Lightweight Formula Racing Car Frame Design Based on Generative Design

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Abstract—The frame of a Formula Racing car is the core component connecting the arm and chassis frames, and it accounts for a relatively large proportion of the overall vehicle mass. In order to reduce the overall weight of the racing car and realize the lightweight innovative design of the frame, this paper utilizes the Fusion360 generative design tool to carry out the lightweight design of the frame structure of the Formula Racing car, and finally uses the ANSYS software to carry out finite element analysis on the generated frame model to verify the generative design of the frame structure to satisfy the mechanical properties at the same time, the quality is reduced by 18.7%, and the maximum deformation is reduced by 4.4%. The results show that the generative design can reduce the mass by 18.7% and the maximum deformation by 4.4% while meeting the mechanical properties. The results show that the generative design can realize the lightweight innovative design of the frame.

Keywords-Generative design; Lightweighting; Formula car; Frame design; Finite element analysis

1 Introduction

Currently, the global automotive industry is in a critical period of transformation and upgrading, regardless of the manufacturing model or industrial form, there is an urgent need for intelligent change [1].

In order to reduce the cost and energy saving, the lightweight technology of electric formula car has become an important research topic in the development of electric formula industry[2], exploring the methods and approaches of lightweight electric formula car, reducing the consumption of materials, and reducing the electric energy consumption in the driving process has become one of the core competitiveness of the electric formula car enterprises. Therefore, for racing cars, the lightweight design of the frame is of great significance. As the carrier of the racing car, the quality of the frame accounts for a large proportion of the whole car, and its lightweight design helps to improve the specific power of the racing car, reduce the fuel consumption rate of the racing car, and improve the power performance of the racing car [3].

In recent years, many scholars have conducted a lot of research on the lightweight design of racing car frame components, Li Fang et al [4] used the topology optimization method of variable density to carry out the lightweight design of the frame; Liu Conghao et al [5] optimized the cross-sectional shape and dimensional parameters of the frame steel tube, and reduced the

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weight of the frame under the requirement of meeting the strength design. reduced the weight of the frame. From the above literature, it can be seen that the current research on the lightweighting of racing car components mainly focuses on topology optimisation, size optimisation and shape optimisation, while there are fewer studies on the generative design of body parts.

With the help of artificial intelligence technology, generative design is able to generate multiple feasible solutions synchronously according to customer manufacturing conditions and product performance requirements, such as strength, weight, and material [6]. Computer simulations and analyses are used to determine the optimal structural parameters to achieve component mass reduction while meeting strength and stiffness requirements. In addition, generative design can be used to assist in material selection by analysing and comparing the properties of different materials to provide designers with recommendations for optimal material selection [7]. Airbus used generative design to develop "bionic bulkheads" for aircraft isolation panels and rear-seat support structures, which ensured strength while reducing mass by 45% [8]; Wang Hongyu et al [9] used generative design method to achieve the lightweight innovative design of the turntable, the turntable structure to meet the mechanical properties of the working conditions at the same time, the quality of 12% reduction.

In this paper, according to the requirements of frame structural design, the generative design module in the cloud-based CAD/CAM/CAE software Fusion360 is used to carry out the generative design of the Formula Racing car frame, exploring the ideal structural form of the frame to achieve the purpose of lightweighting under the premise of meeting the performance requirements.

2 Generative Design of Formula Racing Frames

2.1 Overview of Generative Design

Generative design mimics the way in which organisms evolve in nature and requires only the input of specific design goals, such as mechanical loads, displacement constraints, manufacturing methods, materials, etc. The application specifies the design requirements and then evaluates them in a programmed synthetic design space. The application specifies the design requirements and then evaluates a large number of generated designs in a procedurally synthesised design space to see if they meet the design requirements. Feedback is also given on the performance data of each solution throughout the design space. Objectives and constraints can be adjusted at any time during the real-time evaluation of design solutions to generate new results that meet the optimisation definition. Selection of a satisfactory design solution allows the design to be exported to generate geometric elements for use in other CAD programmes [10].

Fusion360 is a cloud-based CAD/CAM/CAE tool that supports collaborative product development. Fast and easy organic modelling is balanced with accurate solid modelling, with a generative design module that defines the design problem in terms of goals and constraints and generates a design solution that meets the requirements [11].

2.2 Retention and Obstacle Geometry Elements

The design space is defined in the Generative Design module of Fusion360 according to the boundary conditions of the cockpit, the front rocker arm and the rear rocker arm installation. The generative design does not need to give an initial shape, but only determines the retained and obstacle geometry elements of the generative design based on the structure of the original design. Retained geometry elements are entities that are specified to be included in the final shape of the design and are shown in green. Obstacle geometry elements are entities that represent blank areas where material will not be placed during the generative process and are spaces that need to be avoided in the design; these entities are shown in red.

The mounting positions of the driver's seat mounting collar, the front rocker arm mounting collar, the tailgate bracket bushing and the chassis chassis aerodynamic assembly mounting collar are set as retained geometry elements, and the boundary conditions of the driver's cockpit, the front rocker arm, and the rear rocker arm are set as obstacle geometry elements, as shown in Fig. 1 & Fig. 2.

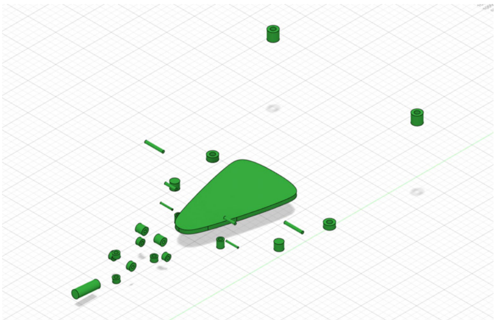

Figure 1 Retained geometric elements

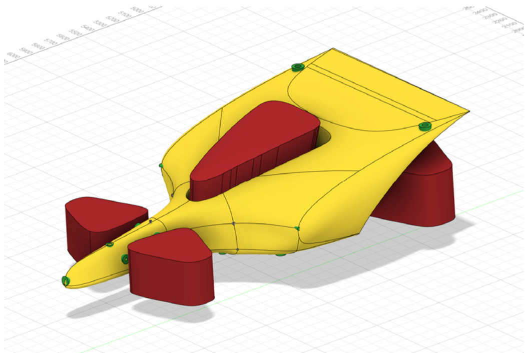

Figure 2 Obstacle Geometry Elements

2.3 Material Selection

The goal of the generative design of the Formula Racing frame is to reduce the mass of the frame structure while meeting the structural strength and stiffness requirements. Therefore, the frame material selection should meet the basic requirements of wide application, light weight, high strength, etc. In this study, two materials, 6061 aluminium alloy and 7075 aluminium alloy, were selected as the analysis materials for testing, and Table 1 shows the properties of the two materials.

The generative design module of Fusion360 can generate different structural models based on the given physical materials and manufacturing methods. The purpose of this study is the exploration of new forms of frame structure, in order to obtain a frame structure that meets the requirements of lightweight design, so the limitation of machining capacity is not considered, and the unrestricted machining method is uniformly chosen among the machining and manufacturing methods.

Table 1 Material properties

Material	Yield strength /Mpa	Tensile strength /Mpa	Permissible stress/Mpa
6061	240	290	120
7075	500	570	250

2.4 Setting Loads and Constraints

An important step in creating a part using Fusion360's Generative Design module is to determine the forces acting on the structural part during its operation. The frame is an important load-bearing component of a Formula Racing car and is required to carry the weight of the entire car and driver. Therefore, it is necessary to analyze the static forces on the frame of a Formula Racing car, which is subjected to the mass of the driver distributed on the cockpit support plate, the mass of the components mounted on the frame, and the mass of the frame itself, and the forces on the frame are shown in Figure 3 and Table 2.

In generative design, the following constraints are applied: the eight points connected to the front and rear suspension are constrained so that they cannot be displaced in the X-, Y- and Z-axis directions.

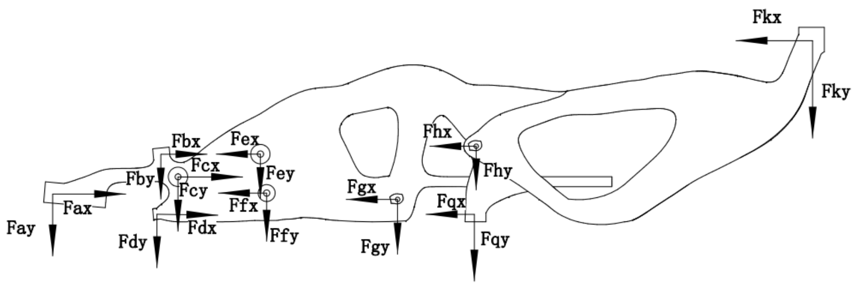

Figure 3 Schematic diagram of frame force

Table 2 Working condition load

working condition	Fa	Fb	Fc	Fd	Fe	Ff	Fq	Fh	Fg	Fk
Loading (Kn)	24	15	35	20	35	35	45	30	20	25

2.5 Result Generation and Preferences

The generative design can be used to obtain multiple design options, which are selected in the post-processing interface by filtering the design options and iteratively correcting the design parameters. The post-processing of the generative design module also provides preliminary feedback on the performance data of the selected design solution, which provides a preliminary understanding of the force state, mass and overall safety factor of the structure. The model of the selected solution has gone through 35 iterations. The iteration process of the model using two materials, 6061 aluminium alloy and 7075 aluminium alloy, is observed in the 3D view, as shown in Figures 4 and 5, and the most reasonable iteration version is selected.

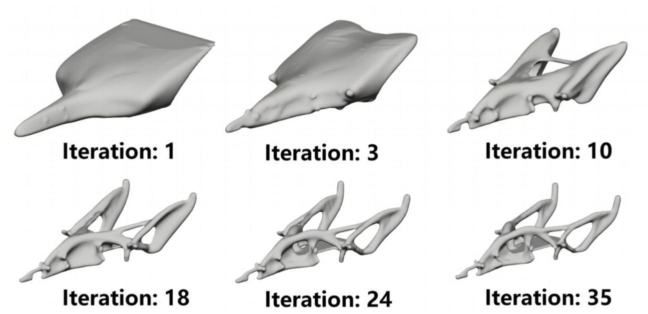

Figure 4 Iterative process for models using 6061 aluminium alloy materials

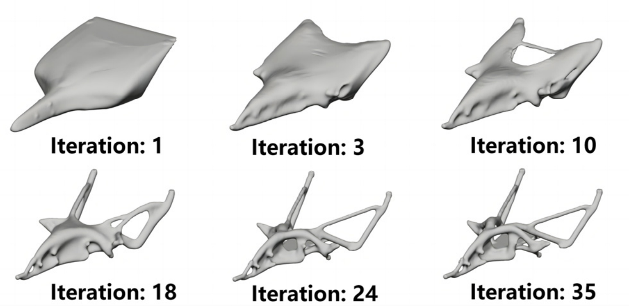

Figure 5 Iterative process for models using 7075 aluminium alloy materials

The generated results of the frame are shown in Table 3. During the generative design in Fusion360, the 30th generated result of the generative design using 6061 aluminium alloy material was finally selected as it was close to the limit for the final few times as the attributes such as mass and strength were combined, and the final selected model was exported as a STEP format file as shown in Fig. 6.

Table 3 Frame Generation Results

Material	Minimum safety factor	Mass/Kg	Maximum global displacement/mm
6061	2.724	235.388	1.426
7075	4.055	132.53	13.753

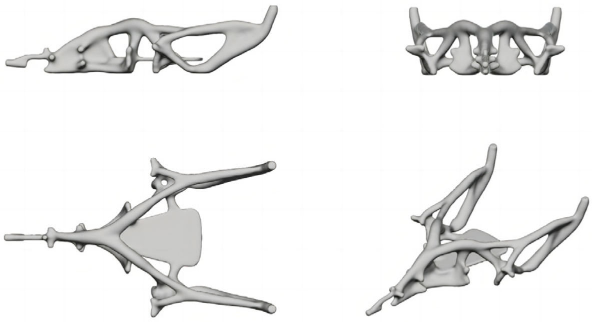

Figure 6 Frame structure obtained by generative design method

3 Comparison of the Analysis of the Results of the Generated Structures

The frame structure generated by Fusion360 and the frame structure before the original generation were simulated and analyzed in the finite element analysis software Ansys, and then the frame structure before and after the generation was compared. Figures 7 and 8 show the comparison of the frame structure before and after generation under normal working conditions. The simulation results show that the maximum stress value of the generated frame structure is located in the middle of the frame, which is 22.165Mpa, much lower than the permissible stress of the material 120Mpa, and the stress concentration range is small, the overall safety margin is large. The maximum total deformation of the generated frame structure occurs in the upper part of the rear end of the frame, which is 3.9299mm.

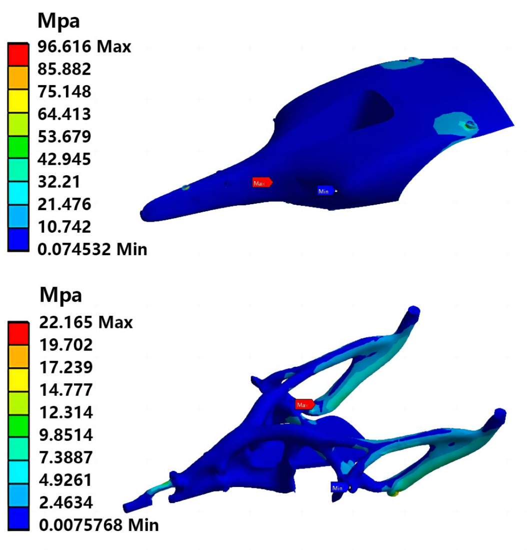

Figure 7 Overall stress cloud of the frame structure before and after generation

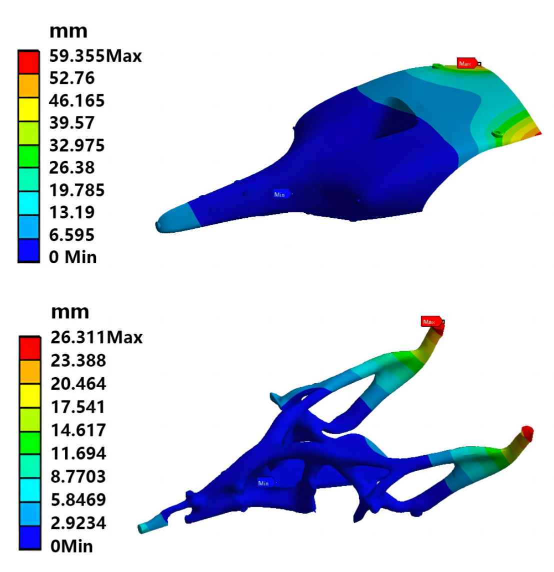

Figure 8 Overall deformation cloud of the frame structure before and after generation

Comparison of the frame structure program indexes before and after generation is shown in Table 4. The frame structure using the generative design balances the maximum stresses in the working conditions, so that the stress levels in the working conditions are greatly reduced compared with the original structure, and the material utilization is improved. The table data obtained from the simulation analysis shows that, compared with the original frame before generative design, the mass of the frame structure obtained by generative design is reduced from 708.41kg to 132.53kg, which is 18.7%, and the maximum deformation is reduced from 59.355mm to 26.311mm, which is 44.3%. It shows that the generative design can ensure that the structure maintains a better stiffness under the premise of satisfying the constraints and minimizing the structural mass, which verifies the effectiveness and rationality of the generative design.

Table 4 Comparison of frame structure before and after generation

	Original structure	**generated structure**	**After/before optimization**
Mass (kg)	708.41	132.53	18.7%
Deformation (mm)	59.355	26.311	44.3%
Equivalent stress (Mpa)	96.616	22.165	22.9%

4 Conclusions

The generative design method is applied to the design of a formula car frame, and the optimized model is subjected to finite element simulation, and the reasonableness and validity of the generative design results are verified by comparing the simulation results. The results show that the use of generative design method can achieve the purpose of lightweight under the design requirements of the Formula Racing car frame.

The generative design optimization result of this study is an idealized model, but the model shows the ideal material distribution of the frame and the optimal transfer state of the frame stress in the case of a fixed hinge point position, which can be a certain guidance for the existing frame design.

In future work, this paper will plan to use additive manufacturing techniques as well as experimental testing of these frame components to fabricate them.

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