive to the renewal of products [3]. The appearance of rolling forming process breaks the original layout of longitudinal beam processing process, but at present, due to the limitations of rolling equipment and technology, only equal cross-section straight beams can be processed, and the U-shaped equal cross-section beams can be folded into the frame shape of front width and rear width along the longitudinal direction by bending machine to produce variable cross-section beams [4].

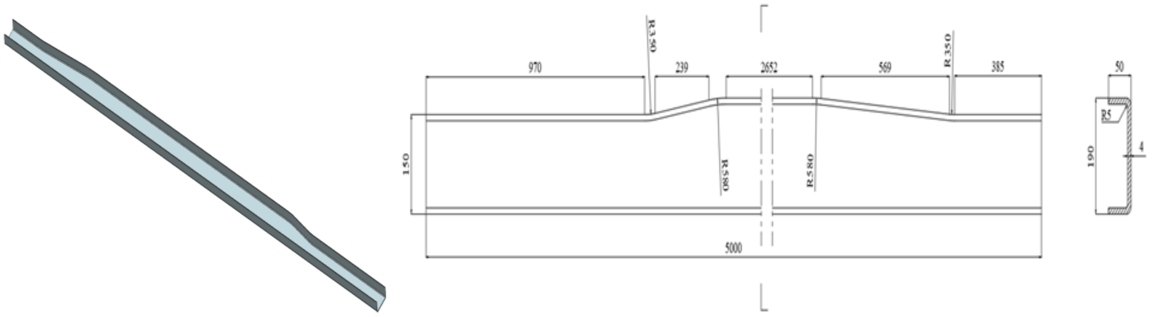
Variable cross-section roll forming technology can overcome the limitations of traditional rolling [5]. By adding an independent servo motor drive on some frames and driving the roll to move laterally through the computer-controlled motor, products with variable cross-section along the longitudinal direction of the sheet metal cross-section can be produced. Such products can better meet the requirements of building and bearing load [6]. Wang Shipeng studied the springback of the edge leg of variable section roll bending profile in the whole bending process, and considered the effects of material properties, plate thickness and edge leg height on springback by means of simulation analysis and experimental research [7]. Xiao Xiaoting and others analyzed and discussed the reasonable process parameters of drawer guide roll forming by using the method of theoretical calculation and finite element simulation [8]. Wang Ting used the improved wrinkling prediction criterion and the finite element method to investigate the wrinkling problem of convex arc compression instability in the process of variable section bending, and calculated the wrinkling factor to study the wrinkling problem around the convex arc of sheet metal [9]. Wang Zailin focused on the fracture of ultra-high strength steel sheet in roll forming, and studied the cracking phenomenon of ultra-high strength steel roll forming with corresponding bending radius by using ductile fracture criterion [10].

In this paper, the finite element simulation of the forming process of variable section longitudinal beam is carried out based on ABAQUS software. This method is used to reduce the design cost of variable section forming and shorten the design cycle of variable section longitudinal beam products.

II. ESTABLISHMENT OF FINITE ELEMENT MODEL

A. *Structural Dimension of Longitudinal Beam*

Taking the automobile longitudinal beam provided by an enterprise as the research object, the finite element simulation is carried out. One side of the longitudinal beam wing plate is a fixed section and the other side is a variable section. The longitudinal beam is made of Q420 steel, with a thickness of 4mm and a total length of 5000mm. The three-dimensional model, size and shape of the longitudinal beam are shown in Figure 1, and the material properties of the longitudinal beam are shown in Table 1.



(a) 3D model drawing of longitudinal beam.

(b) Longitudinal beam size.

Fig. 1. Dimension and shape of longitudinal beam.

Table 1. Material properties.

Material	Young's Modulus /GPa	Poisson's Ratio	Density/Kg/m³	Yield Strength/MPa	Tensile Strength/MPa
Q420	203	0.3	7850	420	680

B. *Finite Element Model*

The model is imported into ABAQUS software for assembly, and six pass rolls are selected for forming, with forming angles of 15 °, 30 °, 45 °, 60 °, 75 ° and 90 ° respectively. The roll spacing is set to 400mm. The display dynamics is used for this analysis and calculation. Since the dimension in the length direction of the sheet is much larger than that in the thickness direction, S4R shell element is selected. Since the deformation of the roll can be ignored, analytical rigid body is selected for modeling. The simulated sheet metal forming speed is set to 2000mm/s, the total simulation time is set to 3.8s and the assembly drawing is shown in Figure 2.

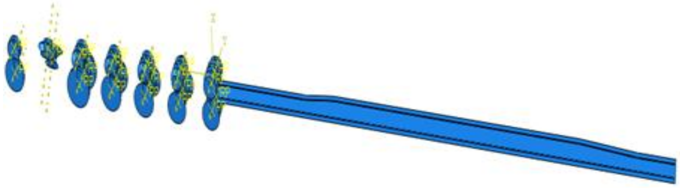
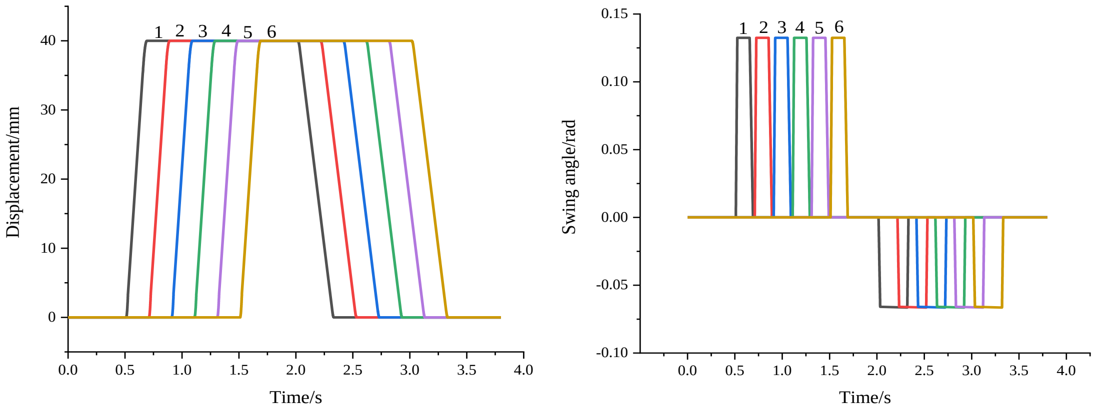


Fig. 2. Assembly model.

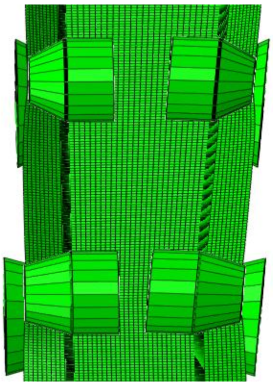
C. *Boundary Condition*

The movement track of each pass roll at the variable section edge is programmed by reading the DXF file of the sheet metal in Python. After determining the contour equation of the sheet metal, interpolation is carried out to take points, calculate the coordinates and slope of the interpolation points, and then convert them into the movement amplitude in ABAQUS. In the forming process, the roller group and the variable section edge of the profile always maintain a vertical relationship. The transverse displacement and swing angle of each pass roll at the variable section edge are shown in Fig. 3. The fixed section side roll does not need to move, and the six degrees of freedom of the roll can be completely constrained.



(a) Displacement diagram of 1-6 passes of e roll.

(b) Swing angle diagram of 1-6 passes of roll.



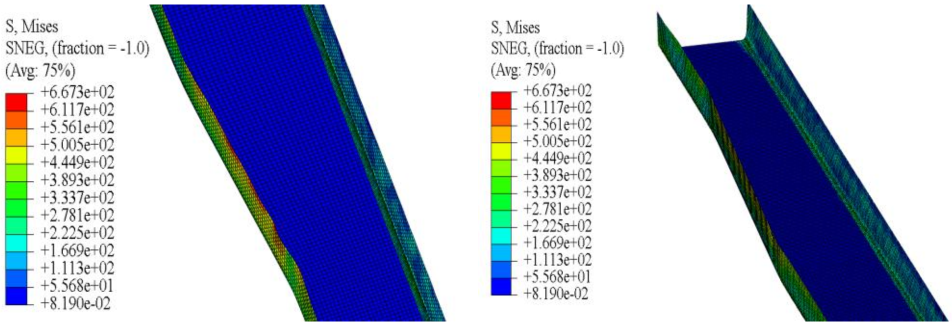
(c) Schematic diagram of roll movement.

Fig. 3. Motion diagram of variable section side roll.

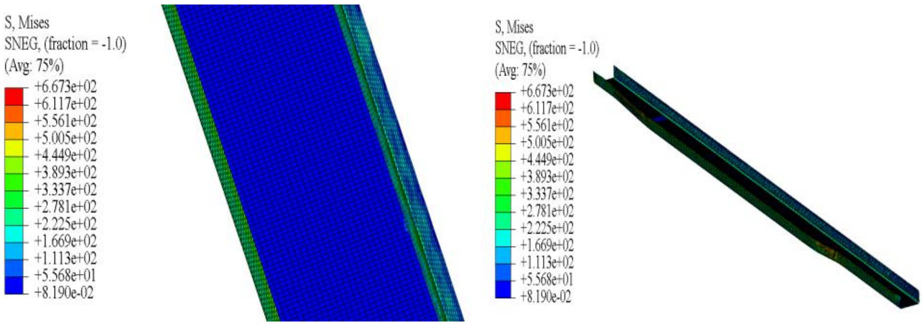
III. ANALYSIS OF SIMULATION RESULTS

A. *Analysis of Overall Simulation Results of Longitudinal Beam*

The stress distribution of the longitudinal beam after forming is shown in Figure 4. The position with the maximum stress is located at the position where the sheet section becomes narrow and wide, and there is a slight wrinkle at the front end. However, the forming condition is good at the position where the sheet becomes narrow and the middle position, and the stress distribution is relatively uniform. The overall stress of variable section wing plate is higher than that of constant section wing plate, which is due to the continuous change of section shape and the large tensile and extrusion force in the forming process, which is consistent with the actual forming situation.



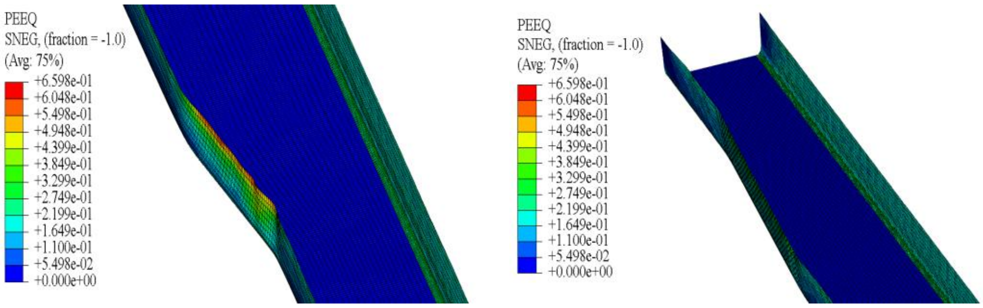
(a) Stress nephogram at narrow and wide section. (b) Stress nephogram at section width narrowing.



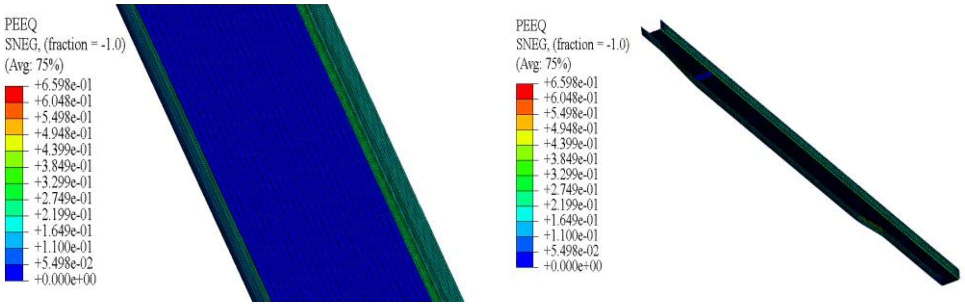
(c) Stress nephogram at middle equal section. (d) Overall stress nephogram.

Fig. 4. Nephogram of longitudinal beam stress distribution.

The strain distribution of the longitudinal beam is shown in Figure 5. The maximum strain is located at the position where the section changes from narrow to wide, which is roughly consistent with the stress distribution. The strain at the narrower section is less than that at the narrow side, but higher than that at the fixed section, which is also caused by the uneven stress of the plate at the variable section.



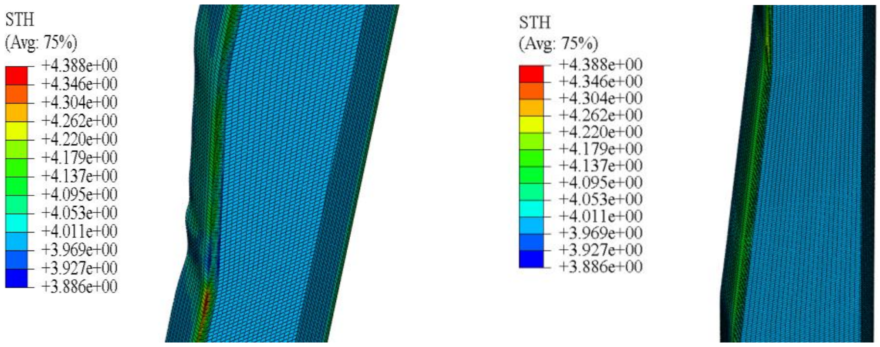
(a) Strain nephogram at narrow and wide section. (b) Strain nephogram at section width narrowing.



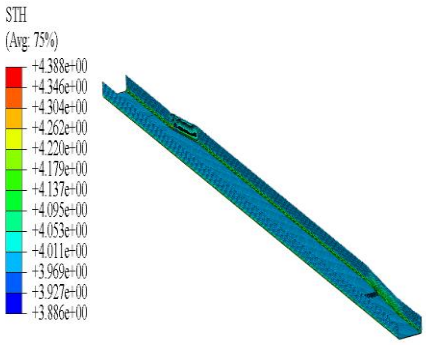
(c) Strain nephogram at middle equal section. (d) Overall strain nephogram.

Fig. 5. Nephogram of longitudinal beam strain distribution.

The thickness distribution of the longitudinal beam is shown in Figure 6. It can be seen from the figure that the material of the longitudinal beam first accumulates and then thins significantly at the position from narrow to wide, with the accumulation amount of 0.388mm and the thinning amount of 0.114mm. In the follow-up, we will focus on the optimization of this position. The thickness changes relatively evenly from wide to narrow, and there is no large fluctuation. On the whole, the position with large thickness change still appears at the position of variable section flange.



(a) Thickness nephogram of narrow and wide section. (b) Thickness nephogram at section width narrowing.



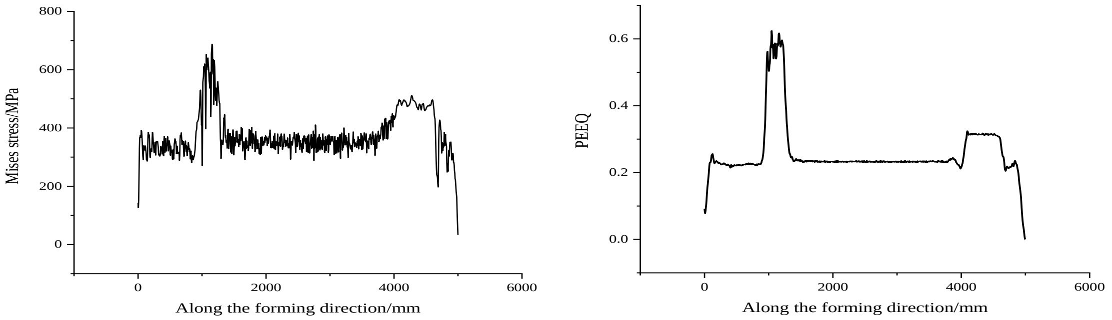
(c) Overall thickness nephogram.

Fig. 6. Nephogram of longitudinal beam thickness distribution.

B. *Analysis of Simulation Results at Variable Section Flange of Longitudinal Beam*

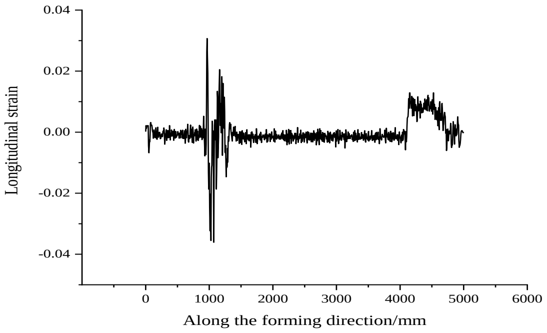
Due to the complex stress on the variable section wing plate of the longitudinal beam and easy to crack and fold, it is the key analysis part. In this paper, the stress and strain of the outermost grid of sheet variable section wing plate after longitudinal beam forming are analyzed.

Figure 7 shows the distribution of equivalent stress, equivalent plastic strain and longitudinal strain of variable section flange along the forming direction. It can be seen from the curve that the stress and strain distribution of the variable section flange at the position from narrow to wide is significantly larger than that at the position from wide to narrow and the middle fixed section. The stress and strain distribution are generally the same, and there are obvious fluctuations in the stress and strain at the position from narrow to wide, From the longitudinal strain distribution diagram, it can be seen that the wing plate is subjected to the fluctuation of tensile and compressive stress in the area from narrow to wide and variable section, resulting in the side wave and folding of the wing plate.



(a) The variable section flange stress nephogram.

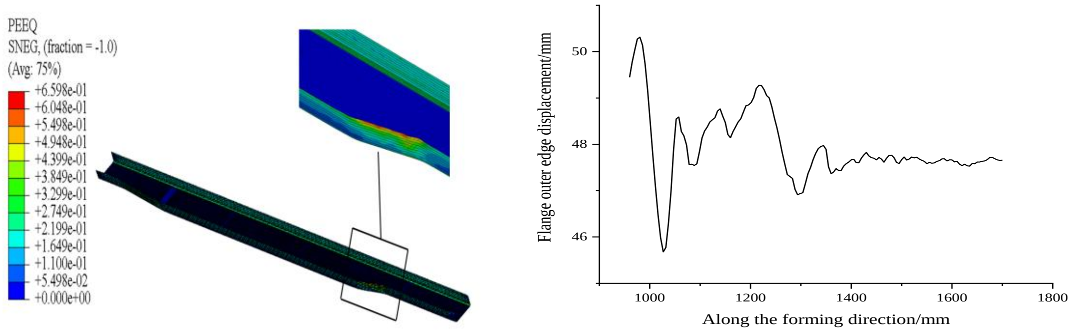
(b) The variable section flange strain nephogram.



(c) The variable section flange longitudinal strain nephogram.

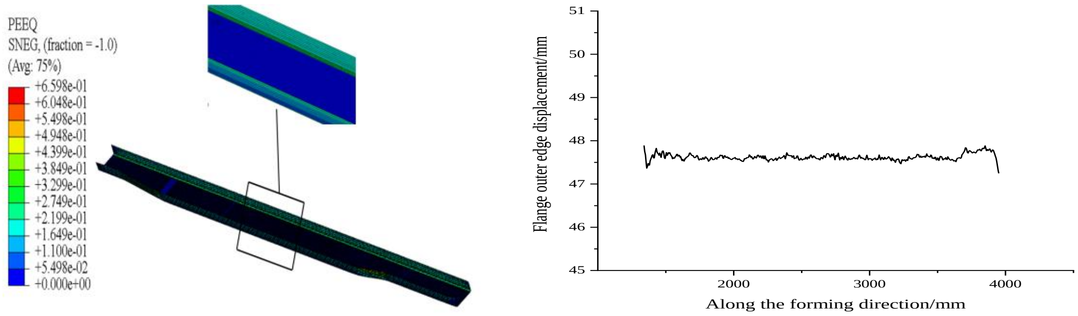
Fig. 7. Nephogram of stress-strain distribution of variable section flange.

By analyzing the stress and strain of the outer edge of the variable section flange after forming, the possible skirt wrinkle and side wave phenomenon of the longitudinal beam at the variable section flange can be predicted. Fig. 8 is the displacement nephogram of the outer edge of the variable section flange, which can intuitively find the distribution of the side wave.



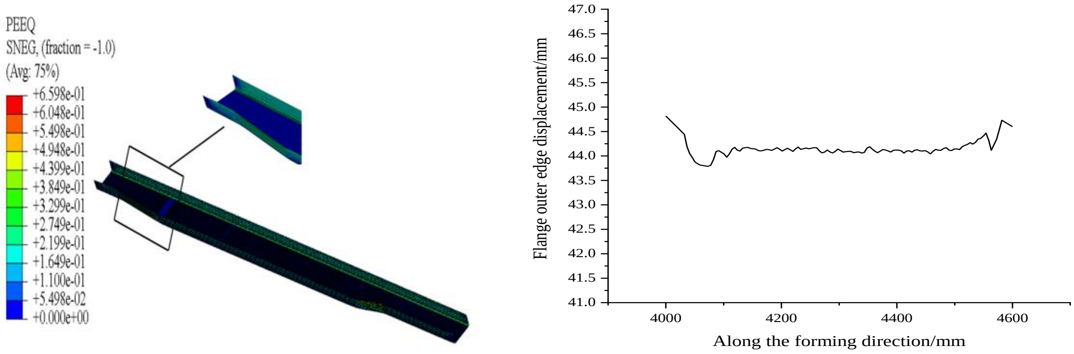
(a) Diagram of side wave at variable cross-section.

(b) Diagram of front flange outer edge displacement.



(c) Diagram of side wave at medial position.

(d) Diagram of medial flange outer edge displacement.



(e) Diagram of side wave at variable cross-section.

(f) Diagram of rear flange outer edge displacement.

Fig. 8. Displacement nephogram of the outer edge of the variable section flange.

As can be seen from Fig. 8, the fluctuation of the outer edge of the flange at the position of narrowing and widening of the variable section is the largest, so there is a more obvious side wave distribution in the flange at this position, while the fluctuation at the middle position and widening and narrowing position is relatively stable as a whole, the forming condition of the flange is relatively good, and there is no obvious side wave phenomenon.

IV. CONCLUSION

In this paper, the rolling forming process of automobile variable section longitudinal beam is designed, including the selection of longitudinal beam material, the determination of variable section forming passes, the distribution of forming angle and the determination of frame spacing. The finite element modeling of automobile variable section longitudinal beam rolling forming is studied, including the selection of plate model, roll model, element selection, forming speed Determination of boundary conditions and control of roll trajectory in forming process.

1. The stress-strain distribution of each part on different sections and the side wave in local area are analyzed. By comparing the stress variation law of profile in the whole forming process, the defects of wing plate forming after forming are explained.
2. The stress and strain of the variable section from narrow to wide wing plate is greater than that of other parts of the section, and the stress and strain of the corner is greater than that of the middle of the wing plate. By analyzing the variation of the lateral displacement of the wing plate in the forming process of the longitudinal beam, the area where the side wave is easy to occur in the forming process of the profile is determined;
3. The side wave degree of the longitudinal beam from narrow to wide position is greater than that of other positions. According to the side wave situation at the variable section wing plate, the corresponding optimization design can be carried out for this position.

Through the research of this paper, the finite element method is used to simulate the roll forming of automobile variable section beam, which can get more appropriate results. This method is used to reduce the design cost of roll forming of automobile variable section longitudinal beam and shorten the product design cycle of variable section longitudinal beam.

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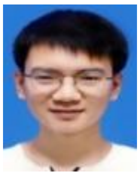

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