Axial Air-cooled Road Wheel Design

Guangyuan Liu1*, Hua Huang1, Mengyao Wang1 and Shaowei Liu2

1Beijing Institute of Technology, Beijing, China
2Chongqing Tiema Transmission Co., Ltd.
*Corresponding author’s e-mail: liugychd@163.com

Abstract. Aiming at the problem of improving the reliability and thermal stealth of the road wheel on the tracked vehicle, an axial air-cooled road wheel structure scheme is proposed. The spokes of the road wheel are designed as the shape of the axial fan blade, and the kinematics analysis is carried out. The CAE software is used to simulate the flow field. The velocity field, pressure field, and axial flow at the maximum speed of the road wheel are obtained, and the result is compared with the wheel of the plane spoke.

1. Introduction

The road wheel is an important part of the tracked vehicle action system. Its function is to support the vehicle body, and the vehicle's gravity is evenly distributed over the entire track grounding section. The normal operation of the road wheel is a necessary condition for ensuring the smooth, safe and reliable performance of the tracked vehicle. [1][2] The road wheels mainly include two types of all-metal road wheels and the road wheels with rubber flanges. The road wheels with rubber flanges have long service life and better ride comfort, and have been widely used in tracked vehicles.

Due to the hysteresis loss characteristics of the rubber itself, the rolling resistance of the road wheel with rubber flanges is larger than that of the full metal load wheel. When the road wheel rotates at a high speed, the rubber layer will generate a large amount of heat due to the internal friction, which causes the temperature of the road wheel to rise. The traditional road wheel mainly relies on air cooling, which has poor heat dissipation capability, and has a high balance temperature. Excessive temperatures can cause spalling separation between the rubber layer and the rim, which reduces the service life. The geometric characteristics of the wheel are obvious. The road wheel is easily recognized by the infrared detector in the working environment, which reduces the infrared stealth of the tracked vehicle. Therefore, it is necessary to study new ways to improve the heat dissipation of the high-speed tracked vehicle's load-bearing wheels. [3]

In this paper, a new type of axial-flow air-cooled high-speed tracked vehicle road wheel is designed. Compared with the traditional road wheel, it has a structure similar to the axial flow fan, which increases the convective heat transfer of the road wheel while ensuring the service life.

2. Structural design of axial flow air-cooled road wheel

2.1 Kinematics analysis of axial flow air road wheel

The theory of axial flow machinery is the basis for designing axial flow air-cooled road wheels.[4][5] The movement of fluid on the cylindrical surface of a vane axial flow machine is a compound motion,
The rotation of the blade drives the air to rotate so that the air has a peripheral speed \( u \). The direction is consistent with the direction of rotation of the blade. The flow velocity of the fluid relative to the blade after entering the cascade is relative velocity \( \omega \), and the direction is related to the structure of the blade. The absolute velocity of the fluid is a vector superposition of \( u \) and \( \omega \). The velocity triangle formed by \( u \) and \( \omega \) is tangent to the cylindrical surface. The absolute speed can be divided into a circumferential speed \( v_u \) and a shaft surface speed \( v_m \). Since the influence of the radial motion is small, it can be neglected. Therefore, the axial speed is also the axial speed, which is expressed by \( v_z \).

\[
v = v_z + v_u \tag{1}
\]

As shown in Figure 1, the velocity of the fluid at the inlet and outlet of the cascade is triangular, and the air enters the cascade at a certain speed \( v_1 \), and flows out of the cascade at a speed \( v_2 \). The speed has a certain angle with the fan axis \( \beta \), that is, the blade mounting angle. By decomposing the absolute velocity \( v_2 \) of the air flowing out of the cascade, \( v_{2u} \) and \( v_{2a} \) can be obtained, where \( v_{2u} \) is parallel to the plane of the cascade, that is, it rotates along the circumference under actual conditions. \( v_{2a} \) is a vertical cascade, flowing in the axial direction of the fan under actual working conditions. It is obvious that the actual axial flow at the actual working condition is \( v_{2a} \), perpendicular to the cascade, which reflects the axial flow of the vane axial flow machine, and the speed \( v_{2u} \) cannot produce axial flow.

![Figure 1. Cascade inlet and outlet speed triangle](image)

2.2 The parameter of road wheel
The key to the parameter design of the axial flow air-cooled road wheel is the design of the spoke. The design of the axial-flow air-cooled road wheel in this section is based on the relevant parameters of a certain type of road wheel.

In addition, the maximum load of the road wheel is 3.75 t, and the maximum speed is 70 km/h. The main part of the road wheel is made of high-strength (2A05) aluminum alloy, and the material of the hanging rubber layer is natural rubber.

The road wheel spokes need to be designed according to the structural parameters of the aircraft wing to ensure better axial flow characteristics. In order to simplify the calculation, the outer diameter of the road wheel is taken as the rolling radius, and the maximum speed of the road wheel is

\[
s = \frac{v}{\pi D} = \frac{70000 / 60}{0.67 \times \pi} = 555 \text{ r/min}
\]

Outer diameter of road wheel \( D_1 \):

\[
D_1 = 670 - 2 \times 40 - 2 \times 10 = 570 \text{ mm}
\]

Wheel ratio \( \Delta_d \):

\[
\Delta_d = \]
The number of spokes \( z \) has a certain influence on the total pressure and efficiency of the wheel, which is usually selected according to the hub ratio \( \overline{d_h} \). When \( \overline{d_h} = 0.42 \), the number of spokes \( z \) ranges from 4 to 8. Considering the structural strength of the road wheel and the problem that even-numbered spokes are prone to resonance, choose \( z = 7 \). [6]

Blade installation angle has an important influence on the axial flow performance of the fan. Within a certain range, with the increase of blade installation angle, the axial air flow of the fan also increases. For axial flow fan, blade installation angle is generally not more than 35 °, so for axial air-cooled road wheel, this article set the spokes installation angle to 35 °.

The three-dimensional model of the established road wheel is shown in Figure 2. The brown part indicates the outer edge of the road wheel and the material is natural rubber. The green part indicates the main part of the road wheel. The material is high-strength aluminum alloy.

3. Flow field analysis

3.1 Initial conditions
According to the working environment of the road wheel, the watershed around the road wheel is divided into an inner basin and an outer basin. The inner basin is the air basin inside the road wheel, and the outer basin is a watershed that is set in consideration of the translational state of the road wheel. [7] The watershed outside the wheel is shaped like a regular hexahedron. According to the movement state of the weight wheel, the air velocity of the inner basin is 555 r/min, the air inlet velocity of the outer basin is 70 km/h, and the direction is opposite to that of the road wheel. The number of grids generated in the left wheel is 181,196, while there is 185,929 in the right. The nodes generated in the left is 31,435, and 32221 is in the right. In the outer basin of the road wheel, 2519317 is meshed and 23761 is generated.

3.2 Flow field calculation and result analysis
Figure 3 is the flow chart of the air velocity of the road wheel at the maximum speed. It can be seen that: Firstly, the maximum air velocity around the road wheel is 27.35 m/s. The air with the translational speed flows from the upper and lower sides and the middle of the load wheel, respectively. The air inlets of the upper and lower road wheels have air entering, flowing between the spokes and flowing out from the outlet. The flow state of the air on the road wheel is from the air inlet of the lower wheel, a part of the air flows from the air outlet of the lower wheel into the air inlet of the upper wheel, and the other part of the air flows directly out of the road wheel. Secondly, the fluid flow line flowing out from the exit of the road wheel is initially spiral, which is the axial flow motion generated after the air is subjected to the road wheel, and then gradually becomes a linear type, which is the air flowing at a constant speed on both sides of the road wheel. Figure 4. shows the air surface pressure distribution around the spoke at the maximum speed. The positive value indicates that the absolute pressure is greater than the atmospheric pressure, otherwise the absolute pressure is lower and the negative pressure occurs. It can be seen from the figure that the air flow area around the wheel of the road wheel is basically under
negative pressure. From near the hub side to near the rim side, the negative pressure around the spoke increases, because: according to the Bernoulli principle, when the fluid is flowing, the pressure at a large flow rate is small. Therefore, the air flow rate is larger in the area near the rim side. After calculation, the axial air flow of the road wheel is 1350 m$^3$/h.

Figure 3. Air flow diagram
Figure 4. Pressure profile

Figure 5 shows the velocity streamline diagram of the road wheel outer watershed at the highest speed. The air with constant translational speed flows around the road wheel and the movement state changes around the road wheel, but after go through the road wheel, it is quickly restore to the previous state of motion.

Figure 5. Outer basin air velocity streamline diagram

3.3 Comparison with plane spokes
The difference between the axial flow air-cooled road wheel and the conventional road wheel is that the spokes of the conventional road wheel are generally flat or other non-axial flow structures. In order to analyze the difference between them better, this paper designed a plane spoke wheel in the simulation software. Figure 6 is obtained through simulation. The analysis results are compared with the new road wheel, it can be seen from Figure 7, as the rotational speed increases, the new road wheel increases the axial flow rate more than the conventional road wheel. At the highest speed, the conventional road wheel is 813 m$^3$/h, while the new road wheel is 1350 m$^3$/h. Obviously, the axial flow effect of the new road wheel is obviously better than that of the traditional road wheel, which can significantly increase the axial flow and improve the axial convective heat transfer capacity of the road wheel.
4. Experimental verification

In this section, the performance index test of the new road wheel is carried out. The performance index of the actual working condition is measured, and the numerical analysis result is compared with the experimental measurement result to facilitate the subsequent design improvement of the model.[8][9] Because the theoretical basis and working principle of the new road wheel are very similar to those of the axial flow fan, and the test only measures the axial flow performance of the road wheel at the non-translational speed. Therefore the equipment for measuring the performance of the axial-flow fan was used. According to the standard GB/T1236-2000, the test bench shown in Figure 8 was built. The road wheel model in Figure 9 is processed.

In the same environment (at room temperature 22 °C), the dynamic and static pressure difference of the fluid at a specific speed in the range of 250-555 r/min was measured several times, and the measurement results were averaged. The results are shown in Table 1.

| Speed (r/min) | Axial flow of test (m³/h) | Axial flow of simulation |
|--------------|--------------------------|-------------------------|
| 555          | 4619                     | 4512                    |
| 500          | 4132                     | 4010                    |
| 450          | 3772                     | 3562                    |
| 400          | 3374                     | 3124                    |
| 350          | 2922                     | 2714                    |
| 300          | 2385                     | 2231                    |
| 250          | 2066                     | 1986                    |

It can be seen from Table 1, under the test condition, the axial flow of the road wheel varies with the rotation speed: as the rotation speed increases, the axial flow of the road wheel also increases, and the
The relationship between them is a linear positive correlation, which is also obtained under simulated conditions. However, when the rotational speed is the same, the experimental measurement of the axial flow of the road wheel is lower than the theoretical analysis value. The reasons for this may be as follows:

1. There is a transmission device and a speed-regulating motor at the air outlet of the road wheel. When the air flows out from the road wheel, it will be affected by these devices.

2. The flow measuring device used in this paper is the DEBIMO test piece, which takes a plurality of points in the pipe and obtains the average value as the measured value output. Although the average value can reduce the error, it does not guarantee complete and accurate reflection. The average pressure of a section in the pipe is out, so this measurement calculation method also produces errors.

5. Conclusion

In this paper, based on the axial flow mechanical principle, a new type of road wheel is designed for the heat dissipation requirements of high-speed tracked vehicle. The main size of the road wheel is calculated and modeled in three dimensions. The flow field of the road wheel which is analyzed by the finite element software, the axial flow, the velocity distribution and pressure distribution of the road wheel are obtained. The simulation results are verified by experiments. Both the simulation and test results showed that the new structure significantly improves the axial flow capacity of the road wheel, and the axial flow has a large difference between the axial flow with parallel speed and the axial flow with no speed. In these two cases, the air axial flow state of the road wheel is different, and the translational air outside the road wheel has a great influence on the axial flow field of the road wheel.

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