ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0004

Structure Optimization and Cost Analysis of Automotive Front Rail

Xing Hu[1, a, *]

[1]School of Mechanical Engineering, Shanghai Dianji University, Shanghai 201306, China

[a]Email of Corresponding Author: hux@sdju.edu.cn

Abstract

The development of new vehicles often goes through a long process. Simultaneous engineering could integrate process and development of products in parallel. The front rail is one of the important components of the body frame. According to the recent studies, this paper proposes the structural design process of the front rail by using the basic theory of simultaneous engineering. Then the stamping process analysis of the front rail is carried out, and the structure optimization and cost analysis are completed. Hence, the CAD model of the part is perfected at the part design stage, so as to reduce the development cost, shorten the development time and improve the quality of design.

Keywords

Simultaneous engineering; front rail; structure optimization; cost analysis.

1. INTRODUCTION

The traditional automotive product development method is called Serial Engineering. This method is characterized by the development of different parts of the product in different departments. The latter developing process begins after the previous process is completed [1, 2]. Therefore, the work of the previous process often does not take into account the needs of the latter work. This will make a lot of adjustments and modifications in the later stage, increase the workload, waste manpower and material resources, extend the development cycle, and increase the pressure on warehouse inventory. For example, the product manufacturing is at the end of the entire development cycle. Manufacturing formability is often overlooked until the product is fully designed. This will cause some manufacturing defects to be exposed at the end of the entire development cycle [3].

Simultaneous Engineering (SE) is an effective method to solve product quality, cost and cycle [4]. SE is a systematic approach to the simultaneous design of the entire product development process, which promotes developers to consider all factors (including quality, cost, schedule, and user requirements) from concept formation to the final disposal throughout the whole product life cycle [5]. It synchronizes the current inter-departmental work (including suppliers and collaboration units) as much as possible. The stamping SE combines stamping process with computer-aided engineering. This will lead to the discovery of the stamping defects advances from the late car verification stage to the early design phase. In this way, not only time would be solved for problem solving, but also a large number of design changes and post-verification costs can be avoided. The application of stamping SE could play a vital role in shortening the development cycle of sheet metal parts, reducing the cost of tooling, sheet and post production, and improving product quality[6,7].

The front rail is the most important energy absorbing element in the energy absorbing structure at the front of the vehicle body [8-10]. When a frontal collision occurs in the vehicle,

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0004

the bumper collapses, and the front rail is deformed to absorb the collision energy. The ideal deformation energy absorption mode of the front rail is to produce wrinkles to absorb more collision energy. The front rail has a complicated shape with a high surface quality requirement, a sharp change in the section height, and a local forming feature.

This paper uses the basic theory and technical methods of stamping SE. The structural design flow of the front rail is proposed. Then the stamping process of the front rail is analyzed. And the structural improvement of front rail is carried out by using stamping finite element simulation software taking into consideration the whole stamping process. The manufacturing cost of the parts is analyzed based on the obtained optimization structure and stamping process. Hence, perfecting the digital model in the early design stage could help to reduce cost, shorten time and improve the quality during automotive body development.

2. STAMPING SIMULATION OF FRONT RAIL

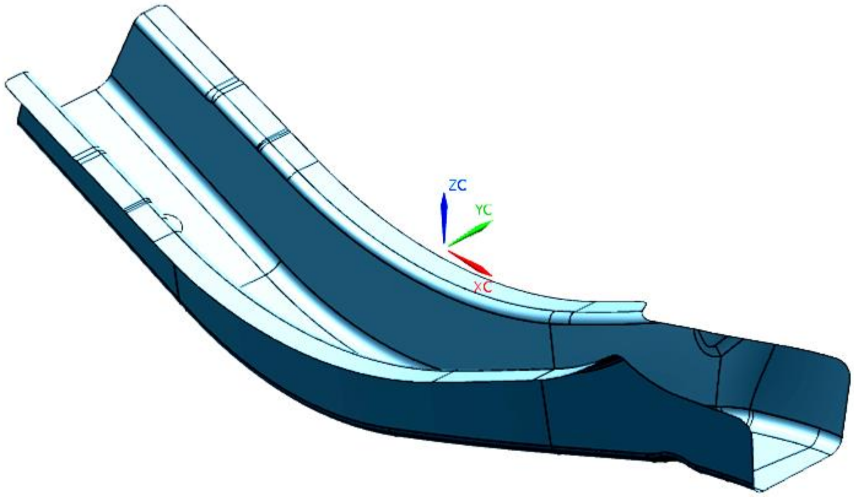

Fig 1. Geometry model of the front rail

The object of this study is the front rail of some car from SGM. Fig.1 shows its original geometry. The 3D space size of the part is 570×120×240 mm with a thickness of 2.2 mm. The front rail has a complicated shape with a high surface quality requirement, a sharp change in the section height, and a local forming feature. Its stamping process and mold design have certain difficulties. In order to meet its functional and safety performance, the strength and stiffness of the part must be guaranteed, while the strength level of the raw materials is increased [11]. The structural characteristics of the front rail results in the difficulty of controlling the forming quality.

The stamping simulation is produced by finite element analysis software to deal with geometry model and part stamping process. Thus the defects that may occur during stamping process would be noticed. This paper uses the stamping finite element simulation software to study the forming process of the front rail. The analysis process is shown in Figure 2.

After importing the digital 3D model into the stamping finite element analysis software, it is necessary to mesh the digital model by software. The quality of meshing will directly affect the computational efficiency and accuracy, and as well will affect the convergence of the computational results. The finer the mesh is, the higher the computational accuracy, but the computational efficiency will decrease. Therefore, engineers must perform meshing according to the requirements of the enterprise when performing stamping simulation analysis.

ISSN: 2472-3703
DOI: 10.6911/WSRJ.201908_5(8).0004

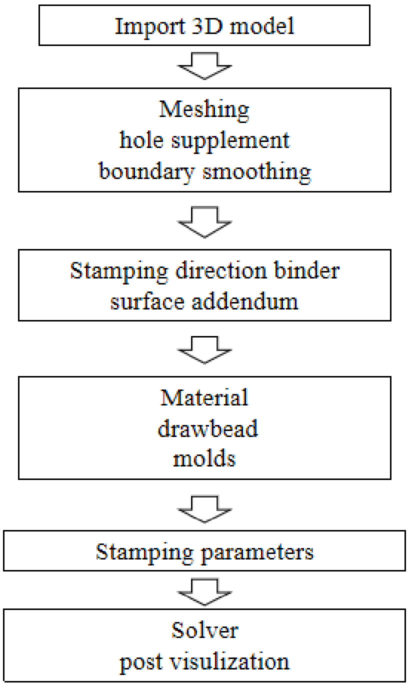

Fig 2. Numerical modeling procedure of front rail

Determining the punching direction is an important step after setting the 3D digital model related properties. In general, there are two aspects to consider when determining the direction of stamping: First, there is no undercut angle stamping. And second, the punching depth should not be too deep and relatively uniform. Meanwhile, the blank and the punch must have good contact to ensure that there are no defects such as wrinkles in the formed part.

The Z direction (paper facing inward) in Fig.3 is the punching direction of the front rail. According to the shape characteristics of the front rail, the drawing direction has a moderate drawing depth, the left and right sides are relatively balanced, and there is no undercut drawing, and the blank and the punch can be ensured to have good contact condition.

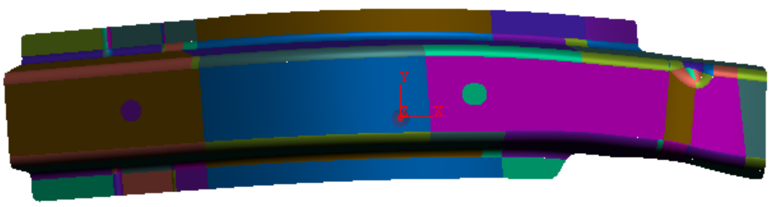

Fig 3. Stamping direction of front rail

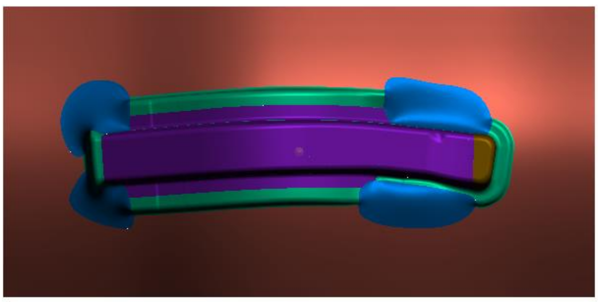

Fig 4. Addendum surfaces for front rail stamping

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0004

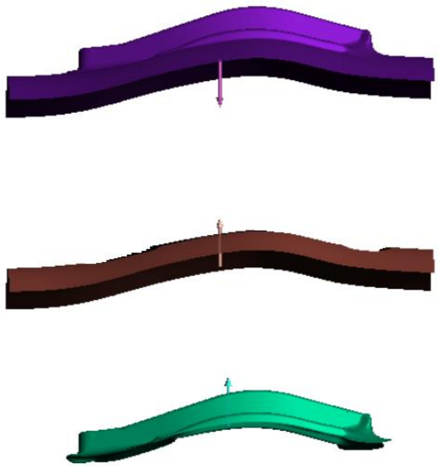

Fig 5. Finite element model of front rail

The binder surface is obtained by choosing the addendum surfaces. The addendum surfaces complement the holes and faces of the part to make it a closed and complete surface [12]. The addendum surfaces directly affect the deformation conditions, deformation amount, deformation distribution, surface quality, wrinkling and cracking of the sheet during stamping. The addendum surfaces will be trimmed after the deep drawing process is completed. Therefore, the addendum surfaces should be as small as possible, so as to improve material utilization, save cost, and leave enough margins for the subsequent trimming, flanging and other processes. For the front rail, its structure is long and narrow, and it has fewer holes, so its addendum surfaces are mainly located at both ends and the root. The addendum surfaces of the front rail in this study is as shown in Fig.4.

It is convenient to design the die, the punch, the binder and other molds of the part in the finite element software. According to the previous addendum surfaces, the finite element analysis model of the front rail is shown in Fig. 5.

The shape of the blank has an important influence on the material utilization and the stress-strain distribution during the stamping process, which is the key factor to the qualification of the stamping parts [13]. The shape of the front rail is complex, and the shape of the blank can be calculated by the finite element software's blank size estimation function. Through the actual engineering experience, considering the layout of the sheet and its economic requirements, a more regular and reasonable blank geometry is designed. After several optimizations and comparisons, the blank of the front rail is a rectangular panel of 580 × 320 mm.

The selection of blank material is one of the contents of the stamping process plan. A galvanized sheet for cold forming is used for front rail. The material type is HX340LAD with a thickness of 2.2 mm, which is shown in Tab.1.

Tab 1. Material properties of HX340LAD

Material	Density	Elastic Modulus	Poison's Ratio	Yield Strength	Tensile Strength	Plastic Strain Ratio
HX340LAD	7.8×103 kg/m3	210 GPa	0.3	340 MPa	510 MPa	0.694

Blank holding force is one of the important process parameters for controlling sheet metal forming, which directly affects the quality of stamping. Adjusting the correct blank holding force has a significant effect on controlling wrinkles and cracking, and suppressing springback and

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0004

other defects. The design of the blank holding force should be continuously optimized according to the part requirements, work experience, simulation analysis results, etc[14]. The unit blank holding force of the front rail is set to be 3 MPa. By correctly selecting the friction coefficient, the friction state during stamping process can be realistically simulated, so that the numerical simulation results are more consistent with the actual stamping. According to the production conditions, technical level and practical work experience of the domestic mold production companies, the friction coefficient in the stamping simulation is set to be 0.15[15].

Fig.6 shows the forming results of front rail. The seven colors including red, orange, yellow, green, gray, blue, and purple, represent different forming conditions of the material during the stamping process. The red area (Splits) represents that the material in this part of the area will be cracked during the stamping process. The orange area (Excess. thinning) represents the excessive thinning of the material during the stamping process, where is close to crack. The yellow area (Risk of splits) represents the risk of cracking of the material in the area. The green area (Safe) represents the safe deformation of the material during the stamping process. Materials there could meet the requirements of the quality and safety performance of the part. The gray area (Insuff. stretch) represents that the material in this area is insufficiently stretched and has no plastic deformation. The blue area (Compress) represents that the part of the material is subjected to in-plane compressive stress during the stamping process, and there is a risk of wrinkling. The purple area (Thickng) represents the wrinkling of the sheet during the stamping process.

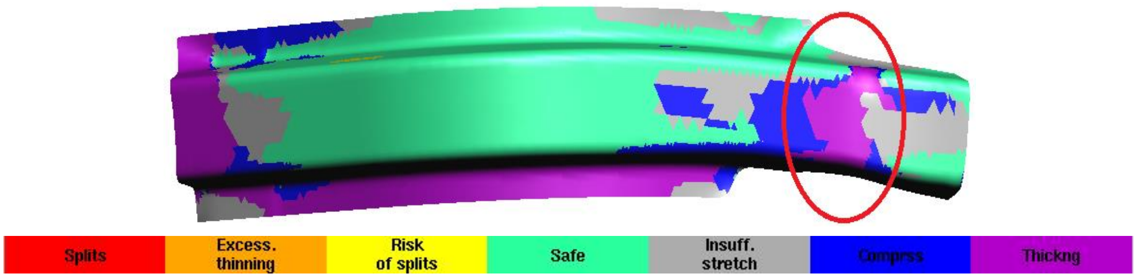

Fig 6. Forming results of front rail stamping

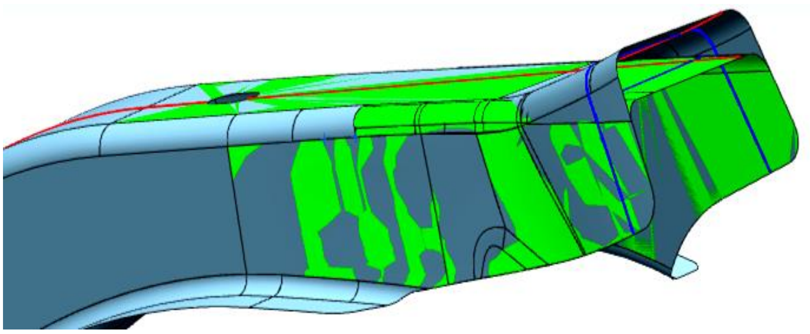

Fig 7. The modification of front rail surfaces

It can be seen from Fig. 6 that there exist local wrinkles in the stamping of the front rail, and the formability of the front rail can't meet the manufacturing requirements. So it is necessary to optimize the 3D digital model by stamping SE technology. The reason for the wrinkling of the sheet is the accumulation of materials caused by poor material flow. In order to solve the wrinkles appearing in sheet metal forming, it is necessary to make a targeted modification of the original 3D digital model to improve the flow of the materials during stamping. The area

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0004

where the front rail is prone to wrinkle is shown in Fig. 6, which is located at the connection area between the front and the middle zone. This area is located on the final front rail, so it affects the mechanical properties and structural properties of the entire part. And the surrounding curved surface at this area changes a lot. Smoothing surface connection of this area is considered to eliminate wrinkle defects. The 3D digital model modification is shown in Fig.7. This modification can reduce the local compressive stress and slow the compression of the material during stamping, and help to eliminate wrinkle defects.

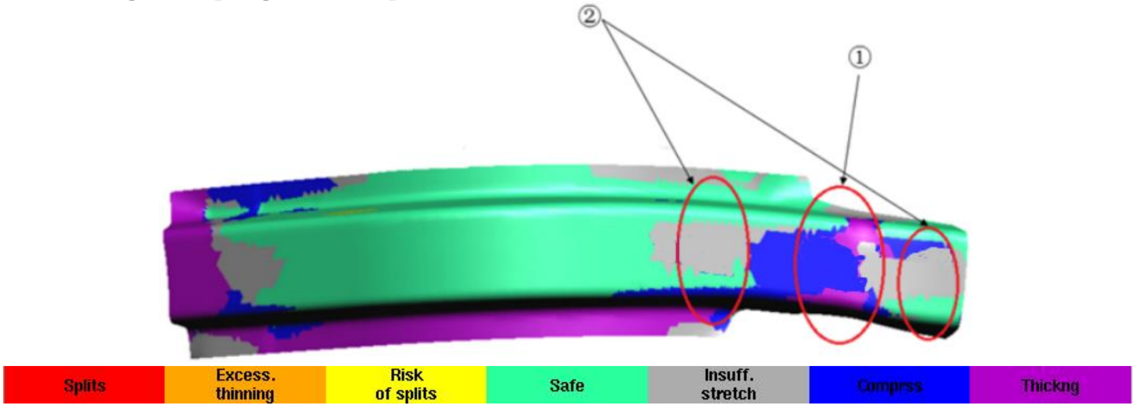

Fig 8. Forming results after model modification

Fig.8 shows the forming results after model modification. The stress state in zone ① area where wrinkles happened is changed into compressive stress state. The stress state in zone ② where materials are under compressive stress state is changed into insufficiently stretched. It is obvious that the wrinkled area is significantly eliminated after the 3D digital model is changed.

3. STAMPING COST ANALYSIS OF FRONT RAIL

Deep drawing is one of the basic stamping processes. The following calculations are based on the existing 3D digital model to get the stamping tonnage of the press, and the actual production situation of the enterprise to calculate the stamping cost of the front rail. When selecting the press tonnage required for cold stamping, the tonnage of the press can be selected according to the calculation of punching force and pressure of the stamping part [16].

The press tonnage is calculated as follows,

$$F \geq F_{punch} + F_{pressure} \tag{1}$$

$$F_{punch} = KLt\sigma_b \tag{2}$$

Where

K——coefficient, K=1;

L——perimeter of the digital model, mm;

t ——thickness of the part, mm;

σ_b ——tensile strength of the material, MPa.

According to the measurement, the front rail has a perimeter of 1555 mm, a thickness of 2.2 mm and a tensile strength of 500 MPa.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0004

$$F_{punch}=1\times1555\times2.2\times500=1710500(N)=1710.5(kN) \quad (3)$$

Take a tonnage of 170 ton for the punch force.

$$F_{pressure}=PA \quad (4)$$

Where

P——unit blank holding force, Mpa;

A——area of stamped part, m2.

The unit blank holding force of the front rail is set to 3MPa. Due to the complex structure of the front rail, the actual stamped area is not easy to measure accurately. Here, it is estimated that half of the sheet (320 mm × 580 mm) material is stamped.

$$F_{pressure}=PA=3\times(0.5\times320\times580)=278400(N)=278.4(kN) \quad (5)$$

Take a tonnage of 28 ton for the blank holding force.

$$F\geq F_{punch}+F_{pressure}=170+28=198(ton) \quad (6)$$

Take a tonnage of 200 ton for the press.

Check the relevant data and enterprise data, and obtained cost prices as shown in Tab.2. According to the market price, HX340LAD for the front rail is 8 yuan/kg, and the density of the material is 7.8×103kg/m3.

Therefore, the stamping costs are calculated as follows:

$$\begin{aligned}C&=C_{stamp}+C_{mat}\\&=(0.4+0.4+0.3+0.3+0.3)+580\times320\times2.2\times10^{-9}\times7.8\times10^{3}\times8\\&=1.7+25.5\\&=27.2(\text{yuan})\end{aligned} \quad (7)$$

Hence, the cost of stamping of a single front rail is 27.2 yuan.

Tab 2. Costs of stamping processes

No.	Operation	Tonnage/ton	Cost/yuan
1	Blanking	150	0.4
2	Deep Drawing	200	0.4
3	Trimming	150	0.3
4	Piercing	150	0.3
5	Restriking	150	0.3

4. CONCLUDING REMARKS

In this paper, the structural optimization and stamping cost calculation of the front rail is carried out in combination with the technical methods of stamping SE and the practical work experience of structural optimization. The stamping simulation of the front rail and the analysis of the forming results are used to analyze the possible causes of the forming defects. The corresponding structural improvement is made to the parts where the stamping forming defects may occur based on the stamping experiences. The formability comparison of the parts before and after the structural improvement is made under the same stamping condition. Based on the structural improvement, the stamping cost of the front longitudinal beam is analyzed. The analysis results are of great significance for shortening the development cycle, reducing costs and improving product quality of the front rail.

ACKNOWLEDGEMENTS

The author acknowledges the support from Shanghai University Teacher Production and Research Practice Plan (No.CXYDJ19013) in 2019.

REFERENCES

[1] Cheng G, Xie H, Yang D, Zhong Z. Research on the key technologies of simultaneous engineering for the development of automobile body die [J]. Die and Mould Technology, 2008, 1:5-9.

[2] Chen x, Gao H, Peng Y, Hu R, Fang T.Application of stamping simultaneous engineering on automobile development[J]. Journal of Xinxiang University(Natural Science Edition), 2013,1: 49-51.

[3] Wang W, Ji G. Brief introduction of the application of stamping simultaneous engineering in automobile development process [J]. Equipment Manufacturing Technology, 2013, 6: 112-114.

[4] Yuan Z, Zhao X, Hu J, Cheng A.Design Process Analysis of Vehicle Body Based on Simultaneous Engineering[J]. Development and Innovation of Machinery and Electrical Products, 2009, 22(05): 81-83.

[5] Shen D. Application of Simultaneous Engineering in BIW Development [J]. Auto Engineer, 2017, 8: 52-55.

[6] Xiong J, Yang Y, Du K. Research on the application of SE for B.I.W design and development [D]. SAE-C2009C132, pp.1391-1396.

[7] Huang X, Shen D, Cheng A. Analysis and research of pressing process simultaneous engineering on vehicle body development [J]. Development and Innovation of Machinery and Electrical Products, 2010, 23(05):73-75.

[8] Li C, Yang Y. Spring-back control on front rail of auto-body [J]. Forging and Stamping Technology, 2016, 41(11):58-61.

[9] Cui Z, Yang D. Analysis and treatment of stamping cracking of front longitudinal of Ultra-High Strength steel [J]. Journal of Netshape Forming Engineering, 2017, 9(06):42-46.

[10] Zhang S, Gao J, Men Y, Liu X, Wang D. Welding deformation optimization research for the truck rack girder based on finite element analysis [J]. Manufacturing Automation, 2013, 35(11): 37-41.

[11] Chen F, Wang Q, Zhang G, Wang X. Study on Energy-Absorbing characteristics of stiffened Thin-Walled tubes subject to axial crushing [J]. Computer Simulation, 2016, 33(3):139-143.

[12] Li L, Wu X. Multi-objective optimization on drawing technological parameters of medium channel part [J]. Forging and Stamping Technology, 2017, 42(5): 30-33.

[13] Huang Y. A method to improve material utilization ratio of automobile covering parts [J]. Forging and Stamping Technology, 2016, 41(8):59-62.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.201908_5(8).0004

[14] Chen P, Shi Z, Ci Y, Xiang X. Stamping simulation analysis based on tribological properties of die-binder area[J]. China Surface Engineering, 2018, 31(1): 59-66.

[15] Luo Y, Wang R, He D, Zhang Y. Determination of friction coefficient in sheet metal deep drawing [J]. Journal OF Shanghai Jiaotong University, 2001, 35(7):969-971.

[16] Yan C, Li P, Ma J. The tonnage selection of punching press in cold plate punching process[J]. China Metalforming Equipment and Manufacturing Technology, 2010, 45(1):93-94.