Drag reduction of locomotive and practical scene

Sichen Lu

Shanghai experimental Cambridge international school, Shanghai, China

lucolin0822@ldy.edu.rs

Abstract. As an important tool for people's long-distance travel and transportation, the design accuracy of the high-speed railway must be strictly controlled. In addition, the train design needs to conform to aerodynamics, such as improving the linearity of the train flow to ensure that the gas flows smoothly through every part of the train, or reducing the front pressure to reduce the wind resistance, so as to reduce the problems of train instability, high noise and high energy consumption. This paper will analyse the design concept, flow linearity and how to reduce the resistance of locomotives under high-speed motion of Shinkansen trains in Japan. Because the Shinkansen trains developed in the early and later generations are mainly flat-headed, the study of Shinkansen can understand the significance of flat-headed trains. The practicability and manoeuvrability of ' flat head' and 'bullet head' locomotives and the application of locomotives in real life are analysed in detail. Finally, it is concluded that the bullet train has a large turning angle and needs to open up a special road to run smoothly, but the bullet train is faster than the flat head. The flat-head train is highly practical and suitable for driving in the city, and another advantage of the flat-head train is that it can still maintain high stability and safety when carrying many passengers.

Keywords: Locomotive, practical scenarios, design of locomotive

1. Introduction

The development of the train can be traced back to the steam engine era at the end of the 18 th century. At that time, as the main tool for travel, the carriage was much faster than the first train, and at that time a carriage cost only 5,000 pounds, while the light train railway cost up to $ 28,753 per mile, equivalent to the middle class decades of annual income. However, with the development of the train, the speed of the carriage began to be slower than that of the train, and the practicability was greatly improved. Because of the high capacity and high speed of the train, people basically use him as a main means of transportation for coal mines, stone mines and other materials. In the middle of the 18 th century, Europe began the first industrial revolution. The steam engine burned water to produce steam to promote the piston movement, that is, heat energy was converted into kinetic energy, but water vapor as a medium would consume a lot of energy. After that, Watt transformed the steam engine, making it more efficient and less energy-consuming. This also led to the development of the internal combustion engine, which is the originator of the engine. In the middle of the 19 th century, Japan 's Tokaido Shinkansen was put into operation in 1964, which opened the prelude to the world 's high-speed railway. Following Japan, other countries in the world, especially European countries such as France and Germany, have also vigorously developed high-speed railways. But it also spent 36 million marks, which is half of Germany 's annual income. Other European countries have also spent heavily on railway transportation, but far less than Germany 's railway development. However, the main reason why Germany successfully promoted steam locomotives and surpassed Britain is that it has a great relationship with geographical location. Germany is located in the central region of Europe, which also makes Germany the most important trading medium in Europe. After that, German railway transportation has been widely used and developed, and has become an important support for German industrial and economic development. Germany has also made a lot of contributions to the train. They have made major changes to the axle and torque, making the train more stable and rapid. The earliest steam locomotive was invented by British engineer George Stephenson in 1814, which could travel at a speed of 8km / h. Later, with the further development and progress of the locomotive, the external combustion engine completely replaced the internal combustion engine, and the traction and speed of the train also increased, but the external combustion opportunity produced a huge waste of energy. At that time, coal would be put into the boiler to burn, and the heat energy generated could push the piston, while only a small part of the heat would directly enter the cylinder of the engine, turning the heat energy into kinetic energy. The rest will be emitted into the air and converted into heat energy that is ineffective for the train. The rest will be emitted into the air and converted into heat energy that is ineffective for the train. Therefore, people began to try to use the internal combustion engine to make the fuel burn inside to generate kinetic energy. The automobile after the 20 th century is a particularly good example. The fuel will burn inside to push the piston to generate kinetic energy. Now, the train has been able to achieve all-electric, and the engine has also changed from an internal combustion engine to a motor. The electric energy is input into the electric generator through the pantograph, and the electric energy is converted into kinetic energy. Its principle is that there are enough rotatable coils and a permanent magnet. Force will be generated when the magnet passes through the coil. When the motor works, the rotor rotates rapidly in the stator. This also makes the traction bigger and bigger. However, the pursuit of saving fuel and increasing speed also requires the train to have an aerodynamic appearance, as well as lightweight materials that can withstand wind pressure. The researchers found that when the high-speed rail runs at a speed of 340 kilometers per hour, air resistance accounts for 75 % of the total resistance ratio [1]. By analyzing the differences between each country, we found that some countries still use flat head design. We will analyze Japan and China. The most obvious example is Japan. After the war, Japan 's economy expanded on a large scale. Ordinary citizens have long been accustomed to commuting by train. After the defeat, economic growth has also brought about a super-scale growth of population and cities. Many suburbs have also become urban areas, and the situation in different cities and different periods is different. If it is necessary to ensure the general performance of vehicles, it is naturally flat-headed to facilitate the arrangement of through-doors. Even if the through door is not arranged, the flat-headed vehicle can put down a larger riding area within the specified total length. Compared with the bullet, the flat-headed design will greatly increase the carrying capacity. Because the flat head car is not fast, nor does it need to drive fast, so the speed of 80 is just right for the flat head car. At this time, the air resistance of the flat head car will not particularly affect the train, and the model can be modified at will. However, some passengers still cannot enter the car during the peak period. In China, the flat head train also evolved into the subway, the subway head tilt angle is even higher than 60 degrees. Sometimes there are 80-90 degrees. This shows that bullet trains are not practical between cities. The maximum turning angle of the bullet should not be higher than 15 degrees, otherwise the train will have the risk of rollover. However, the flat head train can reach a turning angle of 35 degrees. This will allow the subway to travel on the curved railway due to the terrain. However, the cost of bullet trains is particularly high. Not only is the price of a high-speed rail about 172 million yuan, but also a special track needs to be built for it. According to statistics, most of the high-speed rail track construction is about 100 million yuan per kilometer, and a small part is about 150 million yuan. Most of the investment needs to be put on track. Each purchase of high-speed rail and track costs more than 50 billion yuan. Although the subway is short, a subway only needs 40 billion yuan, which is suitable for shuttle between small cities without a lot of investment. This makes the subway a ' train ' in the city and a means of transportation for countries with a small territory.

DOI: 10.54254/2753-8818/31/20240931

2. Methods in the Research

2.1. Research on trains shape

There are two kinds of designs on the types of trains around the world, one is flat head design and the other is bullet head design. Japan is the earliest country in the development of trains, and it is also a country that promotes trains. They let the train into people 's lives, also slowly evolved into two kinds of transportation, subway and train. The first batch of Shinkansen high-speed rail used a flat head design. Its design advantages are small blind area of vision, stable turning, and can accommodate more passengers. Therefore, the flat head will be used for functional trains, but the flat head cannot run at high speed. As shown in the Figure 1, P ∞ is the atmospheric pressure. The concave area is the low pressure area, and the convex area is the high pressure area. When the train is on the train, the formation of the pressure area can be controlled by controlling the concave and convex. The flat head train works in a high wind pressure environment, and the high pressure and strong area of the nose increases. There will be a large area of negative pressure area above and below the head. It makes it difficult for trains to run. Later, after the improvement of the train, the bullet design was used on the locomotive, and the overall structural material was aluminum alloy. Titanium alloy has good corrosion resistance and hardness, and its weight is only one third of that of steel, so titanium alloy has become the preferred material. If the mass of the whole train is converted into 16 vehicles, it will increase by about 40 t compared with the 0 series Shinkansen [2].

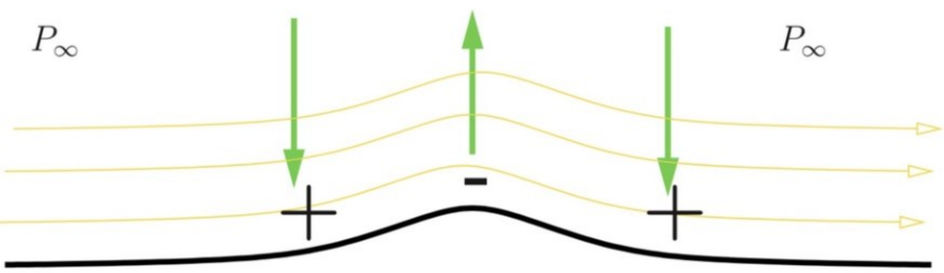

Figure 1. Atmospheric pressure [3]

In the design of the locomotive, was shown in the Figure 1. when the train advances rapidly for a certain distance, the air in the front of the carriage will be immediately squeezed and cannot spread around, thus forming a high-pressure zone. Because the rear part of the tail frame leaves the original position, the surrounding air has no time to fill the space it once occupied, so the air pressure here is lower than the surrounding area, forming a low pressure area, that is, a vacuum area, and the train nose is a high pressure area, and the shoulder and the tail of the train will form a low pressure area because the air cannot flow. When the cross-sectional area between the front and rear of the high-speed track increases, this will increase the resistance on the high-speed track, and when passing through the tunnel, the noise will increase because of the turbulence. Therefore, the design of the locomotive head requires that the air can pass through the high-pressure area quickly. When the train runs quickly, the high-pressure and low-pressure areas are reduced as much as possible, so that the train forward resistance and decrease. Therefore, the flow linearity of the train will become particularly important. The bullet design can not only reduce the wind resistance, but also reduce the noise caused by air disturbance. With the increase of the streamline length of the train, the nose tip of the train evolved from round to flat width, and the morphological characteristics of long nose tip and large nose gradually appeared. The front face of the train offsets the sudden change of the section change rate of the driver 's cab position by reducing the cross-sectional area around the driver 's cab, so that the protrusion of the driver 's cab is obvious. In order to continuously reduce the cross-sectional area of the middle section of the train shoulder, resulting in the relative protrusion of the driver 's cab and side, and the large turning of the curved surface [3]. As

DOI: 10.54254/2753-8818/31/20240931

an alternative solution for analyzing the locomotive, we recommend the method of geometric shape analysis. This method has been evaluated as an appropriate solution to track and analyze changes in atypical and complex shapes; morphometrics used in evolutionary biology is representative (Cardillo, 2010). In particular, this method is very useful for tracking continuous changes [1]. We can divide the train head into three parts. The first part is the nose, the second part is the shoulder, and the third part is the front of the train, that is, the connection between the train head and the body. The nose can be regarded as a semi-circular shape, because the sphere can make the force evenly distributed, which is more conducive to dispersion. Coupled with the small cross-sectional area, when the train runs fast, the high-pressure area will only appear in a small part. The airflow will be distributed around after passing through the nose, so if the train wants to make the airflow pass smoothly, there will be no airflow disorder. Because the air disorder will make the train turn, the left and right forces are not uniform, resulting in the risk of rollover. In general, wind tunnel experiments can analyze the design defects of trains through high Reynolds number airflow, and can visually see the direction of airflow movement. In the wind tunnel experiment, most of the vehicles have taken into account the streamlined design to dredge the wind resistance in the high-pressure area, so that the air flow can pass smoothly so that the air flow can pass smoothly when the wind resistance is reduced. The train has little influence on the aerodynamic force of the upstream highway vehicle, but has a great influence on the downstream highway vehicle, and the lateral force coefficient of the highway vehicle is most significantly affected by the train interference effect [4]. On the shoulder, the train will be basically a ladder, so that the wind resistance in the high-pressure area can be migrated to the upper and left and right sides of the train, and the wind speed can be weakened. The formula shows that the increase of vehicle speed, air density and train cross-sectional area will lead to the increase of air resistance, so we should try to avoid these points. The bullet design knots are used in the 0-series, 100-series, 200-series and 500-series of the Shinkansen. The 300 series, 400 series, E1 series, and E2 series all adopt flat head design. Now the train has almost integrated the flat head and the bullet head. Although the structure is very similar to the bullet head, the bottom is shortened by shortening the distance between the head and the bottom, and the whole locomotive is also stretched. The shape is flatter than the bullet. This change increases the safety of the train compared to the bullet and broadens the driver 's field of view. When the speed exceeds 300 per hour through the tunnel, the sound explosion will be greatly reduced, so that the noise can be greatly controlled. Now the design of flat-headed bullets has become the mainstream. In 2022, the global bullet train and high-speed rail market reached 674.845 billion yuan (RMB), which also indicates that the development prospect of bullet trains is very promising. In order to make the head shape have a strong sense of integrity, the surface of the shape should be considered as smooth and smooth as possible, and the front and side of the head should be designed with a large surface. The transition surface between the major surfaces adopts a smooth surface with a large curvature radius, and the smooth transition method without edges is adopted at the street junction of each surface. In order to ensure the overall streamline of the front, the front window glass adopts a large curved glass that is compatible with the steel structure shape. The side window is a horizontal push-pull openable plane window for the driver 's observation platform. In order to increase the field of view, a triangular plane glass is added to the front of the side window. In order to avoid the large contrast between the straight edge contour and the streamlined shape, the corner of the side window is rounded in the design, so that the overall shape is coordinated with the window [5]. Moreover, the track of the bullet train will also be particularly long, and there will be no bends. When the train is running, the effect of the track on the train is also particularly large. The rail resistance must be small, but it is necessary to ensure that the train can brake urgently. Moreover, the wheel-rail dynamic response caused by track irregularity will have a direct impact on the safety of driving and the comfort of passengers. When the train speed is lower than the critical speed, the strength of the track, subgrade and bridge structure meets the relevant requirements in time. When the track is not smooth, the vehicle vibration and wheel-rail force caused by the line will also increase greatly. Therefore, the design of high-speed railway track has higher requirements for smoothness, which is the control condition for the construction of high-speed railway. It is also one of the main characteristics of high-speed railway to distinguish between medium and low speed railways

DOI: 10.54254/2753-8818/31/20240931

[6-8]. However, with the increase of driving speed, the damage effect of uneven settlement of subgrade on track structure and track components is increasing. The larger the settlement amplitude, the more severe the vibration of the track structure [9], so we also need to ensure that the use of roadbed materials as balanced as possible.

2.2. The explore of the methods

In most countries, flat-headed trains and bullet trains exist at the same time, so we can design an experiment to infer the practical terrain and scene of flat-headed trains by analyzing the travel of flat-headed and bullet trains and passing cities. First of all, we divide the train into two types, one is the flat head train, one is the bullet train. In the flat-head and bullet-head trains, we count the distance data of each type of train one by one to make a tabular form, and then analyze the image trend, and compare the speed and distance of the bullet-head and bullet-head trains. Then find out the comparison relationship between flat head and bullet head and speed. We found that the traction force is also an important data that affects the head of the train. When the traction force is greater, the more he needs the design scheme of the head tip. In the aspect of train inclination, it will also greatly affect the data, so we should also make a comparative analysis of the slope. Flat-head trains and bullet trains have different slopes, but there will also be a maximum and minimum tilt. Therefore, we need to find the maximum slope and the average slope for analysis respectively. Finally, we summarize four points that need to be counted. The first is the train head design, the second is the train traction, the third is the main driving distance and scene of the train, and the fourth is the train tilt slope.

3. Discussion

The Shoupingtou train and the bullet train are developing in two directions. The flat head train needs small investment and high practicability. Compared with the bullet train, the flat head has a significant advantage in turning. When building the track, there is no need to open another road, only to shrink in the city. However, the flat-headed train does not run fast, and there are usually more than a dozen stations. It needs to be bent and wound to increase the distance. Sometimes it needs to stop to pick up passengers, which will waste a lot of time, make the average speed slower, and even the time required for the destination is slower than that of the car. The bullet train is suitable for shuttle between big cities, so that the time from some remote areas to big cities is greatly reduced, which can speed up the flow of resources between cities. Resources can be allocated quickly, and there will be no problem of resource isolation. We also studied the short-distance trains in Germany, Singapore and France respectively. We found that the suburban short-distance trains still use bullets, just like Singapore and France. In the urban area, Singapore and Germany are almost 60 tilt flat car, in Germany is almost 90 degrees. In China China 's land spans 5400 kilometers from east to west and 5200 kilometers from north to south, which determines the huge demand for medium and long distance passenger and freight traffic. Railway is an economical and fast transportation mode, so it has great development potential. From 1998 to now, more than 20 cities in China have studied and developed high-speed railway [10]. The Renaissance is a particularly classic example. It has a cumulative distance of nearly 1.9 billion kilometers, which is equivalent to a full 4,800 circles around the earth. The Fuxing used bullets as a whole, with a speed of more than 350 per hour. On the train system, Fuxing adopted fully automatic driving, which is also a major milestone for the train. The whole journey of the ship covers Beijing, Harbin, Jilin, Shenyang, Shanghai, Hangzhou, Guangzhou and Xi 'an. There are also special train tracks, so that the Fuxing can move forward at full speed. In terms of traction, we find that the weight and structure of the train also determine the inertia and traction resistance of the train. Weight and resistance are the two aspects that affect the traction most. From decades ago to the present, the weight of the train has not been increasing. According to statistics, the weight of the eight-section marshalling is about 400 to 500 tons on average. Therefore, the influence of the weight of an ordinary train on the traction force is almost the same.

DOI: 10.54254/2753-8818/31/20240931

4. Conclusion

After investigating the influencing factors of the train, the most important result is that the speed and traction are linked, and they will increase in proportion, so the general speed of the train will use the bullet design. At present, there is also a method for controlling the traction force, which includes steps: determining the target traction force of the maglev train; according to the train position of the maglev train, the position of the stator segments of multiple stator segments located on the tracks on both sides of the running line and the working conditions of the stator segments, the target traction force is distributed to at least one stator segment located at the position of the train. Among them, multiple stator segments on the same side of the track choose one to run, and the corresponding stator segments on both sides of the track choose one to change step. Secondly, the location and city of the train also have a great influence on the head of the train. In crowded cities, the train will adopt a flat head design with high safety. In the sparse place of the city, the area will be broad, so the bullet design will be adopted.

References

[1] Sun-Joong Kim, Ji-Hyun Lee. The Evolutionary Changes of the Streamlined High-speed Locomotives. 2020.

[2] Yu Zhanxian.The development history of Japanese Shinkansen. 2003.

[3] Li Yi. Yang Lan. Ji Peng. Liu Lijun. Research on collaborative design of shape and property of Japanese Shinkansen locomotive. 2022.

[4] Li Wenqiao. Research on streamline shape and structure of high-speed rail head. 2021.

[5] https://image.baidu.com.

[6] Zhou Yunfeng. Xue Fanrong. He Xuhui. Han Yan. Liu Qinkuan. Aerodynamic wind tunnel test of train. 2021.

[7] Xiao Jian. Xu Juan. Li Jun. Chen Mingfeng. Zhao Haitao. Zhong Siqi. A traction mode and device of maglev train. 2022.

[8] DongJiang. Architectural design. Research on design concept of high-speed railway track engineering. 2017.

[9] Shi Wei. Analysis of the influence of structural defects of slab track on dynamic performance of high-speed railway. 2011.

[10] Liu Si. Technical papers on high-speed railway. 2015.