Optimization Design of FSAE Racing Car Sprocket Based on ANSYS

Jing Zhou1,*, Yu Lin2, Zhengzhi Zhou3

1 Beijing Institute of Technology, Zhuhai, Zhuhai city, Guangdong province, China, 519088
2 Gac Hino Motor Co. LTD, Guangzhou city, Guangdong province, China, 510931
3 Weifang Xiashan urbn Construction investment development Co.,LTD, Weifang city, Shandong province, China, 261000
*Corresponding author’s e-mail: 04036@bitzh.edu.cn

Abstract. In order to improve the dynamic performance of FSAE racing car, the finite element analysis and lightweight design of racing sprocket are studied in this paper, Firstly, the parametric modeling of the big sprocket of FSAE formula racing car was carried out, and then the finite element modeling and analysis of the initial design scheme was carried out based on ANSYS Workbench software. The lightweight design was designed on the premise of meeting the design requirements, and the reliability of the sprocket design was ensured. Finally, the strength, safety factor and life of the optimized model were simulated and verified, the sample was manufactured, and the physical experiment was carried out by assembling and integrating the model into the racing car. The results show that the optimized sprocket meets the work requirements.

1. Introduction
Formula University is a car designed and manufactured independently by team members and participated in FSAE competitions, which is funded by universities or automobile companies according to the rules promulgated by the Society of Automotive Engineering (SAE)[1]. Designers need to consider the rationality of structural design, design cost, power, fuel economy, handling stability and durability, the overall design requirements are high. As one of the important parts of power transmission, the main reducer has been introduced in many literatures over the years.

In 2014, a university professor applied Cruise, ADVISOR and Matlab to study the optimization and matching problem of the power unit of FSAE racing car, and quantitatively analyzed the relationship between vehicle power performance and main deceleration ratio[2]. In 2017, Hubei Institute of Automotive Technology made the parameter matching of transmission and main reducer in the transmission system, and complete the overall design, simulation and test of the vehicle[3]. According to the existing literature analysis, in the research of the driving system of racing car, the main reducer matching problem is mainly focused on the engine and the driving system, but the lightweight design and optimization of the main reducer, especially the big sprocket, is rarely introduced.

Chain drive is a flexible drive, which is composed of a chain and a sprocket, and transmits power and motion through the meshing of the sprocket teeth and the chain link[4]. It is widely used in the power system of formula student racing car because of its inelastic slip and integral slip during transmission, low installation and manufacturing accuracy and cost. The sprocket, as one of the key
parts of the racing speed transmission device, should have sufficient strength, stiffness and durability to meet the requirements of dynamic and static evaluation during the structural design, but also should have lightweight characteristics to improve the energy saving effect of the vehicle.

2. Optimization of chain drive parameters

The minimum number of teeth of pinion in general racing car is 13, and 11 can be selected in extreme case. According to the general layout and available space of the engine room of the university formula racing car, a small sprocket with 11 teeth is adopted in this paper. The number of the small sprocket is selected as 11, and the main reduction ratio of the racing car is determined as 3.18, so the number of the big sprocket is 3.18×11=34.98, rounded to 35. Then the chain drive parameters are calculated. So Actual transmission ratio \( i = \frac{z_2}{z_1} = 3.1818 \).

520-H model chain is selected for this racing car, Chain pitch \( p = 15.88 \text{mm} \), roller diameter \( d_2 = 10.16 \text{mm} \).

2.1. Preliminary determination of center distance \( a_0 \)

When the center distance is preliminary determined, \( a_0 = (30-50) p \) is optimal; The calculation formula of the minimum center distance is shown in Table 1.

| \( i \) | \(<4\) | \( \geq 4\) |
|---|---|---|
| \( a_{0\text{min}} \) | \( 0.2z_1 \) | \( (i+1) \) \( p \) | \( 0.33z_1 \) | \( (i-1) \) \( p \) |

When determining the center distance, it is also necessary to consider the remaining space of each system layout in the engine room, so as to avoid interference between systems, or transmission efficiency reduction caused by excessive angle between half shaft and wheel core[2].

2.2. Determine the number of chain joints \( L_p \)

\[
L_p = \frac{2a_0}{p} + \frac{z_1 + z_2}{2} + f_3 = \frac{2a_0}{p} + \frac{z_1 + z_2}{2} + \left(\frac{z_2 - z_1}{2\pi}\right) \frac{p}{a_0} \approx 52.16, \quad L_p = 52
\]  
\( f_3 \) is the coefficient of the number of chain joints calculated by the number of teeth.

2.3. The chain length \( L \)

\[
L = \frac{L_p p}{1000}
\]  

2.4. Calculate the theoretical center distance \( a' \)

When \( z_1 \neq z_2 \): \( a' = p(2L_p - z_1 - z_2)f_4 \)

\( f_4 \) is the proportion effect coefficient of center distance

2.5. Actual center distance \( a \)

\[ a = a' - \Delta a \]

Usually take \( \Delta a = (0.002\sim 0.004)a' \).

2.6. Chain speed \( v \)

\[
v = \frac{z_1 n_1 p}{60 \times 1000}
\]  
\( n_1 \) is the speed of the small sprocket.

2.7. Effective circular force \( F_1 \)

\[
F_1 = \frac{1000P}{v}
\]

\( P \) is the transmission power, kW. \( F_1 \) is the effective circumferential force, N.
2.8. The force acting on the axis \( F \)

Nearly vertical drive: \( F \approx 1.05k_AF_1 \)  \( k_A \) is the impact coefficient, and the value is 1.4.

The force on the shaft of the chain drive can be analyzed and calculated by calculating the force on the supporting structure of the chain drive.

3. Determination of sprocket parameters

3.1. Measure the diameter of a circle \( d \)

\[
d = \frac{p}{\sin 180^\circ / z}
\]  \( \text{(7)} \)

3.2. Addendum circle \( d_a \)

\[
d_{\text{amax}} = d + 1.25p - d_1
\]

\[
d_{\text{amin}} = d + \left(1 - \frac{16}{z}\right)p - d_1
\]  \( \text{(9)} \)

The crown circle diameter can be selected from any value between \( d_{\text{amax}} \) and \( d_{\text{amin}} \). Be sure to keep within these two limits in the process of selecting the value of tooth tip roundness. If the selected value is less than \( d_{\text{amin}} \), the sprocket load capacity decreases. If the selected value is greater than \( d_{\text{amax}} \), the top cutting will occur in the driving process, reducing the load capacity of the sprocket and shortening the sprocket life.

3.3. Diameter of root circle \( d_f \)

\[
d_f = d - d_1
\]  \( \text{(10)} \)

3.4. Depth \( H_a \)

\[H_a = 0.27p\]  \( \text{(11)} \)

3.5. Maximum root pitch \( L_x \)

\[L_x = d \cos \frac{90^\circ}{z} - d_1\]  \( \text{(12)} \)

3.6. Diameter of shaft flange \( d_g \)

\[d_g < p \cot \frac{180^\circ}{z} - 1.04h_2 - 0.76\]  \( \text{(13)} \)

3.7. The thickness of the wheel hub \( h \)

\[h = K + \frac{d_k}{6} + 0.01d\]  \( \text{(14)} \)

\( d_k \) is the diameter of the hole; \( K \) is a coefficient that depends on \( d \), When \( d < 50 \text{mm} \), \( K \) is 3.2.

3.8. Tooth width \( b_f \)

\[b_f = 0.95b_1\]  \( \text{(15)} \)

3.9. The tooth flank radius \( r_x \)

\[r_x \geq p\]  \( \text{(16)} \)
3.10. Chamfering wide $b_a$

$$b_a = 0.13p$$ (17)

3.11. Chamfering depth $h_1$

$$h_1 = 0.5p$$ (18)

3.12. Radius of flange fillet of tooth side $r_a$

$$r_a \approx 0.04p$$ (19)

To sum up, the parameters of sprocket are shown in Table 2.

| reference diameter | tip diameter | height of tooth | Maximum root pitch | Diameter of shaft flange thickness s | Tooth width | The tooth flank radius |
|--------------------|--------------|----------------|--------------------|-------------------------------------|-------------|-----------------------|
| Big sprocket       | 56.37        | 62.3           | 4.29               | 45.49                               | 38          | 6.03                  | 6.03                  | 723                   |
| Small sprocket     | 177.15       | 184.9          | 4.29               | 106.73                              | 62          | 6.03                  | 6.03                  | 723                   |

4. Sprocket Finite Element Analysis

The sprocket is made of 7075 aluminum alloy. First check 7075 aluminum alloy material in Engineering Data of ANSYS software, and then import the 3D solid model of sprocket. Mechanical mesh is automatically divided, and the average quality coefficient of the generated mesh is 0.69, indicating that the mesh quality is good(Figure 1). Then according to the sprocket working principle, the sprocket boundary conditions are set[3]. First, a fixed constraint is imposed on the central spline part of the big sprocket, and then a force load is applied on the gear of the outer ring[4][5]. The analysis process and results are shown in the figure2.

The results show that the maximum stress of the sprocket is 261.91MPa, less than the yield strength of 7075 aluminum alloy, the maximum shape variable is 0.31mm, and the minimum safety factor is 1.93, which meets the requirements of the minimum safety factor of 1.5 and meets the design requirements.(fig.1-5)
Figure 3. Graph of the distribution of geometric variables.

Figure 4. Stress map

Figure 5. Safety factor distribution diagram.

Figure 6. The sprocket

5. Physical experimental verification of sprocket

According to the CAD sprocket model that meets the requirements of the simulation check, the sprocket produced by mechanical CNC is shown in the figure 6.

Finally, the sprocket is integrated and assembled on the car to obtain the whole physical test car as shown in the figure 7. The car was tested on the campus road for trial running and basic deceleration parking brake, and in the karting track for a long time endurance test, no abnormal sprocket was found. In the whole evaluation process, the sprocket did not appear abnormal. The sprocket was disassembled in the school laboratory. Figure 8 shows the disassembled sprocket without obvious deformation or cracking, indicating that the lightweight sprocket meets the basic performance requirements.

Figure 7. The racing car assembly.

Figure 8. The sprocket

6. Conclusion

In order to improve the dynamic performance of racing car, this paper studies the finite element analysis and lightweight design of racing sprocket. First of all, the parametric modeling of the big sprocket is carried out, and then the structural optimization design is carried out to achieve the purpose of weight
reduction of parts, which is of great significance to improve the dynamic performance of the racing car. Finally, the design is verified by the actual car is reasonable and reliable.

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